Technical report of IMTA demonstration in two sites

NWG-M, UNDP/GEF Yellow Sea Large Marine Ecosystem (YSLME)

Phase II Project;

Yellow Sea Fisheries Research Institute, CAFS

CONTENTS

1. **INTRODUCTION**

The IMTA system in essence integrated species from different trophic levels within a certain area to maintain optimal production but reduce the negative effects of feed loss (Chopin et al., 2010; Fang et al., 2014; Fang et al., 2016). In that system, the waste nutrients produced from higher trophic species can be re-used by lower trophic species. The design to combine different species are complicated but important concerning the aquaculture setup in certain areas. Farming species for different trophic levels should be carefully chosen. The combination of shellfish-seaweed is a basic IMTA mode. There is no additional biogenic element input through management in the filter-feeding shellfish-seaweed mode, moreover, it is an important mode that is beneficial for the environment (Tang et al., 2011). Seaweed can absorb dissolved biogenic elements, such as carbon dioxide (CO_2), dissolved inorganic carbon (DIC), ammonia (NH_3), nitrite (NO_2^-), nitrate (NO_3^-) and phosphorous (P), while simultaneously produce oxygen. While the filter-feeding shellfish can utilize organic particles and produces NH_3^- and CO_2 for seaweed. At the same time, shellfish can imbed quite significant quantity of carbon into their shells in the form of $CaCO_3$ during the calcification process. Thus, the two species benefit each other in the IMTA system.

Land-based IMTA integrating the biological characteristics and ecological habits of different cultured organisms takes full advantage of pond space and resources, which is making effective use of organic composition and obtaining the output at the same time. It achieves self-healing aquaculture environment. At present, compared with monoculture, Land-based IMTA can get economic benefits of output without reducing the culture density of main species, which greatly reduces the cost of monoculture (Wang and Wei, 2008). Therefore, the Land-based IMTA provides significant economic benefits. Development of Land-based IMTA improves the quality of products and environment recovery. To promote IMTA at different trophic levels, it is needed to enhance the ecological complementarity and mutual benefit, as well as the economic and ecological benefits; it is a good way to abandon and transform some ponds, rebuild wetland ecosystems, and protect aquaculture ecosystems. By utilizing the biological characteristics of different aquaculture species and rationally collocating the aquaculture pond structure, the economic and ecological benefits of seawater pond aquaculture can be realized through the regulation of water quality and the establishment of ecological disease prevention technology. The result will promote the transformation of Land-based aquaculture mode. The technology will establish sustainable development of aquaculture mode.

According to the amended "Project Cooperation Agreement Between the United Nations Office for Project Services and Yellow Sea Fisheries Research Institute of Chinese Academy of Fishery Sciences of Ministry of Agriculture (YSFRI-CAFS-MOA), People's Republic of China" (PCA) in Dec. 2018, the RWG-M group should give technical support to two IMTA demonstration sites. The IMTA sites are in the south of Sanggou Bay and Haiyang Yellow Sea Aquatic Product Co., Ltd., a land based aquaculture area, in the south of Haiyang City. We demonstrated "filter-shellfish and seaweed" IMTA in the Sanggou Bay. And a "fish, sea cucumber and filter–shellfish" land-based IMTA system has been demonstrated in Haiyang. The technical procedures are listed in this report.

2. STUDY AREAS

2.1 Demonstration site in Sanggou Bay

Sanggou Bay (37°01–37°09′ N, 122°24′–122°35′ E), located in Shandong Provence, China, is a well known typical IMTA area. There were more than 30 important aquaculture species of which shellfish and seaweed were the main cultured ones (Zhang et al. 2007). The IMTA demonstration site in Sanggou Bay located at Rongcheng Chudao Aquatic Co., Ltd (Fig. 1).

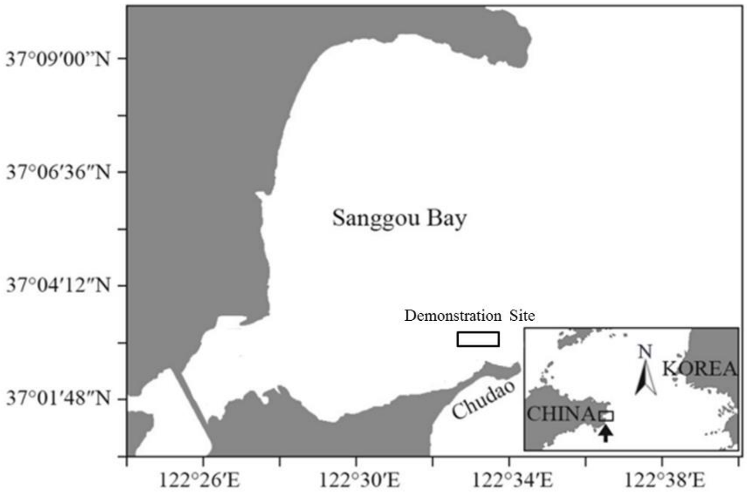

Fig. 1 The IMTA demonstration site in the Sanggou Bay

2. 2 Land-based IMTA demonstration site in Haiyang

Haiyang Yellow Sea Aquatic Product Co., Ltd. was established in 1998. In 2004, it was run together with the Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences. It is a typical enterprise that combines scientific research with production. The company has 16000m^3 for indoor aquaculture, 30000 m^3 for modern technical aquaculture (main recycling aquaculture system), 10000 m^3 for ecological aquaculture pond, and 140 ha^2 for pond aquaculture. The IMTA system including indoor and outdoor ponds will be demonstrated in part of the aquaculture area (Fig. 2).

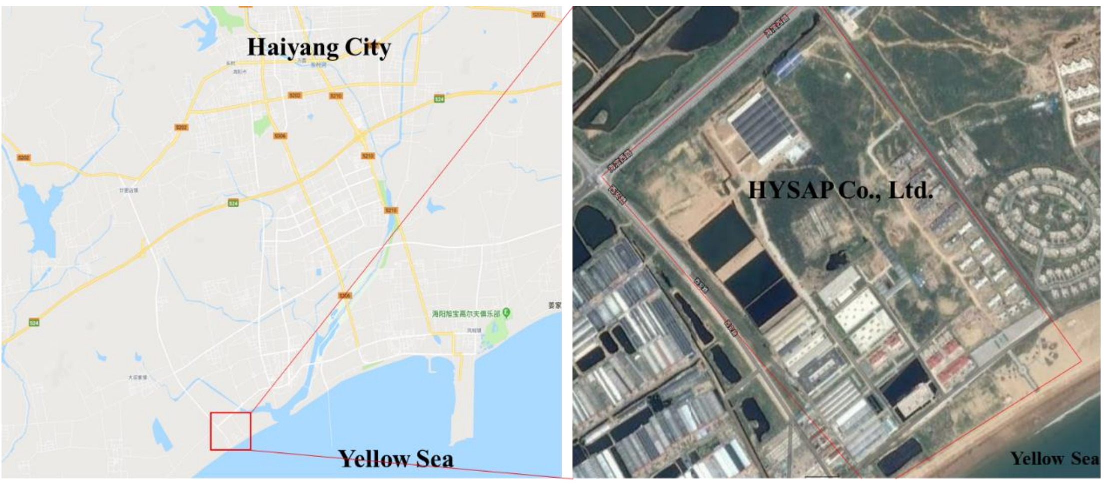

Fig. 2 The location of Haiyang Yellow Sea Aquatic Product Co., Ltd. (HYSAP Co., Ltd.).

3. THE IMTA DEMONSTRATION IN SANGGOU BAY

3.1 Site selection

Site for farming shellfish and seaweed using the longline culture system usually require reasonable shelter from waves and wind, high water quality, adequate tidal flow, depths of at least 5 m up to 20 m and ample phytoplankton food supply. The muddy sand sediment type is better to the placement of longline facilities. Further, the site should have no industrial or sewage pollution, and environmental indicators should meet the requirements of the national standard.

3.2 Filter-feeding bivalves and seaweed integrated aquaculture system

According to the mutual benefit and biological characteristics of the filter-feeding bivalves and seaweed, *Saccharina* is the suitable bioremediation species during winter and spring, while *Gracilaria* is more suitable during summer and autumn.

Longline culture is mostly used in integrated aquaculture of filter-feeding bivalve and seaweed. The direction of the longline should be consistent with the direction of the seawater. The section of the longline holding the buoys or floats is called the backbone (Fig. 3). Typically, the length of each backbone is 100 m with a 5 m gap between each other. A synthetic rope of 2.4 cm called a warp is attached to the edge of the backbone. The warp is generally three times the depth of the water. The warp is moored on the seabed by a heavy weight anchor or stake anchor. Buoys with 30 cm diameters are spaced appropriately to support the mass of growing bivalves on the backbone. The lantern net with scallops or oysters inside are hung on the backbone. The space between the 2 lantern nets is 2.3 m with 43 units per 100 m backbones. Horizontal kelp rope cultivation is the typical method for kelp longline culture system. Each kelp rope is combined with two short kelp ropes with the length of 2.5 m. Between two adjacent floating backbones there are 174 kelp ropes parallel. The floating backbones and kelp ropes are connected by two hanging ropes and one hanging buckle. About 40 individuals of kelp are planted on each kelp rope.

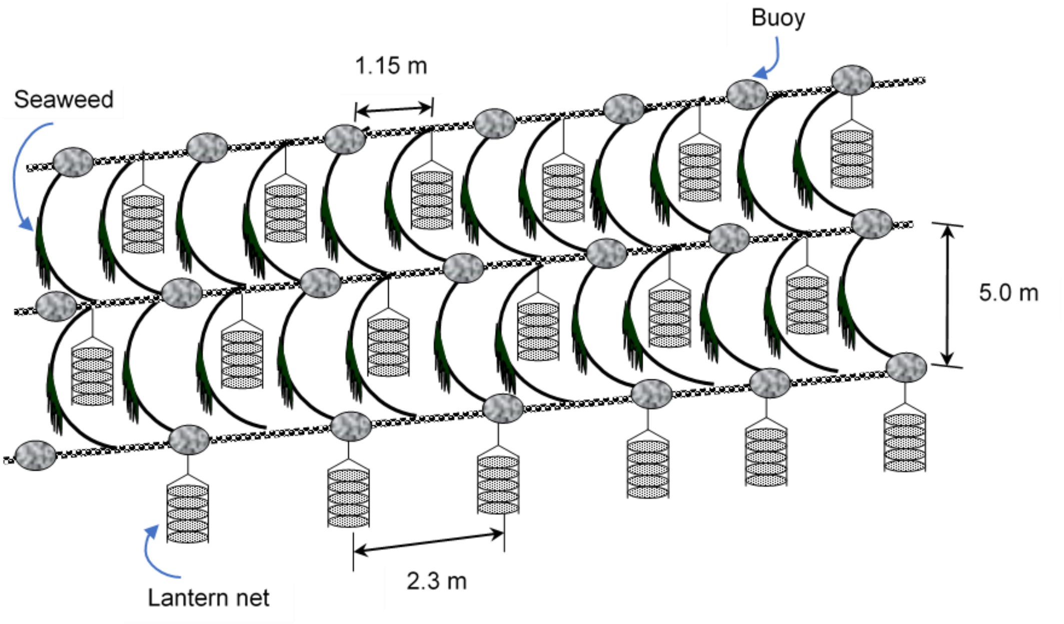

Fig. 3 The structure of longline system for shellfish and seaweed integrated aquaculture

3.3 Requirements of seeds

Seeds should be produced by enterprise with seed production license. They are used after inspection and quarantine to prevent the seed that does not meet market requirements.

When the kelp seedling is harvested, the kelp exceeds 15 cm are taken and used for seeding. The seedlings are collected and placed in the seedling baskets in sequence. The seedlings should not be damaged when they are harvested. The collection and transportation should be shortened as much as possible. The action should be light and fast.

Gracilaria sp. is usually used the adult fragment as the seedlings.

Oysters are selected to have the characteristics of fast growth and less disease. The monomeric oyster is used in this area. The length of the oyster are more than 3 cm.

3.4 Seeding time and density

The Seeding time of kelp seedlings varies according to the sea area, which is depending on the water temperature. Generally, when the water temperature drops below 20℃ in autumn, the seeding can be started. It is from November to December at the demonstration site, which is also the right seeding time in the northern China seas.

Gracilaria sp. is usually seeding in June and July of the year, which is after the harvest of kelp.

Oysters generally start seeding when the water temperature in the northern seas is around 10 degrees, that is, from April to May in spring.

3.5 Stocking density

The algae seeding ropes are spaced 1.15m apart, and each seeding rope has 32 seedlings. The number of seeding ropes per 100m long line rope is about 87 seeding ropes, about 52,500 seedlings per ha^2.

The spacing of the monomeric oyster cages is 1.5m high, 10 layers, 20-30 individuals per layer. The oyster density is about 300,000 individuals per ha^2.

3.6 Daily management

Daily management is necessary to maintain the good growth condition of the organisms, which includes the cleaning of fouling organisms, maintaining the facilities, examining the quantities of the buoys, monitoring related environmental factors. Moreover, it is important to keep records so as to trace the products through all stages of production.

3.7 Production and economic income

The average length, width and wet weight of kelp in IMTA demonstration area were 323.75cm, 43.45cm and 1227g, respectively. The kelp in monoculture area were 273.75cm, 39.50cm and 830.5g respectively. The average shell length, shell height and wet weight of oyster in IMTA demonstration area were 10.22 cm, 5.69 cm and 124.73 g, respectively.

Compared with monoculture area, the density of kelp in IMTA demonstration area decreased by 33.43%, the average wet weight of kelp increased by 47.74%. The yield rate increased by 14.8%, the labor cost decreased by 10%, and the economic benefit increased by 57.85%. The monomeric oysters was increased from the average weight of 6.25g to 124.73g. The comprehensive benefit of the IMTA demonstration area was increased by 131.1% (Table 1).

Table 1 The parameters of IMTA demonstration and kelp monoculture

Parameters	IMTA	Monoculture
average wet weight of kelp (kg)	1.24	0.85
Production (kg)	151032	166663
Dry kelp : wet kelp	0.142	0.125
Dry kelp production (kg)	21446	20832
Kelp price (Yuan/kg)	6	5.4
Total income (Yuan)	289926	112492
Material cost (Yuan)	87000	11000
Labor cost (Yuan)	89000	52000
Other cost (Yuan)	18000	8000
Profit (Yuan)	95926	41492
Oyster production (kg)	26875	—
Oyster price (Yuan)	6	—
Profit improved (Yuan)	+131%	—

3.8 The water quality at the demonstration site

In April, July, November 2018 and January 2019, the project conducted a survey on the physical and chemical factors and bio-distribution at the IMTA demonstration site. The parameters of the survey included temperature (*T*), salinity (S), dissolved oxygen (DO), pH, Water transparency, dissolved inorganic and organic nutrients (nitrate nitrogen, nitrite nitrogen, ammonia nitrogen, phosphate, silicate, total dissolved inorganic nitrogen (DON)), graded chlorophyll, particulate organic matter (POM) content. Because the main factors restricting the primary productivity of Sanggou Bay are the availability of nutrients and the existing chlorophyll levels, the main environmental parameters and nutrient salt and chlorophyll levels obtained from the surveys were summarized in Table 2:

Table 2 The main environmental variables, Chl *a* and POM concentrations in the four seasons at the demonstration site in Sanggou Bay

Parameters	Spring	Summer	Autumn	Winter
Temperature (°C)	12.14	23.96	12.80	3.66
Salinity (psu）	32.28	31.90	29.44	32.72
Transparency (m)	2.55	4.30	1.10	0.60
pH	7.96	8.09	7.97	7.99
Dissolved Oxygen (mg/L)	8.67	7.68	8.62	10.62
NO_3^- (μmol/L)	0.01	0.29	0.51	0.02
NO_2^-(μmol/L)	0.06	0.14	0.10	0.31
NH_4^-(μmol/L)	0.49	1.84	1.48	1.38
PO_4^{3-}(μmol/L)	0.36	0.09	0.10	0.51
TN	0.55	2.27	2.08	1.69
N:P	/	24.10	21.28	/
SiO_4^- (μmol/L)	0.03	2.13	/	/
Total Chl-*a* (μg/L)	0.29	2.71	4.15	0.42
Chl-*a* 0.45-2μm (μg/L)	0.00	0.94	0.24	0.10
Chl-*a* 2-20μm (μg/L)	0.16	1.25	2.81	0.10
Chl-*a* ＞20μm (μg/L)	0.13	0.52	1.11	0.22
POM (mg/L)	6.14	9.96	4.20	2.76

During the survey period, the seasonal variation of temperature was obvious. The range of variation during the year was 3.66-23.96 °C. The salinity was stable and was the lowest in autumn and highest in winter, with the value of 29.44 and 32.72, respectively. The transparency of seawater varied from 0.6 to 4.3 m in the four seasons, The DO was 7.68 mg/L in summer, and 10.62 mg/L in winter. The total inorganic nitrogen concentration in surface water was the lowest in spring and highest in summer, with the range of 0.55-2.27 μmol/L. The chlorophyll-*a* concentration in the surface was the lowest in spring and the highest in autumn, followed by summer. The phytoplankton with a size strange of 2-20μm in autumn was 2.81μg/L, accounting for 67.7% of total chlorophyll, while in summer, phytoplankton size was mainly in the range of 0.45-2μm and the proportion is 46.1%. The total particulate organic matter (POM) was the lowest in winter and the highest in summer, with the value of 2.76 and 9.96 mg/L, respectively. According to the National Sea Water Quality Standard of China (GB 3097-1997), the parameters of the IMTA demonstration area mentioned in GB 3097-1997 are in accordance with the highest standard. The IMTA system could keep high environmental quality and economic profit.

4. LAND-BASED IMTA DEMONSTRATION IN HAIYANG

4.1 Site selection

The construction of aquaculture ponds should be selected in a region with stable seawater salinity and convenient drainage. There is no source of sewage discharge around, and no large amount of fresh water injected. The area should be close to the low tide line to ensure the water quality is good. Sea water well is also good choice for the indoor fish aquaculture. The water quality in the sea meets the requirements of the Water quality standard for fisheries (GB 11607-1989).

4.2 Land-based IMTA system

Land-based IMTA system includes indoor aquaculture area and outdoor ponds. The water from the sea or well pumped into the indoor area then flow into the outdoor area. The species in indoor ponds are fed species including fish, shrimp et al. The feces and unfed feed are flowing with the water. The farming ponds must have perfect access gates and channels. The drainage channel should be divided. The height of the bottom of the ponds should not be lower than the low tide line of the seawater. The drainage gate should be built at the lowest position of the bottom of the pond, so that the water flow in the pond can be smooth and the bottom water can be drained. A reservoir should be established with a corresponding pump. The reservoir can be designed at a high level, using a combination of sea water and underground water. When the high tide comes, the water is in with tide, and when the tide is low, the water is in with pump. The maximum daily water exchange capacity is above 30%.

The outdoor ponds area can be adapted to local conditions, generally $1hm^2$ - $10hm^2$. The depth of the pool is above 2.5m. The bottom is a sandy bottom with a hard bottom. The dam should have strong wind and wave resistance. It should be protected by cement slab or stone. The slope ratio is 1:1.5-1:2.5. The outdoor ponds are connected with indoor ponds. The water comes from indoor discharged water. It is $1ha^2$ outdoor pond corresponding to 6000 m^3 indoor aquaculture pond.

4.3 The species

The indoor area cultures fishes such as turbot, Japanese flounder, tongue soles, American black sea bass, and shrimps such as Chinese shrimp, Japanese prawn et al. The species cultured in indoor ponds are high economic value. They are fed with artificial feed. The whole life of the species are stay in the artificial environment. The larvae, fry are from artificial breeding. They density is reducing as the individuals growing up. Different species have various densities in the indoor area.

The water discharged by the indoor area flows along the channels into the outdoor pond. There are a lot of wild algae in the channels, which could absorb the dissolved nutrients. The organic materials, nutrients are taken into the pond. The sea cucumber and scallop are the main species, which could consume the organic particles. The scallop filters the water to feed on microplankton which is a main population absorbing the dissolved nutrients. There are also some wild algae in the pond, which could absorb the dissolved nutrients. The feces of scallop is a good food resource for the sea cucumber.

4.4 The facilities in the outdoor pond

The facilities in the outdoor pond mainly are the artificial reefs for sea cucumber, which include scallop culture cages, plastic sunshade net and stones etc.

The scallop culture cages are connected end to end, and are stretched and fixed to the bottom of the pond with a rope. Some stones can be placed in the cage to prevent it from rolling. The scallop cage net has lots of openings for the freely movement of sea cucumber.

The plastic sunshade net is 2m~3m wide and 20m~30m long. It is double-layered and fixed just above the bottom of the pond. The bottom layer is 3cm - 5cm from the bottom, the height is 30cm from the bottom of the pool, the upper layer is 10cm from the bottom of the pond, and the height is 50cm from the bottom of the pond. A lot of openings on the net are needed for the movement of the sea cucumber. It covers about two-thirds of the total area of the pond.

The stones at the bottom of the pool are ridged or piled. The size of the stone is preferably 10kg to 20kg. The ridge (or pile) has a bottom width of 1 m to 1.5 m, a height of 0.5 m to 0.6 m, and a pitch of 1 m to 3 m.

The ponds are built as conventional earthen ponds with sandy bottom, with a bottom aeration system to increase culture capacity. A boat is need in the pond for daily management. The water discharged from the indoor ponds contains large amounts of food debris, feces and other organic particles which are food source for filter-feeding shellfish and sea cucumber. Thus, when the indoor culture water is discharged into the outdoor ponds through the circulating channels, phytoplankton and most debris can be directly absorbed by shellfish. The particles could attached on the artificial reefs for the sea cucumber. They will feed on the particles on the reefs. The remaining part will be broken down into small organic and nutrient particles by microorganisms and phytoplankton, and then absorbed by shellfish and sea cucumber.

4.5 The seeding in the outdoor pond

The juvenile sea cucumber is 200 ind/kg to 20 ind/kg. Generally, the juvenile sea cucumber is putted in plastic bags without water and air. The plastic bag containing the sea cucumber and then placed in a foam box with ice. The transport time of this method is better within 7h-8h.

The juvenile bay scallop is 3cm-4cm. It is transported in the foam box with ice. The transportation should be within 5h.

Seeding is carried out in spring or autumn, and the pond water temperature is 10 °C - 20 °C. Usually, the seedlings are placed between April and May in the spring, or the seedlings are placed between October and November in the autumn.

The seedling density varies depending on the pond conditions and the size of the seedlings. In principle, the amount of sea cucumber in the pond should be about 2000 kg/ha^2. The bay scallop should be 20,000-40,000 ind/ha^2.

When the seed arrive, the plastic bags of sea cucumber are placed on the surface of the pond to get a similar temperature with the water. After the temperature inside and outside of the bag is the same, the bag is opened and the sea cucumber is spread into the pond.

4.6 Management and harvest

Regular observation of water color, water temperature, salinity, dissolved oxygen and microplancton growth conducted in the pond every day. The animals' activity should be pay attention. Make sure that the daily water exchange rate is between 10% and 30%. When the water quality is not good, it is necessary to increase the amount of water exchange. After the heavy rain, the surface water should be discharged in time to supplement the high salinity water, and the salinity should be maintained above 25. If necessary, use an aerator to increase oxygen.

When the sea cucumber grows to a body weight above 150 g/ind, it reach the commercial size and can be harvested. When the water temperature in spring and autumn is between 10 °C and 20 °C, the sea cucumber is activity and easy to harvest. The scallop should be harvested in the autumn when the size is above 7cm.

4.7 The production and profit in outdoor pond

Compared to the common indoor aquaculture, the outdoor pond in the land-based IMTA system is an extra part. The outdoor pond in the demonstration site in Haiyang is only cultured sea cucumber and scallop. The investment and income are the extra fee compared to the indoor aquaculture. The sea cucumber is harvested when the body weight is about 150g. The sea cucumber production is 2,250kg. The bay scallop is harvested when the shell length is about 7.0-8.0cm. The bay scallop production is 700kg. According to the price of the product and the cost in 2019, the profit of the outdoor pond (1 ha^2) is 190,300 Yuan (Table 3).

Table 3 The production and profit of the outdoor section of the Land-based IMTA system

Parameters	Data
Average wet weight (g)	150
Sea cucumber production (kg)	2,250
Sea cucumber price (Yuan/kg)	140

Scallop production (kg)	700
Scallop price (Yuan/kg)	4
Total income (Yuan)	317,800
Material cost (Yuan)	75,000
Labor cost (Yuan)	15,000
Other cost (Yuan)	37,500
Profit (Yuan)	190,300

4.8 Environmental effects

The debris in water from the indoor aquaculture area can be eaten by sea cucumber and scallop. The wild macroalgae can absorb the nutrients excreted by the fed species in the indoor area, which can also produce oxygen for the animals in the system. The microplancton can also absorb the nutrients, which can also be used as food for feed zooplankton and shellfish. The land based IMTA system improved the efficiency of the feed. According to the water quality monitoring, the discharged water of the land-based IMTA system is much better than the water from the indoor aquaculture part. The nitrogen and phosphorus in the wastewater was significantly reduced by IMTA pond (Table 4). Before entering the IMTA pond (discharged from the indoor pond), the particulate organic matter in the indoor wastewater is mainly the unfed feed and feces of the fish. After passing through the IMTA pond, the particulate organic matter in the discharged water is mainly plankton. The organic matter (bio-elements) is transformed into alive organisms.

Table 4 The substances in the discharged water from indoor pond and IMTA pond

Parameters	Indoor pond	IMTA pond	Reduced (%)
TPM (mg/L)	15.30	15.25	0.33
POM (mg/L)	3.87	3.84	0.78
PO_4^{3-} (umol/L)	2.27	1.57	30.99
NO_2^- (umol/L)	6.54	3.76	42.51
NH_4^- (umol/L)	40.15	7.57	81.15

5. CONCLUSIONS

IMTA is a sustainable concept of aquaculture development, as the nutrient recycle is an important process in the ecosystem based on the theory of material and energy conservation. IMTA with different trophic levels (e.g., feeding organisms, filter-feeding shellfish, macro algae and sedimentary animals) can efficiently operate input energy and nutrients and reduce nutrient loss and economic risks, allowing the culture system to have high carrying capacity and profit. IMTA can balance the extra nutrient input by culture activity, which contributes to self-rehabilitation of the ecosystem.

At the demonstration sites of the project, there are at least four key points:

(1) The usage efficiency of the aquaculture area has been significantly improved.

(2) The income of the demonstration areas improved.

(3) The ecological effects of fed aquaculture have been reduced in land-based IMTA.

(4) IMTA improves efficient of energy and nutrients and reduces nutrient loss and economic risks.

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