Workpackage 3
Support the application of Integrated Multi-Trophic Aquaculture (IMTA)

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Case studies on successful polyculture examples in coastal Chinese seas

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Case studies of

Integrated Multi-Trophic Aquaculture in Sanggou Bay

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Introduction

With the rapid development of intensive mariculture, the impact of the industry on the ecosystem has become serious, and in turn the degraded environment results in higher mortality of mariculture organisms. The mariculture industry worldwide is searching for sustainable methods. Integrated multi-trophic aquaculture (IMTA) is a new aquaculture approach that by integrating the culture of fed species, such as finfish, inorganic extractive species such as seaweeds, and organic extractive species such as suspension- and deposit- feeders, can minimize the negative effects of aquaculture industry on the natural ecosystems. IMTA has been proposed for mitigating aquaculture waste release, and has advantages that may include a reduced ecological footprint, economic diversification and increased social acceptability of culturing systems. IMTA has the promise to contribute to the sustainability of aquaculture. However, most studies have focused on land-based systems, and only a few have to-date investigated the possibilities of IMTA farming in open water. In the past fifteen years, the integration of seaweeds with marine fish culturing has been examined and studied in Canada, Japan, Chile, New Zealand, and USA (Buschmann et al., 2008; Troell et al., 2003; Chopin et al., 1999, 2001, 2008; Abreu et al., 2009). IMTA have been commercially successful at industrial scales in China for many years. The main purpose of the demonstration is to show effectiveness of polyculture vs. monoculture. Therefore, comparison of the both ways is important, including productions, economic gains in one side, and environmental impacts on another side.

1. Theoretical design of IMTA

According to the prevailing conditions at the culture site there are many different possibilities of IMTA combinations. Given the vast number of cultured species around the world there are combinations that can be used in all situations from tidal flats to tropical estuaries and sandy beaches. One only has to select species from different trophic levels that have appropriate interactions. The following section will describe some possibilities that are currently in use for the different conditions occurring along the Shandong peninsular.

2. Principles of IMTA

2.1 IMTA of long-line culture abalone and kelp

In this IMTA system, the excretory and waste products generated by the abalone are taken up as nutrients by the kelp and converted into plant biomass to provide food for the abalone (Fig.2.1).

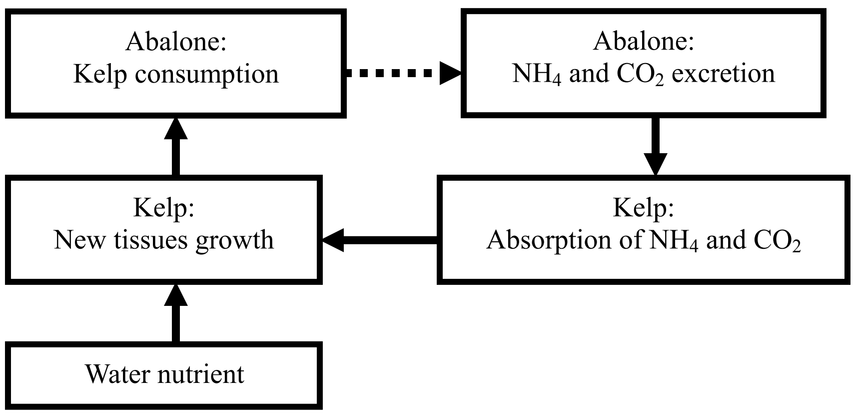

Figure 1. Diagrammatic representation of IMTA of long-line culture abalone and kelp

Culture of marine animals results in production of ammonia as the primary nitrogenous excretory product. The accumulation of nitrogen in the environment can cause the phenomenon of eutrophication and other environmental problems, which has serious effects on the sustainable development of aquaculture. In contrast, seaweed can transform ammonia-nitrogen into plant protein-nitrogen by photosynthesis, which can be used as a source of nutrition for herbivores, e.g. abalone.

2.2 IMTA of long-line culture of finfish, bivalve and kelp

In this IMTA system, seaweeds can also be used to remove and transform dissolved inorganic nutrients from effluents of both finfish and bivalves and in return provide dissolved oxygen (DO) to the finfish and bivalves. Bivalves in the system are used as the filters to remove the suspended particle organic materials, which come from the faeces of fish, small size residual feed and the phytoplankton (Fig 2.2).

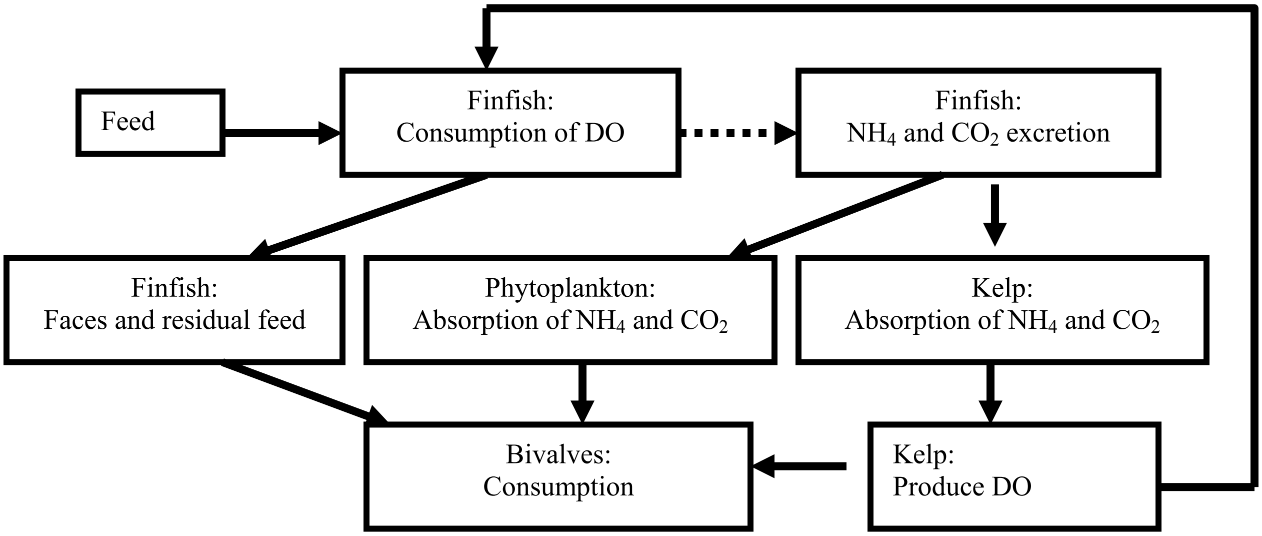

Figure 2.Diagrammatic representation of IMTA of long-line culture finfish, bivalve and kelp.

2.3 IMTA of benthic culture of abalone, sea cucumber, clam and sea weed

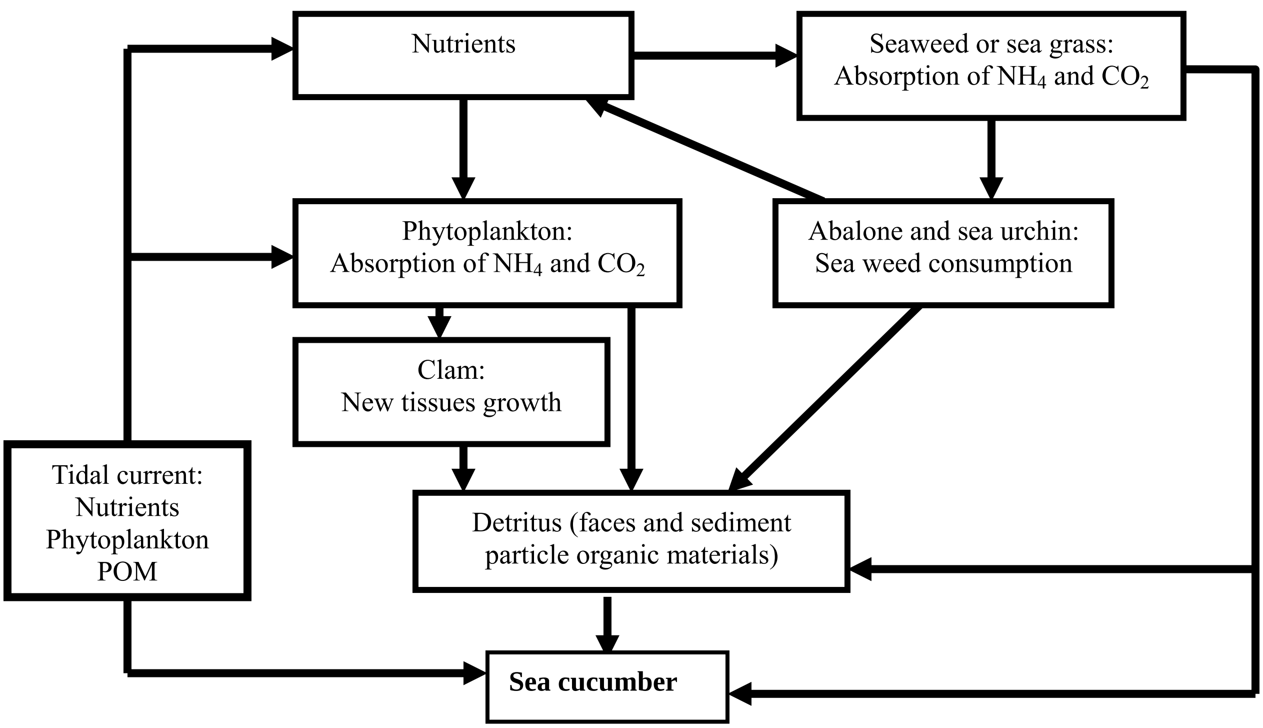

Figure 3. Diagrammatic representation of IMTA of benthic culture of abalone, sea cucumber, clam and sea weed

In this IMTA system, seaweed and clam result from natural recruitment. Seaweed is used as food for abalone and sea urchin, while sea grass in the system is regarded as having the function of providing the shelter for swimming animals and benthic organisms and for nutrient cycling. In this system, the faeces of clam and abalone, and natural organic sediment are utilized as food by the sea cucumber. The ammonia-nitrogen excreted by feeding animals is absorbed by phytoplankton and seaweed. Phytoplankton is used as the food of clam. Meanwhile, seaweed and phytoplankton provide DO to the animals (Fig. 2.3).

3. Review of current efforts on IMTA, including the environment impacts and economic impacts to farmers

Current monoculture practices especially that of carnivorous fish culture can potentially negatively impact the environment. Integrated multi-trophic aquaculture (such as seaweeds, herbivores, omnivores and detritivores) has a significant economic advantage compared with monoculture as the three dimensional space is used and the waste products of one trophic level are utilised by the other, hence densities can be increased. IMTA is just at the experimental stage in the open sea in China, and its uptake depends on the willingness of each farmer in Sanggou Bay.

A multi-species model for shellfish and kelp polyculture in Sanggou Bay had been developed, the model integrates a bay-scale ecological simulation with individual-based modelling of scallops and oysters, and upscales the individual processes for the target species by means of a multi-cohort population dynamics model. The model includes physical exchanges with the ocean boundary, biogeochemical processes within the bay, individual growth and population dynamics of target species and human exploitation (seeding and harvesting). The model is forced by light, temperature, man and exchanges of dissolved inorganic nitrogen, phytoplankton and suspended particulate matter at the ocean boundary. The model has been used to estimate the exploitation carrying capacity for scallops and oysters in the system, the harvest potential for different seeding and harvesting scenarios and the impacts on the ecosystem of different polyculture management strategies. Recently, a new mathematic model for finfish mariculture in the north of Sanggou Bay was developed. In this model, the response of environmental factors to fish culture was simulated and the carrying capacity of finfish in a virtual farm was estimated. Base on the above theoretical models, we have setup the IMTA of finfish (*Sebastodes fuscescens)*, with long-line culture of bivalve (scallop *Chlamys farreri*, oyster *Crassostrea virginica*) and kelp (*Laminaria japonica*) model. Currently, we are running the model.

4 Case studies of IMTA in Sanggou Bay

4.1 Longline culture of abalone (*Haliotis discus*) and kelp (*Laminaria japonica*)

Longline mariculture of abalone is predicted to expand rapidly in Northern China recently in order to meet the increasing consumer demands. As abalone are cultured in stacked plastic trays, feed needs to be supplied (fresh and dry macroalgae usually are main feed), the resulting excretory products and food detritus will have negative effects on natural ecosystem and may eventually impact of the health of the cultured abalone if the water quality decreases sufficiently. New approaches that include the introduction of integrated mariculture of abalone and kelp are required to minimize the negative effects of the growing mariculture industry on the environment. A potential benefit of IMTA is that of cycling of nutrients is facilitated. Excretory and waste products generated by the abalone are taken up as nutrients by the kelp and converted into plant biomass to provide food for abalone.

Method: Demonstration area of longline culture of abalone and kelp was setup at Xunshan Fishery Company, located in north coast of Sanggou Bay (Fig.4).

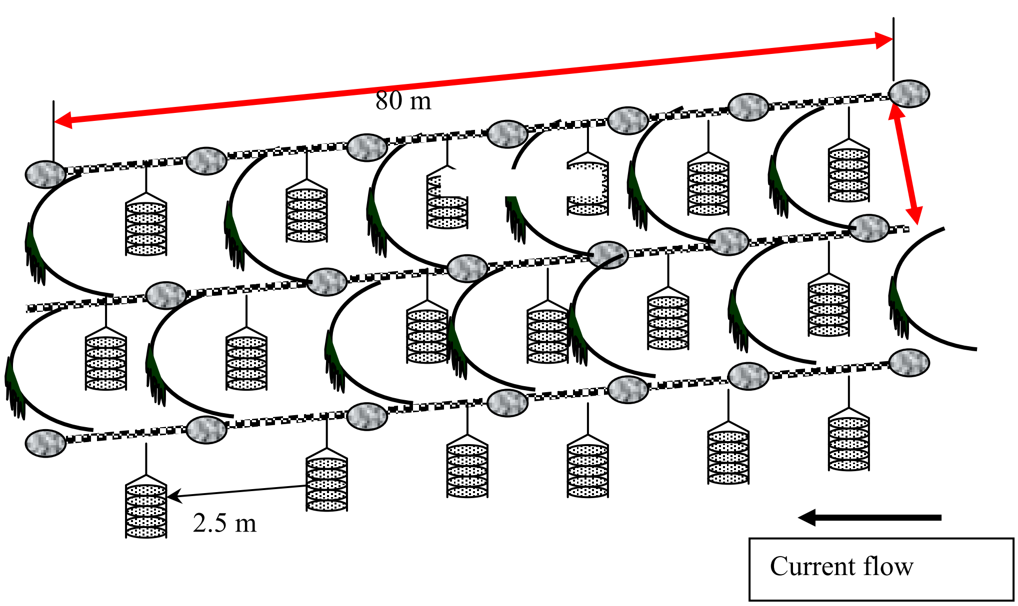

Figure 4. Cultivation units of the IMTA of kelp and abalone

For each cultivation units, there were four longline rafts. The length of one longline is 80m, the distance between two longlines is about 5m. Therefore, the total area was about 1600m^2. For each longline, 30 net cages are hung and kept at 5m in depth. About 280 abalone (shell height: 3.5-4cm) were cultivated at each net cage.

The kelp, *Laminaria japonica,* are hung at horizontal level between the abalone lantern nets. There are about 70 kelp plants cultured on each rope. The interval between two kelp culture ropes is about 2-3m. Totally, about 33600ind. of abalone and 12000ind. of *Laminaria* were cultivated at each cultivation units. Kelp was cultivated from Nov. 2008, and harvested at June, 2009.

When the *Laminaria* reach to 1m longer, it can be taken away from the culture rope, and put it into the net cage for feeding abalone. The net cage should be fed and cleaned once a week. In this way, the abalone can reach to market size (8-10cm) in 2 years.

Environmental parameters were monitored at the cultivation site (8sampaling site in the mariculture area, 2 sampling site beside the mariculture) and control site (at the outside of Sanggou Bay, without any mariculture). Water temperature, PH, DO and salinity were measured with YSI6600. Water samples were collected from 2m depth and filtered through 0.45um filter paper. The ammonium, nitrite, nitrate, phosphorus, POM, COD and chla were performed following the GB standard.

The optimum co-culture proportion of abalone and seaweed

Kelp production for abalone food wasn't more likely to limit potential abalone production than removal of ammonia excreted by abalone. Water quality is an important factor to assess the impacts of abalone farming on the environment. From our survey results at the abalone farm areas, ammonia concentration showed significant increase in summer. Therefore, at the co-culture mode (abalone and kelp), ammonia were considered as the limited factor. Ammonia excretion rates of abalone should not exceed uptake rates by kelp in order to ensure good water quality for abalone growth. According to the ammonia excretion rate of abalone and the biomass of abalone at a mariculture unit, the total ammonia released into the water column from April to November was estimated to be 2.16 kg N. Based on the growth rate of kelp and its content of N (1.34% of dry weight), the theoretic biomass of kelp that is needed to absorb the Nitrogen excreted by the abalone from one mariculture unit was calculated to be 10080 ind. In the demonstration area of abalone and kelp longline mariculture, 12000 individual of kelp were cultivated per unit which is enough to absorb the ammonia excreted by abalones. The yield of abalone every 2 years of such IMTA units is about 900kg. Based on the market price in 2009, the production value of each IMTA unit is about 70000yuan/ 1600m^2 (equal to 10000US$) in two years.

4.2 IMTA of enhancement of abalone, sea cucumber, clam and sea weed

The IMTA experiments of sea-ranching of abalone, sea cucumber, were carried out at the area of Chudao Island Company, located in south cape of Sanggou Bay. The enhancement of abalone, sea cucumber, sea urchin, clam and seaweeds takes place at 5-15m depth. The main sediment type in Chudao Island was sandy-silt, while most part of Sanggou Bay's surface sediments belonged to the type of clay-silt. The total IMTA demonstration area is nearly 665ha The main species of enhancement are sea cucumber *Apostichopus japonius*, abalone, *Haliotis discus hannai*, sea urchin *Strongylocentrotus nudus*, arkshell *Scapharca broughtonii* and clam *Ruditapes philippinurum*. In the IMTA area, the natural sea grass and seaweed are abundant, and the cover area by sea grass is about 400ha. In the spring (April or may) of every year, nearly 300000 juveniles of sea cucumber and 150000 juveniles of abalone are released into the area with the other species naturally recruiting.. In 2009, the production of demonstration area (665 ha) was 1.5 tonnes for abalone, 20 tonnes for sea cucumber, 180 tonnes for manila clam 80 tonnes for arkshell and 2.5 tonnes for sea urchin with a value of more than 10450 yuan RMB per ha.

Table 1. Annual production, market price and income of some sea-ranching species and natural species in Chudao Island

Species	Annual Production (kg)	Unit price (Yuan/kg)	Sub sum (yuan)
Sea Cucumber *Apostichopus japonius*	20000	160	3200000
Abalone *Haliotis discus hannai*	1500	600	900000

*Sea urchin *Strongylocentrotus nudus*	2500	56	140000
*Manila Clam *Ruditapes philippinurum*	200000	7	1400000
*Conch *Rapana venosa*	20000	10	200000
*Agar *Gelidium amansii*	80000	6	480000
Pacific oyster *Crassostrea gigas*	300000	0.5	150000
*Washington Clam *Saxidomus purpurratus*	80000	6	480000
Total Sum			**6950000**

Note: * show that it is natural species

4.3 IMTA of fish and algae

In China, marine fish cage farming has proved to be a productive sector of the industrial economy and has already become the main fish culture method in the coastal zone. Following this rapid development, marine fish cage culture has systematically been implicated as a potential source of serious environmental impacts on its surrounding aquatic environment. The greatest impact of marine fish cage farming on its surrounding environment results from the output of large amounts of organic wastes, in the form of uneaten food, faeces, and excretory products which may cause localized hyper- nutrification that could lead to eutrophication. In order to reduce such effects, integrated multi-trophic aquaculture (IMTA), where “extractive” and “fed” species are grown simultaneously, has been proposed as a means of using the waste resource.

The field work was carried out at the farm site of Ailian bay, Yellow sea, China (Figure 6.4). The surface area is 5.56 km^2 and the maximum water depth is 11.0 m. A total 26 cages were cultured in this area. Sea bass *Lateolabrax japonicus* and black rock fish *Sebastodes fuscescens* are the main species cultured in cages which occupied 71.82% and 28.18% respectively. There were 26 polyethylene fish cages (dimensions 5 m × 5 m × 5 m). 500 indiduals were cultured with an annual production of about 125 kg per cage. Fishes were fed with iced trash fish (*Engraulis japonicus*, *Ammodytes personatus*, *etc*) and the culture period was usually from April to January of the next year.

6.4.1 Metabolism physiology of fish

Growth

The Specific Growth Rate *(SGR)*, was calculated by

$$SGR = 100 \times \frac{(\ln W_{t_2} - \ln W_{t_1})}{t_2 - t_1}$$

where W_{t2} and W_{t1} are the body weight at time t_2 and t_1, respectively.

The special growth rate of *L. japonicus* and *S.s fuscescens* is shown in Table 6.4. It can be seen that the SGR in May was negative growth which can be explained by the adaption process of the larval fish after stocking in the cage in April. During the culture period, the growth trend was different for *L. japonicus* and *S. fuscescens.* From June to December, the SGR of *L. japonicus* ranged from 0.0571 to 0.5214 and reached to the peak in August, while the SGR of *S. fuscescens* ranged from 0.1709 to 1.0229 and reached to the peak in September. Relationship between SGR and temperature was positive correlation for *L. japonicus* and *S. fuscescens*, the correlation coefficient was 0.38(n=8, α=0.05) and 0.65(n=8, α=0.05) respectively. The relationship between SGR and weight was positive correlation for *L. japonicus* (r=0.344,n=8, α=0.05), while negative correlation for *S. fuscescens*(r=-0.268,n=8, α=0.05). SGR of *L. japonicus* was higher than *S. fuscescens.*

Table 2. Special growth rate of main cultured fish

Month	Temperature(□)	*Lateolabrax japonicus*		*Sebastodes fuscescens*	
		Weight(g)	SGR	Weight(g)	SGR
May	10.4	205.0	-0.6400	438.0	-0.0710
June	15.2	235.0	0.4406	280.0	0.2391
July	19.0	295.0	0.7335	285.0	0.0571
August	21.0	335.0	0.4102	335.0	0.5214
September	21.6	460.0	1.0229	365.0	0.2767
Octomber	18.0	525.0	0.4264	375.0	0.0872
November	12.0	630.0	0.5881	390.0	0.1265
December	7.5	664.0	0.1709	425.0	0.2780

Ingestion

For *Sebastodes fuscescens*:

$$\ln(R+1) = (S + 0.307 + 0.018T) / 0.778$$

$$F = RW / 100$$

Where F, R, T, W are food consumption rate (g·ind^{-1}·d^{-1}), ratio of ingestion (%), temperature (□) and wet weight (g).

For *Lateolabraxjaponicus*:

$$\ln C = -13.3031 + 1.3380T - 0.0237T^2 + 2.2570\ln W - 0.2203T\ln W + 0.0042T^2\ln W$$

$$F = CW/100$$

Where, F, C, T, W are food consumption rate (g·ind^{-1}·d^{-1}), average ratio of ingestion (%), temperature (□) and wet weight (g).

Ingestion rate was calculated by food consumption rate and standing stock (Table 6.5). Results showed that the ingestion rate for *L. japonicus* ranged from 1.36% to 4.38% and *S. fuscescens* ranged from 0.06% to 3.50%. The maximum ingestion rate appeared in August and July respectively for *L. japonicus and S. fuscescens* suggesting higher ingestion activity in summer.

Table 3. Food consumption of main cultured fish in different seasons

Month	*Lateolabrax japonicus*			*Sebastodes fuscescens*		
	quantity (×10^5 ind.)	standing stock (t)	food consumption (t)	quantity (×10^5 ind.)	standing stock (t)	food consumption (t)
April	1.2	48.37	29.50	0.99	44.31	7.73
May	1.02	21.99	9.25	1.12	48.97	23.78
June	1.02	27.38	19.82	1.01	39.77	15.15
July	2.19	43.24	51.48	1.10	42.16	45.76
August	2.19	46.93	63.70	1.06	42.88	32.46
September	2.19	65.22	7.39	1.10	44.94	23.40
Octomber	2.19	81.16	68.68	0.68	25.34	12.94
November	2.19	96.54	59.33	0.75	28.87	15.59
December	1.33	57.56	30.49	1.22	39.56	18.68

Oxygen consumption

Table 4. Oxygen consumption of main cultured fish in different seasons

Month	*Lateolabrax japonicus*		*Sebastodes fuscescens*	
	Weight (t)	Oxygen consumption (t)	Weight (t)	Oxygen consumption (t)
April	48.37	1.81	44.31	0.62
May	21.99	1.37	48.97	1.15

June	27.38	2.37	39.77	1.19
July	43.24	5.73	42.16	1.75
August	46.93	6.42	42.88	1.63
September	65.22	7.11	44.94	1.61
Octomber	81.16	6.41	25.34	0.89
November	96.54	5.09	28.87	0.82
December	57.56	2.32	39.56	0.75

Table 5. Faeces production (t) of main cultured fish in different seasons

Month	*Lateolabrax japonicus*	*Sebastodes fuscescens*
April	0.610	0.014
May	0.402	0.052
June	0.506	0.048
July	1.625	0.058
August	2.427	0.036
September	3.145	0.030
Octomber	1.715	0.032
November	0.947	0.030
December	0.681	0.016

4.2 The optimum co-culture proportion of fish and seaweed

Nitrogen was selected as the parameter to balance the seaweed absorption and fish produce, nitrogen entered into water was composed of three parts: feed residue, faeces, nitrogen excretion. The nitrogen balance equation can be represented as follows:

$N_{\text{(seaweed)}} = N_{\text{(fish excretion)}} + N_{\text{(feed residue)}} + N_{\text{(fish dead)}}$.

Results of metabolism physiology for fish show that nitrogen quantity in (Winter & Spring) and (Summer & Autumn) were 591.68 kg and 1544.4 kg respectively. Based on the biological characteristic, *Laminaria* and *Gracilaria* were selected as the bioremediation species in December~May (Winter & Spring) and June~November (Summer & Autumn) respectively.

Nitrogen content of *Laminaria* and *Gracilaria* was 1.34％(dry weight) and 2.70％(dry weight) respectively, So it can be estimated that the optimum co-culture proportion of fish stocking (kg) and macroalage (kg) in this area was 1 kg fish :353.25 kg *Laminaria* and 1 kg fish : 457.6 kg *Gracilaria.*

4.4 IMTA of Abalone *Haliotis discus hannai*, kelp *L. japonica* and sea cucumber *Stichopus japonica*

The sea cucumber is a detritivore species feeding on decaying organic matter in coastal sediments. This makes it an interesting candidate for use in integrated multi-trophic aquaculture (IMTA), where its feeding on sedimented particulate matter is an unused ecological niche compared to other extractive organisms such as filter-feeding bivalves (extracting suspended particulate matter) and seaweeds (extracting dissolved inorganic nutrients). In China, sea cucumbers have a high market price and are commonly cultured in tidal ponds or indoor tanks. Abalone and kelp are co-cultured on a large scale from suspended longlines in the coastal waters of North China. In this study, sea cucumbers were added directly to abalone cages without any modification of the culture equipment, for a simple and low cost production. To evaluate the feasibility of this co-culture model, growth of sea cucumbers was studied during a 7 month field experiment in Lidao, near Sanggou Bay, Shandong Province, North China.

Method: The cages used were standard abalone cages (60x50x50 cm) containing 3 layers, suspended from kelp longlines to a depth of 5 m. Abalones (52.3±0.9 mm) were stocked at 250 cage^{-1} and fed with kelp according to normal production procedures. Sea cucumbers (65.5+2.0 g) were added to the cages at 4 densities: 1, 2, 4 and 6 individuals per layer (treatments named “1SC”, “2SC, “4SC” and “6SC”). One control cage contained 1 sea cucumber per layer, but no abalones (”1SC-0A”). There were 3 replicate cages for each treatment, except for 6SC and 1SC-0A, which had only one replicate. The experiment lasted from October 2008 to May 2009. Wet body weight of all sea cucumbers was recorded monthly. Water was sampled monthly for analysis of particulate organic matter (POM) and total nitrogen (TN). In March, April and May, sediment traps were deployed at culture depth for calculation of sedimentation rate.

Results: Results showed that during the 7 month experiment, average sea cucumber body weight increased by 96 %, from 65.5 g in October to 128.8 g in May. Average specific growth rate (SGR) for all treatments during the whole experiment, calculated as average percent growth per day, was 0.33 % day^{-1}. Growth was highest during the first month (October-November) with an average SGR of 1.00 % day^{-1} (Table 8.9). As the temperature dropped from 18 °C in October, to 3 °C in January the growth rate decreased. During the winter (November-April) growth was slow, with an average SGR of 0.14 % day^{-1}. In May, the temperature had increased to 11 °C, and during the last month (April-May) average SGR increased to 0.48 % day^{-1} (Figure 8.5).

Table 5. Average body weights of all sea cucumbers each month and specific growth rate (SGR) since previous month Values are means (±SE, n=84) for all sea cucumbers in all treatments.

Month	BW(g)	SGR(% day^{-1})
Oct.	65.5±2.0	
Nov.	90.3±2.4	1.00
Jan.	96.1±2.5	0.13
Feb.	105.2±2.9	0.26
Mar.	109.9±3.0	0.20
Apr.	110.9±3.1	0.03
May.	128.8±4.1	0.43

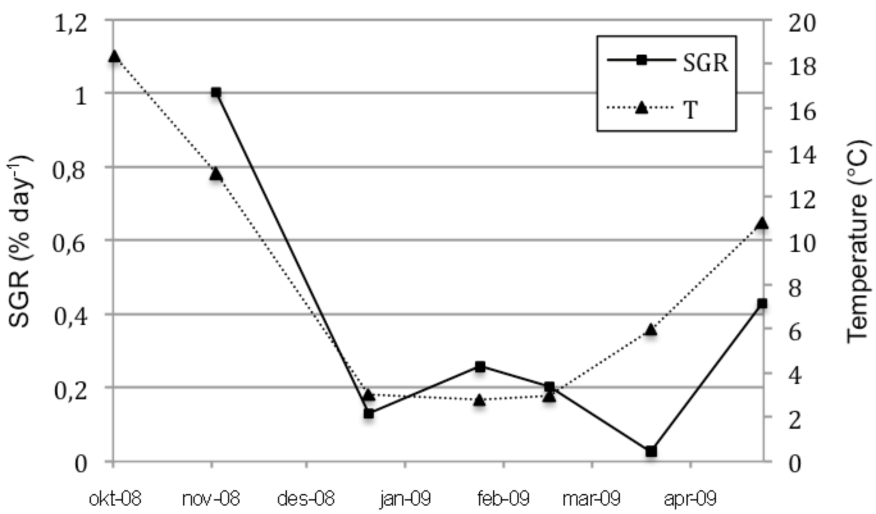

Figure 5. Specific growth rate (SGR) and temperature. SGR values are average specific Growth rates of all sea cucumbers (all treatments) since previous month.

Average SGR for the whole experiment, calculated per treatment, was highest for 1SC (0.40±0.04 % day^{-1}), and lowest for 6SC (0.30±0.01 % day^{-1}), but no statistically significant differences were found between any treatments (Table 6.10) and no clear trend is visible (Figure

8.6). All treatments showed a high growth rate during the first month, but at low temperatures during the winter (November-April) it appears that a low density of sea cucumbers gave higher growth (Figure 6.7). In the last month the trend becomes unclear again, although 1SC had the highest growth rate.

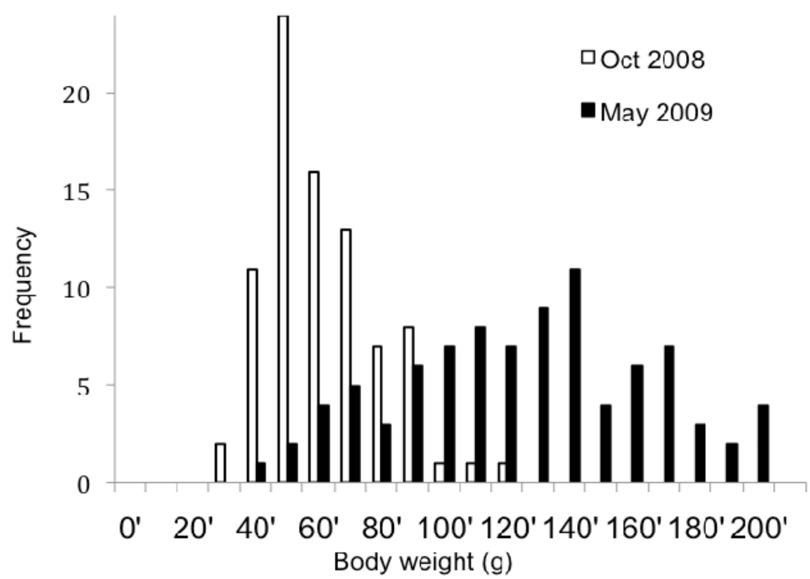

Figure 6. Size distribution. Histogram of sea cucumber body weight in October 2008 and May 2009 in 10 g-intervals.

During the experiment period from October to May, the fresh mean body weight of sea cucumbers increased from 70g/ind with the suitable culture density of 6ind./cage. To almost 140g/ind. The bigger individuals is more than 200g/ind. Sea cucumber, *Apostichopus japonica* will stop its growth when water temperature higher than 20^{o}C According to the record of local water temperature change in summer, Until early July, the water temperature is lower than 20^{O}C in the experimental site. This means that there is another 2 month for sea cucumber to grow, and there is no problem for produce 1kg sea cucumber by each net cage and by then, all most all individuals of sea cucumber can reach to market size. In 2009, the market price of fresh sea cucumber is 160yuan/kg. The production value of sea cucumber is about 160yuan/cage. Just as described above, there are 30 net cages hung in one longline for abalone culture. Therefore, the extra production value of sea cucumber co-cultured with abalone will reach to 19000yuan/1600m^2.

Including the value of abalone, the unit production value is almost 90000yuan/1600m^2, much higher than the IMTA of seaweed and abalone. Deducting the cost of juveniles of abalone and sea cucumber, the net income of such IMTA is about 37000yuan/1600m^2.

Moreover, in such kind of IMTA can produce higher environmental effect more than others because the sea cucumber in such system can utilize the POM maximally by feeding the faeces of abalone and the bio-deposit inside the net cage.

The available food sources for the sea cucumbers, includes abalone faeces, kelp detritus and “background” sediments from the water. The high sedimentation rate and the high growth rate of the sea cucumbers control group (1SC-0A), indicates that background sediments may be an important food sources. Large amounts of sediments were observed in the cages when they removed from the water.

The high overall growth rate of sea cucumbers measured in this experiment shows that adding sea cucumbers directly to abalone cages may be a feasible production technique. Compared to production in land based facilities, tidal ponds, or extensive bottom culture, this method is simple and requires a minimum of extra labour or additional investments. Considering the high market price of sea cucumber, it should be an economically interesting idea for abalone farmers. In addition to adding income to farmers and increasing the production output, the sea cucumbers may reduce the aquaculture impact on the local environment by assimilating nutrients and organic matter wasted by other farmed species.

5 Analyses of the environmental and economic benefits of IMTA

As one of the major human activities, aquaculture provides not only material products but also many other service functions. Based on the 17 major valuating parameters and methods by Costanza et al (1997), the core services of mariculture ecosystem in Sanggou Bay were selected and quantified by the market value approach, carbon tax approach and shadow project approach, respectively. Using the systemic evaluation approach, the value of the mariculture ecosystem services on four different modes including Kelp monoculture mode, Scallop monoculture mode, abalone & Kelp IMTA mode, Kelp& Abalone& Sea cucumber IMTA mode in Sanggou Bay were estimated and evaluated. The following figure shows the classification of aquaculture ecosystem service and function. Using the method of “systemic evaluation approach” we evaluated the total value of the different mariculture modes.

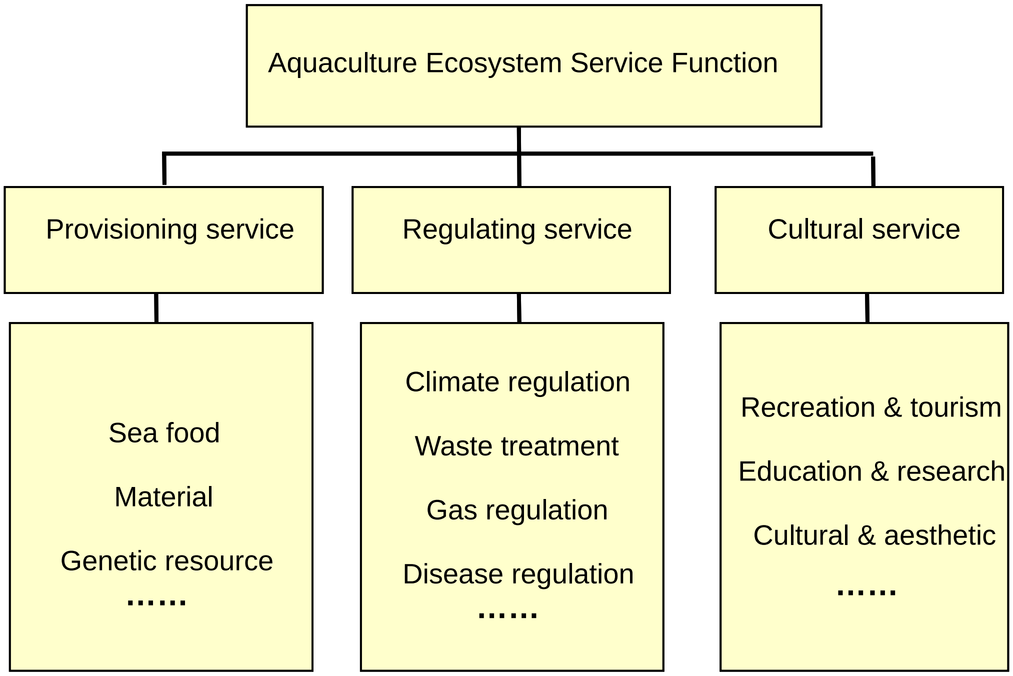

Fig 7. Classification of aquaculture ecosystem service & function

5.1 Value of food provision service in difference aquaculture mode

Aquaculture mode	Aquacultre species	Yield kg/ha/a	Market price y/kg	Income (Y/ha/a)	Cost (Y/ha/a)	Value (Y/ha/a)
monoculture	kelp	27000	6.0	162000	67500	**94500**
monocultue	scallop	18000	4.6	82800	22500	**60300**
IMTA	kelp	30000	6.0	0	72900	0
	Abalone	17308	200	1730769	1032808	697962
	Add up			1730769	1105707	**625062**
IMTA	kelp	30000	6.0	0	7.2900	0
	abalone	16615	200	1661538	926815	734723
	Sea cucumber	3600	120	216000	21600	204000
	Add up			1877538	948415	**929123**

5.2 Value of waste treatment service in difference aquaculture mode

Aquaculture mode	Removed TN (kg/ha/a)	Released TN (kg/ha/a)	Removed TP (kg/ha/a)	Released TP (kg/ha/a)	Value (Y/ha/a)		
					Benefit	lost	total
Monoculture kelp	440.1	0	102.33	0	813.65	0	813.65
Monoculture	1079.108	408.1829	/	1.2689	1618.66	614.18	1004.48

scallop							
IMTA kelp+abalone	2769.288	0.769712	113.7	/	4324.48	1.155	4323.33
IMTA kelp+abalone +sea cucumber	2768.566	0.754151	118.7438	0.00015	4360.965	1.1776	4359.79

5.3 Value of climate regulating service in difference aquaculture mode

Aquaculture mode	Fixed & removed C (kg/ha/a)	Released CO_2 (kg/ha/a)	Value (Y/ha/a)				
			Benefit		Lost		Total value
			Reforested cost	Carbon tax	Reforested cost	Carbon tax	Average value
Monoculture kelp	8424．00	0	2197.822	9232.704	0	0	5715.26
Monoculture scallop	1741.169	22.3460	454.2711	1908.322	5.8301	24.4913	1166.14
IMTA kelp+abalone	23638.85	32.0394	6167.375	25908.18	12.3668	51.9512	16005.62
IMTA kelp+abalone +sea cucumber	24054.75	31.0211	6275.884	26364.01	8.0934	33.9991	16298.54

5.4 Value of air quality regulating service in difference aquaculture mode

Aquaculture mode	Produced O_2 (kg/ha/a)	Consumed O_2 (kg/ha/a)	Value (Y/ha/a)		
			Benefit	Lose	Total value
Monoculture kelp	32400	0	12960	0	12960
Monoculture scallop	0	15.5181	0	6.2072	-6.2072
IMTA kelp+abalone	36000	22.24956	14400	8.8998	14391
IMTA kelp+abalone+ sea cucumber	36000	21.5424	14400	8.6169	14391

5.5 Total value in difference aquaculture mode

Aquaculture mode	Total benefit (Y/ha/a)	Total lost (Y/ha/a)	Economic value(Y/ha/a)	Environmental value(Y/ha/a)	Total value (Y/ha/a)
Monoculture kelp	185006	67500	94500	23006	117506
Monoculture scallop	86327	23145	60300	2882	63182
IMTA kelp+abalone	1765531	1105769	625062	34700	659762
IMTA kelp+abalone+sea cucumber	1912619	948459	929123	35036	964160

It can be seen that the value of the mariculture ecosystem services provided by IMTA mode were much higher than monoculture and IMTA mode.