unuftp.is Final project 2014

POTENTIAL OF COMMERCIAL AQUACULTURE OF MANTIS SHRIMP IN CHINA

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ABSTRACT

This project plans to test the possibility of building a cost-efficient way to breeding and culture mantis shrimp *Oratosquilla oratoria* in idle ponds and benefit the local communities in northern China, and the stable supply of mantis shrimp juveniles for successful aquaculture can also play a key role as a means of restoring and enhancing mantis shrimp stocks in future. In 2014, the breeding and rearing of mantis shrimp were conducted by ecosystem based management on ponds from March to October in Pikou, Liaoning Province, China. The wild-caught broodstock was artificial accelerated matured in the concrete tanks by feeding of polychaete *Nereis succinea*. The embryo development time was 30s days and larvae developed to post settlement mantis shrimp within 20 days at the salinity of 30-32 ‰ and temperature of 16-24 ℃ in ponds. The mysid *Neomysis awatschensis* was cultured as the best biofeed of larval mantis shrimp for its logistically and economically feasibility. 35.1 thousand larval mantis shrimp per square meter was evaluated in 2 m depth pond on 20 June. Pond culture of post settlement mantis shrimp is possible and they grow well. The aquaculture of mantis shrimp can be proved commercial by feeding low price stray fishes and clams. The mantis shrimp reached marketable size at September with the body length of 11.00 ± 0.97 cm (n=10).

This paper should be cited as:

Xing, K. 2015. *Potential of commercial aquaculture of Mantis shrimp in China.* United Nations University Fisheries Training Programme, Iceland [final project]. http://www.unuftp.is/static/fellows/document/xing14prf.pdf

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1 INTRODUCTION

Mantis shrimp *Oratosquilla oratoria* is found on muddy bottoms in coastal waters and distributed throughout the West Pacific from southern Russia, Japan, China, Vietnam, eastern Australia to New Zealand (Ahyong 2012) (Figure 1). It is exploited commercially along the coastline of China (Pan *et al.* 2013). As a popular delicacy and the landing is far from satisfying the market demand in China since 1990s. Landings of mantis shrimp in northern China have significantly declined due to high fishing intensity and illegal trawling along the coastline from the 1990s (Deng and Jin 2001). The sustainable exploitation and utilization of mantis shrimp in China has been becoming an urgent issue. A decade ago a collaborative group was established at Dalian Ocean University to conduct research on breeding and eco-physiological requirement related to the aquaculture of mantis shrimp mantis for many years (Liu *et al.* 2006, Lin *et al.* 2008, Xu *et al.* 2008, Liu *et al.* 2009, Liu *et al.* 2012, Liu *et al.* 2013a, Liu *et al.* 2013b). In my project, I will present our study on the breeding and culturing of mantis shrimp.

Figure 1: The mantis shrimp *Oratosquilla oratoria* (Crustacea, stomatopoda) (Photo by Qi Liu).

1.1 The life history of mantis shrimp

The mantis shrimp is the dominant species in the coastal fishery in China (Yu *et al.* 2011). Size at first maturity is estimated to be around 7 cm-8 cm body length (Zhai and Jiang 2002, Kodama *et al.* 2004). The mantis shrimp copulates before spawning season and the sperm preserves in female until egg-laying (Hamano 1988). Single spawning tends to take place in 1 m waters following a spawning migration every year (Herbert 2011). In Tokyo Bay, the spawning season is from May to September depending on different body size. Most large females (body length > 10 cm) spawn in May (Kodama et al. 2005). In northern China, the spawning season is from June to July when the temperature of sea water is above than 18 ℃ (Liu *et al.* 2013b). Females guide the eggs in their burrows (Mili *et al.* 2011). They do not leave their burrows and do not feed while the eggs incubation (Wang *et al.* 1998).

The larval development of mantis shrimp is divided into eleven stages (Hamano and Matsuura 1987). The body size and duration of each stage are shown in Table 1 (Liu *et al.* 2009). The pelagic larvae of mantis shrimp exhibited positive phototaxis (Dingle 1969, Hamano and Matsuura 1987), while the post settlement mantis shrimp is living in burrows (Dingle and Caldwell 1972).

Table 1: The body length and duration of incubation of different developmental stages in larval mantis shrimp in the pond (P: peudolarvae, n=20) (Liu *et al.* 2009).

Larval stage	Time (d)	BL (mm)
P Ⅰ	1	1.71±0.07
P Ⅱ	1-2	2.17±0.12
P Ⅲ	3-4	2.93±0.24
P Ⅳ	5-10	3.20±0.27
P Ⅴ	6-12	4.72±0.21
P Ⅵ	11-17	6.34±0.86
P Ⅶ	16-20	9.27±1.36
P Ⅷ	19-26	11.56±0.85
P Ⅸ	22-28	14.39±0.59
P Ⅹ	24-30	16.23±0.65
P Ⅺ	27-	19.98±1.12
Post settlement mantis shrimp	33-	17.82±0.60

1.2 The aquaculture of mantis shrimp

Aquaculture of mantis shrimp can be divided into three main parts, the feeding of larvae and adult, the breeding of larval mantis shrimp and the culturing of post settlement mantis shrimp, to answer these concerns are the key point for the potential aquaculture of mantis shrimp.A series of experiments are carried out in order to analyse the feasibility of breeding and aquaculture of mantis shrimp. Firstly, the feeding habit of *Mantis shrimp* is examined in the laboratory in order to study the feeding patterns and prey selection in the aquaculture. Secondly, the economical and operable ways on the feeding on the post settlement mantis shrimp is also required.

1.3 The objective of the study

The purpose of breeding mantis shrimp is to develop a low-cost and environmentally friendly way to culturing large numbers of larvae for aquaculture and potential restocking programmes. The objective of ecosystem based breeding on mantis shrimp is to maximize the biomass production and keep the ecosystem stability through artificial modification in ponds. The specific objectives of the experiments include:

A) To test the best and most economical feed for the larval mantis shrimp.
B) To optimize the condition in the pond for the breeding and rearing of larval mantis shrimp.
C) To analyse the growth potential and growth rate of post settlement mantis shrimp.

2 MATERIALS AND METHODS

The experiments took place at the Jinrui aquaculture rearing station from March to October 2014, where was located in the Pikou, Dalian, in the north of Yellow sea of China (39°23'42.13"N, 122°20'51.05"E). The station was close to the coastline and good accessed to non-polluted sea water.

2.1 The feeding habit of larval and post settlement mantis shrimp

2.1.1 The feeding habit of larval mantis shrimp

In order to test the feeding selectivity of different feed of larval mantis shrimp, and the effect of the mysid *Neomysis awatschensis* as the biofeed for larval mantis shrimp, laboratory experiments on the feeding preference of larval mantis shrimp were done in the breeding plant on June 2009 and July 2011.

For the experiment on June 2009, the square aquaria (8 L, 36 cm L × 25 cm W × 9 cm H) with the aerated filtered seawater was used of the temperature 20.0-23.6 ℃, salinity 22.5-25.0 ‰ and pH 7.80-8.40. The body length of larval mantis shrimp ranged from 19.82 to 25.51 mm in 2009, the frozen mysid, the living mysid, the pelleted complete shrimp feed, the mixed group of the living mysid and the pelleted complete shrimp feed, and fresh clams were used as the feed on larval mantis shrimp, respectively. Every feed item and 10 larval mantis shrimps were placed together as one group to test the feeding preference, the experiments lasted for 48h (Liu *et al*. unpublished results). The uneaten feed was observed in the end of the experiment to test the appetite of larvae mantis shrimp.

The experiments on the feeding rate of larval mantis shrimp were conducted in June 2011 (Liu *et al*. 2012). 15 larval mantis shrimp and 30 mysid were placed together in square aquaria (8 L, 36 cm L × 25 cm W × 9 cm H), and three groups were repeated. The aerated filtered seawater used in this experiment was of the temperature 22-24 ℃, salinity 27 ‰ and pH 8.45-8.60. The body length of mysid was 5.19-8.91 mm, the average weight was 0.058 g. The feeding of larval mantis shrimp was determined by more than half of mysid body was eaten in the aquaria, the experiment lasted for 24 hours, and the feed rate of individual larval mantis shrimp was calculated by the multiplication of the number of the eaten mysid and the average weight of them.

2.1.2 The feeding habit of post settlement mantis shrimp

A laboratory experiment was conducted in 2010 to examine the feeding patterns and feeding rate of adult mantis shrimp. The body weight of the adult mantis shrimp was 18.03 ± 4.24 g (n= 13), the carapace width was 20.07 ± 2.89 mm (n= 13). The common species polychaete *Nereis succinea* was used as the feed for the post settlement mantis shrimp, the *N. succinea* was added at the start of the experimental period. Each adult mantis shrimp was fed separately in the square aquaria (8 L, 36 cm L × 25 cm W × 9 cm H), 13 individuals of mantis shrimp were used (Body weight: 18.03 ± 4.24 g, n=13). The feeding rate of mantis shrimp was determined by the feed intaking on *N. succinea* over 24h period under the seawater temperature of 15-18 ℃ in the aquaria.

2.2 The experimental ponds and tanks

2.2.1 The description of ponds

To our experience, the area of rearing ponds should be larger than 0.1 hectares. In 2014, we used two ponds for the breeding of mantis shrimp. A 1200m^2 (60 m × 20 m) 1 m depth pond and a 1400m^2 (40 m×35 m) 2 m depth pond were used in the breeding and rearing of mantis shrimp (Figure 2 and 3). Both the ponds were unaerated.

2.2.2 Preparation of ponds

When preparing ponds for the breeding of mantis shrimp, two factors have to be considered, the substrate need to be suitable for the burrowing habit of the mantis shrimp and living feed need to be abundant for the larvae after the hatched.

The management of ponds was started from March 2014 when the seawater temperature had become higher than 10 ℃. The burrowing behavior of mantis shrimp preferred the clay to sand as the pond sediment, the layer of clay should be suitable for burrowing spawning of broodstock. For the management of ponds, firstly, the pond were drained and fine mud, soft sand and humus in the pond bottom were removed by heavy machinery, then the pond bottom sediment was kept under the blazing sun and disinfected by the quick lime applied 500-750 kg ha^{-1} for one week before filling the pond with sea water. After that, the seawater was drained or pump from the adjacent ditches near the sea.

The main predators of mantis shrimp are the common crab *Helice tientsinensis* Rathbun and gobiidae *Synechogobius ommaturus*. We used plastic shield around the pond to the avoidance of entry of crab and bottom crab nets to trap the gobiid fish. Temperature in the two ponds was recorded during the breeding and culture of mantis shrimp, and the sample of phytoplankton and macrobenthos in the 2 m pond was made with a plankton net (Area of net mouth: 0.1 m^2, mesh: 77 μm), and the biomass of samples was determined by hemocytometer and stereoscopic microscope, respectively.

Figure 2: The management of the 1 m pond at a depth of 1 m on average and an area of 1200 m^2 (60 m × 20 m) from March to April 2014. A) Before the removement of the bottom sediemnts and facilities in the pond; B) The water was filled at the high tide after the usage of quick limes; C) The pond was enriched by fermented chicken feces and surrounded by the plastic shield.

Figure 3: The management of the 2 m pond at a depth of 2 m on average and a area of 1400 m^2 (40 m×35 m) form March to April 2014. A) The soft sediments were removed from the pond; B) The seawater was pumped into the pond and enriched by ferment chicken feces.

We used a combination of the organic fermented chicken feces and inorganic fertilizer to enrich water. The chicken feces were fermented for 1 month anaerobically and applied to the ponds by 150 kg ha^{-1} on 20 April for the enrichment of the phytoplankton. In order to maintain the productivity of phytoplankton, a urea fertilizer was used by 15 kg ha^{-1} every week to adjust the water color. Although the dense color was more desirable for the water management, a mass mortality of phytoplankton would result in the oxygen depletion of the water, especially of the burrow-living mantis shrimp, so water exchang was carried out according to the water color and temperature in order to get rid of more progressively increased phytoplankton. Secchi disc transparency should be higher than 50 cm in ponds on summer in order to avoid the emergent vegetation due to eutrophication. Temperature, pH, and salinity of sea water in the pond were monitored every day.

Phytoplankton played an important role in maintaining the water quality and stabilizing the ecosystem by enhancing the productivity and diminishing the potential occurrence of the harmful algae bloom in the pond. The existence of the dominant green algae reduced the potential bloomy of red tide of harmful dinoflagellate. The phytoplankton also supply the food to mysid in the pond. We transferred the artificial cultured chlorella in order to increase the biomass of phytoplankton in the pond. About 10 to 20% of water in the pond was exchanged every week during the high temperature season from June to August in order to get rid of more progressively bloomy harmful phytoplankton and filamentous algae in the 2 m ponds. The dominant species of phytoplankton were recorded under the microscope during the breeding work.

During the breeding period of mantis shrimp in 2014, the mysid was extensive cultured as the biofeed in the pond. The broodstock of mysid was transferred from a nearby eutrophic trenches and ponds by dip nets during the breeding period of mantis shrimp in the breeding pond. The mysid can grow well by fed on the phytoplankton and mashed non-food fish meal. Frozen artemia was also used for the feed of transferred mysid with the usage of 10-15 kg ha^{-1} every day. The mysid population was sampled by dip nets and the development, fertility and recruitment was recorded monthly.

2.3 The selection of broodstock and the breeding of mantis shrimp

2.3.1 The preparation of broodstock

The availability of adequate broodstock was the prerequisite for the breeding. The broodstock for nursery was all the locally wild caught mantis shrimps during the spawning season at the end of April by trawling net.

The selection of broodstock was strictly conducted with a gonadal matured size (body weight > 20 g, and body length > 10 cm) and a uniform ovarian developmental stage to ensure the synchronous appearance of the larvae to avoid cannibalism. Fecundity can be evaluated visually by the development of ovary. Spawning will take place within days after the ovarian shape on the ventral side of telson was full of yellow ovary. The broodstock should be of healthy appearance, the carapace and second raptorial appendages should be intact and not damaged, and the feeding behavior was active.

The broodstock of mantis shrimp was acclimated in the concrete tank (4.5 m^3, 3 m L × 1.5 m W × 1 m H) for 2-3 days in order to exclude the inactive ones before transferred to the breeding ponds. Aerated sand-filtered seawater was used in the concrete tank and square aquarium, the water temperature was kept around 20-22 ℃. The polychaete *N. succinea* was used in the artificial maturation of the broodstock during the acclimation, and then the gonadal maturated and healthy ones were selected for breeding in the pond.

2.3.2 The stocking pond for breeding mantis shrimp

On 25 April 2014, 630 individuals of broodstock were placed in the 1 m pond, and on 30 April 2014, 720 broodstock was placed in the 2 m pond. Thus, the density of the broodstock was about 0.30-0.35 inds m^{-2} for in both breeding ponds.

2.3.3 The evaluation of larval production

The first appearance of larval mantis shrimp was monitored at night by their positive phototaxis, the crab pots were used to trap predators of larval mantis shrimp, including the post hatching broodstock. The development of larval mantis shrimp was observed under the stereoscopic microscope, and the developmental stages were determined by Table 1.

On 19 June 2014, when the PⅩ-PⅪ larval mantis shrimp was observed in the 2 m breeding pond. Before the transformation of mantis shrimp from the pelagic larvae to the burrowing post settlement juveniles, the total amount of larvae produced were estimated by randomly sampling at 6 sites near the edge of 2 m pond at night. In order to reduce the error by the concentrated distribution due to its positive phototaxis in pelagic larvae of mantis shrimp. On 20 June, the sampling was filtered through a 0.5×0.3 m diameter dip net of 4 mm mesh size within a distance of 1 m in the pond. The number of larval mantis shrimp in every net was calculated by average weight (0.033 ± 0.005 g, n=20) divided by the total weight.

2.4 The culturing of post settlement mantis shrimp in 2 m ponds and concrete tanks

In 2014, two 2 m ponds were used for the culturing of post settlement mantis shrimp from June to October. Fresh or frozen trash fish, mussel, clam were used as feed, the usage of feed were about 5 % of the total weight of mantis shrimp stocking in the pond and adjusted by the amount of remnant feed. Living prey from the naturel breeding in the ditches near the sea was also recommended as the biofeed through water exchange was undertaken every week from July to September when the temperature was high than 26 ℃.

After the estimation of the larval mantis shrimp in the 2 m breeding pond, half of larvae were transferred to an adjacent 2 m pond for the culturing. The body length and the body weight were recorded monthly from June to October, the samples were collected by snorkeling and gillnets. We collected juvenile and adult mantis shrimp from their burrows directly in both the 2 m ponds by snorkeling on 15 July, 17 August and 20 September when the temperature was 27.5 ℃, 26.0 ℃ and 23.0 ℃, respectively. A gillnet was used on 30 October when the temperature was only 12.0 ℃. Field survey by snorkeling was also conducted to estimate the stocking of mantis shrimp in the pond.

2.5 The data analysis in the culturing of mysid and post settlement mantis shrimp

For the evaluation of culturing of post settlement mantis shrimp in the 2 m ponds, the growth of mantis shrimp was recorded monthly, the absolute growth rate (Kautsky *et al.* 2000) and SGR (specific growth rate, % day^{-1}) were measured by the follow formula.

$$GR=\frac{W_t - W_0}{T - T_0}$$

$$SGR=\frac{\ln W_t - \ln W_0}{T - T_0} \times 100$$

Where W_t was the final weight of culturing mantis shrimp in pond, and W_0 represented the initial weight of last developmental stage of larval mantis shrimp, respectively. $T-T_0$ represented the time of the experiment in days.

3 RESULT

3.1 The feeding habit of mantis shrimp

3.1.1 The feeding preference of larval mantis shrimp

The laboratory experiments were carried out in order to test the effective of the cultured mysid as the biofeed of larval mantis shrimp in the breeding ponds.

The number of food item left shows the selective feeding preference of larval mantis shrimp. On June 2009, the result showed that pelleted complete shrimp feed and pieces of fresh clam fresh were total uneaten after 48 h. Larval mantis shrimp showed little appetite for frozen mysid compared to the living mysid (Table 2).

In living preparations under stereoscopic microscope, the larvae of mantis shrimp can prey mysid in the early developmental stages within their raptorial appendages (Figure 4), the slow swimming mysid was preferred as the best feed for the mantis shrimp.

For the experiment of feeding rate of the larval mantis shrimp on June of 2011, the individual foraged 0.145 ± 0.012 g (wet weight, n=3) of mysid (average weight = 0.058 g) in 24 hours of the temperature, about 2.5 mysids were foraged by each larval mantis shrimp of the body length of 19.82-25.51 mm every day.

Table 2: The feeding preference experiment made in 2009 showed the forage on 5 different feed by larval mantis shrimp. At the beginning of the experiment, 30 food items were placed in the aquaria with 10 larval mantis shrimp, the result shows the number of food item left after 48 hours.

Time	Frozen mysid	Living mysid	Living mysid + Complete shrimp feed (pellets)	Complete shrimp feed (pellets)	Fresh clam (pieces)
0h	30	30	15+15	30	30
48h	23	19	2+15	30	30

Figure 4: The feeding of mysid by larval mantis shrimp under stereoscopic microscope.

3.1.2 The feeding habit of adult mantis shrimp

Mantis shrimp aggressively grabbed the food and gulp it down to the pyloric stomach without further chewing. Laboratory experiment showed the fast feeding behavior where organisms reach fullness within one hour. The feed intaking of mantis shrimp was recorded by the weight of stomach content. There was positive correlation between the feed intaking and body size of mantis shrimp. The amount of *N. succinea* consumed within 24 hours was directly related the body size of mantis shrimp. Linear relationship was found between appetite and carapace width Linear relationship was found between the weight of stomach content of *N. succinea* and the body weight of mantis shrimp ($y = 0.0632x - 0.2261$, $R^2 = 0.5717$, $n = 13$) (Figure 5), the 24h feeding rate was about 5%.

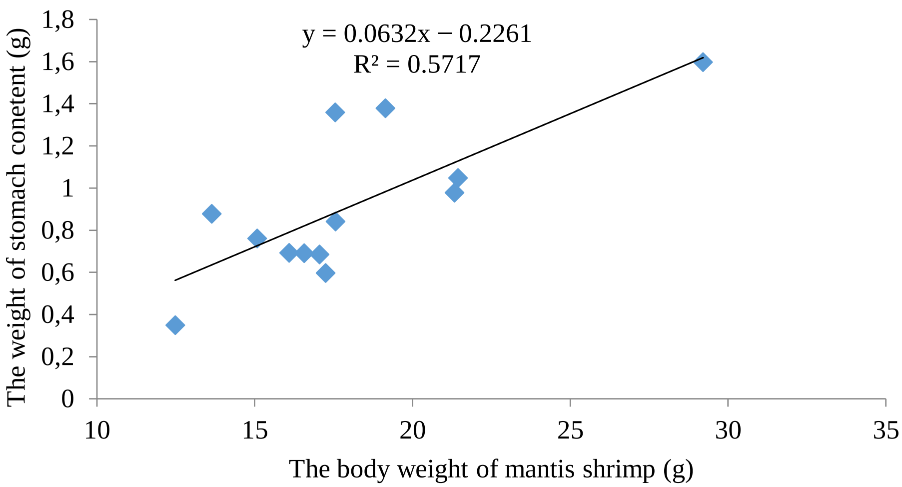

Figure 5: The feed intaking of mantis shrimp on polycheate *Nereis succinea* in the 8 L square aquaria, Pikou, Dalian (n=13).

3.2 The monitoring of the breeding ponds

The larvae grow well in 1 m and 2 m ponds. Temperature showed similar tendency in both ponds (Figure 6). After the first appearance of post-settlement mantis shrimp on 20 June, the temperature was remained above 25 °C until the end of September. The temperature was about 1-2 °C higher in the 1 m pond than the 2 m one. On 5 July 2014, the temperature in the 1 m pond reached 30.1 °C, pH 9.2, the filamentous algae was decomposing and all the larvae died (Figure 7). At that time, the temperature in the larger pond of the depth of 2 m was 28.1 °C. With the increasing temperature of the seawater in the summer time from July to September, nutrient enrichment will lead to abundant growth filamentous algae on the bottom (Figure 8).

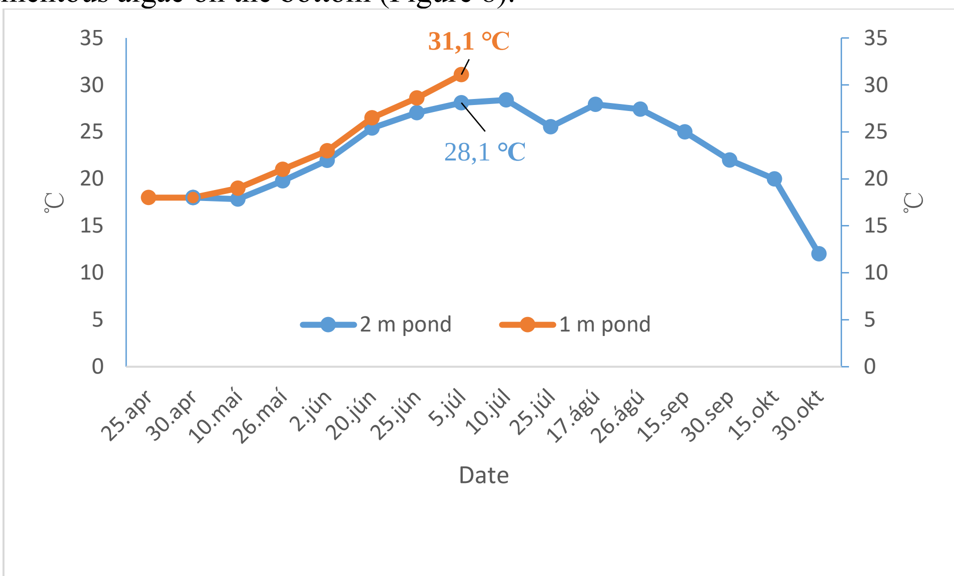

Figure 6: The environmental fluctuation and the related events in both 1 m and 2 m pond in Pikou, Dalian. The temperature was always 1-2 °C higher in the 1 m pond than the 2 m pond after 10 May 2014. The mass mortality of larvae in 1 m pond happened On 5 July 2014 when the temperature was 30.1 °C, and then the the temperature was 28.1 °C in 2 m pond.

Figure 7: The bloomy of red tide in the 1 m pond by an area of 1200m^2 on 5 July 2014 when the temperature was outreached 30.1 °C in the 1 m pond, Pikou, Dalian. All the larval mantis shrimp died dued to the red tide.

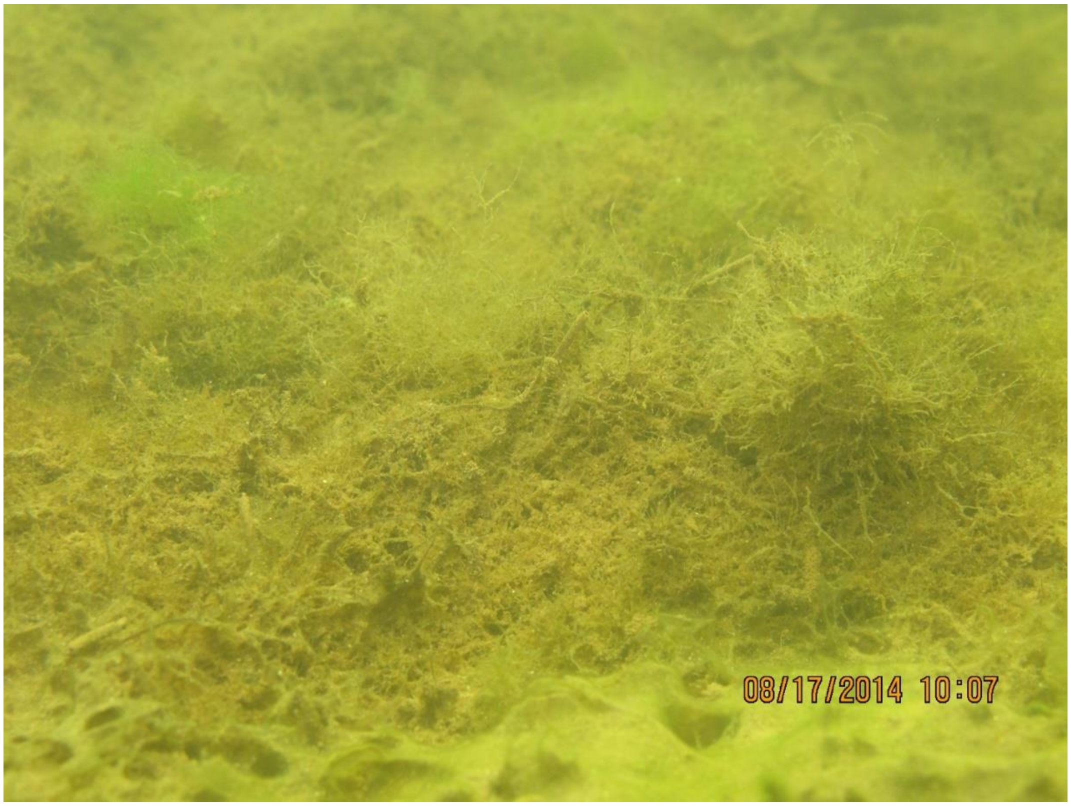

Figure 8: The filamentous algae on the bottom of the 2 m pond on 17 August 2014, Pikou, Dalian.

Except for the transferred mysid and *Chlorella* spp, benthic invertebrate and filamentary algae were abundant. there were many benthos living in the mud bottom or the filamentous algae. Dominent species were the the crustecean *Corophium chinensis*, *Microsetella novegica*, and nematodes (Table 3). These all the ominivorous feeder play an important role in the recycling of the decomposing organic materials.

Table 3: The main primary producers and drominent species of benthos in the enriched 2 m pond, Pikou, Dalian.

Primary producers		Primary consumers	
Name	Numbers ($\times10^4$ cells cm^{-3})	Name	Numbers ($\times10^4$ inds m^{-3})
Chlorella spp	9.16	*Corophium chinensis*	10
		Microsetella novegica	135
		Nematodes	65

3.3 The breeding of mantis shrimp

3.3.1 Brookstock acclimation

The broodstock of mantis shrimp were acclimatized in a 4.5 m^3 concrete tank (Figure 9A) and mature individuals (Figure 9A) were selected for the breeding in the pond. The breeding of mantis shrimp started at the end of April when the temperature was exceeded 18 ℃. The broodstock were stocked into the ponds at a density of about 5000 inds ha^{-1}. The body length of mantis shrimp was 12.70±1.28 cm, and the body weight was 31.05±10.36 g (n=20). The gonad index (%) was 15.24±1.87 (n=20). The shrimp always spawn within days after on the ventral side of telson was full of yellow ovary (Figure 9B). The mantis shrimp immediately burrowed and breeding in the soft sediment on the bottom of ponds. The breeding in the 1 m pond was started on 25 April and on 30 April in the 2 m pond. The breeding time in both the ponds was 36 and 33 days, respectively (Table 4).

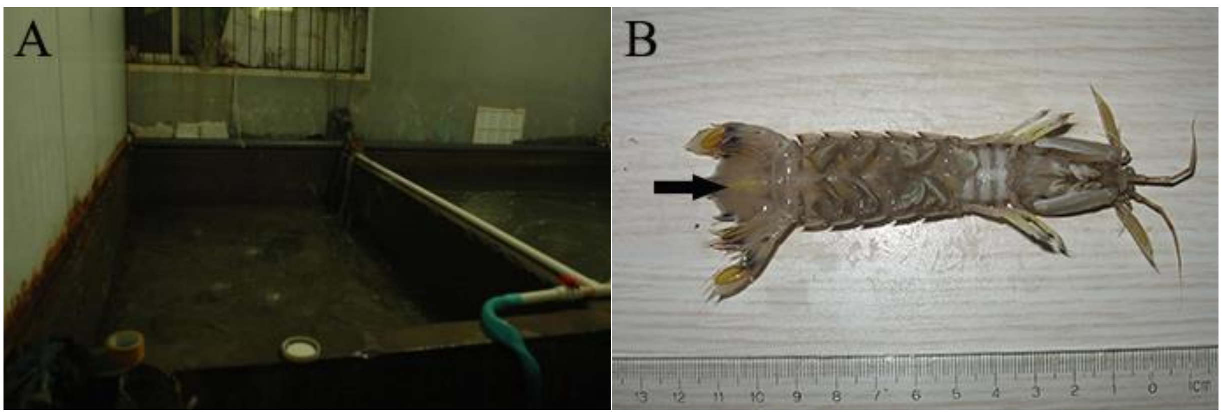

Figure 9: The acclimation of brookstock. A) The 4.5 m^3 concrete tank was used to rear the brookstock of the density of 100 inds m^{-3}; B) The mature brookstock pending spawning. The arrow shows the yellow ovary on the ventral side of the telson.

Table 4: The progress of rearing of mantis shrimp and basic environmental parameter in the 1 m and 2 m ponds.

The depth of the pond （m）	The start time of breeding	The appearance of larvae	Numbers of broodstock (Inds)	The area of the pond （m^2）	Salinity (‰)	Temperature (℃)	Breeding time (Days)
2	30, April	2, June	720	1400	30-32	16-24	33
1	25, April	30, May	630	1200	30-34	16-25	36

3.3.2 The breeding of mantis shrimp

The breeding of mantis shrimp has proved to be operable and feasibility in the ponds of northern China, we called it the ecosystem based breeding of larvae mantis shrimp which is characterized by high stocking density of biomass and environmental friendliness by feeding larvae with living mysid (Liu *et al*. 2013a). Integrated resource utilization and controlling environmental risks in the pond is the key point to understand the ecosystem based culturing of mantis shrimp. Broodstock is placed in managed ponds and breeded in burrows. We had built the cost-effective ways to culture the mysid as feed for the larval stages of mantis shrimp, it is more ecological and economical than fresh feed and the artificial feed designed for direct consumption by the larval mantis shrimp.

3.3.3 The estimation of the production of larval mantis shrimp

The first appearance of larvae in the two ponds was on 30 May in the 1 m pond and 2 June in the 2 m pond. With the rising water temperature (25℃ on 6, June), the development of larvae was fast. Larval phase lasted for less than 20 days in 2014.

On 20 June, the abundance of PⅩ-PⅪ stages was estimated in the 2 m breeding pond. On average 158 larvae were captured (206, 158, 125, 119, 169, 169 individuals for each net) within 1 m distance by the dip net in the pond, the total number of the larvae was 2,528,000 with the body length of 17.80±3.18mm and body weight was 0.033±0.005 g (n=67).

3.4 The culture of mantis shrimp in the 2 m ponds

The feed intaking of post settlement mantis shrimp was increased as mantis shrimp grew large. Living food such as the mysids, palaemon shrimps and goby fishes which coming with water exchange were also necessary complementary biofeed (Figure 10).

In 2014, there were more than 2 million larvae in the breeding pond. Half of the larvae were transferred to an adjacent pond of the same 2 m depth on 20 June. Stocking evaluation of post settlement mantis shrimp in both 2 m ponds was conducted by underwater photography. Burrows of mantis shrimp on the bottom were observed and counted (Figure 11A). The stocking of mantis shrimp is estimated by the number of burrows in a given area. The density of mantis shrimp collected on 17 August by snorkeling in was about 1 inds m^{-2}.

A field survey for the growth of mantis shrimp was carried out monthly in both ponds by snorkeling on 19 July (body weight: 0.55 ± 0.11 g, n=9), 17 August (body weight: 4.35 ± 2.22 g, n=13) (Figure 11B) and 20 September (body weight: 8.60 ± 0.96 g, n=10). The last sampling of mantis shrimp was collected by gillnet on 30 October (body weight: 10.51 ± 0.62 g, n=8) when the water temperature was 12.0 ℃. The growth of post settlement mantis shrimp in ponds was rapid during the high temperature season from July to September of which the monthly sampling temperature was 27.5 ℃, 26.0 ℃ and 23.0℃, respectively. Growth of mantis shrimp was slowed at the temperature dropped steadily from 23 ℃ on 20 September to 12 ℃ on 30 October 2014 (Figure 12). The mantis shrimp grew very fast. The absolute growth rate was 0.079 g day^{-1}, and the specific growth rate (SGR) was 4.37 % day^{-1}.

Figure 10: The palaemon shrimps *Palaemon macrodactylus* and goby fishes *Synechogobius ommaturus* in the pond.

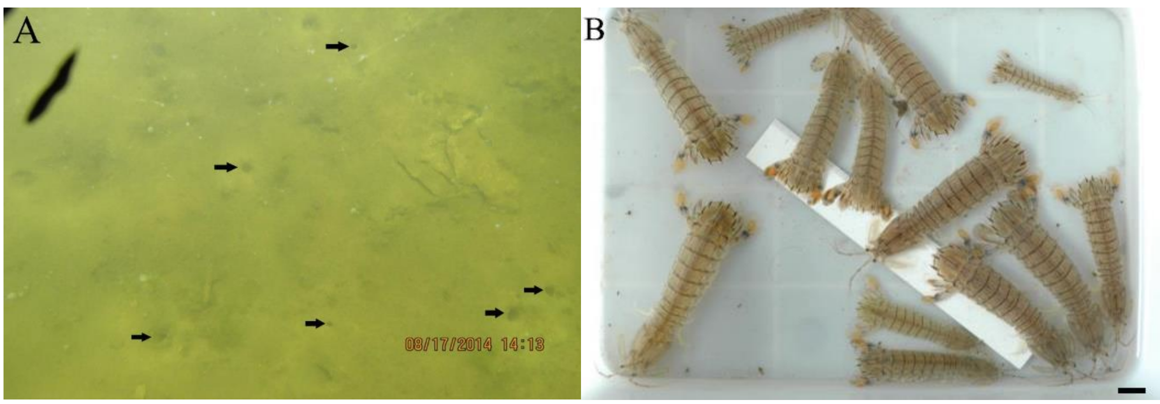

Figure 11: The culturing of mantis shrimp in the 2 m pond from June to October in Pikou, Dalian. A) The bottom burrowing sediment was uniformly distributed in the pond on 17 August 2014, the arrow showed the burrowing caves of post settlement mantis shrimp; B) The cultured mantis shrimp in the pond, which were sampled by snorkeling on 17 August 2014, Pikou. China. The average body length of the mantis shrimp was 7.077 ± 1.55 cm, the average body weight was 4.35 ± 2.22 g (n=13). Scale bar=1 cm.

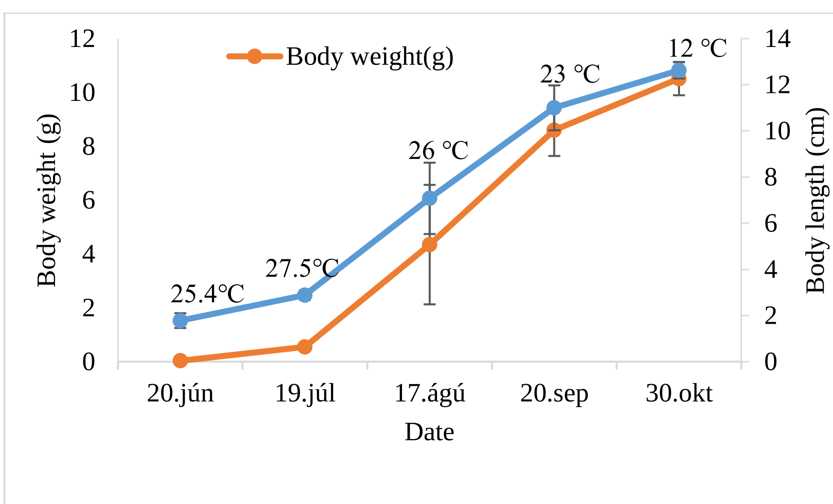

Figure 12: The growth of mantis shrimp in the 2 m ponds from 20 June to 30 October.

4 DISCUSSION

In northern China, the typical sea cucumber ponds with mud sediment are suitable for the breeding of mantis shrimp. The pond selectivity requires sufficient depth and area to stable and optimal conditions for the mass production of larval mantis shrimp. Water exchange was necessary to avoid hypoxic stress and low-salinity during high temperature and rainstorms in summer. In 2014, our breeding experiment in 2 m pond received the satisfactory results compared to the anecdotal studies (Yan *et al.* 2004, Wang *et al.* 2004), there were 35.1 thousand larvae per square meter by a field evaluation in the 2 m pond.

For an ecosystem based management of the breeding of mantis shrimp in ponds, we took charge of full use of the ecological relationship of different trophic levels. The larval mantis shrimp showed strictly selective feeding preference on mysid rather than other food items. The supplementary result on feeding preference of larval shrimp showed the living mysid was preferred as the best feed for the mantis shrimp, and the frozen mysid could be the important complementary feeding for the breeding of larval mantis shrimp. In order to increase the production of larval mantis shrimp in pond we must build the cost-effective and the effective ways to culture the adequate mysid used as biofeed for larval mantis shrimp, we are transferring the brookstock of mysid to the pond for the high quality supplemental biofeeds for direct consumption.

The report on the commercial culture technology of mantis shrimp was studied in southern China (Jiang *et al.* 1999). Juvenile mantis shrimp (body length: 4.3±1.0 cm) was fed by fresh and frozen fish trash in the pond from 1 May to 16 July, 1998. The individuals can attain first sexual maturity until the end of the spawning season around September by an body length of ≥7 cm by the field survey in Tokyo Bay (Kodama *et al.* 2004), which was similar to our results on the culturing of mantis shrimp in the pond. In our experiment, the breeding-reared mantis shrimp was grew fast in the 2 m ponds, we used low price stray fishes and clams as the artificial feed of mantis shrimp in the ponds, during 4 months' culturing, the mantis shrimp can reach the market size at 20 September. For the commercial aquaculture of mantis shrimp, the most concerning question was the low stocking of mantis shrimp. In the ecosystem based management of aquaculture of mantis shrimp, the living prey is the important food sources through water exchanging and natural propagation in the pond. Additionally, before the ponds were frozen in December, the cultured mantis shrimp can be captured by gillnets and acclimated in the concrete tank for the marketing in the winter at a relative high price.

Pond culture of post settlement mantis shrimp is possible and they grow well. By now the most serious challenge is how to increase the stocking of mantis shrimp in ponds for the commercial aquaculture. The low stocking in ponds of mantis shrimp was presumably due to the lack of ecological niche and optimal feed.

In order to increase the ecological niche of culturing mantis shrimp in ponds, the PVC pipeline (55 cm in diameter, 20 cm in length) can be placed on the bottom as the suitable artificial burrow for adult mantis shrimp (Personal observation), and the semi-intensive polyculture with other commercial important species in the pond should also be considered. There are large numbers idle ponds after extensive culture of jellyfish *Rhopilema esculentum* from June to August. In the future, the polyculture with other commercial important species in the pond of the utterly utilizing of the ecological niche in the pond ecosystem is required.

Feeds constitute the single biggest cost item (Naylor *et al.* 2000), currently, there are no commercial artificial feed for mantis shrimp. Mantis shrimp is a carnivorous opportunistic hunter that feeds on a variety of benthic organism and swimming fish (Dingle and Caldwell 1972). Fresh preys constituted the largest portion in stomach of the mantis shrimp by field survey (Xu *et al.* 1995, Shen *et al.* 2009). In ponds, from the complete metamorphosis of larvae to post settlement mantis shrimp, they change their lifestyle from pelagic to benthic and alter their diets by large amounts of fresh diets, which can be extensive cultured by feeding fresh or frozen trash fish, mussel, clam, or squid, or living food, such as the mysids, the palaemon shrimps and goby fishes through water exchange. By now, the living prey is the important food sources through water exchanging and natural propagation in the pond, but the biomass of living prey was very low due to the shortage of primary producer in summer, we should improve the primary production further and build the mutual relationship in the pond food chain in the next experimental aquaculture of mantis shrimp.

As a conclusion, the ecosystem based breeding and rearing of mantis shrimp links to the integrated utilization of marine environment. We do not use antibiotics and herbicides in the ecosystem based pond. Ecological crisis is controlled in a minimum degree. The breeding of mantis shrimp is easily accessed to the stable supply of shrimp juveniles for further commercial aquaculture by ecosystem based management in the pond of northern China. The aquaculture of mantis shrimp can be proved feasible by the artificial feeding and beneficial from the stabilized supply for commercial trading in the seafood market. The development of breeding technology can also replenish the fishery resource in the littoral area in order to increase the stock abundance of mantis shrimp in the future.

ACKNOWLEDGEMENTS

First and foremost, I offer my sincerest gratitude to my parents for their constant support and encouragement without whom it was impossible for me to fulfill my life dream.

I am particularly grateful to my supervisor Professor Skúli Skúlason for his assistance and guidance during the course of the project. His patience and inspiration are commendable.

I am highly indebted to the fund provided by United Nations University Fisheries Training Programme (UNU-FTP). I would also like to extend my heartfelt thanks to the Director of the UNU-FTP, Dr. Tumi Tómasson, and Deputy Director of the Programme, Mr. Thor Asgeirsson and Project manager, Mary Frances for assistance and guidance during the course. I also thank Office Manager Sigriður Kr. Ingvarsdottir for the timely support and most of the practical things during the programme.

I thank all the lecturers during the course for academic nourishment.

I am indebted to the director of the Marine Research Institute (MRI) and staff for the facilities and friendship. I also wish to thank the staff in the Department of Aquaculture and Fish Biology of Hólar University College. A special thanks must be given to Prof. Helgi Thorarensen and Mr. Ólafur Sigurgeirsson for their warm care of my living in Hólar.

I pay tribute to UNU-FTP 2014/2015 colleagues for their friendship, cultural exchange and moral support during the training.

Special thanks go to the Dalian Ocean University for granting me study leave to attend the training.

At last, I want to take this opportunity to acknowledge my research staff in Dalian Ocean University all whom are under the supervision of Prof. Haiying Liu.

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