The status of mariculture in northern China

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INTRODUCTION

The People's Republic of China has a long history of mariculture production. The mariculture industry in China has achieved breakthroughs in the hatchery, nursery and culture techniques of shrimp, molluscs and fish of high commercial value since the 1950s.

The first major development was seaweed culture during the 1950s, made possible by breakthroughs in breeding technology. By the end of the 1970s, annual seaweed production had reached 250 000 tonnes in dry weight (approximately 1.5 million tonnes of fresh seaweed). Shrimp culture developed during the 1980s because of advances in hatchery technology and economic reform policies. Annual shrimp production reached 210 000 tonnes in 1992. Disease outbreaks since 1993, however, have reduced shrimp production by about two-thirds. Mariculture production increased steadily between 1954 and 1985, but has been growing exponentially since 1986, mostly driven by mollusc culture. Mollusc culture in China began to expand beyond the four traditional species (oyster, cockle, razor clam and ruditapes clam) in the 1970s. Mussel culture was the first new industry to emerge, followed by scallop aquaculture in the 1980s. Abalone culture has become a major industry in the 1990s. Traditional oyster and clam culture has also advanced and expanded in recent years. Now more than 30 species of marine molluscs are cultured commercially in China. Because of the rapid development in recent years, mollusc culture has become the largest sector of the Chinese mariculture industry, accounting for 81 percent of the total production by weight.

Therefore, the industrialization level and culture techniques for the major species in China have reached an advanced international level, with some leading the world aquaculture sector. China is also the largest country in mariculture.

Marine aquaculture has grown rapidly over the last decade. Marine cultivable areas in China, which include shallow seas, mudflats and bays, are estimated to occupy more than 1.33 million ha, as most marine plants and animals can be cultivated within the 10 m isobath using current culture technologies. In 2002 the area under cultivation and the output reached 1 352 000 ha and 12.1 million tonnes, respectively.

The principal species cultured in northern China are listed in Table 1.

TABLE 1
Marine species cultured in northern China

Molluscs	*Crassostrea gigas, C. plicatula, C. rivularis, C. talienwhensis, Chlamys farreri, Argopecten irradians, Patinopecten yessoensis, Mytilus edulis,Ruditapes philippinarum, Meretrix meretrix,Cyclina sinensis, Mercenaria mercenaria, Mactra antiquata, M. veneriformis, Saxidomus purpuratus, Tegillarca granosa, Scapharca subcrenata, S. broughtonii, Sinonovacula constricta, Haliotis discus hannai, H. gigantea, Rapana venosa, Bullacta exarata*
Marine fish	*Pagrus major, Lateolabrax japonicus, Fugu* sp., *Paralichthys olivaceus, Scophthalmus maximus, Cynoglossus semilaevis, C. trigrammus, Kareius bicoloratus, Verasper variegates, Sebastodes fuscescens, Mugil cephalus, Liza tade, Hexagrammos otakii, Seriola lalandi*
Crustaceans	*Fenneropenaeus chinensis, Penaeus monodon, P. japonicus, P. merguinsis, Litopenaeus vannamei, Eriocheir sinensis, Callinectes sapidus, Scylla serrata*
Seaweeds	*Laminaria japonica, Undaria pinnatifida, Porphyra yezoensis*
Echinoderms	*Apostichopus japonicus, Strongylocentrotus intermedius, S. nudus*

HATCHERY SEEDLING PRODUCTION TECHNOLOGY OF MAIN CULTURED SPECIES

Molluscs

Many species of molluscs (e.g. scallop, oyster and abalone) can be hatchery reared with well-developed technology. The following sections describe the scallop and abalone hatchery procedures.

Scallop (Patinopecten yessoensis)

Breeding and larval rearing

Broodstock culture: Broodstock are selected in late winter or early spring. They are then transferred to conditioning tanks where water temperature is initially 2–3 °C. Water temperature is then increased daily by 0.5 or 1 °C until it reaches 7 °C. This temperature is kept stable until spawning. During conditioning, broodstock are fed either on artificial diet or unicellular algae, mostly *Phaeodactylum tricornutum, Chaetoceros muelleri, Monochrysis simplex, Isochrysis galbana, Tetraselmis tetrathele* and *Nannochloropsis oculata.*

Spawning, fertilization and hatching: Before spawning occurs, the water is prepared with the temperature at 10.5 °C. When the density of eggs reaches about 30 per ml, the aeration must be stopped and the parent scallops removed from the tanks. After the spawning is over, the water in the hatching tanks should be stirred with swing boards for 30 min to prevent the eggs from sinking to the bottom.

Larval cultivation: The rearing density depends on the rearing technique, food supply, capacity of the tanks and the quality of larvae. It ranges from 5–15 larvae per ml. During the period of larval rearing, the feeding behaviour and growth of the larvae are observed every morning before the water is renewed. In general, the normal larvae are usually swimming in the upper and middle layers of the water. The feeding ration can be adjusted according to the food content in the stomach of the larvae. The number of larvae should be counted and their shell lengths measured every two or three days.

The growth and development of larvae are closely related to salinity, temperature, rearing density, water quality and food supply. Under suitable rearing conditions as mentioned above, the eyespot, which is located in the stomach region, will appear 18 days after fertilization, with the shell height at 190–200 µm.

Spat collection: The appearance of the eyespot is an indication that the larvae are approaching the settling stage. Once the eyespot appears, the larvae should be sieved and transferred to another well-cleaned tank. The spat collectors are then put into the tank for larvae to settle on as soon as the transfer is completed. Two kinds of collectors are commonly used in northern China. One is made of palm fibre rope and the other of pieces of polyethylene net.

Nursery culture

Nursery or intermediate culture involves transfer of the spat to the open sea and rearing them until they attain 7 mm in shell height. Before transfer, the temperature of the rearing water should be lowered by 1–2 °C every day to approximate the temperature of the sea. This is important for increasing the survival. Each transfer leads to better survival and better growth rate. The water temperature of the sea area must reach 5 °C when the spat are transferred.

Because of the differences in the size of spat, condition of the sea area, culture materials and management, high mortality occurs after the spat are transferred to the open sea. At present, the survival rate in nursery culture ranges from as low as 10 percent to 30–40 percent.

Two kinds of material are used at present. One is a plastic pipe, 60 cm long and 25 cm in diameter, covered with plastic net (mesh smaller than the shell height of the spat) at both ends. The other, which is more common, is made of polyethylene bags. The size of the bag depends on the size of the spat collectors and is generally 30x40 cm. Every ten bags are strung together on a rope.

Abalone (e.g. **Haliotis discus hannai***)*

Commercial abalone seed production was accomplished in 1987 in Dalian, Liaoning. From 1987, abalone aquaculture in China grew steadily, with most research focused on the development of hatchery seed production techniques and grow-out modes. A series of key techniques involving spawning, larval rearing and juvenile and seed nursing were established. Sufficient seed supply is crucial to the development of abalone mariculture. All abalone seed are hatchery produced with sophisticated technology The technology to produce hybrid and triploid abalone has been successfully developed by researchers and is ready to be introduced to the commercial production sector.

Seed hatchery production

Broodstock selection and conditioning: Seed production typically begins in early spring with broodstock conditioning and gradually elevated temperatures and stabilization at 20 °C. The most widely used and effective method for abalone to ripen is by effective accumulative temperature (EAT) control. Meanwhile, plenty of algal food (*Laminaria japonica*, *Undaria pinnatifida* and *Ulva pertusa*) should be provided with this conditioning method.

Spawning and hatching: To induce spawning, well-developed abalones are exposed to air for desiccation and then subjected to ultra-violet-irradiated seawater. Adult spawning is usually induced by combined thermal shock and UV-treated seawater exposure. Males usually are induced one hour later than females because they are more sensitive to inducement. Fertilized eggs are incubated at 21–22 °C.

Larval cultivation: Approximately 60 hours postfertilization, *H. discus hannai* larvae are ready for settlement. Eyed larvae are set on the collecting plates made of transparent corrugated plastic that is diatom-precoated for *H. discus hannai*. The diatoms must be supplied in sufficient quantities as well as be of good quality to ensure the growth and survival of postlarvae. Water quality and light level should be carefully controlled during this critical period.

Juvenile nursery: Juveniles are manually moved from settlement plates to nursery culture plates at the size of 3–7 mm. For *H. discus hannai*, spat are usually transferred to large punctured plastic plates with dark colour. During early juvenile stages, an artificial diet is exclusively used as food supply. Several commercial diets from various feed manufacturers are available to aquaculturists. The major ingredients of artificial diets are dried kelp powder and fish meat powder. Fresh kelp is the principal food for older juveniles. The quality of artificial diet plays an important role in post-settlement survival.

Challenges to abalone mariculture

Mortality frequently occurs during the first month of the juvenile phase, following the movement of juveniles from settlement plates to the nursery culture plates, especially when the juveniles are taken off the diatom plates at <5 mm shell length. It is generally believed that the change of feeding habits is the major cause of this high mortality. Survival in this critical nursery period had dropped to lower than 5 percent at the lowest level during the early 1990s. Survival of early juveniles has been much improved by hybridization breeding, lowering juvenile density in the collecting plate and extension of diatom feeding, therefore, allowing the juveniles to be removed at a larger size than normal to the nursery culture plates. In particular, hybridization was made between Japanese and Chinese broodstock to produce hybrid seed. When all diatoms on the settlement plate are consumed, juvenile abalone (approximately 2–3 mm) are transferred to another batch of transparent corrugated plastic plates that are well covered by diatoms. Therefore, size of juvenile abalone reached 5–7 mm when transferred to the nursery culture plate, enhancing the adaptive ability of juveniles to artificial diets. The practice of transferring juvenile abalone is now becoming part of routine hatchery procedure. With the application of hybridization and plate-transfer techniques, production of *H. discus hannai* remains stable in the northern Chinese coastal areas.

The mortality problem, however, was not solved completely due to incomplete understanding of the physiological variation associated with the change of feeding habits following larval metamorphosis. In addition, a lack of quality control with respect to broodstock often leads to failure of utilization of heterosis. Hybrid abalone seed have now been widely adopted throughout the northern coasts. Nevertheless, breeding of high-quality lines of abalone will be the best solution in terms of genetic modification.

Availability of adequate commercially formulated diets is another problem for the abalone aquaculture industry in China. Abalone is a slow feeder, therefore, reducing leaching of water-soluble ingredients from artificial diets is a key to good diets. Furthermore, dietary essentials should be balanced to meet the nutrient requirement of abalone. As yet, however, the nutritional requirements of the cultured species are not yet fully demonstrated.

Echinoderms

Sea cucumber

Apostichopus japonicus is the only species of sea cucumber to be cultured in northern China. This is due to its high meat quality and the success of commercial hatchery techniques.

In the early 1980s, the shortage of sea cucumber seed was a bottleneck for developing aquaculture. The Ministry of Agriculture prioritized setting up hatcheries for sea cucumber (*A. japonicus*) and improving techniques for seed production. Since then, sea cucumber farming has become a vigorous sector in mariculture.

The procedure for artificial reproduction of sea cucumber is as follows:
Broodstock condition and spawning

- Broodstock collection: Broodstock are collected from late May to early July.
- Broodstock care in land-based tanks: Broodstock are held at 30 individuals per m^3, with dissolved oxygen (DO) over 5 mg/liter, and a feeding rate about 5–10 percent of body weight.
- Spawning stimulation: Spawning is induced by thermal shock (water temperature raised by 3–5 ºC) and desiccation followed by seawater jet for 10–15 min.
- Fertilization: Artificial spawning allows the hatchery operator to better control the concentration of spermatozoa and the stocking density of eggs. The maximum density is 1 million eggs per m^3 in hatchery tank.
- Hatching: The hatching rate may exceed 90 percent.

Larval rearing

Rearing the pelagic stages of *A. japonicus* requires considerable attention and constant monitoring of the culture medium.

Larval density: In order to ensure fast growth and a high metamorphosis rate, larval density should be maintained at between 3 to $4x10^5$ individuals/m^3.

Feeding: The use of different species of microalgae is crucial for the development of the larvae. *Dunaliella euchlaia, Chaetoceros gracilis, C. muelleri, Nizschia closterium* and *Phaeodactylum tricornutum* can be used to feed the larvae. The most important species are *D. euchlaia, C. gracilis* and *C. muelleri,* whereas *Dicrateria zhanjiangensis, Isochrysis galbana* and *Chlorella* sp. are usually added as a supplement but are never used alone. For a balanced diet, a mixture of two to three species is highly preferable. The microalgae are fed at a concentration ranging between 10 000 and 40 000 cells/ml. Food levels are increased gradually as the larvae develop. In order to enhance larval growth and decrease the rate of malformation of the young sea cucumbers, marine yeast and/or photosynthetic bacteria (PSB) are often supplied.

Water quality: High-quality seawater in a sea cucumber hatchery is an important prerequisite. Research findings indicate that numerous physical and chemical factors (e.g. temperature, pH, salinity, ammonia, DO, heavy metal concentration, turbidity, etc.) will influence the success of culture. As these parameters tend to vary significantly from one region to another, careful monitoring of the seawater quality is essential.

Selection and use of settling bases: The traditional substrates used for the settlement of the sea cucumber juveniles are frames fitted with fine polyethylene (PE) or polypropylene (PP) cloth. In recent years, some hatcheries have started to use PE corrugated plates measuring 50×50 cm fixed together in stacks of 8–10 pieces. This latter method has been used with some success. In the traditional method, benthic diatoms need to be cultivated on the settling bases before they can be used. Currently, some hatcheries no longer cultivate benthic diatoms, but rather provide a food supply soon after the juvenile sea cucumbers have settled. This method has two advantages: no equipment is needed to rear benthic diatoms and the settling plates are easier to clean during routine hatchery operations. The settled sea cucumbers are fed with benthic diatoms that have settled on specifically designed mesh bags or other materials placed in the rearing tanks and with a powdered macroalgae soup typically prepared using *Sargassum* spp. such as *S. thunbergii.* The correct feeding rate is essential to ensure a high survival rate of the juveniles.

Juvenile rearing

Rearing juvenile sea cucumbers may take several months, but may require as long as six months if the rearing conditions are not favourable.

Food: The food must be free of contamination, be of the right particle size and contain all the essential nutrients. A balanced diet not only accelerates the juvenile sea cucumbers' growth rate, but also increases their survival rate.

Transfer of the juveniles: Juvenile sea cucumbers are particularly vulnerable during the early rearing stages. High mortality rates are caused by high density, overfeeding, faeces on the settling plates and competition for space among themselves and with other opportunistic organisms such as *Ciona intestinalis.* This species of tunicate can also secrete a toxin that can kill juvenile sea cucumbers. Therefore, juveniles should be regularly transferred to new settling plates, sorted by size and injured individuals transferred to separate tanks. Light anaesthesia is usually used to reduce stress and facilitate handling of the sea cucumbers. *Microsetella* sp. (Ectinosomatidae) is commonly found in rearing tanks and can form large colonies in a short time, killing all the sea cucumber juveniles in 1–2 days when the situation gets out of control. Trichlorfon was formerly used to kill *Microsetella* sp., but the copepods have developed a strong resistance to this biocide and therefore have become difficult to eradicate. In 2003 a new and effective pesticide known as *Mei Zao Ling* was developed by the author. This product has little side effect on sea cucumbers.

Nursing of juvenile sea cucumbers: As the juveniles grow, the water quality and DO must be maintained at the optimal level. Increasing aeration and water exchange rates becomes necessary. The oxygen level has to be maintained above 5 mg/litre. It is also important to use formulated feed that can be digested and absorbed easily. Experimental results have shown that the growth rate of juveniles fed on the formulated feed is at least two times higher than that of individuals fed on traditional feed during the 20 to 30 day period. In recent years, studies on a series of formulated diets revealed that diet is a key factor for improving the survival and growth rates of juveniles in the nursing stage.

As the accumulation of excess food and faeces increases, harmful germs tend to multiply rapidly and can cause very serious disease outbreaks among juvenile sea cucumbers, including what is known as "stomach ulcer". Another disease is "white muscle syndrome", in which muscle tissues turn white and become rigid. More applied research is urgently required to find effective remedies to these problems.

Sea urchin

Broodstock management

Broodstock should be 3–4 years of age and 6–7 cm in test diameter. The shell of broodstock shouldn't be damaged. Photoperiod and water temperature are considered to be important in the control of reproductive maturation. Experimental broodstock cultivation has shown that multiple spawning is possible when well-fed sea urchins are cultivated in darkness in relatively warm water. So after being caught, the mature sea urchins are placed into dark tanks and reared with filtered seawater (8.0–15.5 °C and about 31.5 ‰ salinity). The density of broodstock is less than 20 sea urchins per m^2 and the sea urchins are fed with *Laminaria japonica*. Airstones are used to provide the oxygen to the broodstock. One half of the water in the tanks is changed daily, and every four days, all the water in the tank should be changed to remove any debris from the bottom.

Induction of spawning, fertilization and hatching

There are three ways to induce spawning:

- injection of 1–2 ml of 0.5M KCl solution easily induces mature sea urchins to spawn;
- putting the sea urchin in the shade and in running seawater; and
- removal of the mouthparts.

After spawning induction, the female and male sea urchins are placed separately into seawater to spawn. After enough eggs and sperm are released, the eggs are collected into a plastic barrel and mixed with some sperm to fertilize them. The quantity of the sperm is enough if there are 10–100 sperm around each egg.

The fertilized eggs hatch at 20–30 eggs/ml in the hatching barrel and rinsed of excess sperm once an hour. Before hatching, the water should be mixed twice an hour to avoid the fertilized eggs becoming deposited on the bottom of the barrel. The hatching temperature should be between 16 and 18 ºC. After approximately 16 hours, the fertilized eggs will hatch.

Larvae rearing

<u>Culture vessel</u>: A pond (10–20 m^3) or aquarium (1.4 m^3) can be used as the culture vessel.

<u>Planktonic microalgae for larviculture</u>: Many species of cultured algae support rapid growth and development through metamorphosis. The planktonic microalgae's size, concentration, flavor and the stage of larval development will all influence larval feeding rate and microalgae selection.

The planktonic microalgae are reared at 15–30 ºC and 7 000–10 000 Lux as measured by photometer. The nutrient salts included 5–20 mg $NaNO_3$, 0.5–1 mg KH_2PO_4 and 0.05–0.2 mg $Fe(NH_4)_3(C_6H_5O_7)_2$ in a 1000 ml volume. During the rearing process, the water should be maintained at a suitable quality and not polluted by other algae. After the density increases to 1 million cells/ml, it can be fed to the larvae.

<u>Larvicuture management</u>: After the blastulae float with little active movement at the surface of the water, the healthy larvae should be selected, the quantity estimated and the larvae transferred to the culture pond. The water should be changed twice daily, with half of the water each time,.

Larval development involves growth and elaboration of the larval body. After three to four days, the larvae have developed to the early pluteus stage, which requires planktonic microalgae as food. The four to eight-armed larvae should be fed with planktonic microalgae four times per day at 5 000–40 000 cells/ml/day.

The density is initially 1.0 larvae per ml, but decreases to 0.4–0.7 individuals per ml at the end of the eight-armed larval stage. The photometer should show a light level of less than 300 Lux. The salinity of the seawater is 30–31.5ppt, temperature is 16–18 ºC, DO is 6.5–8.0mg/liter and pH is 7.9–8.3.

Benthic diatom cultivation and settlement

Settlement presents a variety of problems for echinoid larvae. Larvae must detect suitable habitat to switch from planktonic living to benthic living. Induction of settlement and metamorphosis occurs in response to environmental factors that signal the availability of suitable benthic habitat. A solution of 0.5M KCl can also be used to induce metamorphosis.

The attachment that induced the settlement uses polyvinyl chloride wavy plates (42x33 cm, each group having 20 plates) covered with the benthic diatom that serves as the food source for the juvenile sea urchin. The plates should be inoculated with the benthic diatom on both sides 20–30 days in advance of providing them to the sea urchins. Nutrient salts are added to stimulate algal growth. When the podium or thorn appears on the larvae, they should be put into the tanks with the plates covered with benthic diatoms. The larvae should be stocked at around 300–500 larvae per plate. The water in the tanks should be changed twice a day with half of the water removed at each time.

Early juvenile rearing

After all the larvae are metamorphosed, the sea urchins should be reared with continuous flow seawater to exchange water around three times per day (water flow of 100–500 percent). The photometer should indicate less than 3 000 Lux. The water should be aerated to provide enough oxygen for the sea urchin. Nutrient salts are added to the tanks every day to stimulate diatom growth. When the juveniles reach 2–3 mm in size, they should be transferred to the netcage and fed with *Ulva* sp. and *Laminaria japonica*.

Seaweed *(Undaria pinnatifida)*

Undaria pinnatifida is the main seaweed species under cultivation in Dalian. The Dalian area contributes more than 80 percent of the yield from Chinese cultivation.

<u>Collecting zoospores</u>: Collection of zoospores begins in April to June when the plants become fertile. The matured sporophylls are kept in a dark, moist container for several hours to induce mass discharge of the spores. The spores attach themselves to the substrate and develop into male and female gametophytes.

<u>Nursing of young sporelings</u>: As young sporelings 3 to 5 cm long become overcrowded in their breeding station, they are moved to grow-out sites when seawater temperature drops below 20 ºC, e.g. around mid-October in northern China. The purpose of such a move is to stimulate their growth to a length of 10 to 25 cm before their transplantation. During this nursing period, young sporelings grow very rapidly.

<u>Transplantation of young sporophytes</u>: At the end of the nursing period, young seedlings are transplanted to kelp-culture ropes for final grow-out on floating rafts. The procedure is similar to the transplantation of young rice plants in paddy culture. The outgrowing of sporelings starts in the autumn when the water temperature is below 20 ºC.

GROWOUT METHODS

Several grow-out methods are being practiced in northern China.

Floating raft culture

There is a long history of using floating rafts for shallow-sea farming. This system can be used for a variety of species such as seaweeds (kelp and laver), filtering organisms (scallop, oyster, and mussel) and abalone, combined with culture in lantern cages.

The major advantages of this culture method are better growth rates and quality. The survival rate is also better when compared to bottom-culture methods, mainly due to the fact that bottom-dwelling predators (e.g. starfish and drills) are unable to reach the cultured oysters. However, with this method the rafts and cages can be easily damaged by storms and the cages fouled by a number of benthic organisms and seaweeds. The cages are periodically cleaned to avoid becoming blocked.

Pond culture

A high proportion of the area under cultivation is devoted to pond culture in marine and brackishwaters. Often, fishers culture shrimp, crab or marine finfish. Some benthic species such as Manila clam and razor clam are also cultured in the ponds. In recent years, pond culture of sea cucumber (*Apostichopus japonicus*) has developed in Liaoning and Shandong provinces, mainly centered in the Dalian area. The details are described below.

Optimal culture pond conditions

Pond size and water quality: Ponds are usually located in the intertidal zone for convenience of water exchange. The salinity should be maintained >28 ppt all year round, however, it can drop to 24–26 ppt over a short period in the summer. Water quality should remain high, and it can be renewed by opening and closing the sluice gates. The optimal pond size is usually 2–6 ha with a water depth maintained at 1.5–2.5 m.

Pond cleaning and sterilization: The best farming results are obtained in leak-proof ponds with a muddy sand substratum that requires sterilization prior to the rearing phase. This is done by first removing the bottom silt. At this point the pond is filled with seawater and the level adjusted to 0.2–0.3 m. Calcium oxide or bleaching powder is subsequently added.

Settlement substratum: According to the natural behaviour of the sea cucumber, the pond bottom requires a layer of adequate substratum for larval settlement to occur. Stones, roof tiles, bricks and other suitable structures can be used. The quantity of the substrate should be in the range of 150–1 500 m^3/ha, however, this can vary depending on the pond characteristics and production method employed. Stones remain the best choice, each of about 15–40 kg in weight. The settlement substratum should be added to the pond one month prior to the introduction of the sea cucumber juveniles.

Water conditioning: In order to ensure the right quantity of diatoms, the water should be inoculated at least 15 days before the juveniles are seeded. The most common fertilizer used is urea at about 30–60 kg/ha.

Juvenile rearing and growout

Growout season: The growout season can commence either in September/October or in March/April when the seawater temperature ranges between 10 and 15 °C. In a polyculture situation, the shrimp postlarvae are usually introduced in May-June.

Transportation of juveniles: The juveniles are placed in temperature-controlled boxes for transportation. They should not be fed for 1–2 days prior to this operation. The temperature should be maintained below 18 °C. The shrimp postlarvae are generally transported in oxygen-filled plastic bags with a sufficient quantity of seawater.

Juvenile size and rearing density: The juveniles may be from the wild or hatchery produced. Juveniles usually range between 2 and 10 cm in length, and their stocking density varies depending on the pond conditions, food supply and availability of settlement surfaces. The number of sea cucumber juveniles released is 15–40 individuals/m^2 for individuals measuring 2–5 cm, 15–25 individuals/m^2 for individuals of 5–10 cm, and 5–8 individuals/m^2 for individuals that are 10–15 cm in length.

There are two methods for releasing the juveniles. The first one is to place them on the sea bottom directly by hand or by simply releasing them from a boat using individuals larger than 4–5 cm. The second method, used when handling individuals smaller than 3 cm, is to place the juveniles in mesh bags with an opening at one end. The mesh bags are 30x25 cm in size and each one may contain up to 500 individuals. They are placed beside the settlement substratum.

The shrimp species used for polyculture with sea cucumber are the Chinese or Japanese shrimp species. The shrimp juveniles re usually 2–3 cm in length and are stocked at a density of 3–6 individuals/m^2.

Feeding: Sea cucumber juveniles usually do not require any additional food supply. However, the addition of food is necessary to maintain a high rearing density and to favour growth during spring and autumn. Ground pieces of *Sargassum* and *Zostera* are generally used.

Pond management: The seawater is renewed by opening and closing the sluice gates with the change of tide. About 10–60 percent of the total seawater should be exchanged depending on the water quality and temperature in the ponds. In summer, the water level in ponds should be kept higher in order to maintain a lower temperature. The salinity is maintained by regular water exchanges. The temperature, salinity, pH and DO levels should be monitored daily as well as the growth, survival rate and behaviour of the sea cucumbers.

During the winter months, the following additional tasks need to be performed:

- maintaining the water level at 2 m; and
- removing ice formations from the surface of the pond to keep the air-water interface free and ensure acceptable oxygen concentrations in the pond.

Harvest: The sea cucumbers are collected when they reach 150–200 g. Harvesting is done following drainage of the ponds or with the use of SCUBA. The shrimp are generally collected using nets placed at the sluice gates.

Mud flat culture

Mud flat culture is very popular in China because it does not require large quantities of food and it does not pollute the environment. This system is especially suitable for farming benthic species such as Manila clam (*Ruditapes philippinarum*), hard-shelled clam (*Meretrix meretrix*), blood cockle (*Tegillarca granosa*), razor clam (*Sinonovacula constricta*) and seaweeds such as *Porphyra* spp.

Net-cage culture

In China, marine fish farming entered a new era in the 1990s, following the great advances made on understanding the biology and rearing technologies of cultured species. The principal culture method for marine fish is net-cage culture. In northern China, the main species cultured are *Lateolabrax japonicus*, *Paralichthys olivaceus*, *Sciaenops ocellatus*, *Sebastodes fuscescens*, *Hexagrammos otakii* and *Fugu* sp.

Inshore cage culture is very popular world-wide, especially in China. Advantages include low investment and easy routine management. However, this system is one of the main sources of inshore pollution and a contributor to red tides. As most farmers use trash fish to feed high-value cultured fish, it does not take long before a great quantity of faeces and food residues accumulate on the sea floor and pollute the entire area. Another problem is that floating cages cannot resist strong winds and waves. The losses from such problems can be very serious.

Large-sized, current-resistant submerged netcages have been recently developed using fairly high-tech systems. These may help promote the sustainable development of marine fish farming. Meanwhile, mariculture using submerged cages has become a major aquaculture activity for utilizing the wider ocean for fish production.

Intensive indoor culture

This system is especially suitable for abalone and flounder culture. Abalone can be considered as one of the gastropods that have a high potential for commercial exploitation in the Asia-Pacific region. They command a high price and are highly relished in a number of Asian countries, particularly in China, Japan, the Republic of Korea and the Democratic People's Republic of Korea. In this system, concrete tanks of around 3–50 m^3 are used. A dark PVC basket of 40x30x13 cm is commonly used, usually in a stack of 8–12 tiers arranged in rows in a tank. The baskets occupy 40–70 percent of the tank capacity. Fresh kelp, mostly *Laminaria japonica*, is the primary food during growout, and artificial diets are used when algae are not available. The major husbandry measures include adequate feeding, control of water flow, periodic elimination of abalone wastes and adjustment of the culture density. Usually this grow-out system has a high running cost, including the costs for pumping water, heating and aeration.

POLYCULTURE

Polyculture has a long history in freshwater aquaculture in China and could be applied more often in the marine environment. In marine polyculture, bivalves, seaweed and marine finfish are produced together. By using such complementary species, the wastes of one species can be converted to protein by the others. In finfish production, for example, feed that is not consumed filters down to suspension-feeding bivalves or mixes with faecal waste and is taken up by primary producers such as seaweed (harvested directly) or phytoplankton, which is then consumed by bivalves.

Bivalve and seaweed raft polyculture system

This form of culture shows much promise in increasing sustainability in many types of aquaculture, since it maintains a balance of nutrients in the environment and increases the efficiency of protein production.

In northern China, for example, kelps cultured on rafts provide shading, create sheltered areas less exposed to current flows, release oxygen as a product of photosynthesis and generally improve water fertility. Overall, *Laminaria* plants create a "mini-ecosystem" in otherwise open shallow seawater, making conditions more favourable for commercial production of scallops and other marine organisms. In turn, scallops and other cultured marine organisms in a polyculture system produce metabolic byproducts, especially dissolved N, P and CO_2, which act as natural fertilizers to meet the nutrient requirements of seaweed plants.

Polyculture in ponds

The main polyculture modes in ponds are shrimp-fish (e.g. mullet, tilapia, *Fugu* spp., perch, seabream and others), shrimp-sea cucumber, and shrimp-crab. The shrimp-fish system is the most successful. Some experts infer that there are two factors involved in the healthy growth of shrimp in the shrimp-fish system: predatory fish eat sick or morbid shrimp, thus reducing the spread of disease in the ponds; and there is an improved balance in the mini-ecology of shrimp ponds. Effluents rich in organic matter from shrimp culture can also be utilized by bivalves. Many species can filter out small particles and utilize microalgae from the effluent. These can be commercially valuable species for harvest or non-valuable species for use as fish-meal.

Another polyculture mode is crab-shrimp-bivalve, and this system is successful in Shandong and Jiangsu provinces; the crab is blue crab (*Callinectes sapidus*), the shrimps are *Penaeus chinensis*, *P. japonicus* or *Litopenaeus vannamei*; and the bivalves are *Ruditapes philippinarum*, *Argopecten irradians* or *Sinonovacula constricta.*

MARINE ENHANCEMENT

The capture fishery is unable to provide further increase to the total yield to meet the increasing demand for seafood for human consumption, particularly for the high-valued species that are either depleted or overfished. Thus the enhancement of fishery resources is an important measure that can be used to rebuild depleted stocks. Stock enhancement has been used for more than 20 years and has recently developed very quickly in China. The main species involved are high-value species as shown in Table 2.

TABLE 2
Aquatic species used in marine enhancement trials in northern China

Crustaceans	*Penaeus chinensis, P. japonicus, Litopenaeus vannamei*
Shellfish	*Patinopecten yessoensis, Haliotis discus hannai, Scapharca subcrenata, S. broughtonii*
Marine Fish	*Paralichthys olivaceus, Chelon haematocheila, Pagrus major, Pseudopleuronectes yokohamae, Larmichthys crocea, Acanthopagrus schlegelii schlegelii*
Echinoderms	*Stichopus japonicus, Strongylocentrotus intermedius S. nudus, Hemicentrotus pulcherrimus*
Jellyfish	*Rhopilema esculentum*

Shrimp
Penaeus chinensis is mainly distributed in the Bohai Sea and Yellow Sea. It has supported a very important fishery in the north. During 1985 to1992, 8.645 billion juvenile shrimp were released in the Bohai Sea. Shandong Province released 200 million juvenile shrimp into the waters around Shandong Peninsula in 2004.The recapture rate ranged from 0.001 percent to 1.88 percent.

Fish
Many fish species have been released into coastal waters in order to increase their stock size, but often intermittently, such as red seabream (*Pagrus major*), marbled flounder (*Pseudopleuronectes yokohamae*), So-iny mullet (*Chelon haematocheila*), black porgy (*Acanthopagrus schlegelii schlegelii*) and bastard halibut (*Paralichthys olivaceus*). Although the benefit is high, the input required is also high. In recent years, croceine croakers (*Larmichthys crocea*) have been released into the East China Sea to help rebuild the depleted stock.

Jellyfish
Following the depletion of some jellyfish fishing grounds, institutions in Liaoning, Shandong, Tianjin and Hebei started the experimental release of ephyra in the 1980s. Between 1994 and 2003, an average of 69.6 million ephyra were released annually into the bays around Shandong Peninsula by the province, resulting in an average catch of 4 994 tonnes per year. The abundance of jellyfish is closely related to environmental conditions; therefore, the economic benefit is highly variable. The recapture rate was 0.68–2.65 percent.

Shellfish and others
Seabed seeding is used to enhance shellfish and other resources, including scallop, clam, abalone, sea cucumber, trumpet shell, sea urchin, etc. This method is usually difficult to distinguish from mariculture, but it has the advantage of reducing disease compared with mariculture. The recapture rates for abalone and sea cucumber are much more predictable than that of shrimp. According to data recorded from commercial captures, the recapture rate for abalone may be as high as 50–70 percent. For sea cucumber, the rate depends more on site selection and improvement, with sheltered areas being more favourable.

In general, sea ranching is a good system to enhance or to re-establish a population that has declined, but numerous factors influence results. There is still a long way to go to reach the desired goals.

PROBLEMS AND SOLUTIONS IN MARICULTURE DEVELOPMENT
Major problems
There are three main limiting factors influencing mariculture development in China.

Seed quantity and quality

Two major constraints should be considered:

- Stable seed supply is not available for all major mariculture species.
- Mariculture seed available is not based on a good system of selective breeding and the genetic material available is still equivalent to the wild species. Selective breeding is needed to improve growth, disease-resistance and quality.

Many mariculture species have been or are being developed in China, the breeding techniques for most have been developed, and seed can be provided to farmers and cooperatives. However, relatively limited systematic research has been conducted on artificial selection and genetic improvement. This situation contrasts with investments in agriculture and livestock, and should be remedied.

Aquatic animal and plant diseases

In China the aquaculture industry developed quickly, and the variety of marine aquatic products has surpassed 40. The scale of cultivation also expands unceasingly and the output increases on a large scale. In the last few years, however, disease has occurred continually in aquaculture, with the country suffering economic losses of billions of Yuan every year. Shrimp disease losses have been serious since 1993. Fish disease, sea scallop disease, kelp disease, abalone disease and so on have occurred unceasingly. Improvements in disease control are, therefore, critical to future mariculture development in the region; and governments, researchers and farmers all have an important role to play.

Environmental pollution

The condition of the inshore sea environment has a close correlation with the mariculture industry. Along with fast social and economical development in coastal areas, massive amounts of industrial wastes and sewage are discharged into the nearshore without effective treatment. The result is that the water quality in the nearshore worsens gradually, with direct impacts on the survival and development of the mariculture industry. On the other hand, environmental pollution from mariculture is also noticeable. Because many farmers use poor-quality fish food, the food conversion ratio (FCR) is high and a large quantity of food is discharged, leading to harmful environmental pollution. The misuse and abuse of some antibiotics, disinfectants and water quality improvement medicines sometimes occurs, leading to other ecological impacts. In addition, the "irrational" layout of farms causes water quality problems, harmful algae and disease microorganisms, eventually harming the survival and development of mariculture.

Suggestions for continued development

Develop intensive cultivation and enhance output

In the twenty-first century, Chinese seawater cultivation will convert from extensive to intensive farming. Intensive cultivation has the virtues of high output, stable production, potentially minimal impacts on the environment if conducted efficiently, water saving and so on, with significant developmental potential.

Through the development of high-value cultured species, the seawater cultivation standard can be enhanced significantly. The present task is to develop modern aquaculture systems and technologies, such as new anti-storm cage techniques, economical and practical water treatments, automatic feeders, environmental monitoring, etc.

Application of biotechnology

The application of biotechnology in mariculture is a key issue, including the use of new species, gender control, germplasm preservation, disease prevention and control, etc. With the support of the hi-tech "863" project, Chinese researchers have obtained important breakthroughs in cellular engineering breeding techniques. Triploid and hybrid oyster, scallop and abalone; all-female prawn and flounder; and kelp, *wakame* and laver have been developed through hi-tech approaches and will soon enter the industrial stage. Biotechnology research should receive high priority in mariculture research and development.

Develop healthy aquaculture and prevent diseases

Reasonable farm layout, proper scientific management and developing healthy cultivation techniques and management are vital steps to prevent disease occurrence. Something must be done to optimize the ecological environment of the culture system and provide good survival for the cultivated species. Research on disease epidemiology should be strengthened to determine the ecology of the pathogens and to find ways to prevent their spread in the environment. Other areas that need to be addressed include immunity, technology and management practices for prevention and control of disease, and development of new medicines. Rapid examination and diagnostic systems should be established to enable early action to be taken and reduce the associated losses.

Feeds and feed management

The use of high quality feed enhances product quality, reduces cost and disease occurrence by minimizing water pollution and improves economic efficiency. Technical improvements in feed and feeding plays a major role in increasing the output value of aquaculture. The use of high quality feed is an indication of progress in aquaculture technology. Research on nutrition and feed development needs to catch up with the demand from a rapidly industrializing aquaculture sector. Most of the aquatic products rely on natural animal feed, which results in high cost, low efficiency and poor sanitation. To promote the healthy development of the mariculture industry, we should energetically develop artificial feeds with high quality, good stability, good attractability, good absorbency and low FCR.