Chapter 4
Bivalve Production in China

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Abstract Bivalve is the main species of mariculture in China. In 2015, bivalve production was about 12.4 million tonnes, accounting for more than 66% of China's total mariculture production. The first record of shellfish culture in China, about oyster culture, can be tracked back to 2000 years ago. The large-scale aquaculture started in the 1950s with the breakthrough in seed breeding techniques for *Tegillarca granosa* and *Ruditapes philippinarum*. Subsequently, with the promotion of seed breeding and artificial seed collection for mussels, scallops and oysters, the bivalve aquaculture industry has rapidly developed. In the twenty-first century, the scale of bivalve farming is constantly expanding, with increasing culture species and yield.

The length of the coastline of China is about 18,000 km comprising 11 coastal provinces (Liaoning, Hebei, Tianjin, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Guangxi and Hainan provinces), all suitable for bivalve culture. Due to the significant difference in climate, the distribution of bivalve species is obviously regional. The major culture methods in China are longline culture (major species oysters, scallops, mussels, etc.) and bottom culture (clams). In this paper, we will describe the process of the longline cultured bivalve (Pacific oyster *Crassostrea gigas* and thick shell mussel *Mytilus coruscus*), and the bottom cultured ones (Manila clam *Ruditapes philippinarum* and cockle clam *Tegillarca granosa*).

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Abstract in Chinese 贝类是中国海水养殖的主要种类，2015年贝类养殖产量约为1360万吨，占中国海水养殖总产量的72.4%，其中双壳贝类产量约为1240万吨，占贝类总产量的90%以上。中国的贝类养殖历史悠久，距今2000多年前就有牡蛎养殖的记载，但规模化养殖始于20世纪70年代，这主要得益于贝类的苗种繁育技术得到了提高；随后，贻贝、扇贝、牡蛎等多种贝类的苗种繁育和人工采苗技术的建立，推动了贝类产业的迅速发展。进入21世纪，贝类养殖规模不断扩大，养殖种类不断增加，养殖产量大幅度提高。中国海岸线长度为1.8万公里，从北到南跨越辽宁、河北、天津、山东、江苏、上海、浙江、福建、广东、广西和海南11个省(直辖市)，大多数海域都适合贝类养殖，因气候差异显著，贝类分布具有明显地域性。中国贝类养殖方式主要包括筏式养殖和底播养殖，前者主要养殖种类包括牡蛎、扇贝、贻贝等；后者主要养殖种类包括菲律宾蛤仔、毛蚶、文蛤、虾夷扇贝等。本文分别以长牡蛎、厚壳贻贝为代表介绍了筏式养殖贝类的苗种生产和养殖过程；以菲律宾蛤仔和泥蚶为例介绍了滩涂贝类的苗种繁育和养殖过程。

Keywords Longline culture · Bottom culture · Seed breeding · Production process

关键词 筏式养殖 · 底播养殖 · 苗种繁育 · 生产过程

4.1 Overview of the Bivalve Production

The historical evidence of bivalve culture in China can be traced back to 2000 years ago, but the large-scale mariculture of bivalves was extensively practiced since the 1950s. The annual production of mariculture in China was about 10,000 t in 1950 and oyster was the major culture species then.

In the following 20 years, mussel and kelp had joined the oysters to make up the most cultured species in China. However, the bivalve seeding mainly comes from wild breeding in this period. After the 1950s, Chinese government and scientists paid great efforts on artificial breeding and natural collection of clam seeds such as cockle *Tegillarca granosa*, razor clam *Sinonovacula constricta*, clams *Ruditapes philippinarum* and *Cyclina sinensis*. In the 1970s, the mussel farming industry grew rapidly according to the persistent exploration of mussel hatchery and wild seed collection techniques. The farming area for mussels exceeded 2000 hectares and the annual production approached 60 kt in 1977, marking the rise of the Chinese shallow sea bivalve culture industry.

In the early 1980s, when the artificial breeding of scallops became mature and applicable in hatcheries (especially for the imported species bay scallop *Argopecten irradians*), together with the wild seed collection and improved longline culture technologies, scallop mariculture has greatly expanded. With the development of feeding eco-physiology, bivalve aquaculture industry gradually stepped into a new era in the fields of natural seed collection, seed breeding in hatchery, and variety of culture methods such as longline, sea ranching and pond culture.

Since 1990, mariculture (main categories: molluscs (bivalves and gastropods), algae, crustaceans, fish and others) in China has experienced a stage with flourishing

Table 4.1 The production of molluscs from 2006–2015 in China in tons * 10000 (10^4)

Year / Species	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Total	1113.6	993.8	1008.1	1053.0	1108.2	1154.4	1208.4	1272.8	1316.6	1358.4
Oyster	389.2	350.9	335.4	350.4	364.3	375.6	394.9	421.9	435.2	457.3
Clam	301.9	295.7	305.8	319.2	353.9	361.3	373.5	385.4	396.7	400.9
Scallop	114.9	116.5	113.7	127.7	140.7	130.6	142.0	160.8	164.9	178.5
Mussel	74.6	44.9	48.0	63.7	70.2	70.7	76.4	74.7	80.6	84.5
Razor clam	67.9	66.7	74.2	68.4	71.4	74.5	72.0	72.1	78.7	79.4
Cockle	31.6	28.0	29.0	27.7	31.0	29.3	27.8	33.7	35.3	36.4
Sea snail	24.9	25.9	22.5	20.4	20.8	20.3	21.4	21.3	23.3	24.3
Abalone	2.2	2.5	3.3	4.2	5.7	7.7	9.1	11.0	11.5	12.8
Pen shell	1.8	1.2	1.1	1.5	3.1	3.0	1.5	1.7	1.8	1.8
Others	104.6	61.5	75.0	69.8	47.1	81.2	89.7	90.2	88.5	82.3

development (FAO 2014; Bureau of Fisheries, Ministry of Agriculture 2016). Until 2015, the cultured mollusc production is about 13.6 Mt., accounting for 72.4% of the total mariculture production (Bureau of Fisheries, Ministry of Agriculture 2016), and is about 4.4 times of that in 1995 (3.1 Mt), 48.9 times of that in 1975 (277,538 tonnes) The annual production of cultured bivalves in 2015 is around 12.4 Mt., accounting for about 91.2% of the total annual mollusc yield. Table 4.1 showed the annual production of cultured molluscs from 2006 to 2015.

Nowadays, the bivalves cultured in China has rose from around 10 species to approximately 70 since the 1960s (Tang et al. 2016), and among them two species, bay scallop (*A. irradians*) and Yesso scallop (*Patinopecten yessoensis*), were successfully introduced and applied in commercial scale production. The most productive bivalves include oysters (*Crassostrea gigas*, *C. rivularis* and *C. plicatula*); scallops (*Chlamys farreri*, *P. yessoensis*, *A. irradians* and *C. nobilis*); clams (*Meretrix meretrix*, *Ruditapes philippinarum* and *Mactra veneriformis*), razor clams (*Sinonovacula constricta* and *Solen grandis*), cockles (*Scaphaributica subcrenata*, *Scapharca broughtonii* and *Tegillarca granosa*), mussels (*Mytilus galloprovincialis*, *M. coruscus* and *Perna viridis*) and etc.

4.1.1 Production Distribution

China's coastline is about 18,000 km, crossing the tropics, subtropical and temperate zones, Different climatic zones and eco-environment provide varieties of survival and reproduction condition for various bivalve species (Fig. 4.1).

The major cultured bivalves and gastropods include scallops, abalones, mussels, sea snails and manila clam in Liaoning province along the North Yellow Sea coast. The sea ranching and longline culture of Japanese scallop *P. yessoensis* and mudflat

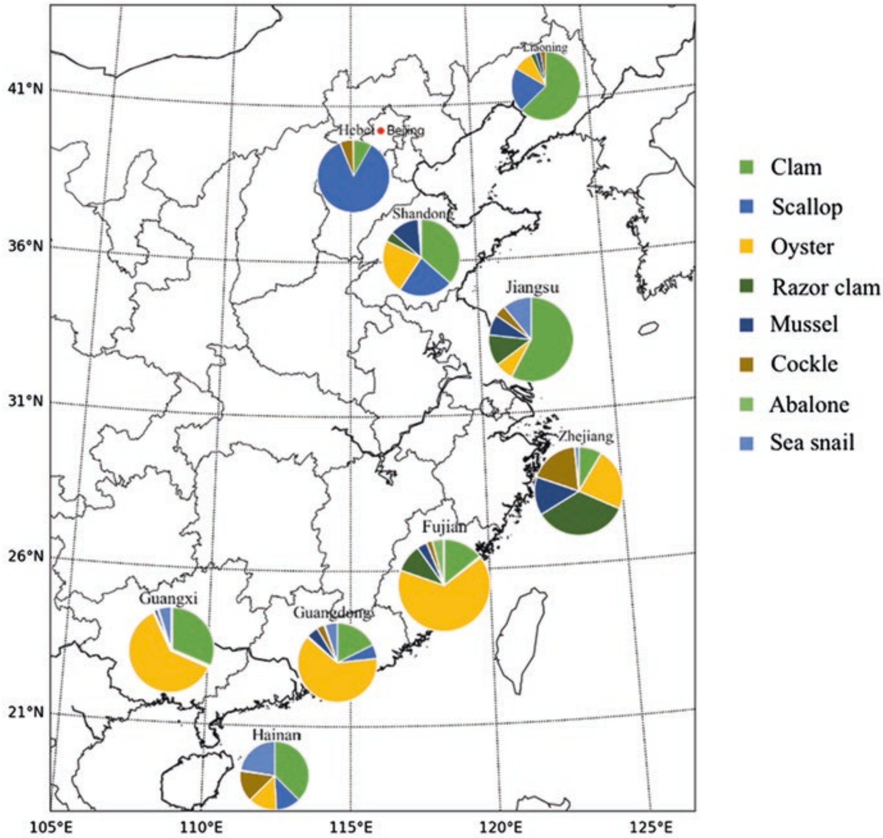

Fig. 4.1 Major culture shellfish species and production percentage in coastal provinces in China

culture of *R. philippinarum* are the major farming methods for aquaculture industries here.

Bohai Bay, Liaodong Bay and Laizhou Bay are the major aquaculture areas along the Bohai Sea coast with the major cultured species being mudflat shellfish such as clams, razor clams, conchs, oyster and cockle. Changdao Islands, located crossing the boundary of the Yellow Sea and Bohai Sea, are the high yield area for abalone (*Haliotis discus hannai*), Scallop (*C. farreri* and *P. yessoensis*) and cockle (*S. broughtonii*).

High diversity of mariculture species has been well practiced in Shandong Peninsula with various culture methods such as bottom, pond and longline culture. Mostly popular cultivated species includes abalone (*Holiotis discuss hannai*), scallop (*C. farreri*), Pacific oysters, manila clam (*R. philippinarum*), snails (*Bullacta exarata*), razor clam (*S. constricta*) and cockle (*S. broughtonii*). The seaweed-bivalve polyculture and Integrated Multi-Trophic Aquaculture (IMTA) of seaweed, bivalves, fish and sea cucumber have been conducted in Sanggou Bay for decades, leading the development of eco-farming in the world.

Haizhou Bay is located between southern Shandong peninsula and north of Jiangsu province, which is productive in blue mussel (*M. galloprovincialis*) and mudflat bivalves; the intertidal bottom clam culture and shallow sea longline culture are the major culture modes.

Culture species in Zhejiang and Fujian provinces include clams, Fujian oyster (*C. angulata*), abalone, mussel, conch and others. Pond culture of clams in Zhejiang province is well known in China, even in the world. The abalone culture has become popular in Fujian province in the last decade, which also promoted the culture of seaweed as feed for abalone. Meanwhile, the seed breeding of Manila clam in ponds gradually became one of the most important industries for local communes in Fujian province. In 2013, the total seed production of Manila clam (with shell length about 1 cm) in Fujian province was 7952 tons, which has fulfilled more than 80% of the seed demand for Manila clam farming in China. Moreover, the Manila clam is also farmed with shrimp, fish and crab in pond IMTA systems; this mode has been well practiced at commercial scale in the above two provinces.

Guangdong and Guangxi provinces are located along the coast of South China Sea. Major culture species here are Hong Kong oyster (*C. hongkongensis*), pearl oyster (*Pinctada martensii*), scallops (*C. nobilis*) and clams. The mariculture of pearl oyster is the traditional industry but recently has suffered a depression; the causes are supposed to be the stress from both climate change and human activities. The production of seawater pearl oyster has dropped from 38.6 tons in 2000 to 3.6 tons in 2015 (Zhu et al. 2019).

Hainan Island is located between tropic and subtropic zones, and the major cultured species include scallops (*C. nobilis*), sea snails (*Babylonia areolata*), green mussel (*P. viridis*), pearl oyster (*P. martensii*), oyster (*C. hongkongensis*) and others.

4.2 Bivalve Seed Production

Bivalve breeding technology is the basis of large-scale bivalve farming in China. After the 1950s, China has conducted artificial breeding on mud flat species such as *T. granosa*, *S. constricta*, *R. Philippinarum* and *Cyclina sinensis*, and successfully established the artificial breeding techniques. In the 1970s, the indoor hatchery technology and wild seed collection of mussel had been well practiced. In the early 1980s, artificial breeding, wild seed collection and longline culture technology of scallop gradually matured. Especially in 1982, the introduction of the bay scallop (*A. irradians*) greatly promoted China's scallop aquaculture, and contributed to the formation of several latest culture modes such as the alternative culture of seaweed and scallop and the polyculture of scallop, seaweed and shrimp. New culture modes and technology effectively promoted the development of China's marine aquaculture industry, and formed China's third wave of large scale mariculture activity. At present, there are two major seed production methods of bivalves in China, one is factory hatchery and the other is eco-hatchery in earth pond. The following introduces these two methods with representative species, Pacific oyster (*C. gigas,* factory) and Manila clam (R. *philippinarum*, earth pond), respectively.

4.2.1 Artificial Breeding of Pacific Oysters

The oyster is a worldwide commercial bivalve with diverse species, wide distribution and high adaptability. China's oyster farming can be traced back 2400 years to the ancient book "*Pisciculture*" written by the famous politician, strategist, Taoist and Economist FAN Li (Liu 1959). The production of oysters has ranked first position in a variety of cultivated bivalves in China. Natural seed collection was the major means for seed production before the 1980s, and was then replaced by the artificial seeding technique. In Shandong and Liaoning province the reproductive season continues from May to August, while in Zhejiang coastal region the reproductive time is in June and July (Gao et al. 1982; Wang and Wang 2008).

Taking the Pacific oyster (*C. gigas*) as an example, the seed breeding process was introduced below:

Bivalve farming covers the life cycle from larvae to adult, mainly including seed production and commercial size production (Fig. 4.2). Seed production is of vital

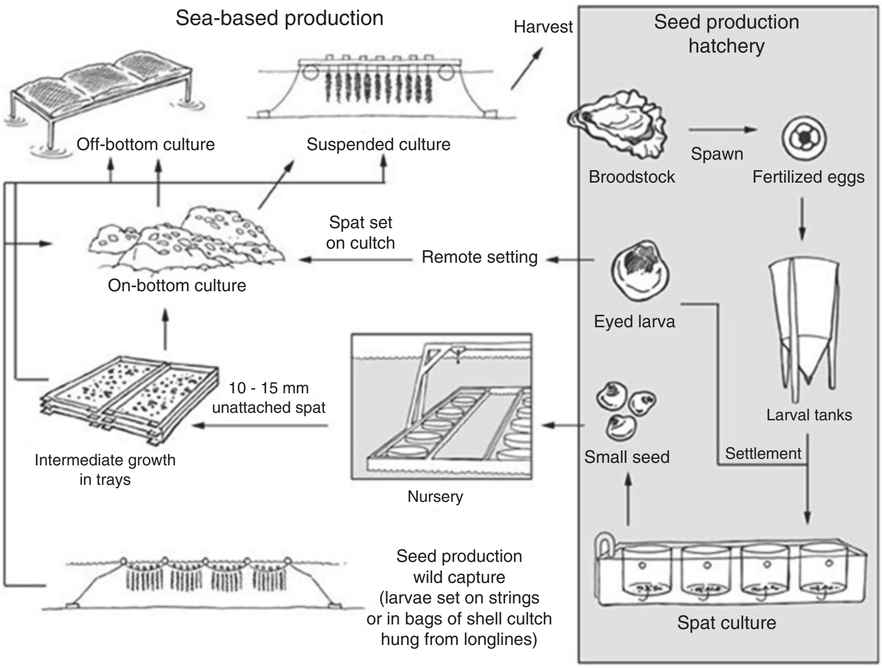

Fig. 4.2 Process and method of oyster farming (http://www.fao.org/fishery/culturedspecies/*Crassostrea_gigas*/en)

importance for the sustainable development of bivalve farming. The major methods are seed production in hatchery, semi-artificial seed breeding in ponds, wild seed collection and intermediate nursery in ponds or shallow seas.

4.2.1.1 Choice and Conditioning of Broodstock

The choice of broodstock oysters is of vital importance because high quality germplasm is fundamental to producing excellent offspring (Sui et al. 1997). Each year in March–April, oysters with shell length greater than 12 cm will be selected from phytoplankton-rich waters as broodstock and moved to the hatchery. After surface attachments and creatures have been removed, broodstock oysters will be transferred to the indoor tank of the hatchery for conditioning with a density of 35–50 ind./m^3. During the conditioning period, microalgae, such as diatoms (*Phaeodactylum tricornutum, Nitzschia closterium* and *Chaetoceros muelleri*), Chrysophyta (*Isochrysis galbana* and *Dicrateria zhanjiangensis*), Chlorophyta (*Chlorella vulgaris* and *Platymonas hegolandica*) are the major feed for broodstock oysters with feeding density about 200,000 cell/ml in 24 h. The conditioning water temperature is gradually increased from the beginning by 1 °C per day, and maintained stable at around 20 °C until ready for spawning (Yang et al. 1995).

4.2.1.2 Hatching and Larval Rearing

When the broodstock oysters' gonads mature, stimulation for spawning can be conducted. After drying 6–10 h in shade, the broodstock is put into the floating cages and placed into hatching tanks prepared for spawning. When the spawning egg density reaches 30–50 cells/ml, the spawning broodstock will be moved to another tank for continuous spawning. Generally, with the water temperature about 20 °C, in 24 h or so, fertilized eggs can be hatched to veliger larvae (D-larvae).

4.2.1.3 Larval Rearing

Larval rearing refers to the process of the veliger larvae (D-larvae) growth to spat. It takes about 7–9 days for veliger larvae grow to the umbo larvae, then about 19–22 days to grow into post larvae (eyespot larvae) and finally about 21–26 days to finish metamorphosis and transform into spat. The larvae are cultured at a temperature of 23–24 °C, and about 40%, 50% and 80% of water need be replaced daily for D-larvae, umbo larvae and eyespot larvae stage respectively. Usually every 7–8 days the tank will be refreshed. After the last refresh, the substrate will be placed in the tank for seed settlement. Chrysophyta are the best starting feed for D-larvae. When shell length of the larvae reached greater than 130 μm, high concentration Chlorophyta (*Platymonas* spp.) can be added to the feed. Feed density is better at 20,000 cell/ml for D larvae stage, 30,000–40,000 cell/ml for the umbo

Fig. 4.3 Substrate used in artificial breeding of oyster. (Photo from Mao)

larvae stage and 50,000 cell/ml for eyespot larvae stage per day. The best substrate for oyster larvae is scallop shells. When the larvae shell length grows to more than 280 μm and eyespots emerge gradually, then substrates are gradually placed into the settling tank with a density about 5000–6000 shells/m^3 (Fig. 4.3). When larvae attach to substrate and finished metamorphosis, the amount of feeding needs to be increased based on the feeding status of the spat. The feed is made up of diatom (*P. tricornutum, N. closterium*), Chlorophyta (*Platymonas* spp., *Chlorella* spp.) and Chrysophyta (*I. galbana*). Fifteen days after the settlement, spats can be moved to outdoor ponds or the sea for nursery.

4.2.2 *Artificial Breeding of Manila Clam (*R. philippinarum*) in Ponds*

R. philippinarum, which belongs to *Veneridae*, *Ruditapes*, is a species widely distributed in coastal areas of China and is highly productive in Shandong, Liaoning, Zhejiang and Fujian coastal areas. Annual production of *R. philippinarum* (about 3.2 Mt) accounts for about 62.7% of mudflat bivalve production and about 24.3% of total bivalve production in 2014 (Yan 2014).

The reproductive season of Manila clams varies in regions: from June to August along Liaoning coast, in late May and late September along Shandong coast, and in late September to November along Fujian coastal region. Appropriate reproduction water temperature is at 20 °C. With a fecundity of about 2–6 million per clam per year, Manila clam spawns 3–4 times during the reproductive season, and most spawning activity happens during the high tide and in the evening (Yan 2005; Zhang et al. 2006). The process and methods of seed production of Manila clam in ponds are as follows: Seed production pond is usually built in the intertidal zone near the shore, with no flood or storm threats and sufficient water exchange. The most suitable region is in the sheltered area with sandy muddy sediment.

4.2.2.1 Construction of the Seed Production Pond

Specified area for seed production ponds are varied from 1–100 ha and rectangle ponds are recommended. With water depth of 1.5–2 m, the pond wall height should be at least 1 m above the maximum tide level. A gate is used to control the water exchange. The number, size and location of gates should be determined according to the topography, area, flow direction, water flux and other related aspects. Generally, inlet gate and outlet gate should be built in pairs, the size of the gate should be able to fill or drain the pond in one day during spring tides (Fig. 4.4).

The bottom of the pond should be flattened with a longitudinal ditch about 0.5 m deep in the middle of the pond. A thin layer of fine sand with particle size about 1–2 mm should be laid on the pond bottom for spats and juveniles. A broodstock support frame is designed for stimulating spawning of broodstock, which is built close to the inside of inlet gate. The frame needs to be covered with netting in order to support and prevent the broodstock clam from escaping into the pond. Size of the support frame is varied with the pond size.

4.2.2.2 Preparatory Work Before Seed Production

Pond Cleaning: Clean the mud, stones and other debris, seaweed (*Ulva* spp.) and other attachments in the pond.

Drying: Drain the water in the pond, flatten the pond bottom, disinfect and bleach to improve substrate condition for helping spat settlement.

Cultivation algae: After disinfection and 7–10 days before the nursery stage, 30–50 cm of seawater filtered with nylon screen (ca. 50–5 μm) should be filled in the pond. About 0.5–1 ppm urea, 0.25–0.5 ppm superphosphate and 0.1 ppm silicate are added into the pond to promote the growth of phytoplankton.

4.2.2.3 Spawning

Gonadal status need to be identified before cleaning and temporarily reared.

Broodstock shellfish are usually to be placed in the support frame for temporary rearing at a density of 300–600 kg/ha. The procedure of stimulating spawning including drying the broodstock in the shade for 4–8 h and then exchange the pond water with flow rate of 35 cm/s for 2–3 h. When the broodstock spawned, continuing inflow is necessary for well fertilization and evenly distributed for fertilized eggs. The suitable D-larvae density is 3–4 ind./ml.

Fig. 4.4 Inlet gate with channel higher than water level; and outlet gate with channel lower than water level. (From Mao)

4.2.2.4 Larval Rearing

Water supplement: about 10–20 cm water filtered with the screen will flow into the pond daily during high tide in order to promote larvae growing and stabilize the temperature and salinity of pond water.

Fertilization: The density of phytoplankton in the pond should be maintained at the concentration of 20,000–40,000 cell/ml for meeting the feeding demand of larvae. To maintain such density, fertilizers should be applied according to the variation of phytoplankton concentration. About 0.5–1 ppm urea, 0.5 ppm superphosphate and other nutrients should be added every 1–2 days. During D-larvae period, feed density should be around 15,000 cell/ml, and increase to 30,000 cell/ml during umbo larvae period. If the microalgae density is high enough, fertilize is not necessary.

4.2.2.5 Spat and Juvenile Cultivation

Juvenile cultivation is a key stage of shellfish culture. The growth from spat to juvenile (about 1 cm in length) is an important stage in shellfish lifecycle. If right after the settlement, the filter organ gill, water pipe and shell are not well formed for the spat, mortality will be high and the survival rate is about 10%. At this point, measures such as suitable substrate selection, water quality management and sufficient food supplement should be applied (Wang and Wang 2008).

4.3 Shellfish Longline Farming

Longline farming is one of the most common bivalve culture methods in China (Fig. 4.5), the annual production of longline cultured bivalves exceeded 4 Mt. in recent years. There are many species of longline cultured bivalves and gastropods, such as scallops, oysters, mussels and abalone. Longline farming has a variety of types according to different regions. Aquaculture technology has developed through years, and currently the poly-culture of bivalves and seaweed (i.e. IMTA) has become the latest eco-farming mode. With this method, bivalves and algae mutually benefit, which achieves a double-win result with both ecological and economic benefits.

Below, approaches to longline culture of two important taxa, oysters and mussels, are discussed.

4.3.1 Oyster Farming

Oyster farming methods are mainly shallow sea longline farming in northern China and mudflat farming in southern China. China's oyster production ranked first in the total production of shellfish and has been on rise continuously. Oyster yield reached 4.6 million tons in 2015, accounting for 33.7% of total bivalves output (Bureau of Fisheries, Ministry of Agriculture). The major Chinese longline cultured oysters are *C. gigas*, *C. rivularis*, *C. plicatula*, *O. denselamellosa*, and *C. angulata*. Among

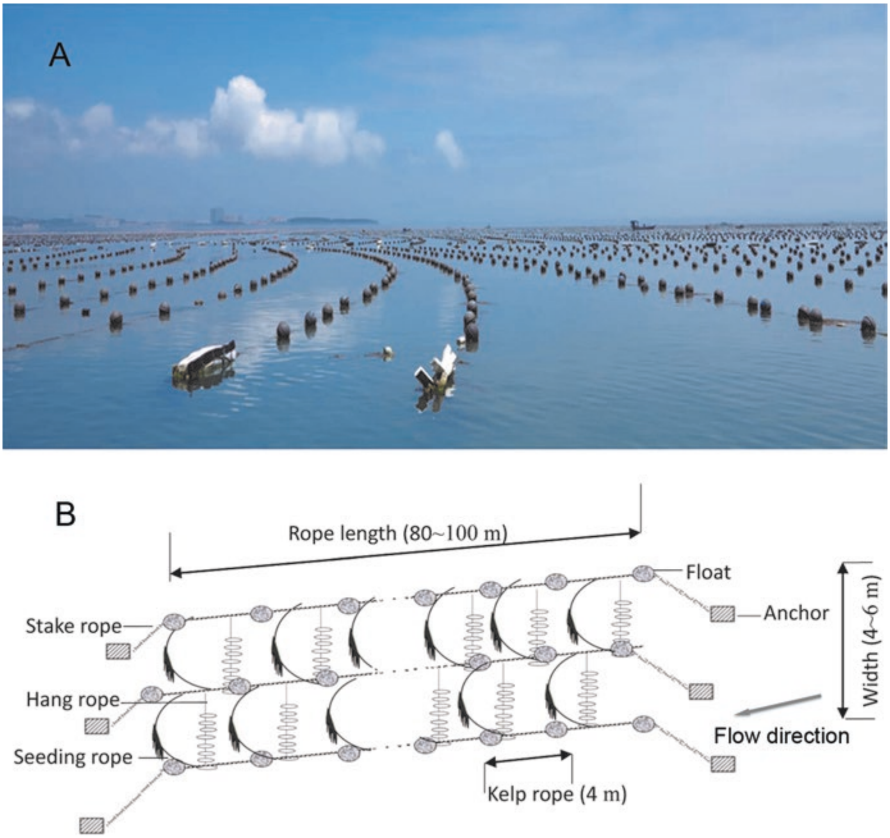

Fig. 4.5 Longline culture in China (above); Schematic diagram of longline culture in China (below)

them, Pacific oyster (*C. gigas*) is mainly cultured in northern China, while the other three species are mainly cultured in southern China. Below, we introduce the longline culture technology with the Pacific oyster as an example.

4.3.1.1 Pacific Oyster (*C. gigas*)

Pacific oysters have the advantages of high growth rate and high yield. The successful artificial breeding of oysters has provided abundant seeds for large-scale culture.

The main process of Pacific oyster longline culture is as follows:

4.3.1.2 Area Selection

Sea area for Pacific oyster longline culture should be relatively calm, water depth at low tide greater than 4 m, and water temperature above the freezing point in winter and less than 30 °C in summer. Flow rate of about 0.3–0.5 m/s is appropriate for oyster longline culture. The amount of phytoplankton in the sea area is generally no less than 40,000 cells/L. Additionally the culture area should be far from where mussels, sea squirts and other competitive species exist, and away from pollution (Li 2006).

4.3.1.3 Facility Set Up

The direction of the longline stake rope should follow the current, and polyethylene rope with a diameter of 2.4 cm is used as the stake raft rope. The raft rope length is about 150 m in total, about 80–100 m of which is used for cultivation. There are about 25 m at each end attaching to the fixed pile. The space between two consecutive longlines is 7 m wide. Float number is gradually increased according to the oyster growth. Polyethylene rope with 0.4 cm diameter and 3.0 m long is used for hanging oyster, hanging space between each rope is about 1 m. When oyster is cultured in a cage, the hanging space should be 1.2–1.5 m (Fig. 4.5).

4.3.1.4 Density and Scale

Oyster farming is mainly conducted in sheltered waters. The farming density and farming scale is planned based on carrying capacity according to local environmental parameters (Fang et al. 1996). To prevent over farming, a better way is to implement shellfish-algae polyculture.

4.3.1.5 Harvest

The harvest of Pacific oysters is slightly different according to the situation in north China. Some aquaculture areas have been harvested in November–December, some areas with sufficient food supply and non-frozen winter usually harvest from March–June in the following year (Lian and Mao 2010). At present, the harvest of oysters is in a traditional and high labor cost way with manual operation. Nowadays, researchers and enterprises are developing relevant mechanized harvesting means to reduce the labor costs.

4.3.2 Mussel Farming

Longline culture is the major mussel culture mode in China. Mussel species include *Mytilus galloprovincialis*, *M. coruscus* and *Perna viridis*. *M. galloprovincialis* and *M. coruscus* are mainly distributed in the Yellow Sea and the East China Sea, while *P. viridis* is only found in the South China Sea. At present, the majority of mussel seed comes from natural sea area collection, and a small amount from artificial breeding. Below, the culture method of thick shell mussel is described as an example.

4.3.2.1 Thick Shell Mussel (*Mytilus coruscus*)

M. coruscus are the representative mussel species as their higher market price. The raft culture of *M. coruscus* is introduced as an example at a typical area in Shengsi, Zhejiang.

The main process of Thick shell mussel longline culture is as follows:

4.3.2.2 Area Selection

Mussels are usually cultured in sheltered areas with sand and mud sediment. Sufficient water exchange, abundant natural phytoplankton and detritus, and a water depth between 5–20 m at low tide are preferred conditions. *M. galloprovincialis* and *M. coruscus* can survive in a condition with salinity between 18–34 psu and temperature between 0–29 °C (temporary frozen period in winter).

4.3.2.3 Facility Set Up

Longline raft set up for mussel is similar to that of Pacific oyster. The major differences are in the longline and float distances. The raft rope length is about 63 m in total, raft is set every 17 m along the rope. There are about 25 m at each end attaching to the fixed pile. The space between two consecutive longlines is 7 m wide. Length of the longline is about 65 meter, the cultured thick shell mussels are attached to a rope hanging every 4 m on the longline and is attached to a float; Distance between each longline is about 17 m and 7 longlines forms a culture unit, with an area about 6667 m^2, culturing a total of 105 ropes of thick shell mussel (Fig. 4.6).

4.3.2.4 Nursery Facility

During the breeding, the thick shell mussel seed will be sorted several times. When seed leaves the nursery, the seed will be put into net bags for intermediate cultivation. After the seed grows to about 0.5–1.0 cm in length, farmers will conduct the second resocking into polyethylene mesh.

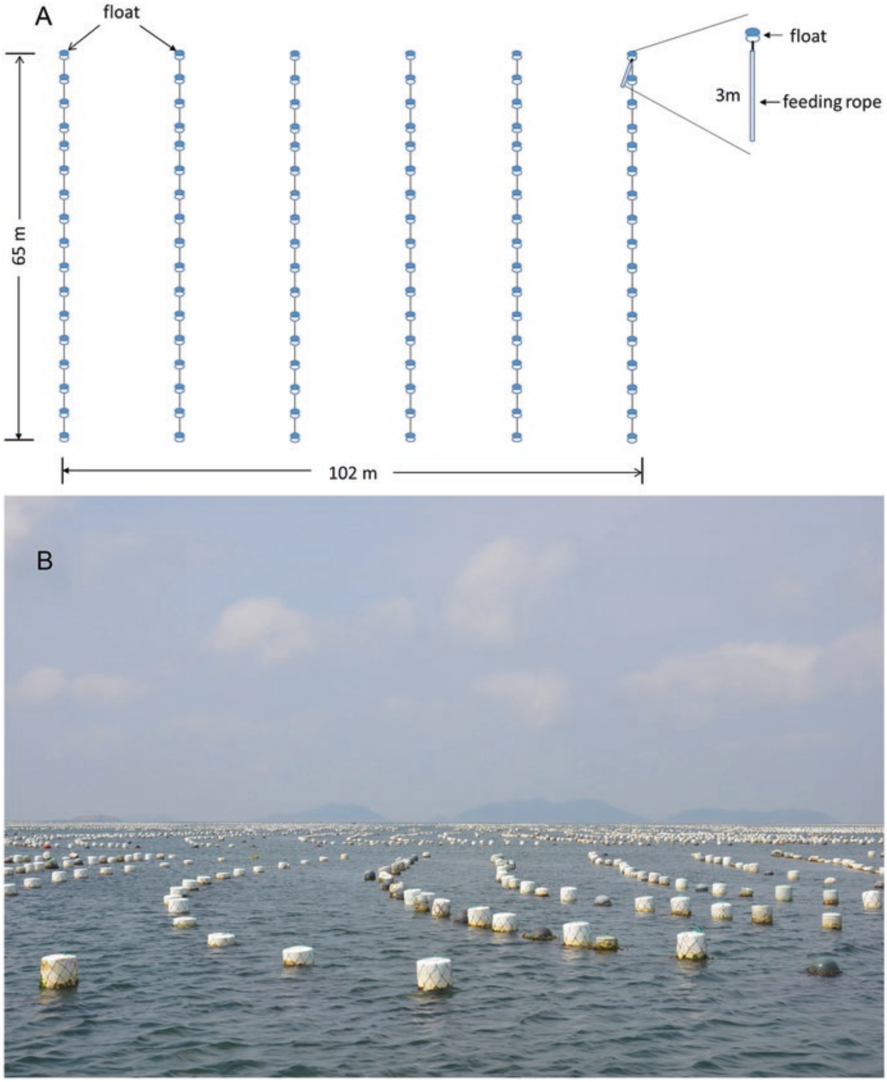

Fig. 4.6 Facility of thick shell mussel longline culture (**a**, Schematic; **b**, Field photograph)

Packing mesh and tying rope: Seed packing mesh should be woven with polyethylene. The length of the package mesh should be 30–50 cm longer than the breeding rope. The initial package is 30 cm wide and 0.5–1.0 cm aperture mesh, and latter package is 40 cm wide and 1.5–2.5 cm aperture mesh.

Normally, rubber or polyethylene ropes are used as the nursery and culture ropes for mussel farming in China, while for thick shell mussel, hemp rope is usually applied as the culture rope, with the diameter around 2.0 cm and length between 2.5–3.0 m (Fig. 4.7a). At present, the widespread use of a self-dissolving material is conducive to the growth of mussels with less labor and financial cost. The sock-type

Fig. 4.7 Culture ropes and bagging the juvenile mussel (**a** the Rope; **b** bagging juvenile mussel; **c** shematic of the bags)

bag will automatically break when the mussels attach to the breeding rope. The sock-type bag is usually made with paper-like material, the width of the bag is about 20–25 cm and the length is a bit shorter than the culture rope. The juvenile mussels are filtered through a sieve with a diameter of 2–3 cm to ensure they are separated sufficiently. When putting juvenile mussel into the bag, farmers usually place 30–50 individuals every 10 cm along the net, when all the individuals are placed, rolling the net and attach it to the culture rope with some thin hemp ropes to make the bag (Fig. 4.7b, c), each culture rope will be attached to a float during the culture period (Fig. 4.6).

Hanging rope: Generally, polyethylene rope with a diameter of about 5 mm is used for hanging mussels. To prevent the rotation of the device, paired hanging rope can be applied.

4.3.2.5 Harvest of Mussels

Mussels are usually harvested twice a year, during early summer and early winter, when the shell height reached about 6–7 cm. Now the thick shell mussels are harvested in a semi-mechanized way (Fig. 4.8). Harvested mussels are usually sorted and cleared for further processing.

4.4 Bivalve Bottom Culture

Bivalve bottom culture is another major method in China. Mudflat bivalves, such as clam, razor clam and arc shell, are the main bottom culture species. In 2015, 3 species mentioned before produced more than 5 Mt. of shellfish, accounting for more than 1/3 of the total shellfish production. Mudflat shellfish farming has developed rapidly in recent years, the price showed a trend of continuous increasing, and has become major species in Chinese market.

Fig. 4.8 Harvesting of the thick shell mussel

General methods to bottom culture of two important taxa, Manila clam and cockle clam, are discussed below.

4.4.1 Manila Clam Farming

4.4.1.1 Mudflat Modification

The mudflat is usually modified to suitable condition before the clam culture. By applying bottom plowing and sediment drying to clean the dead shells and loosen the sediment, the humus in the sand is decomposed and then washed away by seawater.

4.4.1.2 Seed Source

Major sources include: Indoor artificial seed production, natural seeds collected from Shandong and Liaoning province, artificial seed produced in ponds from Fujian Putian city.

4.4.1.3 Sowing

Seeds are sown in spring or autumn. Neap tide and sunny windless days are preferred for the dry release of seeds. Seed size from 3–10 mm can be sown; sowing density is controlled at 1000–2000 ind./m^2 and distributed uniformly (Mitchell et al. 1992; Cigarría and Fernández 1998; Zhou et al. 1998). Seed around 10 mm have better survival rate, growth rate and yield.

4.4.1.4 Subtidal Zone Culture (Water Depth Within 20 m)

Clams cultured in the subtidal zone have no exposure time, and are less affected by high temperature, freezing and flood, which prolongs the effective feeding time. The growth rate and relative fatness of clams are found increased by 67.9% and 26.9%, respectively, compared to the clams cultured in mudflats, and the survival rate was above 80%. In the subtidal zone, shell growth rate of cultured Manila clams is more than 4.0 mm/month and the culture cycle is shorted by 6 to 12 months compare to the mudflat culture, which improves both product quality and commodity value.

4.4.1.5 Predators

The major predators affecting Manila clam culture are shrimp and crabs, snails (*Rapana venosa* and *Glossaulax didyma*), sea anemones, starfish, fish (*Acanthogobius* spp.), and birds (seagulls and sea ducks). In China, artificial catchment of predators is the major way to protect the clams from being predated. The coverage of plastic protective nets in the heavily damaged areas has greatly increased the survival rate of cultured clams abroad (Cigarría and Fernández 2000; Spencer et al. 1992).

4.4.1.6 Harvest

Manila clams are harvested throughout the year. In the intertidal zone, manual capture is the major method and smaller individuals will be left for continued growth. In the subtidal zone the clams will be captured with motor boats.

*4.4.2 Cockle Clam (*T. granosa*) Farming*

T. granosa bottom culture can be divided into two ways: field farming and pond farming.

4.4.2.1 Field Farming

Field farming is popular in Guangdong and Fujian coastal regions, and refers to the farming on non-water retained flat sediment. A common choice for farming sites is on the inner soft mudflat in the intertidal zone. Such method benefits from construction convenience and sufficient water exchange, which is suitable for large-scale farming. Field farming area can reach up to 50–60 ha. Selected areas are divided into several square or rectangular zones according to topography and marked with bamboo or sticks. Shallow channels are constructed between each square for water outlet and prevention of clam seed escape. In some regions, the farm area is surrounded by nets to protect clams from predators.

4.4.2.2 Pond Farming

Clam ponds are usually built in the mid tidal flushing area; in the low tide area the pond walls are frequently eroded by tidal flow and in the high tide area water exchange is insufficient (Mojica and Nelson 1993). Tidal cycles are used for water level control in the pond, which leads to the comprehensive utilization of the tidal zone. In addition, feeding time of cultured clams is prolonged according to the retained water in the pond, higher survival and growth rate are expected. However, the high labor cost for pond construction has limited the farm scale. And during low tide the pond water become stagnant which it is unsuitable for high-density farming (You et al. 2002). In winter, emphasis should be paid to the solidity of the pond walls and to prevent the deposition of sludge. Sediment should be firm enough to prevent water leakage.

Clam culture density varies greatly in different regions and is determined by culture method and conditions. Farming density on mudflats can be estimated with 100–150 kg/ha production for large size clam individuals, that is, when harvested, about 4.5 million individuals will be collected per hectare. Sowing is generally during low tide on cloudy days and clam seeds are evenly distributed into the pond (Fig. 4.9).

4.4.2.3 Aquaculture Management

Scatter: clam seeds are captured every 10 to 15 days with mesh drip bags and then re-distributed to a larger farming area to adjust farm density for growth promotion. During this process, competitive species and predators are removed, and the epiphytic organisms on clam shells are cleaned.

Salinity maintenance: during the rainy season, high precipitation may dilute the seawater. To maintain a certain degree of salinity, if the proportion of seawater fell below 5 psu for more than 3 days, 600 kg/ha of salt should be added to the pond during low tide.

Fig. 4.9 Pond farming in Zhejiang province (From Mao), in the picture, the pond is surrounded by the channels with water, and when clam farming starts, the central pond will be submerged with seawater

Aestivate and overwintering: in South China, the summer sunlight often overheats the retained surface water covering the clam field and leads to high mortality. Therefore, in clam field farming, seawater retention should be avoided. In clam pond farming, on the contrary, water storage should be increased to keep a certain water depth and to avoid a sharp water temperature rise in the pond. Along the North China coast, overwintering is the major concern. Clam farms are moved to the subtidal zone to keep away from low surface temperature. Clam seed overwintering ponds are usually built in the intertidal zone and overwintering migration should be completed before October. Late transportation may increase the seed mortality due to freezing. During the overwintering process, pond water depth is kept between 20–30 cm with no leakage allowed.

Predator capture: clam farms need to be inspected frequently. Predators such as other clams (*Musculus senhousia*), starfish, crabs, fish (*Acanthogobius* spp.), red snails (*Rapana* spp.) and others are cleaned manually. If necessary, mesh cover or other methods can be applied to prevent clams from being preyed upon.

Harvest: The commercial specifications for cultured cockle clam are set as: shell length > 2.5 cm and reach 200 ind./kg. It usually takes 2–3 culture years in South China and 3–4 culture years in North China to satisfy commercial requirements. Afterwards the net profit decreases due to lower growth rate. Generally, clams are harvested in the winter fatness period with good taste. Southern harvest occurs from

December until the following March; in the north it is from November to December. After 3 years of farming, more than 20 tons of clams can be harvested from each hectare.

4.5 Conclusions

In recent years, the species of cultured bivalve in China has been continuously increased from 10 species in the 1950s to more than 70 species now. The bivalve production has been gradually increasing. The bivalve aquaculture production in 2015 was 12.4 Mt., accounting for 66.0% of the total marine aquaculture production.

Bivalve cultured in China have obvious geographical distribution characteristics, among which clams and oysters are all over the country culture species.

Longline culture and bottom culture are the major methods of bivalve farming in China. The main longline cultured bivalves include oysters, scallops, mussels, etc.; bottom cultured ones include clams such as *R. philippinarum* and *T. granosa*.

Artificial breeding techniques of bivalves including oysters, clams and scallops have been extensively applied in China, and has supplied the majority of the seed sources of almost all the main cultured bivalves. Pacific oysters are the representative species of longline cultured bivalves; Manila clam *R. philippinarum* is the representative species of bottom cultured bivalve.

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