Chapter 5
Production of Pearls

Changbo Zhu, Paul C. Southgate, and Ting Li

Abstract The pearl is known as the queen of jewels, and has been used for adornment and as a symbol of material wealth throughout human history. Pearls are formed by the secretion of nacre from epidermal cells within mollusc mantle tissue. But particular conditions are required for loose natural pearls to form and this occurrence is rare. However, utilization of this process for cultured pearl production now supports industries in more than 30 countries including China, Japan, Australia, Indonesia, French Polynesia, Philippines, Cook Islands, Thailand, Malaysia, India, Sri Lanka, Myanmar and Mexico, of which China has the largest production. Analysis of FAO global statistics shows that in the past decade (from 2005 to 2014), the average annual output of Chinese pearls was 3540 tonnes (t) valued at 15 million USD. This output accounted for over 98% of global cultured pearl output, of which freshwater pearls accounted for 99.5%. Japan has been the world's major marine pearl producer for over a century, and has developed advanced technology in pearl oyster culture and pearl production. In the past decade, the average annual value of marine cultured pearl production in Japan was 127 million USD, accounting for 51.6% of global pearl output value. Average annual production of marine cultured pearls was 23 t in Japan, 18.6 t in China and 12.9 t in French Polynesia. Chinese pearl production is typified by a high-yield, low-value industry structure. Overall, global pearl production fell by 60% while output value fell by 39% over the past

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decade. Cultured pearl production typically includes five stages: oyster selection, nucleus implanting, nurturing, harvesting and pearl processing, of which nucleus implantation is the key step. Compared with other aquaculture sectors, pearl production has a complex process and a relatively long farming cycle which make it economically risky. Pressures to increase production, as well as external pressures such as urbanization, have placed pressures on the pearling industry that require appropriate management practices that support sustainable industry growth.

Abstract in Chinese 珍珠被誉为宝石中的皇后,是由贝类外套膜壳侧上皮细胞的分泌物形成,具有装饰、药用、美容保健三大功用和悠久的历史文化。目前世界上养殖珍珠的国家和地区有中国、日本、澳大利亚、法属波利尼西亚、库克群岛、泰国、马来西亚、印尼,印度、斯里兰卡、缅甸、菲律宾和墨西哥等30多个。其中,中国珍珠产量和养殖规模最大,根据FAO全球统计数据分析,过去十年(2005–2014)中国珍珠平均年产量3540吨(产值约1500万美元),占世界平均年总产量的98%以上,其中99.5%为淡水珍珠。日本是珍珠养殖的传统大国,其珍珠养殖和加工技术世界先进,过去十年来平均总产值达1.27亿美元,约占世界珍珠产业年平均总产值的51.6%。世界海水珍珠平均年产量:日本23吨,中国18.6吨,法属波利尼西亚12.9吨。淡水珍珠主要产自中国。由于各种环境和经济因素,近年来全球海、淡水珍珠产量均逐年下降。总体而言,在过去的十年间世界珍珠总产量下降60%,产值下降了39%。珍珠的生产过程包括:育苗、插核、育珠、收获、加工5个阶段,其中,插核是珍珠养殖的关键技术。相比其他产业,珍珠养殖生产周期长,流程复杂,具有较高的经济风险。受到业内提高产量的压力以及城市化等外部环境压力的双重作用,珍珠产业必然需要采取合适的管理调控措施以支撑产业的可持续发展。

Keywords Pearl culture · Pearl oysters · Pearl mussels · Pteriidae · Unionidae · Margaritiferidae

Keywords in Chinese 珍珠养殖 • 海水珠母贝 • 淡水珠母贝 • 珍珠贝科 • 珠蚌科 • 珍珠螺科

5.1 History of Pearl Production

The pearl is known as the queen of jewels, a symbol of material wealth throughout human history, yet one that is distinctively associated with modern civilization as the only gem produced by mankind. Many ancient civilizations had their own myths and legends about pearls, and showed great appreciation for them (Zhang and Fang 2003; Strack 2006). Before pearls were artificially cultured, they were collected rarely and by chance from oysters gathers from their natural habitat for food, or for the mother-of-pearl lining their shells that was used for decorative purposes (Strack 2008). Historical sources of pearls collected in this way included the Gulf of Mannar, between India and Sri Lanka, the Bay of Bengal, the Egyptian coast

Fig. 5.1 Pendants of pearl Buddhas; blister pearls produced on the inner shell surfaces of freshwater mussels. (Source: Guangdong Ocean University)

(Red Sea) and the Persian Gulf (Saudi Arabian coast) (Matlins 2001; Strack 2008) where the economy was particularly dependent on pearl fishing prior to the twentieth century (Carter 2005). The scene changed dramatically in the early 1900s when natural pearl fisheries became increasingly exhausted and many countries that had a long history of pearling became less significant in a world market that was increasingly dominated by cultured pearls.

China was the first country to culture pearls and people in the Song Dynasty (960–1279 AD) already knew how to grow blister pearls on the inner shell surfaces of freshwater mussels (Xie and Min 2003). In the late thirteenth century (Ming Dynasty) this primitive technique continued to be used to produce pearl Buddhas (Fig. 5.1) that were sold in temple markets (Abbott 1972; Alagarswami 1987). Modern round pearl cultivation owes its founding and status to development of the Mise-Nishikawa-method in Japan in the early 1900s (Taylor and Strack 2008). Commercial production of cultured marine pearls using this method was pioneered by Kokichi Mikimoto (1859–1954). Considered a national hero in Japan, and the 'father' of modern cultured pearl production, Mikimoto opened a new era for pearl cultivation (Alagarswami 1987; Wang et al. 1993) that today supports a global multi-million-dollar industry, producing pearls in more than 30 countries and offering economic opportunities to coastal communities in less developed countries (Southgate 2007). The major cultured pearl producing countries now include China, Japan, Australia, Indonesia, French Polynesia, Cook Islands, Philippines, India, Sri Lanka, Myanmar, Thailand, Malaysia and Mexico (Gervis and Sims 1992; Southgate 2007; Southgate et al. 2008a).

Japan was the world's major cultured marine pearl growing country for over a century, and developed advanced and systematic technology in pearl culture (Fassler 1992). The Japanese cultivated their first spherical marine pearls in 1907 (Wang et al. 1993) using the Akoya pearl oyster (*Pinctada fucata martensii*) and Akoya pearls have been mass-produced since 1945. Annual output reached its peak in 1966, with production of 127 tonnes (t) (Mizumoto 1979; Alagarswami 1987), but since then output has decreased substantially to a level of 20–25 t per year in 2014 (Southgate et al. 2008a; FAO 2016). Although Japan has made several refinements to methods used for oyster husbandry and pearl production, the pearl cultivation techniques used today differ little from those developed a hundred years ago (Taylor and Strack 2008). Because of the monopolistic marketing and strict technology-protection policy in the early years of Japan's cultured pearl production, Japan still remains the dominant force in today's pearl industry (Gervis and Sims 1992; FAO 2016).

China was one of the first countries in the world to harvest and use marine pearls. The earliest record of Chinese pearl collection dates back to 2200 BC, and from the Han Dynasty (206 BC–220 AD) onward, the Chinese collected marine pearls in the South China Sea. However, modern marine pearl culture (spherical pearl cultivation) only began in 1949, after the founding of the People's Republic. It began to flourish after successful artificial breeding of Akoya pearl oysters in 1965 and, by the end of the 1990s, Akoya pearl production was greater than 20 t per annum (Wang et al. 2007; Southgate et al. 2008a).

Other countries such as Indonesia, Australia, French Polynesia and the Cook Islands, which have a relatively brief history of pearl cultivation, now play rather significant roles in the world's pearl market (Strack 2008). Indonesia and Australia are the major producers of white 'South Sea pearls' from the silver or gold-lip pearl oyster *Pinctada maxima* (Southgate et al. 2008a), that are the largest and most valuable of culture pearls. Indonesia currently produces almost 4 t of cultured pearls from *P. maxima* per annum. Smaller producers of cultured pearls from *P. maxima* include Myanmar, Malaysia and Papua New Guinea, with China also having success in developing round pearl culture using this species (Xie and Min 2003; Southgate et al. 2008a). French Polynesia, the Cook Islands and some other Pacific island nations have produced 'black' South Sea pearls from the black-lip pearl oyster, *Pinctada margaritifera*, since the mid-1970s (Southgate et al. 2008a). Pearl culture has become a major export earner for both nations (McElroy 1990; Gervis and Sims 1992), and is second in value only to tourism in French Polynesia. Development of pearl oyster culture offers economic and livelihood opportunities in smaller Pacific nations and research in the western Pacific, in particular, has helped develop commercial pearl culture in smaller nations such as Fiji (Southgate et al. 2008a).

China is by far the major producer of cultured freshwater pearls. Freshwater pearl culture using natural pearl mussels was first demonstrated in Guangdong in 1958, and a significant breakthrough in the artificial breeding technology of Unionidae mussels was later achieved in Zhejiang in late 1970s (Bai et al. 2014). Since then, freshwater pearls have been produced on a large scale with annual output of more than 300 t in 1984 overtaking that of Japan (Hua and Gu 2002; Bai et al. 2014). By the 1990s, China had over 1000 pearl mussel farms and annual output has increased to over 2000 t within 40 years (Yang et al. 2003).

5.2 Mother of Pearl

Almost all species of mollusc are capable of producing pearl-like objects, technically termed "calcareous concretions" (McGladdery 2007). However, those of value and of interest as gemstones are limited to those produced by species capable of secreting nacre or mother-of-pearl (MOP), sometimes referred to as 'mother-of-pearl shell'. Two different groups of MOP shell are widely used for pearl cultivation: (1) marine pearl oysters of the family Pteriidae; and (2) freshwater pearl mussels of the families Unionidae and Margaritiferidae.

5.2.1 Marine Pearl Oyster

Several pearl oyster species from the family Pteriidae have been extensively exploited for pearl production for over a century. From the genus *Pinctada*, important commercial species include the Akoya pearl oyster *Pinctada fucata/martensii*, the gold or silver-lip pearl oysters, *Pinctada maxima*, and the black-lip pearl oyster, *Pinctada margaritifera*. While *Pteria penguin and Pteria sterna* are used for commercial pearl production to a lesser degree (Southgate et al. 2008a; Wada and Temkin 2008). These species support pearl production across a wide area of the Indo-Pacific including the Pacific coast of Mexico. The culture methods used for these species are well established (Southgate 2008; Southgate et al. 2008a) and the methods used for production of their various pearl products are described by Taylor and Strack (2008).

Pinctada fucata/martensii: these oysters are best considered a 'species complex' (Wada and Temkin 2008) and are the most commonly utilized for commercial pearl production. This species complex ranges from the Western Atlantic region (Caribbean region, Gulf of Mexico), Western Pacific Ocean (Korea, Japan, southern China and Australia) to the Indian Ocean, including the Red Sea and Persian Gulf (Gervis and Sims 1992; Wada and Temkin 2008). *Pinctada martensii* (Fig. 5.2) is

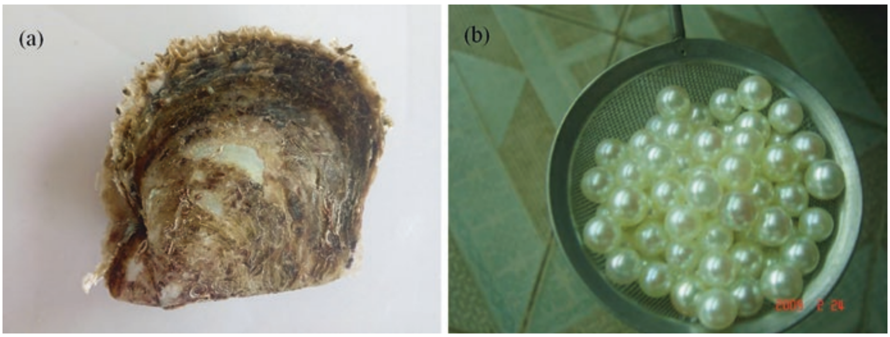

Fig. 5.2 Specimen of *Pinctada martensii* (**a**) and Akoya pearls produced by *P. martensii* (**b**). (Photo: Dahui Yu, South China Sea Fisheries Research Institute)

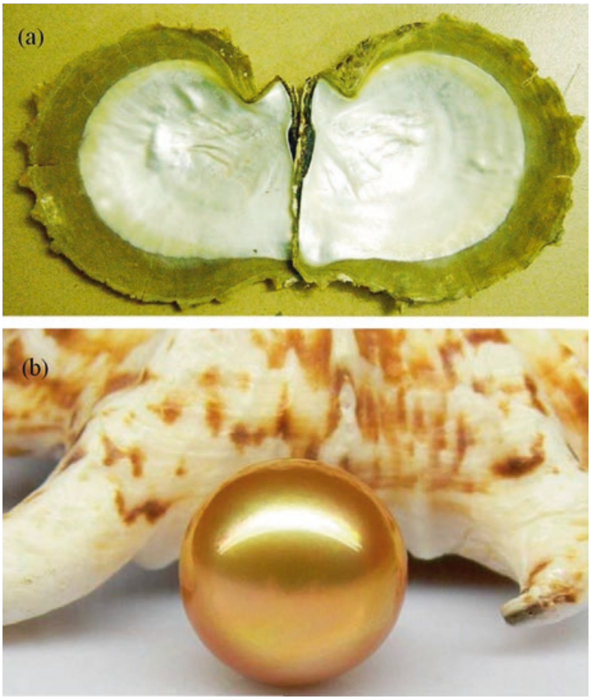

Fig. 5.3 Specimen of *Pinctada maxima* (**a**) and a gold South Sea pearl produced by *P. maxima* (**b**). (Source: Guangdong Ocean University)

found in Japan and China; it is a variety of *Pinctada fucata*, one of the smallest among pearl producing oysters, and is used in both Japan and China for the production of Akoya pearls (Kripa et al. 2007; Southgate et al. 2008a).

Pinctada maxima: the largest pearl oyster species (Fig. 5.3) is used for production of golden and silver South Sea pearls, mainly produced in Indonesia, northern Australia, Philippines, Malaysia and Myanmar (Southgate et al. 2008a). This species produces the largest and most valuable of cultured pearls (Fig. 5.3b).

Pinctada margaritifera: this is the second largest of the pearl oysters that has a broad distribution across the Indo-Pacific, from the eastern Pacific Ocean to the east coast of Africa and the Red Sea (Gervis and Sims 1992; Wada and Temkin 2008). This species is particularly abundant in the atolls of Polynesia where it supports significant production of 'black' or 'Tahitian' pearls in French Polynesia and the Cook Islands. It is also cultured for commercial round pearl production in Fiji where it produces a unique range of colours that is distinct from Polynesian pearls.

Pteria penguin: this species is commonly known as the winged pearl oysters or penguin's wing oyster (Fig. 5.4), is widely distributed in Southeast Asia, particularly China, Japan, Thailand, Indonesia, The Philippines, Malaysia, and Australia. The Japanese name for this species '*mabé gai*' and it is traditionally used for half-pearl or mabé production (Fig. 5.4b). Because of its anatomical structure, this species is difficult to use for round pearl production and reports of successful round pearl production from this species are limited (Liang et al. 2008; Xie et al. 2012).

Fig. 5.4 Specimen of *Pteria penguin* (**a**) and half-pearl or mabé produced by *P. penguin* (**b**). (Source: Guangdong Ocean University)

Fig. 5.5 Cultured round and near-round pearls produced from the Rainbow-lipped pearl oyster, *Pteria sterna*, in Mexico. (Source: Douglas McLaurin, Perlas del Mar de Cortez, Mexico)

Pteria sterna: this species is restricted to the Gulf of California, Mexico (Urban 2000; Mao et al. 2004) and, like *Pteria penguin*, it was initially utilized for half-pearl production (Ruiz-Rubio et al. 2006). However, the high quality of nacre produced by this species prompted research towards commercial production of round and near-round pearls which was successful (Kiefert et al. 2004) and resulted in some of the most colorful cultured pearls (Fig. 5.5).

5.2.2 Freshwater Pearl Mussels

Freshwater pearl mussels can be cultured in freshwater ponds, rivers, or lakes. Over 98% of freshwater pearls are produced in China (FAO 2016), with the remainder produced in Japan, Australia, America, Vietnam, and other countries (Yang et al. 2003). In China, there are more than 100 species of freshwater mussels, but only about ten are used for commercial pearl production. They belong to the families Unionidae and Margaritiferidae, and include *Hyriopsis cumingii* (Triangle sail mussel), *Cristaria plicata*, *Lamprotula leai, Lamprotula rochechouarti*, and *Margaritiana dahurica* (Bai et al. 2014). Among these, the most productive is *Hyriopsis cumingii* (Fig. 5.6), followed by *Cristaria plicata*. In China, these two species are readily obtained by pearl farmers, easy to operate, and in relative terms have a higher pearl production rate and produce better quality pearls than other species (Xu et al. 2011). Other than these endemic mussels, several species have been introduced to China for pearl production including *Hyriopsis schlegelii* (native to Japan) which has a strong nacre secretion ability, and *Potamilus alatus* (native to North America) which can produce high quality black freshwater pearls. *Hyriopsis schlegelii and Margaritiana dahurica* are the most commonly used mussels for pearl production in Japan (Alagarswami 1970; Huang 2008).

Fig. 5.6 Specimen of the Triangle sail mussel *Hyriopsis cumingii*. (Source: Hua and Gu 2002)

5.3 Pearl Production

The pearl is unique, since it is the only gem formed inside a living organism. It results from the secretion and deposition of nacre by the epidermal cells of mollusc mantle tissue; the same process that is involved in shell formation. Pearls have the same physical properties and composition of natural shell nacre, with calcium carbonate as the main component and pearl formation had thus been termed biomineralization (Taylor and Strack 2008). Pearl cultivation is based on the natural ability of the mantle tissue of the Pteriidae, Unionidae and Margaritiferidae to secrete nacre, and technical intervention to provide a suitable substrate and environment for nacre secretion. Today's cultured pearls can be divided into three major categories:

1. half-pearls or mabé;
2. beaded 'round' cultured pearls, including most of the marine pearls; and
3. non-beaded freshwater cultured pearls, such as Biwa (Japanese freshwater) pearls and Chinese freshwater pearls.

Half-pearl production involves adhesion of semi-spherical nuclei to the inner shell surface of an oyster. The oyster is then placed back into its culture environment and a period of 10–12 months is generally required for it to adequately cover the nucleus with nacre to form the half-pearl (Ruiz-Rubio et al. 2006; Fig. 5.5b). It is usual for multiple nuclei (usually up to five) to be implanted into one oysters (Ruiz-Rubio et al. 2006; Kishore et al. 2015), and anesthetics are sometime used to relax oysters prior to implantation (Kishore et al. 2015) to minimize oyster stress, and to improve operator access to the inner shell surface for nucleus placement.

5.3.1 Production Cycle of Pearls

Production of beaded and non-beaded cultured pearls is more technically demanding than half-pearl production and generally includes five major stages: oyster selection, nucleus implantation, nurturing, harvesting, and pearl processing (Fig. 5.7).

Oyster Selection Selection of suitable host oyster/mussel for pearl production. There are two sources of mollusc stock for pearl production: (1) collection from the wild, such as in Australia and French Polynesia; oysters are collected as adults or as juveniles and grown to a size suitable for pearl production (Southgate 2008); and (2) produce seed/spat (juveniles) through artificial propagation in a dedicated hatchery facility or from 'spat collection' programs. The latter relies on deployment of appropriate substrates to the water column, at an appropriate time, to provide substrates

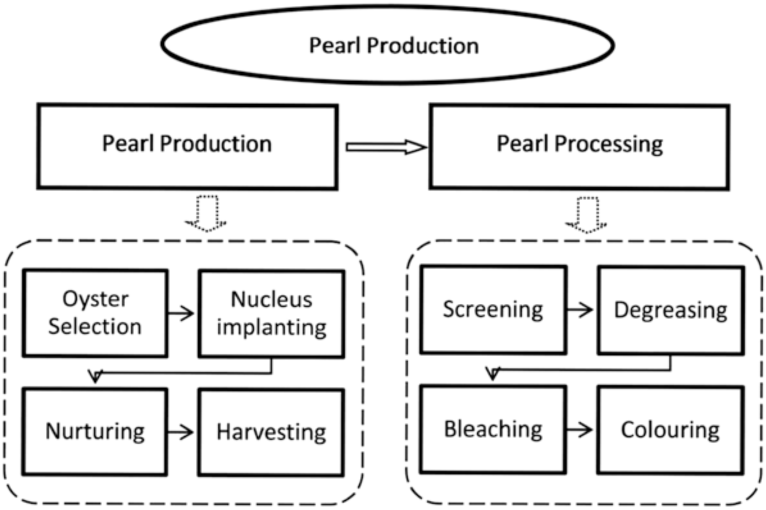

Fig. 5.7 Diagrammatic representation of the stages of pearl production

Fig. 5.8 A pearl oyster farm in South China. (Source: Guangdong Ocean University)

for larval recruitment (Southgate 2008). Juveniles are then grown to a size suitable for pearl production. At least a year and a half is needed for pearl oyster larvae to grow to a size appropriate for pearl production (Yin et al. 2012). Freshwater mussels are much faster growing than pearl oysters and become suitable for pearl production within a year (Huang 2008). The aquatic environment for farmed molluscs must be clean, have a suitable water temperature, and be free of harmful organisms with minimal fouling and predation (Fig. 5.8).

Nucleus Implantation This is the key step in cultured pearl production. In order to grow marine pearls, a tiny piece of mantle tissue (called a graft, or 'saibo' in Japanese), approximately 3 × 3 mm in size, is removed from a suitable donor oyster and implanted with a spherical polished shell-bead or nucleus into the gonad of a recipient or host oyster. For freshwater pearls to grow, a piece of mantle graft alone serves the same purpose, so a nucleus is not a pre-requisite for pearl production. There are still some technical difficulties associated with growing beaded pearls within the visceral mass of freshwater mussels because of their physiological structure (Xie et al. 2015). A period of 'conditioning' or pre-operative treatment is often needed to prepare oysters/mussels for implantation, and appropriate post-operative husbandry reduces stress and helps maximise nucleus/graft tissue retention after implantation (Taylor and Strack 2008; Liang et al. 2016). Survival rate and nucleus retention rate of implanted oysters are strongly correlated with factors such as size and age of oysters, size of nucleus and grafting method (Yukihira and Klumpp 2006; Kripa et al. 2007; Liang et al. 2015).

Nurturing After the nucleus is inserted, implanted oysters/mussels need to be carefully nurtured in a resting zone for at least 2 weeks, a critical period for mortality and nucleus rejection, then returned to the ocean in an area of calm water at a depth of 2–3 m (Wang et al. 1993). Appropriate water temperature is critical for survival of implanted oysters and optimal nacre secretion rate in *P. maxima* occurs at 25–30 °C, when nacre is first secreted onto the nucleus from around 45 days after operation (Liu et al. 2012). In *P. margaritifera*, graft tissue proliferates to create a 'pearl-sac' that completely covers the nucleus within 14 days of grafting, when the epithelial cells responsible for nacre secretion are fully developed; however, first nacre secretion onto the nucleus was not observed until 32 days after grafting (Kishore and Southgate 2016). Nucleated oysters are generally cultured for a further 1–2 years before resulting marine pearls are harvested. A culture period of 1–5 years is usually required for freshwater pearl production depending on culture method and species (Xu et al. 2011; Yin et al. 2012; Lin et al. 2016a).

Harvesting in winter or when water temperature is relatively low, the nacre secretion rate slows, resulting in a more detailed, smooth, and lustrous pearl surface. Thus colder conditions are the best time to harvest pearls (Wang et al. 1993). Akoya and South Sea pearls are grown within the gonad tissue of host oysters (Taylor and Strack 2008). They are grown one pearl at a time which limits the number of pearls at harvest. Oysters that produce high quality South Sea pearls are often implanted with a new, larger bead, then returned to the water for another 2–3 years of growth for the next pearl producing cycle (Taylor and Strack 2008; Lin et al. 2016a). It is possible using this method to produce up to four pearls from a single oyster and Kishore et al. (2015) reported improvements in both pearl size and shape in 'second-graft' pearls produced by *P. margaritifera*. Freshwater pearls are grown in the mantle, where up to 20 grafts may be implanted within each of the two mantle lobes. On this basis, freshwater mussels have a substantially higher pearl yield than marine oysters with usually more than 10 pearls harvested from one mussel (Lin et al. 2016b).

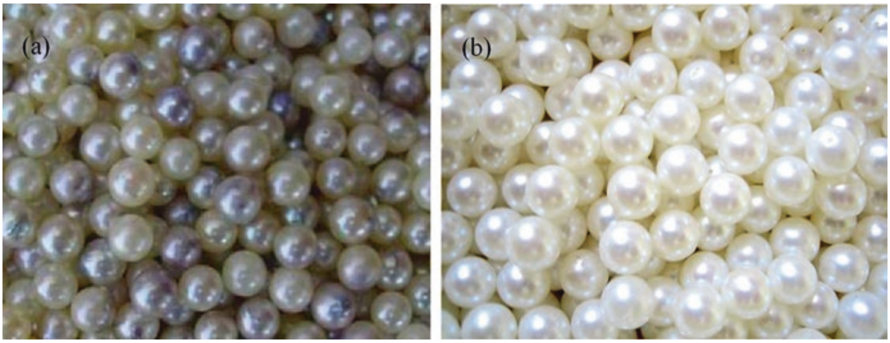

Fig. 5.9 Akoya pearls before (**a**) and after (**b**) bleaching procedure. (Source: Guangdong Ocean University)

Pearl Processing Due to variations in colour and the degree of surface defects, more than 90% of cultured pearls cannot be used directly to produce jewelry or other products (Huang 2008). However, raw pearls may have to be processed to improve their quality to meet the standards of gem-quality merchandise, and pearl enhancement is routinely used for Akoya pearls and freshwater pearls (Strack 2006). Pearl processing techniques may include screening, degreasing, decontamination, bleaching, whitening, colouring etc. (Tang et al. 2016). Pearl appearance and value can be greatly improved by these technical procedures, which enhance colour and surface texture (Fig. 5.9). While fine-quality cultured pearls (marine and freshwater) are selected to make jewelry, small non-beaded cultured pearls, which have little value, may be processed into drugs and cosmetics (Yang et al. 2016).

South Sea pearls are generally not treated in their countries of origin and are promoted as having minimal enhancement consisting of washing and polishing only (Taylor and Strack 2008); however, South Sea pearls are treated by a number of Japanese pearl companies (Strack 2006). As well as colour, pearl luster can be enhanced by mechanical polishing and through the use of solvents and polishing materials such as bees wax.

5.3.2 Output and Value

In the past decade, Japan, French Polynesia and China have been the three major marine pearl producing countries, but over 98% of pearls produced worldwide are freshwater pearls from China (Fig. 5.10). Annual output of Chinese pearls averaged 3540 t of which freshwater pearls accounted for 99.5%. Since 2007, China's marine pearl production declined significantly, from 34.5 t in 2006 to 3.7 t in 2014 (Fig. 5.11). Marine pearl output also decreased in Japan from 29 t to 20 t per year over the same period, but increased in French Polynesia from 9 t per year to 15 t per year (Fig. 5.11). The United States, Japan, Switzerland, Germany, Hong Kong,

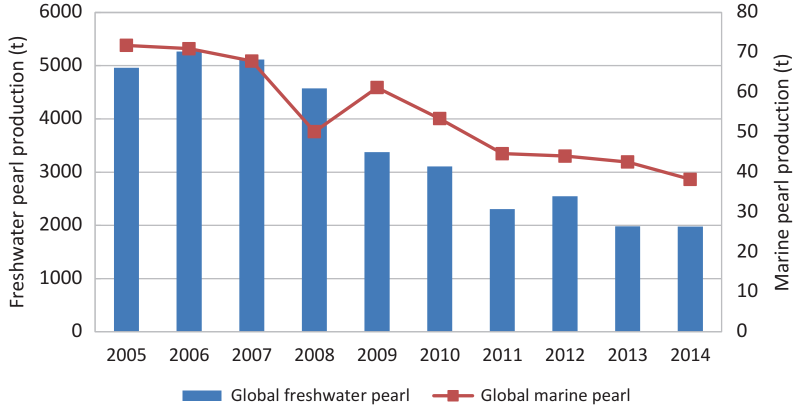

Fig. 5.10 Global pearl production (2005–2014) (All data from FAO 2016), data includes China, Japan and French Polynesia, the three major global pearl producers. Data for other countries, which only accounted for a small part of total pearl output, were not in the database or were incomplete, and were therefore not included. Half-pearl or mother of pearl production was also not included, likewise in Figs. 5.11 and 5.12)

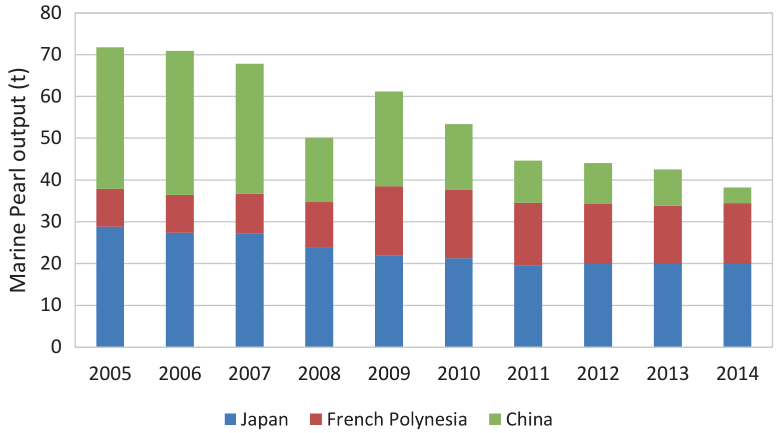

Fig. 5.11 Global production of marine pearls (2005–2014)

France, Britain, Belgium, Italy, Spain, Canada, India and Saudi Arabia are the world's largest pearl importers, ranked by volume (Lin 2004).

Japan was not only one of the largest pearl producers and exporters, but also the largest importer and processing centre of pearls, playing a significant role as a distribution hub in the global pearl industry. In addition, Japan controls the world's leading technology in pearl oyster breeding and pearl production and processing (Fassler 1992) and held about 51.6% of the world's output value in the past decade. The average annual value of pearl production was 127 million USD in Japan, 104 million USD in French Polynesia, and 15 million USD in China (Fig. 5.12).

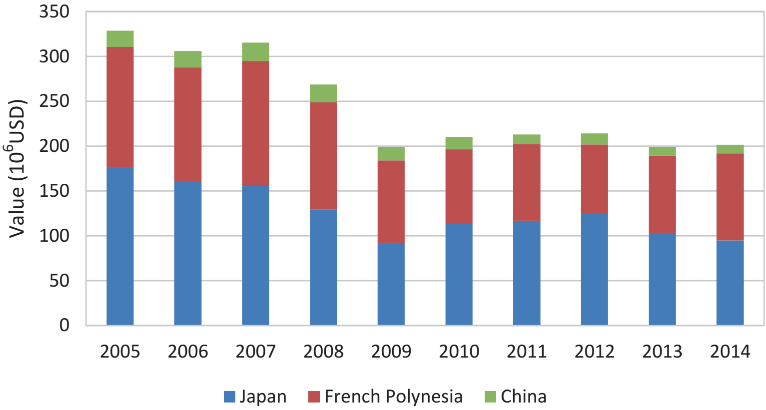

Fig. 5.12 Total output value of global pearl production (2005–2014)

Although China is the largest producer and exporter of pearls, because the market price of freshwater pearls is much lower than that of marine pearls, over 98% of the world's pearl production only corresponds to about 5% of the output value (Fig. 5.12). The extremely unbalanced development between Chinese low-end pearl production and high-quality pearl production has resulted in a high-yield, low-value industrial structure. Overall, global pearl production fell by 60% (Fig. 5.10), while output value fell by 39% over the past decade (Fig. 5.12).

5.4 Goods from Pearls

5.4.1 Types and Value

Based on their method of formation, pearls can be divided into natural (or wild) pearls and cultured pearls. The value of a pearl is determined by a combination of a number of characteristics including size, luster, color, amount of surface flaws, and shape. Pearls are usually categorized into eight basic shapes: round, semi-round, button, drop, pear, oval, baroque, circled and double-boulder (Pan et al. 1994).

Natural pearls form within oysters and mussels when nacre-secreting epithelial cells are transferred into the viscera by 'accidental' means, and their continued secretion of nacre forms a pearl over time (Taylor and Strack 2008). Transfer of epithelial cells may result from the actions of predators or parasites, for example, or from foreign materials that become lodged within oyster tissues. Formed without human intervention, natural pearls take different shapes, and perfectly spherical natural pearls are extremely rare, and highly valuable. Hundreds of pearl oysters or mussels must be gathered and opened to find even one natural pearl; yet for many centuries, this was the only way to obtain pearls, and the reason pearls were so highly regarded in the past. Natural pearls can be distinguished from cultured pearls by X-ray that will reveal no nucleus or curved cavity structures in the centre of the pearl, and a uniform, onion-like structure (Krzemnicki et al. 2010).

Cultured pearls result from a tissue implant and human intervention that utilizes the ability of mollusc tissue to produce and secrete nacre. Marine cultured pearls generally follow the shape of the implanted nucleus resulting in round or near-round pearls. The output of 'round' marine pearls is relatively low, about 54 t per year globally (Fig. 5.11). But marine pearls are much more valuable than freshwater pearls, especially high quality South Sea pearls from *Pinctada maxima* (gold or silver, 10–20 mm in diameter) and Tahitian 'black' pearls (9–20 mm in diameter) (Southgate 2007). They are famous for their unique color and luster, and are the largest, rarest, and most valuable cultured pearls in the pearl market. Freshwater cultured pearls are rarely round, mostly pear-shaped or oval, and the overall quality is poor. Generally, only 1–2 pearls meeting gem-quality standards can be obtained from 100 raw freshwater pearls (Yang et al. 2003). Common natural colors of freshwater pearls are white, pink and purple, and some progress has been made towards cultivating high-quality round freshwater pearls in China (Xie 2010; Xie et al. 2015; Lin et al. 2016b).

5.4.2 Services

Decoration Pearls are the most versatile of gemstones, with three major functions that have been developed over thousands of years. Pearls are used for decoration like all the other gems, and infer a sense of status and material wealth. Pearls with a special luster may become beautiful ornaments and have been used to decorate items such as the crowns of monarchs as symbols of elegance and nobility. Pearls and MOP shells may function as collector's items as one of their services to humans; this aspect is addressed in Duncan and Ghys (2019).

Medical and Biomedical Applications Pearls are used to produce medicine. The history of pearl medicine in China goes back more than 2000 years (Pan et al. 1994). Pearls are a product of the defense mechanism of organic immune systems, and studies of their medicinal value have shown distinct anti-oxidant and anti-inflammatory effects. Extracts from pearls have been used in variety of clinical treatments for ulceration, cataracts, and tumours (Lin 2004; Zheng and Mao 2004).

The process of nacre formation or biomineralization progresses from secretion of a fluid, through film formation and mineralization, to formation of the mature nacre structure composed of sequential layers of aragonite tablets (Fougerouse et al. 2008). Improved understanding of this process, and the unique qualities of nacre, have stimulated considerable interest in the potential biomedical applications of nacre, including its possible use as a substitute for human bone and in bone repair (Southgate et al. 2008b). For example, pearl oyster nacre has been shown to induce mineralization by human osteoblasts (Lopez et al. 1992), to be cyto-compatible with human bone (Cognet et al. 2003), and to stimulate bone repair (Lamghari et al. 1999) and form a dual biomineralized unit (with bone) in sheep (Lopez et al. 2004). Such research has potential for significant biomedical outcomes.

Body Care Pearls are also used in many body care therapies because they are rich in elements that are beneficial to the human body, particularly the skin. Pearls consist of calcium, over 20 different trace elements, more than 15 amino acids, alkaline phosphates, and natural taurine (Huang 2008; Zhang et al. 2014), and meet important health requirements. Pearls may be processed into powdered products for skin whitening, and as calcium supplements (Yang et al. 2016).

Bioremediation Because of their high filtration rates and their ability to accumulate heavy metals, pollutants (including nutrients) and bacteria, pearl oysters and mussels have considerable potential for bioremediation of polluted coastal environment (O'Connor and Gifford 2008). Marine pearl oysters are particularly well suited to this role because their pumping and filtration rates are among the highest reported for bivalve molluscs, and up to ~22 L per hour per oyster (Lucas 2008). They are able to process large quantities of water, removing particulates and being exposed to large quantities of pollutants. They also have a high requirement for nitrogen and phosphorous and an ability to remove large quantities of these nutrients from the water column (Gifford et al. 2005). Pearl oyster based 'bioremediation' also has advantages because oysters used in this way can still produce valuable products (e.g. pearls and MOP), but they do not need to be a product suitable for human consumption (O'Connor and Gifford 2008). The potential for such bioremediation systems was demonstrated by Gifford et al. (2005) who reported that for each tonne of Akoya pearl oysters harvested, 7.4 kg of nitrogen, 0.5 kg of phosphorous and up to 0.7 kg of metals were removed from the water.

Like other bivalves, pearl oysters/mussels have the ability to improve water quality by transforming suspended particulate matter (including microalgae) into faeces and pseudofaeces through biodeposition, which is a very important component of the biogeochemical processes of coastal ecosystems (Ferreira and Bricker 2016). Biodeposition by shellfish is addressed in detail in other chapters of this book.

5.5 Problems and Perspectives

Pearl farming is a very challenging and labour-intensive activity. In general, post-operative survival of nucleated oysters is less than 70% and, of these, 30–40% are likely to reject the implanted nucleus, 20% will produce salable pearls, but only 5% will produce top quality gemstones (Fassler 1992; Norton et al. 1996). For pearl production from *P. margaritifera* for example, it is generally accepted that 5% of the total pearl harvest will generate around 95% of farm profits (Haws 2002). Compared with other aquaculture sectors, pearl production has a more complex procedure and a longer farming cycle which increases economic risk. Urbanization and industrialization in traditional pearl farming areas, and stressed and impoverished coastal environments have led to some serious problems and big challenges for sustainable development of the pearl aquaculture industry. These include reduced oysters supply to the industry, reduced growth rates and survival and reduced pearl yield and quality. Increased reliance on hatchery-produced juveniles brings its own potential problems relating to artificial selection and inbreeding. Striving for increased production has resulted in over-stocking of pearl farms leading to a shortage of nutrients and ecological deterioration at the farm site that increases the probability of epidemic disease outbreaks. Production pressures may also encourage shortening of the pearl production cycle resulting in pearls with a thin nacre covering that do not pass the product inspection standard. Finally, consistent production of high quality pearls relies on the availability and skills of professional pearl grafting technicians (Porter 1991; Fassler 1992). Expansion of pearl farming in some areas has led to a shortage of well-trained technicians and the use of inexperienced technicians or grafting by under-trained farmers. All the above issues have the potential to affect pearl production and quality, as well as farm profitability, and may explain the decline of pearl production in the past decade, especially in China.

If we consider the present situation of China's pearl industry as an example, Liusha Bay was the main production base of Chinese marine pearls (Zhu et al. 2011) and, in 2010, accounted for over 80% of national production. Chinese Akoya pearls, known as 'Nanzhu' in China, referred specifically to pearls produced from *Pinctada martensii* in the Beibu Gulf area. Liusha Bay is located at the junction of Xuwen County and the southwestern of Leizhou City sea area (20°22′–20°31′N, 109°55′E–110°1′E), in the southwestern part of Leizhou Peninsula in Guangdong province. Liusha Bay is a semi-enclosed system with a total area of 69 km^2, an annual average water temperature of 26.4 °C, and its natural geographical condition is particularly suited for *Pinctada* oyster culture. It was historically the production center of Akoya pearls in China, with a farming area of around 20 km^2. However, since 2000, the industry in Liusha has plunged into serious recession. In the late 1990s, a number of alternative aquaculture commodities and cultivation techniques were introduced into Liusha Bay, including cage finfish culture and scallop (*Argopecten irradians concentricus*) culture. Because of the relatively long farming cycle of pearl culture, a complicated situation of multiple aquaculture structures developed in Liusha Bay. In 2007–2008, a series of natural disasters made the situation even worse for pearl production in Liusha and a large number of traditional pearl farmers diverted into cage fish culture, resulting in a dramatic increase in the number of cages in Liusha Bay. As a result, the culture space for *Pinctada martensii* was significantly reduced, and potential food resources for pearl oysters were largely consumed by cultured scallops. Furthermore, the sediment environment worsened, pearl oyster growth slowed and survival decreased (Luo et al. 2014). The Nanzhu cultured pearl industry currently faces a major threat.

The pearl industry of the future will continue to face the dilemma of productivity and reduced profitability, unless radical remedial measures are taken to improve the culture environment and standards. Sustainable development of the pearl culture industry requires management measures that are guided by scientific development relating to breeding and husbandry of pearl oysters and mussels, as well as product processing, and marketing. In addition, appropriate management must also consider social, economic, and environmental factors. Pearls should continue to shine in the modern commodity market, and continue to decorate human civilization.

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