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Use and exchange of genetic resources in molluscan aquaculture

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Abstract

Molluscs are major aquaculture species worldwide. Molluscan aquaculture accounts for approximately 27% of the total world aquaculture production. The use and exchange of genetic resources have played an important role in the development of molluscan aquaculture. The introduction and use of non-native species have been instrumental in oyster and scallop aquaculture; for example, the Pacific oyster, translocated from Japan, supports major aquaculture industries in many countries of North and South America, Europe, Asia and Africa. Bay scallops introduced from the USA account for an annual production of over 600 000 t in China. Non-native genetic materials have also been used for the genetic improvement of native species through interspecific and intraspecific hybridization. Unique genetic lines, such as disease-resistant strains, have been developed through selective breeding in some molluscs, although significantly more efforts are needed. Although the importance of genetic resources is apparent, the identification, protection and utilization of molluscan genetic resources remain a challenge.

Key words: aquaculture, genetic diversity, hybridization, mollusc, non-native species, selective breeding.

Introduction

Molluscan aquaculture

Molluscs are an important source of food for human consumption and are major fishery and aquaculture species around the world. Molluscan aquaculture has been developing rapidly in recent decades, reaching 14 million t in 2006, accounting for approximately 27% of the total world aquaculture production (FAO 2009). In some regions of the world, molluscan aquaculture is a significant part of the coastal economy (Guo *et al.* 1999), providing significant employment opportunities and food sources to local communities.

Molluscs are one of the most species-rich groups of animals, second only to arthropods. The phylum Mollusca contains approximately 100 000 extant species, and only a tiny fraction of the phylum has been explored for food production. Major molluscan aquaculture species include oysters, clams, scallops, abalones, mussels and pearl oysters (Guo *et al.* 1999; Wang & Wang 2008), each of these groups contains dozens or hundreds of species, but only a small number are used in aquaculture. For example, there are approximately 400 living scallop species (family Pectinidae), but only approximately 10 species are currently cultured (Shumway & Parson 2006). Many molluscan species have the potential to be cultured or used for genetic improvement of species already cultured. The use of these diverse genetic resources is important for the sustainable development of molluscan aquaculture because genetic variation is the necessary foundation for any genetic improvement of cultured stocks. Therefore, the recognition and protection of these genetic resources are critical.

One of the greatest advantages of most cultured molluscs, such as oysters, clams and scallops, is that these species are filter feeders and do not require external feed inputs, thereby minimising environmental impacts. Because of the net removal of organic matter from the waters, molluscan farming may also help to reduce eutrophication of estuaries, bays and near-shore waters (Dame 1996). Shells of molluscs are made of forms of calcium carbonate and thus molluscan farming contributes to carbon sequestration.

Genetic resources

Genetic resources, in the form of the genes and genetic variation that we see today, are formed over millions of years of evolution. They are unique, finite and can be lost. The preservation and effective use of genetic resources are critical for the sustainable development of aquaculture because genetic variation is the key to the long-term improvement of cultured stocks. The use of genetic resources in molluscan aquaculture can be classified into three categories: (i) the introduction and use of non-native species as new aquaculture subjects; (ii) the addition of non-native genetic material to increase genetic diversity and culture performance in farmed populations; and (iii) the development of genetic resources through genetic technologies to improve the performance of farmed populations. Examples of these uses are briefly reviewed below.

Use and exchange of molluscan genetic resources

Introduction and use of non-native species

Most agricultural crops and livestock are non-native species and this paradox has been dealt with recently with respect to aquaculture (De Silva *et al.* 2009). Corn, for example, originated in Central America and is now cultivated all over the world. Without the introduction and use of non-native species, the agriculture sector as we know it would not exist, and it would not be able to support the food needs of the current human population. Aquaculture may follow the same development path to some degree (De Silva *et al.* 2009). Non-native species have already been used in molluscan aquaculture (Table 1). In several cases, the introduction of non-native species has been successful and has revitalized troubled aquaculture industries, although non-native species come with certain risks.

The Pacific oyster

The Pacific oyster (*Crassostrea gigas* Thunberg, 1793) is one of the best examples of non-native molluscs that have benefited aquaculture development. *Crassostrea gigas* is native to East Asia. They are abundant in the coastal waters of Japan, Korea and North China. The Pacific oyster was introduced to the west coast of the USA and Canada in the early 1900s, to supplement a declining oyster fishery of the native Olympia oyster (*Ostrea conchaphila* Carpenter, 1857). The Olympia oyster is a small and slow-growing species, needing 4–5 years to grow to market size (50 mm) (Quayle 1988). In contrast, the Pacific oyster is fast growing. Depending on the environment, it can reach 60–100 mm in approximately 1 year. The Pacific oyster is highly fecund and easy to produce in hatcheries. Because of these advantages, *C. gigas* quickly replaced the Olympia oyster as the preferred aquaculture species. Now the oyster aquaculture industry on the west coast of the USA is almost exclusively based on the Pacific oyster. In 2005, the USA produced 21 300 t of Pacific oyster with an estimated value of approximately US$53 million (USDA 2006).

The USA and Canada are not the only countries to have introduced the Pacific oyster for aquaculture

Table 1 Introduction of non-native molluscan species for aquaculture based on public and personal knowledge

Species	Origin	Destination	Outcome
Crassostrea gigas	Japan	USA, Canada, Europe, Australia, New Zealand, Mexico, Peru, Chile, Argentina, South Africa	Successful and significant aquaculture
Crassostrea gigas	Japan, Australia	Southern China	Unsuccessful
Crassostrea angulata	China	Europe	Successful aquaculture
Crassostrea sikamea	Japan	West Coast, USA	Successful aquaculture
Crassostrea ariakensis	Japan	West Coast, USA	Experimental aquaculture
Crassostrea virginica	East Coast, USA	West Coast, USA	Small-scale aquaculture
Ostrea edulis	Europe	Both coasts, USA	Small-scale aquaculture
Argopecten irradians irradians	USA	Shandong and Liaoning, China	Successful and significant aquaculture
Argopecten irradians concentricus	USA	Southern China	Small-scale aquaculture
Argopecten purpuratus	Peru	Shandong, China	Experimental, ongoing
Pecten maximus	Europe	Liaoning, China	Unsuccessful
Patinopecten yessoensis	Japan	Shandong and Liaoning, China	Successful and significant aquaculture
Placopecten magellanicus	Canada	Shandong and Liaoning, China	Experimental, ongoing
Spisula solidissima	USA	Shandong and Liaoning, China	Experimental, ongoing
Panopea abrupta	USA	Shandong, China	Experimental, so far unsuccessful
Mercenaria mercenaria	USA	Zhejiang, Shandong and Liaoning, China	Experimental aquaculture
Ruditapes philippinarum	Japan	USA, Europe	Successful and significant aquaculture
Haliotis discus hannai	Japan	Ireland	Small-scale aquaculture
Haliotis laevigata	Australia	Guangdong, China	Small-scale aquaculture

Reviews in Aquaculture (2009) **1,** 251–259

purposes. *Crassostrea gigas* was introduced from Japan to France and other European countries in the 1960s in response to a troubled industry of the Portuguese oyster *Crassostrea angulata* Lamarck, 1819, which is also a non-native species in France and Europe. It is believed that *C. angulata* was brought from Asia to Portugal after navigation routes opened between Europe and the Far East (Boudry *et al.* 1998; O'Foighil *et al.* 1998). A recent study found major populations of *C. angulata* across a wide geographic range in southern China (Guo *et al.* 2008a), which supports the hypothesis of a historic transfer from China to Europe. *Crassostrea angulata* was introduced from Portugal to France in approximately 1860 to fill a production gap of the native European flat oyster *Ostrea edulis* Linne, 1758 (Leffler & Greer 1991). *Crassostrea angulata* established in France and became the main aquaculture species. Beginning in the 1960s, however, *C. angulata* began to suffer from diseases and heavy mortalities. *Crassostrea gigas* was introduced in the 1960s and quickly dominated oyster production. In 2007, France produced 110 800 t of *C. gigas* from aquaculture with an estimated value of approximately US$355 million (FAO 2009). *Crassostrea gigas* production accounted for 98% of the national total, and the other 2% was from the native *O. edulis*.

In addition to the USA, Canada and France, the Pacific oyster has also been introduced to many other countries (Fig. 1). Countries that are currently culturing the Pacific oyster as a non-native species include Australia, New Zealand, Mexico, Peru, Chile, Argentina, South Africa and several European countries. In Australia, the Pacific oyster accounts for approximately 70% of oyster production, which is approximately 10 000 t year^{-1} and US$50 million in value (Peter Kube, pers. comm., 2009). Although the Pacific oyster is native to North China, it has been introduced from Japan and Australia several times since the 1980s. Introductions to southern China were not successful, probably because the summer in southern China is too warm for this species.

The bay scallop

The bay scallop (*Argopecten irradians* Lamarck, 1819) is native to the Atlantic coast of North America. There are three subspecies: the northern bay scallop *Argopecten irradians irradians*, the southern bay scallop *Argopecten irradians concentricus* Say, 1822 and the Gulf bay scallop *Argopecten irradians amplicostatus* Dall, 1898 (Beaumont 2006). The northern bay scallop is found from Massachusetts to New Jersey, the southern bay scallop is found from New Jersey to Florida, and the Gulf bay scallop is found in Texas and west. The northern bay scallop has been introduced from Massachusetts to Nova Scotia, Canada, and has established a small population there.

In 1982, the northern bay scallop was introduced from the USA (Stonington, CT) to China (Qingdao, Shandong) (Zhang *et al.* 1986). Of the 128 scallops transported, only 26 scallops survived and produced a founder population that gave rise to a sizable aquaculture industry. The bay scallop is a functional hermaphrodite. It has a lifespan of <2 years, but grows fast during the first year. Because of its fast growth and the fact that it is produced in the hatchery early in the spring, bay scallops can reach market size within 1 year. This is a great advantage over the native Chinese

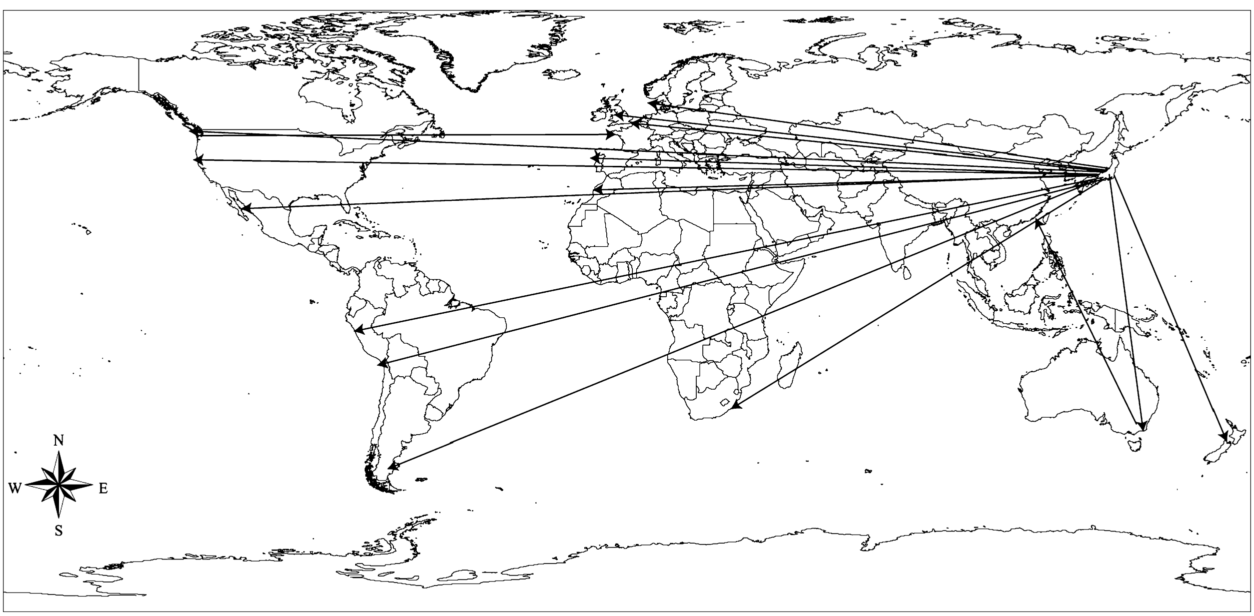

Figure 1 Map of historical introductions of the Pacific oyster *Crassostrea gigas* around the world.

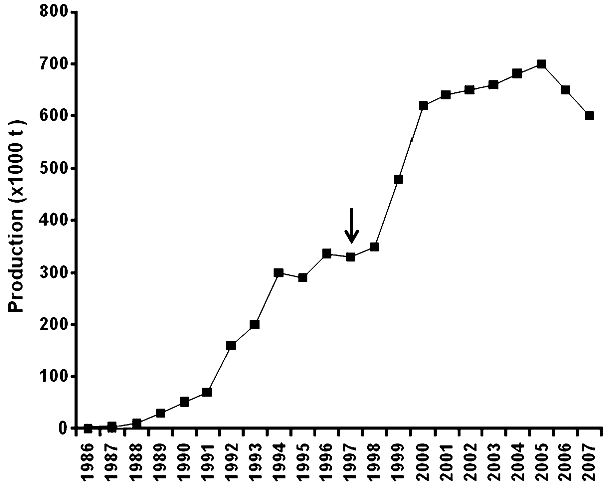

Figure 2 Aquaculture production of the non-native bay scallop *Argopecten irradians* in China. The arrow points to the production in 1997 when the native scallop *Chlamys farreri* began to suffer massive summer mortalities.

scallop (*Chlamys farreri* Jones et Preston, 1904), which takes 18 months to harvest (Guo & Luo 2006). Bay scallops quickly gained acceptance by scallop farmers in China. In approximately 10 years, bay scallop production in China reached 300 000 t (Fig. 2). By the late 1990s and early 2000s, problems as a result of inbreeding became apparent and new broodstocks were introduced from the USA and Canada to expand the gene pool (Guo & Luo 2006). The southern bay scallop was also introduced to southern China (Zhang *et al.* 1994), although most bay scallop production in China comes from the northern bay scallop cultured in north China, primarily in the Shandong, Hebei and Liaoning provinces.

In 1995, the native *C. farreri* industry began to experience summer mortalities (Guo *et al.* 1999; Xiao *et al.* 2005). In 1997, a massive summer mortality of cultured native scallops resulted in a two-third reduction in production. This mortality was probably caused by a viral disease that does not affect bay scallops (He *et al.* 2003). After 1997, more scallop farmers began to culture bay scallops. In 2007, bay scallop production in China reached approximately 600 000 t (Fig. 2), accounting for more than half of the global scallop production; this is regarded as one of the most successful introductions in molluscan aquaculture.

The Japanese scallop

The Japanese scallop (*Patinopecten yessoensis* Jay, 1856) was introduced from Japan to China in the early 1980s. It is a large scallop and commands a higher market price than the native and bay scallops. It is a cold-water species cultured on the bottom or in suspended cages primarily in the Liaoning and Shandong provinces in north China. Production of the Japanese scallop was small in the first two decades after its introduction, but production has been through a period of rapid expansion in recent years. This expansion has come about as a result of market demand and recent advances in hatchery technology. Now China produces approximately 250 000 t of Japanese scallops from aquaculture annually, with an estimated value of approximately US$500 million. In the past 2 years, cultured Japanese scallops have suffered heavy summer mortalities. Mortalities were higher in scallops cultured in suspended cages than on the bottom. This industry is in urgent need of genetically improved stocks or alternative species.

Other species

The Manila clam (*Ruditapes philippinarum* Adams et Reeve, 1850) was accidentally introduced to the west coast of North America with shipments of Pacific oysters from Japan. It now supports a significant aquaculture industry with an annual production of approximately 3955 t (USDA 2006). Several clam species have recently been introduced from North America to China as candidates for aquaculture. These include the hard clam (*Mercenaria mercenaria* Linnaeus, 1758), the Atlantic surfclam (*Spisula solidissima* Dillwyn, 1817) and the Pacific geoduck (*Panopea abrupta* Conrad, 1872); of these species the hard clam appears promising.

The introduction of non-native species carries certain risks. First, the non-native species may become invasive and damage ecosystems. Pacific oysters have spread and established in several European countries and may be affecting local benthic ecosystems (Reise *et al.* 2006). In Australia, the Pacific oyster is considered to be a competitor species for the native Sydney rock oyster, and regulations have been introduced to control its importation in some areas (Nell & Perkins 2005). However, most bivalve molluscs introduced for aquaculture have not been shown to be invasive, such as the introduction of the Pacific oyster to the west coast of the USA and the introduction of Japanese and bay scallops to China.

Another concern is the spread of pests and diseases. A well-documented example is the introduction of the oyster drill (*Ceratostoma inornatum* Recluz, 1851), a small gastropod that preys on bivalves, with oyster shipments brought to North America from Japan (Quayle 1988). The oyster parasite *Bonamia ostreae* Pichot *et al.*, 1980 was introduced from California to France in the 1960s and subsequently devastated the European oyster industry (Elston 1990). The risk of introducing pests and pathogens can be reduced by following proper quarantine practices and guidelines, such as the International Council for the Exploration of the Sea (ICES) protocol for the introduction of non-native marine species (ICES 2005).

Infusion of new genetic material through hybridization

Hybridization is widely used for the genetic improvement of agricultural stocks. Although not widespread, hybridization has contributed significantly to finfish aquaculture in some areas (Bartley *et al.* 2001; Na-Nakorn & Brummet 2009). Hybridization, intraspecific or interspecific, depends on the availability of diverse genetic resources. In general, hybridization offers two benefits: the combination of useful traits developed in different stocks or species, and the restoration or expansion of genetic variability. Interspecific hybridization can also be used to produce sterile individuals (Bartley *et al.* 2001). Maintaining variability is critical for the genetic improvement and domestication of cultured stocks.

The Pacific abalone

Abalone is a highly valued seafood in many parts of the world. Depending on size, it can fetch US$3–30 per animal in some markets. Because of its high value, abalone is cultured or being tested for culture in several countries, including Australia, Canada, Chile, China, Japan, South Africa, the USA, and in many other Asian countries.

Abalone culture in China began in the late 1980s in North China with the Pacific abalone *Haliotis discus hannai* Ino, 1952. Technologies for large-scale seed production were developed around 1986 in Dalian (Zhao 1999), which lead to rapid development of abalone culture in China. By the early 1990s, abalone aquaculture had become a large and profitable industry. In 1994, however, diseases caused serious mortalities (over 90%) in juveniles in the hatchery and in adults during grow-out (Zhao 1999; Zhang *et al.* 2004). To improve the survival of cultured abalone, *H. d. hannai* stocks from Japan were introduced and intraspecific hybrids between the Chinese and Japanese stocks were created. The hybrids improved survival significantly (by 100%) and growth (by 30%), resulting in the production of approximately 25 000 t of abalone from aquaculture each year, over 95% of which are intraspecific hybrids (Guofan Zhang, pers. comm., 2009). The use of hybrid abalone saved the abalone industry in China and is a strong testimony to the benefits of preserving and using molluscan genetic resources for stock improvement. As most farmers are now using hybrid abalone, the maintenance of pure lines, however, becomes a challenge.

In Australia, an interspecific hybrid abalone, the tiger abalone, was created between greenlip (*Haliotis laevigata* Donovan, 1808) and blacklip (*Haliotis rubra* Leach, 1814) abalone. The hybrid grows faster and combines desirable traits from both parental species. Unlike the blacklip abalone, the hybrids do not aggregate or escape in culture, a trait that is valued by farmers. More than 50% of abalone cultured in Australia are tiger hybrids (Peter Kube, pers. comm., 2009).

Other species

Interspecific hybrids have been produced between the native weathervane scallop (*Patinopecten caurinus* Gould, 1850) and the introduced Japanese scallop in British Columbia, Canada. The hybrid 'Pacific' scallop grows fast and has strong resistance to diseases and to mortality during grow-out (Smith 2006). These hybrids have provided a valuable product for scallop farming in British Columbia, Canada.

Development and use of new genetic resources

Genetic resources with enhanced performance for aquaculture can be developed using genetic techniques, such as selective breeding, ploidy manipulation and transgenesis. Selective breeding can produce new combinations of genes that can give selected stocks new genotypes and traits. The genomes of molluscs are highly polymorphic (Guo *et al.* 2008c). This high genetic diversity makes molluscs good subjects for selective breeding. However, selective breeding in molluscs is still in the early stages. Many studies have reported positive responses after 1–2 generations of selection, but well-defined strains are few. For oysters, over 80% of aquaculture production comes from wild seed.

Disease-resistant oysters

Disease resistance is one of the most important traits for aquaculture production. The eastern oyster (*Crassostrea virginica* Gmelin, 1791), for example, encounters three major diseases: multinucleated sphere X (MSX; caused by the parasite *Haplosporidium nelsoni* Haskin *et al.*, 1966), Dermo (caused by the parasite *Perkinsus marinus* (Mackin, Owen & Collier) Levine, 1978) and juvenile oyster disease (JOD; caused by the bacterium *Roseovarius crassostreae* Boettcher *et al.*, 2005) (Ford & Tripp 1996; Boettcher *et al.* 2005). Each of these diseases can cause 80–90% mortality in naïve oysters or juveniles. The first two diseases are primarily responsible for the destruction of oyster fisheries in the mid-Atlantic region of the USA, and are also causing serious losses to the aquaculture industry. Juvenile oyster disease has been a serious problem for oyster nurseries in the northeastern region of the USA.

Disease-resistant strains of the eastern oyster have been developed in the USA using traditional selective breeding. Selective breeding for MSX resistance began in 1960, and strong resistance to MSX was obtained after five generations of mass selection (Ford & Haskin 1987). Selection for Dermo resistance started in 1990, and moderate resistance was obtained after four generations of selection (Calvo *et al.* 2003; Guo *et al.* 2008b). Several selected strains of the eastern oyster are currently available that have strong resistance to MSX and moderate resistance to Dermo. A JOD-resistant strain was also developed after 1–3 generations of selective breeding (Farley *et al.* 1998). The JOD-resistant strain is also known for its superior growth and was developed through long-term selective breeding, but this strain has no or little resistance to MSX and Dermo. Hybrids between the Rutgers MSX/Dermo-resistant strain and the JOD-resistant strain provided the best performance by combining the Dermo resistance and superior growth from the two strains (Guo *et al.* 2008b). These disease-resistant and fast-growing strains have contributed to eastern oyster farming in the USA.

In the Pacific oyster, lines that resist summer mortalities have been developed after three generations of selection (Hershberger *et al.* 1984). In the Sydney rock oyster (*Saccostrea glomerata* Gould, 1850), selected lines have shown a significant reduction in time to market size and dual resistance to winter mortality and the Queensland unknown (QX) disease caused by *Marteilia sydneyi* Perkins and Wolf, 1976 (Nell & Perkins 2006).

Lines with superior growth

In the Pacific oyster, lines with superior growth rate have been developed using family-based selection in the USA (Langdon *et al.* 2003) and in Australia (Peter Kube, pers. comm., 2009).

Selection for colouration in scallops

Colouration is an important trait, particularly in scallops, and red is desired in China. Red strains of the bay scallop (Zhongke Red) and the Chinese scallop (Penglai Red) have been developed through selective breeding (Guofan Zhang & Zhenmin Bao, pers. comm., 2009). They have become popular stocks for scallop farmers in China.

Current practices

Introduction of non-native species

Although non-native species have made significant contributions to the development of aquaculture, they may become invasive and cause serious economic and ecological damage in new environments. Many countries have enacted laws regulating the introduction of non-native species. The regulative frameworks are complex and beyond the scope of this review. The following are just some examples that are known to the author.

In the USA, strict laws including the National Aquatic Invasive Species Act of 2005 have been enacted to prevent the introduction of potentially invasive species. Although not all species are invasive, any introduction of non-native species is strictly scrutinized. The proposed introduction of a non-native oyster, *Crassostrea ariakensis* Fujita, 1931, to Chesapeake Bay is a good example. *Crassostrea ariakensis* is native to China, Japan and Korea. It resists the MSX and Dermo diseases that have devastated the native eastern oyster populations (Calvo *et al.* 2001) and it grows well in the low salinity environment of Chesapeake Bay. The introduction of *C. ariakensis* was proposed as a way to rebuild the oyster industry. The proposal encountered strong opposition from environmental groups, concerned citizens and state agencies. An environmental impact study was initiated to investigate potential risks associated with the proposed introduction. After several years of studies and debates, the relevant federal and state agencies have decided against the introduction of *C. ariakensis* to Chesapeake Bay (http://www.dnr.state.md.us/dnrnews/infocus/oysters.asp).

In contrast to strict regulations in the USA, some countries have a more relaxed policy on the introduction of non-native species. Throughout the 1980s, China encouraged the introduction of non-native species for aquaculture. Many non-native species, not limited to molluscs, were introduced into China (Jiashou & Zhongjie 2009). Some of the introductions, such as bay and Japanese scallops, have been successful, but many have not led to significant commercial production. In 2005, the Ministry of Agriculture of China issued new regulations on the importation and exportation of aquatic species. These regulations prohibit the importation of species that are potentially invasive or carriers of dangerous diseases, but allow the introduction of valuable aquaculture species with proper review and authorization. The regulations ban the exportation of aquatic species that are valuable and unique to China. Despite these regulations, some non-native species are still imported to China without proper authorization or without following the ICES protocols (ICES 2005). Species are often brought in without going through customs.

Exchange of selectively bred stocks

Although selectively bred stocks are valuable for aquaculture, they may interbreed with wild populations and this may be a problem. Selected stocks are usually inbred and may behave differently compared with wild populations. They may cause unwanted changes in the wild population when interbreeding occurs. However, there are no confirmed cases of selectively bred molluscs impacting wild populations. One possible example is the native scallop (*Chlamys farreri*) cultured in China (Guo *et al.* 1999). The culture of this species began with hatchery-produced seed. Years of rapid aquaculture development have led to the establishment of reproductive stocks in some bays in Shandong. These stocks became self-recruiting and provided abundant natural seed, replacing the need for hatchery production, which is expensive. Some believe that the hatchery origin of these stocks has resulted in a reduction in the fitness of cultured scallops, but such speculation has not been backed by scientific evidence.

There are no known restrictions on the use and exchange of selectively bred stocks. The interbreeding of domesticated stocks with wild stocks can be avoided by using sterile stocks for aquaculture. Triploid molluscs may provide a useful tool for the genetic containment of cultured stocks (Guo *et al.* 2009). Triploid *C. ariakensis* has been used for field evaluation of this non-native species in Chesapeake Bay in the USA (Calvo *et al.* 2001). It should be cautioned that triploid oysters are not 100% sterile. They do produce some gametes and viable offspring, although the probability of this is extremely low compared with diploids (Guo & Allen 1994; Gong *et al.* 2004). A small proportion of triploids may revert to diploids or diploid/triploid mosaics (Guo *et al.* 2009). Despite these shortcomings, the use of triploid stocks can significantly reduce the potential for cultured stocks to interbreed with wild populations.

In addition to their potential use in population control, triploid molluscs also have other benefits to aquaculture. Triploid molluscs grow significantly faster than diploids in most species studied to date (Guo *et al.* 2009). Because of their sterility, triploid Pacific oysters have better meat quality than diploids during the spawning season, when diploids cannot be sold for the half-shell market (Allen & Downing 1986).

Protection of genetic resources

The importance of genetic resources in sustaining molluscan aquaculture cannot be overstated. Even if a species has no apparent commercial value at the present time, it may possess genes that could become extremely valuable in the future. *Crassostrea ariakensis* is a good example in this respect. It is not a preferred species for oyster farmers in China. *Crassostrea ariakensis* co-exists with *Crassostrea hongkongensis* Lam and Morton, 2003 in southern China and the latter, because of its white meat colour and unique taste, is preferred by oyster farmers and consumers. *Crassostrea hongkongensis* seeds collected from the wild often contain some *C. ariakensis*. The farmers often reject seeds with high proportions of *C. ariakensis*, which acts as a selective pressure against *C. ariakensis*. There are few major populations of *C. ariakensis* left in China, and the remaining populations are being threatened by pollution and habitat destruction (Guo *et al.* 2008a). However, studies have shown that *C. ariakensis* has resistance genes against two important diseases of *C. virginica* (Calvo *et al.* 2001). Hence, it is important to protect this unique genetic resource, although it has little commercial value in China at the present time. China has set up two reserves for the protection of *C. ariakensis* populations: one in Weifang in Shandong and the other in Nantong, Jiangsu province.

Perspectives

There are powerful examples of how the use and exchange of genetic resources have benefited molluscan aquaculture. The use of non-native species is particularly valuable. The Pacific oyster, bay scallop and Japanese scallop are good examples of successful introductions. The introduction of these three non-native species has produced huge economic returns with little or no known impacts on the environment. The Pacific oyster may compete with native species and may be considered a nuisance. It may also have other impacts on ecosystems that are either unknown or deemed acceptable by the public. Negative impacts of the introduced bay scallop on native scallops have not been reported. There has been no establishment of wild bay scallop populations in China, despite large-scale farming for the past 26 years. Bay scallops do spawn and produce spat during the summer, but the spat do not survive the first winter probably because of predation and a lack of suitable habitats. Given the success of non-native molluscs in aquaculture, we can expect that more non-native molluscs will be introduced and evaluated. The benefits of non-native species must be balanced with the potential risks. It is important that we establish reasonable guidelines for the introduction of non-native species. Regulations that are overly relaxed or excessively strict may prove to be counterproductive.

The preservation of molluscan genetic resources requires a good understanding of these resources. Molluscs as a group are under studied and poorly understood. Many new species or genetically different populations remain to be characterised. For oysters in China, the identity of several major aquaculture species has not been clear until recently (Wang *et al.* 2004; Guo *et al.* 2008a). The taxonomic status of some oyster species remains unknown (Ximing Guo *et al.*, unpubl. data, 2008). There is a great need to use modern genetic technologies to identify species and populations. Only when we know what genetic resources exist can we effectively use and protect them. We need to identify all molluscan species by their DNA sequences and characterize major geographic populations with genetic markers. Studies should not be limited to genetic analysis. Characterizing economically important traits in each population is also important.

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