The ornamental fish industry in Singapore

Article · February 2019

DOI: 10.11964/jfc.20180911442

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文章编号: 1000-0615(2019)01-0116-12 DOI: 10.11964/jfc.20180911442

· 综述 ·

新加坡观赏鱼产业发展的机遇与挑战

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摘要: 新加坡是一个小岛国，农业用地及用于养鱼的海域面积均很有限。但新加坡观赏鱼产业相当独特和成功，是世界第一观赏鱼出口国，向80多个国家出售超过1 000种鱼类，2016年的年收入达到4 300万美元。该产业的成功主要源于其在许可证颁发，生物安全控制，养殖，包装，运输和疾病控制等各方面所具有的独特特征。新加坡正在努力驯养和培育许多高价值的海洋物种和新的淡水物种，并开发新型的循环水养殖系统。上游研究侧重于开发和使用基因组工具来培育新品种并维持野外种类的遗传多样性。但由于养殖鱼类的空间有限，邻国竞争激烈，该行业面临诸多挑战，其市场份额正在减少。在这篇综述中，我们将总结新加坡观赏鱼产业的现状和发展，讨论其面临的挑战，并提出保持该产业领先地位的建议。

关键词: 观赏鱼; 发展; 挑战; 新加坡

中图分类号: S 965.8 **文献标志码:** A

Today, the world ornamental fish industry involves over 125 countries. Over 2 500 species of ornamental fish are being traded, with over 90% of these species originating from freshwater, and the remaining from brackish water or the sea[1]. Global exports of ornamental fish since 2000 rose steadily from US$177.7 million to a peak of US$ 364.80 million in 2011 (Fig. 1). In 2013, the total ornamental fish industry was valued at approximately US$ 15 billion[2].

Singapore is a very small (ca. 721 km^2) country made up of Singapore Island and over 60 smaller islands[3-4]. Since its independence in 1965, its gross domestic production (GDP) and population have grown rapidly with the latest estimated at US$ 349.7 billion and 5.86 million in 2017, respectively. Although there is limited land for agriculture and fish farming, Singapore is commonly regarded as the capital of the ornamental fish industry[2]. The city state

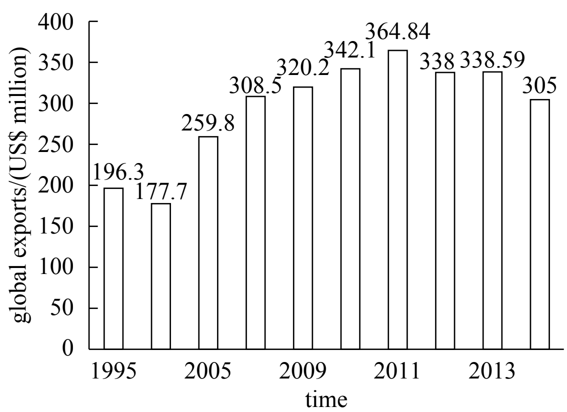

Fig. 1 Values of global exports of ornamental fish since 1995

is rich in fish species due to its location at the centre of Southeast Asia. Its tropical climatic conditions (i.e. high temperature and all-year-around rainfall), as well as its excellent communication links and network of flight connections, make Singapore an ideal place for culturing tropical fish[5]. Nevertheless, these favourable

Received: 2018-09-05 **Revised:** 2018-12-26
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conditions alone are not guarantee of success. In this review, I will summarize the development, research, challenges and outlook of the ornamental fish industry in Singapore.

1 Status of the ornamental fish industry and research in Singapore

The ornamental fish industry in Singapore actually includes two interdependent sectors: fish farming and export trade[5]. During the past few decades, well-developed distribution systems for ornamental fish, comprising farmers, wholesalers and exporters, have been established. Ornamental fish farms specialize in producing high quality fish species and new varieties. Fish produced by local farms were either sold to exporters or to wholesellers. Wholesellers buy fish from local farms and neighbouring countries, condition the imported fish, then proceed to repack and distribute them to exporters. Exporters, who are in most cases also importers, sell their fish to buyers in other countries. To date, five Singapore farms-cum-exporters have achieved the distinction of being awarded the ISO 9002 quality management system certificate as well as the ISO 14001 environment management systems certificate. Singapore exporters deal with over 1 000 species of ornamental fish, buying from local farms, which account for about 40% of sales. Since the 1980s, Singapore has been the world number one exporter of ornamental fish[2]. However, its market share is decreasing in recent years. From 1995 to 2000, the figure was between 24% and 30%. In 2007, Singapore had 21% of the global export market. According to the latest data from the Food and Agriculture Organisation of the United Nations (FAO), Singapore held top spot in 2009 with exports of US$59.9 million and 18.7% of the market share, but in 2016 the figures dropped to 43 million USD and only 14.1% of market share (Fig. 2). The company QianHu (www.qianhu.com), listed in the Singapore stock market, is the largest ornamental fish company in Singapore. Its export accounts for about 3%–5% of the world total ornamental fish export. The main importers of ornamental fish from Singapore in the world are the US, UK, Japan and Germany. In 2012, these countries imported ornamental fish from Singapore with values of US$ 11.0, 10.1, 5.4 and 4.1 million, respectively (Fig. 3).

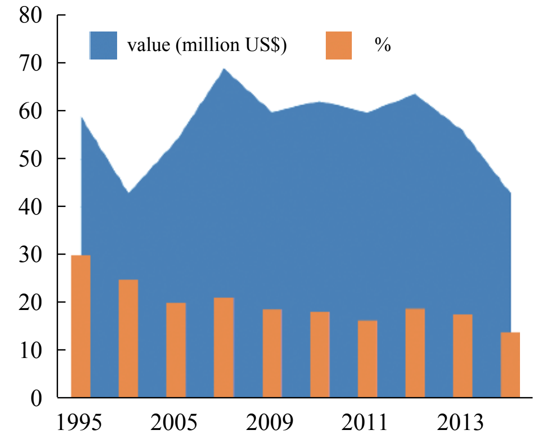

Fig. 2 Values and market share (%) of export of ornamental fish from Singapore since 1995

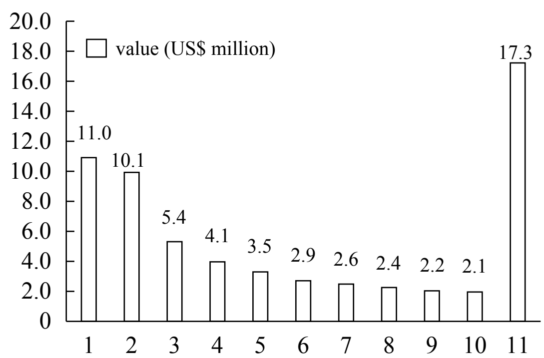

Fig. 3 Values of export of ornamental fish from Singapore to different countries on 2012

1. USA, 2. UK, 3. Japan, 4. Germany, 5. Holland, 6. France, 7. Russia, 8. Canada, 9. Spain, 10. Italy, 11. others

2 Ornamental fish species cultured/exported in Singapore

Among the over 1 000 ornamental fish species, the vast majority (>90% of species) are freshwater species. Of these, the majority (>90%) are captive bred. In contrast, only a few marine ornamental fish are captive bred. In Singapore freshwater, there are 135 fish species reported, including native and introduced species. Most ornamental freshwater species here were imported from neighbouring countries, including Thailand, Indonesia, Malaysia and other countries. Hence, the ornamental fish industry in Singapore relies heavily on the export and import of introduced species. Efforts are being made to breed and domesticate many of the high value marine species and new freshwater species. The following six species (Fig. 4) are the most popular ornamental fish species exported from Singapore.

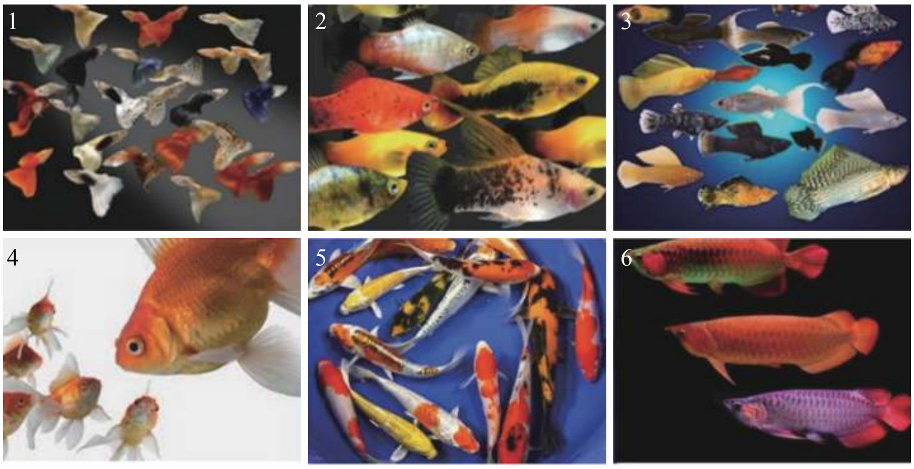

Fig. 4 Six major ornamental fish species exported by Singapore

1. guppies, 2. mollies, 3. platyfish, 4. goldfish, 5. Koi Carp, 6. Asian arowana

2.1 GUPPIES

The guppy is one of the most widely distributed tropical fish species (*Poecilia reticulata*) in the world[6] and is one of the most popular freshwater ornamental fish species. It is a cheap fish, sold at a price of between 20 cents and 50 cents each, depending on size and colour.

2.2 MOLLIES

Mollies are a tropical fish species (*Poecilia sphenops*)[7] which is versatile and easy to culture and breed. They are also hardy and are therefore a popular aquarium fish. Normally, they are sold for between 20 cents and 50 cents each in the ornamental fish market, depending on their body size and colour.

2.3 PLATYFISH

Platyfish is a common name of freshwater fish in the genus *Xiphophorus*[8] that lack a sword at the bottom of their tails. This fish is an easy-care fish and popular with beginning aquarists. In the platyfishes, there are many colour variations, including red, yellow, blue, black, golden and purple, with the most common one being a solid red. In the ornamental fish market, they are sold for between 20 and 50 cents each, depending on size and colour.

2.4 GOLDFISH (*Carassius auratus*)

Goldfish was first domesticated in China over a thousand years ago, and several distinct breeds have since been developed[9]. The goldfish is one of the most commonly kept aquarium fish and is a domesticated version of a less-colourful carp. Each goldfish costs between $3 and $150 each, depending on their size, variety and colours.

2.5 KOI carp (*Cyprinus carpio*)

The koi carp are descendants of the common carp. They were selectively bred in Japan in the 1820s[10], and numerous colours and patterns were developed. These fish are typically kept for decorative purposes in outdoor ponds or water gardens. They vary in colours, but some of the common colours are white, black, red, yellow, blue and cream. They are peaceful freshwater fish and have an average life span of 15 to 20 years. Prices range from US$ 3 to 1 000, depending on size and variety.

2.6 Asian arowana (*Scleropages formosus*)

The Asian arowana is a fish species from the *Osteoglossidae* family[11]. There are four different color varieties: Cross Back Golden from West Malaysia, Super Red from West Kalimantan of Indonesia, Red Tail Golden from Pekanbaru, Indonesia, and

Green found in Cambodia, Indonesia, Laos, Malaysia, Philippines, Vietnam and Thailand[12] (Fig. 5). The bright colors, very large scales, large-mouth structure, quick swimming, late sexual maturity and low fecundity have made Asian arowana the king of aquarium[13]. With its close resemblance to the Chinese ancient dragon, many Chinese believed that Asian arowana symbolizes luck, wealth, prosperity and strength[14]. The demand for the Arowana increased dramatically in the past 30 years and arowana hobbyists are said to be among the richest people. Some beautiful arowana individuals (Fig. 5-a) are sold for up to US$ 300,000[15]. Due to over-fishing for profits and destruction of its natural habitats, the wild stocks of Asian arowana have declined rapidly[16]. The Golden and Red varieties have reached a stage of near extinction since 1980s. The Asian arowana was listed in CITES appendix I in 1975[12, 14, 17] and the IUCN Red List in 2006. Captive breeding of Asian arowana was first successfully carried out in Singapore in 1981[18].

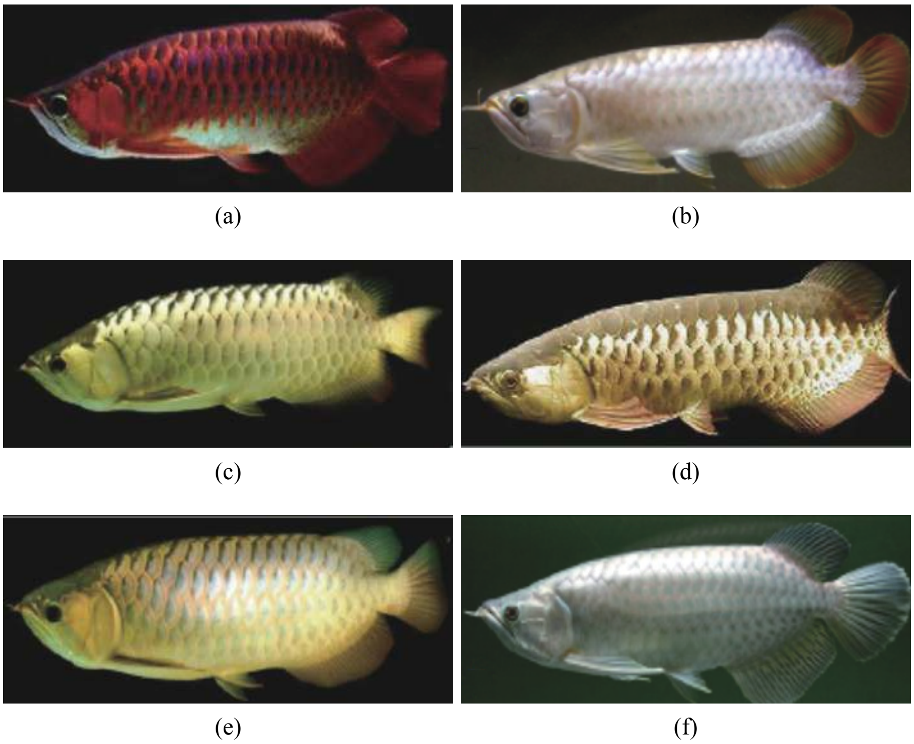

Fig. 5 Different colour varieties of Asian arowana (modified from Chang[19]).

(a) Red grade 1 arowana; (b) Red grade 2 arowana; (c) Malaysian Gold arowana; (d) Indonesian Gold arowana; (e) Tong Yan Hybrid Arowana; (f) Green arowana

Although over 1 000 ornamental fish species have been imported and exported in Singapore, there are still many challenges that need to be tackled in ornamental fish species. In most traded ornamental fish species, their life history and other basic scientific knowledge are not well -known. For large-scale production, it is essential to know broodstock management, spawning induction, larval rearing, nutrition, live feed, diseases and culturing systems. Certainly, reducing rearing cost is also important for commercial production. The dependence on import and wild caught fish will also affect the sustainability of the industry in the near future. Therefore, the industry needs to take measures to protect the fishes in the wild.

3 Culture and packing systems of ornamental fish in Singapore

Despite its small size, Singapore is ideal for rearing tropical fish due to its climate, temperature and rainfall. Production and export of ornamental fish started in the early 1960s. Currently, there are 65 licensed ornamental fish farms. Most of Singapore's ornamental fish farms are located in Lim Chu Kang and Sungei Tengah on the north-western end of the country. Farmers have used different culture systems. In the 1970—80's, pond culture was the most popular culture system. Most ponds are earth-ponds. The types and sizes of ponds depend on species. The water level in the pond is dependent on the existing hydrology, and during times of drought, they must be supplemented with well water in many areas. The water quality is dependent on the soil type. Classically, ponds in areas with high organic matter are acidic, and their total alkalinity and hardness may be low. Currently, several companies (e.g. Apollo Aquarium (Pte) Ltd) (http://apolloaq.com.sg/) are using vertically stacked glass tanks to culture ornamental fish, which saves space and allows stocking capacity to be ramped up sevenfold (Fig. 6-a). The company is also developing and using a recirculating aquaculture system that allows ornamental fish to be grown and kept in smaller space. QianHu Corporation has developed intensive multi-tier automated recirculation systems (Fig. 6-b). These types of multi-tier systems increase the holding capacity, while using just half the amount of water. They also use less manpower. Leveraging on these sort of technologies enables them to do more with less space and less manpower. They also enable farms to move indoors, which opens up more locations for ornamental fish farms in Singapore. Many farmers and exporters have shifted to recirculation systems in their farming and export operations.

(a)

(b)

Fig. 6 New recirculating aquaculture systems for ornamental fish in Singapore

(a) Vertically stacked glass tanks at Apollo Aquarium (Pte) Ltd save space and allow stocking capacity to be ramped up sevenfold. (b) QianHu' multi-tier automated recirculation systems

The current state of the art in the packaging of ornamental fish focuses mainly on the control of metabolic waste products to reduce the stress imposed on the fish during transport[20]. The existing packaging system is characterized by a very high fish loading density, which helps to reduce the freight cost of the fish consignment, but at the same time, leads to very high ammonia and carbon dioxide, and low pH in the transport water at unpacking[21]. Deterioration of water quality may cause severe stress to the fish and would result in about 10% of cumulative mortality at seven days post shipment. Stress resistance is an important factor determining the post-shipment performance of the fish[22]. However, insufficient attention has been paid to enhancing the stress resistance of the fish to increase their chances of survival after transport. To increase the loading density and reduce post-shipment mortality of ornamental fish, efforts should be made to lower the stress responses of the fish and enhance their stress resistance. As the effects of transport of ornamental fish extend beyond the actual transportation period, emphasis should also be placed on the preparation of the fish for the transport and recovery of the fish after shipment[20]. Control of the stress response of ornamental fish should start on the farm. Farmers can contribute by applying nutritional prophylaxis before capture and minimize stress to the fish during the capture operation. Feeding the guppy with diets supplemented with vitamin C at 2 000 mg/kg for 10 days enhances both disease resistance to Tetrahymena and the stress resistance of the fish, leading to reduced post-shipment mortality[22]. For exporters, the visual inspection for pathological problems is not satisfactory, as parasitic infection could be mild and asymptomatic, and the fish may show symptoms only after shipment[23]. Exporters may use the salinity stress test to identify fish lots of good quality for transport to reduce fish loss after shipment[20]. Quality enhancement through health prophylaxis to eradicate parasites would significantly reduce the cumulative mortality of ornamental fish on the 7th day post shipment. A new treatment protocol involving treatment in pre-packaging and actual transport water has been developed to eliminate the need of tank maintenance, thus leading to saving in manpower and space[22]. Recent experiments using guppy suggested that starvation for one day is effective in enhancing their stress resistance. The fish should be starved for an optimal duration only, as prolonged starvation leads to a decrease in the stress resistance of the fish. A low concentration of salt should be used to enhance the stress resistance of guppy, both in the transport water and in the recovery water after shipment. High salinity should be avoided as the salt content reduces the efficiency of clinoptilolite and lowers the quality of transport water. Data on the water quality of transport water suggest that the current practice in reducing the metabolic wastes in transport water is insufficient to lower ammonia and stabilize pH to acceptable levels. Use of anaesthetics to lower the metabolic rate and enhance the stress resistance of the fish could be a promising solution[24], but it warrants further research. To lower fish loss due to thermal shock or heat loss, further research on the design of styrofoam boxes with better insulation properties is needed. Finally, as the mortality is stress-mediated and occurs during the first week recovery period, the industry should consider revising the basis of the warranty system to their customers, from death on arrival (DOA) to cumulative mortality on the 7th day post shipment (or death after seven days) to reduce fish losses after shipment. Besides new farming methods, the purchase and use of suitable equipment also increase productivity. To improve its fish packing process, Red Sea Aquarium Pte Ltd acquired the Aqua-Clipper Sealing Machine, which requires less effort, time, and energy as compared to the traditional method of sealing bags with rubber bands.

4 Biosecurity, import and export permit

The government agency Agri-Food & Veterinary Authority of Singapore (AVA) has formulated aquatic animal disease surveillance programmes for ornamental fish in Singapore[25]. The surveillance programmes cover diseases, which include the diseases notifiable to the World Organisation for Animal Health (OIE), and emerging new diseases that may be of concern to the trade industry. Disease surveillance requirements are often subject to change depending on risk assessments conducted by AVA and/or the requirements raised by importing countries. In addition to routine samples collected, diseased or sick fish observed during inspection visits will also be collected for testing. This ensures that only healthy fish are exported out from Singapore. Data collected from the surveillance programmes are useful in identifying disease trends and risks, which will aid in the review of AVA‟s surveillance programmes. In response to positive detection of disease, AVA carries out regulatory actions and measures which are in line with international standards. These follow-up actions safeguard the ornamental fish trade by ensuring that disease is not spread to other local ornamental fish establishments and also maintain Singapore’s disease-free status to avoid disruption to the export. AVA possesses competent authority which is able to guarantee that there are controls in place ensuring that the importing countries’ requirements are adhered to. The import and export of ornamental fish are regulated by AVA, Quarantine and Inspection Department (QID), Import & Export Regulation Division (IERD), Ornamental Fish Section. Prior to the import and export of ornamental fish, a company must possess a Licence to Import or Export Live Fish issued by AVA.

5 Transport

Ornamental fish is very fragile. The industry usually ships fish out on passenger aircraft, in order to meet the delivery time of between 24 to 36 hours[20]. A delay in flight will have an unfavourable impact on them. Singapore is very successful in avoiding such delays and is well known to be a one-stop shop ornamental fish provider in the region[26]. Qian Hu Fish Farm Trading and Aqua-Nautic Specialist Pte Ltd (https://www.aqnautic.com/) computerised their pre-export checking and invoicing processes. With this new system, the processes can now be paperless and companies can retrieve last-minute amendments to their orders in real time. For the exporter centre located at the airport of Singapore, the exporters heavily invested into high-tech and advanced management system in their new facility. This enables the exporters to further enhance their capability to adapt to the new international changing environment.

6 Research and development

Innovation has been driven mostly from within the industry, and also from local universities and research institutes. Most researches were conducted by ornamental fish farms and exporters with financial support from the government and focused on the following four main areas:

(1) Developing water recirculation systems: Two water recirculation systems have been designed and developed for intensive ornamental fish farming and for holding of ornamental fish for export. Use of the systems have resulted in increased yield and better-quality fish. One of these systems was developed by the Apollo Aquaculture Group with S$300,000 from government enterprise development agency SPRING Singapore. The system allows water to be filtered and reused in tanks - cutting down waste water disposed of during water changes by up to 70 per cent. Other efforts include those by ornamental fish giant QianHu Corporation, which conducts its own research and development programme to invent its Hydra system. The technology uses electricity to neutralise the harmful effects of ammonia and nitrite in fish waste, and in devices ranging in size from commercial ponds to home aquariums. Many farmers and exporters have shifted to recirculation systems in their farming and export operations.

(2) Developing a fish quality evaluation system: Development of this system has enabled farmers and exporters to screen the resistance of their Guppy against stress, by subjecting the Guppy to osmoregulatory stress tests. With this system, exporters can identify which of their sources are providing excellent Guppy. This allows them to avoid taking in or shipping out weak or unhealthy fish that may perish during shipment. In 1996, QianHu developed quality systems for its operations, leading to ISO 9002 certifications for conditioning and packing of ornamental fish for export. QianHu was the first company in the region to be awarded ISO 9002 certification. This further distinguished them from their competitors and gave quality assurance to their customers

(3) Enhancing fish quality: AVA has jointly developed with the industry several treatment protocols that aim at enhancing the health quality of the guppy and angelfish through eradication of fish parasites prior to export. Performance of the protocols in export operations have resulted in the improvement of fish health. The AVA Quality Assurance Scheme (AQUAS) is a continuous effort by AVA to align their quality assurance processes on farm management and fish disease control to meet the requirements of local regulatory authorities, international standards and also overseas importing countries.

(4) Production of new fish varieties: AVA has jointly developed (with a commercial farm) a new Dragon Fish hybrid known as the Rainbow Dragon. Breeders in Singapore are also active in developing new varieties of Asian arowana, guppy, discus, swordtail, mollie, platy and fighting fish through selective breeding.

Local research institutions in cooperation with local ornamental fish companies conducted some upstream research on guppy, zebrafish and Asian arowana. In the early 1990s, most research focused on guppies, including culture methods[27], feeding[22], genetic variations[28-29], diseases[30], molecular sexing[31], packing and transportation[32]. In 1999, Professor Zhiyuan Gong, from the Department of Biological Sciences, National University of Singapore, generated the first transgenic ornamental zebrafish, “GloFISH” (Figure 7), by inserting a fluorescent jellyfish gene into zebrafish[33-34]. His technology was patented in the USA. The fish was sold at a price of US$ 5/each in the

Fig. 7 Ornamental zebrafish, "GloFISH" generated by Professor Gong at the National University of Singapore

USA ornamental fish market, creating a market value of US$ 50 million since it went to the ornamental fish market.

Since 1998, the Temasek Life Sciences Laboratory (TLL) has started developing and using novel genomic tools to facilitate the improvement of the productivity of the ornamental fish industry. It has developed DNA markers[35-37] and sex-markers[38], constructed a linkage map[39], and sequenced the complete mitochondrial[40] and nucleus genomes[41] of one of the most expensive ornamental fish, Asian arowana. Besides contributing to the understanding of the status of genetic diversity of arowana in the wild[36], these genomics resources have enabled the farms to sex their arowana at young stages (e.g. fingerling stage)[38], to conduct family-based selective breeding[19] and to set up mating schemes to produce expected traits. For example, QianHu used DNA technologies to identify the sex of Asian arowana at fingerling stage and conducted molecular parentage analysis to identify mating pairs of arowana in ponds[19]. TLL has also developed DNA markers for Sulawesi shrimp *Caridina ensifera* and studied its mating behaviour under captive breeding using these DNA markers[42]. The study found a high frequency of multiple paternity in the freshwater shrimp species under captive culture condition, suggesting that it is essential to put more females than males in a tank to reproduce more offspring of this species. Recently, TLL has sequenced and assembled the complete genome of the ornamental fish *Beta splendens* (unpublished data). Using the sequence data together with GWAS, TLL has identified the genomic region determining the sex of the species. Using the DNA markers linked with different phenotypes, TLL is able to generate fighting fish of different types of tails and colour varieties. This fish is expected to be a model organism for teaching genetics in secondary and high schools as it is easy to culture and maintain broodstocks, and many traits show Mendelian inheritance[43].

Local polytechnics have also contributed notably to research and development in ornamental fish. For example, Temasek Polytechnic has collaborated with local ornamental fish farms and AVA in various industry-centric aquatic research related to nutrition and pathogen detection. Republic Polytechnic has started offering training in Marine Science and Aquaculture. These upstream researches and education help to solidify the leading position of Singapore's ornamental fish industry.

7 Challenges

Although Singapore's ornamental fish industry was successful, its portion of world trade is gradually decreasing (Figure 2). The industry needs to meet several challenges for it to be successful in future years[5]. These challenges include:

(1) High production cost. Compared to Singapore, neighbouring countries such as Malaysia, Indonesia and Thailand have cheaper, more available labour and wider swathes of land to farm on. They also have rapidly-improving international connections, that have undermined Singapore's strategic role in linking buyers from the west with suppliers in Asia.

(2) Lack of R and D. Although some research and development have been carried out, most was done by the industry itself. Local universities and research institutes conducted few studies on ornamental fish due to the lack of funding. In addition, research institutes have scaled down efforts since the industry's heydays in the 1990s[5] due to the change of research focus to biomedicine.

(3) Difficulty of securing investment: Because of the uncertainty within the industry right now, including the possibility of having land tenders revoked, outside investments will be difficult, if not impossible, to find.

(4) Considerations due to limited ornamental fishery resources: the need for their conservation and sustainable use; the need to ensure that benefits are equitably shared; problems caused by habitat loss and degradation, harmful fishing practices (over-fishing and destructive fishing, such as the use of cyanide); and changes in international trade patterns and concerns about the introduction of exotic species.

(5) The sector also uses coral, both as dried decoration and as living components of fish tanks. International trade in hard corals is restricted by Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). In addition, many soft corals have hard coral bases to which they are attached and as such, the soft corals also become restricted under CITES. Industry NGOs are critical of the fact that about 3, 000 mt of coral are traded in the ornamental fish industry, but this has to be compared with hundreds of thousands, or indeed millions of tons of live coral mined for construction purposes (Ornamental Aquatic Trade Association information). Unfortunately, irresponsible parties have exacerbated coral reef destruction through negligent collection practices.

8 Suggestions to ensure the top position of the local ornamental fish industry

(1) Education of young generation. Skilled manpower is essential for each industry field. Measures should be taken to encourage new generation of fish farmers to gain new knowledges (e.g. molecular breeding using genomic tools[44]) and apply new technologies [(e.g. robotics and IoT (Internet of Things)[45-46]] and skills to the industry.

(2) To remain competitive, the industry must find ways to account for their limited land resources. They must innovate to counter their limited labor resources. Technologies, including robotics and IoT can improve worker productivity and reduce manpower requirement, but outside investors will likely be necessary.

3). Developing new varieties with novel technology. This can even include incorporating selective breeding programmes for economically-important ornamental fish species using genomic tools, including Crispr/ Cas-9[47].

4). Measures to secure investments into research and development must occur for the industry to stay competitive.

5). For developing new marine species, it is essential to research on life history and other basic scientific knowledge including broodstock management, spawning induction, larval rearing, nutrition, live feed, diseases, systems to reduce rearing cost.

6). Companies and institutes involved in the industry should cultivate an ethos that always looks for new things to do or new ways of doing things, instead of always wanting to remain in the status quo, as the latter makes it very difficult to continue to be able to earn a respectable profit from this trade.

9 Conclusion

Singapore's ornamental fish industry has been very strong for several decades. However, there are many challenges. To maintain its leading position in the world, fundamental research on genetics, breeding, culturing systems, feeds and disease prevention of high value freshwater and marine species must be strengthened. New technologies, including robotics and IoT should be used to reduce the cost associated with manpower. It is also essential for new generation of fish farmers to gain new knowledge and apply new technologies and skills to the industry. Through such effort and innovation, the future of the local ornamental fish industry is bright.

Acknowledgements

We thank the Temasek Life Sciences Laboratory for supporting our previous work on ornamental fish. We are also very grateful to people working in the ornamental fish industry for providing information on culturing, packing and trading of ornamental fish.

参考文献：

[1] Domínguez L M, Botella A S. An overview of marine ornamental fish breeding as a potential support to the aquarium trade and to the conservation of natural fish

populations[J]. International Journal of Sustainable Development and Planning, 2014, 9(4): 608-632.
[2] Ladisa C, Bruni M, Lovatelli A. Overview of marine ornamental species aquaculture[M]. FAO Aquaculture Newsletter, 2017, 39.
[3] Corlett R T. The ecological transformation of Singapore, 1819−1990[J]. Journal of Biogeography, 1992, 19(4): 411-420.
[4] Yaakub S M, McKenzie L J, Erftemeijer P L A, *et al*. Courage under fire: Seagrass persistence adjacent to a highly urbanised city-state[J]. Marine Pollution Bulletin, 2014, 83(2): 417-424.
[5] Ling K H, Lim L Y. The status of ornamental fish industry in Singapore[J]. Ornamental Fish Industry in Singapore, 2005, 32: 56-59.
[6] Magurran A E, Seghers B H, Shaw P W, *et al*. The behavioral diversity and evolution of guppy, *Poecilia reticulata*, populations in Trinidad[J]. Advances in the Study of Behavior, 1995, 24: 155-202.
[7] Alda F, Reina R G, Doadrio I, *et al*. Phylogeny and biogeography of the *Poecilia sphenops* species complex (Actinopterygii, Poeciliidae) in Central America[J]. Molecular Phylogenetics and Evolution, 2013, 66(3): 1011-1026.
[8] Kallman K D. The platyfish, *Xiphophorus maculatus*[M]//King R C. Handbook of Genetics. Boston, MA: Springer, 1975: 81-132.
[9] Chen S C. A history of the domestication and the factors of the varietal formation of the common goldfish, *Carassius auratus*[J]. Scientia Sinica, 1956, 5: 287-321.
[10] Bestor T C. Tsukiji: The Fish Market at the Center of the World[M]. Los Angeles: University of California Press, 2004.
[11] Greenwood P H, Rosen D E, Weitzman S H, *et al*. Phyletic Studies of Teleostean Fishes, with A Provisional Classification of Living Forms[M]. New York: Bulletin of the American Museum of Natural History, 1996 338-456.
[12] Dawes J, Chuan L L, Cheong L. Dragon Fish[M]. Kingdom Books England, 1999.
[13] Tavip W J. The Asian Arowana: King of the Aquarium[M]. Tropical Fish Hobbyist, 1995: 84-89.
[14] Goh W, Chua J. The Asian arowana[M]. Singapore: Dragon Fish Industry, 1999: 26-27.
[15] Voigt E. The Dragon Behind the Glass: A True Story of Power, Obsession, and the World's Most Coveted Fish[M]. Simon & Schuster, 2016.
[16] Fernando A A, Lim L C, Jeyaseelan K, *et al*. DNA fingerprinting: Application to conservation of the CITES-listed dragon fish,*Scleropages formosus* (Osteoglossidae)[J]. Aquarium Sciences and Conservation, 1997, 1(2): 91-104.
[17] Dawes J. Update on the dragon fish trade[J]. Aquarama, 2006, 7: 7-11.
[18] Joseph J, Evans D, Broad S. International trade in Asian bonytongues[J]. Traffic Bulletin, 1986, 8: 73-76.
[19] Chang A K W, Liew W C, Orban L. The reproduction of Asian arowana: Analysis by polymorphic DNA markers[J]. Aquaculture, 2007, 272(S1): S249.
[20] Lim L C, Dhert P, Sorgeloos P. Recent developments and improvements in ornamental fish packaging systems for air transport[J]. Aquaculture Research, 2003, 34(11): 923-935.
[21] Cole B, Tamaru C, Bailey R, *et al*. Shipping Practices in the Ornamental Fish Industry[M]. Waimanalo, Hawaii USA: Center for Tropical and Subtropical Aquaculture Publication, Oceanic Institute, 1999.
[22] Lim L C, Dhert P, Chew W Y, *et al*. Enhancement of stress resistance of the guppy *Poecilia reticulata* through feeding with vitamin C supplement[J]. Journal of the World Aquaculture Society, 2002, 33(1): 32-40.
[23] Gratzek J B. Parasites associated with ornamental fish[J]. Veterinary Clinics of North America: Small Animal Practice, 1988, 18(2): 375-399.
[24] Brown L A. Anesthesia in fish[J]. Veterinary Clinics of North America: Small Animal Practice, 1988, 18(2): 317-330.
[25] AVA. Vol. 2(ed AVA) (AVA, 2011).
[26] Cheong L. Overview of the current international trade in ornamental fish, with special reference to Singapore[J]. Revue Scientifique et Technique (International Office of Epizootics), 1996, 15(2): 445-481.
[27] Fernando A A, Phang V P E. Culture of the guppy, *Poecilia reticulata*, in Singapore[J]. Aquaculture, 1985, 51(1): 49-63.
[28] Khoo G, Lim K F, Gan D K Y, *et al*. Genetic diversity within and among feral populations and domesticated strains of the guppy (Poecilia reticulata) in Singapore[J].

Marine Biotechnology, 2002, 4(4): 367-378.

[29] Khoo G, Lim T M, Chan W K, *et al*. Genetic basis of the variegated tail pattern in the guppy, *Poecilia reticulata*[J]. Zoological Science, 1999, 16(3): 431-437.

[30] Hegde A, Teh H C, Lam T J, *et al*. Nodavirus infection in freshwater ornamental fish, guppy, *Poicelia reticulata* - comparative characterization and pathogenicity studies[J]. Archives of Virology, 2003, 148(3): 575-586.

[31] Phang V P E, Fernando A A. linkage analysis of the X-linked green tail and blue tail color genes in the guppy, *Poecilia reticulata* (Genetics)[J]. Zoological Science, 1991, 8: 975-981.

[32] Teo L H, Chen T W, Lee B H. Packaging of the guppy, *Poecilia reticulata*, for air transport in a closed system[J]. Aquaculture, 1989, 78(3-4): 321-332.

[33] Gong Z Y, Wan H Y, Ju B S, *et al*. Generation of living color transgenic zebrafish[M]//Shimizu N, Akoi T, Hirono I, *et al*. Aquatic Genomics. Tokyo: Springer, 2003: 329-339.

[34] Gong Z Y, Wan H Y, Chen M R, *et al*. Applications of transgenic technology in ornamental fish[J]. Fisheries Science, 2002, 68(S2): 1063-1066.

[35] Yue G H, Chen F, Orban L. Rapid isolation and characterization of microsatellites from the genome of Asian arowana (*Scleropages formosus*, Osteoglossidae,Pisces)[J]. Molecular Ecology, 2000, 9(7): 1007-1009.

[36] Yue G H, Li Y, Chen F, *et al*. Comparison of three DNA marker systems for assessing genetic diversity in Asian arowana (*Scleropages formosus*)[J]. Electrophoresis, 2002, 23(7-8): 1025-1032.

[37] Yue G H, Zhu Z Y, Lin G, *et al*. Novel polymorphic microsatellites for studying genetic diversity of red Asian arowanas[J]. Conservation Genetics, 2006, 7(4): 627-629.

[38] Yue G H, Ong D, Wong C C, *et al*. A strain-specific and a sex-associated STS marker for Asian arowana (*Scleropages formosus*, Osteoglossidae)[J]. Aquaculture Research, 2003, 34(11): 951-957.

[39] Shen X Y, Kwan H Y, Thevasagayam N M, *et al*. The first transcriptome and genetic linkage map for Asian arowana[J]. Molecular Ecology Resources, 2014, 14(3): 622-635.

[40] Yue G H, Liew W C, Orban L. The complete mitochondrial genome of a basal teleost, the Asian arowana (*Scleropages formosus*, Osteoglossidae)[J]. BMC Genomics, 2006, 7: 242.

[41] Bian C, Hu Y C, Ravi V, *et al*. The Asian arowana (*Scleropages formosus*) genome provides new insights into the evolution of an early lineage of teleosts[J]. Scientific Reports, 2016, 6: 24501.

[42] Yue G H, Chang A. Molecular evidence for high frequency of multiple paternity in a freshwater shrimp species *Caridina ensifera*[J]. PLoS One, 2010, 5(9): e12721.

[43] Wallbrunn H M. Genetics of the Siamese fighting fish,*Betta splendens*[J]. Genetics, 1958, 43(3): 289-298.

[44] Yue G H. Recent advances of genome mapping and marker - assisted selection in aquaculture[J]. Fish and Fisheries, 2014, 15(3): 376-396.

[45] Shin K J. Development of autonomous bio-mimetic ornamental aquarium fish robotic[J]. KIPS Transactions on Software and Data Engineering, 2015, 4(5): 219-224.

[46] Kiruthika S U, Raja S K S, Jaich R. IOT based automation of fish farming[J]. Journal of Advanced Research in Dynamical & Control Systems, 2017, 9(1): 50-57.

[47] Ran F A, Hsu P D, Wright J, *et al*. Genome engineering using the CRISPR-Cas9 system[J]. Nature Protocols, 2013, 8(11): 2281-2308.

The ornamental fish industry in Singapore

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Abstract: Singapore is a small island country with limited land for agricultural purposes and restricted sea waters available for fish farming. However, the ornamental fish industry of Singapore is quite unique and successful, being the world No. 1 exporter of ornamental fish, selling over 1 000 fish species to over 80 countries and generating an annual revenue of USD 43 million in 2016. Its success is mainly thanks to its specific capabilities in licensing, biosecurity controls, culturing, packing, transporting and disease control. Efforts are being made to breed and domesticate many of the high-value marine species and new freshwater species and to develop novel reciculating culture systems. Upstream research has focused on developing and using genomic tools to breed new varieties and to maintain genetic diversity in the wild. However, due to limited space for culturing fish and strong competitions from neighbouring countries, Singapore's ornamental fish industry is facing many challenges, and its market share is reducing. In this review, we will summarize the status and development of Singapore's ornamental fish industry, discuss its challenges and make some suggestions for maintaining the leading position of the industry.

Key words: ornamental fish; development; challenges; Singapore

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