The state of finfish diversification in Asian aquaculture

Liao I.C.

Recent advances in Mediterranean aquaculture finfish species diversification

Zaragoza : CIHEAM
Cahiers Options Méditerranéennes; n. 47

2000
pages 109-125

The state of finfish diversification in Asian aquaculture

I.C. Liao
Taiwan Fisheries Research Institute, 199 Hou-Ih Road, Keelung 202, Taiwan

SUMMARY – Aquaculture in Asia has a rich and experience-filled history of more than 2500 years. Asia is recognized as the leading aquaculture region in the world contributing 90% of the total world aquaculture production in 1996. About 100 species of finfish listed in the FAO yearbook are cultured in this area. This diversity of cultured finfish may be attributed to environmental and social factors. Recently, economic prosperity allowed people to change their preferences on seafood consumption. Furthermore, aquarium enthusiasts have got the opportunity to keep ornamental fishes as a delightful hobby. These factors motivated aquafarmers to diversify their cultured species while the aquarists imported more exotic species. The exploitation of new cultured species and introduction of exotic species are the two means in diversification. Generally, freshwater finfish are the primary exotic species in most countries of Asia. However, owing to their high economic value and market demand, marine finfish and ornamental fish have played the principal role to diversification. Applications of biotechnology in aquaculture and domestication are other possible approaches that may yield new species for culture. Species diversification offers both biological and economic benefits, and is thus, worth to pursue in the long-term. The approaches to finfish cultured diversification in Asia may provide a good example for other areas to follow.

Key words: Diversification, exotic, domestication, aquaculture, Asia, Taiwan.

***RESUME –** "Etat de la diversification des poissons dans l'aquaculture asiatique". L'aquaculture en Asie possède un historique riche et rempli d'expériences sur plus de 2500 ans. L'Asie est reconnue en tant que première région aquacole du monde, et elle a représenté 90% de la production aquacole mondiale en 1996. Environ 100 espèces de poissons figurant sur l'annuaire de la FAO sont cultivées dans cette région. Cette diversité de poissons cultivés peut être attribuée à des facteurs environnementaux et sociaux. Récemment, la prospérité économique a permis aux habitants de changer leurs préférences concernant la consommation de produits de la mer. En outre, les aquariophiles ont ainsi eu l'occasion d'avoir des poissons ornementaux comme hobby passionnant. Ces facteurs ont encouragé les aquaculteurs à diversifier les espèces qu'ils cultivent tandis que le secteur de l'aquariophilie a importé plus d'espèces exotiques. L'exploitation de nouvelles espèces cultivées et l'introduction d'espèces exotiques sont les deux moyens de diversification. En général, les poissons d'eau douce sont l'espèce exotique primaire dans la plupart des pays d'Asie. Cependant, en raison de leur grande valeur économique et de la demande du marché, les poissons marins et les poissons ornementaux ont joué le rôle principal dans la diversification. Les applications de la biotechnologie en aquaculture et la domestication sont d'autres possibles approches qui peuvent apporter de nouvelles espèces pour l'élevage. La diversification des espèces présente des avantages biologiques et économiques, et par conséquent il est intéressant de l'appliquer à long terme. Les approches concernant la diversification des poissons élevés en Asie pourrait être un bon exemple à suivre dans d'autres domaines.*

***Mots-clés :** Diversification, exotique, domestication, aquaculture, Asie, Taiwan.*

Introduction

Asia is the biggest region in the world, roughly comprising three-fifths of the world land. It is indeed a very vast region encompassing a myriad of races and cultures. It is also an area where the population density is very high. Maintaining adequate food supply and production are among the major concerns of the various governments in Asia. Foremost among these concerns is the reliable source of inexpensive protein. If livestock meat is available, it is expensive for the most, and the supply is often inadequate. There is a need, therefore, for a cheap source and readily available supply of protein to meet the more fundamental and basic human necessity – food. Aquatic products, or fishes, in particular, can meet this need.

Two approaches are being used in the harvest of aquatic products. One is by capture fisheries and the other, by aquaculture. Although fishing gears and methods have improved, production from capture fisheries has already reached its limits. When considering fish for human consumption only, aquaculture acquires greater importance since over a quarter of the total world supply was result of aquaculture (Basurco and Abellán, 1999). Aquaculture is getting more and more important to obtain aquatic products. Furthermore, the pressure from increased population stresses the need to continuously provide fish as an inexpensive source of animal protein especially in the low-income food deficit countries (LIFDCs). This situation has reflected the continuing trend in these countries of increased use of aquatic resources to further diversify food production (FAO, 1997) and the recent change in government policy towards fisheries development programs in many countries in Asia.

It is widely believed that the culture of aquatic organisms had its beginning in Asia (Bardach *et al.*, 1972). Aquaculture in Asia has a rich and experience-filled history of more than 2500 years. Aquaculture, primarily piscine culture, or keeping fish at ancient time probably began about 500 BC in China, due to the desires of an emperor to have a constant supply of his favourite fish. A treatise titled "Fan Li on Pisciculture" is most likely the earliest work and treatise on fish raising in the world. However, in the 7th-10th century AD, Emperor Li of the Tang Dynasty prohibited the culture of the common carp because its local name sounded like his surname. This imperial edict may seem absurd but no one dared to disobey the emperor then for fear of execution. This tyrannical act, however, was a big boon to carp culture because it motivated the people to look for other species to culture like silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), and grass carp (*Ctenopharyngodon idellus*) to meet their needs. This prohibition might have led to a diversification of cultured finfish. This development spread throughout Asia when Chinese migrated to various parts of Asia to seek out a new life. Brackish water milkfish (*Chanos chanos*) culture in Indonesia did not begin until the 15th century. Milkfish was introduced to the Philippines and Taiwan in 16th century. In the Philippines, milkfish is the major cultured species and is considered as the "national fish". Indeed, milkfish culture became a regular part of the rural economy especially in South-east Asia.

Through the years, the region has remained in the forefront of aquaculture development and continues to produce the lion's share of the global aquaculture output. In 1996, Asia produced 31 million metric tons that contributed more than 90% of the total world aquaculture production. About 200 species of aquatic plants and animals listed in FAO yearbook (FAO, 1998) are being raised in this area, more than in any other regions. Estimates from FAO and official Taiwanese statistics show that 95% of farmed aquatic produce comprised the following numbers of species: seaweeds, 6; molluscs, 43; crustaceans, 27; and finfish, 105 (Pullin, 1996). The status of finfish diversification in Asian aquaculture is reported in this paper. The advantages in the diversification of cultured species are also discussed.

Factors and methods that led to finfish diversification in Asian aquaculture

In 1998, about 100 species of finfish listed in FAO yearbook are raised in Asia (Table 1). Indeed, this list is even longer than that in FAO yearbook. This diversification on finfish aquaculture is attributed to environmental, and, also, to social factors. It is significantly affected by the wide income gap existing among Asian countries and religious prohibition, food preference or fixed traditions. For instance, diverse aquatic environments and climate conditions, from rivers to coral reefs and from the tropics to the temperate zones, can be found within Asia. In Asia, fish-eating is not only a way to get animal proteins but also is inspired as a cultural heritage. A fish dish for the Chinese is considered as a symbol of "bounty". The Japanese distinguish themselves as a "fish-eating" people by the pointed shape of Japanese-style chopsticks. In different regions, the favourite fish may vary. Milkfish is regarded as "national fish" in the Philippines while sea bream is preferred in Japan. In addition, the raising of living standard changed people's style on seafood consumption. For example, in 1986, per capita consumption of aquatic products per person in China was only 4.5 kg, even lower than the world average of 16 kg (Liao, 1992). In 1995, ten years after, per capita consumption of aquatic products per person in China was 20.2 kg. The growth rate of aquaculture was about 350%, the production increased from 8,000,063 to 24,433,321 metric tons (FAO, 1997). Also, the popularity of sport fishing in ponds has provided a vast market demand for aquaculture. More recently, transfers of ornamental fish for aquarium trade have also sharply increased. These factors encouraged aquafarmers to introduce exotic species or to exploit new cultured species to satisfy the demand.

The very vastness of Asia would make an all-encompassing discussion of aquaculture in this region both difficult and lengthy. Taiwan's aquaculture, having the fastest growth over the past 30 years, shall be used as a model for Asian aquaculture.

Table 1. Aquaculture of finfish in Asia (order by amount of production, FAO, 1998)

Common name	Scientific name
Silver carp	*Hypophthalmichthys molitrix*
Grass carp	*Ctenopharyngodon idellus*
Common carp	*Cyprinus carpio*
Freshwater fish nei	*Osteichthyes*
Bighead carp	*Hypophthalmichthys nobilis*
Crucian carp	*Carassius carassius*
Nile tilapia	*Oreochromis niloticus*
Roho labeo	*Labeo rohita*
Catla	*Catla catla*
Mrigal carp	*Cirrhinus mrigala*
White amur carp	*Parabramis peckinensis*
Milkfish	*Chanos chanos*
Marine fish nai	*Osteichthyes*
Japanese eel	*Anguilla japonica*
Japanese amberjack	*Seriola quinquerqdiata*
Mud carp	*Cirrhinus molitorella*
Black carp	*Mylopharyngodon piceus*
Torpedo-shapes catfish	*Clarias* spp.
Tilapia nei	*Oreochromis* spp.
Japan sea bream	*Pagrus major*
Mozambique tilapia	*Oreochromis mossambicus*
Mandarin fish	*Siniperca chuatsi*
Climbing perch	*Anabas testudineus*
Thai silver barb	*Puntius gonionotus*
Cyprinids nei	*Cyprinidae*
River eel nai	*Anguilla* spp.
Java barb	*Puntius javanicus*
Trouts nei	*Salmo* spp.
Rainbow trout	*Oncorhynchus mykiss*
Snakeskin gourami	*Trichogaster pectoralis*
Bastard halibut	*Paralichthys olivaceus*
Barramundi	*Lates calcarifer*
Nile carp	*Osteochilus hasselti*
Mullets nei	*Mugilidae*
Ayu sweetfish	*Plecoglossus altivelis*
Coho salmon	*Oncorhynchus kisutch*
Giant gourami	*Osphronemus goramy*
Pangas catfish	*Pangasius pangasius*
Gilthead sea bream	*Sparus auratus*
Striped snakehead	*Channa striata*
Kissing gourami	*Helostoma temmincki*
Puffers nei	*Tetraodontidae*
Sea basses	*Dicentrarchus* spp.
Flathead grey mullet	*Mugil cephalus*
Japanese jack mackerel	*Trachus japonicus*
Blackhead sea bream	*Acanthopagrus schlegeli*
Mangrove red snapper	*Lutjanus argentimaculatus*
Freshwater siluroids	*Siluroidei*
Groupers nei	*Epinephelus* spp.

Table 1 (cont.). Aquaculture of finfish in Asia (order by amount of production, FAO, 1998)

Common name	Scientific name
Porgies, sea bream nei	*Sparidae*
Jack and horse mackerels nei	*Trachurus* spp.
Scorpionfishes nei	*Scorpaenidae*
Greasy grouper	*Epinephelus tauvina*
Channel catfish	*Ictalurus punctatus*
Indonesian Snakehead	*Channa micropeltes*
Hoven's carp	*Leptobarbus hoeveni*
Areolate grouper	*Epinephelus areolatus*
Grouper, sea basses nei	*Serranidae*
Pond loach	*Misgurnus anguillicaudatus*
Snakeheads	*Channa* spp.
Philippine catfish	*Claria batrachus*
Russell's snapper	*Lutjanus russelli*
Striped bass, hybrid	*Morone chrysops* × *M. saxatili*
Japanese sea bass	*Lateolabrax japonicus*
Grourami nei	*Trichogaster* spp.
Goldlined sea bream	*Rhabdosargus sarba*
Atlantic salmon	*Salmo salar*
Scads	*Decapterus* spp.
European sea bass	*Dicentrarchus labrax*
Asian redtail catfish	*Mystus nemurus*
Snappers, jobfishes nei	*Lutjanidae*
Marble goby	*Oxyeleotris marmorata*
Goldfish	*Carassius auratus*
Acanthopagrus berda	*Acanthopagrus berda*
North African catfish	*Clarias gariepinus*
Snapper nei	*Lutianus* spp.
Oreochromis spilurus	*Oreochromis spilurus*
Knifefishes	*Notopterus* spp.
Atka mackerel	*Pleurogrammus azonus*
Sargo bream nei	*Diplodus* spp.
Cobia	*Rachycentron canadum*
Threadsail filefish	*Stephanolepis cirrhifer*
Spinefeet	*Siganus* spp.
Croakers, drums nei	*Sciaenidae*
Lai	*Monopterus albus*
White-spotted spinefoot	*Siganus canaliculatus*
Spotted coral grouper	*Plectropomus maculatus*
Snubnose pompano	*Trachinotus blochii*
White sea bream	*Diplodus sargus*
Hong Kong grouper	*Epinephelus akaara*
Freshwater gobies	*Gobiidae*
Filefish	*Cantherines* spp.
Hong Kong catfish	*Clarias fuscus*
Crimson sea bream	*Evynnis japonica*
Isok barb	*Probarbus jullieni*
Blue tilapia	*Oreochromis aureus*
Jack, crevalles nei	*Caranx* spp.
Scats	*Scatophagus* spp.

Considerations for species diversification

Choice of the right species

When aquafarmers consider diversifying, the foremost considerations are the choice of species (Liao, 1995), which are implied by the expansion of the market (Basurco and Abellán, 1999). Aquafarmers can choose from exotic and native species. Choosing native species poses little problems. For the exotic species, aquafarmer must consider the impact to the native environment. Furthermore, the aquafarmers must also consider the economic feasibility and the acceptability of the chosen species to consumers in order to ensure a large-scale development of aquaculture.

Establishment of related techniques appropriates for local condition

These include the prevention and cure of diseases, the requirement of basic nutrition and the techniques of management as well as farming.

Possible approaches to finfish culture diversification

To introduce exotic species

With the development of aquaculture, it is hard to avoid the introduction of exotic species. Introduction of exotic species can enrich the state of local cultured species. Exotic species often command a higher market price than native species and may provide local economies means to acquire foreign currency from tourism or through export (Reynolds and Greboval, 1989). By these reasons, many species of aquatic organisms have been transferred to the regions where they are not naturally occurring. The term "exotic" species refers to any species introduced by man from a foreign land (McCann, 1984). This should not be confused with "transplanted" species, native species moved by man into an ecosystem outside their native range, but still within their country of origin, and with "non-native" species, any species introduced by man into an ecosystem outside its original native range, including both exotic and transplanted (McCann, 1984). The main goals of voluntary introductions were initially to improve sport fisheries, artisanal fisheries and aquaculture, or to develop biological control of aquatic diseases, insects and plants (Leveque, 1996). For example, the top minnow (*Gnathopogon* sp.) was introduced to Taiwan from Hawaii in 1913 to control malaria. In certain countries, endemic fish are facing extinction due to the serious destruction of habitat, overfishing and pollution. By the introduction of new species for aquaculture, local resources can be restored. Aquaculture plays an important role in the importation of exotics (Welcomme, 1988). This situation is more evident in freshwater finfish, since the fresh water is a closed body. The two major families are the Cichlidae and the Cyprinidae, of which 36 and 37 species have been transferred. A total of 35 species have been transferred from Asia and 22 into Asia (De Silva, 1989).

Although, the development of aquaculture is different in each country of Asia, freshwater cyprinids are the primary exotic species in most countries of Asia. This is because cyprinids can survive easily with fast growth in an extensive culture system, and Chinese emigrants migrated to various parts of Asia with these fishes. In 1996, Asia produced 10 million metric tons of cyprinids and these fishes occupied the first five positions on the list (Table 2) of major cultured finfishes in the region. Cichlids, salmonids and catfishes were sequentially introduced and became popular in Asia by their economic values and the development of aquaculture. In Taiwan, it is regrettable that the history of introduction of exotic finfish has not been well recorded (Table 3) (Liao and Liu, 1989). Survey of cultured exotic finfishes has been done only recently. Data in 1997 shows that almost all of the cultured freshwater fishes are exotic (Table 4) (Taiwan Fisheries Bureau, 1998).

Many ornamental fish are originally from South-east Asia and, also, a variety of ornamental fish has been imported from Africa and Latin America into Asia. In Taiwan until 1994, about 350 species of ornamental fish were recorded. Most of them were exotic species (Table 5) (Liao and Liu, 1989; Huang and Liu, 1994).

At present, the introduction of exotic species is relatively easy because basic information and culture techniques on certain species are already available. However, careful consideration still has to be made on possible problems such as diseases, particularly parasitic diseases (Hoffman and Schubert, 1984), and impact on local ecosystem and local gene pools (Liao *et al.*, 1993). Although the introduction of species has been encouraged all around the world by policy makers, nowadays many ecologists consider it to be like Pandora's box (Leveque, 1996). An assessment of the impact of fish introduction in Asia indicates that the native species in the region has suffered few losses from exotic species (De Silva, 1989). It should be emphasized that critical evaluation and test on exotic species to the native ecosystem are obligatory before making any serious introduction (Bartley, 1996).

Table 2. Production of major culture finfish species in Asia during 1996 (FAO, 1998)

Common name	Scientific name	Production (t)
Silver carp	*Hypophthalmichthys molitrix*	2,829,019
Grass carp	*Ctenopharyngodon idellus*	2,436,118
Common carp	*Cyprinus carpio*	1,828,415
Bighead carp	*Hypophthalmichthys nobilis*	1,412,762
Crucian carp	*Carassius carassius*	692,896
Nile tilapia	*Orecochromis niloticus*	554,663
Roho labeo	*Labeo rohita*	493,393
Catla	*Catla catla*	419,456
Mrigal carp	*Cirrhinus mrigala*	412,313
White amur bream	*Parabramis pekinensis*	379,148
Milkfish	*Chanos chanos*	364,425
Japanese eel	*Anguilla japonica*	206,208
Japanese amberjack	*Seriola quinqueradiata*	145,889
Mud carp	*Cirrhinus molitorella*	130,022

Table 3. Exotic species introduced into Taiwan

Common name	Scientific name	Area of origin	Date of importation
Bighead carp	*Aristichthys nobilis*	China	–
Crucian carp	*Carassius auratus*	China, Japan	–
Mud carp	*Cirrhina moltiorella*	China	–
Grass carp	*Ctenopharyngodon idellus*	China	–
Silver carp	*Hypophthalmichthys molitrix*	China	–
Snail carp	*Mylopharyngodon piceus*	China	–
Common carp	*Cyprinus carpio*	Japan	Before 1950
Mozambique tilapia	*Oreochromis mossambicus*	Indonesia	1944
Redbelly tilapia	*Tilapia zillii*	South Africa	1963
Nile tilapia	*O. niloticus*	Japan	1966
Blue tilapia	*O. aureus*	Israel	1974
Red tilapia	*Oreochromis* sp.	Philippines	1979
Wami tilapia	*O. hornorum*	Costa Rica	1981
Red breast tilapia	*Tilapia rendalli*	South Africa	1981
Top minnow	*Gnathopogon* sp.	North America	1913
Rainbow trout	*Salmo gairdneri*	Japan	1957
Thailand catfish	*Pangasius sutchi*	Thailand	1970

Table 3 (cont.). Exotic species introduced into Taiwan

Common name	Scientific name	Area of origin	Date of importation
Walking catfish	*Clarias batrachus*	Thailand	1972
Channel catfish	*Ictalurus punctatus*	USA	Mid 1970's
European eel	*Anguilla anguilla*	Europe	1976
Bar or sultan fish	*Leptobarbus hoevenii*	Indonesia	1979
Wu-Chang fish	*Megalobrama amblycephala*	China	1979
Largemouth bass	*Micropterus salmoides*	North America	Late 1970's
Freshwater pompano	*Colossoma bidens*	South America	1981
Freshwater grouper	*Cichlasoma managuense*	South America	1985
King fish	*Boulengerochromis microlepis*	Africa	1988
Red drum	*Sciaenops ocellatus*	USA	1987
Hybrid stripped bass	*Morone saxatilis* × *Morone chrysops*	USA	1989
Silver perch	*Bidyanus bidyanus*	Australia	1991
Sauger	*Stizostedion* sp.	USA	1995
Australian perch	*Macquaria* sp.	Australia	1995

Table 4. Major finfish species cultured in Taiwan in 1997 (Taiwan Fisheries Bureau, 1998)

Common name	Scientific name	Production (t)	Value (NT dollar)
Tilapia	*Orecochromis* spp.	42,304	1,316,367
Common carp	*Cyprinus carpio*	2,470	125,913
Crucian carp	*Carassius auratus*	2,470	125,913
Grass carp	*Ctenopharyngodon idellus*	4,495	240,793
Black carp	*Mylopharyngodon piceus*	1,139	65,172
Bighead carp	*Aristichthys noilis*	3,757	157,163
Silver carp	*Hypophthalmichthys molitrix*	689	24,602
Mud carp	*Cirrhinus molitorella*	57	3,214
Eel	*Anguilla japonica*	22,337	8,549,519
Freshwater catfish	*Parasilurus asotus*	196	10,834
Sea perch and sea bass	*Lateolbrax japonica* *Lates calcarifer*	5,683	483,570
Loach	*Misgurnus anguillicandatus*	388	38,014
Trout	*Salmo gairdneri*	1,288	201,117
Sweet fish	*Plecoglossus altivelis*	352	128,063
Milkfish	*Chanos chanos*	62,748	2,656,834
Black sea bream	*Acanthopagrus* spp.	4,372	529,558

To exploit new native culture species

Besides the traditional cultured species, such as carp, bighead carp, silver carp, grass carp, trout, and milkfish, in recent years, many local wild species, either freshwater or marine, have been cultured or even domesticated. This situation may be due to the development and improvement of aquaculture. However, domestication of most farmed aquatic organisms has not progressed far and has no histories comparable to those of crops and livestock. Indeed, it has been proposed that the current trend in commercial aquaculture is directed towards exploring the potential of local species (Welcomme, 1992). In China, for example, there are more than 800 species of fish, but less than 200 species contribute to food production, while 21 species are exotic food fish (Li, 1993). There is still a significant number of local species that can be exploited for culture purposes. This observation further suggests that since Asia has a large number of aquatic species, it has an advantage in diversifying species for culture.

Table 5. List of cultured ornamental fish in Taiwan

Abudefduf oxyodon
Abudefduf starcki
Abudefduf melanopus
Acanthophthalmus semicinctus
Acanthopsis choirorhyncus
Acanthurus leucosternon
Acarichthys geayi
Acarichthys heckelii
Achirur errans
Adioryx spinosissimus
Aeotiscur strigatus
Aequidens paraguayensis
Aluteres scripta
Alesres taeniurus
Ambassis laza
Amblycioras hancockii
Amphiprion biaculeatus
Amphiprion clarkii
Amphiprion frenatus (Brevoort)
Amphiprion ocellaris cuvier
Amphiprion perideraion (Bleeker)
Amphiprion parasema
Amphiprion polymnus
Amphiprion sebae
Anoptichrthys jordani
Aphyocharax rubropinnis
Aphyocyprinus sp.
Aphyosemion australe
Aphyosemion bivittatum
Aphyosemion calliurmahli
Aphyosemion sjoestsdti
Aphyosemion arnoldi
Apistogramma ramirezi
Aplocheilus dayi
Apogon maculatus
Apogon orbiculatus
Apteronotur albifrons
Arapaima gigas
Arnoldichthys spilopterus
Astronotus ocellatus
Astronotus acellatus var.
Aulonocara nyassae

Bacantiocheilus melanopterus
Badis badis
Balantiocheilus melanopterus
Balistoides conspicillum
Barbodes fasciatus
Barbus everetti
Barbus fasciatus
Barbus lateristriga
Barbus nigrofasciatus
Barbus schwanefeldi
Barbus semifasciolatus varia
Barbus tetrazona
Barbus titteya
Betta splendens
Bodianus amthioides
Bodinus loxozonus
Botia horae
Botia lecontei
Botia macracantha
Botia modesta
Botia pulchripinnis
Boulengerochromis microlepis
Brachydanio albolineatus
Brachydanio nigrofasciatus
Brachydanio rerio
Brachygobius xanthozona
Brycinus longipinnis

Calloplesiopa altinelis
Callochromis pleurospilus
Capoeta tefrazona
Carassius auratus
Carnegiella srrigata
Colisa lalia
Corydoras aeneus
Centropyge argi
Centropyge bicolor
Centropyge ferrugatus
Centropyge fisheri
Centropyge loriculus
Centropyge multicolor
Centropyge nox
Centropyge potteri
Cephalopholis urodlus
Chaetodermis spinosissiums
Chaeton ephippium
Chaeton octofasciatus
Chaeton quaddimacularus
Chaeton rainfordi
Chaeron reticulatus
Chaeton sp.
Chaetodontoplus duboulayi
Chaetodontoplus mesoleucus
Chalceus macrolepidotus
Chalinochromis brichardi
Chanda ranga
Cheirodon axelrodi
Chelmo rostratus
Chilodus punctatus
Chiloscyllum colax
Chrysiptera starki
Cichla femensis
Cichla ocellaris
Cichlasoma citrinellum
Cichlasoma salvini
Cichlasoma severum
Cichlasoma severum Golden
Cichlasoma synspilum
C. synspilum × *C. citrinellum*
C. citrinellum × *C. synspilum*
Colisa chuna
Colisa fasciatus
Colisa labiosa
Colisa lalia
Condylactis sp.
Coris julis
Corydoras metae
Corynopoma riisei
Cromileptes alrivelis
Cynolebias bellottii
Cynorilapia afra
Cyphotilapia frontosa

Daino malabaricus
Dascyllus auranius
Dascyllus melamurus
Dascyllus resticulatus
Dasyatis kuhlii
Datniodes microlepis
Datniodes quadrifuscatus
Dendroctrirus zebra
Dianema longibarbis
Dipzoprion bifascatum
Distichodus lusosso
Distichodus sexfasciatus

Ecsenius bicolor
Eigenmanni virescens
Enoplometopus occidentalis
Epalzeorhynchus kallopterus
Epinephelus tauvina
Eretmodus cyanosticrus
Esomus malayan
Euxiphipips sextriatus
Euxiphipips nevarchus
Euxiphipips xanrhometopon

Flamneu sammara

Gasteropelecus levis
Gastercrsteus aculeatus
Gaterin ctraetodonides
Genicanthus larmark (Lacepede)
Geophagus jurupari
Geophagus thayeri
Gobiodon sp.
Glymmistes sexlineatus
Gnathonemus macrolepidotus

Table 5 (cont). List of cultured ornamental fish in Taiwan

Gnarhonemus petersi	Lebrasoma reliferum	Plevicachromis pulcher
Gymnocorymbus ternetzi	Lepisosteus oculatus	Poecilia latipinna
Gyrinocheilus aymonieri	Lepomis megalotis	Poecilia velifera
	Leporinus fasciatus	Poecilia veticulata
Halichoeres chrysus	Lienardella fasciata	Poecilobrycon auratus
Hapalochlaena maculosa	Lima scabra	Poecilobrycon puctatar
Haplochromis abli	Lo vulpinos	Pogonoculiur zebra
	Loricaria filamentoa	Polycentrus shomburgki
Haplachromis boadzulu	Lutjanus sp.	Polyodon spathula
Haplachromis compressiceps		Pomacanthus annularis
Haplochromis desfontainesi	Macrognathus aculeatus	Pomacanrhus arcuatus
Haplochromis linni	Macropodur opercularis	Pomacanthus chrysurur
Helostoma rudolphi	Maso literatus	Pomacanthus coeruleus
Helostoma temmincki	Mastacembelus maculatus	Pomacanthus imparotor
Hemichromis guttatus	Melanochromis auratus	Pomacanthus maculosus
Hemigrammus grcrcilis	Melanotaenia boesemani	Pomacanthus paru
Hemigrammus ocellifer	Melanotaenia nigrans	Pomacanthus zonipectus
Hemigrammus pulcher	Mesogonistlus chaetodon	Premnas biaculeatus
Hemigrammus rhodpstomus	Metynnis roosevelti	Prevagor melanocephalus
Hemiodus gracilus	Metynnis schreitmuzlerii	Pristella riddlei
Hemiodus semiraenitatus	Microgeophagus ramirezi	Prochidodus amazonensis
Hemitaurichrhys polylepis	Microlabichthys tukapascalus	Prochidodus insignis
Hippocampus coronatus	Microphis smithi	Prochidodus taeniurus
Hippocampus kellggi	Moenkhausia sanctaefilomenae	Prognathodes aculeatus
Hippocampus sp.	Moenkhausia oligozepis	Pseudobalistis fuscus
Holacanthus arcuarus	Mogurnda mogurnada mogurnd	Pseudoplatystoma fasciatum
Holacanthus ciliaris	Molzienisia sphenops (latipinna)	Pseudotropheus sp.
Holacanthus clarionensis	Momadactylus argentens	Pterois antennata
Holacanthus isabelita	Monodactylus sebae	Pterophyllum eimekei
Holacanthus passer	Muraena pardalis	Pterophyllum hecker
Holacanthus tricolor	Mylossoma duriventris	Puntius conchonius
Hymenocera sp.		Puntius schroanenfeldi
Holplolatilus purpureaus	Nannostomus anomalus	Purple chromis
Hyphessobrycon callistus	Nemaptereleoteris magnificus	Pysolites diacanthus
(Callistus callistus)	Nemateleotris sp.	
Hyphessobrycon callistyus	Neosilurus ater	Rasbora borapetensis
rosaceus	Neopetrolisthes ohshimai	Rasbora dorsiocellata
Hyphessobrycon flammeus	Notopterus chitala	Rasbora heteromorpha
Hyphessobrycon herbertaxelrodi		Rasbora maculata
Hyphessobrycon hererorhabdus	Opistognathus aurifons	Rasbora trilineata
Hyphessobrycon innesi	Opistognathus whitehurstii	Rhinomurena amboinensis
Hyphessobrycon pulchripinnis	Osphronemus goramy	Rhynchocinetes sp.
Hyphessobrycon rubrostigma	Osteochilus vittatus	
Hyphessobrycon scholzei.	Osteochilus hasselti	Scolcpsis sp.
Hypostomus sp.	Osteoglossum bicirrhosum	Scorpaenodes littoralis
Hypseleotris compressa	Osteoglossum ferreirai	Selenotoca multifasciata
	Oxymonacanthus longirostris	Semaprocbilodus taeniurus
Julidochromis transcriptus		Serranus spilurus
Julipocheromis transcriptus	Pamacanthus imperator	Shaerichthys osphromenoides
	Pangastus sutchi	Siganus vulpinur
Kryptopterus bicirrhis	Panque nigrolineatus	Spilotichthys picturatus
Kryptopterus macrocephalus	Pantodon buchholz	Stenopus hispidus
	Paracheirodon axelrodi	Symphysodon aquifasciata
Labeo bicolor	Paracheirodon innesi	Symphysodon discus
Labeo erythrurus	Parambassis gulliveri	Synaphobranchus sp.
Labeo frenatus	Pelotropclma melanoleucus	
Labeo numensis	Pengasius polyuranodon	Synchiropus splendidur
Labeotropheus trewavasae	Peocilabrycon aqratus	Syngnathus boversi
Labroides dimidiatus	Phenaxorgammus interruptus	Synodontis angelicus
Lactoria cornuta	Pholidichthys leucotaenia	Synodontis davidi
Lamprologus brichardi	Pimelodus clarias	Synodontis nigriventris
Lamprologus compressicep	Platax teira	
Lamprologus leleupi	Platax pinnatus	Tamichthys albonubes
Lebistes reticulatusi	Plecostomus punctatas	Telmatherina ladigesi

Table 5 (cont.). List of cultured ornamental fish in Taiwan

Tetraodon fluviatilis	*Trichogaster trictzopertus*	*Xanthichthys* spp.
Thayeria boehlki	*(sumatranur)*	*Xiphophorus hellerii*
Thayeria sanctaemariae	*Trichogaster microlepis*	*Xiphophorus maculatus*
Tilapia buttikoferi	*Triportheus elongatus*	
Toxotes jaculator	*Tropheus duboisi*	*Zebrasoma veliferum*
Trematocranus jacobfreibergi		*Zebrasoma scopas*
Trichogaster leeri	*Uara amphiacanthoides*	

Domestication is considered synonymous with natural selection in a domestic environment (Doyle, 1983) and its achievement is dependent on a long-term effort in basic and applied research. Indeed, breeding and culture in captivity are prerequisite and essential to domestication (Pullin *et al.*, 1998). Based on Taiwan experiences, both good performances of aquaculture and fundamental researches are very important to domestication. In Taiwan, about 100 species of finfishes are cultured commercially (Tables 6 and 7) (Liao, 1991, 1993), over 65 species of finfish can be artificially propagated (Table 8) (Liao, 1993).

The advantages of exploiting local species for diversification are that they are already adapted to the local environmental conditions and are probably more preferred by consumers. But some disadvantages are also apparent, such as a genetic drift, an increase in the number of homozygotes in captivity, and competitive interactions between domestic and wild species that may result in genetic variability (Ryman *et al.*, 1994).

Applications of biotechnology on finfish diversification in aquaculture

Applications of biotechnology in aquaculture offer an effective means in developing new stocks with specific traits such as enhanced growth rate, improved survival, sterility, and disease resistance. Aside from the obvious economic advantage of these new stocks, another benefit is the possibility of not disturbing the native stock. To date, some species propagated from hybridization and chromosome manipulation may be added to the list of new cultured finfish.

Hybridization

The most prominent success in genetic research in Taiwan has been the hybridization of tilapias. Hybridization is conducted mainly to produce monosex offspring, sterility and polyploidy, and to increase hybrid vigor (Liao and Chen, 1983). Tilapia hybrids produced in Taiwan are listed in Table 9.

Tilapia

In Taiwan, the first cultured tilapia was *O. mossambicus*. Despite its high reproductive ability and feasibility for rearing, it has undesirable traits such as precocity, low growth rate and condition factor [(body weight/body length cm^3) $\times$ 100], deep black colour of the body, small body size and poor tolerance to low water temperatures. The successful hybridization between the *O. mossambicus* (female) $\times$ *O. niloticus* (male) was carried out (Kuo, 1969). This hybrid, called "Fu-So fish" (i.e. lucky fish in Chinese), has a better body colour, body size, growth rate, condition factor and cold tolerance. But this hybrid is not a big body sized strain and male:female ratio is low. Another hybrid, *O. niloticus* and *O. aureus,* has been propagated and is commercially cultured due to its better growth rate, large body size, and high male:female ratio in the offspring (Hu and Yu, 1977). Recently, *O. spilurus* has been introduced into Taiwan from Saudi Arabia. *O. spilurus* is tolerant to salinity as high as 40 ppt. Salinity tolerant hybridized strains are being worked on to produce new species for culture.

Hybridization of tilapia has been successful in improving growth rate, sex ratio, cold tolerance, body size and salinity tolerance (Kuo, 1969; Hu and Yu, 1977). Monosex culture of male tilapias is more profitable because males grow faster than females. Hybridization often occurs among mouth-breeding tilapia. In Taiwan, the main mouth-breeding tilapia are *Oreochromis nioticus, O. aureus, O.*

hornorum, O. chmossambicus, white tilapia and red tilapia. Morphological studies have been conducted (Tsay *et al.*, 1992) and molecular genetics researches are carrying out on these tilapias.

Table 6. Current commercially cultured finfish species in Taiwan

Common name	Scientific name
Yellow fin sea bream	*Acanthopagrus berda*
Black sea bream	*Acanthopagrus latus*
Black porgy	*Acanthopagrus schegeli*
Southern black sea bream	*Acanthopagrus sivicolus*
European eel	*Anguilla anguilla*
Japanese eel	*Anguilla japonica*
American eel	*Anguilla rostrata*
Red fish	*Anthias disper*
Silver croaker	*Argyrosomus japonica*
Bighead carp	*Aristichthys nobilis*
Silver perch	*Bidyanus bidyanus*
Mudskipper	*Boleophthalmus pectinirostris*
Goyan fish	*Caranx ignobilis*
Crucian carp	*Carassius auratus*
Snakehead	*Channa maculata*
Milkfish	*Chanos chanos*
Green wrasse	*Choerodon schoenleinii*
Freshwater grouper	*Cichlasoma manguense*
Mud carp	*Cirrhina molitorella*
Pacu	*Colossoma macropomum*
Walking catfish	*Clarias fuscus*
Mice grouper	*Cromileptes altivelis*
Grass carp	*Ctenopharyngodon idellus*
White fish	*Culler erythropterus*
Redfin fish	*Culter erythropterus*
Common carp	*Cyprinus carpio*
Four finger threadfin	*Eleutheronema tetradactylum*
Red grouper	*Epinephelus akaara*
Banded grouper	*Epinephelus awoara*
Red-spotted grouper	*Epinephelus coioides*
Black-saaled grouper	*Epinephelus fario*
Tiger grouper	*Epinephelus fuscoguttatus*
Giant grouper	*Epinephelus lanceolatus*
Malabar rockcod	*Epinephelus malabaricus*
Long-finned grouper	*Epinephelus quoyanus*
Estuary grouper	*Epinephelus tauvina*
Smallscale blackfish	*Girella melanichthys*
Balck grunt	*Hapalogenys nitens*
Silver carp	*Hypophthalmichthys molitrix*
Large yellow croaker	*Larimicthys crocea*
Giant perch	*Lates calcarifer*
Japanese sea bass	*Lateolabrax japonica*
Common slipmouth	*Leiogmathus equulus*
Red-finned cigar shark	*Leptobarbus hoevenii*
Common lenjan	*Lethrinus haematopterus*
Blue emperor	*Lethrinus nebulosus*
Largescale liza	*Liza macrolepis*
Red eye liza	*Liza subviridis*

Table 6 (cont.). Current commercially cultured finfish species in Taiwan

Common name	Scientific name
Gray snapper	*Lutjanus argentimaculatus*
Firespot snapper	*Lutjanus malabaricus*
One spot snapper	*Lutjanus monostigma*
Yellowfin snapper	*Lutjanus rivulatus*
Fingermark snapper	*Lutjanus russelli*
Seba's snapper	*Lutjanus sebae*
Spotted snapper	*Lutjanus stellatus*
Wu-Chang fish	*Megalobrama amblycephala*
Largemouth bass	*Micropterus salmoides*
Brown croaker	*Miichthys miiuy*
Pond loach	*Misgurnus anguillicaudatus*
Rice eel	*Monopterus salmoides*
Hybrid stripped bass	*Morone saxatilis* × *M. chrysops*
Grey mullet	*Mugil cephalus*
Speckled drum	*Nibea diacanthus*
Blue tilapia	*Oreochromis aureus*
Mozambique tilapia	*Oreochromis mossambicus*
Nile tilapia	*Oreochromis niloticus*
(hybrid)	*O. niloticus* × *O. mossambicus*
(hybrid)	*O. niloticus* × *O. aureus*
Rainbow trout	*Oncorhynchus mykiss*
Red sea bream	*Pagrus major*
Narrow-banded batfish	*Platax orbicularis*
Ayu sweetfish	*Plecoglossus altivelis*
Three-banded sweetlip grunt	*Plectorhynchus cinctus*
Leopard coral grouper	*Plectropomus leopardus*
Thick-lipped grunt	*Plectorhynchus pictus*
Leopard coralgrouper	*Plectropomus plebejus*
Thailand catfish	*Pangasius sutchi*
Chinese catfish	*Parasilurus asotus*
Blue-spotted grouper	*Plecoglossus leopardus*
Five thread fin	*Polynemus plebejus*
Banded grunter	*Pomadasys hasta*
Cobia	*Rachycentron canadum*
Spadefish	*Scatophagus argus*
Red drum	*Sciaenops ocellatus*
Greater yellowtail	*Seriola dumerili*
Dusky spinefoot	*Siganus fuscescens*
Golden spinefoot	*Siganus guttatus*
Net-pattern rabbitfish	*Siganus oramin*
Sand borer	*Sillago sihama*
Freshwater grouper	*Siniperca chuatsi*
Goldlined sea bream	*Sparus sarba*
Tiger puffer	*Takifugu rubripes*
Three striped tigerfish	*Tetrapon jarbua*
Red belly tilapia	*Tilapia zillii*
Snubnose pompano	*Trachinotus blochii*
Taiwan shoveljaw carp	*Varicorhinus barbatulus*

Table 7. Candidate finfish species for commercial culture in Taiwan

Common name	Scientific name
Genuine goby	*Acanthogobius flavimanus*
Cardinal sea bream	*Evynnis cardinalis*
Flathead goby	*Glossogobius giuris*
Lembus goby	*Kyphosus lembus*
Bif-mouthed flounder	*Psettodes erumei*
Reticulated rabbitfish	*Siganus vermiculatus*

Table 8. Status of finfish artificial propagation in Taiwan

Common name	Scientific name	Year of first success	Spawning season
Grass carp	*Ctenopharyngodon idellus*	1963	March-June
Silver carp	*Hypophthalmichthys molitrix*	1963	April-August
Bighead carp	*Aristichthys nobilis*	1963	April-August
Mud carp	*Cirrhina molitorella*	1963	April-August
Rainbow trout	*Salmo gairdneri*	1964	October-December
Black carp	*Mylopharyngodon piceus*	1966	March-June
Grey mullet	*Mugil cephalus*	1969	October-January
Walking catfish	*Clarias fuscus*	1970	April-September
Snakehead	*Channa maculata*	1970	April-September
Chinese catfish	*Parasilurus asotus*	1971	April-June
Thailand catfish	*Pangasius autchi*	1976	July-October
Pond loach	*Misgumus anguillicaudatus*	1977	February-August
Milkfish	*Chanos chanos*	1978	April-October
Australis sea bream	*Acanthopagrus australis*	1979	November-April
Grey fin sea bream	*Acanthopagrus berda*	1979	November-April
Black progy	*Acanthopagrus schlegeli*	1979	November-April
Red sea bream	*Pagrus major*	1979	January-April
Sweetfish	*Plecoglossus altivelis*	1979	September-November
Yellowfin sea bream	*Acanthopagrus latus*	1980	October-February
Japanese sea bass	*Lateolabrax japonica*	1980	December-February
Wu-Chang fish	*Megalobrama amblycephala*	1982	March-July
Net-pattern spinfoot	*Siganus oramin*	1982	March-July
Malabar grouper	*Epinephelus malabaricus*	1982	April-October
Largemouth bass	*Micropterus salmoides*	1983	January-April
Giant perch	*Lates calcarifer*	1983	May-September
Blue emperor	*Lethrinus nebulosus*	1983	March-May
Silver sea bream	*Sparus sarba*	1984	December-March
Pacu	*Colossoma macropomum*	1984	April-October
Suitan fish	*Leptobarbus hoevenvii*	1984	April-October
Red snapper	*Lutjanus argentimaculatus*	1984	May-October
Kooye	*Varicorhinus barbatulus*	1986	January-April
Red-spotted grouper	*Epinephelus suillus*	1986	March-October
Coral grouper	*Plectropomus leopardus*	1989	May-October
Long dorsal fin pompano	*Trachinotus blochii*	1989	March-October
Permit fish	*Trachinotus falcatus*	1989	April-October
Three-stripped tiger fish	*Therapon jarbua*	1989	April-October
Yellow spotted grunt	*Plectorhinchus cinctus*	1990	January-April
Flathead goby	*Glossogobius giuris*	1990	May-October

Table 8 (cont.). Status of finfish artificial propagation in Taiwan

Common name	Scientific name	Year of first success	Spawning season
Silver grunt	*Pomadasys hasta*	1990	March-May
Croaker	*Nibea diacanthus*	1991	March-June
Red drum	*Sciaenops ocellatus*	1991	September-November
Silver croaker	*Argyrosomus japonica*	1994	March-May
Common lenjan	*Lethrinus haematopterus*	1994	March-April
Round batfish	*Platax orbicularis*	1994	March-May
Cobia	*Rachycentron canadum*	1994	February-October
Tiger puffer	*Takifugu rubripes*	1994	–
Five thread fin	*Polynemus plebejus*	1995	March-October
Four thread fin	*Eleutheronema tetradactylum*	1996	March-October
Tiger grouper	*Epinephelus fuscoguttatus*	1996	May-October
Stripe grunt	*Plectorhinchus diagrammus*	1996	January-April
Great yellow tail	*Seriola dumerili*	1996	February-April
Doctor fish	*Siganus fuscescens*	1996	May-July
Star siganus	*Siganus guttatus*	1996	April-June
King grouper	*Epinephelus lanceroratus*	1997	May-October
Big scale liza	*Liza macrolepis*	1997	February-March
Red eye liza	*Liza subviridis*	1997	February-March
Three-banded sweetlip grunt	*Plectorhinchus cinctus*	1997	January-April
Short dorsal fin pompano	*Trachinotus ovatus*	1997	March-September
Goyan fish	*Caranx ignobilis*	1998	April-May
Mice grouper	*Cromileptes altivelis*	1998	March-October
Green wrasse	*Choerodon schoenleinii*	1998	March-May
Common slipmouth	*Leiogmathus equulus*	1998	March-May
Yellowfin snapper	*Lutianus rivulatus*	1998	March-April
Seba's snapper	*Lutianus sebae*	1998	March-April
White-spotted snapper	*Lutianus stellatus*	1998	March-May
Pink snapper	*Lutianus erythropterus*	1998	March-October

Table 9. Studies on tilapia hybridization in Taiwan (Liao *et al.*, 1993)

Female	Male	Male progeny (%)
Oreochromis aureus ×	*O. aureus*	55-70
	O. hornorum	100
	O. mossambicus	45-53
	O. niloticus	48-83
O. hornorum ×	*O. hornorum*	46-67
	O. aureus	67
	O. mossambicus	37
	O. niloticus	55-78
O. mossambicus ×	*O. mossambicus*	51-53
	O. aureus	77-91
	O. hornorum	100
	O. niloticus	20-65
O. niloticus ×	*O. niloticus*	45-87
	O. aureus	74-100
	O. hornorum	100
	O. mossambicus	50-76

Red tilapia was first found on private farm in 1968 and it was concluded that this red tilapia was a mutant albino from *O. mossambicus*. *O. niloticus* was crossed with these mutants to improve growth rate (Kuo, 1978). Through yearly selective breeding, the hybrid acquired a glorious reddish colour. The expression of pigmentation of red tilapia varied with age and was affected by the environment. To fix the coloration of red tilapia selective breeding of red tilapia needs further study. The growth rate of the red tilapia progeny improved when red tilapia was crossed with *O. hornorum*, *O. niloticus* and *O. aureus* in a three-way cross and reciprocal cross (Liao *et al.*, 1993; Liao and Chang, in press).

Other fishes

Grass carp (*Ctenopharyngodon idellus*) and Wu-chang fish, also known as blunt snout bream (*Megalobrama amblycephala*) are important freshwater fishes. Hybridization between female grass carp and male Wu-chang fish was carried out (Tang and Huang, 1989; Tang *et al.*, 1990). Fertilization did not succeed in the reciprocal hybridization of female Wu-chang fish and male grass carp. Sterility was found in the hybrid.

In ornamental fishes, the hybrid blood parrot fish has been a prominent success in Taiwan. Blood parrot is a hybrid between *Cichlasoma citrinellum* × *Cichlasoma synspilus* and its reciprocal cross. Value of the blood parrot depends on body colour, which should be reddish, and head shape, which should be parrot-like. Its red body colour can be improved by using appropriate feed (Liao *et al.*, 1993).

Chromosome manipulation

Polyploidy

Triploidy is considered valuable in aquaculture because it provides functional sterility. Sterile fish are advantageous in aquaculture because fish population size in the water can be controlled, which is a benefit to ecological concerns. In Taiwan, by using temperature shock treatments, triploid blue tilapia (*O. aureus*) (Chang and Liao, 1993), loach (*Misgurnus angillicaudatus*) (Chao *et al.*, 1986, 1993), and common carp *(Cyprinus carpio*) (Liao *et al.*, 1993) have been produced.

Importance of species diversification

Scientists and aquafarmers more or less agree that, just like in agriculture, species diversification offers both biological and economical benefits in aquaculture.

Biological viewpoint

With a variety of cultured species available, aquafarmers can use the facilities maximally by rotating their crops. For example, species diversification allows the pond to recover from unfavourable changes resulting from the culture of one species (Liao, 1995). The optimum utilization of the facilities leads to an important feature that answers the need for an ecologically balanced aquaculture environment. In the same time, the possibility of working with other species that can be reared in different seasons and with similar technology and facilities may also mean a more efficient way of using resources (Basurco and Abellán, 1999).

Economic viewpoint

More species means that aquafarmers are able to provide the market with alternative commodities. It also means that consumers have a wide choice, and offering new species may help to enlarge existing markets and develop prospects for market penetration. Furthermore, market niches for certain fish are limited. Once supply exceeds demand, prices drop dramatically below economical limits. Aquafarmers can avoid the risks by shifting to another species to spread the risk. Aside from the risk of declining prices due to over production, the other risk with limited number of cultured species is the disaster of diseases. With species diversification, the aquafarmers may avoid or reduce these risks.

Conclusion

Diversification of cultured species can be achieved by the introduction of exotic species and the exploitation of new cultured species. Critical evaluation of the impact of new species to the native ecosystem must be required before the introduction of an exotic species is done. Aquaculture species diversification offers both biological and economic benefits. Aquafarmers have more species for culture and may utilize at optimum their facilities, making sustainable aquaculture possible, a practice in harmony with socio-economic aspects that does not deplete renewable resources while meeting demands from the public and creating a profit for the industry. Consumers have more variety to choose from to satisfy their food preferences. This diversification can avoid the problems associated with few cultured species and reduce the risk of declining prices resulting from over-production. So, from the viewpoint of economic prosperity and aquaculture prospect, diversification of cultured species is positive to whole industry and should be the long-term aim to pursue. The approaches to finfish culture diversification in Asia may provide a good example to follow.

References

Bardach, J.E., Ryther, J.H. and McLarney, W.O. (1972). *Aquaculture. The Farming and Husbandry of Freshwater and Marine Organisms*. Wiley-Inter Science, New York.

Bartley, D.M. (1996). Conservation of biological diversity in hatchery enhancement programmes. In: *Biodiversity, Science and Development: Toward a New Partnership*, Di Castri, F. and Younes, T. (eds). University Press, Cambridge, pp. 424-438.

Basurco, B. and Abellán, E. (1999). Finfish species diversification in the context of Mediterranean marine fish farming development. *Options Méditerr., Series B*, 24: 9-25.

Chang, S.L. and Liao, I.C. (1993). Triploidy induced by heat shock in *Oreochromis aureus*. In: *The Third International Symposium on Tilapia in Aquaculture*, ICLARM Conf. Proc. 41, Pullin, R.V.S., Lazard, J., Legendre, M., Amon Kothias, J.B. and Pauly, D. (eds). International Center for Living Aquatic Resources Management, Manila.

Chao, N.H., Chen, S.J. and Liao, I.C. (1986). Triploidy induced by cold shock in cyprinid loach, *Misguruns anguillicaudatus*. In: *The First Asian Fisheries Forum, Asian Fisheries Society*, Maclean, J.L., Dizon, L.B. and Hosillos, L.V. (eds). Manila, pp. 101-104.

Chao, N.H., Yang, C.P., Tsai, H.P., Liang, W.H. and Liao, I.C. (1993). Studies on chromosome manipulation in cyprinid loach (*Misgurnus anguillicaudatus*), common carp (*Cyprinus carpio*), and small abalone (*Haliotis diversicolor*). *Spec. Issue Biol. Int.*, 28: 72-80.

De Silva, S.S. (1989). Exotics – A global perspective with special reference to finfish introductions to Asia. In: *Proceedings of a Workshop on Introduction of Exotic Aquatic Organisms in Asia*, De Silva, S.S. (ed.). Asia Fisheries Society, Manila, pp. 1-6.

Doyle, R.E. (1983). An approach to the quantitative analysis of domestication selection in aquaculture. *Aquaculture*, 33: 167-185.

FAO (1997). *Fishery Statistics, Catches and Landings, 1995*, Vol. 80. FAO, Rome.

FAO (1998). *Aquaculture Production Statistics, 1987-1996*. FAO, Rome.

Hoffman, G.I. and Schubert, G. (1984). Some parasitic of exotic fish. In: *Distribution, Biology, and Management of Exotic Fish*, Courtenay, W.R., Jr and Stauffer, J.R., Jr (eds). The John Hopkin University Press, Baltimore, pp. 233-261.

Hu, S.H. and Yu, T.G. (1977). Hybridization and culture of *Sarotherodon aurea*. *Bull. Taiwan Fish. Res. Inst.,* 29: 81-93 (in Chinese with English abstract).

Huang, J.F. and Liu, F.G. (1994). Introduction of freshwater ornamental fish culture in Taiwan. *Taiwan Fish. Res. Inst. Newsletter,* 72: 8-15 (in Chinese).

Kuo, H. (1969). Notes on hybridization of tilapia. *Chin. Am. Jt. Comm. Rural Reconstr. Fish. Ser.*, 8: 116-117.

Kuo, H. (1978). Studies on the variety improvement of tilapia. *Sci. Fish. Anim. Prod.*, 5(11): 9-19 (in Chinese).

Leveque, C. (1996). Introduction of fish species in freshwater: A major threat to aquatic biodiversity. In: *Biodiversity, Science and Development: Toward a New Partnership*, Di Castri, F. and Younes, T. (eds). University Press, Cambridge, pp. 446-451.

Li, S.F. (1993). A review of freshwater fish genetic conservation research and practices in China. In: *Selective Breeding of Fishes in Asia and the United States*, Main, K.L. and Reynolds, E. (eds). The Oceanic Institute, Honolulu, pp. 48-59.

Liao, I.C. (1991). Aquaculture: The Taiwanese experience. *Bull. Inst. Zool. Acad. Sinica,* Monograph 16: 1-36.

Liao, I.C. (1992). Aquaculture in Asia: Status, constraints, strategies, and prospects. In: *Aquaculture in Asia: Proceedings of the 1990 APO Symposium in Aquaculture*, Liao, I.C., Shyu, C.Z. and Chao, N.H. (eds). TFRI Conference Proceedings 1, pp. 13-27.

Liao, I.C. (1993). Finfish hatcheries in Taiwan: Recent advances. In: *Finfish Hatchery in Asia: Proceedings of Finfish Hatchery in Asia '91*, Lee, C.S., Su, M.S. and Liao, I.C. (eds). Tungkang Marine Laboratory Conference Proceedings No. 3, pp. 1-25.

Liao, I.C. (1995). *Significance of species diversification on the prawn culture industry*. Aquaculture in Asia and Pacific (Asian Productivity Organization Seminar Report), pp. 129-152.

Liao, I.C. and Chang, S.L. Status of tilapia genetics research in Taiwan and its prospects for the 1990s. In: *Aquaculture Genectics Research Initiatives in Asia, Africa and the Pacific*, Main, K.L. and Reynolds, E. (eds) (in press).

Liao, I.C. and Chen, T.P. (1983). Status and prospects of tilapia culture in Taiwan. In: *Proceedings International Symposium on Tilapia in Aquaculture*, Fishelson, L. and Yaron, Z. (eds), Tel Aviv, 1983, pp. 588-598.

Liao, I.C. and Liu, H.C. (1989). Exotic aquatic species in Taiwan. In: *Proceedings of a Workshop on Introduction of Exotic Aquatic Organisms in Asia*, De Silva, S.S. (ed.). Asia Fisheries Society, Manila, pp. 101-111.

Liao, I.C., Su, M.S. and Chang, S.L. (1993). A review of fish genetic research and conservation issues in Taiwan. In: *Selective Breeding of Fishes in Asia and the United States*, Main, K.L. and Reynolds, E. (eds). The Oceanic Institute, Honolulu, pp. 162-181.

McCann, J.A. (1984). Involvement of the American Fisheries Society with exotic species. In: *Distribution, Biology, and Management of Exotic Fish*, Courtenay, W.R., Jr and Stauffer, J.R., Jr (eds). The John Hopkin University Press, Baltimore, pp. 1-7.

Pullin, R.S.V. (1996). Biodiversity and aquaculture. In: *Biodiversity, Science and Development: Toward a New Partnership*, Di Castri, F. and Younes, T. (eds). University Press, Cambridge, pp. 409-423.

Pullin, R.S.V., Williams, M.J. and Preston, N. (1998). Domestication of crustaceans. *Asian Fisheries Society*, 11: 59-69.

Reynolds, J.E. and Greboval, D.E. (1989). *Socio-economic effects of the evolution of Nile perch fisheries in lake Victoria: A review*, Commission on Island Fisheries of Africa Technical Paper 17. FAO, Rome.

Ryman, N., Utter, F. and Laikre, L. (1994). Protection of aquatic biodiversity. In: *Proceedings of the World Fisheries Congress, Plenary Session,* Voigtlander, C.W. (ed.). Oxford and IBH Publishing Co. Pvt. Ltd, New Delhi, pp. 92-115.

Taiwan Fisheries Bureau (1998). *Fisheries Yearbook Taiwan Area 1997*. Taiwan Fisheries Bureau, Taipei.

Tang, H.C. and Huang, C.F. (1989). Comparison of early developmental stages of grass carp and hybrid grass carp (grass carp x *Megalobrama amblycephala*). *Bull. Taiwan Fish. Res. Inst.*, 46: 119-125.

Tang, H.C., Huang, C.F. and Liao, I.C. (1990). Comparison of early developmental stages, yearly growth and morphology of grass carp, *Ctenopharyngodon idellus*, Wu-chang fish, *Megalobrama amblycephala*, and their hybrid. In: *The Second Asian Fish. Forum*, Hirano, R. and Hanyu, I. (eds). Asian Fisheries Society, Manila, pp. 511-514.

Tsay, T.T., Chien, Y.H., Yu, T.C. and Liao, I.C. (1992). Morphological and meristic variation in cultured tilapia in Taiwan. In: *Annu. Conf. Fish. Soc. Taiwan: Abstr.* Fisheries Society of Taiwan, Keelung, Taiwan, p. 121 (in Chinese).

Welcomme, R.L. (1988). *International introduction of inland aquatic species*, Fisheries Technical Paper 294. FAO, Rome.

Welcomme, R.L. (1992). A history of international introductions of inland aquatic species. *ICES Marine Science Symposia*, 94: 3-14.