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Use and exchange of aquatic resources relevant for food and aquaculture: common carp (*Cyprinus carpio* L.)

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Abstract

This review describes the genetic resources of common carp relevant for food through fisheries and aquaculture. Common carp is naturally distributed in a large part of Asia and Europe and has been introduced worldwide and is reputed to have been cultured for centuries. Its status in Asia and Europe is discussed in detail. The rich diversity of carp in Asian aquaculture is described, with an emphasis on China, the largest producer in the world. In Central and Eastern Europe common carp is the most important 'freshwater species', and 60 'national' and 25 'foreign' strains are described in the most recent Catalogue of Carp Breeds (Bogeruk 2008). There are different systems for the management and conservation of carp genetic diversity depending on the level of state involvement, and these systems are described for selected countries/regions, such as China and central and eastern European countries. The latter countries are in a current 'transition period' and a tendency of 'state-withdrawal' is evident. However, it is not yet clear whether the market alone is able/ready to take over the responsibility and cost of the management and conservation of carp genetic diversity.

Key words: Asia, common carp, Europe, genetic resources.

Introduction

Members of the carp family (Cyprinidae) dominate aquaculture, especially in Asia where production increased from 5.1 million t in 1990 to 18.5 million t in 2007, at an annual growth rate of 7.9%. Globally, common carp is a major culture species, accounting for 15.2% of all cyprinid production in 2007, second only to silver carp and grass carp. In Europe, cyprinids are the fourth most important species group in aquaculture production by volume (following salmonids, mussels and oysters), and common carp (which represents more than 80% of cultured cyprinids) is the most significant species, particularly in central and eastern Europe. The common carp is one of the oldest domesticated species of fish for food (Balon 2006). In 2007, world production of cultured common carp reached 2.9 million t (Food and Agriculture Organization of the United Nations (FAO) 2009a) from approximately 80 countries and regions (Fig. 1), which was 9.9% of total global freshwater aquaculture. Common carp production increased by an average global rate of 7.9% year^{-1} between 1980 (365 000 t) and 2007 (Fig. 1). The top producer countries are shown according to total production (Fig. 2a) and per capita production (Fig. 2b).

The present review covers the genetic resources of common carp, concentrating on the major carp-producing countries. Most of the data presented is from China, which is the leader in common carp production, and Europe, including Russia, Ukraine and Belarus. Both wild and cultured varieties of common carp are discussed and country-related issues are covered when published data are available.

Carp genetic diversity

According to Kirpichnikov (1999) the common carp is divided into three subspecies: the European subspecies *Cyprinus carpio carpio*, the Far Eastern subspecies *Cyprinus carpio haematopterus* and the South-East Asian subspecies *Cyprinus carpio viridiviolaceus* (Fig. 3).

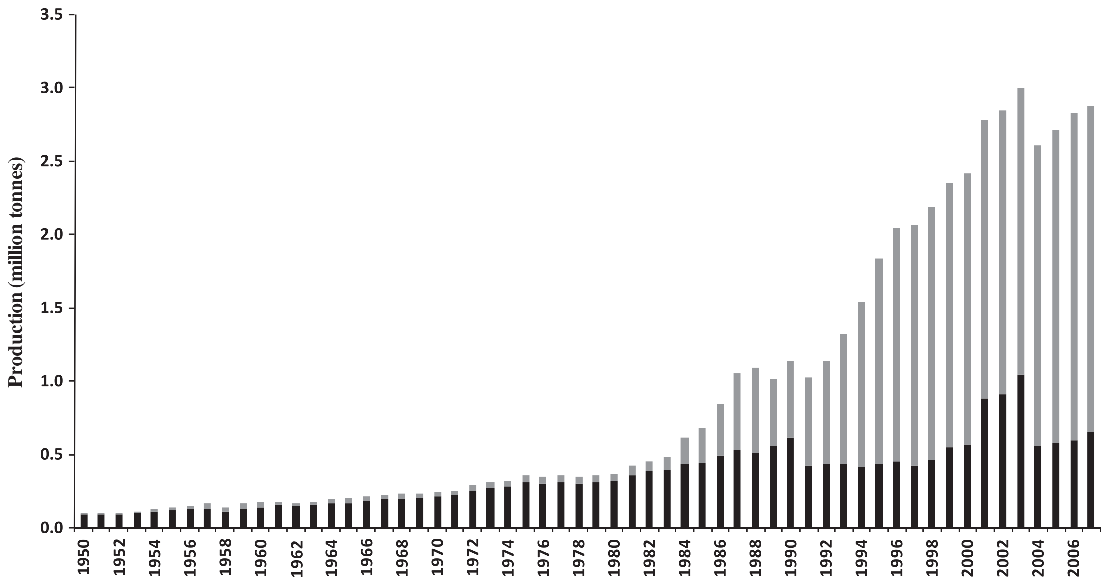

Figure 1 Global aquaculture production of common carp (*Cyprinus carpio* L.). ■, China; ■, rest of the world.

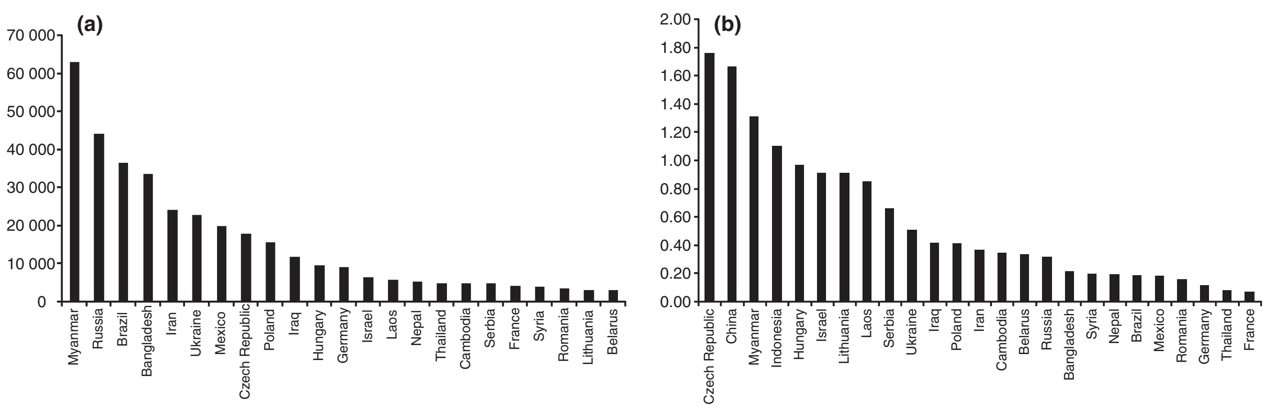

Figure 2 Main producer countries of *Cyprinus carpio* in 2007 (FAO 2009a). (a) Total production (China (2 228 585 t) and Indonesia (264 349 t) are not shown) and (b) per capita production (with China and Indonesia).

Microsatellite polymorphism data suggest an ancient separation of European/Central Asian from East/South-East Asian carps and a single origin of European carp in Central Asia as already inferred from previous allozyme and mitochondrial DNA (mtDNA) restriction fragment length polymorphism (RFLP) studies (Kholman *et al.* 2005). According to Kholman *et al.*(2005) the taxonomic status of subspecies assigned to European (*C. c. carpio*) and East Asian carp (*C. c. haematopterus*) is supported. However, because of its close relationship to European carp, it is generally thought that Central Asian carp does not deserve a separate subspecies status (i.e. *C. c. aralensis*).

Productive farmed populations were domesticated from these ancestral forms, as well as from their mutual hybrids and backcrosses followed by mass selection (Vandeputte 2003). The many and various strains of common carp that have evolved over the course of millions of years of natural selection and several thousand years of artificial breeding exhibit a wide range of morphological and genetic variabilities.

Asian carp diversity in aquaculture

There are many hypotheses about the origin of common carp in Asia. China has a long history, at least 2500 years, of culturing common carp (Balon 2006). There are now many varieties of common carp that are commonly used for aquaculture in India, Indonesia, Bangladesh, Thailand

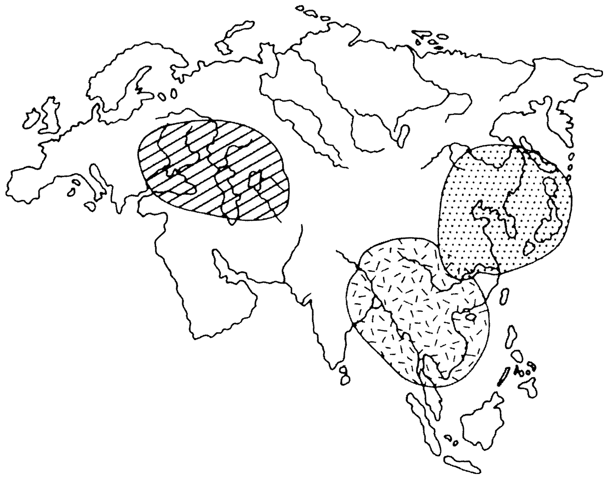

Figure 3 Ranges of wild common carp populations in Eurasia (Kirpichnikov 1999). [hatched symbol], The European subspecies *Cyprinus carpio carpio*; [dotted symbol], the Far Eastern subspecies *Cyprinus carpio haematopterus*; [dashed symbol], Asian subspecies *Cyprinus carpio viridiviolaceus*.

and Vietnam. The species is distributed naturally in rivers, lakes, reservoirs and swamps. It is also cultured in ponds and ditches and in cages in rivers, lakes and reservoirs. In addition, the concurrent and rotational culture of rice and fish using common carp has its origin in Asia (Halwart & Gupta 2004).

In China, examples of common carp varieties (see Table 1) include *Cyprinus carpio wuyuanesnsis*, *Cyprinus carpio singuonensis*, Jian carp (*Cyprinus carpio* var. *jian*) and mirror carp among many others. Selection, crossing, gynogenesis, polyploidy, gene transfer and introducing alien varieties have been used for carp genetic improvement and have resulted in advances in production and economical benefits.

National natural ecological pools (gene banks) have been created to preserve, develop and utilize the germplasm resources of common carp in China, for example, Heilongjiang local common carp, Wuyuan hebao red carp and Xingguo red carp, Huanghe common carp, and Xiangjiang local common carp in the provinces of Heilongjiang, Jiangxi, Henan and Hunan, respectively (Lou 2001). These gene banks play an important role in the conservation of genetic resources and in the extension of broodstock and quality seed.

The Chinese National Certification Committee for Aquatic Varieties is an organization that was established to evaluate genetic resources, broodstock, seed quality, alien species and hybrids in China. The committee has approved more than 60 breeds to be distributed through extension programmes around China. Among them are 20 varieties/hybrids/alien strains of common carp (Table 1) (Lou 2001).

Common carp is one of the most important fish cultured throughout Bangladesh and the varieties cultured are the scaly carp *Cyprinus carpio* var. *communis*, the mirror-carp *Cyprinus carpio* var. *specularis* and the leather carp *Cyprinus carpio* var. *nudus* (Hussain & Mazid 2005).

Cyprinus carpio is also one of the three major species cultured and caught in the inland waters of Thailand. This species is found naturally throughout the country in rivers, reservoirs and swamps. It is also cultured in ponds, paddy fields and ditches (Pongthana 2005).

Its hardiness, fast growth, easy propagation, omnivorous feeding habit, ability to readily accept supplementary feed, resistance to disease and tolerance of a wide range of climatic conditions have made common carp a popular species in India, where production reached 443 000 t in 2003. Production is mostly based on two introduced strains, the Prussian and Bangkok (Reddy 2005), and the many farm stocks that have evolved from them through the continuing process of domestication.

Common carp is a popular indigenous cultured cyprinid species in Vietnam, particularly in North Vietnam where it is readily marketable and commands a good price. There are eight local varieties of *C. carpio* in Vietnam. The local varieties, identified on the basis of morphology and coloration are: white scaled, Bac Can, Ho Tay, South Hai Van, Red, Violet, High Body Depth and Scattered Scale (Dan *et al.* 2005).

Similarly, *C. carpio* is one of the most economically important species for aquaculture in Indonesia; several strains that vary in colour and body form are cultured in Indonesia. Culture of *C. carpio* began in the middle of the 19th century and it is cultivated in ponds, rice fields, bamboo or wooden cages in rivers and floating net cages in lakes and reservoirs. Presently, common carp is cultured in all provinces of Indonesia and comprises 50.8% of total fish production (Emmawati *et al.* 2005).

Intraspecific hybridization of common carp has been conducted in Japan since the late 1960s. Six crossing groups with different varieties, including local strains, mirror carp and scale carp from Europe and China, have obvious heterosis (Lou 2001). Artificial selection and hybridization have been used to improve different strains of Koi carp and 100 strains have been bred as ornamental fish.

European carp diversity in aquaculture

European strains of common carp are derived from wild carp of the Danube valley. Productive populations were domesticated from ancestral forms, as well as from their mutual crosses and backcrosses followed by mass

Table 1 List of the 20 varieties of common carp approved for extension by the Chinese National Certification Committee for Aquatic Varieties (Lou 2001)

Variety	Sources	Breeding technology	Purpose
Hebao red carp	*Cyprinus carpio* var. *wuyuanensis*	Selection	Aquaculture, parent fish for breeding
Xingguo red carp	*Cyprinus carpio* var. *singuoensis*	Selection	Aquaculture, parent fish for breeding
Huanghe carp	*C. c. haematopterus*	Selection	Aquaculture
Wan'an transparent red carp	*C. carpio* var. *wananensis*	Selection	Aquaculture
Jian carp	*Cyprinus carpio* var. *jian*	Selection, crossing, gynogenesis	Aquaculture
Anti-cold strain of Hebao red carp	*C. carpio* var. *wuyuanensis* ♀ and Heilongjiang local common carp	Selection, crossing	Aquaculture
Selected strain of Germany mirror carp		Selection	Aquaculture, parent fish for breeding
Selected strain of scattered mirror carp		Selection	Aquaculture, parent fish for breeding
Songpu carp	*C. carpio* var. *wuyuanensis*, Heilongjiang local common carp, Germany mirror carp, scattered mirror carp	Selection, crossing, gynogenesis	Aquaculture
Xiangyun carp		Triploid	Aquaculture
Songhe carp	*C. carpio* var. *wuyuanensis*, Heilongjiang local common carp, scattered mirror carp	Selection, crossing, gynogenesis	Aquaculture
Feng carp	*C. c.* var. *singuonensis* ♀ and Scattered mirror carp ♂	Hybrid	Aquaculture
Heyuan carp	*C. carpio* var. *wuyuanensis* ♀ and *C. carpio* var. *yuankiang* ♂	Hybrid	Aquaculture
Tri-crossed carp	(*C. carpio* var. *wuyuanensis* ♀ and *C. carpio* var. *yuankiang* ♂) ♀ and Scattered mirror carp ♂	Hybrid	Aquaculture
Ying carp	Scattered mirror carp ♀ and nuclear-cytoplasmic hybrid fish f_2 ♂	Hybrid	Aquaculture
Yue carp	*C. carpio* var. *wuyuanensis* ♀ and Xiangjiang local species ♂	Hybrid	Aquaculture
Lotus carp	Scattered mirror carp ♀ and *C. c.* var. *singuonensis* ♂	Hybrid	Aquaculture
Molong carp	Koi species	Selection, crossing	Ornamental fish
Germany mirror carp	Introduced from Germany	Domestication	Aquaculture, parent fish for breeding
Scattered mirror carp	Introduced from Russia	Domestication	Aquaculture, parent fish for breeding

selection. These populations have been widely spread throughout the continent (Fig. 4). The earliest attempts at culture date back to the Roman Empire and the spread of Christianity in Europe, and this is where domesticated forms were later introduced to other continents (Balon 2006). At present, the main common carp producer countries in Europe are: Russia, Ukraine, the Czech Republic, Poland, Hungary and Germany (FAO 2009a).

Pokorny *et al.* (1995) reported 12 'original' Czech common carp populations that were bred in the 1930s, 1940s and 1950s as well as 11 breeds imported from neighbouring countries. Ten hybrids, developed from pure breeds, are also maintained in the live gene bank of the Research Institute for Fisheries at Vodnany. Nine pure breeds of common carp have been considered to be important genetic resources and are used in farming in the Czech Republic (Flajšhans *et al.* 1999).

In Hungary, work on the genetics and selection of common carp resulted in collections of strains during the 1970s and 1980s. Bakos and Gorda (1995) reported that 15 Hungarian and 15 foreign strains were maintained in the live gene bank in Hungary. Three highly productive hybrids were produced using the genetic resources maintained in the live gene bank. By the mid 1980s, 80% of carp production in Hungary was based on these three hybrids (Bakos & Gorda 1995).

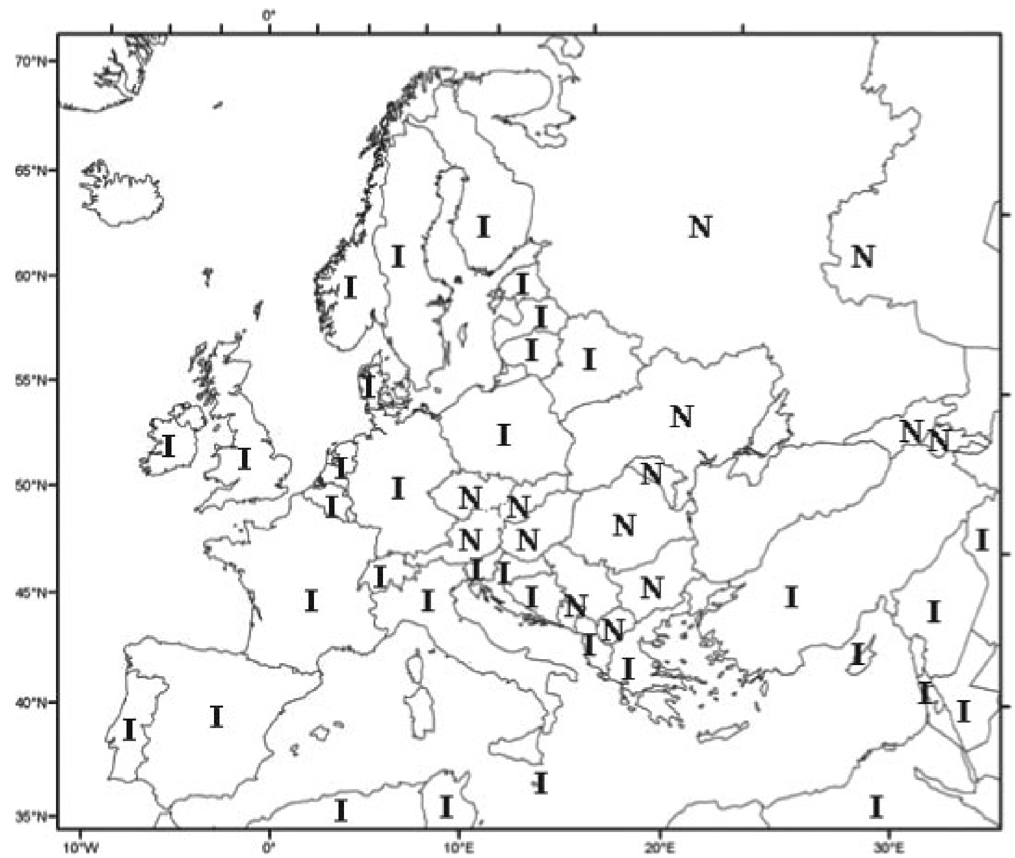

Figure 4 Status of the origin of common carp in Europe (Flajšhans & Hulata 2006). I, Introduced; N, native.

In Poland, the live gene bank at the Institute of Ichthyobiology and Aquaculture at Golysz, comprises 19 breeding lines with considerable genetic variation in survival rate, forming a strong basis for genetic improvement. Out of these 19 lines, five are Polish and 14 are 'foreign': five Hungarian lines, two Ukrainian lines, two Lituanian lines, one line each from Israel, France, Germany and Yugoslavia, and one ornamental line (Irnazarow 2008).

In Germany, aquatic genetic resources are described at the following website: http://www.genres.de/genres_eng/agr/agr_index.htm. The National Inventory for Aquatic Genetic Resources is available in German at http://agrdeu.genres.de/agrdeu/index. This inventory lists all German common carp broodstocks genetically characterised by microsatellites to date. No live gene banks exist for carp in Germany and local carp farmers maintain the strains. Currently, financial support is not available for maintaining such strains. However, this may change in the near future. Farmers will then get limited support for keeping strains if they meet specific conditions, such as, for example, minimum broodstock sizes. No state-approved strains exist in Germany at present (Klaus Kholman, pers. comm., 2009).

Bogeruk (2001) described 14 Russian strains of common carp, officially recognised by the Russian State. In a recent study, Bogeruk (2008) gave an overview of carp breeds in seven important carp-producing countries, with detailed data on biology, genetics, production and other parameters. In total, 60 'national strains' (including four wild strains) and 25 'foreign strains' are described in the Catalogue of Carp Breeds (*Cyprinus carpio* L.) of the countries of central and eastern Europe by Bogeruk (2008); these breeds are summarised in Table 2.

Table 2 Genetic resources of common carp in major European carp-producing countries based on Bogeruk (2008)

Country Strains	Belarus	Czech Republic	Hungary	Moldova	Poland	Russia	Ukraine
National	3	14	14	3	7	13	6
Foreign	5	8	NR	NR	11	1	NR
Total	8	22	14	3	18	14	6
Cryo-bank	NR	Yes	Yes	NR	NR	NR	NR

Numbers represent the number of strains in use. NR, not reported.

Management of carp genetic diversity

In China, the state has 'overall ownership' of the genetic resources of common carp. The Chinese National Certification Committee for Aquatic Varieties and other local management organizations have control of the management of genetic resources, broodstock and seed quality. The National Quality Control Centre of Fishery Seedlings examines and evaluates the quality of broodstock, seed, alien species and hybrids according to a set of germplasm standards (Lou 2001).

The general framework for the management of germplasm consists of five levels: (i) national germplasm resource pools are organized according to water catchment area and provide original stocks to broodstock farms; (ii) broodstock farms aim to preserve existing and potential culture species and provide breeders with access to good quality seed farms and research institutes; (iii) good quality seed farms have the mandate to introduce breeders from broodstock farms, preserve alien species and provide brood fish for the hatcheries; (iv) hatcheries usually introduce broodfish from broodstock farms and seed farms, and also produce fry and fingerlings on a large scale to farmers; and (v) farmers get seed from hatcheries and culture common carp in monoculture and polyculture in different systems, including ponds, cages, lakes, reservoirs, paddy fields and running water systems, to produce food fish.

Although common carp has been cultured in China for several thousand years, an understanding of the characteristics of wild fish strains and how these can be used to improve farmed stocks is still a work in progress. The work of building collections, both broodstock collections and cryopreserved gene banks, has just commenced. Currently there are few organizations and coordinated actions to aid the development of fish gene banks.

As a result of recent political events in central and eastern Europe, there has been a change from what has been largely a state-controlled genetic management plan for carp to more decentralized approaches. Until 1990, state/public ownership guided large-scale state farms and cooperatives in the implementation of genetic and selection work. After the major changes, private and small-scale fish farms continued this work. In Hungary even strains and breeds were 'privatised' together with the farms. In other countries, such as Poland and the Czech Republic, the state retains the responsibility for financing and maintaining these valuable genetic resources.

Gene banking includes the collection of live broodstock and cryopreserved sperm. Live broodstocks are usually kept in ponds, with controls in place to ensure that these broodstocks and their progeny do not escape. Individual strains may have originated from different watersheds and need to be kept from mixing genetically with the local fish. Storage facilities for cryopreserved sperm can range from small tanks of liquid nitrogen on site in a research laboratory or farm, to rented space in large liquid nitrogen tanks in a livestock insemination centre. In Europe, the genetic resources of common carp are available from a range of public gene banks:

- live gene banks, both *in situ* and *ex situ*;
- cryopreserved gene banks;
- tissue collections for genetic studies
- collections of databases on population genetics and production characteristics.

Live gene banks (or strain collections) of common carp breeds were kept and new forms were continually tested in, for example, the Research Institute for Fisheries, Aquaculture and Irrigation, Szarvas, Hungary (http://www.haki.hu/), the Institute of Ichthyobiology and Pond Culture of the Polish Academy of Sciences, Golysz, Poland (http://www.fish.com.pl), the University of South Bohemia, Research Institute of Fish Culture and Hydrobiology, Vodnany, Czech Republic (http://www.vurh.jcu.cz/en/informace-o-ustavu) and the Federal Center for Fish Genetics Research, Russia.

Global pools of common carp (in the form of live gene banks) do not exist and are probably not realistic at this stage. However, to improve the use and exchange of genetic resources of common carp, separate databases on different genetic resources of carp could be integrated into a 'Global Database on Genetic Resources of Common Carp'. Such a database could include information on the population genetics and production characteristics of carp. At a global level, collections of cryopreserved sperm or preserved tissue samples (maintained with unified methodologies) may be practical in the future.

International cooperation is essential if Asia is to achieve its goals in conserving some of the greatest concentrations of biodiversity of fish and achieving development through the sustainable use and management of these resources. Major live gene banks of common carp have been established in China and in central and eastern Europe (Hungary, Czech Republic, Poland and Russia). There is an ongoing collaboration on carp genetics and breeding between the Hungarian Research Institute for Fisheries, Aquaculture and Irrigation (HAKI) and the Chinese Freshwater Fisheries Research Centre (FFRC), China. A regional cooperation project 'Genetic Improvement of Common Carp Species in Asia' is being coordinated by the WorldFish Center. Six participant Asian countries, Bangladesh, China, India, Indonesia, Thailand and Vietnam, are involved in the selection and genetic improvement of economically important common carp. Several regional networks, such as the Consortium on Common Carp Genetics and Breeding organised by the

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Network of Aquaculture Centres in Asia (NACA) and the Network of Aquaculture Centres in Central and Eastern Europe (NACEE) are of vital importance to the exchange and use of common carp genetic resources (http://www.enaca.org/modules/news/article.php?storyid=1789).

Conservation of carp genetic diversity

In Asia, conservation of biodiversity has engaged the broad attention of various countries. Farming of aquatic animals requires a steady supply of genetic variability. The requirement for genetic diversity is probably even greater for farmed aquatic animals than for livestock because the very high fecundity of aquatic animals makes it far too easy for farmers to obtain all their seed requirements from a few individuals, which is an unhealthy practice that could lead to a dramatic reduction in genetic variability.

The population genetics of many key species require closer examination. Interactions of wild and domesticated species need more detailed studies. There should be an intensification of live, cryopreserved and molecular gene banking efforts that are strongly linked to both *ex situ* and *in situ* conservation. On-farm preservation of carp genetic resources could be a vital alternative with sufficient systems of interest generated. More research is needed in the area of effective sterilization techniques for domesticated and genetically improved aquatic organisms to avoid their negative impacts on natural ecosystems. *In situ* conservation and the establishment of protected areas are the most effective measures for conserving biodiversity (Pullin 2007). This means protecting valuable natural ecosystems and habitats for wild fish that can reproduce and evolve in the ecosystem and maintain ongoing ecological processes in the system.

In Europe, feral populations, some of which could be hundreds of years old, dominate most of the drainage systems (Fig. 4). However, the genetic structure of wild populations is very poorly understood. Most population genetics studies have involved farmed stocks, and have investigated differences between them, genetic variability within and among populations, and the genetic distance among them. Only occasionally have studies examined wild stocks. Little can be said about local adaptation given the poorly understood and largely unknown status of wild populations (Flajšhans & Hulata 2006).

Most carp production throughout the world is carried out using unselected strains (Vandeputte 2003). When they exist, breeding programmes are mostly based on crossbreeding (Wohlfarth 1993; Bakos & Gorda 1995; Hulata 1995) because it results in rapid improvement in growth performance (heterosis) in the F_1 generation; breeding programmes are widely used in Hungary, Israel and the Czech Republic. Crossbreeding of subspecies (*C. c. carpio* and *C. c. haematopterus*) has been shown to improve the survival rate of fry and increase disease and cold resistance; however, improper use of hybrids for further breeding has been shown to contaminate purebred stocks in the Czech Republic (Flajšhans *et al.* 1999). The occurrence of original wild Danubian carp populations is questionable at present and, if they do occur, these populations are probably limited to a few areas in the drainage system and are threatened by anthropogenic effects and farm escapees and the restocking of farmed populations into open waters (Flajšhans & Hulata 2006).

There are three main incentives for the conservation of carp genetic resources, as for most cultured species. The first is a shortage of genetically improved varieties in aquaculture that have stable genetic characteristics and are fit for extension. The second is maintenance of characteristics of the natural germplasm. Natural populations of common carp have been depleted, biodiversity has been lost, desirable properties and purity have degenerated, leading to deterioration of the natural germplasm. The third is the need to counteract germplasm degeneration and inbreeding depression in farmed stocks. The replacement of broodstock in some hatcheries has been slow and the quantity of effective reproductive genetic resources has been reduced. Breeders used for many years degenerate. Inbreeding and inbreeding depression occurs easily because little attention has been paid to the selection of breeders. Negative selection is even found in some hatcheries. In China, the government subsidises the conservation of genetic resources by maintaining gene banks of cultured fish species, including common carp, in research institutes. Incentives for farmers to conserve genetic diversity are originating from the market (Lou 2001).

Genetic resource conservation can be financed either by the market or by public sources. In Europe, because of the low to medium value of common carp as a commodity, at present it does not seem realistic that the market could/would pay for the use and exchange of carp genetic resources. In developing countries, carp could belong to a higher-value group of products and commercial benefits could be considered.

Asia has many varieties of common carp, some found only within Asia, but only a few of these varieties are used in aquaculture and restocking and have been the subject of research and the development of improved stocks. Selected and improved strains of *C. carpio* contribute to a large proportion of aquaculture production. Common carp varieties have been widely exchanged between countries in Asia and some varieties were introduced from Europe (Penman *et al.* 2005). However, there is still a need for the exchange of good local varieties, improved strains and technology among Asian countries to further contribute to aquaculture and food security.

In China, with the destruction of ecosystems, environmental pollution and overexploitation of fisheries resources, living aquatic resources are degenerating and many populations are in imminent danger of extinction. For example, it is now difficult to catch indigenous common carp in the Yuanjiang River (Yunnan Province). A number of natural habitats of Huanghe carp strains in the Yellow River have been destroyed and made unfit for the fish (Zhu Jian, pers. obs., 2009).

In Europe, the use and exchange of common carp genetic resources is based on costly national breeding programmes and the maintenance of live and cryopreserved gene banks. These programmes need continuous maintenance, which is an expensive exercise. Public funds are essential for the sustainable maintenance of activities in the use and exchange of genetic resources of carp.

Exchange of genetic resources

Many of the species or strains cultured throughout the world are not indigenous, having been introduced from other countries or regions. A total of 259 introductions of cyprinid species has been recorded in the 27 countries and regions of Asia (Acosta & Gupta 2005). Out of these introductions, 72% (186 records) were from countries within Asia, 10% (26 records) were from countries outside Asia and another 18% (47 records) were from 'unknown' countries. Common carp (*C. carpio*) was the most often introduced species in the region (52 records); 60% (31 records) were from countries within Asia, 29% (15 records) were from countries outside Asia and another 11% (6 records) were from 'unknown' countries (see Penman *et al.* 2005). This high frequency of translocations of *C. carpio* could result from the fact that common carp has the longest history of culture and domestication among all finfish (Acosta & Gupta 2005).

With the rapid development of aquaculture over recent years, China alone has introduced more than 100 aquatic species from other countries, 60 of which have been used in commercial aquaculture and three of which are common carp varieties: scattered mirror carp and Russian scaly carp introduced from the Soviet Union in 1958 and German mirror carp introduced from Germany in 1984 (Li *et al.* 2007).

Although Bangladesh is rich in endemic fish genetic resources, the introduction of different varieties of alien fish species (mostly Chinese carps) has been common since 1960. As many as 15 alien cultivable species (carps, including the common carp) have been deliberately introduced into Bangladesh, first in 1960 from China and a new strain from Vietnam was introduced in 1995 with the objective of increasing fish production (Hussain & Mazid 2005).

In addition to indigenous strains, seven strains of carp have been introduced into Thailand and used in aquaculture. The common carp was first introduced approximately 80–100 years ago and is establishing a foothold in Thailand (Pongthana 2005).

The common carp was introduced to India in 1937 (Prussian strain) and in 1957 a Bangkok strain was introduced to utilize pond bottom food resources in composite fish culture and this strain has now become an integral part of Indian freshwater aquaculture (Reddy 2005).

There are three introduced varieties of *C. carpio* in Vietnam; the Hungarian scaled, Hungarian mirror and Indonesian yellow varieties. These alien varieties are now commonly cultured in Vietnam (Dan *et al.* 2005).

The common carp was apparently introduced into Indonesia from China in the 18th century (Emmawati *et al.* 2005). Following this initial introduction, additional common carp strains were introduced from Taiwan, Japan and Europe (Galician, French and German strains). In the early 1900s, various introduced strains were widespread throughout Indonesia. These strains were often hybridized to improve production traits and collectively these strains are now known as Indonesian local common carps. Several races of Indonesian common carp, such as Maalaya, Punten, Sinyonya, Cangkringan, Rajadanu, Wildan and Szarvas, have been used by farmers (Emmawati *et al.* 2005).

The Japanese koi carp is reared as an ornamental fish. Koi carp originated from the Chinese red common carp in the early 19th century. The Japanese have selected and improved different varieties since the 1830s. In 1960, the mirror carp was introduced from Germany and hybridized with Koi carp, from which new varieties have been created. To date, the Japanese have bred approximately 100 varieties. The popularization of Koi carp has a history of more than 30 years. In 1973, the Koi carp was transmitted to China as a friendly herald between China and Japan. At present, many large production centres of Koi carp have been established in China to meet the needs not only of the internal aquarium trade, but also the needs of the international market (Lou 2001).

Carp genetic resources in Europe exist in different forms (pure breeds, unselected and selected strains, hybrids, and genetically altered forms (e.g. triploids, gynogenetic, androgenetic, all-male progenies, all-female progenies and XX neomales)). Pure breeds and crossbreds are used for exchange programmes and are usually produced on the basis of *ex situ* gene banks. The Database on Introductions of Aquatic Species (DIAS) contains more than 120 items on common carp introductions

(FAO 2009b, available at http://www.fao.org/fishery/dias/en). The value of the database will increase as the proportion of referenced sources of information increases.

Management of genetic material transfers

Basic knowledge on the management of genetic material transfers for carp genetic resources is available. The basic principles of establishing and using live and/or cryopreserved gene banks have been developed and are available (Pullin 2007). No real technological/technical restrictions exist with regard to improving the way in which genetic materials are moved around. However, the establishment and maintenance of facilities are expensive 'exercises' in this field. Incentives and funding appear to be the major limiting factors for improved practices, particularly when the market cannot or is not ready to compensate for the additional costs related to these activities.

Basic knowledge with regard to the exchange of carp genetic resources is also available. This activity could be limited by legal and financial conditions. International exchange of genetic resources is regulated by international law (Bartley *et al.* 2007). Epidemiological and ecological concerns are the major arguments against the transfer of carp among different countries and continents. In Europe, the principle of zoning or water catchment area is applied to regulate the transfer/movement of carp among countries (http://www.oie.int/Eng/normes/fcode/A_summry.htm). Spreading of the Koi Herpes Virus in Europe and in some parts of Asia could be a frightening example of uncontrolled exchange of carp genetic resources. The ecological consequence of the 'carp story' in Australia is a 'good example of a bad introduction', resulting in the 'contamination' of natural water bodies with a non-indigenous species (http://www.dpi.nsw.gov.au/fisheries/pests-diseases/freshwater-pests/species/carp). Australia is the only country in the world in which common carp is designated as a 'noxious species', and perhaps this status may have a cultural bias rather than an explicit biological basis.

From a technological point of view, it can be reiterated that there are no major technological restrictions/constraints to the genetic material transfer of common carp. Common carp is usually transported between fish farms in plastic bags (early life stages) or in specialised containers (older life stages). The technology of carp transportation is well developed and routinely applied. For long-distance transportation, in most typical cases, carp fry are transported in plastic bags filled with water and oxygen (Berka 1999).

Financial restrictions are typical for international transportations as a result of the high costs of air transportation. The transportation price is often 100–1000-fold higher than the real value of the transported early life stage of the carp.

There is an urgent need for intervention and collaboration with regard to developing strategies for the conservation and utilization of genetic resources and breeding programmes for common carp species in Asian countries. Good genetic resource management needs to be promoted to avoid negative impacts on biodiversity and the environment. Species and traits relevant to low-input systems need to be prioritised for genetic enhancement programmes that better address food security issues.

The development of a common approach and methodology for the characterization of common carp genetic resources is a basic requirement for the exchange of genetic resources. Current exchange practices should conduct work aimed at developing an inventory of common carp genetic resources and at defining their status, engage gene banks in the conservation of genetic resources and develop broodstock management guidelines for live gene banks.

Conclusions: carp genetic management in the 21st century

Sustainable management of carp genetic resources will require interest and active participation by a wide range of stakeholders, including aquaculturists, fisheries scientists, public policy specialists and other professionals. Genetic improvement of cultured fish that increases productivity and turnover rate, and results in better use of resources and reduces production costs should be given higher priority by government, non-government organizations and commercial organizations than it is at present. Such improvement methods include: multiple trait selection programmes; efficient breeding plans, in which selection is combined with other genetic technologies; better genetic management for monitoring the progress of breeding programmes; more education and training programmes for aquaculture geneticists, particularly in developing countries; the establishment of national and international genetic controls (operation and analysis), including homozygous and heterozygous clonal populations for key species to help compare genetic results and genetic material from different research institutions; increased global cooperation and enhanced research efficiency; continued genetic improvement and domestication of cultured organisms, such as some common cyprinids species, that still rely on wild seed.

The challenge to aquaculturists, fisheries scientists and policy-makers is to strike an appropriate balance between realizing the potential for economic development posed by aquaculture technology and minimizing any risks to the environment and human health.

The use of common carp genetic resources in European countries is subsidy driven. As an example, strain owners in Hungary can receive a government subsidy only if they participate in a 'Strain Evaluation Process' and they have to cover part of the cost of 'Progeny Performance Testing, which is obligatory once every 5 years. In exchange, they are 'certified' to sell their stocking material outside of their farms. Profit obtained from this activity represents their incentive. As a result of this set-up, there is a basic awareness among strain owners about the use of carp genetic resources. In the case of ownership of wild carp strains, owners are interested in stocking natural waters with the progeny of their strains. Such activities are subsidised from governmental/public funds (e.g. National Fund for Fisheries in Hungary).

In Europe, fish farmers represent/defend their interest through associations. As an example, in Hungary the National Association of Fish Producers and Product Council (Haltermosz) is supposed to 'advocate' their interest at both a national and international level. Because of their status and function, these associations could play a more important role in the management of the genetic resources of common carp in Europe.

To date no major coordinated action has been initiated for the use and exchange of common carp genetic resources. Currently, no fish strains/breeds or species are included among government-recognized animal broodstocks protected either as endangered or representing a valuable national resource. Awareness of the importance of fish and, in particular, carp genetic resources should be raised, particularly at the level of the European Union. Currently it is not clear who could or should pay incentives for the proper use and exchange of genetic resources of common carp.

In Asia, research on genetic resources and genetically improved aquatic organisms should continue because of their potential benefits, particularly in developing countries; however, a much greater understanding of the potential environmental impacts is necessary. Linkages should be formed among the general public, organizations, scientists, industry and governments to address genetic issues and to support the development of practical regulation and sound policy. Dissemination of genetically improved aquatic organisms for aquaculture should only be carried out within the framework of adequate regulations and policy.

Collaborative networks to develop protocols for and to conduct sound and safe reviews of genetically improved aquatic animal research are needed to help ensure that the results are beneficial. Cooperative learning from previous research oversights, rather than competitive secrecy, should also enhance future research economically and technologically.

In recognition of the growing body of genetic research pertaining to aquaculture, the Network of Aquaculture Centres in Asia-Pacific (NACA) together with the Network of Aquaculture Centres in Central and Eastern Europe (NACEE) convened a consultation to discuss the formation of a consortium on common carp genetics and breeding, to encourage collaboration and sharing of resources, and to identify and prioritise key researchable issues/projects on fish breeding and genetic resource management (http://www.enaca.org/modules/news/article.php?storyid=1789).

Networks (e.g. the International Network for Genetics in Aquaculture (INGA), the Consortium on Freshwater Fish Genetics and Breeding) can play a very important role in strengthening collaborative efforts on genetic study and breeding of common carp, and in promoting the sharing of genetic resources, information and experience in common carp conservation among countries that often have limited resources (human, physical and financial). Such networking may also facilitate the elaboration of appropriate mechanisms and strategies for responsible trans-boundary exchange of natural germplasm resources and genetically improved common carp strains, which will promote the sustainable use of aquatic genetic resources and aquaculture development and contribute to food and nutritional security and rural livelihoods.

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