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Use and exchange of aquatic genetic resources for food and aquaculture: *Clarias* catfish

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Abstract

There are 58 species of *Clarias* recognized in FishBase (as of January 2009), 33 in Africa and 25 in Asia. Aquaculture of clariids is important with 30 countries reporting a total production of over 300 000 t worth nearly US$400 million in 2006. Most production involves the African *Clarias gariepinus* (Burchell, 1822) and three Asian species, *Clarias batrachus* (Linnaeus, 1758), *Clarias macrocephalus* (Günther, 1864) and *Clarias fuscus* (Lacep'de, 1803). In much of Asia, hybrids of introduced *C. gariepinus* with native species dominate aquaculture and may pose threats to the purity and viability of wild populations. Many local strains have evolved within farms, some of which have been described and included in genetic management programs. Genetic variation among species and populations is significant, but to date little work on selective breeding of the group has been reported. Conservation efforts have so far focused on *ex situ* methods, primarily for farmed stocks, but these are few and expensive and farmed stocks are often of lower genetic diversity than wild stocks. *In situ* conservation of genetic material, both for aquaculture and for the maintenance of fitness in wild populations in light of changes occurring in the watershed, needs to be considered as a more viable long-term strategy. The preservation of ecosystem functional integrity is thus a prerequisite for the long-term conservation of *Clarias* genetic resources for food and aquaculture.

Key words: genetic diversity, genetic impact, translocation, walking catfish.

Introduction

Catfish of the genus *Clarias* (Siluroidei, Clariidae) are widespread in freshwaters of tropical Africa and Asia. Having evolved in the Pliocene epoch (upper Tertiary period) approximately 7–10 million years ago (Sudarto 2007), there are now 58 species recognized in FishBase (as of January 2009), 33 in Africa and 25 in Asia. Clariid catfish are characterized by an elongated body, long dorsal and anal fins and four pairs of barbels, and they lack a dorsal fin spine and an adipose fin (except for a vestigial remnant in *Clarias ngamensis* Castelnau, 1861). The synapomorphic characteristic of the family Clariidae, which also includes the genera *Bathyclarias*, *Channallabes*, *Clariallabes*, *Dinotopterus*, *Dolichallabes*, *Encheloclarias*, *Gymnallabes*, *Heterobranchus*, *Horaglanis*, *Platyallabes*, *Platyclarias*, *Uegitglanis* and *Xenoclarias*, is the suprabranchial organ (Teugels 2003), which functions like a lung and renders clariids capable of aerial respiration and thus able, under conditions of low dissolved oxygen, to still meet 80–90% of their oxygen requirements (Moreau 1988).

This ability of clariids to feed and grow in the virtual absence of dissolved oxygen, coupled with fast growth, an omnivorous diet and generally high resistance to stress, make them of particular interest in aquaculture. Rapidly growing in importance since 1985 (Fig. 1), clariid catfish are grown by small-scale and large-scale fish farmers in 30 countries with a total production of over 300 000 t, which was valued at nearly US$400 million in 2006. Currently cultured clariid production contributes nearly 60% to the total global production (FAO 2009). Twenty countries in Africa, Asia and Europe produce at least 100 t per annum (Table 1).

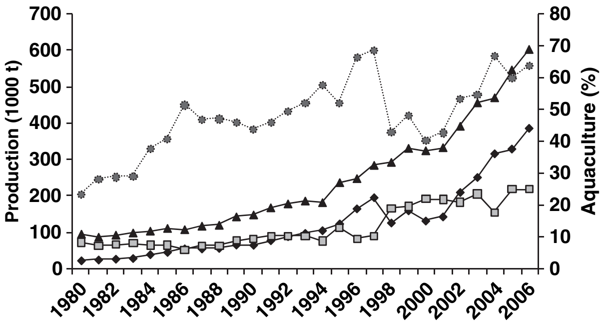

Figure 1 Global growth in clariid catfish aquaculture from 1950 to 2006 and the percentage contribution from aquaculture to global catfish availability (FAO 2009). —◆—, Culture; —□—, capture; —▲—, total; ···●···, culture (%).

Table 1 Countries reporting at least 100 t of cultured clariid catfish in 2006 (FAO 2009)

Country	Quantity (t)
1. South Africa	100
2. Cameroon	110
3. Italy	115
4. Romania	118
5. Togo	200
6. Belgium	250
7. Mali	300
8. Kenya	302
9. Brazil	362
10. Poland	380
11. Cambodia	800
12. Syria	1030
13. Hungary	1724
14. Philippines	2376
15. Netherlands	4500
16. Malaysia	18 486
17. Uganda	20 941
18. Nigeria	51 916
19. Indonesia	77 332
20. Thailand	146 000

Clariid genetic resources for aquaculture

African species

Among the 33 species of the genus *Clarias* found in Africa, *Clarias gariepinus* (Burchell, 1822) is the main culture species at present and to a much lesser degree, *Clarias anguillaris* (Linnaeus, 1758). These two species, the only two members of the subgenus *Clarias*, are very similar (Volckaert *et al.* 1995; Rognon *et al.* 1998; Teugels 1998, 2003) and hybridize naturally under certain conditions. *Clarias gariepinus* is the more widely studied and cultured of the two, largely because of the relatively restricted natural distribution of *C. anguillaris* in the Nile and West Africa. At present, *C. gariepinus* has been introduced to at least 35 countries (FishBase 2007) for culture as a pure species and/or as a hybrid with native species (e.g. *Clarias macrocephalus* (Günther, 1864); Nukwan *et al.* 1990). Captive farm stocks have been maintained in some countries, for example, at least two genetically distinct groups originating from the Central African Republic and Egypt (Li *et al.* 2000) are maintained in four Thai hatcheries (Wachirachaikarn *et al.* 2009). These stocks are valuable for further genetic improvement programs.

In addition to the genus *Clarias*, there are three other Clariidae genera that are of some potential interest and that have been tested in aquaculture. An endemic *Bathyclarias* species, which flocks in Lake Malawi, ranges in size from 60 to 135 cm and has been tested in ponds in Malawi (Msiska *et al.* 1991). *Gymnallabes typus* (Günther, 1867), native to the lower course and delta of the Niger River and Cross River basin in Nigeria and Cameroon, has been tested as an alternative to eels in trials in the Netherlands (Teugels & Gourène 1998).

Reaching over 1 m in length and 55 kg in weight (Skelton 1993), the non-*Clarias* clariid that has received the most attention by fish farmers and is produced in a number of African countries is *Heterobranchus longifilis* (Valenciennes, 1840). Otémé *et al.* (1996) reported that under optimum conditions *H. longifilis* grows twice as fast as *C. gariepinus*. This species, known as vundu in southern Africa, is found throughout Africa in the Nile, Niger, Senegal, Congo, Gambia, Benué Volta and Zambezi River systems as well as in all coastal basins from Guinea to Nigeria, and in Lakes Tanganyika, Edward and Chad (Skelton 1993; Teugels 2003). Of particular interest has been the hybrid between *H. longifilis* ♀ and *C. gariepinus* ♂ first produced in South Africa and commonly known as 'heteroclarias' (Hecht & Lublinkhof 1985).

Asian species

At least three Asian species have been used for aquaculture: *Clarias batrachus* (Linnaeus, 1758) in India (Sahoo *et al.* 2008), *C. macrocephalus* in South-East Asia (Na-Nakorn 2001) and *Clarias fuscus* (Lacep'de, 1803) in Taiwan and Hawaii (Szyper *et al.* 2001; Huang *et al.* 2005). Notably, the so-called *C. batrachus* found in South-East Asia, Java and India appears to comprise four (sub)species as evidenced by morphological and karyological data (Ng & Kottelat 2008). Ng and Kottelat (2008) suggested using the names *C. batrachus*, *C.* aff. *batrachus* 'Indochina' (aff. stands for 'affinis' and is used when the identity of a species is unknown, but it has a striking similarity or close relationship with a known species), *C.* aff. *batrachus* 'Sundaland' and *Clarias magur* (Hamilton, 1822) for species from Java, Mekong River drainage, and the Malay Peninsula and India, respectively. High levels of genetic differentiation of '*C. batrachus*' from southern Thailand (in the Malay Peninsula) and from the Mekong and Chaophraya River basins were also noted by Attha-insi *et al.* (2001).

In Thailand, *C.* aff. *batrachus* 'Indochina' has been successfully cultured in ponds since the 1980s. However, since 1990, it has been almost completely replaced in culture by a hybrid between *C. macrocephalus* ♀ and *C. gariepinus* ♂ (Na-Nakorn 2001) and currently is rarely found either on farms or in natural habitats in Thailand. As of October 2008, it was still occasionally seen in markets in southern Laos (Pakse) (Uthairat Na-Nakorn, pers. obs., 2008). Only two stocks are currently maintained *ex situ*, one stock at two stations (Ratchaburi Inland Fisheries Station and Kalasin IFS) and another stock at the Surin Fisheries Research and Development Center in Thailand (Yanyong Tantapakun, pers. comm., 2009).

Largely because of its perceived better qualities as a table fish, *C. macrocephalus* commands the highest market price (US\$2.35–2.94 kg^{-1}; US\$1 = Thai Baht 34) compared with US\$0.73–1.17 kg^{-1} for *C. batrachus* and *C. gariepinus*). In addition, having been largely replaced in culture by the hybrid *C. macrocephalus* × *C. gariepinus* (valued at >US\$1000 million; FAO 2009), broodstock of this species has been collected from wild stocks until recently (Josefa T. Fermin, pers. comm., 2009).

Clarias fuscus, native to China, Taiwan, Vietnam, Cambodia, Laos and the Philippines has been widely cultured in Taiwan (Huang *et al.* 2005) and Hawaii where it was introduced over 100 years ago (Szyper *et al.* 2001). As with *C. batrachus* and *C. macrocephalus*, a decline in pure *C. fuscus* on farms and in the wild has been documented, perhaps because of replacement by hybrids between this species and the introduced *C. gariepinus* or *C.* aff. *batrachus* 'Indochina' from Thailand (Huang *et al.* 2005).

Clarias nieuhofii (Valenciennes, 1840), distributed throughout South-East Asia in peats, lakes and lowland forest streams (FishBase 2007), is another species that has shown aquaculture potential. Artificial breeding of *C. nieuhofii* was successful in 1986 (Apakulanu & Lokulprakit 1987) and the development of specific aquaculture technology for this species is ongoing, especially in areas of southern Thailand (http://www.vcharkarn.com/vblog/37722).

Genetic improvement of *Clarias*

In Africa, selective breeding of *C. gariepinus* has recently been initiated in Egypt (2005) and Kenya (2006), but to date there is little to show for these efforts and, in general, any genetic improvements have been achieved through *ad hoc* mass selection on private farms (Ponzoni & Nguyen 2008).

In Thailand, its high economic value has encouraged genetic improvement programs for *C. macrocephalus*. All of the programs have used simple selective breeding (e.g. mass selection, within family selection) to improve the performance of base populations derived from mixing several wild populations recognized as genetically distinct (Na-Nakorn *et al.* 2004). In early trials in Thailand a slight improvement in growth, 11.8% in four generations (Jarimopas *et al.* 1990) and 0.98% in two generations (Komainprairin *et al.* 2004), and resistance to *Aeromonas hydrophila* (Chester, 1901) Stanier, 1943 (Na-Nakorn *et al.* 1994) have been observed. The limited progress of these selective programs, although not explained by the authors, may result from low additive genetic variance of the target traits and more sophisticated selection methods, for example, family selection, may be required (Falconer & Mackay 1996). However, all of the genetic improvement programs were terminated prior to the establishment of recognizably improved strains. *Clarias gariepinus* and its hybrid, which can grow twice as fast (i.e. 3–4 months to reach 250 g relative to 6–8 months for *C. macrocephalus*), are expected to continue to dominate culture for the foreseeable future (Na-Nakorn 1999, 2001). At present, seven pure stocks of *C. macrocephalus* are maintained in Thailand and, although there are no specific regulations governing their use and release, they are generally available only for research purposes after receipt of a formal request (Table 2).

By far the most common form of genetic improvement practiced in South-East Asia is hybridization. Hybrids between *C. gariepinus* and *C. batrachus* or *C. macrocephalus* have been widely produced, reportedly combining the faster growth of the African catfish with the more appealing culinary attributes (e.g. the preferred yellow *vs* white flesh color) of the Asian fish (Uraiwan 1993; Sahoo *et al.* 2003). Thailand, the world's largest catfish producer, grows almost exclusively a *C. macrocephalus* ♀ × *C. gariepinus* ♂ hybrid (Na-Nakorn 1999).

In Malaysia, two wild populations of *C. macrocephalus* and one of *C. batrachus* show very low genetic variability (Daud *et al.* 1989) and the response to mass selection for resistance to *A. hydrophila* in *C. macrocephalus* in early trials in Thailand have shown little gain (Na-Nakorn *et al.* 1994).

Translocations of *Clarias*

By far the most widely disseminated clariid is *C. gariepinus*, introduced for aquaculture throughout Africa and Asia and, to a lesser extent, Europe and Latin America, either for culture as a pure species or for hybridization with indigenous clariids (Table 3). Whether or not this highly adaptable species becomes established in the wild depends mostly on minimum water temperatures; cold water below approximately 8°C is fatal to clariids (FishBase 2003).

Table 2 Information on domesticated (or genetically improved) stocks of *Clarias* spp. in Thailand

Species/owners	Location	History	Accessibility
Clarias macrocephalus			
Vithaya Phandpla Farm (Prawit Niemvong)	Tumbol Lumpum, Amphur Muang, Pattalung Province	Founded from a stock from Pattani Province, captive for 15–16 generations	Not for sale, available for research on request
Department of Aquaculture, Faculty of Fisheries, Kasetsart University	50 Paholyothin Rd, Jatujak, Bangkok	Founded from crossing three wild populations, genetic improvement for three generations	Not for sale
Udornthani Fisheries Research and Development Institute, Department of Fisheries	Tumbol Maagkaeng, Amphur Muang, Udornthani Province	Founded from stocks bought from markets in Udornthani Province, domesticated for five generations	Not for sale, available for research on request
Choomporn Fisheries Test and Research Center, Department of Fisheries	Choomporn Province	Founded from southern stocks, history unclear	Currently not available to the public
Pitsanulok FTRC, Department of Fisheries	Pitsanulok Province	Genetically improved stock	Currently not available to the public, will be disseminated in future
Phetchaburi FTRC, Department of Fisheries	Phetchaburi Province	Founded from southern stocks, history unclear	Currently not available to the public, will be disseminated in future
Ayudhya FTRC, Department of Fisheries	Ayudhya Province	Stock translocated from Phetchaburi Province	Currently not available to the public
Clarias aff. *batrachus* 'Indochina'			
Surin Fisheries Research and Development Institute, Department of Fisheries	Amphur Muang, Surin Province	Collected from Surin Province for more than 10 years	Currently not available to the public
Ratchaburi Inland Fisheries Station, Department of Fisheries	Amphur Muang, Ratchaburi Province	Founded from a wild stock from Suratthani Province	Currently not available to the public
Kalasin Inland Fisheries Station, Department of Fisheries	Amphur Muang, Kalasin Province	Same stock as Ratchaburi	Currently not available to the public

FTRC, Fisheries Test and Research Center.

Among the Asian clariids, *C.* aff. *batrachus* 'Indochina' and *C. macrocephalus* have been introduced from Thailand to many countries (e.g. China (Ma *et al.* 2003); the Philippines, Taiwan, China, USA and Hong Kong (FishBase 2007)). Their establishment in the wild in the Philippines, although not well documented, is believed to be responsible for the loss of endemic cyprinids in Lake Lanao, Mindanao, and for the displacement of native *C. macrocephalus* in Luzon (Ravindra C. Joshi, pers. comm., 2009).

Clarias fuscus was introduced to Hawaii by Chinese immigrants in the 1800s and has been commercially produced there since the 1980s (Szyper *et al.* 2001), with annual production rising from 15 000 to 50 000 kg from 1990 to 1999. Most of the fish produced are sold alive on the pond bank by the producers or by small-scale brokers. The market on Oahu is reasonably well understood, but the situation is less well known on neighboring islands (Szyper *et al.* 2001).

Translocation within countries

In general, translocation within countries occurs without documentation and anecdotal reports are the main source of information. Although it is technically illegal in many countries to move fish among watersheds or to introduce them to areas where they are non-indigenous, such regulations are often ignored (FAO 2005). Clariids are particularly easy to move around because they are able to survive for long periods without dissolved oxygen and only minimal water. In Nigeria, unregulated movement of *Clarias anguillaris* (Linnaeus, 1758) is believed to have contributed to genetic contamination of pure *C. gariepinus* held on farms in both Nigeria and in the Netherlands (Anene & Tianziang 2007). Within Thailand, maintaining broodstock of *C. macrocephalus* is problematic because of its vulnerability to diseases and parasites (Na-Nakorn 2001), and the few hatcheries in central Thailand that have maintained broodstock distributed them throughout the country. Further complicating matters, stocks in the Malay Peninsula of southern Thailand were transferred to central Thailand for the production of hybrid fingerlings during the winter season (November–February) when the southern stocks spawn, but not the central stocks. Translocation of stocks has occasionally been carried out for *C.* aff. *batrachus* 'Indochina' by government, for example, translocation of Suratthani stock (southern Thailand) to north-eastern province, Kalasin.

Trends in genetic diversity

At the species level, African *Clarias* that are important to aquaculture are under no particular danger of extinction

Table 3 Reported translocations of *Clarias gariepinus* (from FishBase 2007)

Date	From	To	Status in the wild
Unknown	Unknown	Syrian Arab Republic	Established
Unknown	Unknown	Argentina	Established
Unknown	Unknown	Belgium	Unknown
Unknown	Unknown	Czechoslovakia (3 importations)	Probably not established
Unknown	Unknown	France	Not established
Unknown	Unknown	Greece	Unknown
Unknown	Unknown	India	Established
Unknown	Unknown	Iraq	Established
Unknown	Unknown	Israel	Established
Unknown	Unknown	Saudi Arabia	Unknown
Unknown	Unknown	Russia	Not established
Unknown	Unknown	Jordan	Established
Unknown	Côte d'Ivoire	Netherlands	Probably not established
1972	Central African Republic	Côte d'Ivoire	Probably not established
1972	Central African Republic	Cameroon	Established
1972	Central African Republic	Zaire	Probably established
1973–1978	Central Africa Republic	Gabon	Probably established
1973	Central African Republic	Congo	Probably established
1974	Israel	Cyprus	Not established
1974	Central African Republic	Vietnam	Established
1980	Vietnam	Laos	Established
1981	Egypt	China	Established
1981	Central African Republic	China	Established
1982	Vietnam	Cambodia	Probably established
1985–1986	Netherlands	Indonesia	Established
1985	Unknown	Hungary	Not established
1985	Taiwan	Philippines	Probably established
1985	Thailand	Philippines	Probably established
1985	South Africa	Indonesia	Probably established
1986–1989	Thailand	Malaysia	Probably established
1986	Africa	Brazil	Established
1987	Laos	Thailand	Established
1989	Thailand	Bangladesh	Probably established
1989	South Africa	Mauritius	Unknown
1989	Netherlands	Poland	Not established
1990–2000	Unknown	Singapore	Probably established
1990	Thailand	Myanmar	Established
1993	Rwanda	Burundi	Established
1993	Thailand	India	Probably not established

at present (IUCN 2007). Nevertheless, Mohamed *et al.* (1999) found that sections of the Nile River that received heavy levels of industrial pollution contained significantly fewer *C. gariepinus* than other sections and attributed this difference to poor water quality. As they are originally best adapted to swampy forest habitats, *Clarias* species worldwide have come under increasing pressure as forests become increasingly fragmented (Sudarto 2007).

As with other cultured species, domestication or captive holding on fish farms has resulted in a certain amount of genetic change, usually deterioration. Da Costa (1998) found a 20% difference between cultured and wild stocks of *C. anguillaris*, with the cultured stock growing significantly slower. Otémé (1998) and Agnèse *et al.* (1995) found that a population of *H. longifilis* held for four generations on a government research station had reduced genetic variability, lower fry growth rate and survival, higher levels of fry deformity and greater variability in larval growth rate. Van der Bank (1998) found that mean heterozygosity in a captive population (0.3%) of *C. gariepinus* was an order of magnitude less than in a wild population (5%). Hoffman *et al.* (1995) reported that wild *C. gariepinus* grew 15–43% better under culture conditions than populations that had been held on farms. van der Walt *et al.* (1993a) reviewed genetic variability in *C. gariepinus* and found strong evidence of inbreeding, founder effects and genetic drift in most captive populations. According to Fleuren (2008), in the Nether-

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lands, the country outside of their native range with the greatest *Clarias* aquaculture output (Table 1), genetic management is a generally haphazard affair with little regard for the potential consequences of inbreeding.

Good genetic management can reverse many of these negative consequences of domestication and can even improve performance. Van der Bank *et al.* (1992) and Grobler *et al.* (1997) showed that outcrossing to other captive stocks and with wild fish raised the mean heterozygosity of a farmed population to 7.6% compared with 5% in a wild stock. Similarly, Teugels *et al.* (1992) found that populations of *C. gariepinus* that were purposefully outcrossed among research stations were significantly more heterozygous than fish held in isolation on a single station. Wachirachaikarn *et al.* (2009) reported moderate genetic variation within four populations of African catfish introduced to Thailand approximately 20 years ago. Crossbreeding of two genetically distinct strains did not improve growth of the hybrid over that of the parental strains, but mean phagocytosis activity and variation at the alpha region of the Major Histocompatibility Complex (MHC) class I gene of the crossbreds were significantly higher than in the parental strains.

Among *C. gariepinus* stocks, significant variation in growth indicates that selection for better performance in aquaculture is possible (Van der Bank 1998). van der Walt *et al.* (1993b) showed that a well-maintained experimental line of cultured *C. gariepinus* out-performed wild strains and a population held at a local hatchery. In the Netherlands, de Matos Martins *et al.* (2005) documented significant variation in growth among juvenile *C. gariepinus*, implying that selection is possible. There appears to be a significant amount of genetic differentiation across the distribution of *C. gariepinus*, with populations in West/Central Africa differing morphometrically (width of premaxillary toothplate, length of occipital process and dorsal fin length) from those in Eastern and Southern Africa (Teugels 1998), possibly reflecting earlier taxonomic recognition of three species, two of which (*Clarias mossambicus* (Peters, 1852) and *Clarias lazera* (Valenciennes, 1840)) have since been incorporated into *C. gariepinus* (Skelton 1993). Transcontinental movement of populations used for aquaculture may pose a threat to this differentiation.

In Thailand, extensive survey data on the genetic diversity of *C. macrocephalus* (based on eight polymorphic isozyme loci) have revealed that genetic variation of wild populations varies considerably relative to distribution. Diversity was high ($H_o = 0.056$) on the central plain, which is well supplied with many river systems, moderate on the north-eastern plateau ($H_o = 0.038$) and low in the south ($H_o = 0.029$), which is relatively mountainous with disconnected habitats (Na-Nakorn *et al.* 2004). *Clarias* aff. *batrachus* 'Indochina' shows relatively low genetic variation ($H_o = 0.025$) compared with *C. macrocephalus* (Attha-insi *et al.* 2001), implying a lower effective population size for the former. It was apparent that populations of *C. batrachus* in the south (Malay Peninsula) were genetically differentiated from those of the mainland.

Genetic variation of *Clarias nieuhofii* (Valenciennes, 1840) varied considerably among five Thai populations based on allozymes (mean number of alleles per locus was 1.3–1.5; percentage of polymorphic loci was 10–30%; observed heterozygosity was 0.022–0.065; Jundam *et al.* 2001). Genetic differentiation among populations was marked (genetic distance was 0.000–0.198). The level of genetic differentiation was associated with the connectivity of their habitats.

Genetic impacts of translocation

Translocation of non-native species or populations may result in the spread of diseases, competition with indigenous species and/or genetic contamination if the introduced fish is capable of producing fertile hybrids with the native fish. In Africa, the *H. longifilis* × *C. gariepinus* hybrid, once thought to be sterile, has recently been shown to have the capacity to interbreed with wild *C. gariepinus* (Tom Hecht, pers. comm., 2007). Models seem to indicate that such genetic introgression can compromise reproduction of the pure species and lead to species extinction (Allendorf & Luikart 2007). Although not documented, Tom Hecht (pers. comm., 2005) observed a reduction in overall fecundity and therefore in the fitness of the introgressed stocks, leading to a decline in wild stocks. Euzet and Pariselle (1996) found that 'heteroclarias' juveniles were susceptible to *Henneguya* infections to which both pure *Heterobranchus* and *Clarias* were immune, raising further questions about the wisdom of creating this hybrid.

In Asia, the widely produced *C. macrocephalus* × *C. gariepinus* hybrid has been escaping from fish farms and interbreeding with wild *Clarias* spp. for many years, causing widespread concern about the effects of the introgression of *C. gariepinus* genes into the local species, potentially reducing the value of wild genetic material for future fisheries and aquaculture applications. Introgression of alleles from the *C. gariepinus* genome into that of *C. macrocephalus* has been reported in wild populations across Thailand based on isozyme loci (Na-Nakorn *et al.* 2004; Senanan *et al.* 2004). In Thailand, the introduction and escape from aquaculture of the *C. macrocephalus* × *C. gariepinus* hybrid has been related to declines in wild stocks of *C. batrachus* (Main & Reynolds 1993). Conversely, escape of *C. batrachus* from culture facilities has been linked to the virtual disappearance of wild *C. macrocephalus* in the Philippines (Main & Reynolds

1993; Lever 1996). Likewise, in Taiwan *C. batrachus* has interbred with the indigenous *C. fuscus*, which is now in serious decline as a pure species (Lever 1996).

In addition to the dangers posed to indigenous biodiversity by these interspecific and intergeneric hybrids, concerns have been expressed about the possible negative consequences of escapees from monogenetic, but domesticated culture populations reducing the fitness of conspecific wild populations. Much of this argument has been put forward by researchers studying declines in Atlantic salmon (*Salmo salar* Linnaeus, 1758) populations in Europe (c.f. Hutchinson 2006). With few captive strains of clariid catfish available, such impacts are probably not of major concern at the present time, particularly in light of rapidly declining environmental quality, which poses a much greater threat in the short term. However, if hybrids between escapees from aquaculture and wild fish exhibit higher than average fitness in the local environment, a certain amount of genetic variability linked to less well-adapted genes might eventually be lost from the wild population (Hartl 1980; Stearns 1992). Nevertheless, shifting gene frequencies are a natural consequence of any significant change in the environment and whether or not alterations in frequencies *per se* represent threats to the survival of significant wild biodiversity depends largely on the stability of the ecosystem in which the species or population in question lives (Stearns 1992).

Conservation of clariid gene pools

Only a small percentage of the threats to clariid biodiversity come from aquaculture. Like other freshwater fish, *Clarias* catfish have been facing severe threats from urbanization, pollution and habitat fragmentation. In much of Asia, it may be too late for conservation in the wild through the preservation of intact and functional aquatic ecosystems, usually considered the most practical and effective approach overall (Gibson & Pullin 2005). *Clarias macrocephalus* and *C.* aff. *batrachus* 'Indochina', for example, inhabit swamps and inundated rice paddies where they are directly exposed to pesticides and vulnerable to overharvesting when their habitats dry out. To date, no systematic *in situ* conservation strategy, either in the wild or on farms, has been documented for clariid catfish.

Technology for *ex situ* conservation is, however, available and although expensive may represent the only realistic option, particularly for Asia. Cryopreservation of embryos, sperm and eggs has been piloted in Africa, but with very limited success except for sperm (Van der Bank & Steyn 1992; van der Walt *et al.* 1993b; Volckaert & Agnèse 1996; Allendorf & Luikart 2007). Huang *et al.* (2005) mentioned a proposal to include *C. fuscus* in Taiwan's Council of Agriculture Genebank Preservation Program. Likewise, the Indian *C. batrachus* is being subjected to research attempting to establish a program for the cryopreservation of embryonic cells and sperm (Kuldeep K. Lal, pers. comm., 2009). Sperm cryopreservation protocols for *C. macrocephalus* have been established in Thailand and samples of cryopreserved sperm of one cultured and five wild populations are now housed at the Cryopreservation Unit, Department of Fisheries, Thailand (Polachart Pewnane, pers. comm., 2009). At present, no guidelines for accessing these materials for either research or culture have been elaborated.

Fin-clip samples of *C. batrachus* and *C. nieuhofii* have been preserved in the DNA bank at the Inland Aquatic Resource Research and Development Institute, Department of Fisheries, Thailand. The DNA bank was established to provide referenced genetic information for genetic monitoring of target species/populations. In addition, the genetic information will be used to clarify ownership whenever required (Wongpathom Kamonrat, pers. comm., 2009). The DNA bank is designed to accommodate the deposition of samples and the storage of genetic data and an electronic database is now available for researchers.

Problems on clarification of ownership

Documentation of aquatic genetic resources is a prerequisite for defining ownership and access arrangements. However, the material currently available through DNA banks and cryopreservation units is of limited diversity (in terms of species coverage) and accessibility to researchers. To date, even brief documentation of clariid gene pools is available for only five species, *C. gariepinus* (Van der Bank *et al.* 1992; van der Walt *et al.* 1993b; Volckaert *et al.* 1995; Van der Bank 1998); *C. macrocephalus* (e.g. based on allozymes (Daud *et al.* 1989; Na-Nakorn *et al.* 2004; Senanan *et al.* 2004) and microsatellites (Na-Nakorn *et al.* 1999)), *C.* aff. *batrachus* 'Indochina' (e.g. based on allozymes (Attha-insi *et al.* 2001)), *C. nieuhofii* (based on allozymes, (Jundam *et al.* 2001)) and *C. fuscus* (based on RAPDs, (Huang *et al.* 2005)).

Conclusions and recommendations

Clarias catfish make important contributions to food security and their culture generates income all over the world, in particular in developing countries, where they have been extensively translocated. The ecological impacts of these movements are poorly documented, but probably include reductions in genetic purity and, possibly, in the abundance of indigenous clariids.

Except for the widespread use in Asia of hybrids between local species and the African *C. gariepinus*, clariids have been subjected to only limited genetic improve-

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ment, despite significant evidence of genetic variability and thus selection potential for culture traits.

Although the importance of clariid genetic resources is widely recognized, systematic management of farmed stocks, sperm cryopreservation, DNA banking and various *in situ* conservation measures are at an early stage. There are at present no systematic identification and documentation systems in place to regulate national or international access to stored material or to determine ownership.

To facilitate the efficient use and exchange of clariid genetic diversity, we recommend establishing a standardized set of neutral molecular markers and economically important traits for the characterization and documentation of farmed and wild strains of clariids that can be used to better manage their transfer and genetic integrity (particularly selective breeding). The biodiversity and economic impacts of translocation, positive and negative, should be systematically evaluated and measures to limit further damage should be considered. Most importantly, *in situ* conservation plans aimed at protecting the functional integrity of ecosystems are urgently required and should receive more attention and input to cope with increasing threats to the important aquatic genetic resources they harbour.

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