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Use and exchange of genetic resources of emerging species for aquaculture and other purposes

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Abstract

From a genetic resources viewpoint, emerging aquaculture species and species groups are examined mainly in terms of food use. In addition, we include species that are becoming increasingly important for biodiversity conservation and related ecotourism aspects. Together with ornamental fish species, we argue that these species are facing increasing vulnerability and warrant attention. Our intention is to raise awareness of the potential for increasing production and revenues from emerging species/species groups with an emphasis on an underlying link to biodiversity conservation and ecosystem preservation, and how this information will inform policy on access to the genetic resources and the sharing of benefits derived from their use. For food purposes, the fastest growing aquaculture sector is mariculture, and within this sector groupers and wrasses are considered to be the most important because they cater to the relatively lucrative live food fish restaurant trade (LFFRT), which is rapidly expanding in selected South-East Asian countries. In the Asian region, ecotourism is an emerging sector and a prominent fish group for this purpose is considered to be mahseer. A number of mahseer species are culturally and commercially important and are often seen as a group of indigenous species that are suitable for aquaculture. This review summarizes much of the limited information related to the patterns of use and exchange of genetic resources on emerging aquatic species/species groups, with particular reference to Asia.

Key words: aquaculture, emerging species, genetic resources, marine finfish, ornamental fish.

Introduction

General scope of the review

For the purposes of this review, we focus on cultured food fish that are rapidly growing to high levels/volumes of production (mainly for export), and to a lesser extent on ornamental fish species as well as those species recognised to be of importance in the relatively new recreational fishery sector, related to ecotourism, in Asia. The emphasis on Asia primarily results from the fact that this region contributes over 90% to global aquaculture production (FAO 2007) and is the predominant supplier to the ornamental fish trade (Rixon *et al.* 2005). Furthermore, we have chosen to restrict our attention to finfish only because of the limited information on other taxa. With regard to our choice of species/species groups, there is an underlying link to biodiversity conservation and ecosystem preservation.

There are an increasing number of emerging species in the mariculture subsector in Asia. Mariculture is the fastest growing subsector in Asian aquaculture accounting for 1.1 million tonnes (~US$4 billion) in 2007 (FAO 2007). Over the past decade this subsector has grown at an annual rate of approximately 8%. This subsector, like other aquaculture practices in Asia, continues to be small-scale, farmer owned, operated and managed systems, often clustered together in areas that are conducive for mariculture, such as in enclosed or semi-enclosed coastal bays and lagoons. The main species/species groups in this development are members of the subfamily Epinephelinae of the family Serranidae (groupers), Labridae (wrasses, including Napoleon wrasse

Cheilinus undulatus Rüpell, 1835) and the single species of the family Rachycentridae, cobia (*Rachycentron canadum* (Linnaeus, 1766)) (Sadovy 2000).

We also consider species and/or species groups that are becoming increasingly important from conservation and related ecotourism aspects. In the Asian region, and indeed in the developing world as a whole, ecotourism is an emerging sector and one of the most prominent groups for this purpose is considered to be mahseer; a number of mahseer species are considered to be the 'salmon' of Asia from a recreational fishery viewpoint (Ogale 1997, 2002). In addition, mahseer is also emerging as a high-value cultured freshwater fish species in some regions of Asia (Ingram *et al.* 2005, 2007).

Aquaculture, unlike other animal food production sectors, currently includes large numbers of diverse taxa (FAO 2007), encompassing many different aquatic environments and ecosystems. The number of farmed species is steadily increasing. Aquaculture has involved the exchange of genetic resources across natural ranges of distribution, as well as resources changed through processes of genetic alteration, for example, hybridization and comparable technologies, usually targeting higher productivity and/or to suit new environmental parameters beyond those natural to the cultured taxa. In general, the area of genetic resources of taxa of significance to sustainable food production is not as advanced as higher animal taxa, and it is opportune and imperative that this aspect receives the attention and emphasis it deserves if global biodiversity is to be conserved and food production improved and sustained. The international community has addressed issues of genetic resources in terrestrial crops (CGRFA 2009) and animals (CGRFA 2007a) and now is the time to include aquatic animals in this process (CGRFA 2007b).

Why consider emerging aquaculture species in relation to the new access and benefit sharing rules?

The rules referred to above originated with the establishment of the Convention on Biological Diversity (CBD), which resulted from the United Nations Conference on Environment and Development held in Rio de Janeiro, Brazil, in 1992. The three goals of the CBD are to promote the conservation of biodiversity, the sustainable use of its components, and the fair and equitable sharing of benefits arising out of the utilisation of genetic resources. With regard to the latter, the CBD introduced a system for the regulation of collection, utilisation and other types of access to genetic resources: the Access and Benefit Sharing (ABS) system.

The Conference of the Parties to the convention adopted the 'Bonn Guidelines' (Secretariat of the Convention on Biological Diversity 2002) to facilitate the implementation of the ABS system, which is intended to guide both the providers and users of genetic resources in the application of the ABS system. The guidelines identify the steps in the access and benefit-sharing process, with an emphasis on the obligation of users to seek the prior informed consent of the providers. The guidelines also cover other elements, such as incentives, accountability, means for verification and dispute settlement, and detail suggested elements for inclusion in material transfer agreements and provide an indicative list of both monetary and non-monetary benefits.

Taking up the mandate from the Johannesburg World Summit on Sustainable Development in 2002, the Conference of the Parties decided to create an international framework on ABS, the ABS Regime, and negotiations on the regime formally started in 2005.

The Norwegian Atlantic salmon experience (see Olesen *et al.* 2007) suggests that it is preferable to put in place rules for access to aquatic genetic resources early in the development of new species/species groups for culture; otherwise the genetic resources are moved about, developed and used by others in a variety of ways making later 'protection and control of access' much more tedious. Thus, the original owners or developers of the resource may be denied appropriate benefits. For this and other reasons, it is argued that it is most opportune to discuss emerging species/species groups and develop new access strategies.

This review deals with issues related to the genetic resources of emerging aquaculture species and related to new developments, such as ecotourism of aquatic species in Asia and the ornamental finfish trade. It also explores issues related to patterns of use and exchange of aquatic genetic resources in relation to the above three facets.

Current status and issues on aquaculture related to genetic resources

Aquaculture, the farming of aquatic organisms, is expanding rapidly and now accounts for approximately 50% of aquatic food that is directly consumed (FAO 2007). In contrast to terrestrial farming systems, where most global production is limited to a small number of animal and plant species, in aquaculture 336 different animal and plant species, representing 115 families, are cultured (FAO 2007). Most aquaculture species are finfish species and more species are emerging to serve the increasing global demand for seafood (Subasinghe *et al.* 2009).

The translocation and introduction of non-native species (also referred to as alien or exotic species) in aquaculture are controversial and have attracted much attention (Moyle & Leidy 1992; Gopal 2005; De Silva *et al.* 2006). It is often suggested that species introduction is an important factor impacting biodiversity (Barel *et al.*

1985; Moyle & Leidy 1992; Naylor *et al.* 2001; Collares-Pereira *et al.* 2002). Asia, in particular South-East Asia, is a primary hub for the wildlife trade (Committee for International Trade in Endangered Species: http://www.cites.org) and for the aquarium/ornamental fish trade. The aquarium/ornamental fish trade is also very much linked to problems related to fish introductions (Courtenay & Stauffer 1990; Rixon *et al.* 2005), and as such offers an additional indirect threat to indigenous biodiversity.

However, from a food production viewpoint, alien species in aquaculture play a significant role in Asia (De Silva *et al.* 2006) and in countries where aquaculture is emerging or recently developed, such as Chile, where major sectors may be largely dependent on introduced species (Gajardo & Laikre 2003). The balance of evidence suggests that translocations in aquaculture have been beneficial from a food production and livelihood viewpoint and that there is no explicit evidence to demonstrate that alien species in aquaculture have overly negatively impacted on biodiversity (Crivelli 1995; Gozlan 2008). Accordingly, in the sections below, we will deal with those species of aquaculture importance that are considered to be emerging species and/or species groups.

Marine fish

Groupers

Groupers are classified into 14 genera of the subfamily Epinephelinae, which comprises at least half of the approximately 449 species in the family Serranidae (Tucker 1999). Throughout most warm and temperate marine regions, serranids are highly valued for food, and some are kept in aquaria. There are 15 major grouper species that are cultured (Ottolenghi *et al.* 2004). The species that are most consistently and abundantly captured for culture purposes and also reared in hatcheries are *Epinephelus coioides* (Hamilton, 1822) (frequently misidentified either as *Epinephelus tauvina* (Forsskäl, 1775) or *Epinephelus malabaricus* (Bloch & Schneider, 1801)) and *Epinephelus fuscoguttatus* (Forsskäl, 1775). Other important species include *Epinephelus bleekeri* (Vaillant, 1878), *Epinephelus akaara* (Temminck & Schlegel, 1842), *Epinephelus awoara* (Temminck & Schlegel, 1842) and *Epinephelus areolatus* (Forsskäl, 1775). Also cultured in small numbers are *Epinephelus amblycephalus* (Bleeker, 1857), *Epinephelus malabaricus* (Bloch & Schneider, 1801), *Epinephelus lanceolatus* (Boch, 1790), *Epinephelus sexfasciatus* (Valenciennes, 1828), *Epinephelus trimaculatus* (Valenciennes, 1828), *Epinephelus quoyanus* (Valenciennes, 1830), *Epinephelus bruneus* Bloch, 1793, *Epinephelus polyphekadion* (Bleeker, 1849), *Epinephelus coralicola* (Valenciennes, 1828), *Cromileptes altivelis* (Valenciennes, 1828) [*Epinephelus altivelis* after Ding *et al.* (2006)], *Plectropomus leopardus* (Lacepede, 1802) and *Plectropomus maculatus* (Bloch, 1790) (Ottolenghi *et al.* 2004).

Owing to a similarity in morphological traits and body colouration changes at different development stages of the life cycle, groupers are reputedly complex in terms of taxonomy and nomenclature. Although species identification guides are available for almost all grouper species worldwide (Heemstra & Randall 1993), there is still much confusion and misidentification of grouper species (Heemstra & Randall 1993; Leong 1998; Sadovy 2000). In addition, as with many other species groups, the common names used for groupers are also confusing. Each species may have more than one common name and sometimes different species share the same common name (Table 3).

Demand for groupers. Aquaculture of groupers is practised in many South-East Asian countries, including Indonesia, Malaysia, the Philippines, Taiwan, Thailand, Hong Kong, the south-east of China and Vietnam, and in other parts of the tropics, for example, in south-eastern USA and the Caribbean. Grouper culture is also undertaken in India, Sri Lanka, Saudi Arabia, Korea and Australia, but to a much lesser extent (Ottolenghi *et al.* 2004). Grouper culture is driven by high prices, particularly for the live food fish restaurant trade (LFFRT) in Hong Kong, Singapore and China, leading to concerns around the decreasing wild-caught product as a result of over fishing (Sadovy *et al.* 2003). The LFFRT is almost exclusively confined to selected South-East Asian nations, often with a predominance of ethnic Chinese.

The LFFRT is usually dominated by reef fishes, in particular groupers (Family Serranidae), snappers (Family Lutjanidae) and some wrasses (Family Labridae). Over time the LFFRT has attracted the attention of conservationists with regard to the depletion of resources (e.g. concerns about fishing impacts on spawning aggregations) and destruction of habitats (Pet 1997; Mous *et al.* 2000; Pet-Soede *et al.* 2004). It has been suggested that fisheries for reef fish that cater to LFFRT have spread through a considerable proportion of the Indian and Pacific Oceans (Sadovy *et al.* 2003). Regions with coral reefs are often over fished and are in a state of increasing vulnerability (Sadovy 2005; Scales *et al.* 2007). The gradual spread of reef fisheries over time has been compared with the phenomenon of roving bandits, an expression used by Berkes *et al.* (2006) for step-wise exploitation of stocks as each gets depleted, engaged in the exploitation of common natural resources (Scales *et al.* 2006).

Until recently, many reef fish market demands were dependent to a significant extent on wild-caught fish, and often fish caught using destructive fishing methods (Pet 1997). The exact extent of such practices for LFFRT remains controversial, but many of these fishing methods leave a trail of destruction of the habitats of the target species; habitats that are mostly fragile, slow-growing coral reefs. The rates of recovery of these fragile habitats are very variable (Jones & Steven 1997) and some do not recover at all (McManus *et al.* 1997). This destruction is bound to result in a loss of biodiversity of these sensitive and fragile habitats.

The LFFRT has become increasingly lucrative because of the huge difference in price for the same fish species when dead as opposed to being sold live in the LFFRT; the LFFRT is linked to increasing living standards and higher levels of disposable income with increases in people dining out (Pawiro 2005). It is estimated that the current market for live food fish is significant; approximately US$275 million, with approximately 40% of the trade being channelled through Hong Kong (Johnston & Yeeting 2006).

Genetic studies on groupers. Historically, attempts to elucidate evolutionary relationships among groupers have been hindered by the large number of species, a pan global distribution and the lack of morphological specializations traditionally used in ichthyological classification. Recently, several studies have used molecular markers to address this issue. The studies conducted in the Asia–Pacific region using mitochondrial DNA (mtDNA) cytochrome b partial gene sequences (Ding *et al.* 2006), microsatellite markers (Koedprang *et al.* (2007) and random amplified polymorphic DNA (RAPD) markers (Govindaraju & Jayasankar 2004) all point to the fact that there is great diversity among grouper species, but equally that there is significant confusion in taxonomy. However, the existing confusion on taxonomy is genetically resolvable (Koedprang *et al.* 2007).

A very limited number of studies have been undertaken in groupers with an emphasis on characterisation of diversity at the species level. Details on the samples, markers used and major findings are given in Table 1. For example, a high level of population genetic structure was reported for *E. coioides* from Thailand and Indonesia (Antoro *et al.* 2006), in *E. polyphekadion* three geographical clusters were found, that is, (i) Palau, (ii) Pohnpei and the Marshall Islands and (iii) the Great Barrier Reef and New Caledonia (Rhodes *et al.* 2003); a study on

Table 1 Studies on the genetic characterisation of groupers

Sample origin	Marker	Major findings	Authors
Epinephalus coioides Thailand Nakornsrithammarat, Trang Indonesia Sibolga, Lampung, Jepara, Flores	Microsatellites (Nugroho *et al.* 1998)	High level of population genetic structure Samples from Makorsithammarat and Trang in Thai waters were found to be distinct	Antoro *et al.* (2006)
Epinephalus polyphekadion New Caledonia Great Barrier Reef Palau Marshall Inslands Pohnpei 1997 Pohnpei 1998	Microsatellites (Chapman *et al.* 1999; Rhodes *et al.* 2003)	Three clusters were found: (i) Palau, (ii) Pohnpei and the Marshall Islands and (iii) the Great Barrier Reef and New Caledonia Temporal genetic differentiation was observed in samples from Pohnpei	Rhodes *et al.* (2003)
Plectropomus leopardus Australia Torres Strait, Townsville, Capricorn Bunkers, Scott Reef, Abrolhos Islands *Plectropomus maculatus* Australia Torres Strait, Townsville, Capricorn Bunkers, Kimberly coast, Dampier, Pilbara coast	Mitochondrial DNA sequences of partial control region Microsatellites (van Herwerden *et al.* 2000) Sequences of the nuclear intron EST2	Evidence of hybridization between the two species on the east coast of Australia Mitochondrial DNA revealed contrasting regional interspecific patterns, whereas nuclear markers revealed contrasting patterns among markers irrespective of region	van Herwerden *et al.* (2006)

Australian populations of *P. leopardus* and *P. maculatus* revealed that there was evidence of hybridization between the two species on the east coast of Australia and that mtDNA revealed contrasting regional interspecific patterns, but nuclear markers revealed contrasting patterns among markers irrespective of region (van Herwerden *et al.* 2006).

Movements of the genetic resources of groupers. Grouper genetic resources are one of the most extensively moved around in the Asia–Pacific region, as reviewed by Sadovy (2000). The results of these findings together with updated information from field visits by the authors are summarised in Table 2 and schematically represented in Figure 1. Groupers, as a group, differ from most other cultured groups in that the genetic resources are moved as fertilized eggs, hatchlings, fingerlings and yearlings, and adults as broodstock; all these movements of resources are linked to aquaculture operations and to the LFFRT. Regulations governing these movements are relatively sparse (see Table 2) and the implications of these movements are equally undetermined and uncertain.

Aquaculture of groupers. The total aquaculture production of groupers in 2007 was reported to be approximately 70 000 tonnes, with nearly 90% from China and Taiwan (FAO 2007). However, this figure is believed to be an underestimation because production from some countries, such as Vietnam, is not reported separately, but rather included in other categories such as 'marine finfish' production. It is also acknowledged that it is difficult to obtain accurate statistics on farmed grouper production because wild-caught fish are usually held for a few weeks in cages before being sold, leading to difficulties in differentiating these fish from those cultured/held for a longer period of time (Ottolenghi *et al.* 2004).

Trends in grouper production and the relative contribution of aquaculture are shown in Figure 2. Currently aquaculture contributes nearly 40% to the total, all of which is from Asia, and these numbers have been increasing steadily. Importantly, cultured groupers now contribute very significantly to the LFFRT. There is a growing acceptance of farmed fish, often supported by campaigns of conservation groups seeking to guide consumers on responsible eating practices (http://www.livefoodfishtrade.org). The growth of grouper aquaculture and the resultant decline in the wild fishery and the concurrent use of destructive fishing methods are expected to have positively impacted grouper and related habitat conservation.

However, grouper aquaculture still depends to some extent on wild-caught seed, particularly for some of the popularly sought after species. As indicated earlier (Fig. 1; Table 2) seed is collected and transported across many South-East Asian nations (Sadovy 2000). Increasingly, major breakthroughs in the hatchery technology of a number of important grouper species are leading to closure of these life cycles and hatchery seed production/commercialisation (Table 3; Sim *et al.* 2005). Unfortunately, the extent of reliance of grouper aquaculture on wild-caught seed is still often overstated; for example, recently it was stated that 'Because grouper are particularly difficult to culture in closed systems, full-cycle culture of most grouper species is not yet possible' (Tupper & Sheriff 2008, p. 240). In addition, greater understanding of the drivers of this changing situation will be useful. For example, the source of grouper fingerlings (e.g. hatchery *vs* wild caught) seems to be driven primarily by economic factors, rather than by sustainability demands. For instance, in Aceh, Indonesia, there is an established grouper nursing industry that sources wild-captured *E. coioides* and hatchery-reared *E. fuscoguttatus* (Rimmer & Phillips 2008) because *E. fuscoguttatus* is more valuable than *E. coioides*.

Likewise, the extent of production of hatchery-reared groupers is often understated or misrepresented. Tupper and Sheriff (2008, p. 240) stated that 'It is important to realize that the equivalent of the typical annual amount of seed produced in the hatcheries in the whole of Southeast Asia (excluding TPoC), i.e. 20 000–80 000 fry, can be caught by one fisherman in one night'. In reality, 20 000–80 000 fry can be produced from a single production run, even in a 'small-scale' or 'backyard' hatchery (Sim *et al.* 2005). In contrast, 43 (40 'small-scale' and three 'complete') hatcheries in Buleleng Regency, northern Bali, produce around six million *E. fuscoguttatus* fingerlings each year, and smaller numbers of *C. altivelis* and *P. leopardus* (Suko Ismi, pers. comm., 2008), indicating the increasing shift towards the use of hatchery-produced seed stock in aquaculture.

It is expected that further commercialisation of hatchery seed production of more grouper species will develop, driven by industry demand and price, with a consequent decline on dependence on wild-caught seed. However, increasing production of hatchery-reared grouper fingerlings will not necessarily eliminate the problem of translocation of broodstock and seed stocks because the above developments are relatively unevenly spread across countries in the region, and will only be eliminated when all grouper farming countries develop their capabilities to comparable levels.

Cobia, Rachycentron canadum *(Linnaeus)*

Cobia represents a single species taxon that is a migratory, pelagic marine teleost, widely distributed in tropical, subtropical and warm temperate waters (Briggs 1960),

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Table 2 Translocation patterns of fry and fingerlings of groupers and wrasses in South-East Asia

Country	Species	Area of collection	Export to	Rules/regulations
Indonesia	*Epinephelus bleekeri* *Epinephelus coioides*	Aceh, NE Sumatra (P. Kampai, P. Sembilan, Jaring Halus), western Sumatra (Sibolga Bay), southern Sumatra (Lampung), Java (Banten Bay), eastern Java (Situbundo) Northern Bali and Nusa Tenggara province (Sena S. De Silva, pers. obs., 2009)	Hong Kong, Hainan Island of China Java, Sulawesi, Malaysia and Thailand	Ministerial Decree of Agriculture No. 375/KPTS/1K.250/95 (16 May 1995) prohibits capture of humphead wrasse (*Cheilinus undulates*) except for research and cultivation Directorate General of Fisheries No. 330/DJ.8259/95 (6 September 1995) allows fishermen to catch humphead wrasse in selected fishing ground with boats <5 gross tonnes using hook and line, fish trap and gill net and for only animals of 1–3 kg Any company purchasing/exporting such fish must have a permit Ministerial Decree of Trade No. 94/KP/V/95 (24 May 1996) bans all exporters of humphead wrasse except for those animals caught as specified by law
Malaysia	*Epinephelus bleekeri* *Epinephelus coioides* *Epinephelus malabaricus*	East Malaysia: Tuaran and Sandakan West Malaysia: Besut and Setiu	No export	Fertilised eggs and grouper seeds cannot be imported to Sabah for culture to avoid spreading of fish diseases In West Malaysia, grouper fry fishing is not allowed during November and December No export permitted of grouper fry/fingerlings smaller than 15 cm
Thailand	*Epinephelus bleekeri* *Epinephelus coioides*		Taiwan, China, Hong Kong Also illegal trade with neighbouring countries (i.e. purchased from Myanmar and Sabah and sold to Malaysia, or purchased from Cambodia and Vietnam and sold to Singapore)	Limit the use of pish bet (sacbag) and fyke nets. Push net trawlers should not be used within 3 km of shore and trawler mesh size must be ≥2.5 cm
Phillipines	*Epinephelus coioides* *Epinephelus malabaricus*	Bacgacay Bay, Batasan Island, San Miguel Bay, Buguey, La Union	Taiwan, Hong Kong, China	Transportation and export of fish and fisheries products requires permits from the Quarantine section, including a health certificate from the Fish Health section of the Bureau of Fisheries and Aquatic Resources (BFAR) The Philippines Fisheries Code of 1998 (RA 8550), Article II, Section 51 regulates gear/structures and operation zones for fish capture and culture
Vietnam	*Epinephelus areolatus* *Epinephelus coioides* *Epinephelus malabaricus*	Quang Ninh, Nghe An, Quy Nhon	China, Hong Kong, Taiwan	Prohibit export of groupers less than 500 g (former Ministry of Fisheries) For export, a health certificate from a provincial office, Fisheries Resources and Environment Conservation Sub-Department is needed
China	*Epinephelus bleekeri* *Epinephelus coioides* *Epinephelus malabaricus*		Import only	Limit the number of grouper fry fishers and the capture quantities of grouper seed A licence is needed for transporting marine fry Export of fry is prohibited
Taiwan†	*Epinephelus coioides* *Epinephelus malabaricus*		Import from Thailand, Sri Lanka, Indonesia, the Philippines, Malaysia	In the Penghu islands, fishers are not permitted to catch any grouper seed of <6 cm to protect the fingerlings that have been released during 'restocking' exercises The use of cyanide for fishing is illegal
Hong Kong	*Epinephelus coioides* *Epinephelus malabaricus* *Epinephelus fuscoguttatus*		Import from Taiwan, China, Malaysia, the Philippines, Thailand, Myanmar, Indonesia, Sri Lanka, Vietnam	No regulations that apply to the capture of grouper fry or their import or export Culture of grouper must be licensed

†Note also that Taiwan exports both hatchery-produced and import fish. Data source: Sadovy (2000).

Table 3 Major grouper species of interest to the live reef fish trade and an assessment of the origin of the seed stocks

Common English (FAO) name	Scientific name	Main farming countries	Seed production
Highfin (Humpback) grouper	*Cromileptes altivelis*	Indonesia, with smaller amounts (based largely on seed from Indonesia)	Successful in hatchery production. More than 80% produced from hatchery-reared seed
Tiger (brown marbled) grouper	*Epinephelus fuscoguttatus*	Widely cultured	Successful in hatchery production. More than 90% produced from hatchery-reared seed
Camouflage (flowery) grouper	*Epinephelus polyphekadion*	Cultured in small quantities throughout the region	Reliant on wild capture; hatchery technology developed, but growth rates reportedly too slow to interest farmers
Green (orange-spotted) grouper	*Epinephelus coioides*	Cultured in small quantities throughout the region	Reliant on a mix of wild and hatchery-reared seed; hatchery technology developed, but low value species – less profitable for hatcheries compared with *E. fuscoguttatus*
Malabar (black-spotted) grouper	*Epinephelus malabaricus*	Cultured in small quantities throughout the region	Successfully bred; not commercialised
Giant (giant) grouper	*Epinephelus lanceolatus*	Not commercialised; experimental stage	Successfully bred; limited commercial production, mostly in Taiwan
Leopard (leopard) coral grouper	*Plectropomus leopardus*	Cultured in small quantities throughout the region	Successfully bred; limited commercial production in Taiwan, Thailand, Indonesia
Spotted (spotted) coral grouper	*Plectropomus maculatus*	Cultured in small quantities throughout the region	Successfully bred; not commercialised
Humphead (Napoleon) wrasse	*Cheilinus undulatus*	Convention on International Trade in Endangered Species (CITES) of Wild Fauna and Flora listed, some illegal movement. Holding of wild caught fish only	Limited success in breeding, reportedly very slow growth
Hong Kong (red) grouper	*Epinephelus akaara*	Hong Kong	Initial success

except for the eastern Pacific (FishBase 2009). Cobia is characterised by a very high growth rate and possesses a life cycle that enables relatively straightforward artificial propagation, traits that are very amenable for aquaculture (Liao & Leaño 2007). The bulk of the current production of cobia comes from China and Taiwan, totalling approximately 30 000 t in 2007 (FAO 2007). Production of this species is set to expand rapidly, not only in Asia, but also in the Americas (Liao & Leaño 2007).

Cobia aquaculture started in Taiwan in the early 1990s. Mass culture techniques were initially developed in Taiwan and sea cage culture of cobia immediately followed (Liao & Leaño 2007). One consequence of this development was that fingerlings produced in Taiwan have been translocated to a number of other countries, including Japan (Nakamura 2007), Indonesia (Wahjudi & Michel 2007), Vietnam, Malaysia, Singapore, Mainland China and the Philippines (Niels Svennevig, pers. comm., 2009), as well as La Reunion Island (Gaumet *et al.* 2007) near Africa and the United Arab Emirates (Niels Svennevig, pers. comm., 2009) in the Middle East. In Indonesia, separate importations have been made to the Seribu Islands in Java (Wahjudi & Michel 2007), northern Bali (Tatam Sutarmat, pers. comm., 2008) and Lampung in southern Sumatra (Muhammad Murdjani, pers. comm., 2008). Cobia sourced from Australia is being grown-out in sea cages in the Republic of the Marshall Islands in the Western Pacific (Good Fortune Bay Fisheries 2009).

Cobia is often regarded as a newly introduced species. For example, in northern Bali, local farmers report that cobia was not seen prior to its introduction for sea cage farming in the early 2000s (Tatam Sutarmat, pers. comm., 2008). Now it is commonly found associated with sea cages in Pegametan Bay, Bali. The introduction of Australian-sourced cobia to the Majuro Lagoon in the Republic of the Marshall Islands has been contentious, with disagreement on whether cobia is native to Majuro Lagoon. It is likely that cobia has been introduced through aquaculture operations to areas where it is native. Perhaps cobia populations may be relatively small in these areas, which would explain why many fishers are unfamiliar with it, in which case there may be a significant genetic impact from the release or escape of farmed cobia.

In some cases, original Taiwan stock have been grown-out, matured and used as broodstock for subsequent local hatchery production (Gaumet *et al.* 2007; Wahjudi & Michel 2007). Although little information on the genetic diversity of these broodstocks is available from published sources, it is likely that the founder populations were of limited genetic diversity (because of the high fecundity of marine finfish a single batch of fingerlings are often full siblings) and thus second-generation broodstock populations may have restricted genetic diversity.

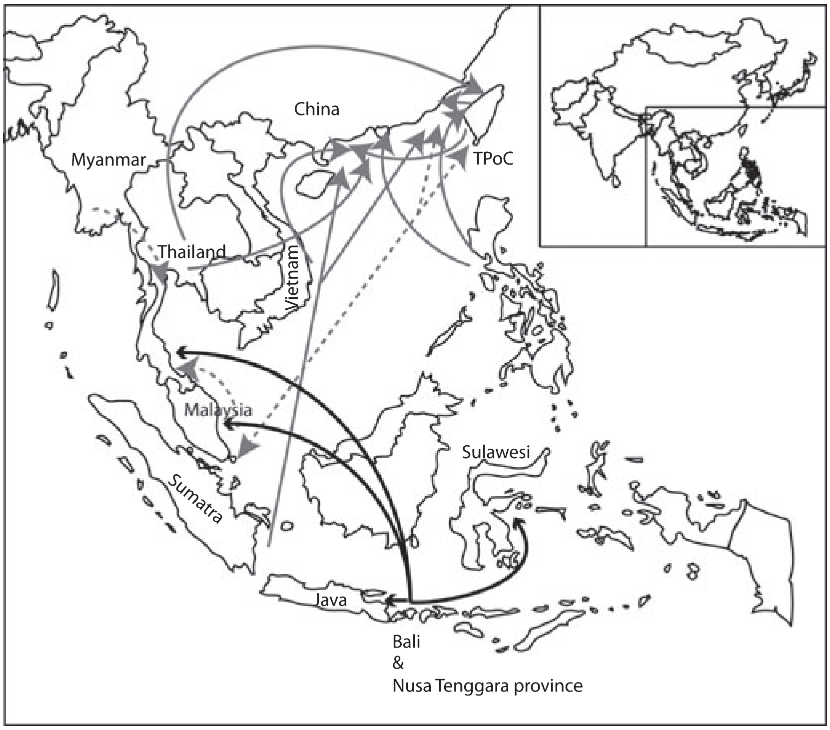

Figure 1 Movement of grouper genetic resources (modified from Sadovy 2005). The thicker arrows indicate movement of grouper genetic material based on personal observations (Sena S. De Silva, 2009).

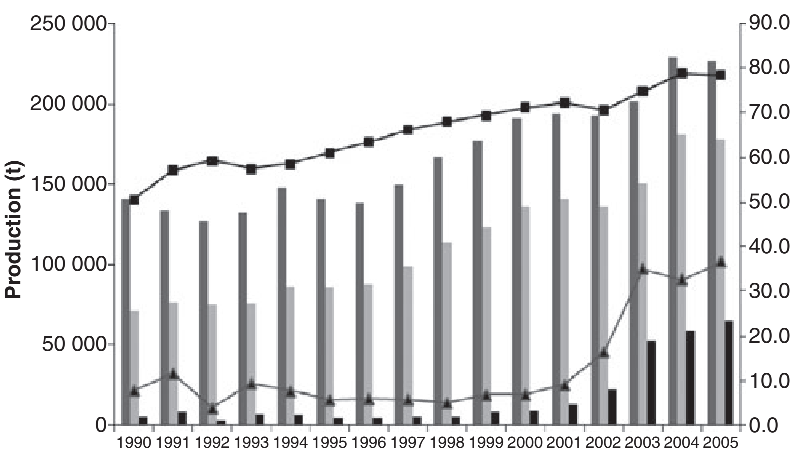

Figure 2 Trends in grouper catches with aquaculture production globally including the contribution (%) from Asia to the global catch and the contribution of aquaculture production to grouper production in Asia. Note that the apparent sudden increase in aquacultured grouper production in 2003 and subsequent years is an artefact caused by the disaggregation of marine finfish production data by China; prior to 2003 grouper production was grouped with marine finfish data. ▬, World (t); ▬, Asia aquaculture; –■–, Asia (%); ▬, Asia (t); –▲–, aquaculture (%).

Species related to other developments and trade

Finfish genetic resources in relation to sectors other than aquaculture for food fish production warrant attention. In this regard, the emerging developments of the recreational fishery linked to ecotourism and conservation and the traditional ornamental fish trade are worthy of increased future attention and research, particularly in the context of biodiversity conservation and ABS.

Species/species groups of ecotouristic and conservational value

In recent years there have been attempts to revive and develop recreational fisheries and related ecotouristic ventures of selected species in many countries, for example, India and Malaysia (Ogale 2006). Initial developments have taken place around the group mahseer, a number of members of which are believed to be the equivalent of salmon for recreational fishers (Ng 2004).

The group mahseer includes 46 species of the genera *Neolissochilus* and *Tor* and this group has a mainly tropical Asian distribution, ranging from the Himalayan Range in the west to Borneo Island in the east, and Nepal in the north to Indonesia in the south. This group of species has traditionally been of economic value for isolated aboriginal populations that depend on them as a food source through artisanal fisheries. However, with increasing developments, particularly deforestation and damming of pristine habitats, the populations of many species of mahseer have reportedly declined (Sungan *et al.* 2006).

Mahseers. Several species of mahseer have been reported as regionally threatened. For example, *Tor putitora* (Hamilton, 1822) and *Tor tor* (Hamilton, 1822) are listed as vulnerable in West Bengal, India (Mijkherjee & Praharaj 2002), and both are supposedly in danger of extinction in Nepal (Shrestha 1990), whereas *Tor yunnanensis* (Wang, Zhuang & Gao, 1982) is listed as endangered in China (IUCN 2003). *Tor* species are known to prefer clear, swift-flowing pristine waters with stony, pebbly or rocky bottoms. However, these habitats have been significantly degraded by the often dramatic changes associated with agricultural and industrial development (Ambak *et al.* 2007).

Tor tambroides (Bleeker, 1854) and *Tor douronensis* (Valenciennes, 1842) are high valued in Malaysia and are very much sought after. Both species currently fetch a very high market price (e.g. in 2004 prices for either species ranged from Malaysian Ringgit 160 to 240 kg^{-1} (Thuy T. T. Nguyen, pers. obs., 2004; 3.80 Malaysian Ringgit = US$1) and are of high cultural value. *Tor douronensis* for example, has been designated as the 'State Fish' of the state of Sarawak, East Malaysia. The aquarium trade also increasingly seeks juveniles of these two species. The Government of Sarawak, recognising the importance of these two species, made a concerted attempt to evaluate their aquaculture potential commencing in the 1990s, including captive breeding using long-term pond-reared broodstock. However, limited success was achieved until 2002–2004 when an international collaboration between researchers from Australia and Sarawak was able to breed both species in captivity using hormone induction techniques on long-term, pond-reared broodstock (Ingram *et al.* 2005, 2007).

Breeding techniques are being developed for several mahseer species in a number of countries. Most hatchery production of *Tor* juveniles, including *Tor khudree* (Sykes, 1839), *Tor mussullah* (Sykes, 1839), *T. putitora* and *T. tor*, for stocking programmes are derived by hand stripping mature spawners caught from reservoirs, lakes and rivers during spawning seasons, with or without using hypophysation (Ogale 1997). Recently Ingram *et al.* (2005) made a breakthrough in the breeding of *T. tambroides* and *T. douronensis* using pond-reared broodstock in Sarawak, East Malaysia, and the technology has now been adopted in West Malaysia for commercial production of *T. tambroides*.

The successful hatchery production of *T. tambroides* and *T. duoronensis* brought to the forefront problematic questions regarding documentation of genetic variation. First, the taxonomic status of these two species and the genus as a whole remains highly contentious (Roberts 1999); the descriptions provided by different authors and the related drawings in most instances are inconsistent and highly variable, leading to potential misidentification. Although some authors consider *T. tambroides* and *T. duoronensis* to be two valid species (Zhou & Cui 1996; Ng 2004), Roberts (1999) considered them to be a single species and a junior synonym of their congener, *T. tambra* (Valenciennes, 1842).

Phylogenetic studies of the mahseer group were recently reviewed by Nguyen (2008) using three mtDNA gene regions. It was found that *T. macrolepis* (Heckel, 1838) described in Pakistan is a synonym of *T. putitora*. High levels of divergence were found in *T. douronensis* in regard to stocks in Sabah, Sarawak and Sumatra. Detailed examination of the population genetic structure of *T. douronensis* in Sarawak indicated that this species has two major clusters, namely the 'north-western cluster' and the 'south-eastern cluster'. The former in turn comprises two subclusters, the Trusan River and the Limbang River, and the latter has three subclusters, the Rejang and the Sarawak Rivers, the Layar River and the Batang Lupar River (Fig. 3). This information was used to develop plans for broodstock management for *T. douronensis* in Sarawak. The plans take into account the difference between breeding for stock enhancement, which is very much an increasing trend for mahseer, as well as in aquaculture.

The approach to conservation of mahseer resources in Sabah is rather different and provides an interesting case for better understanding future directions of management of aquatic genetic resources research and practices. The State Government of Sabah has passed a new fisheries law, the Sabah Inland Fisheries and Aquaculture Enactment of 2003. This act gives the State Department of Fisheries (DoF) powers to manage and regulate all fisheries activities in the inland waters of the state. One of the strategies used was to implement community-based management, locally known as the 'Tagal System', which is a partnership between communities and the government, with DoF Sabah as the lead agency for protecting, rehabilitating, conserving and managing fishery resources in the state. To participate in this partnership, each

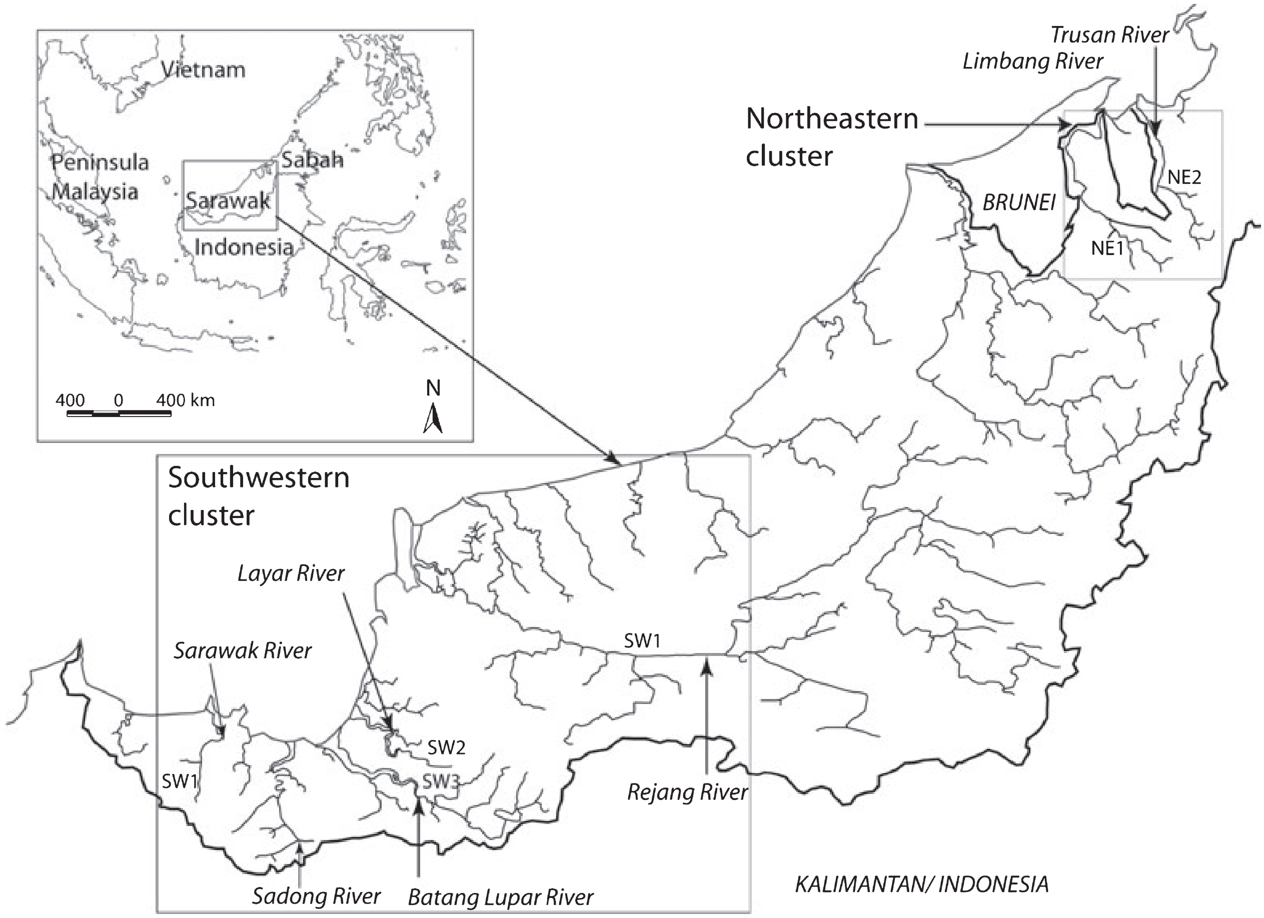

Figure 3 Population structure or *Tor douronensis* in Sarawak, Malaysia (Nguyen 2008). NE1 and NE2 are two subclusters of the north-eastern cluster; SW1, SW2 and SW3 are three subclusters of the south-western cluster. Samples from the Sadong River appear to be an admixture of individuals from the north-eastern and south-western clusters.

community must have traditional user rights, preferably to several deep pools in the river and manage and use its fishery resources under the leadership of the headman of the community (Wong 2006). By 2006, the 'Tagal' system of management had been set up at 234 sites in 11 districts involving 124 rivers and, consequently, had successfully revived the depleted river fish populations, including many with mahseer (Wong 2006).

A similar approach has been reported from Corbett Park in India, in which the 'Conserving the "tiger fish" (i.e. mahseer)' project aims to tap the potential of ecotourism in the buffer area of Corbett National Park. This project has involved people of nearby villages who are employed to patrol the area and stop illegal activities. Guided by enhancement of the prospects for tourism, residents from several villages have been working to conserve mahseer in the River Ramganga and in other streams in the region. Locals have been taught about the importance of conserving the mahseer species, thus leading to increases in population size of mahseer (Anonymous 2008).

This example of mahseer also illustrates the value of shifting the emphasis in many aquaculture operations from exotic to indigenous species; a principle that is receiving increasing support elsewhere, for instance, the Aquaculture of Indigenous Mekong Species, a component of the Mekong River Commission Fisheries Programme (http://www.mrcmekong.org/programmes/fisheries.htm) and others (Bartley *et al.* 2005). However, as pointed by De Silva *et al.* (2006) there are clear trade-offs that need to be taken into consideration, such as the special needs of small island countries and geographic regions with high degrees of biodiversity.

Ornamental fish

The freshwater aquarium fish trade, which is worth billions of US dollars (European Commission 2008), accounts for some of the most genetically modified species/species groups of finfish. Certain species groups have been hybridized and selectively bred for numbers of generations, over many decades, if not centuries (see Jeney & Zhu 2009), and it has become a common art that is applied by many aquarists throughout the world. However, there is a proportion of the aquarium fish trade that greatly depends on the capture of wild stocks for export purposes; most of these species are of high value from environmentally specialised habitats (Pethiyagoda 1991). The list of such species is too long to detail here, but in general it could be said that such species groups tend to be endemic to certain geographic areas, many of which are biodiversity hotspots, for example, the Western Ghats (Bossuyt *et al.* 2004). Similarly, in Sri Lanka, which is known to have a relatively meagre freshwater fish fauna (62 species and nearly 50% endemics), many freshwater fish species are exploited for the aquarium trade (Pethiyagoda 1991; Ekaratne 2000). The species and conservation status of these endemics are listed in Table 4. Similarly, in the Indonesian Papua region, one group that is exhaustively exploited for the aquarium trade is the rainbow fish (family Melanotaeniidae), in which approximately 71 species have been described to date (FishBase 2009). The pristine habitats of these species are being disturbed by an increasing number of anthropogenic activities and consequently these species are becoming very vulnerable. Of the rainbow fish in the region, only four species are cultured, whereas over 30 species are caught from the wild and exported (Laurent Pouyaud, pers. comm., 2009). With respect to the African continent, it has been estimated that of the 223 freshwater fish species of the ornamental trade in the East African region, 221 are endemics and 27% of these are in a threatened status, whereas for the West African region 57% of the species are in a threatened status (European Commission 2008).

In general, there has been a lack of entrepreneurship among aquarists to artificially propagate such species. There is a continuing trade in aquarium species caught from wild populations that are often subjected to increasing environmental threats arising from anthropogenic development (Nguyen & De Silva 2006). Furthermore, the aquarium trade is also purported to be one of the primary causes of unintentional translocations, which impact on indigenous biodiversity (Rixon *et al.* 2005).

Implications for access and benefit sharing issues

Identification of genetic resources

One of the first steps in developing mechanisms for access and benefit sharing is to identify the critical resources that have been maintained by local communities or have some degree of ownership or stewardship associated with them. Several efforts have been made to maintain information with regard to species names, distributions and other biological characteristics; e.g. Eschmeyer's Catalogue of Fishes (California Academy of Sciences Ichthyology 2009) and FishBase (FishBase 2009). However, as indicated in the introduction, genetic resources also include species level variation at the population, strain and breed levels. It is recommended that effort be put into developing a database to collate available information on the genetic resources of at least the major cultured species, including emerging species, similar to the database for livestock animals (i.e. Domestic Animal Diversity Information Service (DAD-IS); http://dad.fao.org/) or the Encyclopaedia of Life (http://www.eol.org/).

Knowledge and capacity building

The paucity of genetic knowledge on cultured species and their wild counterparts is a major impediment to developing meaningful and pragmatic strategies to address issues of access and benefit sharing. As is evident from previous sections, the genetic understanding of most emerging aquaculture species, as well as the endemic species that form a significant proportion of the ornamental fish trade, is relatively limited. Currently, there is unplanned and haphazard movement and translocations of emerging cultured species rather extensively in the Asian region. Foremost of these are the groupers and the wrasses, and

Table 4 Endemic freshwater fish species of Sri Lanka as important aquarium resources and their conservation status

Common name	Scientific name	Status
Cherry barb	*Puntius titteya*	Highly threatened
Black ruby barb	*Puntius nigrofsciatus*	Threatened, export is restricted
Mountain labeo	*Labeo fisheri*	Threatened, export is prohibited
Wilpita rasbora	*Rasbora wilpita*	Threatened under IUCN, endangered on National Red List
Ornate paradise fish	*Malpulutta kretseri*	Low risk, threatened, not protected
Combtail	*Belontia signata*	Threatened under IUCN, but not under the National Red List, exported is restricted
Giant snakehead	*Channa ara*	Threatened under IUCN, but not under the National Red List, exported is restricted
Lipstick goby	*Sicyopus jonklaasi*	Threatened under IUCN, export is restricted
Tiger loach	*Acanthocobitis urophthalmus*	Threatened under IUCN, no restrictions for exports
Walking catfish	*Clarias brachysoma*	Threatened under IUCN, export is restricted

IUCN.

this movement is primarily driven by the economic value of these species and their relatively easy marketability.

For many endemic ornamental fish species, which often have very restricted distribution ranges and specialised habitat requirements, some countries have brought about legislative measures curtailing their export. However, such moves have not gone hand in hand with corresponding developments in artificial propagation techniques. Therefore, faced with a shortage of farm-raised fish, unscrupulous entrepreneurs continue the trade on protected species through illegal means, with negative impacts on the vulnerability of the species and their gene pools. For example, East Asia is often cited as the primary hub for the wildlife trade (Committee for International Trade in Endangered Species: http://www.cites.org) and the aquarium trade.

In general, in most developing countries, it appears that an understanding of access and benefit sharing of aquatic genetic resources is relatively poor. Increased awareness of this future need combined with building stronger capacities among most stakeholders should be a priority. For example, in most developing countries technical knowledge on the application of modern genetic techniques in aquaculture is far from satisfactory. In general, geneticists in developing countries tend to work in watertight compartments and have little understanding on international conventions that are applicable to aquatic genetic resources management. There is an urgent need to bridge this gap so that when countries embark on drawing up relevant legislation geneticists with aquatic resources background can contribute to the process.

Collaboration in research

Often there is lack of coordination in genetic characterisation projects and the use of different methods and studies limited to a specific geographic area make comparisons difficult. Thus, original research results often become fragmented and incomparable, leading to inefficient use of funds and resources. Attempts to bring about better complementarities on genetic studies of cultured species have been initiated in a small way; for example, in the case of common carp resources in Europe and Asia (NACA 2008), and other initiatives exist for major species (e.g. oysters, marine shrimp and trouts). Such initiatives need to be broadened and coupled with broader support through the endorsement and support of groups such as the Commission on Genetic Resources for Food and Agriculture.

Gene banking

Clearly in all commodities discussed in this review, attempts to conserve the genetic diversity of most of these species are still limited. Several attempts have been made to study cryopreservation of groupers and mahseer sperm (Ogale 2002; Basavaraja & Hedge 2004), but only at a research level, and there are no gene banks in place for these species to date.

Maintenance of a gene bank (live or cryopreserved sperm) for cultured aquatic organisms warrants urgent consideration (Harvey *et al.* 1998). Such an initiative needs to go hand in hand with appropriate capacity building in developing countries where aquaculture is a focal point; however, it is important to note that gene banking is still controversial and is an expensive exercise. The controversy in respect of aquatic organisms, primarily exists unlike in the case of seed crops, that gene banking in the former group, does not make complete sense where only the sperms can be effectively banked but not the eggs.

Ecosystem-based management and sustainability

It is also imperative that a pragmatic application of genetic resources management be linked to other ongoing initiatives, such as an ecosystem approach to fisheries and aquaculture (Bianchi & Skjoldal 2008; APFIC 2009; Bartley 2009). In this way, issues related to aquatic genetic resources would be able to find their proper place as part of a move to broaden sustainability concerns. To date, most thinking tends to focus on the biosecurity of aquatic resources related to the transfer of pathogens and their impacts on commercially important species, the ecosystem and human health (AusAID undated). There is a need for a more balanced mix of social and environmental concerns blended with economic factors. Biosecurity issues need to be extended in scope to include aspects of genetics not only in legislation, but also as a component of action planning.

Access and benefit sharing legislation

Background on the origin and need for an ABS initiative was dealt with earlier. The present review is the first to deal with aquatic organisms specifically in relation to emerging aquatic species. In general, there is a lack of comprehensive treatment by law makers on policies related to access to and benefit sharing of aquatic genetic resources. Such legislation exists in some important aquaculture countries such as the Philippines and Malaysia. However, it is not yet clear what impacts this legislation has had on access to these resources. There have been suggestions that limitations on access have adversely impacted scientific research (Pethiyagoda 1991), but more data are needed on defining more specifically such impacts. For this reason, it is imperative that countries that are in the process of preparing ABS legislation do so in consultation with aquatic resources management personnel and users of aquatic genetic resources, that is, farmers and retailers. By the same token, aquatic genetic scientists, farmers and other users need to become more aware of and involved in legislation development processes to ensure that such rules are well thought out in terms of the needs of most stakeholders without unduly hindering the development and effective use of aquatic genetic resources.

In the present review, we have attempted to deal with a heterogeneous group of aquatic organisms lumped together as 'emerging species' on the belief that all these species have a future role to play in relation to ABS. The organisms dealt with in the present review include representatives of the fast growing mariculture sector in Asia, species associated with the emerging aquatic ecotourism industry and the associated development of recreational fisheries (Ng 2004) and the ornamental fish trade (Ekaratne 2000; European Commission 2008). Apart from some legislative aspects relevant to ABS for groupers and wrasses (see Table 2) and on the prohibition of export of endemic species (Ekaratne 2000) in some countries, there has been very limited legislation available with respect to aquatic genetic resources ABS.

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