Where are they all from? – sources and sustainability in the ornamental freshwater fish trade

HANS-GEORG EVERS[1] | JOHN K. PINNEGAR[2,3*] | MARTIN I. TAYLOR[3]

[1]Poppenbuetteler Weg 131b, Hamburg, Germany.

[2]Centre for Environment, Fisheries & Aquaculture Science, Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk, , UK.

[3]School of Biological Sciences, University of East Anglia, Norwich, UK

Correspondence

John K. Pinnegar, Centre for Environment, Fisheries & Aquaculture Science, Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk, NR33 0HT, UK

Email: john.pinnegar@cefas.co.uk

ABSTRACT

The global trade in ornamental fish involves *c*. 125 countries worldwide and is worth *c*. US $15–30 billion each year. This total is dominated (90%) by freshwater fishes, most of which are sourced from breeding facilities located in developing countries, typically in Asia or South America, but also in Israel, USA and Europe. Some fish are obtained from natural (wild) sources in Asia and South America, but the exact percentage of wild-caught fish is difficult to quantify given a lack of reliable data. Although *c*. 1000 species of freshwater fishes are widely available (from a total of > 5300 on sale), the most dominant freshwater fishes in the market comprise only 30 species from the orders Cyprinodontiformes,

This article has been accepted for publication in the *Journal of Fish Biology* and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/jfb.13930

Perciformes, Characiformes and Siluriformes. In this perspectives review, illustrative example case studies of wild-fish collecting (Barcelos and Rio Xingu, Brazil) and breeding projects (Java, Indonesia) are described. In addition, wild-collecting expeditions to West Papua, Indonesia are discussed, focused on discovering novel species of rainbowfish (Melanotaeniidae) for breeding in captivity. Sustainability of the aquarium industry is considered in its broadest sense. The aquarium industry has been portrayed as both a major threat to natural ecosystems, but also as being part of the solution in terms of helping to maintain species when they have gone extinct in the wild or offering an income to impoverished citizens who might otherwise engage in much more destructive practices.

KEYWORDS

breeding, freshwater, ornamental, sustainability, trade, wild-capture,

1 | THE FRESHWATER AQUARIUM TRADE

Worldwide, the popularity of fish keeping has grown by 14% annually since the 1970s and currently over 1 billion individual fish are traded internationally each year (Maceda-Veiga *et al*., 2016). The global aquarium fish trade (freshwater and marine ornamental fish plus accessory products) is worth *c.* US $15–30 billion (Penning *et al*., 2009) and involves > 5300 freshwater and 1802 marine fish species (Raghavan *et al*., 2013). It is estimated that 90% of total trade volumes of ornamental fish are accounted for by tropical freshwater fishes. Of these, approximately 90% are captive bred, whilst the remaining 10% comprise a diverse array of wild-caught species (Raghavan *et al*., 2013). According to Dey (2016), thirty freshwater fish species dominate the global market. By volume, the guppy *Poecilia reticulata*

Accepted Article

Peters 1859 and neon tetra *Paracheirodon innesi* (Myers 1936) alone account for more than 25% of the market share and more than 14% of the market share by value. Other freshwater species in the top 30 include the molly *Poecilia gillii* (Kner 1863), platy *Xiphophorus variatus* (Meek 1904) and swordtail *Xiphophorus helleri* Heckel 1848, angelfish *Pterophyllum scalare* (Schultze 1823), goldfish *Carassius auratus* (L. 1758), zebrafish *Danio rerio* (Hamilton 1822) and discus *Symphysodon aequifasciatus* Pellegron 1904 (Dey 2016).

Global exports of ornamental fish have risen steadily since 2000, from US $177.7 million to a peak of US $364.9 million in 2011, but then declining slightly to US $347.5 million in 2014 Dey (2016). Of the ten regions supplying the export market in 2014, Asian countries accounted for *c.* 57% of the trade, with exports valued at US $197.7 million. This was then followed by Europe accounted for 27.6% of the total exports (valued at US $95.8 million) followed by South America (7.5%), North America (3.98%), Africa (2.2%), Oceania (1.4%) and the Middle East (0.5%). In 2014, Singapore was the top ornamental fish exporter, accounting for almost 20% of the total supply, with exports valued at US $69.32 million (Dey, 2016; Figure 1). This country remains the main trading hub in Asia (especially for re-exports), with > 30% of the fish exported having been sourced originally from other countries. Owing to its dominance in koi carp production (*i.e.*, colored varieties of common carp *Cyprinus carpio* L. 1758), Japan was the second most important exporting country in 2014 with exports valued at US $41.34 million. The third position in 2014 was occupied by the Czech Republic with exports worth US $32.0 million. Production of ornamental and aquarium fish for hobby purposes has a long tradition in the Czech Republic. Hundreds of small breeders have operated since the 1960s when the culture of tropical fish became a hobby for 40,000 people. In the past decade, since the mid-2000s, farming of freshwater ornamentals has gradually increased in countries that are close to consumers. These include the Czech Republic, Israel, Belgium, Germany and the Netherlands, which have started cultivating fish for European consumers, taking advantage of their closer proximity to the major European markets (Dey 2016).

For many years the world's largest single market for ornamental fish (both freshwater and marine) has been the USA, but imports declined in value from US $60 million in 2000 to US $42.9 million in 2014 (Dey 2016). Europe is the largest global trade bloc, with the UK remaining the largest European importer of ornamental fish (US $29.5 million in 2014; Pinnegar & Murray, 2019). Imports into Europe rose from US $111.8 million in 2000 to US $223.7 million in 2008, but then falling to an all-time low of US $95.8 million in 2014. In 2014, European Union (EU) member countries imported ornamental fish from a total of 59 non-EU countries around the world; they included 44 different countries supplying marine fish and 39 supplying freshwater fish. Other major importers of ornamental fish include Singapore, Japan and China–Hong Kong (US $21.3, $19.5 and $19.3 million, respectively in 2014; Dey 2016).

Collection of freshwater fishes from the wild for the aquarium trade is a practice that divides opinion (Raghavan *et al*., 2013; Watson and Moreau, 2006; King, 2019), especially in terms of environmental effects and long-term sustainability. On the one hand, there may be problems associated with the over-exploitation of a species or a particular population of a species at a certain locality, but also destructive fishing practices and mortality caused by poor handling and quarantine procedures (Dey 2016). On the other hand, some authors consider wild-capture aquarium fisheries an important contributor to local economies that can provide incentives for environmental conservation if well managed (Tlusty *et al*., 2008; Raghavan *et al*., 2013; Watson and Moreau, 2006), habitat destruction is a far higher risk to fish faunas than fish collecting.

Here, we examine what sustainability means for the aquarium–ornamental fish industry. Sustainability of the freshwater aquarium industry is considered in its broadest sense, as viewed by someone who is intimately involved in all aspects of the trade. Also, we discuss some of the main issues facing the global freshwater aquarium trade using four illustrative case studies. These being: (1) The decline of wild-capture fisheries for cardinal tetra *Paracheirodon axelrodi* (Schultz 1956) in the upper Orinoco and Rio Negro Rivers in South America and their gradual replacement by cultured animals from Asia and the Czech Republic; (2) over-exploitation of the zebra pleco *Hypancistrus zebra* Isbrücker & Nijssen 1991 from the Xingu River, a tributary of the Amazon Basin, and recent efforts to aid conservation of this endangered species; (3) efforts to breed and rear clown loach *Chromobotia macracanthus* (Bleeker 1852) in captivity, to alleviate pressures on wild stocks; (4) wild-collecting expeditions in West Papua, Indonesia focused on discovering novel species of rainbowfish (Melanotaeniidae) for breeding in captivity.

2 | CASE STUDY 1: CARDINAL TETRA *PARACHEIRODON AXELRODI* AND BARCELOS, AN INDUSTRY IN DECLINE

Paracheirodon axelrodi is a freshwater fish (family Characidae) that is native to the upper Orinoco and Negro Rivers in South America. It is a very popular aquarium fish, but historically its availability to aquarists (although still commonplace) has been less, when compared with its close relative *P. innesi*, primarily because it was difficult to breed in captivity. An entire industry developed in Barcelos on the banks of Brazil's Rio Negro in which members of local communities catch *Paracheirodon* spp. from shaded rainforest pools where cardinal tetras gather during the dry season, for the aquarium trade (Figure 2). The *P. axelrodi* fishery here is highly valued by local people who act as stewards for the environment of the surrounding rainforest. Hence, some ichthyologists have argued that fish keepers worldwide should continue to support the sustainable *P. axelrodi* fishery of the

Amazon basin, since thousands of people are employed in the region. If such fishermen lost their livelihoods catching *P*. *axelrodi* and other tropical fishes, they might turn their attention to engaging in deforestation (Zehev *et al*., 2015).

Paracheirodon axelrodi is the number one export species in the ornamental fish trade centred on Brazil, accounting for 70% of total Brazilian fish exports (Zehev *et al*., 2015; Tlusty 2002). Due to recent competition pressure from South-east Asia, where artificial breeding of this species has begun, but also due to fall-out from the 2008 economic crisis (affecting both demand and freight costs), exporting of fish from the Rio Negro has come under serious threat and may disappear altogether in the not too distant future. Sales have decreased drastically over the past decade, with a decline in gross yield from US $3 million in 2006 to less than US $1.5 million in 2010. A further threat to the Brazilian wild-capture *P*. *axelrodi* fishery is the back-room breeding of aquarium fish in the Czech Republic; *i.e*., the small-scale production of animals for commercial purposes in apartment blocks and micro-facilities. Exports of freshwater ornamental fish from the Czech Republic now amounts to *c.* US $32 million per year and includes the development of new gold and platinum varieties of *P*. *axelrodi*.

If we consider the two major producing municipalities of Barcelos and Santa Isabel in Brazil, this trade contributes almost 80% to the local economy, supporting more than 10,000 jobs (Zehev *et al*., 2015). This industry also prevents outmigration to urban centres by people seeking alternative employment opportunities (Chao & Prang, 1997; Tlusty 2002). Retaining younger people in rural forest villages serves to keep cultural traditions alive. Thus, the economic development of the ornamental fishery is mutualistic to the preservation of this ecosystem. Rearing captive *P*. *axelrodi*, particularly anywhere outside the country (as are *P*. *innesi* in Florida, USA), could decimate the economy of this area, as well as open up the flooded forest to environmentally destructive industries (Tlusty 2002). For example, *P*.

axelrodi are now being bred in Vietnam and Indonesia in high numbers and the stable supply of fish throughout the year has led to importers relying less on wild-caught *Paracheirodon* spp.

Project Piaba is a fishery initiative located on the Rio Negro that both promotes and researches sustainable aquarium fish collection and the effect of this trade on the environment (Chao and Prang 1997). Project Piaba (www.projectpiaba.org) started with an ecological baseline study of the region in 1989 by a group of researchers and students from the Universidade do Estado do Amazonas (UEA), Manaus and the National Institute of Amazonian Research (INPA), Manaus. This initial survey discovered and documented the importance of the fish trade to the local economy. In subsequent years the project expanded, with its mission statement, “to increase the environmental, animal welfare and social sustainability of the Amazonian aquarium fish trade, to develop and incorporate metrics through which this progress can be assessed and to provide mechanisms to promote this industry”. Project Piaba also has the support of aquariums and zoos around the world and also from the IUCN (www.iucn.org). Because of the sustainable nature of the project, its slogan is "Buy a Fish, Save a Tree!" (Chao & Prang 1997).

3 | CASE STUDY 2: WILD ZEBRA PLECO *HYPANCISTRUS ZEBRA* COLLECTING, RIO XINGU, BRAZIL

Hypancistrus zebra is a Loricariid catfish endemic to Brazil where it occurs exclusively in the Big Bend (Volta Grande) area of the Xingu River, a tributary of the Amazon. This species was first described in 1991 (Isbrücker & Nijssen, 1991) and gets its name from the species’ particularly attractive black and white stripes, resembling the markings of a zebra (Figure 3). Following its discovery, this highly sought-after fish was exported from Brazil in great numbers for sale as an aquarium fish. However, concerns were raised about the long-term sustainability of this wild-capture fishery and hence the Brazilian government moved to introduce bans on the export of several *Hypancistrus* Isbrücker & Nijssen 1991species including *H. zebra* (Pedersen 2016). *Hypancistrus zebra* was placed on the Brazilian Red List of endangered species in 2004 and since this time it has been prohibited to collect; transport or trade this species as an aquarium fish in Brazil.

At the 2016 CITES conference, listing changes were announced for some 500 species of wild plants and animals for which survival is considered threatened or endangered. Brazil proposed *H. zebra* for protection under CITES Appendix III (www.ornamentalfish.org/8902/). Appendix III listings allow trade, but only where legal permits and certificates are obtained by exporters and importers. Hence, Appendix III listings do not impose a complete trade ban, nor do they affect interstate trade within a country. The move to add *H. zebra* to CITES Appendix III was primarily an effort by Brazil to curtail ongoing smuggling of wild-collected specimens *via* neighbouring countries (Pedersen 2016). In its native Brazil, it is illegal to collect, transport and export this species. However, with the ongoing ban and the high price that this species commands on the international market, a thriving black-market trade has developed and with limited supplies the price of this species has reached very high levels.

Ironically, it now seems that one part of the Brazilian government is set on saving a species that is severely threatened by other seemingly unstoppable national plans to build hydroelectric dams in the vast Amazon rainforest (Lees *et al*., 2016; Diemont 2014). It is noteworthy that with the construction of the Belo Monte Dam, which threatens to wipe out the *H. zebra* in its native habitat, some aquarists are openly willing to buy wild-caught fish and are turning a blind eye to smuggling. Many individuals involved in the clandestine trade (both in Brazil and elsewhere) privately rationalize their purchases on the grounds that the fish were doomed anyway, so they might as well be exported and bred by aquarists (Pedersen, 2016).

It has been over a decade since wild-caught *H. zebra* could be legally obtained in the aquarium trade from Brazil, however legitimate large-scale production of this species is now occurring in Asia (Pedersen 2016). *Hypancistrus zebra* are starting to enter the market from suppliers, most notably those located in West Java (Maju Aquarium; www.majuaquarium.com) and Bellenz Aquarium in Indonesia (www.bellenz.com), who rear their fish in high-tech specialised facilities (Figure 3).

Unless urgent action is taken to protect the remaining wild population of *H. zebra* on the Xingu River, it is feared that in the worst-case scenario, the only living *H. zebra* specimens living on the planet will be those in public and private aquaria (Pedersen 2016). Several widely-available aquarium species, most notably the red-tailed black shark *Epalzeorhynchos bicolor* (Smith 1931) and the white cloud mountain minnow *Tanichthys albonubes* Lin 1932 were considered to have been similarly saved from complete extinction by commercial breeders in the ornamental fish trade, although in both cases tiny isolated populations were eventually rediscovered in the wild (Kulabtong *et al*., 2014; Liang *et al*., 2007).

4 | CASE STUDY 3: OVERFISHING CLOWN LOACH *CHROMOBOTIA MICRACANTHUS* AND ALTERNATIVES

The clown loach *C. macracanthus*) or tiger botia, is a well-known tropical freshwater fish belonging to the loach Botiidae family. It originates from inland waters of Indonesia, on the islands of Sumatra and Borneo. It is a popular and familiar fish in the aquarium trade and is sold worldwide (Dudgeon, 2000). Traditionally, the most common collection technique involved using lengths of bamboo with openings cut into each segment (see Figure 4). These are normally weighted with stones to make them sink and hung from overhanging or marginal vegetation. The loaches take refuge in these at night and the fishermen return during the hours of darkness to collect them. Smaller specimens of 20–80 mm have been collected in this way for many decades, usually during January–March but numbers have fallen away sharply since the turn of the century. To satisfy demand in the ornamental fish industry, the out-take in 1997 was 20 million juveniles (Ng & Tan, 1997). In 2009, that number had increased to 50 million (Legendre *et al*., 2012). Industry specialists note a persistent decrease in the number of juvenile fish caught, albeit fished with increasing intensity for almost 30 years (Dudgeon, 2000). It was evidently clear that this species was overexploited and threatened and this prompted the Indonesian government in 2002 to forbid the export of fish > 15 cm, which are considered sexually mature. Given that annual catches of smaller fish have declined greatly, native fishermen in some areas have been forced to change their tactics in order to continue trading.

In nature, this species is a migratory spawner, moving from the main river channels into smaller tributaries and temporarily inundated flood plains during the rainy season. These movements usually begin in September with spawning typically occurring in late September–early October, though the timing of this is beginning to shift with the changing climate (Evers, 2009a). The eggs drift and come to settle in the riparian vegetation where the initially pelagic larvae spend their early days feeding on micro-organisms. Some drift too far, enter the main rivers and are swept downstream and out to sea and hence are lost. However, native fishermen in the Batang Hari river system in Sumatra have come to take advantage of this phenomenon (Evers, 2009b) . Local fishermen now collect the pelagic larvae that drift into the main river channel and grow them on to sell to middlemen or larger distributors (Figure

4). Perhaps as many as 10 million specimens are raised and shipped from the area in this way each year.

At one time all traded fish were wild-collected, mostly from Sumatra, but these days the situation is less clear. While many thousands of wild specimens are still caught and sold annually, farmers in South-east Asia have been artificially breeding the species with the use of hormones for several years (Legendre *et al*., 2012; Ng & Tan 1997). Hormones are used to stimulate oocyte maturation and ovulation (Legendre *et al*., 2012). More recently breeders from the Czech Republic, Russia and other parts of Eastern Europe have perfected a similar technique, which has seen the price of the once-expensive captive-bred fish drop considerably.

5 | CASE STUDY 4: WILD COLLECTING OF RAINBOWFISHES IN WEST PAPUA, FOR BREEDING IN CAPTIVITY

The rainbowfishes (Melanotaeniidae) are a family of small, colourful, freshwater fish found in northern and eastern Australia, New Guinea and several islands of Indonesia. Some melanotaenids are now critically endangered as a result of over-collecting and hence trade is carefully restricted. Notably, Boeseman´s rainbowfish *Melanotaenia boesemani* Allen & Cross 1980 is one of the most popular melanotaenid species in the aquarium hobby. When fully matured, males display a very distinct pattern of half-and-half coloration marked by a brilliant blue anterior and bright yellow to orange-red posterior. Allen & Cross (1980) discovered the species whilst studying material originally collected in 1954–55 by Marinus Boeseman and stored at the National Museum of Natural History in Leiden (Netherlands). The species is known only from the Ayamaru Lakes and tributaries and from Uter-Aitinyo Lake in West Papua; two locations that are 30 km apart and are separated by rugged karsts.

After the first publication describing *M. boesemani* (Allen & Cross 1980), great interest arose in the potential commercial value of this species. It was introduced to the aquarist trade in 1983 and has steadily increased in popularity since then (Polhemus & Allen, 2007). In the mid-1980s, more than 60,000 males were caught and exported monthly from Ayamaru (Allen, 2007). Such over-exploitation quickly brought this species to the verge of extinction in its natural habitat. Consequently, this species was included on the IUCN Red List of endangered species (Allen, 1996) and only farmed animals are now permitted to be exported (Nugraha *et al*., 2015). *Melanotaenia boesemani* has however, been domesticated and produced in Indonesian fish farms since 1983 (Nugraha *et al*., 2015). Visits in 2013 suggest that the population in Lake Uter is stable and apparently healthy, but the Ayamaru lakes have been devastated through the introduction non-native fish species and by pollution, hence fish populations are severely threatened (Evers, 2014)

There are currently 86 recognized species in the genus *Melanotaenia* Gill 1862 and several more in the genera *Glossolepis* Weber 1907 and *Chilatherina* Regan 1914. There is a great appetite to introduce more of these rainbowfishes into the freshwater aquarium trade. Melanotaenids thrive in captivity and thanks to their often brilliant colours, small size and ease of breeding, are highly prized by aquarists. However, in order to avoid some of the same over-exploitation problems associated *M. boesemani*, and because many species have highly-restricted home ranges, collectors are now working with taxonomists and breeding facilities, to secure new broodstock. They are then developing sustainable aquaculture practices, such that wild populations are not put at risk in the future. A particular focus in recent years has been the Birds Head Peninsula, West Papua Province, Indonesia where a multitude of novel species have been discovered (Allen *et al*., 2014, 2016).

Once in captivity it is relatively straightforward to maintain and breed most species of rainbowfish. If rainbowfishes are kept in a species tank with floating plants or a synthetic spawning mop, sooner or later fry will appear. Most rainbowfish species spawn every day, usually in the morning, with the males attracting the females and the pairs spawning in the plants. The tiny, crystal clear eggs adhere to the plants with their sticky filament for about 10 days until the fry hatch. In Indonesia, large well-equipped breeding facilities have emerged, offering many different species and varieties. The Maju Aquarium is now regularly reproducing more than 40 different species of Indonesian rainbow fish under sustainable conditions (social and environmental aspects).

6 | WHAT DOES SUSTAINABILITY LOOK LIKE FOR THE FRESHWATER AQUARIUM INDUSTRY?

Sustainable development infers economic development that is conducted without depletion of natural resources. What sustainability means for the freshwater aquarium industry is a complicated issue, given that the industry has, in some cases, put great pressure on natural ecosystems and has brought species to the edge of extinction in the past. At the same time however, the industry has also been part of the solution in terms of helping to maintain species when they have gone extinct in the wild, or by offering an income to impoverished citizens who might otherwise engage in much more destructive practices. Several authors have questioned whether it is possible for “sinners to become saints” with regard to the freshwater aquarium hobby (Maceda-Veiga *et al*., 2015; King, 2019). Such authors have noted that whilst the relationship between conservationists and the aquarium hobby has often been antagonistic in recent years, ultimately most biologists and aquarists share a love of the species that they study or maintain and this common interest could be the basis for a more positive and productive relationship (Maceda-Veiga *et al*., 2015).

Some of the key concerns that have been voiced about sustainability of the freshwater aquarium industry include that the collection of wild fish for the trade has led to overharvesting and habitat destruction (Andrews 1992; Gerstner *et al*., 2006; Tlusty *et al*., 2008) and that escapes and deliberate releases of aquarium fish into habitats outside their native range have contributed to the problem of invasive species (Keller and Lodge 2007; Gertzen *et al*., 2008). While it is important to ensure that fish stocks are managed to promote sustainable objectives, there are a number of post-capture processes that may also further affect sustainability (Tlusty *et al*., 2008; Tlusty and Lagueux, 2009). Tools such as life cycle analyses (LCA) have been developed for a cradle-to-grave assessment, which can better account for these broader issues.

The over-intensification of fish breeding as practised in some countries, particularly in Asia, has led to some serious problems such as increased susceptibility to disease, antibiotic resistance and poor broodstock quality (in-breeding or uncontrolled hybridisation; Dey 2016). On the other hand, there are many advantages of breeding aquarium fish in captivity beyond simply reducing pressure on wild-populations. Firstly, it ensures a continuous supply of all important species, independent of seasonal weather and increasingly erratic climatic conditions. New strains or varieties can be developed that are highly attractive to consumers. Captive breeding usually ensures fewer instances of fish that are dead on arrival (DOA) due to shorter supply chains and easier logistics. Often cultured animals require shorter quarantine periods and they have better body condition compared with wild-caught individuals of the same species. Furthermore, the people working in these facilities earn higher salaries and, in the case of Maju Aquarium in Indonesia, experience a certain attitude of pride when breeding and distributing the fishes of their own country without exploiting the wild sources.

Many rare fishes are little known among scientists and are largely neglected by governments and conservation organizations, yet their plight has received the attention of specialist hobbyists. These species [including many livebearer, cichlids (Cichlidae) and killifish (Aplocheilidae, Cyprinodontidae, Fundulidae, Profundulidae and Valenciidae) species] are sometimes available at aquarist meetings or *via* online exchanges (Maceda-Veiga *et al*., 2015). Hobbyists often contribute to the development of basic knowledge about the biology and ecology of the species. Expertise is shared through the publication of technical notes and reports on the maintenance and breeding experiences of these species in hobbyist journals and magazines such as *Amazonas* (www.amazonasmagazine.com) and *Practical Fishkeeping* (www.practicalfishkeeping.co.uk) or the large number of aquarium association bulletins published on a regular basis. The content of the articles published by many hobbyists and the by-laws of their associations demonstrate that they are concerned about the welfare of the species they keep and for the effective transfer of knowledge (Maceda-Veiga *et al*., 2015).

Public education and engagement in conservation activities is another beneficial role of the aquarium hobby. As aquarists develop a greater awareness of freshwater conservation through their hobby, they are more likely to become involved in local and international conservation initiatives that benefit a wide variety of organisms and habitats, not just fish (Reid *et al*., 2013). Certification schemes and ecolabels can help empower consumers to support environmentally friendly and ethical commodities and therefore in-turn, they can be very influential in incentivizing more sustainable practices within the industry. Such schemes have become commonplace in the food sector [*e.g*., Marine Stewardship Council (MSC; www.msc.org) accreditation of sustainable seafood (Agnew, 2019)] and have been attempted for the marine aquarium trade (Shuman *et al*., 2004; King, 2019). At present however, there is no unified certification scheme within the freshwater aquarium trade, limiting the capacity for consumers to easily differentiate sustainable products from others. Several authors have advocated the development of such a scheme for freshwater aquarium fish (Watson 2005; Tlusty *et al*., 2006), although Watson (2005) noted the existence of multiple current certification programmes that have varying and potentially competing goals, all of which seem likely to confuse consumers rather than proving further enlightenment.

In short, fisheries and aquaculture aimed at supplying the freshwater ornamental trade can be sustainable if managed and regulated properly. Ensuring better traceability for both wild-caught and tank-reared fish, as outlined per the Nagoya Protocol on access to genetic resources and the fair and equitable sharing of benefits arising from their utilisation (CBD, 2010) will be key to achieving a sustainable freshwater aquarium industry in the long-term.

ACKNOWLEDGEMENTS

This paper is based on an invited keynote presentation by H.G.E. at the Fisheries Society of the British Isles (FSBI) Annual Symposium in Norwich on 12th July 2018. The authors would like to thank the FSBI for their support. We thank Johannes Arlt (Hamburg) for providing the images included in Figure 2.

REFERENCES

Agnew, D. (2019) Who determines sustainability? *Journal of Fish Biology*, this volume

Allen, G. (1996). *Melanotaenia boesemani*. *The IUCN Red List of Threatened Species* 1996: e.T13058A3408005. dx.doi.org/10.2305/IUCN.UK.1996.RLTS.T13058A3408005.en. Downloaded on 07 February 2019

Allen, G.R. (2007) Fishes of Papua. In: *The Ecology of Papua*, part one, Marshall, A. J. and Beehler, B. M. (Eds.), pp. 637-653. Periplus, Singapore.

Allen, G.R. and Cross, N. J. (1980) Description of five new rainbowfishes (Melanotaeniidae) from New Guinea. *Records of the Western Australian Museum* 8: 377-396.

Allen G.R., Unmack P.J. and Hadiaty R.K. (2014) Three new species of Rainbowfishes (Melanotaeniidae) from the Birds Head Peninsula, West Papua Province, Indonesia. *aqua, International Journal of Ichthyology*, 20: 3 – 29.

Allen G.R., Unmack P.J. and Hadiaty R.K. (2016) The Goldiei group of rainbowfishes (Melanotaeniidae) from the Birds Neck Region of New Guinea (Papua and West Papua Provinces, Indonesia) with descriptions of five new species and recognition of *Melanotaenia dumasi* Weber. *aqua, International Journal of Ichthyology*, 22(1): 1-32.

Andrews, C. (1992) The ornamental fish trade and conservation. *Infofish International*, 2: 25–29.

CBD (2010). Convention on Biodiversity: the Nagoya Protocol. www.cbd.int/abs/about/

Chao N.L. and Prang G. (1997) Project Piaba - towards a sustainable ornamental fishery in the Amazon. *Aquarium Sciences and Conservation*, 1:105-111.

Diemont, R. (2014) *Impact of hydroelectric dam Belo Monte in the Xingu River on ornamental fish species, local fishermen and local traders*. Forestry and Nature Conservation 28th August 2014. 53pp.

Dey, V.K. (2016) The global trade in ornamental fish. *Infofish International*, 4/2016: 52-55. www.infofish.org

Dudgeon D. (2000) Riverine biodoiversity in Asia: a challenge for conservation biology. *Hydrobiologia*, 418: 1-13.

Evers, H-G. (2009) Auf nach Jambi! Prachtschmerlen in ihrem natürlichen Lebensraum. *Amazonas*, 24: 18-27

Evers, H-G. (2009) Neue Wege - Prachtschmerlenfang einmal anders. *Amazonas*, 24: 28-37

Evers, H-G. (2014) Boeseman´s Rainbowfish and its rare new cousin.- *Amazonas* (English edition), SEP/OCT 2014: 42 - 51

Gerstner, C., Ortega, H., Sánchez, H. and Graham, D. (2006) Effects of freshwater aquarium trade on wild fish populations in differentially-fished areas of the Peruvian Amazon. *Journal of Fish Biology*, 68: 862–875.

Gertzen, E., Familiar, O. and Leung, B. (2008) Quantifying invasion pathways: fish introductions from the aquarium trade. *Canadian Journal of Fisheries and Aquatic Sciences*, 65: 1265–1273.

Isbrucker, I.J.H. and Nijssen, H. (1991) *Hypancistrus zebra*, a new genus and species of uniquely pigmented ancistrine loricariid fish from the Rio Xingu, Brazil (Pisces: Siluriformes: Loricariidae). *Ichthyological Exploration of Freshwaters,* 1(4): 345-350.

Kadarusman, Hadiaty, R. K., Segura, G., Setiawibawa, G., Caruso, D. and Pouyaud, L. (2012) Four new species of Rainbowfishes (Melanotaeniidae) from Arguni Bay, West Papua, Indonesia. *Cybium*, **36:** 369-382.

Keller, R. and Lodge, D. (2007) Species invasions from commerce in live aquatic organisms: problems and possible solutions. *BioScience,* 57–5: 428–436.

King, T. (this volume) Wild caught ornamental fish: A perspective from the UK ornamental aquatic industry on the sustainability of aquatic organisms and livelihoods. *Journal of Fish Biology*,

Kulabtong, S., Suksri, S., Nonpayom, C. and Soonthornkit, Y. (2014) Rediscovery of the critically endangered cyprinid fish *Epalzeorhynchos bicolor* (Smith, 1931) from West Thailand (Cypriniformes, Cyprinidae). *Biodiversity Journal*, 5 (2): 371–373.

Lees, A.C., Peres, C.A., Fearnside, P.M., Schneider, M., Zuanon, J.A.S. (2016) Hydropower and the future of Amazonian biodiversity. *Biodiversity & Conservation*, 25: 451–466.

Legendre, M., Satyani, D., Subandiyah, S., Sudarto, Pouyaud, L., Baras, E. and Slembrouk, J. (2012) Biology and culture of the clown loach *Chromobotia macracanthus* (Cypriniformes, Cobitidae): 1- Hormonal induced breeding, unusual latency response and egg production in two populations from Sumatra and Borneo Islands. *Aquatic Living Resources*, 25: 95-108.

Liang, X-F., Chen, G-Z., Chen, X-L., Yue, P-Q. (2008) Threatened fishes of the world: *Tanichthys albonubes* Lin 1932 (Cyprinidae). *Environmental Biology of Fishes*, 82: 177–178.

Maceda-Veiga, A., Domínguez- Domínguez, O., Escribano-Alacid, J., Lyons, J. (2016) The aquarium hobby: can sinners become saints in freshwater fish conservation? *Fish and Fisheries*, 17: 860–874.

Ng P.K.L. and Tan H.H. (1997) Freshwater fishes of Southeast Asia: potential for the aquarium fish trade and conservation issues. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 1: 79−90.

Nugraha, M. F. I, Pouyaud, L., Carman, O., Widyastuti, U., Zairin Junior, M., Kadarusman and Avarre, J.C. (2015) Genetic diversity of Boeseman´s Rainbowfish (*Melanotaenia boesemani*) reared in Indonesian farms compared to endangered natural populations. *Tropical Conservation Science*, 8 (3): 796-812.

Pedersen, M. (2016) A smuggler’s favorite, the Zebra Pleco “L46” receives CITES listing. *Amazonas*, 04 November, 2016. (http://www.reef2rainforest.com/2016/11/04/)

Penning, M., Reid, G. McG., Koldewey, H., Dick, G. andrews, B., Arai, K., Garratt, P., Gendron, S., Lange, J., Tanner, K., Tonge, S., Van den Sande, P., Warmolts, D., Gibson, C. (Eds.), 2009. *Turning the Tide: A Global Aquarium Strategy for Conservation and Sustainability*. World Association of Zoos and Aquariums, Bern, Switzerland.

Pinnegar, J.K. and Murray, J. (2019) Understanding the United Kingdom marine aquarium trade: a 'mystery shopper' study of species on sale. *Journal of Fish Biology*, this volume

Polhemus, D.A. and Allen, G.R. (2007) *Freshwater biogeography of Papua*. In: The Ecology of Papua, part one, Marshall, A. J. and Beehler, B. M. (Eds.), pp. 207-245. Periplus Editions, Singapore.

Raghavan, R., Dahanukar, N., Tlusty, M.F., Rhyne, A.L., Kumar, K.K., Molur, S. and Rosser, A.M. (2013) Uncovering an obscure trade: Threatened freshwater fishes and the aquarium pet markets. *Biological Conservation*, 164: 158–169.

Reid, G. McG., Contreras MacBeath, T. and Csatádi, K. (2013) Global challenges in freshwater-fish conservation related to public aquariums and the aquarium industry. *International Zoo Yearbook*, 47, 6–45.

Shuman, C.S., Hodgson, G. and Ambrose, R.F. (2004) Managing the marine aquarium trade: is eco-certification the answer? *Environmental Conservation*, 31: 339-348.

Tlusty, M.F. (2002) The benefits and risks of aquacultural production to the aquarium trade. *Aquaculture*, 205: 203–219.

Tlusty, M.F., Dowd, S. and Halle, B.O.V. (2006) Yes fish need to be certified—a reply to Watson. *Ornamental Fish International – Journal*, 51: 49–52.

Tlusty, M.F., Dowd, S., Raghavan, P. (2008) Saving forests through the fisheries—ornamental fisheries as a means to avoid deforestation. *Ornamental Fish International – Journal*, 56: 21–25.

Tlusty, M.F. and Lagueux, K. (2009) Isolines as a new tool to assess the energy costs of the production and distribution of multiple sources of seafood. *Journal of Cleaner Production*, 17: 408–415.

Watson I. (2005). Do fish need to be certified? *Ornamental Fish International – Journal*, 49: 22–25.

Watson, I. and Moreau, M.-A. (2006) The ornamental fish trade in support of livelihoods. *Ornamental Fish International – Journal*, 50: 20–23.

Zehev, B.S., Vera, A., Asher, B. and Raimundo, R. (2015) Ornamental fishery in Rio Negro (Amazon region), Brazil: combining social, economic and fishery analyses. *Fisheries and Aquaculture Journal*, 6: 143. doi:10.4172/2150-3508.1000143

FIGURE 1 Top 10 countries supplying Values (US $ million) of freshwater aquarium fish from the top 10 producer countries (after Dey, 2016).

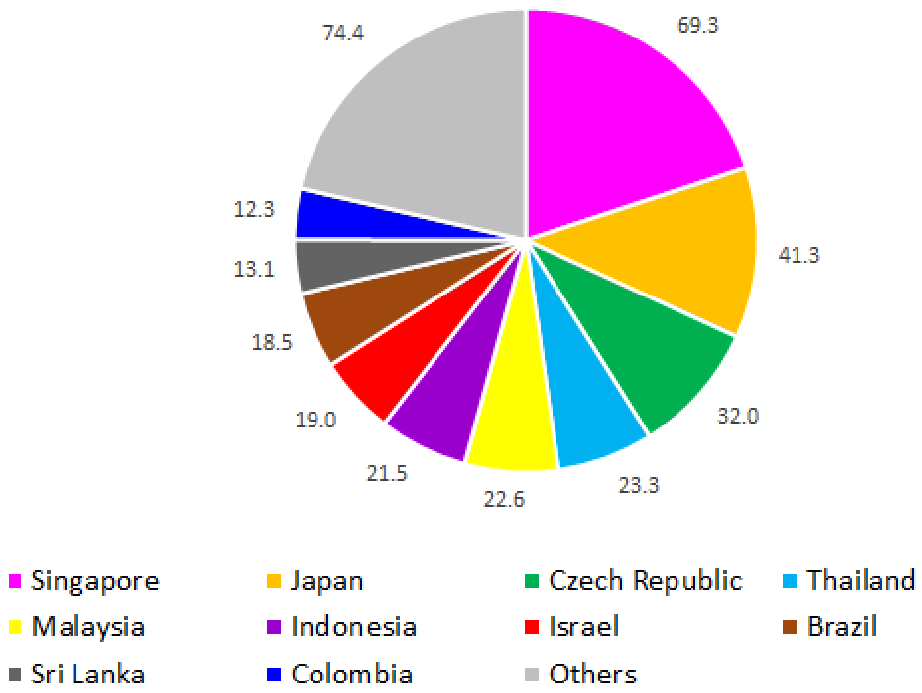


FIGURE 2 (a) Capture of *Paracheirodon axelrodi* by hand in shaded rainforest pools on the Rio Negro, Brazil; (b) fish are transferred to polyethylene bags; (c) fish being shipped down-river to Manaus; (d) fish held in centralised facilities in Manaus prior to international air transportation.

FIGURE 3 (a) The *Hypancistrus zebra;* (b) complex rocky habitat that *H. zebra* favours in the Big Bend (Volta Grande) area of the Xingu River; (c) breeding facilities in Indonesia.

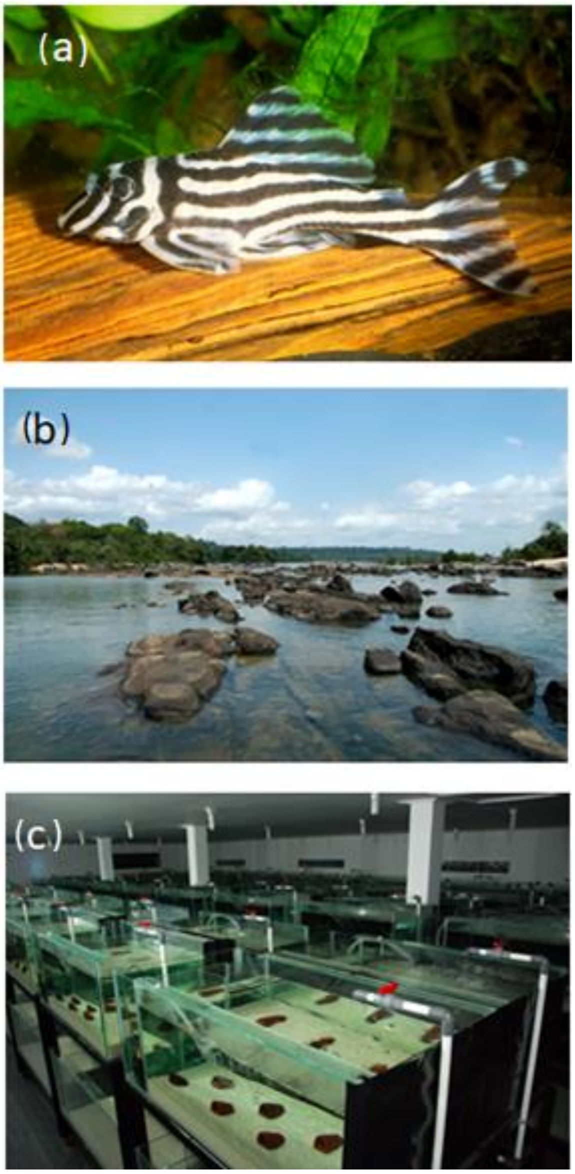
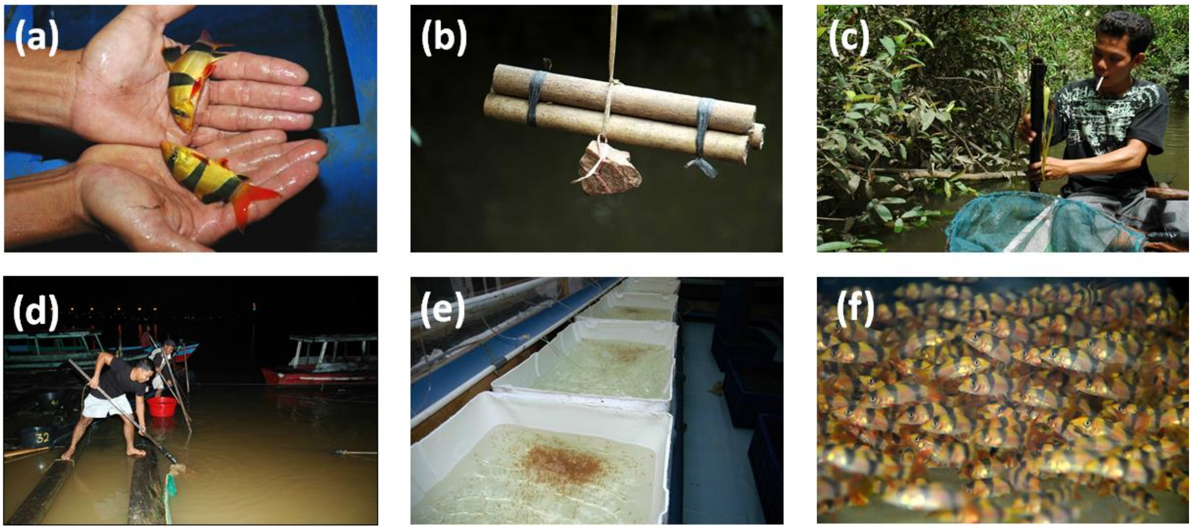


FIGURE 4 The ornamental fishery for clown loach in Sumatra: (a) *Chromobotia macracanthus*; (b)–(c) traditional capture method for using lengths of bamboo weighted with stones, and hung from overhanging vegetation, in which *C. macracanthus* take refuge at night, when (c) the fishermen return during the hours of darkness to collect them. (d) Fishermen from the Batang Hari river capturing *C. macracanthus* larvae at night for (e)–(f) on-growing in simple aquaculture facilities.


(a)
(b)
(c)
(d)
(e)
(f)