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Ghoti

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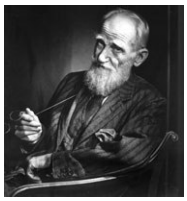

Ghoti aims to serve as a forum for stimulating and pertinent ideas. Ghoti publishes succinct commentary and opinion that addresses important areas in fish and fisheries science. Ghoti contributions will be innovative and have a perspective that may lead to fresh and productive insight of concepts, issues and research agendas. All Ghoti contributions will be selected by the editors and peer reviewed.

Etymology of Ghoti

George Bernard Shaw (1856-1950), polymath, playwright, Nobel prize winner, and the most prolific letter writer in history, was an advocate of English spelling reform. He was reportedly fond of pointing out its absurdities by proving that 'fish' could be spelt 'ghoti'. That is: 'gh' as in 'rough', 'o' as in 'women' and 'ti' as in palatial.

The aquarium hobby: can sinners become saints in freshwater fish conservation?

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Abstract

The aquarium hobby is popular worldwide, but it has positives and negatives for freshwater fish conservation. The most damaging impacts of the aquarium trade on ecosystems are overharvesting and invasive species. Consequently, many conservationists and academics have the perception that aquarium hobbyists are generally harmful to species conservation. Without overlooking these major drawbacks of the aquarium hobby, we aim to establish common ground between hobbyists and conservationists by correcting some misconceptions and showing the benefits of serious aquarium hobbyists in the conservation of freshwater fishes and their habitats. Our overview illustrates that the aquarium hobby is not insensitive to the pernicious effects of this enduring hobby on natural systems and that serious aquarists and their associations can directly assist and fund scientific research, increase conservation awareness among the general public and even participate in *ex situ* and *in situ* conservation programmes for native fish species at national or international levels. Whilst the relationship between conservationists and the aquarium hobby has often been antagonistic in recent years, ultimately most biologists and aquarists share a

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love of the species they study or maintain, and this common interest could be the basis for a more positive and productive relationship.

Keywords Aquarists, aquarium hobbyist associations, aquarium trade, conservation, education programmes, freshwater fish

Introduction

The conservation of natural resources is a complex social, ecological and economic process. Effective management actions are often hindered because many of the species involved are unknown, understanding among stakeholders is lacking, and unilateral decisions are often applied (Lodge *et al.* 2006; Carrete and Tella 2008). The freshwater aquarium hobby typifies this complexity. Worldwide, the popularity of fish keeping has grown by 14% annually since the 1970s, and currently over 1 billion fish comprising more than 5300 freshwater fish species are traded internationally each year (Helfman 2007; Hulme 2009; Collins *et al.* 2012). Whilst a hobby of this magnitude clearly has great economic and social value, the aquarium trade also has major ecological drawbacks. Collection of wild fish for the trade has led to overharvesting and habitat destruction (Andrews 1992; Chao *et al.* 2001; Gerstner *et al.* 2006; Tlusty *et al.* 2008). Escapes and deliberate releases of aquarium fish into habitats outside their native range have contributed to the problem of invasive species (e.g. Keller and Lodge 2007; Gertzen *et al.* 2008; Ng *et al.* 2010), one of the most direct threats to biodiversity and ecosystem function (Clavero and García-Berthou 2005; Simões-vitule *et al.* 2009; Pool and Olden 2012; Capps and Flecker 2013). In an effort to reduce such pernicious effects, conservationists advocate applying the precautionary principle through the prohibition of trade for highly invasive aquarium species and the development of educational programmes for aquarists and other stakeholders to reduce the release of invasive species (Padilla and Williams 2004; Chang *et al.* 2009; Strecker *et al.* 2011). For the conservation of wild stocks, outright bans are usually unrealistic given the economic interests of developing countries, and regulatory schemes have been advanced in these regions to promote sustainable harvesting (Tlusty *et al.* 2008; Silvano *et al.* 2009; Coomes *et al.* 2010; Lopes *et al.* 2011).

The success of these efforts will ultimately depend on many factors including the cooperation between aquarists and professional scientists. The current body of scientific literature, however, seems to indicate that these two groups sail in opposite directions, with a general perception among conservationists that aquarists are damaging species conservation. This perception of the aquarium hobby is probably a consequence of the diverse philosophies of the wide variety of aquarists who fall under the umbrella of the aquarium hobby, including 'pet owners' whose main interest is keeping fish as 'ornaments' (Fig. 1). Without overlooking the dark side of the aquarium hobby, this study aims to find common ground between hobbyists and conservationists by showing the benefits of serious aquarium hobbyists in the conservation of freshwater fishes and their habitats, and correcting some misconceptions about the attitude of aquarists towards the major drawbacks of the aquarium trade. Specifically, we discuss how aquarium hobbyists and their associations can directly assist with scientific research, increase conservation awareness among the general public, collaborate with legal authorities and conservationists to diminish the risk posed by introductions and even participate in *ex situ* and *in situ* conservation programmes for native fish species at national or international levels.

Overharvesting and invasive species: Is the aquarium hobby responsive?

The aquarium hobby is proactive in minimizing these two major drawbacks. Whilst historically many popular aquarium species were captured from wild populations, at present 90% of freshwater aquarium species are raised domestically (Whittington and Chong 2007). The domestic production of fish with new or more extreme shapes and colours clearly responds to a demand of aquarium keepers, as illustrated by a brief survey we conducted for this study of a random sample of aquarists as they left general pet stores in Barcelona and Lugo in Spain and in Cardiff UK. This survey consisted of offering aquarists the choice

Figure 1 Illustrations of different understandings and philosophies about the aquarium hobby. Photographs: (a) this 'invasive pack' consists of two worldwide recognized invaders, the eastern mosquitofish (*Gambusia holbrooki*, Poeciliidae) and the water hyacinth (*Eichornia crassipes*, Pontederiaceae), offered as an ornament at gardens in Barcelona (Spain); (b) street vendors in Oporto (Portugal) offering invasive species such as pumpkinseed (*Lepomis gibbosus*, Centrarchidae) and other aquarium fish species in poor condition; and (c) aquaria from a hobbyist where fish are a component of the ecosystems that he has created in his home.

between pictures of wild-caught and captive-reared specimens of a common fish species in the aquarium trade, the guppy (*Poecilia reticulata*, Poeciliidae), and analysing how preferences were influenced by the origin of the fish. Of 100 random aquarium owners interviewed at the entry of an aquarium retailer, 100% preferred the more colourful captive-reared guppy strain to the drabber Tobago wild type. Together with this bulk of domestic strains, wild-type fishes reared in fish farms or wild caught are also present in the trade (Raghavan *et al.* 2013). Interestingly, for some rare species, captive-breeding programmes to supply aquarium demand have produced a surplus of specimens for reintroduction programmes in the wild (Tlusty 2002; Tlusty *et al.* 2013), but inevitably conservation warnings also arise for wild-captured fishes (Raghavan *et al.* 2013).

Whilst admittedly the abundance and conservation status of many wild populations are poorly known, an inventory of 1133 fish species listed by retailers and wholesalers in south-western Europe (see Maceda-Veiga *et al.* 2013) showed that all of the 13 species that were formally classified as endangered or threatened with extinction in the wild were captive bred rather than wild caught. The status of species was based on the criteria set by the International Union for the Conservation of Nature (IUCN, see Fig. 2). Moreover, documented threats to survival in the wild for these species did not include excessive harvest for the aquarium trade but rather encompassed other commonly recognized threats such as habitat degradation, introduction of exotic species and overfishing for human consumption (Darwall *et al.* 2008). For example, the main threats to wild populations of some of the species were water pollution, physical habitat modifications and introduction of exotic species for the barred danio (*Devario pathirana*, Cyprinidae) (Devi and Boguskaya 2009), Azraq

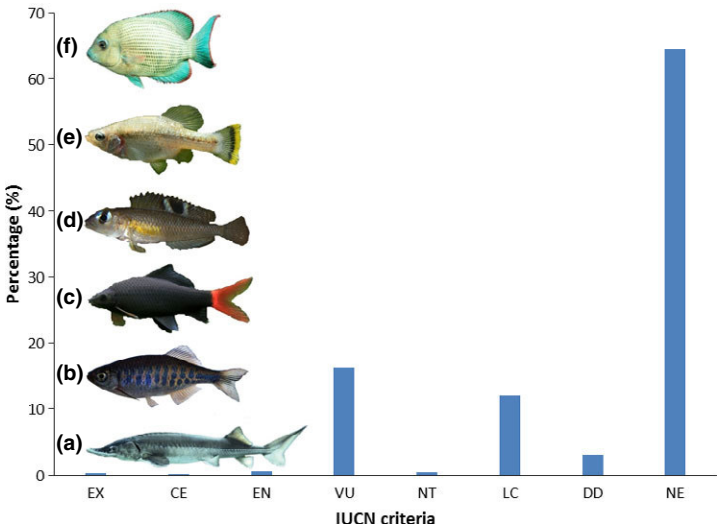

Figure 2 Conservation status based on IUCN criteria (EW, extinct in the wild; CE, critically endangered; EN, endangered; VU, vulnerable; NT, near threatened; LC, least concern; DD, data deficient and NE, not evaluated) of 1133 aquarium freshwater fish species compiled across several national and international wholesalers and aquarium hobbyists inventories for south-eastern Europe (see details in Maceda-Veiga *et al.* 2013). Photographs: (a) sturgeon species (*Acipenser* spp., IUCN: EN), (b) the barred danio (*Devario pathirana*, CE), (c) the redtail sharkminnow (*Epalzeorhynchus bicolor*, EW), (d) the ocellated shell-dweller (*Lamprologus kungweensis*, CE), (e) the butterfly splitfin (*Ameca splendens*, CE) and (f) the pinstrip damba (*Paretroplus menarambo*, EW).

killifish (*Aphanius sirhani*, Cyprinodontidae) (Crivelli *et al.* 2006), Potosi pupfish (*Cyprinodon alvarezi*, Cyprinodontidae) (Contreras-Balderas and Almada-Villela 1996) and redtail sharkminnow (*Epalzeorhynchus bicolour*, Cyprinidae) (Vidthayanon 2011), siltation for the ocellated shell-dweller (*Lamprologus kungweensis*, Cichlidae) (Bigirimana 2006), overfishing for human consumption for the pinstrip damba (*Paretroplus menarambo*, Cichlidae) (Loiselle 2008), and overfishing for human consumption and the construction of dams that blocked migrations for sturgeons (*Acipenser* spp., Acipenseridae) (e.g. Gesner *et al.* 2010). However, the wild status of 67% of the species in the aquarium trade in south-western Europe has not yet been evaluated or is data deficient (Fig. 2). These results illustrate that species with sufficient information to be classified as threatened or endangered are probably not being harvested from the wild in significant numbers for the aquarium trade, but also that there is limited information on the wild status of most aquarium species such that the possibility of excessive wild harvest of some rare species for the aquarium trade cannot be dismissed.

Despite difficulties, the aquarium hobby has proven to be respectful of regulatory schemes designed to reduce overharvesting or the introduction of invasive species. For example, legislation reduced effectively aquarium fish exports from Kerala, India (Jayalal and Ramachandran 2012), whereas the sale and distribution of regulated species, such as the apple snails (*Pomacea* spp.m Ampullariidae), was curbed after they were banned in Spain (Orden ARM/2090/2011 and Real Decreto 630/2013 Acts). In addition to the effectiveness of regulatory schemes, aquarium hobbyist associations also contribute to reduce the release of invasive species from domestic aquaria by developing educational campaigns in their magazines and websites to educate misguided aquarium keepers (e.g. the Cichlid Room Companion) but also accepting fish returns as exemplified on YouTube by the Seville Aquarium Association in Spain (https://www.youtube.com/watch?v=M3NQFGfkc08). The educational task of devoted aquarium hobbyists, however, goes further than just concern about invasives and also aims to promote ethics in fish keeping. Among the most popular species in the aquarium trade (Table 1), there is an array of species (e.g. catfish of the genera *Hypostomus* and *Pterygoplichthys*), which by virtue of their behaviour and/or potential large size are unsuitable for most domestic

aquaria and thus likely to become 'unwanted fish' and released (Fig. 3). Nonetheless, the responsibility for the release of representatives of popular aquarium fish families also encompasses other entities, such as administration (Pyke 2005), academic research centres (Gisbert and López 2007), anglers (Maceda-Veiga 2013), and florists and the general public (Fig. 1).

Aquarium hobbyists: a gateway to fish knowledge and its conservation

Many rare fishes are little known by scientists and largely neglected by governments and conservation organizations, and their plight has received the attention of only a few specialist hobbyists. These species (mainly livebearer, cichlids and killifish species) are exclusively available at aquarist meetings or via online exchanges upon request among serious hobbyists. For example, in south-western Europe, a survey revealed that about 300 of 1133 aquarium species (27%) were only found in the aquaria of members belonging to hobbyist organizations (Maceda-Veiga *et al.* 2013). Some hobbyist associations maintain open access to lists of names and origins of the species kept by their members (e.g. http://www.sekweb.org/censo/index.php). Most interestingly, many of these aquarist consortiums lead to extensive database depositories in which valuable information on

Table 1 The top 30 most popular fish species in the freshwater aquarium industry by region reported in studies on the aquarium hobby as a pathway for invasive species: Strecker *et al.* (2011) in Pacific Northwest (USA), Rixon *et al.* (2005) and Gertzen *et al.* (2008) in Laurentian Great Lakes, and Maceda-Veiga *et al.* (2013) in Iberia.

	Strecker *et al.* 2011	Rixon *et al.* 2005	Gertzen *et al.* 2008	Maceda-Veiga *et al.* 2013	
Scientific name	Pacific Northwest (USA)	Laurentian Great Lakes		Iberia	Mean
Carassius auratus	4	1	1	1	2
Betta splendens	3	2	7	2	4
Paracheirodon innesi	8	4	4	6	6
Poecilia reticulata	10	3	2	7	6
Xiphophorus maculatus	13	8	3	11	9
Xiphophorus helleri	13	7	6	10	9
Poecilia sphenops	11	17	5	8	10
Balantiocheilos melanopterus	12	9	30	12	16
Tanichthys albonubes	14	6	16	30	17
Hypostomus plecostomus	30	10	9	17	17
Corydoras paleatus	5	30	30	3	17
Trigonostigma heteromorpha	15	30	15	9	17
Cyprinus carpio	30	5	30	4	17
Danio rerio	5	30	30	5	18
Puntius tetrazona	1	13	30	30	18
Metynnis hypsauchen	1	16	30	30	19
Gyrinocheilus aymonieri	1	30	18	30	20
Trichogaster trichopterus	2	18	30	30	20
Poecilia latipinna	9	11	30	30	20
Colisa lalia	14	20	17	30	20
Gymnocorymbus ternetzi	6	15	30	30	20
Capoeta tetrazona	30	13	8	30	20
Pterophyllum scalare	30	30	13	13	22
Pterygoplichthys sp.	30	12	30	19	23
Moenkhausia sanctaefilomenae	1	30	30	30	23
Hemigrammus erythrozonus	7	30	25	30	23
Chromobotia macracantha	30	14	21	30	24
Astronotus ocellatus	17	19	30	30	24
Labidochromis caeruleus	6	30	30	30	24
Puntius conchonius	16	21	30	30	24
Hyphessobrycon callistus	30	22	30	15	24

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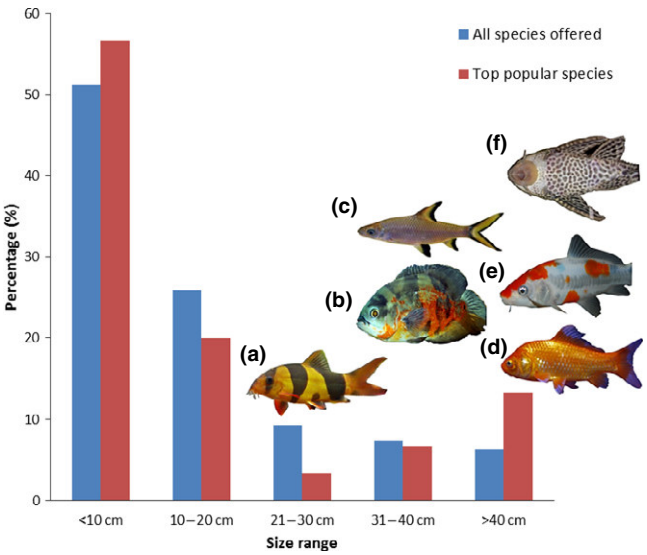

Figure 3 Relative proportions of different length classes of fishes recorded (N = 833 species) from national retailers in Iberia, and national and international wholesalers that offer aquarium fishes in Europe after Maceda-Veiga *et al.* (2013). The proportion of species belonging to the 30th most popular species is indicated at each length class, and photographs of those that exceed 21 cm maximum total length are also portrayed. Photographs: (a) clown loach (*Chromobotia macracanthus*, Cobitidae), (b) oscar (*Astronotus ocellatus*, Cichlidae), (c) bala shark (*Balantiocheilus melanopterus*, Cyprinidae), (d) goldfish (*Carassius auratus*, Cyprinidae), (e) carp (*Cyprinus carpio*, Cyprinidae) and (f) 'pleco' species: *Hypostomus plecostomus* and *Pterygoplichthys gibbiceps*, Loricariidae.

the biology, ecology, distributional range and behaviour of a myriad of fish species can be found, such as the Cat-eLog with datasheets of more than 3000 catfish species including 14 000 images and videos (http://www.planetcatfish.com/). In addition, the hobbyists often contribute to the development of basic knowledge about the biology and ecology of the species through the technical notes and reports they publish on the maintenance and breeding experiences of these species in hobbyist journals such as Rio Negro (www.rionegromagazine.com) (formerly named 'Acuario Práctico'), Practical Fishkeeping (www.practicalfishkeeping.co.uk/), Conscientious Aquarist Magazine (www.wetwebmedia.com), various aquarium websites (e.g. www.aquabotanic.com/) or the large number of aquarium association bulletins published on a regular basis (Appendix 1). Unfortunately, the scientific rigour of this information is often uncertain (see Kullander 2012), but some of these aquarist magazines may record relevant information for some researchers. For instance, first reports of the introduction/location of species in Argentina and adjacent areas are often published in the bulletin Ichthyological Contributions of 'Peces Criollos' of the Argentinean Killifish Club (http://www.killiclub.org/).

The content of the articles published by many hobbyists and the by-laws of their associations demonstrate that they are concerned for the welfare of the species they keep and for the effective transfer of knowledge. Together with aquarium hobbyist reports, knowledge exchange is achieved by organizing regular meetings, such as the International Killifish Show in the Netherlands (www.killifishnederland.nl), as well as by hobbyists maintaining their own personal websites and blogs where they publicize their accomplishments, such as the first breeding event of chocolate gourami (*Sphaerihchtys osphromenoides*, Osphronemidae) in captivity (www.aquarticles.com/articles/breeding/Xema_Chocolate_Gourami.html). Sometimes the results from devoted aquarium hobbyists working on vulnerable species also reach international scientific events, such as the participation of the aquarist association 'Sociedad de Estudios Ictiológicos (SEI)' in the International Union for the Conservation of Nature held in Barcelona in 2008 (http://seiconservation.blogspot.co.uk/). Likewise, several livebearer fish hobbyist associations participate in the International Symposia on Viviparous Fishes held biannually in Mexico (http://www.ictiologiamorelia2014.org/simposium.html). Other examples of knowledge transfer among hobbyists

are the various training courses that occur regularly at aquarium hobbyist associations (Appendix 1). These courses are typically taught by experienced aquarium hobbyists or invited scientists. Many courses are designed to increase the success of maintaining and breeding new wild species being brought into the domestication and often focus on the characteristics of the natural habitat of these species. Some aquatic retailers also provide free training courses on topics such as fish welfare or treatment of diseases in collaboration with academics such as AQA Espai and the University of Barcelona (www.aqaespai.com) in Spain. Aquarium hobbyist associations, such as the Barcelona Aquarium Association (BAA, www.aquariofilabcn.org/), also collaborate with certain specialized aquarium retailers to conduct courses and outreach activities. Whilst the primary reason that most retailers hold such courses is to attract more customers, the courses nevertheless encourage good aquarium practices and link hobbyists with knowledgeable and responsible sources of fish and information.

On the more applied conservation side of the hobby, the populations of fishes maintained in captivity through networks of devoted aquarists provide a germplasm reservoir to prevent the total extinction of the species and to develop reintroduction programmes (Dibble 2010; Domínguez-Domínguez 2010; Grist 2010). Although their merits are part of an ongoing debate (e.g. Gippoliti 2012; Bowkett 2014), *ex situ* conservation programmes often arise as the unique opportunity to save species with a reduced distributional range and exposed to high anthropogenic pressure (Conde *et al.* 2011; Domínguez-Domínguez *et al.* 2005; Domínguez-Domínguez 2010). A good example of the achievements of devoted aquarium hobbyists in this area is an *in situ* and *ex situ* conservation project in Mexico for two species of goodeids extinct (or nearly so) in nature, the crescent zoe (*Zoogoneticus tequila*, Goodeidae) and the golden skiffia (*Skiffia francesae*, Goodeidae), whose populations had been kept by private aquarium hobbyists around the world for 25 years (Dibble 2010; Grist 2010). In Spain, members of the SEI also carry out a successful captive-breeding programme of the endangered Spanish toothcarp (*Aphanius iberus*, Cyprinodontidae) with the release of reared individuals in restored lagoons in the Llobregat delta (www.seiconservation.org). The Spanish Killifish Association (SEK) leads another captive-breeding programme for three endangered *Aphanius* species (*A. apodus, A. danfordii and A. sirhani*) and the wild-extinct Potosi pupfish (*C. alvarezi*) (http://www.sekweb.org/). Besides captive-breeding programmes, such devoted aquarists also participate in the assessment of some populations of *A. iberus* and Valencia toothcarp (*Valencia hispanica*, Valenciidae) in coastal lagoons in north-eastern Spain. Likewise, the distributional range of the Mediterranean killifish (*Aphanius fasciatus*, Cyprinodontidae) in Italy is being assessed by members of the Italian Killifish Association (AIK) through the 'Progetto *Aphanius*' (http://www.aik.it/). Interestingly, thanks to these aquarium hobbyist expeditions, species considered extinct by scientists, such as the black spot allotoca (*Allotoca maculate*, Goodeidae) and ameca shiner (*Notropis amecae*, Cyprinidae), were rediscovered, and the declining conservation status of other fish species in arid areas of Mexico, such as the bold characodon (*Characodon audax*, Goodeidae) and red prince (*C. lateralis,* Goodeidae), was brought to the attention of scientists and conservationists (see Kempkes *et al.* 2013 and http://www.goodeidworkinggroup.com). Most of these *in situ* and *ex situ* conservation efforts led by aquarists are funded by their associations or themselves, and some even do crowd funding through personal websites or fish auctions to fund scientific research, such as 'The PlanetXingu project' in Brazil (http://www.planetcatfish.com/general/general.php?article_id=492).

Turning the tide in the relationship between aquarium hobbyists and research institutions

In addition to leading their own projects, aquarists and aquarium organizations can generate scientific knowledge and/or conserve rare fish species in collaboration with professional scientists. Aquarists have helped researchers locate many fish species in nature. For instance, aquarists from India contacted taxonomists of the Natural History Museum of London, UK, and accompanied them on several field trips during which new species were discovered, such as the catfish *Pseudolaguvia lapillicola*, Erethistidae (Britz *et al.* 2013). In Myanmar, the same scientific crew helped by aquarium fish importers found a new species of cyprinid, *Danionella dracula*, which revealed morphological novelties in fish miniaturization (Britz *et al.* 2009). Likewise, the rainbow killifish (*Nothobranchius rachovii*, Nothobranchiidae) was described from

specimens imported for the aquarium trade to Germany (Shidlovskiy *et al.* 2010), and the goodeid *Zoogoneticus purepechus* was described based on specimens collected by members of the Poecilia Netherlands organization (Domínguez-Domínguez *et al.* 2008). Careful observation coupled with precise tracking of the origin of captive fish populations has also resulted in some serious aquarists recognizing and publicizing morphological divergent populations that were later described as distinct species. For instance, the Belgium Killifish Association (DKG) provided specimens to researchers for the description of the Sahara aphanius (*Aphanius saourensis*, Cyprinodontidae) (Blanco *et al.* 2006). In addition, the DKG in collaboration with Jörg Freyhof (IUCN chair the European Region) funded in 2013 a small project to support Mahmoud Bacha and Chabane Benamirouche from Algeria to search for the species at its type locality and other water bodies in the Oued Saoura (García *et al.* 2010). Likewise, the Azraq killifish (*Aphanius sirhani*, Cyprinodontidae) was rediscovered in the wild by the University of Vienna with the help of the DKG. Further evidence of the importance of these serious aquarists in bringing new species to science is that taxonomists have named some species in their honour, such as *Enigmatogobius lucanusi* Cichlidae (Lamboj 2009) and *Neolamprologus walteri* Cichlidae (Verburg and Bills 2007). Together with species discoveries, the patterns of population differentiation in annual killifishes from La Plata Basin, Paraná-Brazil, have also been revealed with the contribution of aquarists, in this case from the Argentinean Killifish Club (see García *et al.* 2012).

An additional benefit of the collaborative effort in field collections between aquarists and academics is the development of large database depositories with valuable ichthyological information for some regions, such as the Fresh Water Fishes of Mexico (http://www.mexfish.info/default.php?lang=es), or fish groups, such as killifishes (http://www.killidata.org/) and cichlids (http://www.cichlidae.com/) with over 1100 and 1673 records, respectively. These websites present all the available information on fish groups, with details on systematics, morphology, ecology, and genetics, thousands of pictures and videos, and aquarium information for their maintenance and breeding. As a result of the valuable information provided by aquarium hobbyists, the killifish and cichlid organizations also raise funds for aquarists' expeditions. Briefly, aquarists submit a proposal with their aims, the name of the academic researcher they are planning to contract with to donate some specimens of their field collections along with the name of a well-known member of the aquarist association who can confirm their data. Then, an internal advisory committee of academics and aquarists evaluates the proposals, and if awarded, aquarists have agreed to report their results in an aquarium magazine and to deposit their findings in a database. Similar to these initiatives, the American Livebearer Association through their 'Langhammer and Vern Parish Funds' (livebearers.org/modules/content/), the American Cichlid Association through their 'Stuart M Grant and Paul V. Loiselle Conservation Funds' (http://www.cichlid.org/) and the U.S. aquarium industry's C.A.R.E.S. (Conservation, Awareness, Recognition, Encouragement, and Support), preservation programme (www.carespreservation.com) are maintaining captive-breeding stocks of species at risk and supporting research about fish species or their habitats (e.g. Seckinger *et al.* 2002; Burress *et al.* 2013; Da Barbiano *et al.* 2013).

A good example of an aquarist conservation project that is well integrated with academic conservation efforts is the Fish Ark Project (FAP)/Hobbyist Aqualab Conservation Project (HACP) at the Universidad Michoacana de San Nicolas de Hidalgo (UMSNH) in Mexico (Dibble 2010; Domínguez-Domínguez 2010; Grist 2010) (Fig. 4). The goal of this project is to develop and maintain a viable bank of germplasm of the most endangered species of Mexican goodeids, and it was conceived after a visit of members from the North England Zoological Society (NEZS) and the British Livebearing Association (BLA) to the UMSNH in 1998. The first specimens for this project were provided by the Chester Zoo, UK, and consisted of two species thought to be extinct in nature, the crescent zoe (*Z. tequila*) and the golden skiffia (*S. francesae*), that had long been maintained in aquaria (Domínguez-Domínguez *et al.* 2005; Domínguez-Domínguez 2010). Currently, the FAP and associated organizations such as the Goodeid Working Group successfully keep populations of the 12 most endangered or extinct-in-the-wild goodeid species in Mexico, plus 24 threatened species. The FAP and HACP and other similar initiatives have also led to international fish-network projects in which a consortium of zoos, public aquaria, aquarium hobbyists, research centres and universities are involved (Grum-Schwensen 2010). For instance,

Figure 4 Fish Ark Project (FAP) and the Hobbyist Aqualab Conservation Project (HACP) at the Universidad Michoacana de San Nicolas de Hidalgo (UMSNH) in Mexico: an example of cooperative work between aquarium hobbyists, academics and public aquaria. Photographs: (a) field sampling, (b) specimen of the critically endangered *Zoogoneticus tequila*, (c) fish facility at the UMSNH with the late Ivan Dibble and (d) artificial lagoon where endangered fish species were acclimatized before reintroduction into the wild.

the HACP has provided specimens of rare fishes to 34 universities, public aquaria, zoos and other hobbyists in 15 countries to ensure survival of a species if lost at the UMSNH (Domínguez-Domínguez 2010). Aquarium hobbyists also helped initiate and organize the Goodeid Working Group, which first met in Barcelona in 2009 (www.goodeidworkinggroup.com), within which aquarium hobbyists and scientists collaborate to promote captive rearing, research, habitat protection and restoration, and public education to help conserve goodeid fishes in Mexico. Another similar international initiative is the *Parosphronemus* project, which focuses on the conservation of the licorice gourami group (http://www.parosphromenus-project.org/).

The expert advice of aquarium hobbyists has also been fundamental to the development of many *in situ* conservation projects, including the Lake Victoria Species Survival Plan (LV-SSP) in Uganda, an aquaculture initiative developed in collaboration with the American Zoo and Aquarium Association (Hemdal 2008). In North America, similar local conservation initiatives on native fish species have been carried out by the North American Native Fish Association (www.nanfa.org), whose members include both aquarium hobbyists and ichthyologists. Aquarists of the Spanish Killifish Association also participated in the Spanish toothcarp conservation project (LIFE04 NAT/ES000035) supervised by the University of Murcia, Spain (Oliva-Paterna *et al.* 2006). Elsewhere in Spain, the SEI association developed an applied project in collaboration with the Mosquito Control Service to use the endangered *A. iberus* as a mosquito control agent during periodic flooding events in the Llobregat Delta. As *A. iberus* is sensitive to desiccation, a network of permanent ponds was created to allow the fish to naturally colonize the entire flood plain during floods and then return to the permanent ponds as the flooding receded (www.seiconservation.org). Likewise, a co-author (AMV) of this article has been working with a specialized aquaria retailer and the University of Barcelona in the development of a captive-breeding programme for the endangered river blenny (*Salaria fluviatilis*, Blenniidae) (LIFE 04NAT/000033). This partnership has resulted in the first successful captive breeding of the species and has facilitated exhaustive fieldwork to evaluate the potential suitability of agricultural ponds connected to natural channels as artificial breeding grounds for the river blenny in Aragon, Spain (Maceda-Veiga and Sostoa 2008). The author has also worked with hobbyists in the diagnosis of fish diseases and the maintenance of

native fish species in the fish facility at the University of Barcelona.

The last but not the least important aspect in the mutually beneficial relationship between academics and aquarists, including the aquarium trade in its own right, has been the adoption of new models in research, with applications ranging from aquaculture to biomedicine. For instance, the zebrafish (*Danio rerio*, Cyprinidae) was introduced in research as a vertebrate model after George Streinsinger, from the University of Oregon, obtained a stock from a pet shop in the 1960s (Grunwald and Eisen 2002). Likewise, other species originating from the aquarium trade that are easily maintained in captivity have also become popular in academic applications, such as the medaka (*Oryzias latipes*, Adrianichthyidae) (Tanaka *et al.* 2001; Wittbrodt *et al.* 2002). In addition, the study of parasites isolated from fish purchased from aquarium retailers has enabled an increase in our understanding of transmission dynamics of monogenean infections that can have devastating consequences either in wild or in captive fish populations (Richards *et al.* 2012). Such studies have enabled assessment of new therapies (Schelkle *et al.* 2013) or the suitability of these parasites for enhancing the immune system of captive-reared fish in reintroduction programmes (Faria *et al.* 2010). Other applications of resources provided by aquarium retailers in research have been the validation of a non-invasive sampling procedure in the popular angelfish (*Pterophyllum scalare*, Cichlidae) for the detection of internal fish parasites (Williams *et al.* 2013).

The aquarium hobby as a mechanism for increasing conservation awareness

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 more involved in local and international conservation initiatives that benefit a wide variety of organisms and habitats, not just fish (Taylor 1993; Reid *et al.* 2013; Tlusty *et al.* 2013). In fact, early experiences keeping fish in aquariums helped lead many aquatic scientists and conservationists, including the authors of this article, into their professional careers (see other examples in http://www.cichlidae.com/author_docs.php?id=1&type=interview). But even for non-professionals, experiences in the aquarium hobby can build a strong and active conservation ethic. Admittedly, the aesthetic component of an aquarium fuels the entry of members into the hobby, but at the same time, as the maintenance of an aquarium mirrors the functioning of natural systems, it also promotes acquiring basic knowledge about ecological processes. An example of the importance of this aspect in the aquarium hobby is the book entitled 'The Ecology of the Planted Aquarium' (Walstad 2003). Under the philosophy of creating an ecosystem in an aquarium, two tendencies can be observed. On the one hand, there is the business-led approach of creating the most sophisticated aquatic landscape possible and with a goal of receiving recognition for it (http://www.aquatic-gardeners.org/). On the other hand, there is the approach of creating aquatic landscapes that mirror the biotope from where the species originated (http//all4aquarium.ru/en/events/jbl-biotope-contest-2013/entries).

The attractiveness of aquarium landscapes also furnishes a basis by which aquaria can be used by aquarium hobbyist associations and other private and public entities to increase public conservation awareness (Taylor 1993; Cainey *et al.* 2012; Reid *et al.* 2013; Schwan *et al.* 2014). In essence, an aquarium reveals the often hidden aquatic world to the general public in much the same way as films and other media do (Monroe *et al.* 2009; Cooke *et al.* 2013). As an example, the BAA invited the University of Barcelona to set up an information panel and several aquaria with native and introduced fish species found in Spanish rivers to increase public awareness for the conservation of native fish species during the Barcelona Aquarium Meeting in the Mascota Festival and Expo (formerly SIZOO), which attracts more than 26 300 visitors (www.salonmascota.com). Likewise, the Argentinean Killifish Club Association set up information panels and exhibition aquaria to show different aspects on the conservation of freshwater fish to visitors of the Natural Science Museum in Buenos Aires (http://www.killiclub.org/). As another example, the SEI association has an ongoing collaboration with the Zaragoza Aquarium for the *ex situ* conservation of endangered native Spanish species along with increasing public awareness of other native fauna (www.seiconservation.org). Sometimes these eco-friendly initiatives have become, for some particular aquarists, a way of living, as occurred with the develop-

ment of an eco-tourism enterprise in Brazil (http://www.lopeix.com/).

By virtue of their attractiveness and charismatic nature, fish can also be a symbol in their own right to increase conservation awareness among the general public, especially in schools. For instance, the 'Associació per la Defensa i Estudi de la Flora i Fauna Autóctones' in Santa Maria de Merlés, Spain (www.adeffa.cat), works for the restoration of the local freshwater fish fauna through studies of the ecology and biology of native species, such as the endangered river blenny (*S. fluviatilis*) or the European bullhead (*Cottus hispaniolensis*, Cottidae), and assists with education in schools about the conservation of aquatic ecosystems. Similarly, aquarium hobbyists from the LV-SSP help monitor cichlids of the *Haplochromis* genus in their natural habitats and have contributed to the development of a children's colouring book that offers youngsters in the region an entertaining approach to learn about the ecology and problems facing Lake Victoria in Africa (Hemdal 2008). At a more local scale, the SEI Spanish toothcarp project has a strong educational component. Students at 10 schools are taught about the threats to native fish species in the region and how to maintain Spanish toothcarp and collect their eggs and raise fry. The students participate in the release of their captive-reared Spanish toothcarp in selected natural lagoons in the Llobregat Delta guided by the SEI during a social event termed the 'the Spanish toothcarp party'. Local media are invited to publicize the conservation and education initiatives of this project (http://seiconservation.blogspot.com.es/). In doing so, enthusiastic aquarists increase public conservation awareness of local aquatic resources and also urge citizens to join international initiatives to assess the status of freshwater fish populations, such as the recently launched 'Global Freshwater Fish Bio Blitz' (http://www.iucnffsg.org/ffsg-activities-2/global-freshwater-fish-bioblitz/).

The interests of aquarium hobbyists can go further than just the study of particular fish species and lead to collaborations with government and management agencies in monitoring studies of freshwater ecosystems. For instance, members of the BAA in Spain participate in river water-quality monitoring through the 'projecte rius' (www.projecterius.org), which is a long-term government project that uses macroinvertebrates as bioindicators. Members of another aquarium association to which a co-author (JEA) belongs also assist in monitoring of populations of the endangered white-clawed crayfish (*Austropotamobius pallipes* species complex, Astacidae) (but see Clavero and Villero 2014) supervised by technicians from the Autonomous Government of Catalonia, Spain. Other examples of the broad scope of aquarium hobbyist in nature conservation are the field trips organized by the Galician Association of Aquarium Hobbyists to ecologically relevant natural areas, such as the Ancares-Courel Reserve within Nature Network 2000 in Galicia, Spain.

Conclusion

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 they study or maintain, and this common interest could be the basis for a more positive and productive relationship. Our brief overview has attempted to describe some of the positive actions of devoted aquarists in public engagement and the conservation of fish and their habitats either alone or in collaboration with professional scientists. Overall, the cooperative efforts between academics and serious aquarists have been successful, and it would be even more mutually beneficial if there was a greater contact and communication between conservationists and aquarium hobbyists. Such collaboration is also vital to reduce the major drawbacks of this enduring hobby, invasive species and overharvesting, which are mainly the result of short-term business-driven practices far from the essence of the sustainable aquarium hobby and its devoted aquarists.

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Appendix 1 List of 30 aquarium hobbyist associations focused on killifish (Cyprininodontidae), livebearers (mainly Goodeidae and Poeciliidae) and cichlids (Cichlidae), which account for the largest number of affiliations in the freshwater aquarium hobby. The links give access, for free in many cases, to the educational materials and technical folders that these associations provide to members or general public about the maintenance of these fish species, conservation programmes developed in the association, expeditions, lectures and conventions.

Name of aquarium hobbyist association	Link
The American Killifish Association	http://aka.org/
The Argentinian Killifish Association	http://killisargentina.com.ar/smf/index.php
The Russian Killifish Association	http://www.killi.ru/
The Spanish Killifish Association	http://www.mundoacuariofilo.org/
The Italian Killifish Association	http://www.aik.it/
The Belgium Killifish Association	http://www.akfb.be/?lang=fr
The Portuguese Killifish Association	http://www.apk.pt/
The British Killifish Association	http://www.bka.org.uk/
The German Killifish Association	http://www.killi.org/
The Catalan Killifish Association	http://grupcataladekillis.wordpress.com/
The Nothobranchius Project	http://www.proyectonothobranchius.net/
The Nothobranchius maintenance group	http://www.nmg.nothos.org/
The Killi-data online	http://www.killi-data.org/
The Argentinian Killiclub	http://www.killiclub.org/
The Nothobranchius information center	http://users.telenet.be/marc.bellemans/
Seriously Fish	http://www.seriouslyfish.com/
The Netherlands Killifish Association	http://www.killifishnederland.nl/
Killi.uk	http://www.killi.co.uk/
The Iberian Cyprinodontids	http://www.fartet.org/
The French KilliClub	http://www.killiclubdefrance.org/
Barcelona Aquarium Association	http://www.aquariofilabcn.org/
Valencian Aquarium Association	http://socav.com/
The American Livebearer Association	http://livebearers.org/
The French Association of Vivipares	http://www.francevivipares.fr/wordpress/
The British Livebearer Association	http://www.britishlivebearerassociation.co.uk/
Chicago Livebearer Association	http://www.chicagolivebearer.com/
German Livebearer Association	http://www.dglz.de/
Livebearer Research Association	http://www.livebearer.org/Home.html
The American Cichlid Association	http://www.cichlid.org/
The British Cichlid Association	http://www.britishcichlid.org.uk/phpBB3/

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