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Jiří Patoka

André Lincoln Barroso Magalhães

Antonín Kouba

Zen Faulkes

Rikho Jerikho

See next page for additional authors

Authors

Jiří Patoka, André Lincoln Barroso Magalhães, Antonín Kouba, Zen Faulkes, Rikho Jerikho, and Jean Ricardo Simões Vitule

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COMMENTARY

Invasive aquatic pets: failed policies increase risks of harmful invasions

Jiří Patoka[1] · André Lincoln Barroso Magalhães[2] · Antonín Kouba[3] · Zen Faulkes[4] · Rikho Jerikho[5] · Jean Ricardo Simões Vitule[6]

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Abstract

Businesses in the pet trade collect and transport many aquatic species around the globe, and some of these individuals are released into new habitats. Some jurisdictions have introduced laws intended to regulate this trade, but these regulations have rarely had the desired effects. Laws regarding pets and the pet trade are often poorly communicated, poorly enforced, and not aligned with hobbyists' beliefs. Consequently, some laws may increase the number of unwanted introductions instead of decreasing them. A significant change in approach is needed, involving far greater communication with scientists, administrations, politicians, the pet industry, and pet owners, promoting euthanasia of unwanted pets rather than release, and the creation and promotion "white lists" of low risk species that can be sold in the pet trade.

Keywords Invasive species · Legislation · Ornamental animal · Pet trade · Conservation

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✉ Jiří Patoka
patoka@af.czu.cz

[1] Department of Zoology and Fisheries, Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Sciences Prague, Kamýcká 129, 16500 Prague - Suchdol, Czech Republic

[2] Programa de Pós-Graduação em Tecnologias para o Desenvolvimento Sustentável, Universidade Federal de São João Del Rei, Rod. MG 443, KM 7, Fazenda do Cadete, Ouro Branco, Minas Gerais 36420-000, Brazil

[3] South Bohemian Research Center of Aquaculture and Biodiversity of Hydrocenoses, Faculty of Fisheries and Protection of Waters, University of South Bohemia in České Budějovice, Zátiší 728/II, 38925 Vodňany, Czech Republic

[4] Department of Biology, University of Texas Rio Grande Valley, 1201 W. University Drive, Edinburg, TX 78539, USA

[5] Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, Bogor Agricultural University, Kampus IPB Darmaga, 16680 Bogor, Indonesia

[6] Laboratório de Ecologia e Conservação, Departamento de Engenharia Ambiental, Universidade Federal do Paraná, Setor de Tecnologia, Curitiba, Paraná 19020, Brazil

The rate of new established non-native species is predicted to further increase as a result of increasing global trade (Blackburn et al. 2011; Ellis et al. 2013). Importantly, the introduction of non-native organisms might cause negative impacts, even before the establishment phase of the invasion process when the population is not self-sustaining (e.g. Blackburn et al. 2011; Cunico and Vitule 2014). For example, serrated caulerpa (*Caulerpa scalpelliformis* var. *denticulata*; Falcão and Széchy 2005), guppies (*Poecilia reticulata*; Cunico et al. 2009) and red swamp crayfish (*Procambarus clarkii*; Banci et al. 2013), were dumped from aquariums in a bay and streams located in Rio de Janeiro, Paraná and São Paulo States in Brazil. The first two negatively changed fish community structures, and the crayfish preyed on native toads (*Rhinella ornata*). In the Chacamax River, Chiapas State, Mexico, explosive growth of an introduced population of stoichiometrically unique, phosphorus (P)-rich armoured catfish (*Pterygoplichthys* sp.) transformed stream nutrient dynamics by altering nutrient storage and remineralization rates (Capps and Flecker 2013). Once established in the wild, non-native invasive organisms can be very difficult, if not impossible, to eradicate (Lowe et al. 2000). Removing invasive species is not always straightforward because eradication typically involves long term campaigns, huge effort/costs and can affect native species. If the process is not done properly, "eradication success" could be declared too soon, the target invasive species is no longer subjected to control pressure, and the invasive species can "return", a situation known as the Lazarus Effect (Clout and Veitch 2002; Lockwood et al. 2013).

Because biological invasions cause significant environmental and economic losses (Vitousek et al. 1996), and the pet industry is one of the key pathways for introduction of non-native invasive species (Magalhães and Vitule 2013), policymakers have initiated both national and international restrictions on this trade. For example, certain pet-traded aquatic species, such as marbled crayfish (*Procambarus virginalis*) and the red-eared slider (*Trachemys scripta elegans*), are among those banned by European Union Regulation No. 1143/2014. The common yabby (*Cherax destructor*) and walking catfish (*Clarias batrachus*) are banned by the American Federal Register 67 FR 48855 under the Lacey Act (18 U.S.C. 42). In November 2012, the European Commission implemented Decision 2012/697/EU banning the import of all apple snails (genus *Pomacea*). Thus, apple snails should not be introduced into or allowed to spread within the European Union, which means retailers should not be importing, breeding or selling these snails (OATA 2016). The United States Department of Agriculture, Animal and Plant Health Inspection Service (USDA-APHIS) implemented regulations in 2006 to prohibit the import or interstate movement of all members of the Family Ampullariidae, such as the zebra apple snail (*Asolene spixi*; Putnam 2015). In Queensland, Australia, salamanders of the genus *Cynops* are considered potential threats to the local aquatic fauna and, as consequence, their importation is forbidden by the Land Protection Act of 2002 (Queensland Government 2012). Import of non-native live crayfishes is prohibited in France, Portugal and Japan, because of ecological concerns (Lodge et al. 2012). The aquarium ambulia (*Limnophila sessiliflora*), hydrilla (*Hydrilla verticillata*), and the "killer algae" (*Caulerpa taxifolia*) were placed on the Act No. 36 of 1983 and the Federal Noxious Weed List of 1999 making it illegal to import these species into the U.S.A. and South Africa, respectively (Martin and Coetzee 2011; Díaz et al. 2012).

In contrast, other less engaged governments support the pet trade. For example, Brazil allows the trade of 2000 ornamental fish species outside of the Brazilian Amazon (Normative Instruction No. 16/2014) and the import of lionfish species such as the common lionfish (*Pterois miles*), radiata lionfish (*P. radiata*) and Hawaiian lionfish (*P. sphex*), other than the highly invasive red lionfish (*P. volitans*), which is surprisingly completely omitted

in the instruction (Normative Instruction No. 202/2008). The third type of approach to non-native species is to simply ignore the threat or overlook this issue. For instance, with rare exceptions (i.e., piranhas, *Pygocentrus* and *Serrasalmus* spp.), it is possible to import any ornamental aquatic species of commercial interest in Chile, even species with negative history of invasions worldwide (Campos-Larrain and Valenzuela-Alfaro 1996). Since November 1993, everybody in Switzerland needs a concession for releasing non-native fish and crayfish in natural and artificial water-bodies (public and privately owned), and strict legislation, however, does not prevent crime (Pöckl 1999). And in Israel, the Israeli law (National Parks and Nature Reserves Act 1998) protects all freshwater molluscs, non-natives included such as the aquarium species giant ramshorn snail (*Marisa cornuarietis*), assassin snail (*Anentome helena*), acute bladder snail (*Physella acuta*) and the golden apple snail (*Pomacea diffusa*) (Yanai et al. 2017).

The effectiveness of national and international restrictions on the pet trade is questionable. In Brazil, the availability of the banned *P. clarkii* in pet stores, e-commerce and ornamental aquaculture indicates that compliance of Brazilian Federal Ordinance No. 5 of 2008 is not fully respected (Magalhães and Andrade 2015). The Normative Instruction 39 of 1999 prohibits the import of crustaceans (Ministério da Agricultura 1999), but the ornamentals African giant filter shrimp (*Atyopsis gabonensis*), skunk cleaner shrimp (*Lysmata amboinensis*), peppermint shrimp (*L. wurdemanni*), Malawa shrimp (*Caridina pareparensis* var. *parvidentata*), and red cherry shrimp (*Neocaridina davidi*) are easily marketed in aquarium stores and online auctions in Brazil (Magalhães and Andrade 2015; MercadoLivre 2017a, b, c). In the same way, the Normative Instruction 05 of 2004 prohibits the trade of invasive sun coral (*Tubastrea* spp.; Ministério do Meio Ambiente 2004), but the species also is being sold in online auctions in the city of Rio de Janeiro, Brazil (MercadoLivre 2017d). The Federal Law 202/08 for marine ornamental fish does not authorize the importation of fish species with the expression "sp.", but in October 2009, individuals of non-native clown goby (*Gobiodon* sp.) were being sold in aquarium trade in the city of São Paulo (ReefCorner 2009). The Ordinance No. 93 of 1998 was enacted to regulate the management of non-native amphibian and reptiles, and this act emphasizes trade regulation of these non-native taxa through vectors such as importation via the pet trade. Although the Brazilian government has declared the importation of non-native herpetofauna illegal (Brasil 1998), individuals of aquatic species such as the African clawed frog (*Xenopus laevis*), the axolotl (*Ambystoma mexicanum*), Spanish ribbed newt (*Pleurodeles waltl*), the snapping turtle (*Chelydra serpentina*), and *T. scripta elegans* are still sold in Brazil (Magalhães and São-Pedro 2012). Moreover, the recent availability and ease in purchase of illegals species on Brazilian market, such as lemonpeel angelfish (*Centropyge flavissima*), striped catfish (*Pangasianodon hypophthalmus*), snakeskin gourami (*Trichopodus pectoralis*), giant gourami (*Osphronemus gourami*), snakehead (*Channa argus*), forest snakehead (*C. lucius*), Indonesian snakehead (*C. micropeltes*), striped snakehead (*C. striata*), and *C. batrachus* indicate that the compliance of Normative Instructions No. 202 and 203/2008 is not respected (Magalhães 2015). The Normative Instruction No. 204 of 2008 permits the sale of freshwater stingrays such as the porcupine river stingray (*Potamotrygon hystrix*) with a maximum disc width of 14 cm, but bigger individuals (> 14 cm) are sold among Brazilian aquarium hobbyists via face-to-face personal contacts (Magalhães et al. 2017). In Germany, where fishkeeping is well known and widespread, aquarium dumping is prohibited by the German AnimalWelfare Act [113]; §3 Abs. 3, 4 TierSchG, however, ignoring this issue, aquarium hobbyists continue to systematically release ornamental species of such as the bristlenose pleco (*Ancistrus* sp.), convict cichlid (*Amatitlania nigrofasciata*), spotted tilapia (*Pelmatolapia mariae*), Kaira River prawn (*Macrobrachium dayanum*) and the

tape grass (*Vallisneria spiralis*) in Gillbach stream, North Rhine-Westphalia State (Lukas et al. 2017). In England, the purchase of the illegal fish species Chinese sucker (*Myxocyprinus asiaticus*) indicates that the compliance of Prohibition Order 1998 is violated (Hill 2013). Also the sales of illegal and risky crayfish, such as *C. destructor*, spiny-cheek crayfish (*Faxonius limosus*), and *P. clarkii* indicate that compliance of Prohibition Order of 1996 is not being highly respected (Clarke 2007; Hill 2013). In Malaysia, the Fisheries Act 1985-Fisheries Regulations (Prohibition of Import, etc., for fish) (Amendment) 2011 does not allow the import of hybrid cichlid (*Amphilophus trimaculatus*×*A. citrinellus*) but, many individuals are still sold in Malaysian aquarium trade (Ng 2016). In Indonesia, the Regulation No. 41/PERMEN-KP/2014 bans the import of selected 152 non-native fish species. In this law, fishes are defined as "all types of organism in which all or part of its life cycle is in an aquatic environment". Paradoxically, many banned species such as *P. clarkii*, Midas cichlid (*A. citrinellus*), and the auratus cichlid (*Melanochromis auratus*) are cultured and produced in Indonesia in huge quantities because it is legal to release non-native species into the wild and indeed, local people do so for further exploiting. Also, some local people have bred the banned non-native *P. clarkii* in Indonesia for several years (Patoka J. 2017 unpublished data). Despite this, the general regulation of invasive species PERMEN LHK P94/2016 categorizes this crayfish as an invasive species not occurring in Indonesian territory. The ornamental plant, the water chestnut (*Trapa natans*) is banned for sale by the Washington Department of Agriculture, but currently is available for aquarium hobbyists in Washington State, U.S.A. (Strecker et al. 2011) and also in the Czech Republic (Patoka J., unpublished data). Demand for pets may drive the unsustainable collection of species from their native habitats such as the freshwater angelfish (*Pterophyllum scalare*) in Peruvian Amazonia (Juvonen and Salo 2004), and releasing individual pets into new habitats, either accidentally or deliberately (Vitule et al. 2014) like *P. scalare* introduced by hobbyists in Singapore (Liew et al. 2012).

Even if the ideas behind some legislative measures were good, as in the case of European Union and American regulations, hobbyists often do not know reasons why keeping of some species is banned and are not aware the risks and consequences of biological invasions. If faced with improperly communicated regulations, they may tend to release banned pets to the natural environment to avoid possible "complications". Furthermore, releasing pets is usually perceived by the public as more ethical than euthanasia, and mistakenly thought to provide ecological benefits (Drake et al. 2015). We would like to highlight that all the approaches mentioned above may have, in fact, dramatically devastating consequences for native biota and entire ecosystems. The implementation of new strict prohibitions, particularly if combined with penalties, may lead hobbyists to consider releasing their unwanted pets to get rid of the "problem". Conversely, permissive policies (including no policy at all) that allow pets to be moved outside their native habitats may have similarly negative consequences. It is well demonstrated by cases such as *P. volitans* and *T. scripta elegans*, the fish and turtle which are listed in the top 100 of the world's worst invasive species (Lowe et al. 2000), and crayfish *P. virginalis* (Fig. 1). These are successful invaders in many regions where introduced (Whitfield et al. 2002; Ramsay et al. 2007; Patoka et al. 2016).

Obviously, ameliorating the pet trade's contribution to the current sixth mass extinction will call for intensified efforts. Even if the legislation in some countries seems to be sufficient, the international cooperation regarding mitigation of biological invasions must be enforced (Perrings et al. 2010; Lucy et al. 2016). Limiting species loss will require intensive communication between scientists, politicians and other stakeholders (i.e., pet industry), and educating the general public to the value of conserving

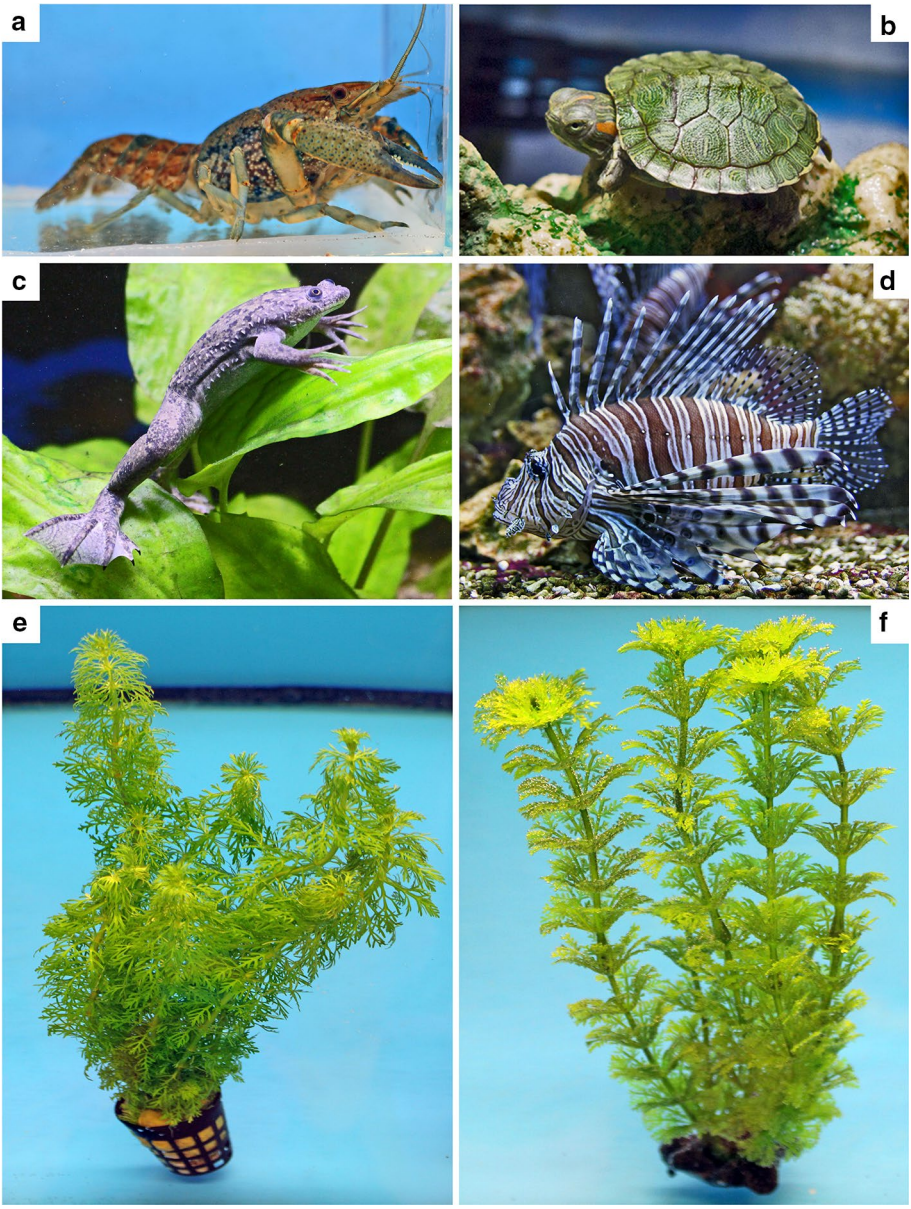

Fig. 1 Selected well-known invasive aquatic species traded as ornamentals in the world: **a** marbled crayfish (*Procambarus virginalis*), **b** red-eared slider (*Trachemys scripta elegans*), **c** African clawed frog (*Xenopus laevis*), **d** red lionfish (*Pterois volitans*), **e** ambulia (*Limnophila sessiliflora*), **f** plastic plant as an alternative to avoid invasions by hobbyists

biodiversity and entire ecosystems (Hulme 2015). A communication bridge which unites scientists, politicians, and the pet industry is a crucial point of effective conservation of native biota and whole ecosystems (Azevedo-Santos et al. 2017). Therefore,

intensive information campaigns must happen before new restrictions related to potentially invasive species are initiated and enacted. We suggest the following points:

(i) Reformulate the aforementioned and other unsuitable laws with the involvement of environmental agencies so that they do not continue to be "dead letters" (laws that exist but are not implemented);
(ii) Make these laws more accessible to layperson (i.e. specialized media such as pet magazines/journals/books, e-commerce, importers, distributors, wholesalers, retailers, aquarium hobbyists, clubs and societies); environmental agencies must seek new communication tools (e.g., WhatsApp Messenger or other smartphone apps) that provide an effective connection to hobbyists. For instance, The Australian Department of Fisheries and The Florida Fish and Wildlife Conservation Commission and the Environment Agency, Scottish Natural Heritage, Natural Resources Wales and the Scottish Environment Protection Agency have developed free apps named WA PestWatch and The Report Florida Lionfish and PlantTracker respectively to provide awareness to laypersons and to assist the detection of new invasions to keep inland and marine waters free of non-native fish and aquatic plants (http://www.fish.wa.gov.au/Sustainability-and-Environment/Aquatic-Biosecurity/Identifying-Pests-And-Diseases/Pages/WA-PestWatch.aspx; http://www.floridawildlifemagazine.com/report-florida-lionfish-app.html); also non-stop "pest hotlines" such as Fishwatch hotline and the "General Biosecurity Obligation" (i.e., everyone is responsible for managing biosecurity risks) under Biosecurity Act 2014 in Queensland, Australia are recommended in this regard;
(iii) Encourage humane disposal, mainly euthanasia, of unwanted pets. This diverges from what scientific literature and educational campaigns in many countries usually suggest. We do not recommend "reverse logistics", such as contacting retailers for possible returns, donating to a public place (e.g., school, hospital, and malls), using an animal adoption fair/website, or giving or trading with other hobbyists. The recipients are typically laypersons who can release these pets improperly, thus maintaining the interminable cycle of intentional introductions. The best way to eliminate aquatic plants is to ensure that they are not able to be transported to an area where they are likely to reproduce themselves. Acceptable means of disposal include incinerating, land filling, desiccating, and composting - only if plants are exclusively submerged and if applied away from surface waters. Other possible ways are microwaving, freezing, and treatment with acetic acid;
(iv) Hobbyists should receive instructions from environmental agencies, universities and NGOs regarding good practices for discarding undesired pets; vendors should mandatorily provide a flyer/pamphlet and packaging paper on pet disposal with every sales; messages about not releasing pets into wild should be printed on the plastic bags in which animals and plants are transported home;
(v) Environmental agencies should work more with social networks (e.g., Facebook, Twitter, virtual pet-shops, and pet-industry websites) to post alert messages in the pictures of non-native species for sale, indicating life traits (e.g., size when fully grown, diet, parthenogenesis, seeds adapted for dispersal by water movements, plants with asexual reproductive output) and behaviour (e.g., aggressiveness, ter-

ritoriality, corals grow out of control, aquatic plants having ability to form dense floating mats over still or slow-flowing water) to reduce further pet dumping;

(vi) Stimulate citizen science nationally and globally with the goal of detecting and controlling invasive pets; development and sharing of user-friendly identification keys are crucial;

(vii) Restrict or prohibit trade in physical stores, e-commerce and face-to-face personal contacts among hobbyists of pet species of concern, such as *Tubastrea* spp., *Pomacea* spp., *P. clarkii*, *X. laevis*, *P. volitans*, *Channa* spp., *T. scripta elegans*, *C. taxifolia* and *H. verticillata;*

(viii) Stimulate campaigns to replace high-risk species on the market by non-invasive congeners listed on the "white list" or "clean list" considered to be acceptable for stocking and culture, hobby keeping etc.; starting locally and consequently working with an international network and community of hobbyists to develop a campaign to replace invasive species with less risky ones (including use of silicone resin/rubber and plastic imitations instead invasive live corals or plants; Fig. 1);

(ix) Environmental agencies and universities should use DNA barcoding to efficiently distinguish of invasive aquatic pets from non-invasive related species (e.g., freshwater fishes: genera *Pygocentrus*, *Piaractus*, *Puntius*; marine fishes: genera *Centropyge*, *Pomacanthus*, *Pterois*; corals: genera *Palythoa*, *Tubastrea*, *Xenia*; crayfish: genera *Procambarus*, *Cherax*, *Faxonius*, plants: genera *Cabomba*, *Caulerpa*, *Hydrilla*) and thus, may be helpful with enforcing a ban on the import of identified invasive species.

(x) Stoichiometrically unique aquarium invaders would be expected to alter nutrient dynamics after invasion if they attain high biomass relative to other species and/or if they modify the flux of limiting nutrients in invaded ecosystems. Thus, ecological stoichiometry can be employed to help predict which species have the potential to exert strong influences on ecosystem structure and function, and allow policymakers to initiate targeted actions to restrict the import of specific organisms in aquarium/pet trade.

These suggestions can be part of the effort to transposed into widespread and enforceable legislation and control intermittent colonization and propagule pressure (sensu Lockwood et al. 2005, 2009; Frehse et al. 2016), for instance, Cassey et al. (2018) stressed that propagule pressure is indeed the most consistent and strongest determinant of alien species establishment and that we need to underpin a clear policy and management target for slowing invasion rates by reducing propagule globally. These strategies are in line with the principles of Aichi Biodiversity Target 9 of the Strategic Plan 2020 of the Convention on Biological Diversity. This target calls for identifying the pathways by which non-native species are introduced and focusing prevention efforts on these (https://www.cbd.int/sp/targets). The intensive information and awareness campaigns aimed on general public such as the Southern California Caulerpa Action Team, The Reduce Invasive Pet and Plant Escapes (RIPPLE) Campaign, Nab the Aquatic Invaders, Habitattitude, Stop Aquatic Hitchhikers, Aquatic Invaders, The National Lionfish Project and The Sun-Coral Project (Anderson 2005; Patterson et al. 2010; CABI 2012; Seekamp et al. 2016; Creed et al. 2017, Michigan Invasive Species 2018) before new restrictions or permissions related to potentially invasive species must be implemented. As we enter the Anthropocene, humanity is

reorganizing the biosphere, and it is alarming that native biota worldwide is also jeopardized by missing, incomplete, and improperly communicated legislation. The costs related with biological invasions are high and to safeguard aquatic ecosystems in the world, invasive aquatic pets should be moved to the top, not the bottom, of the government's environmental priorities lists.

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