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Invasive Alien Fish Species in Freshwater of the Continents

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Abstract

This review article presents the updated informationof freshwater Invasive Alien Species (IAS) of fishes of the continents to understand the homogenate progression in global freshwater ecosystems and the leading pathways of freshwater IAS fish introduction throughout the continents. North America contains 45 freshwater invasive fish species within 18 families, which is the most profuse off all other continents, whereas, Australia possesses the lowermost amount of freshwater IAS fish, 18 species under 8 families. Besides, Asia retains 41 freshwater IAS fish under 14 families and Europe acquires 32 species under 18 families. The uppermost spreader IAS fish family is Cyprinidae followed by Cichlidae subsequently. Nine common fishes (*Carassius auratus, Cyprinus carpio, Onchorynchus mykiss, Oreochromis mossambicus, Poecilia reticulata, Salmo salar, Salmo trutta* and *Salvelinusfontinalis)* turned out invasive in all the continents (without Antarctica). Among IAS introduction pathways, aquaculture causes the highest percentage of freshwater IAS introduction in all continents. Aquaculture root 25% of IAS fish introduction in Africa, 21% in Asia, 19% in Australia, 20% in Europe, 19% in North America and 19% in South America. There is hardly any documentation on freshwater IAS fishes of Antarctica. Therefore, future research consideration may be designed.

Key words: Aquaculture, Freshwater fish invasion, Introduction pathways, Invasive fish, Homogenization

Introduction

The unintentional and deliberate introduction of species to ecosystems, along with other frequent anthropogenic goings-on swaying our environment, has taken place since antiquity (Hughes, 2003; Francis, 2012). When such introductions cause economic and/or ecological harm or adversely affect human health, are classified as IAS. Therefore, in the 21st century, IAS are categorized as "eco-warrior" amongst the noteworthy coercions of the global biodiversity (Pimentel *et al.,* 2000, 2005; Pejchar and Mooney, 2009). Likewise, the biodiversity of global freshwater ecosystem is defined alarming because of its declining rate; which is mostly allied with the existing and potential impacts of IAS (Sala *et al.,* 2000; Vörösmarty *et al.,* 2010). Amongst aquatic organisms, freshwater fishes are one of the absolute introduced taxa around the world (624 species: Gozlan, 2008) and this introductions as well as corresponding ruthlessness of influences can be occurred to a countless extent in ecosystems (Zedler and Kercher, 2004). In accordance with Moyle and Leidy(1992), approximately 20% of the freshwater fish species of the world (ca. 1800 species) are already extinct or in serious declining phase due to IAS introduction. Irrefutably, the vicissitudes caused by IAS are so massive, ecologists have commented that we are inward bound a different era, "The Homogocene" (a term apparently coined by Gordon Orians in the mid-1990s; Rosenzweig, 2001), in which all continents will be connected as a ''New Pangaea'' through the alike biota. Both or either establishment of non-indigenous species and loss of native biodiversity are lessening dissimilarities among regional biota, which can be referred to as biotic homogenization (Rahel, 2002). However, to look at the broad image of global IAS fishes, it is perceived that the remaining information on freshwater IAS in a continental screen is not adequate to picture the overall process of homogenization. There are hardly any documents, for instance, for Antarctic region and only an insufficient number of data of freshwater IAS for South America. Hence, a compilation of current status of freshwater IAS amongst continents is obligatory at this instant. To fulfill the aforementioned issue, this paper summarized IAS fish in freshwater (including diadromous) in the continents of the world including their introduction pathways.

Methodology

All the concerned data of present study was compiled from an extensive variety of sources *i.e.* online database and published articles. Global Information Resources such as Invasive Specie Specialist Group (ISSG), Global Invasive Species Database, FAO and published articles on Introductions of Aquatic Species (DIAS), and some National and Regional Informational Resources such as The Biological Record Centre (BRC), Regional Biological Invasions Centre Information System (RBIC), United States Geological Survey Non-indigenous Aquatic Species (USGS NAS), www.nonnativespecies.org,www.invasive.org,www.invasivespeciesinfo.gov and etcetera databanks were used to collect information on freshwater IAS fish species for each and every continent. To overview the updated status of the topic, all facts and figures have been presented in a core table (Table 1).

Table 1. List of freshwater IAS of fishes in native and received continent with their introduction pathways

Family	Scientific name	Common name	Native continent	Introduced continent/ turned IAS in	Introduction pathways to new continent
Esocidae	*Esox lucius*	Northern pike	North America, Europe, Asia	Africa, Asia, Europe, North America	Unknown
Centrarchidae	*Micropterus salmoides*	Largemouth bass	North America	Africa, Asia, Europe, North America, South America	Aquaculture, sport fishing, angling
Channidae	*Channa argus*	Northern snakehead	Asia	Africa, Asia, Europe, North America	Aquaculture, fishing/hunting, live food trade, pet/aquarium trade
	Channa marulius	Great snakehead	Asia	Asia, North America	Live food trade, pet/aquarium trade
Cichlidae	*Cichla ocellaris*	Butterfly peacock bass	Tropical America	Asia, Europe, North America, South America	Stocking
	Cichlasomaurophthalmus	Mayan cichlid	North America	Asia, North America	Pet/aquarium trade, spread aided by fishermen
	Oreochromis aureus	Blue tilapia	Africa, Asia	Africa, Asia, Europe, North America, South America	Aquaculture, biological control agent for aquatic vegetation, stocking
	Oreochromis mossambicus	Mozambique tilapia	Africa	Africa, Asia, Australia, Europe, North America, South America	Aquaculture, natural dispersal, pet/aquarium trade, taken to botanical garden/zoo
	Oreochromis niloticus	Nile tilapia	Africa	Africa, Asia, North America, South America	Aquaculture, live food trade, stocking
	Oreochromis spp.	Tilapia	Africa, Asia	Africa, Asia	Aquaculture, intentional unofficial release
	Tilapia mariae	Spotted tilapia	Africa	Africa, Asia, Australia, North America	Aquaculture

	Tilapia zillii	Zilli's tilapia	Africa	Africa, Asia, Europe, North America	Unknown
Clariidae	*Clarias batrachus*	Walking catfish	Asia	Asia, Europe, North America	Aquaculture, pet/aquarium trade
Clupeidae	*Alosapseudoharengus* *	Alewife	North America	North America	Aquaculture, natural dispersal, smuggling, purposely introduced
Cobitidae	*Misgurnusanguillicaudatus*	Oriental weather loach	Asia	Asia, Australia, Europe, North America	Pet/aquarium trade, live food trade
Cyprinidae	*Carassius auratus*	Goldfish	Asia	Africa, Asia, Australia, Europe, North America, South America	Pet/aquarium trade, ornamental fish
	Ctenopharyngodon idella	Grass carp	Asia	Africa, Asia, Europe North America, South America	Aquaculture, live food trade, biological control agent for aquatic vegetation
	Cyprinellalutrensis	Red shiner	North America	North America	Bait release
	Cyprinus carpio	Carp	Eurasia	Africa, Asia, Australia, Europe, North America, South America	By acclimatizatio n societies, aquaculture, ornamental purpose, commercial/ recreational fisheries, pet/aquarium trade
	Hypophthalmichthys molitrix	Carp	Asia	Africa, Asia, Europe North America, South America	Aquaculture, landscape/ faunal Improvement, live food trade
	Hypophthalmichthys nobilis	Bighead carp	Asia	Africa, Asia, Europe North America, South America	Aquaculture, landscape/fau na improvement, aquaculture, live food trade
	Leuciscus idus *	Ide	Europe	Asia,	Pet/aquarium

				Europe, North America	trade, smuggling
	Phoxinusphoxinus	Common minnow	Eurasia , North America	Asia, Europe	Unknown
	Rutilusrutilus	Roach	Eurasia	Africa, Australia, Europe	Unknown
	Scardiniuserythrophthalmus	Rudd	Eurasia	Africa, Europe, North America	Natural dispersal, stocking by angling organizations, smuggling by anglers
	Tincatinca	Doctor fish	Eurasia	Africa, Asia, Australia, Europe, North America, South America	Stocking for recreational angling, smuggling by anglers
Gobiidae	*Acanthogobiusflavimanus* *	Spotted goby, Yellow fin goby	Asia	Asia, Australia, North America	Ship ballast water, ship/boat hull fouling
	Neogobiusmelanostomus *	Round goby	Eurasia	Asia, Europe, North America	Ship ballast water
	Tridentiger trigonocephalus *	chameleon goby	Asia	Asia, Australia, North America	Live food trade, ship ballast water, ship/boat hull fouling
Ictaluridae	*Ameiurus nebulosus*	Brown bullhead	North America	Asia, Europe, North America South America	Ignorant possession by commercial fishermen, stocking
	Pylodictisolivaris	Flathead catfish	North America	North America	Stocking
Latidae	*Lates niloticus*	Nile perch	Africa	Africa, North America	Aquaculture, landscape/faunal improvement
Loricariidae	*Glyptoperichthysgibbiceps*	Sailfin pleco	South America	Europe, South America	Pet/ aquarium trade
	Pterygoplichthys anisitsi	Southern sailfin catfish	South America	Asia, North America, South America	Live food trade, pet/aquarium trade, accidental release
	Pterygoplichthys disjunctivus	Vermiculated sailfin catfish	South America	Asia, North America, South America	Live food trade, pet/aquarium trade, accidental

					release
	Pterygoplichthys multiradiatus	Sailfin catfish	South America	Asia, North America, South America	Live food trade, pet/aquarium trade, accidental release
	Pterygoplichthys pardalis	Sailfin catfish	South America	Asia, North America, South America	Live food trade, pet/aquarium trade, accidental release
	Pterygoplichthys spp.	Sailfin catfish	South America	Asia, North America, South America	Live food trade, pet/aquarium trade, accidental release
Moronidae	*Morone americana* ***	White perch	North America	North America	Through the Erie and wetland canals, stocking
Percidae	*Gymnocephaluscernuus*	Ruffle	Asia, Europe	Asia, Europe, North America	Contaminated bait, ignorant possession, ship ballast water
	Percafluviatilis	European perch	Europe	Africa, Asia, Australia, Europe	Stocked as a sport fish
Petromyzontidae	*Petromyzon marinus*	Lamprey	North America	North America	Natural dispersal, used as bait, ship/boat hull fouling
poeciliidae	*Gambusia affinis*	Western mosquitofish	North America	Africa, Asia, Europe, North America, South America	Biological control agent for mosquitoes, transported by ship, taken to botanical garden/zoo
	Gambusia holbrooki	Eastern mosquitofish	North America	Africa, Asia, Australia, Europe	Biological control agent for mosquitoes, pet/aquarium trade
	Phalloceroscaudimaculatus	Spot tail mosquitofish	South America	Africa, Australia, South America	Pet/aquarium trade, smuggling
	Poeciliareticulata	Guppy	South America	Africa, Asia, Australia, Europe, North America, South America	Biological control agent for mosquito, pet/aquarium trade, use in genetic research

	Xiphophorus helleri	Green swordtail	Central America	South America	Pet/aquarium trade
Salmonidae	*Onchorynchus mykiss*	Rainbow trout	North America	Africa, Asia, Australia, Europe, North America, South America	Acclimatization society, aquaculture, landscape/faunal improvement
	Salmo salar *	Brown trout	North America	Africa, Asia, Australia, Europe, North America, South America	Aquaculture, fish farms/ aquaculture industries
	Salmo trutta *	Brook trout	Europe, Africa, Asia	Africa, Asia, Australia, Europe, North America, South America	Aquaculture, stocking
	Salvelinusfontinalis	American lake char	North America	Africa, Asia, Australia, Europe, North America, South America	Aquaculture
	Salvelinusnamaycush	Atlantic salmon	North America	Africa, Asia, Europe, North America, South America	Stocked for recreational fisheries
Synbranchidae	*Monopterusalbus*	Asian swamp eel	Asia	Africa, Asia, Australia, North America, South America	Live food trade

note: * Refers to diadromous fish; *** refers to semi-diadromous fish; all information of table 4 was compiled from Global Invasive Species Database; Courtenay *et al.*, 1989; Wooten & Lydeard, 1990; Page & Burr, 1991; Kailola *et al.*, 1993; McDowall, 2000; Elvira, 2001; Hajjar, 2002; Nico & Fuller, 2004; Courtenay & Williams, 2004; Gomiero & Braga, 2004; Simberloff & Gibbons, 2004; Nguyen & Nakorn, 2004; Linholm *et al*., 2005; Canonico *et al*., 2005; Page & Robins, 2006; Hubilla *et al*., 2008; Nico *et al*., 2009; Franch *et. al.*, 2008; Kottelat & Freyhof, 2008; Mendoza *et al*., 2009.

IAS freshwater fishes of Africa

Africa harbors a well-diversified freshwater ichthyofauna, resulting from a long history of complex climatic and geological events (Lévêque, 1997). Here, the phenomenon 'IAS' is recent (approximately 150 years old), compared to other continents (Chenje & Mohamed, 2006), this time factor may, however, be a reflection of the deficiency of records. Africa has received 14IAS fish from all continents except Australia and Antarctica (Table 2). The most abundant invasive fish family presents in this continent is Cyprinidae (consists of 8 species); subsequently Cichlidae (consists of 6 species); Salmonidae (5 diadromous species); and Poeciliidae (4 species) (Table 3). Invasive fish had been introducing here by several pathways. Of them, 'aquaculture' is a very operative purpose (25%), followed by pet aquarium trade (17%), regional faunal improvement or 'acclimatization society' (12%) and the least is smuggling (2%) (Fig.1).

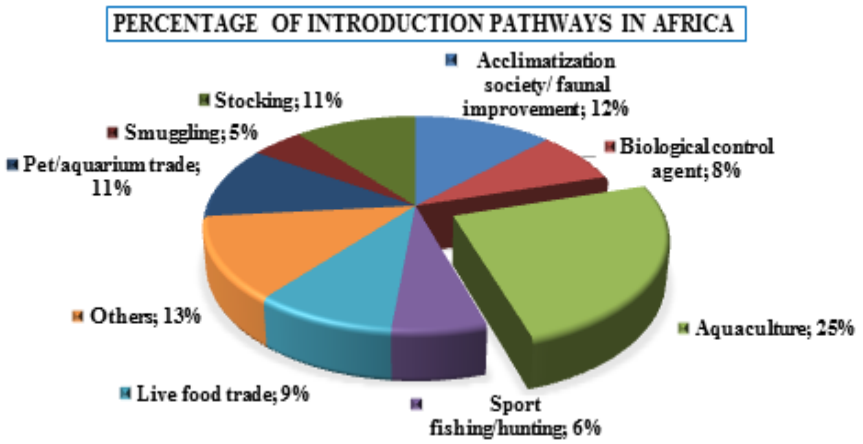

Fig. 1. Percentage of freshwater IAS fish introduction pathways in Africa

Table 2. Number of interchanged IAS fish from donor continents to recipient continents

Recipient continent	**No of invasive fish species spread from native continent**						
↓	Africa	Antarctica	Asia	Australia	Europe	NA	SA
Africa	-	-	14	0	7	8	2
Antarctica	-	-	-	-	-	-	-
Asia	7	-	-	0	9	12	5
Australia	3	-	9	-	5	4	2
Europe	4	-	17	0	-	11	2
NA	7	-	19	0	8	-	6
SA	5	-	10	0	3	9	-

note: NA = North America; SA = South America; No available information for Antarctica. IAS fish from the same continental range are excluded. Species with two or more native continents were tallied more than once.

IAS freshwater fishes of Asia

Asia is host to an enormous amount of freshwater icthyofauna with tremendous species richness and high levels of endemism (Braatz *et al.*, 1992). Despite home to 36% of the world's freshwater resources (UNEP database), Asia's most freshwater ecosystems are, however, under grave threat, and so does the biodiversity in it. Introduction of IAS, which is almost ubiquitous, is one of the root causes of this threat (Dudgeon, 2000). According to World Invasive Species Database, 41 IAS fish within 14 families remains in Asian freshwater (Table 4). Family Cyprinidae and Cichlidae entail with 8 species each, which are the most abundant invader fish family in this continent (Table 3). A wide range of human activities are responsible for IAS fish expansion here, arising from intensive aquaculture (21%), followed by the pet/ aquarium trade (17%), live food trade (12%) and fish stocking (10%) (Fig.2).

IAS freshwater fishes of Australia

Australia possesses an adequate quantity of diversified and unique freshwater fish fauna, although the components of the fauna are fairly small compared to other continents (363 species within 35 families) (Allen, 1989; Page & Brooks, 1991). However, from the 18th century, Australia has been subjected to species arriving from elsewhere. Ecologists have often revealed that Australia has received far more invading species than the number of Australian species invaded elsewhere in the world (Table 2). Australia possesses 18 freshwater invasive fish species within 8 families (Table 4). Alike other continents, 'aquaculture' configures the maximum percentage (19%) of introducing IAS fishes. 'Pet/aquarium trade' holds little lesser position (17%) than aquaculture (Fig.3).

IAS freshwater fishes of Europe

Amendments of freshwater systems through species introduction have an elongated history in Europe, on tracked before the 20th century (Freyhof & Brooks, 2011). But this issue intensified here after mid-19th century by several 'acclimatization societies' (Copp *et al.*, 2005) that was mostly liable for bringing IAS fish from outside of the continent for faunal improvement.

As conscripted by World Invasive Species Database, the number of freshwater invasive fish species in Europe is 32 contained by 13 families (Table 4). The most intensive family of invader fish is Cyprinidae (comprises 10 species), followed by the diadromous family salmonidae (5 species) (Table 3). In description of introduction paths, it can be summarized that the most ostentatious pathway of invasive fish introduction here is 'aquaculture' (21%), followed by 'pet/aquarium trade' (17%) (Fig.4).

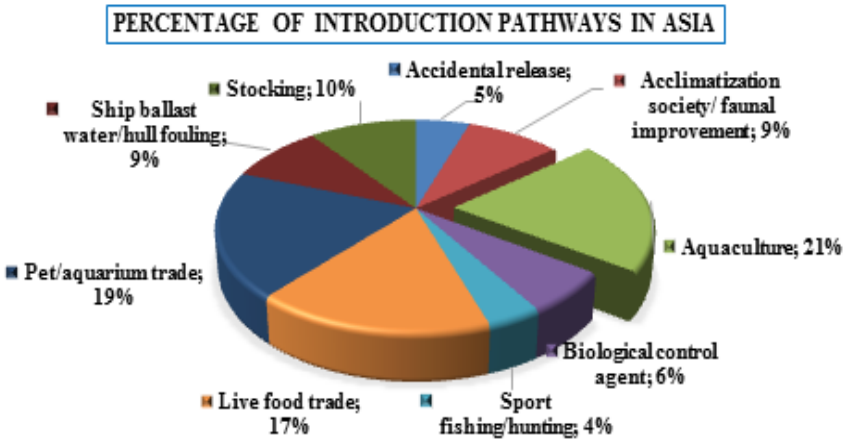

Fig. 2. Percentage of freshwater IAS fish introduction pathways in Asia

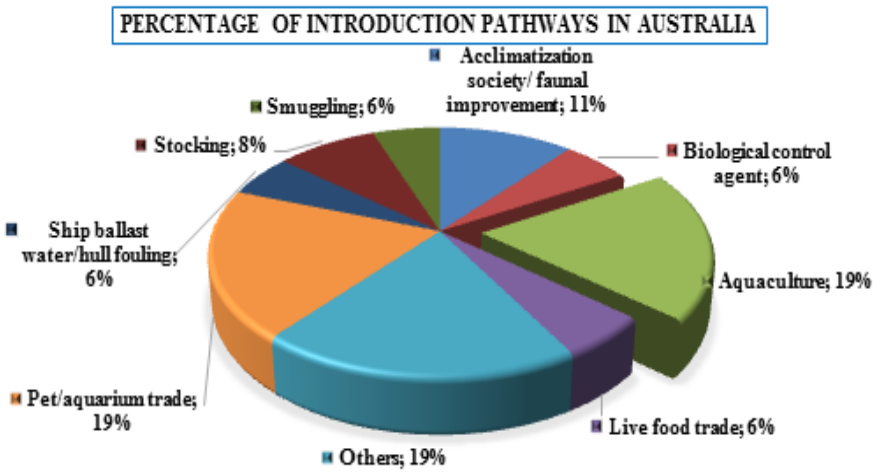

Fig . 3. Percentage of freshwater IAS fishintroduction pathways in Australia

IAS of freshwater in North America

North America has a broad array of freshwater ecosystems within a multitude of habitats resulting rich assemblages of fishes reside; more than 1200 freshwater fish species within 50 families (Page & Brooks, 1991; Abell, 2000). The freshwater habitats and the astonishing biodiversity in it of this continent are, however, facing unprecedented threats from a range of sources; one of which is introduction of IAS from all over the world (Abell, 2000). It can be concised from Tables 1, 2 and 3 that North America consists of 45 freshwater invasive fish species within 18 families, which is the most profuse off all other continents (Table 4). Among 9 different ways, the most frequent pathways of fish introduction here include 'aquaculture' (19%), followed by 'pet/aquarium trade' (17%) and 'live food trade' (15%) (Fig.5).

IAS freshwater fishes of South America

As with many other bunches of flora and fauna, freshwater endemic and invader fishes of South America is far from fully known, as because decades of poor monitoring and the lack of specific studies have limited our knowledge in this regard (Pompeu *et al.*, 2012). However, introduction of IAS are identified as one of the widespread consequences across the continent for incessant loss of freshwater fish species here (Reis *et al.*, 2003; Barletta *et al.*, 2010), even before the whole species diversity of this continent is acknowledged. This continent acquired most IAS fish from Asia and North America, 10 and 9 species respectively (Table 2). The most abundant invasive species exists from both the family Cyprinidae and Loricariidae (6 species from each family) and consequently, 5 species from each family Salmonidae and Cichlidae (Table 3). 'Aquaculture' is the most dominant pathway of fish introduction in this continent (19%), followed by 'pet/aquarium trade' (18%) and 'live food trade' (15%) (Fig.6).

Table 3. Number of existing freshwater IAS fish per family among continents

No of existing freshwater invasive species per family							
Family	**Asia**	**Europe**	**North America**	**South America**	**Africa**	**Australia**	**Antarctica**
Centranchidae	1	1	1	1	1	n/a	-
Channidae	2	1	2	n/a	1	n/a	-
Cichlidae	8	4	7	5	6	2	-
Claridae	1	1	1	n/a	n/a	n/a	-
Clupeidae	n/a	n/a	1	n/a	n/a	n/a	-
Cobitidae	1	1	1	n/a	n/a	1	-
Cyprinidae	8	10	9	6	8	4	-
Esocidae	1	1	1	n/a	1	n/a	-
Gobiidae	3	1	3	n/a	n/a	2	-
Ictaluridae	1	1	2	1	n/a	n/a	-
Latidae	n/a	n/a	1	n/a	1	n/a	-
Loricariidae	4	1	5	6	n/a	n/a	-
Moronidae	n/a	n/a	1	n/a	n/a	n/a	-
Perciidae	2	2	1	n/a	1	1	-
Petromyzontidae	n/a	n/a	1	n/a	n/a	n/a	-
Poeciliidae	3	3	2	4	4	3	-
Salmonidae	5	5	5	5	5	4	-
Synbranchidae	1	n/a	1	1	1	1	-
Total species	**41**	**32**	**45**	**29**	**29**	**18**	**-**

Table 4. Comparison of existing number of freshwater fish species and their families inherent in within continents along with the no of freshwater invasive fish species with families

Continent	**Existed freshwater fish species**	**Existed family**	**No. of IAS fish species**	**No of invader family**	**Reference/s**
Africa	2836	74	29	10	IUCN.org; Kottelat & Whitten, 1996; Dudgeon, 2000; issg.org
Asia	3500	105+	41	14	Kottelat & Whitten, 1996; Dudgeon, 2000; issg.org
Australia	363	35	18	8	Allen, 1989; Page & Brooks, 1991; Allen *et al.*, 2002; issg.org
Europe	546	24	32	13	Page & Brooks, 1991; Kottelat & Freyhof, 2007; issg.org
North America	1200+	50	45	18	Page & Brooks, 1991; issg.org
South America	6025	71	29	8	Reis *et. al.*, 2003; issg.org

note: *No available information on Antarctic region*

Discussion

It is affirmed from the above study that among continents, North America possesses the uppermost number of freshwater invasive fish species; 41 species within 18 families (Table 4), whereas Australia possesses the lowermost number; 18 invasive fish species within 8 families. This review clarified that all IAS fish interchanges (give-and-take) took place within five common continents *viz.* Asia, Europe, North America, South America and Africa. No invasive species winged from Australia to another continent, by contrast fish introduction happened in Australia from all other continents (without Antarctica). Among continents, Asia dispersed the highest extent of invasive fish in every single continent whereas South America shakes out the lowest to all. Observing at Table 2, it is evidently realized that Asia sprinkled the highest amount of IAS fish per continent; 19 species to North America, 17 species to Europe, 14 species to Africa, 10 species to South America and 9 species to Australia. Species that turn out to be legend invaders and propagate in every continents (without Antarctica) are *Carassius auratus*, *Cyprinus carpio*, *Onchorynchus mykiss*, *Oreochromis mossambicus*, *Poecilia reticulate*, *Salmo salar*, *Salmo trutta* and*Salvelinusfontinalis.*

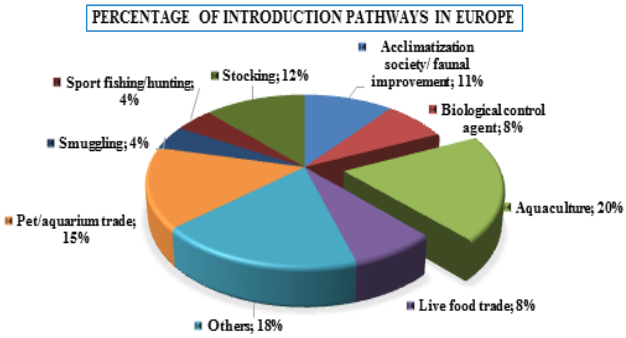

Fig. 4. Percentage of freshwater IAS fish introduction pathways in Europe

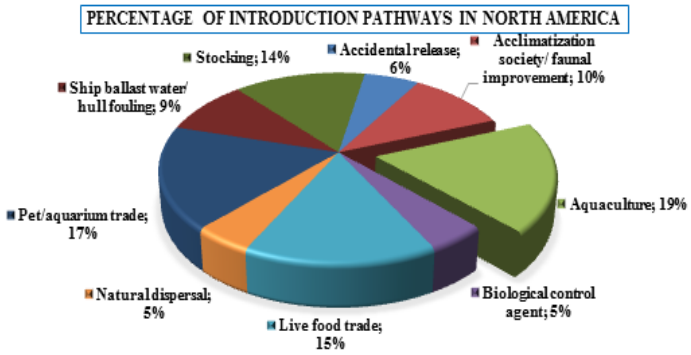

Fig. 5. Percentage of freshwater IAS fishintroduction pathways in North America

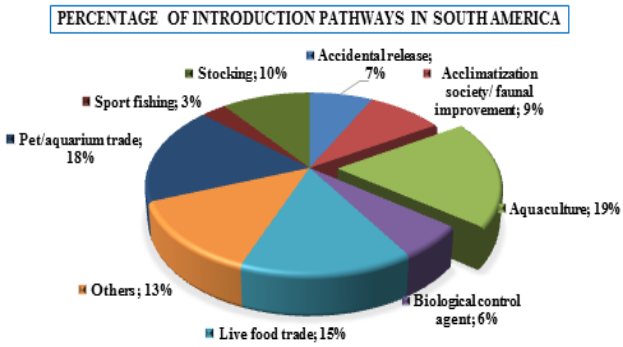

Fig. 6. Percentage of freshwater IAS fishintroduction pathways in South America

This is may be because some of them are fast-growing (*e.g.*, *Cyprinus carpio*), so vastly used for aquaculture, some of them have robust flexibility (*e.g.*, *Salmo salar*), so they can survive in adverse environment and become hostile. *Hypophthalmichthys* spp. and *Oreochromis niloticus* circulated in five different continents without Australia and Antarctica. The species *Gambusia* spp. is introduced in every continent mostly for biological control purpose (controlling mosquito population). It is revealed that the most effective introduction pathway of freshwater invasive fish species is 'aquaculture', which causes the highest percentage of introduction in every single continent (Fig 1). Aquaculture rooted 25% IAS fish introduction in Africa, 21% in Asia, 19% in Australia, 20% in Europe, 19% in North America and 19% in South America. Thereby approaches 'pet/aquarium trade' and 'live food trade' possessed the subsequent potent pathway.

Future research potentials

Firstly, research on Asian freshwater invasion by IAS fish has been largely neglected in comparison to other regions (Peh, 2010). To improve biological invasion research in Asia, it is important to address questions on natural history, taxonomy and ecology of the IAS fishes of this region (*e.g.* Peh, 2002; Peh & Sodhi, 2002; Yap *et al.*, 2002; Yap, 2003). Basic natural history information and supporting baseline data are still

urgently needed as a ground work before strategies for surveying, eradicating and managing biological invasion (Peh, 2010). Secondly, in Antarctic region, there are closely nil research based on freshwater fish diversity, distribution and fish invasion. To understand the trends of freshwater fish diversity and distribution, investigation and a compilation of recent data is a burning issue at this instant. Thirdly, there is an arising indication in invasion ecology that beyond the biological invasions in any ecosystem, there are stimuli of native species diversity and abundance (Peh, 2010). From the Table 4, within continents where there presents high abundance of freshwater fish, IAS of fish emerged there in. Therefore, together with the information of IAS, vigorous documents of diversity and distribution of native species from every continent as well as every biogeographic region is crucial.

Conclusions

The world these days faces a foremost challenge. That is, on the one hand, public outcry at the undesirable detrimental consequences in ecology of several IAS; on the other hand, there is the irrefutable and significant contribution of some IAS fishes to an undeniable need, for instance, food fish requirements. The growing field of invasion science at the moment, poised at a crossroads where ecology and public perception meets, meanwhile is increasing. Therefore, other than focusing on culturing hybrid (*e.g.* carp), predatory (*e.g.*, bass and trout) and fast-growing fishes (*e.g.*, tilapia), we should emphasis on culturing, trading, stocking and consuming fish, which has potential to balance the ecosystem. Side by side, we necessitate a number of workout strategies that could address both needs; *i.e.* cope with wide-reaching hunger and poverty, and simultaneously, deal with and pledge us sustainable use of world's freshwater resources. Thus, the homogenization process could be defended and delayed.

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