Impact of 2018 Kerala Floods on Aquatic Biodiversity with special reference to single location endemic species

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1. BACKGROUND

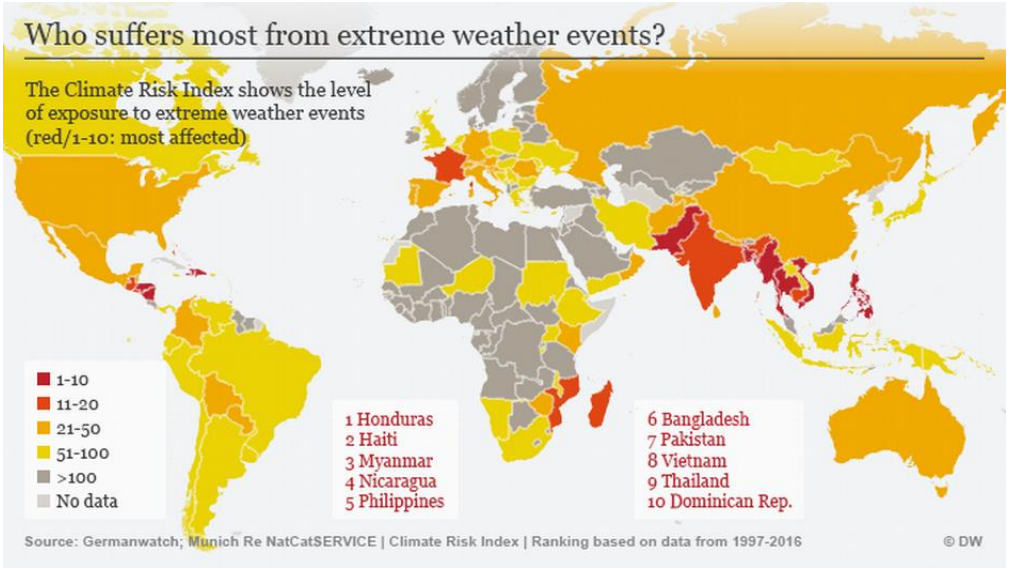
The state of Kerala was impacted by an extreme flooding event in August 2018, considered to be the worst in 100 years, resulting in close to 400 human mortalities and displacement of several hundred thousand people. Kerala received 42% more rainfall than usual since the beginning of the monsoon season in June, i.e. 2346.3 mm of rainfall, instead of the average 1649.55 mm, and all of the 39 dams were opened for the first time in history. The unprecedented floods gave rise to landslides and changes in the morphology and flow patterns of many of the State's rivers. While the socio-economic and anthropogenic impacts of the floods have been discussed widely, there has been little focus on the impacts to biodiversity, and in particular freshwater ecosystems, which comprise a large share of the State's natural capital.

2. OBJECTIVES OF THE STUDY

The objective of the study was to understand the impacts (if any) on the aquatic biodiversity of the state as a result of the catastrophic floods of August 2018 with special reference to the habitats of single location endemic fish species.

3. CLIMATE CHANGE AND EXTREME CLIMATIC EVENTS

Climate change is one of the most important emerging threats to global freshwater biodiversity, capable of significantly affecting ecosystems and their species. Freshwater species are especially vulnerable to climate change given their limited ability to disperse, in the wake of changing climatic conditions. In addition, many freshwater ecosystems around the world are currently exposed to several anthropogenic stressors and an additional threat in the form of climate change will only accelerate habitat loss and species extinctions (Woodard et al. 2010). Changing patterns and extremities in floods, drought and precipitation are likely to make extreme weather events more commonplace in many regions around the world. For example, while in some regions, frequency, intensity, and duration of extreme flooding events is expected to increase, in other regions, intensity and severity of droughts will cause significant losses to freshwater biodiversity (Death et al. 2015). Floods have both direct and indirect impacts on freshwater biodiversity. Direct impacts include displacement or mortality of species, while indirect impacts include changes to either the shape and/or form (geomorphology) of the river/lake (Death et al. 2015). Floods also increase surface run-off, exacerbate soil erosion and introduce increased levels of soil, organic matter and pollutants into the rivers (BES 2016). Catastrophic floods can seriously damage in-stream and riparian habitats and their resident fish populations especially in mountain streams (George et al. 2015). The most important direct effect of severe flooding in mountain streams includes displacement-related mortality (George et al. 2015). Populations and abundance of aquatic plants (mostly submerged and emergent), vertebrates (fish) and invertebrates (molluscs and crustaceans) have also been known to significantly decline as an after effect of extreme flooding events (Jones 2013).



4. Freshwater Biodiversity of the Western Ghats

The Western Ghats Biodiversity Hotspot harbours extremely high levels of endemism for freshwater-dependent taxa such as crabs (92%), amphibians (87%), shrimps (69%) and fish (59%) (Dahanukar & Raghavan, 2013; Raghavan et al. 2015), with majority of endemic species restricted to the southern region of Western Ghats within the state of Kerala (Dahanukar et al. 2011; Dahanukar & Raghavan, 2013; Raghavan et al. 2015). A striking highlight of the endemic nature of freshwater dependent taxa in the Western Ghats is 'point endemism' – i.e. species restricted to a single location (100% of the global population of a species is confined to a single location) (IUCN Red List 2018).

Thirteen species (Table 1) are narrow endemics - known to occur only in single locations, in peculiar microhabitats characterized by specific flow, velocity, depth, entrenchment ratio, light intensity etc (Kurup et al. 2004). All of these species in view of their very restricted distribution and threats to the habitat are categorized as 'threatened' (Critically Endangered, Endangered or Vulnerable) on the IUCN Red List.

Table 1 – List of narrow endemic species, their IUCN Red List Status and location

Species	IUCN Status	Only known location/River System
Dawkinsia exclamatio	Endangered	Shenduruney Wildlife Sanctuary/Kallada
Eechathalakenda ophicephalus	Endangered	Periyar Tiger Reserve/Periyar
Garra periyarensis	Vulnerable	Periyar Tiger Reserve/Periyar
Ghatsa santhamparaiensis	Endangered	Santhampara Hills/Periyar
Ghatsa montana	Endangered	Malakkapara/Chalakudy
Glyptothorax davissinghi	Endangered	New Amarambalam/Chaliyar
Glyptothorax housei	Endangered	Valparai/Chalakudy
Horalabiosa arunachalami	Critically Endangered	Santhampara Hills/Periyar
Hypselobarbus periyarensis	Endangered	Periyar Tiger Reserve/Periyar
Lepidopygopsis typus	Endangered	Periyar Tiger Reserve/Periyar
Mesonoemacheilus periyarensis	Vulnerable	Periyar Tiger Reserve/Periyar
Mesonoemacheilus menoni	Vulnerable	Periyar Tiger Reserve/Periyar
Tariqilabeo periyarensis	Endangered	Periyar Tiger Reserve/Periyar

5. METHODOLOGY

Comprehensive field surveys were carried out in four of the major river systems affected by floods, viz, Periyar, Chalakudy, Pampa and Achankovil. In addition, micro-habitat-based surveys were carried out in the six critical freshwater fish habitats (see also table 1), including Periyar Tiger Reserve, Valparai, Malakkapara, Santhampara, New Amarambalam and Shenduruney Wildlife Sanctuary to determine the abundance, population status and impacts to the habitats of the 'single-location fish species'. This was supplemented by unstructured interviews and focus group discussions with relevant stakeholders including local fishers, forest guards, local communities residing along the river banks and researchers.

Media articles on KUFOS studies on flood impacts on biodiversity

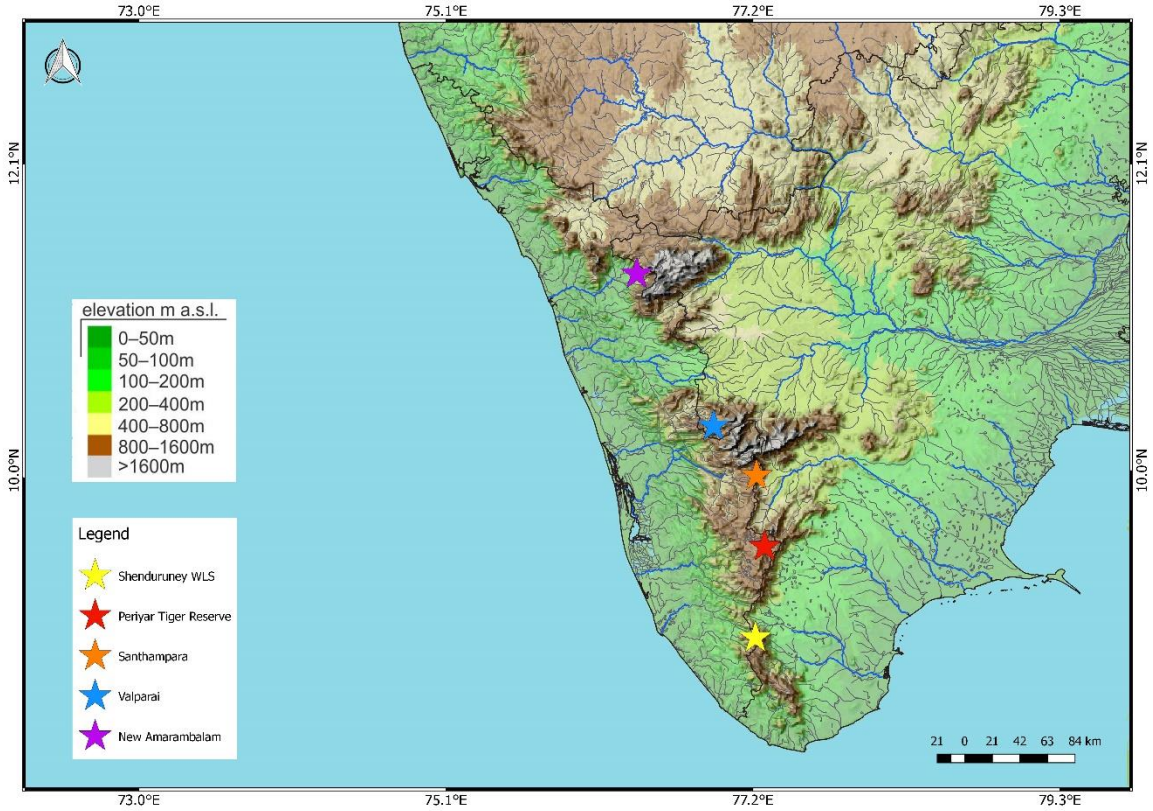
Floods Imperil Western Ghats Ecology – The Hindu, August 29/30 2018
https://www.thehindu.com/news/national/kerala/floods-imperil-western-ghats-ecology/article24813448.ece

KUFOS Study Team at a local fish market

6. EFFECT OF FLOODS ON SINGLE-LOCATION SPECIES

Floodwaters can have devastating impacts for small populations of threatened species, with a single flood event sometimes driving 'single location endemic species' to extinction (FishBio 2018). Floods in Kerala have resulted in impacts to the morphology of critical freshwater habitats, and this has been complicated as a result of landslides.

Detailed microhabitat surveys were carried out at the six critical freshwater fish habitats including Periyar Tiger Reserve, Valparai, Malakkapara, Santhampara, New Amarambalam and Shenduruney Wildlife Sanctuary to understand the current status of the point endemic fish species and compare with baseline data available from previous studies carried out at several random intervals during the last decade.



Map of sampling sites for the single location endemic species

Detailed inventory of fish species in the six critical freshwater habitats revealed that no significant impacts have resulted due to the floods. Populations of all the endemic and threatened fish species occurring in the above-mentioned locations appeared to be stable, and comparable to previous studies carried out between the years 2000 and 2017.

Our studies were carried out from January 2018 to April 2019 and therefore, we do not know whether any sudden impacts had occurred subsequent to the flooding in August/September 2018. The heavy debris washed down by floodwaters could have displaced some endemic fish species from their habitat, but all populations seem to have shown resilience and their populations have no doubt rebounded.

A critical fish habitat in the upper reaches of the Periyar inside the Periyar Tiger Reserve harbouring populations of six endemic species

Tariqilabeo periyarensis, an endangered and endemic species of cyprinid of the Western Ghats

Table 1 – Catch per effort of single location endemic species (pre and post flood)

Species	Location	Catch per effort (pre-flood)	Catch per effort (post-flood)
Dawkinsia exclamation[*]	Shenduruney	7	5
Eechathalakenda ophicephalus[*]	PTR	2	2
Garra periyarensis[*]	PTR	6	7
Ghatsa santhamparaiensis[#]	Santhampara	0.5	1
Ghatsa montana[#]	Malakkapara	0.25	0.5
Glyptothorax davissinghi[#]	NARF	2	3
Glyptothorax housei[#]	Valparai	1	0.25
Horalabiosa arunachalami[#]	Santhampara	0.5	0
Hypselobarbus periyarensis[*]	PTR	12	15
Lepidopygopsis typus[*]	PTR	9	11
Mesonoemacheilus periyarensis[#]	PTR	10	12
Mesonoemacheilus menoni[#]	PTR	7	4
Tariqilabeo periyarensis[*]	PTR	2	1

Catch per effort calculated as catch of the species obtained in 5 continuous cast nettings* and 5 scoop net operations at a habitat

Lepidopygopsis typus, an endangered and endemic freshwater fish of Western Ghats found only in the Periyar Tiger Reserve

Critical freshwater fish habitats inside the Periyar Tiger Reserve

Critical freshwater fish habitats inside the Periyar Tiger Reserve

Mesonoemacheilus menoni, an endemic species of Periyar Tiger Reserve

Hypselobarbus periyarensis, an endemic species of Periyar Tiger Reserve

Garra mlapparaensis, an endemic species of Periyar Tiger Reserve

Mesonoemacheilus periyarensis, an endemic species of Periyar Tiger Reserve

Garra periyarensis, an endemic species of Periyar Tiger Reserve

Glyptothorax davissinghi, an endemic fish species of New Amarambalam Reserve Forest

Dawkinsia exclamatio, an endemic species of the Kallada River

Ghatsa santhamparaiensis, an endemic and a Critically Endangered species of the Santhampara Hills

7. EFFECT OF FLOODS ON FRESHWATER HABITATS

The Kerala floods had much of their impacts on the riverine microhabitats located in the middle and lower reaches of the major river systems affected by floods. The morphology of many middle and lower reach fish habitats has been severely affected and many have been transformed beyond recognition. There has been serious depletion of in-stream and riparian cover in rivers such as Periyar, Chalakudy and Achankovil.

Shoreline vegetation and riparian cover has been significantly affected in the lower reaches of Periyar River especially in the areas around Malayatoor which were critical habitats for species such as the Malabar Puffer, *Carinotetraodon travancoricus* and the freshwater Pipefishe, *Microphis cuncalus*.

Downstream freshwater habitat in Malayatoor before and after the flood.

8. FLOOD AS A PATHWAY FOR ALIEN INVASIVE SPECIES

Extreme climatic events (ECEs) are expected to become more common and widespread in many regions of the world (IPCC 2014). For example, an increase in the frequency, intensity, and duration of extreme flooding in some regions, and intensity and severity of droughts in others could both result in significant net losses to freshwater biodiversity (Death et al. 2015; Milner et al. 2012). Extreme flood events, where river flows are exposed to a 1% annual exceedance probability (AEP) (Rizzo et al. 2018) are known to negatively influence biotic communities in many ways, including facilitating biological invasion, by influencing every stage, viz., introduction, establishment and spread; as they facilitate rapid movement of species towards natural ecosystems and provide lower biotic resistance of indigenous species to invader establishment (Diez et al. 2012).

Invasive Alien Species (IAS) are considered to be a major cause for species endangerment and extinction in freshwater systems (Sala et al. 2000) through the displacement of native species, alteration of hydrologic and nutrient cycles, food web dynamics, introducing diseases and parasites, hybridization with native species, and changes in fisheries composition (Bartley et al. 2005; Poulos et al. 2012). Of more than 60 fish species that have gone extinct since the year 1900, the extinctions of at least 17 have been attributed either wholly or partially to alien species and their impacts.

In the weeks, subsequent to the floods, large numbers of several alien species were recorded in the major rivers and associated backwaters of Kerala. Many of these alien species were encountered for the first time in the natural waters of Kerala, and many species are yet to be identified conclusively and will require advanced DNA based techniques.

Introductions dating from the colonial times have resulted in the establishment of several freshwater alien species in the Kerala part of the WG (Jones & Sarojini 1951-1952; Biju Kumar 2000; Raghavan et al. 2008; Krishnakumar et al. 2009; Biju Kumar et al., 2015). As many as 19 such species were recorded from the WG region until 2018, of which seven have turned invasive (Table 1). However, the catastrophic floods in August 2018 resulted in the first-ever records of several additional alien species from natural waters of this biodiversity hotspot (Table 1), revealing the existence of an unregulated, unscientific, mostly illegal and thriving aquaculture and aquarium fisheries sector based on alien species, especially along the riverine floodplains. Of the alien species for which we either have voucher specimens collected directly from the wild, or through photographs obtained from the print and social media (the accuracy of social media photos were subsequently validated by personal interactions and site visits), seven species were identified to the species level, and an additional species of *Pangasianodon* requires genetic confirmation.

Only 92 species of ornamental fish are legally allowed to be imported to India, of which 79 are of freshwater origin (Government of India http://aqcsindia.gov.in/pdf/trade-14.pdf). But, the aquarium pet industry and associated breeding and farming sector in the WG region is largely unregulated and have been implicated in several conservation issues (see Raghavan et al. 2013; Krishnakumar et al. 2009). Of the seven species that were recorded for the first time from the WG subsequent to the floods, many are illegally introduced and farmed for the aquarium pet trade, as they are not listed in the species allowed to be imported to the country. These included large-bodied and high-risk species such as the Arapaima (*Arapaima gigas*) and Alligator gar (*Atractosteus spatula*), top predators capable of feeding on a range of organisms and a serious threat to the endemic fish diversity of the WG region (Biju Kumar et al. 2019). Although not yet recorded from the wild, questionnaire surveys and personal communication with ornamental fish farmers reveal that additional species such as the Arowana (*Scleropages* spp.), shovelnose catfish (*Pseudoplatysoma* sp.) and Redtail Catfish (*Phractocephalus hemioliopterus*) have also escaped from rearing facilities in the region. Most breeding and farming units for aquarium fish in the WG region have no biosecurity systems, and function along the floodplains of major rivers that are vulnerable to annual flooding events, including ECEs.

Pacu, *Piaractus brachypomus* specimens caught from the Vembanad Lake

Escape of fish from rearing and culture systems in developing nations such as India are unavoidable because of largely inefficient control and management systems for avoiding them (Garcia et al. 2018), and extreme climatic events such as floods make such situations

more complicated. Much of the freshwater aquaculture systems in Kerala are located in the vicinity of the major river systems, with farming systems having very little or no infrastructure to prevent the escape of fish into the adjoining natural water bodies.

Two most important species that were recorded for the first time from the natural waters of Kerala were the arapaima, *Arapaima gigas* (Schinz, 1822) and alligator gar, *Atractosteus spatula* (Lacepède, 1803). Arapaima, endemic to the Amazon is one of the 'mega fishes' of the world, growing up to 4.5 meters in length and 200kg in body weight, while the alligator gar native to the United States of America and Mexico, reaches body length and weight up to 3 meter and 137kg (Froese & Pauly 2018). Both arapaima and alligator gar are illegally introduced into India. Both Arapaima and Alligator gar are top predators capable of preying upon all native fish species of Kerala. Alligator gar are also known to feed on a range of organisms including fish, crustaceans, reptiles as well as aquatic birds and mammals threatening the very existence of freshwater-dependent biodiversity in regions where they are released (or escape into).

Table 2– List of alien species recorded from the natural waters of Kerala after the floods

Species	Common Name	Native Region
Piaractus brachypomus	Pacu	South America
Arapaima gigas	Arapaima	South America
Atractosteus spatula	Alligator gar	Central and North America
Oreochromis niloticus	Nile Tilapia	North Africa
Oreochromis mossambicus	Mozambique Tilapia	Africa
Pangasius hypopthalmus	Pangas/Basa	South East Asia
Pangasius sp	Pangasius	South East Asia
Osphronemus goramy	Gourami	South East Asia
Oreochromis sp.	GIFT Tilapia	
Ctenopharyngodon idella	Grass Carp	China
Cyprinus carpio	Common Carp	Europe

Arapaima gigas recorded from Kodungaloor backwaters after the floods

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OPINION

Jurassic invaders: flood-associated occurrence of arapaima and alligator gar in the rivers of Kerala

A. Biju Kumar, Smrithy Raj, C. P. Arjun, Unmesh Katwate and Rajeev Raghavan

Climate change and invasive species are two of the greatest threats to global biodiversity, and their impacts are compounded when they interact with each other[1]. For example, altered flow regime as a result of climate change is one of the major pathways by which alien species are introduced into new aquatic ecosystems[2], while storms and associated flooding increase their dispersal through escapes from aquaculture facilities[3].

Freshwater ecosystems of Kerala are considered as a global hotspot for fish diversity (~200 species) and endemism (30%)[4,5], with some rivers (e.g. Periyar and Chalakudy) harbouring the only remaining global populations of several threatened species (including Alliance for Zero Extinction (AZE) species)[6]. Unfortunately, these irreplaceable sites are under considerable threat from a range of anthropogenic stressors, including hydropower dams, alien invasive species, overharvest and pollution[5,7,8]. The unprecedented and catastrophic floods in August 2018 has become an additional and perhaps one of the most significant threats to the native freshwater fishes of Kerala, as evidenced by the increasing occurrence of 'fugitive fish'[9] – escapees from aquaculture facilities. What makes this case of fugitive fish hazardous from a biodiversity perspective is the fact that majority comprise of mostly predatory exotic species, which are rapidly spreading, acclimatizing and flourishing in new environments across the globe[10].

Two most notorious alien species which emerged during the 2018 floods, that have the potential to threaten Kerala's exceptionally rich native ichthyofauna are the arapaima, *Arapaima gigas* (Schinz, 1822) and alligator gar, *Atractosteus spatula* (Lacepède, 1803) (Figure 1). Popularly known as 'piscine living fossils', both arapaima and alligator gar are 'ancient fishes'[11,12], with their origin dating back to the Cretaceous or even earlier[13,14]. Arapaima, endemic to the Amazon, is one of the 'megafishes' of the world, growing up to 4.5 m in length and 200 kg in body weight, while the alligator gar, native to USA and Mexico, reaches a body length and weight up to 3 m and 137 kg respectively[15]. Both these species are the focus of organized (and in some cases unregulated) food, recreational and ornamental fisheries in their range countries[15]. While much of the native arapaima populations are currently overfished and their international trade regulated (i.e. Schedule II of CITES)[16], habitat loss due to river engineering structures and indiscriminate fisheries have resulted in significant decline in alligator gar populations in their native range[17]. Concomitant with the population decline in their range countries, is the increasing occurrence of aquaculture associated 'fugitives' of these two giant fishes from outside their natural range, mostly as a result of the unregulated ornamental fish trade[18–20].

As a result of its large body size, life history and feeding ecology, *A. gigas* demonstrates multiple impacts on the ecosystems where it is introduced. For example, in Bolivia, the introduction of *A. gigas* resulted in considerable decline of native species, subsequently affecting fisher livelihoods[18]. On the other hand, impacts of alligator gar introduction/invasion on native species are unknown because of the relatively few studies on this topic, mostly as a result of the recent spread of this species into non-native habitats. Nevertheless, considering its highly predatory nature, adaptations to wider ecological niches and large body size, the 'precautionary principle' needs to be adopted and detailed research on impacts carried out[21].

Both arapaima and alligator gar are illegally introduced into India as they do not figure in the indicative list of 92 ornamental fishes considered for import[22]. In addition, arapaima being listed in the Schedule II of CITES, has been specifically prohibited for import into the country[22]. In Kerala, the 'use of non-domestic fish and fish seeds for fish farming without subjecting them to quarantine proceedings and quality check' has been prohibited through the Kerala Inland Fisheries and Aquaculture Act, 2010, while the Kerala Fish Seed Bill, 2014 demands strict quarantine measures for introduction of any non-native fish into the state. Nevertheless, lack of mechanisms for implementing and enforcing these provisions facilitates the illegal farming of top predators like arapaima and alligator gar in Kerala. Their culture, exhibition and sale continue unabated through public aquarium shows, social media and e-commerce enterprises. Interview and promotion videos of ornamental fish farmers and farms available in the public domain (including several on YouTube™) reveal that the fingerlings of

Figure 1. ***a***, *Arapaima* caught from the Kodungaloor backwaters after the 2018 floods. ***b***, Alligator gar caught from the Kurumali River.

these species originate from the markets in Kolkata, probably illegally imported through Bangladesh.

Our observations based on field surveys carried out in three major river systems affected by the floods, viz. Periyar, Chalakudy and Pampa, and local knowledge of fishers, riverine-dwelling communities, fish vendors, as well as an extensive review of social, print and electronic media revealed that post-flooding, fugitive arapaima were caught from the Chalakudy (a river that harbours many Western Ghats endemic fish species), the Malankara reservoir on the Muvattupuzha River and the backwaters near Kodungallor, while alligator gar were caught from the Periyar and Kurumali rivers and Perumbalam Lake near Cochin. It is more or less certain that the illegal introduction of arapaima has only started recently in farms around River Chalakudy, as previous studies from this river did not record this alien species[23,24]. Though only a limited number of individuals of these two species were caught from the wild, many could still be remaining unrecorded in these water bodies (for example, a farmer from Edathua (9.37N, 76.46E) reported loss of an alligator gar from his stock), as personal communication with expert respondents suggests that rampant farming and rearing of these giant fishes were carried out in many parts of Kerala, which were greatly affected by the floods.

Arapaima has many life-history traits that make it adaptable to the existing eco-biological conditions in the rivers of Kerala. These fishes are obligate, air breathing species that surface every 5–15 min to gulp atmospheric air[25], making them fit for survival even in polluted waters and giving them a competitive edge over many other native species. Arapaima is also a top predator capable of preying upon all native fish species of Kerala[26]; and possessing specialized scales that protect it from other predators[27]. These fishes also demonstrate parental care, a biological trait that is significantly associated with establishment success of non-native fish[28], which ensures greater recruitment success. Though large rapids and waterfalls are known to be barriers to the movement of this species[29], the actual dispersal capabilities of arapaima fugitives in the rivers of Kerala need to be examined in detail. However, we suggest that a precautionary approach be taken in this regard, as the species could successfully invade lakes and reservoirs, which are its ideal habitats. Like the arapaima, the alligator gar is also a top-level carnivore feeding on a range of organisms, including fish, crustaceans, reptiles as well as aquatic birds and mammals[15], threatening the very existence of freshwater-dependent biodiversity in regions where it is released (or escapes into). Unfortunately, alligator gar has already been recorded in public water bodies from many regions of India[30,31], indicating its extensive (and illegal) use in ornamental fish trade and aquarium-keeping.

If a novel species is introduced for aquaculture or aquarium fish trade to a new region, it is unreasonable to assume that it will not disperse geographically[32]. This is because escapes from aquaculture systems are unavoidable due to inefficient control systems for avoiding them[31], and natural calamities like floods make such situations more complicated. Much of the aquaculture of ornamental fishes in Kerala is carried out in farms, granite quarries and homestead ponds in the vicinity of major river systems[7]. These farming and rearing systems have very little infrastructure to prevent the escape of captive fish into the adjoining natural ecosystems (in most cases rivers or backwaters)[7]. In the absence of proper biosecurity measures as well as a general lack of enforcement mechanisms for the existing legal provisions, the only way to safeguard the endemic aquatic biodiversity of the Kerala part of the Western Ghats from alien invasions is to impose a total ban on import and farming of dangerous species, such as the alligator gar and arapaima. It is also imperative that urgent audits be carried out to determine the actual numbers of these two species that existed (and currently existing) in captive facilities (both for sale and exhibition) in the state, and a continuous awareness and monitoring scheme initiated to record the occurrence of fugitive individuals of these two species (as well as other aliens) in the future.

Several studies have documented the distribution of exotic fish species in the natural waters of Kerala, and a list of 27 exotic species introduced into the natural water bodies of India has been recently published by the National Biodiversity Authority[33]. The pre-flood assessment of alien species from the inland waters of Kerala recorded both invasive species (*Cyprinus carpio*, *Gambusia affinis*, *Poecilia reticulata*, *Oreochromis mossambicus*, *Oreochromis niloticus*, *Pterygoplichthys* sp. and *Clarias gariepinus*), and alien species without any confirmed report of invasion (*Ctenopharyngodon idella*, *Hypophthalmichthys molitrix*, *Xiphophorus hellerii*, *X. maculatus*, *Piaractus brachypomus*, *Oncorhynchus* cf. *mykiss*, *Pangasianodon hypophthalmus*, and *Osphronemus goramy*)[34], but no records of either of the two fugitive species, *A. gigas* and *A. spatula* were available prior to the floods.

The lack of strict policies and enforcement mechanisms in the fight against alien invasive species in India, is a classic example of how national policies conflict and contradict with international conservation goals and agreements such as the Convention on Biological Diversity[35]. The most important and significant conflict is with the Aichi Biodiversity Targets (https://www.cbd.int/sp/targets/). The issue of alien species invasions, and the continued absence of policies and management measures in India are in direct conflict with Target 9 (i.e. control and eradication of alien species), as the country has not yet initiated any policies to control and eradicate alien aquatic organisms and at the same time continues to support the aquaculture of non-native species. Continuing neglect of the issue of invasive species in India is also directly conflicting other Aichi Targets, including Target 1 (education and awareness on biodiversity), Target 3 (ceasing harmful incentives and perverse subsidies), Target 7 (sustainable management of aquaculture) and Target 13 (preservation of genetic diversity). There is thus an urgent need for adopting and initiating a nationwide 'alien species management and eradication scheme' following the precautionary and preventive principles, and developing a strict policy by involving local, regional and national biodiversity managers, fisheries experts and policy makers, for managing invasions at the ground level and for meeting international biodiversity targets.

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