

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

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Climate change and invasive species are two of the greatest threats to global biodiversity, and their impacts are compounded when they interact with each other¹. 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 ecosystems², while storms and associated flooding increase their dispersal through escapes from aquaculture facilities³.

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 hydro-power 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 globe¹⁰.

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* (Lacépède, 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 respectively¹⁵. Both these species are the focus of organized (and in some cases unregulated) food, recreational and ornamental fisheries in their range countries¹⁵. 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 range¹⁷. 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 livelihoods¹⁸. 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 high-

ly predatory nature, adaptations to wider ecological niches and large body size, the 'precautionary principle' needs to be adopted and detailed research on impacts carried out²¹.

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 import²². In addition, arapaima being listed in the Schedule II of CITES, has been specifically prohibited for import into the country²². 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 YouTubeTM) reveal that the fingerlings of



Figure 1. a, *Arapaima* caught from the Kodungalloor 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 Kuru-mali 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 air²⁵, 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 Kerala²⁶, and possessing specialized scales that protect it from other predators²⁷. These fishes also demonstrate parental care, a biological trait that is significantly associated with establishment success of non-native fish²⁸, which ensures greater recruitment success. Though large rapids and waterfalls are known to be barriers to the movement of this species²⁹, 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 mammals¹⁵, 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 geographically³². This is because escapes from aquaculture systems are unavoidable due to inefficient control systems for avoiding them³¹, 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 systems⁷. 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 Authority³³. 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*, *Pterogoplichthys* 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 Diversity³⁵. 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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