**Dr. A Bijukumar**

Currently holds the position of Professor and Head of the Department of Aquatic Biology and Fisheries in University of Kerala. He is specialized in marine fisheries and ecology, biodiversity and taxonomy of crustaceans and fish and aquatic invasive species.

**1) How do you compare terrestrial and aquatic alien invasive species? Do they have the same dynamics?**

Habitats play an important role in determining the characteristics of biological invasions, and in general, individual habitats differ in the number of alien species they contain. Only a few studies rely on the quantitative data of alien species across the habitats, on a time scale, particularly in India.

However, invasions generally have a much more pronounced impact on aquatic than terrestrial ecosystems. We have the classic example of Lake Victoria in East Africa, where the introduction of an exotic Nile perch (*Lates niloticus*) eventually triggered the extinction of an ecologically unique assemblage of over 200 species of indigenous cichlid fish, besides causing a series of ecosystem changes. This also serves as a perfect example showing how these changes would ultimately impact society, depending on the indigenous fish resources for their livelihood. While the Nile perch in the lake emerged as a major fishery after its introduction, many traditional fishers settled along the lake's margins lost their jobs, and many were displaced, which ultimately made them ecological refugees. The changes were pervasive too, since the native species of cichlid fishes were sundried, the availability of Nile fish with high-fat content forced the fishers to resort to smoking as a method of preservation. This led to the high demand for firewood in the region, leading to massive deforestation, soil erosion, and desertification! Those who are interested can watch further details in the classic documentary Darwin's Nightmare by Hubert Saupe.

The published research literature also shows that the invasive species are the significant drivers of biodiversity decline or loss in lakes and the third most important driver in streams (after land use and climate) by the end of this century. While we consider that the freshwater ecosystems have the greatest concentration of species per surface area on the planet, as suggested by Prof Dudgeon and his team, the impact would be much more severe than in the terrestrial ecosystem. Moreover, the recent studies highlighted in WWF's Living Planet Report and the report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services indicate that aquatic biodiversity is greatly impacted by its terrestrial counterparts. Further, aquatic ecosystems, especially freshwater systems, are less regulated and protected than terrestrial ones. These global databases also suggest an urgent need to document aquatic invasive species (AIS) and their impact on native fauna and ecosystems.

**2. What are the major pathways of aquatic faunal invasions in Kerala?**

Of the 32 aquatic alien species, 15 were introduced into the natural water bodies through the aquarium hobby and trade. While six species were introduced solely for promoting aquaculture, three species were introduced for mosquito control, and three species for either aquarium keeping or promotion of aquaculture. The rainbow trout, *Oncorhynchus mykiss*, was introduced during the colonial period to promote sport fishing, the only species introduced for this purpose. Three invasive plants, *S. molesta, Pistia stratiotes* and *E. crassipes* were introduced to the region as garden plants or for promotion of research, and their entry into natural systems is believed to be accidental. *Cabomba furcata* is a common aquarium plant, and this might have entered natural waterbodies either from home aquaria or from aquarium ponds adjoining the river basins, which are also used for rearing aquarium plants. While the release of most alien species may be accidental, species such as *Clarias gariepinus* have been illegally introduced for aquaculture. Of the 32 alien species, 11 were native to South East Asia, ten to South America, seven to Central or North America, and four to Africa.

**3. What is the current status of knowledge on aquatic faunal invasions in India?**

In India, the documentation of AIS is far from complete, and the reports are primarily on documentation of species from various ecosystems. Time-scale variation in the catch data of AIS is available to a limited extent from the river Ganga and Yamuna. Similar studies are absent from other water bodies. Invasion biology studies, and modelling studies, however all limited, and the researchers in India need to focus on this issue.

**4. What are the major invasive species and what are their places of origin?**

The data we have published (Smrithy et al., 2021) 32 alien species, including four macrophytes (*Salvinia molesta, Pistia stratiotes, Eichhornia crassipes* and *Cabomba furcata*) and 28 fish from the southern part of the Western Ghats. Seven of these have established natural populations and are invasive, which include *Oreochromis mossambicus*, *O. niloticus* (Cichlidae), *Poecilia reticulata*, *Gambusia affinis* (Poeciliidae), *Pterygoplichthys pardalis* (Loricariidae), *Cyprinus carpio* (Cyprinidae) and *Clarias gariepinus* (Clariidae). *Oreochromis mossambicus* is the most extensively distributed invasive fish in the region. Major reservoirs serve as a spawning hub for species such as *C. gariepinus* and *C. carpio.*

**List of alien/invasive flora and fauna recorded from the water bodies along southern Western Ghats, India**

| Sl. No | Common name | Species | Native Range | Pathway of introduction | Ali In | Presence in a number of water bodies | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Rivers | Reservoirs | Freshwater lakes |
| **FLORA (Macrophytes)** | | | | | | | | |
| 1 | Kariba Weed | *Salvinia molesta* | Southeastern Brazil | GP | In | 44 | 4 | 3 |
| 2 | Water Lettuce | *Pistia stratiotes* | Pantropical | GP | In | 20 | 2 | 2 |
| 3 | Water Hyacinth | *Eichhornia crassipes* | South America | GP | In | 38 | 0 | 1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 4 | Red Cabomba | *Cabomba furcata* | South America | AQ | In | 7 | 0 | 2 |
| **FAUNA (Fish)** | | | | | | | | |
| 5 | Mozambiqe Tilapia | *Oreochromis mossambicus* | Tropical and subtropical Africa | AS | In | 44 | 18 | 2 |
| 6 | Nile Tilapia | *Oreochromis niloticus* | Africa | AS | In | 4 | 0 | 0 |
| 7 | Sailfin Catfish | *Pterygoplichthys pardalis* | South America | AQ | In | 5 | 0 | 1 |
| 8 | Common Carp | *Cyprinus carpio* | Europe to Asia | AS | In | 17 | 29 | 1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 9 | North African Catfish | *Clarias gariepinus* | Pan Africa | AS | In | 7 | 10 | 0 |
| 10 | Guppy | *Poecilia reticulata* | South America | MC | In | 14 | 22 | 0 |
| 11 | Mosquito Fish | *Gambusia affinis* | North and Central America | MC | In | 2 | 5 | 0 |
| 12 | Green Swordtail | *Xiphophorus hellerii* | Central America | AQ | Ali | 1 | 0 | 0 |
| 13 | Southern Platyfish | *Xiphophorus maculatus* | North America | AQ | Ali | 1 | 0 | 0 |
| 14 | Giant Gourami | *Osphronemus goramy* | South east Asia | MC | Ali | 2 | 0 | 0 |
| 15 | Three Spot Gourami | *Trichopodus trichopterus* | South east Asia | AQ | Ali | 1 | 0 | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 16 | Moonlight Gourami | *Trichopodus microlepis* | South east Asia | AQ | Ali | 1 | 0 | 0 |
| 17 | Shortfin Molly | *Poecilia mexicana* | North and Central America | AQ | Ali | 1 | 0 | 0 |
| 18 | Pacu | *Piaractus mesopotamicus* | South America | AS/AQ | Ali | 2 | 0 | 0 |
| 19 | Pirapitinga | *Piaractus brachypomus* | South America | AS/AQ | Ali | 9 | 0 | 1 |
| 20 | Striped Catfish | *Pangasianodon hypophthalmus* | Asia | AS/AQ | Ali | 8 | 0 | 0 |
| 21 | Arawana | *Osteoglossum bicirrhosum* | South America | AQ | Ali | 1 | 0 | 0 |
| 22 | Rainbow Trout | *Oncorhynchus mykiss* | Asia and North America | SF | Ali | 1 | 0 | 0 |
| 23 | Silver Carp | *Hypophthalmichthys molitrix* | East Asia | AS | Ali | 2 | 0 | 0 |
| 24 | Kissing Gourami | *Helostoma temminckii* | Asia (Thailand to Indonesia) | AQ | Ali | 1 | 0 | 0 |
| 25 | Grass Carp | *Ctenopharyngodon idella* | Asia (Eastern China and Russia) | AS | Ali | 5 | 0 | 0 |
| 26 | Forest Snakehead | *Channa lucius* | Asia (Thailand to Indonesia) | AQ | Ali | 1 | 0 | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 27 | Red Tailed Tinfoil | *Barbonymus altus* | Asia | AQ | Ali | 2 | 0 | 0 |
| 28 | Alligator Gar | *Atractosteus spatula* | North America | AQ | Ali | 3 | 0 | 0 |
| 29 | Oscar | *Astronotus ocellatus* | South America | AQ | Ali | 1 | 0 | 0 |
| 30 | Arapaima | *Arapaima gigas* | South America | AQ | Ali | 3 | 1 | 0 |
| 31 | Gold fish | *Carassius auratus* | Central Asia and China | AQ | Ali | 1 | 0 | 0 |
| 32 | Mexican mojarra | *Mayaheros urophthalmus* | Central America | AQ | Ali | 1 | 0 | 0 |

GP: Garden Pond; AS: Aquaculture Systems; AQ: Aquarium System and Ornamental fish trade fish trade; MC: Mosquito larvae control; SF: Sport Fisheries

**5. Apart from their impact on native biodiversity, what are the other impacts of invasive alien aquatic species?**

As freshwater ecosystems harbour the highest species richness per surface area on the planet, the impacts of biological invasions may be disastrous, including homogenisation of fauna by serving as the stepping stones or transits of alien species to nearby watersheds. Impacts of invasive flora and fauna may also vary between freshwater ecosystems. For example, invading macrophytes may alter hydrology, sedimentation and water quality, reducing the space available for co-occurring species, especially those at higher trophic levels such as invertebrates. Fish introductions impact biodiversity in different ways like competition, genetic interactions, disease transmission, habitat alteration and many other ways in which we lack knowledge. Competition between farmed and native species for food, habitat, spawning site and mates has occurred in the case of native tilapias when farmed tilapias have been moved extensively in Africa where native tilapias exist, resulting in the loss of pure strains in many parts of their native range. Introduced species are also responsible for the spread of new diseases which depletes native species, like the case of European lobsters, which

were replaced by introduced American lobsters. Some introduced species significantly alter habitats, like the case of grass carp, which effectively remove aquatic vegetation that provides food and shelter for local species.

**6. How has the 2018-19 floods influenced aquatic faunal invasions?**

Our studies recorded **nine new exotic species** from the water bodies of Kerala after the 2018 flood. The newly recorded exotic species are Arapaima gigas (Schinz, 1822), Atractosteus spatula (Lacepede, 1803), Astronotus ocellatus (Agassiz,1831), Barbonymus altus (Gunther, 1868), Channa Lucius (Cuvier, 1831), Osteoglossum bicirrhosum (Cuvier, 1829), Helostoma temminckii (Cuvier, 1829), Pangasianodon sp and Piaractus mesopotamicus (Holmberg, 1887). Arapaima was caught from Chalakudy River, Malankara reservoir, and backwaters near Kodungalor. The fish was an accidental escapee from culture systems or recreational centres. Arapaimas are ancient fish and are popularly known as living fossils and are also one of the mega fishes of the world. Arapaima is endemic to the Amazon basin and grows up to 4.5 m in length and 200 kg in weight and is greatly exploited for food in its native region. The fish was introduced into Peru for aquaculture in 1970 and escaped into the wild during the flood, causing severe environmental impacts. The large body size and feeding behaviour of these fish have caused significant damage to the introduced ecosystem.

Like Arapaima, the Alligator gar is also another living fossil resulting from the 2018 flood in the water bodies of Kerala. The fish was caught from the Periyar river, Kurumali river and Perumbalam Lake. Alligator gar is native to Mexico and USA, grows to a length of 3m and weighs about 137 kilograms. Alligator gar is a top-level carnivore feeding on various organisms like fishes, crustaceans, aquatic birds and mammals.

Apart from that, Arapaima is included in Schedule II of CITES and banned from importing into the country. The Kerala Inland Fisheries and Aquaculture Act, 2010 and the Kerala Fish Seed Bill, 2014 prohibit the use of non-domestic fish and fish seeds for fish farming without subjecting them to quarantine proceedings and quality checks.

The occurrence of other fishes such *as Astronotus ocellatus, Barbonymus altus, Channa lucius, Osteoglossum bicirrhosum, Helostoma temminckii, Pangasianodon sp* and *Piaractus mesopotamicus* are also the escapees of farms, granite quarries and homestead ponds situated in the flood plains of the river systems. All these farms lack proper biosecurity measures to prevent the escape of fishes into the natural ecosystems during extreme climatic events such as a flood.

**7. In the context of aquatic faunal invasion, how do you look at the proposal for the interlinking of rivers?**

Science has proved that Inter-basin Water Transfers (IBWT) are one of the significant pathways of freshwater invasion. They provide a direct link between previously isolated catchments and may modify the habitat conditions of the receiving waters such that they become more favourable for the establishment of invasive species. The joint impact of IBWT and AIS would further intensify the stress upon native species and their

habitats. Globally there is well-documented information in the Severn and Thames Rivers, where the transfer and establishment of the notorious aquatic invasive species, quagga mussel, and its impact on indigenous mussels have been recorded. In India, the linking of the Godavari and the Krishna rivers in Andhra Pradesh has resulted in the introduction of armoured suckermouth catfish into the Krishna River. Besides other ecological changes, the linking of rivers would serve as a highway for transferring AIS from one basin to the other.

The EIA studies done on an interlinking need to consider this possibility as well, and we need specific studies to help policy makers to make informed decisions about the risks associated with introducing aquatic invasive species under different engineering scenarios.

**8. How can the invasive aquatic fauna in Kerala be managed?**

Preventing the introduction of AIS can be considered as a cost-effective management option along with early detection and rapid response towards eradication in an integrated manner. Extensive research on invasion biology of potentially invasive species and their horizon scanning for prioritisation of IAS to inform decision-making is also recommended for the region. The current strategies in India towards the management of aquatic invasive species remain centred around general regulations and legislations for prevention, quarantine and ban with regard to the use of individual species. However, there is an urgency for an overarching policy that takes care of species-specific assessments based on their invasion biology, a more robust and transparent database on the import and export of aquaculture and aquarium fish, specific programmes for early detection and rapid response, extensive monitoring programmes involving citizen scientists, and ICT-based awareness and education programmes through the decentralised local governance system, civil society and self-help groups.

The 2018 flood has brought several new exotic species into the water bodies of Kerala. Among the new species, the most dangerous ones are the Arapaima and Alligator gar. This is a clear indication of how national policies are violated in a country like India. The culture of exotic fishes without any biosecurity measures and their repeated occurrence in the state's water bodies reminds us of the status of numerous indigenous fishes in our state. A complete ban on the unauthorised organism should be included for safeguarding the endemic species, and apart from that, there is a need for nationwide invasive species management and eradication plan, and strict policy measures should be implemented by involving local, regional and national biodiversity managers fishery experts and policy makers for the successful management of invasions.

**9. Do we require new legislation to contain aquatic faunal invasions?**

Though the existing regulations may be used effectively in managing invasive species, a dedicated regulation would help address the problem more effectively. The available studies unequivocally proved the disastrous consequences of invasive species on our biodiversity and ecosystem services. Also, we need an institutional mechanism (for example, authority or council managed by the scientists) to coordinate the invasive species management programme.

**10. Can you speak on successful alien aquatic faunal management programs across the globe?**

There is a general perception that AIS are more difficult to manage than their terrestrial counterparts. This is partly true, as one could not 'see' the presence of aquatic animal species, and the techniques available for detecting terrestrial species are difficult to apply in aquatic ecosystems. Further, the chemical and biological control methods are difficult in water, as the water bodies are interconnected, and they may prove risky for indigenous species as well.

There are no well-documented success stories of invasive species management in major inland aquatic systems. However, there are many 'success' stories in managing AIS using combinations of chemical and physical methods such as electrofishing, concerning small ponds, waterways and protected areas. However, many of these stories could not be scientifically classified as eradication since they haven't addressed the entire issue of invasion, as there are many instances of reinvasions at later stages.

Probably we have to use modern technologies like environmental DNA to detect the presence of AIS at an early stage and try genetic technologies tried in terrestrial species such as gene silencing and RNA-guided gene drives.

**A. Biju Kumar**
**Professor and Head, Dept. of Aquatic Biology & Fisheries**
**University of Kerala, Thiruvananthapuram 695 581, Kerala, INDIA**