Indian J. Fish., 68(2): 33-42, 2021
DOI: 10.21077/ijf.2021.68.2.101875-05

Food spectrum of two co-occurring invasive fish, *Cyprinus carpio* Linnaeus, 1758 and *Clarias gariepinus* (Burchell, 1822) in Mattupetty Reservoir, Kerala, India

SMRITHY RAJ, SUVARNA DEVI, SHAMNA SALAM AND A. BIJU KUMAR
Department of Aquatic Biology and Fisheries, University of Kerala, Thiruvananthapuram - 695 581, Kerala, India
e-mail: bijupuzhayoram@gmail.com

ABSTRACT

The survey on fish fauna of the Mattupetty Reservoir in the Idukki District of Kerala State, India revealed the presence of four non-native fish species *viz*., *Clarias gariepinus* (family Clariidae), *Cyprinus carpio* (family Cyprinidae), *Poecilia reticulata* and *Gambusia affinis* (family Poeciliidae). Gut content analyses of *Clarias gariepinus* and *Cyprinus carpio* demonstrated no significant dietary overlap among them, though both are omnivorous. Cannibalism was observed in *C. gariepinus* and it was also found to feed on *C. carpio* and the latter feeds on the eggs of the former. Both the invasive fishes showed ontogenetic shift in diet. The initially invaded *C. carpio* might have facilitated the establishment of *C. gariepinus*, with the probable displacement of native species and currently these two invasive species are the only commercially valuable species available in the Mattupetty Reservoir. It is hypothesised that in a resource-scarce ecosystem like a reservoir with multiple invasive species, the invasive species not only feed on the indigenous food items available, but also feed on each other to ensure survival.

Keywords: Alien species, Food and feeding, Melting down hypothesis, Stomach contents, Western Ghats

Introduction

Unprecedented biological invasions in aquatic ecosystems, one of the significant causes for biodiversity loss worldwide, have been triggered mostly by anthropogenic activities (Gallardo *et al.,* 2016; Reid *et al.,* 2019). Therefore, development of proactive strategies and management plans to reduce the impacts of invasive species and better knowledge on invasion biology, are considered as the underpinning factors for the conservation of biodiversity as well as maintenance of ecosystem services (Early *et al.,* 2016; Liu *et al.,* 2019). Among the various inland water bodies, human-made structures such as reservoirs are reported to be susceptible to invasion by non-native species since they have significantly transformed ecological structure and functions compared to the unregulated systems (Ortega *et al.,* 2018; Muniz e*t al.,* 2020). A large number of studies have shown that reservoirs also act as a shelter for invasive species and gateway for their further spread to connected water bodies (Muirhead and MacIsaac*,* 2005; Ahyong and Yeo, 2007; Nunes *et al.,* 2017; Beatty *et al.,* 2019). The reservoirs of India have long been used for the introduction of non-native fish, primarily for enhancing fish production through capture-based culture fisheries (Sugunan, 1995; Sarkar *et al.,* 2018).

Over 300 species of non-native fishes have been introduced to India for various purposes including aquaculture promotion, control of mosquito larvae, augmenting sport fisheries and to support aquarium keeping. The commonly encountered exotic fish species in Indian reservoirs are *Oreochromis mossambicus, Hypophthalmichthys molitrix, Cyprinus carpio, Gambusia affinis, Ctenopharyngodon idella* and *Clarias gariepinus* (Biju Kumar, 2000; Sugunan, 2011; Sandilyan *et al.,* 2018).

In aquatic ecosystems, non-native fishes compete with the endemic species (Simon and Townsend, 2003) and this may lead to competition, especially where there are trophic interactions and niche overlap with limited food resource (Bohn *et al.,* 2008). The invasive species may sometimes show competitive exclusion when they compete for resources or may show exploitative competition when they utilise the food resource without any competition while diminishing the food resources (Schoener, 1983). The non-native fishes have been reported to impact the food web structure and ecosystem properties of Indian reservoirs (Panikkar and Khan, 2008; Khan and Panikkar, 2009; Khan *et al.,* 2015). Although impacts of invasive species on ecosystems and biotic communities as well as between the invasive species are well established, according to Simberloff and Von Holle (1999), exotic species in an ecosystem facilitate each other, increasing the likelihood of survival and ecological impact, a concept commonly known as the invasional meltdown hypothesis. The occurrence of two or more invasive species causing more severe impact to the ecosystem, than a single invader does and several studies have provided supporting evidence for this phenomenon (Ricciardi, 2001; Lizarralde *et al.,* 2004; Golumbia *et al.,* 2007).

The North African catfish, *C. gariepinus* (Burchell, 1822), a species illegally introduced and farmed in India and the common carp, *C. carpio* Linnaeus, 1758, which was introduced formally for augmenting aquaculture, have now been established in many reservoirs of India (Singh *et al.,* 2010; Sarkar *et al.,* 2012). The Bangkok strain of *C. carpio* was introduced to India in 1957 for experimental culture (Biju Kumar, 2000) and subsequently three varieties of common carp (scale carp *C. carpio* var. *communis,* mirror carp *C. carpio* var. *specularis* and leather carp *C. carpio* var. *nudus*) were introduced to the reservoirs of India for promotion of aquaculture (Sugunan, 1995; 2000). In the reservoirs of Kerala, they were introduced in the mid 1970s by the Kerala Fisheries Department as part of the fisheries development programme (Gopinath and Jayakrishnan, 1984; Arun *et al*., 2001). The introduced *C. gariepinus* has negatively impacted the availability of many cyprinids, especially barbs (Sarkar *et al*., 2018). Both these species are omnivorous and as invasive species they impact the native biodiversity worldwide (Chirwa *et al.,* 2016). Though the fish fauna of two major reservoirs of Idukki District of Kerala, Periyar (Chacko, 1948; Arun *et al.,* 1996; Zacharias *et al.,* 1996; Arun, 1999; Radhakrishnan and Kurup, 2010) and Idukki (Gopinath and Jayakrishnan, 1984), is well documented, and the river basins in Idukki District of Kerala is one of the key fish biodiversity hotspots in the Western Ghats, with the largest number of point endemics (Kurup *et al.,* 2004), there is no published data on the fish fauna of the Mattupetty Reservoir and the associated hydro basins. Over the years, the fishery data from the Mattupetty Reservoir, in Kerala State, India, located in the Western Ghats Biodiversity Hotspot, showed the dominance of two non-native species, *C. gariepinus* (family Clariidae) and *C. carpio* (family Cyprinidae) (Biju Kumar, 2019). This paper analyses the food spectrum of these two invasive species in the Mattupetty Reservoir of Kerala, India, to examine how they interact with each other through the food spectrum.

Materials and methods

Survey and collection of fish

The study conducted a general survey of fish fauna in the Mattupetti Reservoir (Fig. 1) with the assistance of local fishers, using hook and lines, gillnets and traps. Extensive use of nets was not permitted in the reservoir situated within a protected area. Fishery data were also collected from the local fishermen, specifically from the tribal people, who used to fish from the reservoir and the fishing operations are regulated through a cooperative society.

The Mattupetty Reservoir (10.106°N; 77.124°E), is located 1700 m above MSL and the region has a mean annual temperature of 18°C and mean annual rainfall of 2012 mm (Thomas, 2012). This reservoir, enclosed by a storage concrete gravity dam, constructed in 1957 under

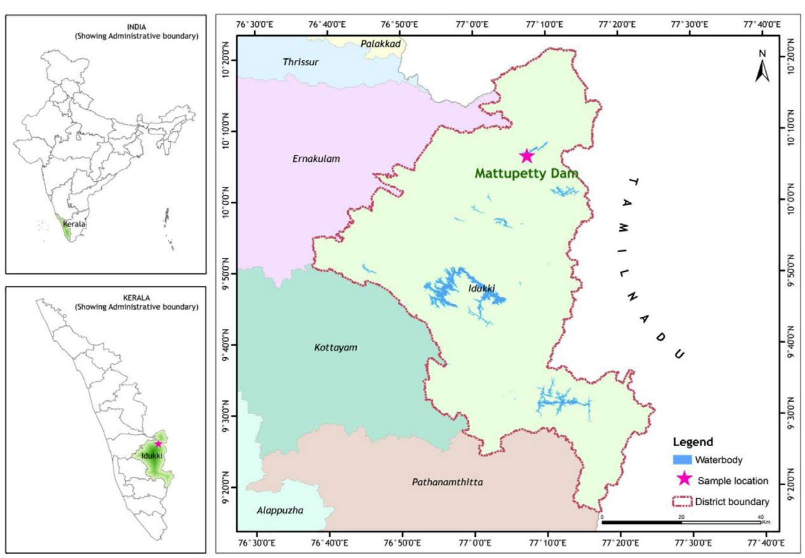

Fig. 1. Map showing the location of Mattupetty Reservoir, Kerala, India

the Pallivasal Hydroelectric Project for power generation and water conservation, is located on Anamudi Peak of the Western Ghats Biodiversity Hotspot. The reservoir has a total surface area of 323.75 ha and a catchment area of 105 sq. km. The total capacity of this reservoir is about 55.4 million m^3 of water at full reservoir level (Pillai *et al.,* 2016).

Food and feeding analyses

The collected specimens were immediately measured for total length and weight, dissected and the stomachs of *C. carpio* (n = 104) and *C. gariepinus* (n = 110), with contents intact were measured, weighed and preserved in 90% ethanol and brought to the laboratory for further examination. The gut contents were then identified up to the lowest taxonomic level as possible, depending upon the stage of digestion. Based on the distension of the stomach and quantity of the prey items, points were allotted (Hyslop, 1980) and the percentage composition of the gut contents were calculated. Frequency of occurrence was calculated following Hunt and Carbine (1951). Gastrosomatic index (GaSI) (Khan *et al.,* 1988) was determined by the percentage weight of the fish gut, to its total body weight. Index of preponderance (Natarajan and Jhingran, 1961) and Index of Relative Importance (IRI) were assessed for *C. gariepinus.* The latter is an integration of the measurements of number, volume and frequency of occurrence of various food items found in the gut of the fish (Pinkas *et al.,* 1971; Kurian, 1977).

Molecular identification of gut contents

The mitochondrial cytochrome oxidase I (COI) gene of food samples from the gut of *C. gariepinus* and *C. carpio* preserved in ethanol were sequenced to confirm the species identity of food organisms. For this, DNA extraction was done using Qiagen's DNeasy Tissue kit and CO1 gene was amplified using the universal primer set LCO1490 (5'-GGTCAACAAATCATAAAGATATTGG-3') and HC 02198 (5'-TAAACTTCAGGGTGACCAAAAAATCA-3') (Folmer *et al.,* 1994). PCR amplification was done using the standard procedures, and gene sequencing was done at Rajiv Gandhi Centre for Biotechnology (RGCB), Thiruvananthapuram, India and the sequences visualised in Bioedit (Hall, 1999). For accurate species identification, DNA sequences obtained from the gut contents were blasted to find out closely allied sequences from the NCBI (National Centre for Biotechnology Information) database.

Results

Fish fauna of Mattupetty Reservoir

The survey of fish fauna of Mattupetty Reservoir revealed the presence of only four non-native species, the North African catfish *C. gariepinus* (family Clariidae), common carp *C. carpio* (family Cyprinidae), guppy *P. reticulata* and the mosquitofish *G. affinis* (family Poeciliidae). No native fishes were recorded from the reservoir and the scope of the survey was limited only within the reservoir and not into the entire hydro basin.

Diet of C. carpio

The diet composition, frequency of occurrence and gastrosomatic index (GaSI) were estimated based on the gut content analysis of 104 specimens of *C. carpio*. Even though the fish species utilise a broad spectrum of food items, they mostly preferred plant matter and the predominant food items were Chlorophyta (14.34%), detritus (12.49%), Ochrophyta (12.23%), Protista (12.16%), Cyanobacteria (12.10%), Plantae (10.93%) and Crustacea (9.81%). Insecta (6.62%), Rotifera (3.71%), Cryptophyta (2.83%) and fish eggs (2.27%) were also represented in the diet. Fishes with empty stomachs were not obtained during the entire period of study. High amounts of mud and sand particles were also found in the gut of *C. carpio,* suggesting its benthic feeding habits.

The highest percentage of occurrence was shown by Ochrophyta, Chlorophyta, Plantae, Protista and detritus with 11% each; Crustacea and Cyanobacteria constituting 10% each, followed by Insecta (9.35%), Rotifera (6.92%), fish eggs (4.85%) and Cryptophyta (4.51%) (Fig. 2).

All food organisms found in the environment are exploited by *C. carpio*, but the degree of abundance in the diet varied. The ontogenetic diet shift is substantiated by the dominance of Ochrophyta and Crustacea in the diet of smaller fishes and plants, insects and fish eggs in adults. GaSI of *C. carpio* was found to be high in fishes of smaller size class (0-50 g), which showed a decreasing trend with increase in size (Table 1). Gut content analyses revealed that *C. carpio* is a euryphagous benthic omnivorous feeder with a broad and diversified food spectrum.

Diet of C. gariepinus

The gut content analysis of *C. gariepinus* revealed that the fishes are omnivorous, with a broad food spectrum and a more definite preference towards animal food. The percentage composition of the diet of *C. gariepinus* revealed that detritus contributed the highest percentage

Table 1. Gastrosomatic index (GaSI) of *C. carpio*

Size class (g)	Mean weight (mg)	GaSI
0 -50	35.17	0.08
50-100	677.6	0.05
100-150	1238.27	0.03
150-200	1817.8	0.02
200-250	2235	0.02
250-300	3592	0.02

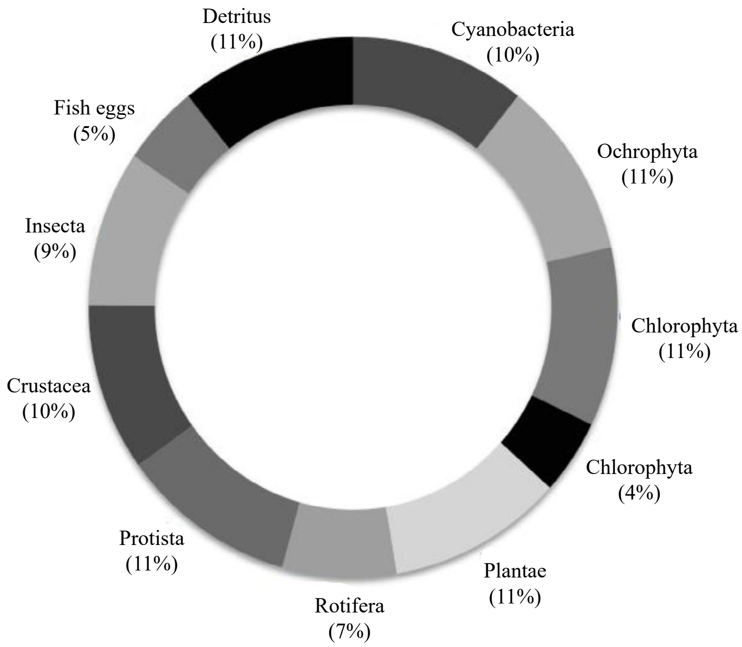

Fig. 2**.** Frequency of occurrence of various food items in the gut of *C. carpio*

(40%) followed by fishes (23.8%), Insecta (20.3%), Crustacea (11%) and Mollusca with the least abundance (5%).

The frequency of occurrence of insects and crustaceans were higher for the fishes below 35 cm in total length, whereas fish dominated in the gut of larger ones. In the overall frequency of occurrence (Fig. 3), detritus formed the significant share with 45%, fishes (27.50%), insects (26.25%), molluscs (5%) and crustaceans with least contribution (1.25%). GaSI, in general, recorded a decrease in value with an increase in weight of the fish (Table 2). This carnivorous nature of the fish with an increase in size is proved to be true when analysing the relative gut length of the fish, with smaller fish showing a relative gut length of about 1, which gradually decreases with increase in the length of the fish.

In terms of percentage occurrence, Index of preponderance and IRI (Pinkas method); miscellaneous items dominated the diet of *C. gariepinus*, while in terms of number, insects were the predominant item; while fishes represented the dominant diet in terms of volume and IRI (Kurian's method) (Table 3).

Molecular identification of gut contents

DNA barcoding of the gut contents of both fish species revealed species level identity of only a few samples. The eggs found in the gut sample of *C. carpio* were confirmed as the eggs of *C. gariepinus*. The fish samples in the gut

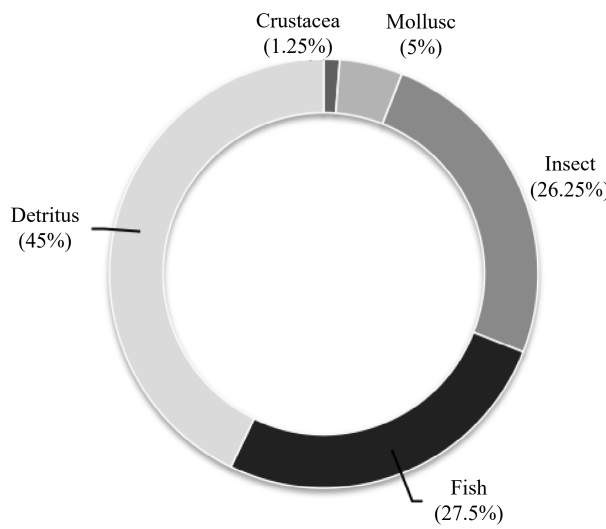

Fig. 3. Frequency of occurrence of food items in the gut of *C. gariepinus*

Table 2. Gastrosomatic index (GaSI) of *C. gariepinus*

Size class (g)	Mean weight (g)	GaSI
0-250	182.78	2.46
250-500	396.90	1.52
500-750	605.00	2.08
750-1000	877.20	2.95
1000-1250	1,145.00	1.53
1250-1500	1,500.00	1.09
1500-1750	1,675.00	1.41
1750-2000	1,825.00	2.44
ABOVE 2000	2,682.00	1.51

Table 3. Percentage occurrence, percentage number, percentage volume, index of preponderance and Index of Relative Importance (IRI) of various food items in the diet of *C. gariepinus*

Food items	%Occurrence	% Number	% Volume	Index of preponderance	IRI (Pinkas method)	IRI (Kurian's method)
Crustacea	5.88	7.81	7.73	0.37	17	2.15
Mollusca	1.20	4.69	9.29	0.43	52.22	2.41
Insecta	24.7	34.38	28.99	28.28	24617.19	21.53
Fish	25.87	21.88	32.01	32.71	18112.58	39.14
Miscellaneous	41.65	31.25	21.98	36.75	28607.89	30.78

of *C. gariepinus* were identified as *C. carpio* and that of *C. gariepinus* itself. Other taxa identified by DNA barcoding using COI gene from *C. gariepinus* includes *Marcia* sp. (Mollusca: Veneridae), *Mesocyclops* sp. (Arthropoda: Cyclopidae), *Eristalis* sp. (Arthropoda: Syrphidae) and *Macromia* sp. (Arthropoda: Macromiidae).

Discussion

The fish fauna of the Mattupetty Reservoir has not been previously documented and the present survey recorded presence of only four non-native species *viz.*, *C. gariepinus* (family Clariidae), *C. carpio* (family Cyprinidae), *P. reticulata* and *G. affinis* (family Poeciliidae). In the absence of previous studies, it is hard to explain the impact of non-native fish on the local biodiversity. However, the river basins of Idukki District is considered as a key biodiversity area, with several endemic species, inluding several 'threatened' species in the IUCN Red List, such as *Eechathalakenda ophicephalus* (Endangered species from Periyar Tiger Reserve/Periyar), *Garra periyarensis* (Vulnerable species from Periyar Tiger Reserve/Periyar), *Ghatsa santhamparaiensis* (Endangered species from Santhampara Hills/Periyar), *Horalabiosa arunachalami* (Critically Endangered species from Santhampara Hills/Periyar), *Hypselobarbus periyarensis* (Endangered species from Periyar Tiger Reserve/Periyar), *Lepidopygopsis typus* (Endangered species from Periyar Tiger Reserve/Periyar), *Mesonoemacheilus periyarensis* (Vulnerable species from Periyar Tiger Reserve/ Periyar), *Mesonoemacheilus menoni* (Vulnerable species from Periyar Tiger Reserve/Periyar) and *Tariqilabeo periyarensis* (Endangered species from Periyar Tiger Reserve/Periyar) (Chacko, 1948; Kurup *et al.,* 2004; Arun *et al.,* 1996, 1999; Zacharias *et al.,* 1996; Radhakrishnan and Kurup, 2010; IUCN Red List 2018; Raghavan, 2019). While Radhakrishnan and Kurup (2010) recorded 54 species from the Periyar Tiger Reserve, 17 species were recorded from the Idukki Reservoir (Gopinath and Jayakrishnan, 1984), both located in the nearby hydrobasins of Mattupetty Reservoir, Idukki District of Kerala.

The major threat to native biodiveisty in both the resevoirs of Idukki District are alien species and the species such as *C. gariepinus*, *C. carpio, O. mossambicus*, *P. reticulata* and *G. affinis* (Arun *et al.,* 2001; Radhakrishnan and Kurup, 2010; Biju Kumar, 2019). While *C. carpio* and *O. mossambicus* have been introduced into the reservoirs in the mid 1970s by the Kerala Fisheries Department as part of the fisheries development programme (Gopinath and Jayakrishnan, 1984), there are no official documents on the introduction of alien species inside the protected areas (Arun *et al.,* 2001). However, the absence of published data on the native fishes of Mattupetty Reservoir and the associated watersheds handicap any forecast on the impact of alien species on the ecosystem and biodiversity.

The introduction of non-native organisms into aquatic ecosystems and their establishment have induced changes both in biodiversity and ecosystem services (Zhang and Chen, 2011). The invasive fishes *C. carpio* and *C. gariepinus* compete with endemic fauna for food and spawning space (Weber and Brown, 2011). Two most common Invasive Alien Species (IAS) established in the aquatic ecosystems of India are the East African catfish *C. gariepinus* and common carp *C. carpio* (Biju Kumar, 2000; Singh and Lakra, 2006; Singh *et al.,* 2010; Singh, 2014).

Several factors are known to influence the quantity and quality of food in the gut contents like seasonal changes, diel cycle, territoriality and differeneces in digestion rate (Bowen, 1996). The studies on the stomach content analyses of two invasive species, *C. gariepinus* and *C. carpio* revealed that no significant food items are shared between these two species and hence there is no niche overlap. They also depend on each other as food; *C. gariepinus* feed on *C. carpio* and the latter feed on the eggs of the former. Cannibalism is also observed in *C. gariepinus*. Both the species also showed ontogenetic diet shifts, *C. carpio* changing from Ochrophyta and Crustacea to Insecta, plants and fish eggs; while *C. gariepinus* shifted from Crustacea and Insecta to fishes with increase in size. Lesser diversity of native fishes, specifically cyprinids, in Mattupetty Reservoir is an indicator towards increasing biomass of voracious feeders like *C. gariepinus*. The larger Chinese carps (*C. carpio*) are not eaten by *C. gariepinus* and the former maintain their populations in the reservoirs probably because of high fecundity rate and variation in ecoclogical niche occupied.

The dominant food item of *C. carpio* was Chlorophyta (14.34%) followed by miscellaneous items (12.49%), Ochrophyta (12.23%), Protista (12.16%), Cyanobacteria (12.10%), Plantae (10.93%) and Crustacea (9.81%). Insecta (6.62%), Rotifera (3.71%), Cryptophyta (2.83%) and fish eggs (2.27%) also contributed very little in the diet showing the omnivorous nature of the fish. Similar food composition in *C. carpio* was reported by Al-Awady (2013) from Main Outfall Drain, Iraq, where Chlorophyta and Cyanophyta (90.89 %), aquatic plants and tissues (83.66%); debris and mud (81.14 %) dominated the diet of fish. Berthou (2001) reported that the food of *C. carpio* mainly consists of detritus, plant material (including debris, diatoms), amphipods (*Echinogammarus* sp.), and phantom midge larvae. Dadebo *et al.* (2015) stated that the food items of common carp included detritus, insects, macrophytes, phytoplankton, ostracods, zooplankton and gastropods. Furthermore, the gut contents of *C. carpio* in Indian lakes contained Algae, Cladocera, Copepoda, Rotifera, benthic organisms, plant residues and mud which may be due to the selective feeding habit of *C. carpio* on readily available benthic organisms and zooplankton rather than other food organisms (Saikia and Das, 2008).

C. gariepinus is a nocturnal fish, feeding on living and dead animal matter and are also capable of swallowing relatively large prey. The stomach content analyses of the fish revealed Crustacea, Insecta, fishes, macrophytes and plant materials, thus showing the euryphagus omnivorous nature of the diet with a broad spectrum of organisms. The presence of *C. gariepinus* from its gut indicates the cannibalistic behaviour of *C. gariepinus* in Mattupetty Reservoir. The occurrence of cannibalism in individuals of *C. gariepinus* was also noticed by Bruton (1979), Spataru *et al.* (1987), Dadebo (2000) Yalcin *et al.* (2001), Wakil *et al*. (2014) and Admassu *et al.* (2015). All these studies on the food and feeding biology of *C. gareipinus* revealed that the major food items present in the gut contents depend upon the prey diversity of the habitat where the fish is present.

Various authors studied the feeding habits of *C. gariepinus* and reported the polyphagus nature of feeding (Dadebo, 2000; Abera, 2007). Bruton (1979) stated that diet of these euryphagous fish is mostly composed of small fish, crustaceans, sometimes insects and rarely plant materials. According to Dadebo *et al.* (2014), detritus, insects, macrophytes and fish were the dominant food categories by occurrence. Similar results were obtained by Spataru *et al.* (1987) where fish was the most abundant food component and constituted the highest biomass. Booth *et al.* (2010) who integrated diet studies with stable isotope analyses reported that large catfish which are highly mobile and aggressive feeders dominate the population. According to Bruton (1979), *C. gariepinus* is omnivorous, exhibiting both scavenging and predatory behaviour. These fishes could utilise a broad range of prey in different habitats which suggest its dietary plasticity, one of the crucial factors responsible for establishing themselves in a wide range of environments (Groenewald, 1964), even in habitats where it is introduced (Vitule *et al.*, 2009; Radhakrishnan *et al.,* 2011). Khan and Panikkar (2009), showed that these non-native catfish in Indian reservoir exert a negative predation impact on all fish prey, including both indigenous and introduced, resulting in cascading positive impacts on insects and zoobenthos. Such trophic cascading may, however, be obscured and is found to be less evident because of the catfish's ability to prey on lower trophic level groups such as insects and zoobenthos.

The establishment of invasive predators in many freshwater ecosystems has a negative role in accelerating the risk of species loss and local extinctions (Leprieur *et al.,* 2008). In the case of *C. gariepinus* and *C. carpio*, the establishment alters the environmental conditions of that particular habitat and decreases the strength of biotic interactions among indigenous species, and reduces their populations. This eventually reduces the resistance of the endemics and increase the risk of predation and competition by invasive non-native species (Baltz and Moyle, 1993; Moyle and Light, 1996). In addition to this, the dietary plasticity of *C. gariepinus* results in the widespread decline of native flora and fauna. The alteration of hydrological regimes in the study systems due to invasion could potentially influence in enhancing the invasion success of this invasive catfish. This study also proved that DNA based methods are useful in the identification of stomach contents as cannibalism of *C. gariepinus* and the ingestion of eggs of *C. gariepinus* by *C. carpio* were established through the identification of species with the aid of DNA barcoding.

The invasional meltdown hypothesis (IMH) (Simberloff and Von Holle, 1999) explains that when the same habitat is invaded by several new species, one species may facilitate the other's establishment, for example, by serving as the source of food or energy resource and this might initiate the invasion process (Simberloff and Von Holle, 1999; Green *et al.,* 2011). In short, this process may speed up the invasion rate, thereby compounding the impacts in the new habitat (Gallardo and Aldridge, 2015). This could be partly true as one species form the energy source for the other in the initial stage and in a resource-scarce ecosystem they also feed upon each other and avoid competition by remaining in different ecological niche. The initially invaded *C. carpio* might have facilitated the establishment of *C. gariepinus*, with the displacement of species; currently they avoid competition by occupying various niche and the co-occurrence of two invasive species might have displaced other native fish in the reservoir. In Mattupetty Reservoir, the phenomenon of "invasional meltdown" is evident, which involves the joint impact of *C. gariepinus* and *C. carpio* and would cause severe effect than that of a single invader. Hence it can be hypothesised that in a resource-scarce ecosystem, like a reservoir, with multiple invasive species, the invasive species not only feed on the indigenous food items available but also feed on each other to ensure survival.

The present results suggest that the non-native *C. gariepinus* and *C. carpio* in Mattupetty Reservoir have different food spectrum and avoid competition for food. But the combined activity of both the species modified the habitat in such a way that they promoted homogenisation of fish taxa, leading to the probable elimination of native fish species from the ecosystem. The study also shows that the reservoir located in the Western Ghats Biodiversity Hotspot may serve as the beachhead for the invasive species. Further studies are suggested to elucidate the inavsion biology of the alien speceis, impacts of all the invasvie species on the biodiversity of the reservoir and the implications of alien fish on subsistence fisheries.

Acknowledgements

The authors thank the Directorate of Environment and Climate Change, Government of Kerala, India for financial support (Project No. DoECC/RD-57/3658/2013) and the Forests and Wildlife Department, Government of Kerala for permission to collect fish from the protected areas.

References

Abera, L. 2007. *Reproduction, food, length-weight relationship and condition factor of African catfish Clarias gariepinus (Burchell,1822) in Lake Babogaya, Ethiopia*. M. Sc. Thesis, Addis Ababa University, Addis Ababa, Ethiopia.

Admassu, D., Abera, L. and Tadesse, Z. 2015. The food and feeding habits of the African catfish, *Clarias gariepinus* (Burchell), in Lake Babogaya, Ethiopia. *Int. J. Fish. Aquac.,* 3(4): 211-220.

Ahyong, S. T. and Yeo, D. C. J. 2007. Feral populations of the Australian red-claw crayfish (*Cherax quadricarinatus* von Martens) in water supply catchments of Singapore. *Biol. Invasions,* 9: 943-946. doi:10.1007/ S10530-007-9094-0.

Al-Awady, A. A. M. 2013. Food habits of common carp (*Cyprinus carpio*) in main outfall drain, Al-Nassiriya, Iraq. *J. Thi-Qar Sci.,* 3(4): 9-17.

Arun, L. K. 1999. Patterns and processes of fish assemblage in Periyar Lake-valley system of southern Western Ghats. *KFRI Research Report,* Kerala Forest Research Institute, Peechi, Kerala, India, 142 pp.

Arun, L. K., Jayasankar, B. and Abraham, K. M. 2001. Biodiversity conservation and livelihood issues of the tribesfolk: A case study of Periyar Tiger Reserve. *Report, Kerala Reseach Programme on Local Level Development,* Centre for Development Studies, Thiruvananthapuram, Kerala, India, 80 pp.

Arun, L. K., Shaji, C. P. and Easa, P. S. 1996. Record of new fishes from Periyar Tiger Reserve. *J. Bombay Nat. Hist. Soc.,* 93: 103-104.

Baltz, D. M. and Moyle, P. B. 1993. Invasion resistance to introduced species by a native assemblage of California stream fishes. *Ecol Appl.*, 3: 246-255. https://doi.org/10.2307/1941827.

Beatty, S. J., Ramsay, A., Pinder, A. M. and Morgan, D. L. 2019. Reservoirs act as footholds for an invasive freshwater crayfish. *Pacific Cons. Biol.,* 26(1): 78-83, https://doi.org/10.1071/PC19012.

Berthou, E. G. 2001. Size- and depth-dependent variation in habitat and diet of the common carp (*Cyprinus carpio*). *Aquat. Sci.,* 63: 466-476. https://doi.org/10.1007/s00027-001-8045-6.

Biju Kumar, A. 2000. Exotic fishes and freshwater fish diversity. *Zoos Print J.,* 15(11): 363-367. https://doi.org/10.11609/JoTT.ZPJ.15.11.363-7.

Biju Kumar, A. 2019. *Survey and mapping of exotic freshwater biodiversity in Kerala using Geographic Information System. Final Project Report.* Directorate of Environment and Climate Change, Government of Kerala, India.

Bohn, T., Amundsen, P. A. and Sparrow, A. 2008. Competitive exclusion after invasion? *Biol. Invasions,* 10: 359-368. https://doi.org/10.1007/s10530-007-9135-8.

Booth, A. J., Traas, G. R. L. and Weyl, O. L. F. 2010. Adult African sharptooth catfish, *Clarias gariepinus*, population dynamics in a small invaded warm-temperate impoundment. *Afr. Zool.,* 45: 299-308. https://doi.org/10.3377/004.045.0208.

Bowen, S. H. 1996. Quantitative description of the diet. In: Murphy, B. R. and Willis, D. W. (Eds.), *Fisheries technology*, American Fisheries Society, Bethesda, Maryland, USA, p. 513-532.

Bruton, M. N. 1979. The food and feeding behaviour of *Clarias gariepinus* in Lake Sibaya, South Africa, with emphasis on its role as a predator of cichlids. *Trans. Zool. Soc. London,* 35: 47-114.

Chacko, P. I. 1948. Development of fisheries of the Periyar Lake. *J. Bombay Nat. Hist. Soc.,* 48: 191-192.

Chirwa, E. R., Mtethiwa, J. W. and Sikawa, D. 2016. Ecological impacts of common carp and the African sharptooth catfish: A review. *Fifth African Higher Education Week and RUFORUM Biennial Conference 2016, "Linking agricultural universities with civil society, the private sector, governments and other stakeholders in support of agricultural development in Africa"*, 17-21 October 2016, Cape Town, South Africa, p. 869-883.

Dadebo, E. 2000. Reproductive biology and feeding habits of the catfish *Clarias gariepinus* in Lake Awassa, Ethiopia. *Ethiop. J. Sci.,* 23(2): 231-246. https://doi.org/10.4314/sinet.v23i2.18168.

Dadebo, E., Aemro, D. and Giorgis, Y. T. 2014. Food and feeding habits of the African catfish *Clarias gariepinus* (Burchell, 1822) (Pisces: Clariidae) in Lake Koka, Ethiopia. *Afr. J. Ecol.*, 52: 471-478. https://doi.org/10.1111/aje.12146.

Dadebo, E., Eyayu, A., Sorsa, S. and Tilahun, G. 2015. Food and feeding habits of the common carp (*Cyprinus carpio)* in Lake Koka, Ethiopia. *Momona Ethiopian J. Sci.,* 7(1): 16-31. https://doi.org/10.4314/mejs.v7i1.117233.

Early, R., Bethany, A. B., Jeffrey, S. D., Joshua, J. L., Julian, D. O., Dana, M. B., Patrick, G., Edwin, D. Grosholz, Ibanez, I., Luke, P. M., Cascade, J. B. S. and Andrew, J. T. 2016. Global threats from invasive alien species in the twenty-first century and national response capacities. *Nat. Communications,* 7: 12485. https://doi.org/10.1038/ncomms12485.

Folmer, O., Black, M., Hoeh W., Lutz, R. and Vrijenhoek, R. 1994. DNA primers for amplification of mitochondrial cytochrome c oxidase subunit I from diverse metazoan invertebrates. *Mol. Mar. Biol. Biotechnol.*, 3: 294-299.

Gallardo, B. and Aldridge, D. C. 2015. Is Great Britain heading for a Ponto-Caspian invasional meltdown? *J. Appl. Ichthyol.,* 52: 41-49. https://doi.org/10.1111/1365-2664.12348.

Gallardo, B., Clavero, M., Sa´nchez, M. I. and Vila, M. 2016. Global ecological impacts of invasive species in aquatic ecosystems. *Glob. Chang. Biol.,* 22: 151-163.https://doi.org/10.1111/gcb.13004.

Gopinath, P. and Jayakrishnan, T. N. 1984. A study on the piscifauna of the Idukki Reservoir and catchment area. *Fish. Technol.,* 21: 131-136.

Green, P. T., O'Dowd D. J., Abbott K. L., Jeffery M., Retallick, K. and Mac Nally, R. 2011. Invasional meltdown: Invader-invader mutualism facilitates a secondary invasion. *Ecology,* 92*:* 1758-1768. https://doi.org/10.1890/11-0050.1.

Golumbia, T., Brand, L., Moore, K. and Bartier, P. 2007. History and current status of introduced vertebrates on Haida Gwaii. In: Gaston. A. J., Golumbia, T. E., Martin, J. L. and Sharpe, S. T. (Eds.), *Lessons from the islands: Introduced species and what they tell us about how ecosystems work, Canadian Wildlife Service Special Publication*, Canada, Ottawa, p. 8-31.

Groenewald, A. A. V. J. 1964. Observations on the food habits of *Clarias gariepinus* Burchell, the South African freshwater barbel (Pisces: Clariidae) in Transvaal. *Hydrobiologia,* 23: 287-291.

Hall, T. A. 1999. BioEdit: A user-friendly biological sequence alignment editor and analysis program for Windows 95/98/NT. *Nucleic Acids Symp. Ser.,* 41: 95-98.

Hunt, B. P. and Carbine, N. F. 1951. Food of young pike and associated fishes in Peterson's Ditches, Houghton Lake, Michigan. *Trans. Am. Fish. Soc.,* 80: 67-73.

Hyslop, E. J. 1980. Stomach contents analysis - A review of methods and their application. *J. Fish Biol.*, 17: 411-429. https://doi.org/10.1111/j.1095-8649.1980.tb02775.x.

IUCN 2018. *IUCN Red List of Threatened Species.* www.iucnredlist.org

Khan, M. S., Ambak, M. A. and Mohsin, A. K. M. 1988. Food and feeding biology of a tropical catfish *Mystus nemurus* (C&V) with reference to its functional morphology. *Indian J. Fish.,* 35(2): 78-74.

Khan, M. F. and Panikkar, P. 2009. Assessment of impacts of invasive fishes on the food web structure and ecosystem properties of a tropical reservoir in India. *Ecol. Model.,* 220: 2281-2290. https://doi.org/10.1016/j.ecolmodel.2009.05.020.

Khan, M. F., Panikkar, P. and Sharma A. P. 2015. Modelling the food web for assessment of the impact of stock supplementation in a reservoir ecosystem in India. *Fish. Manag. Ecol.,* 22(5): 359-370. https://doi.org/10.1111/fme.12134.

Kurian, A. 1977. Index of relative importance - A new method for assessing the food habits of fishes. *Indian J. Fish.*, 24(1&2): 217-219.

Kurup, B. M., Radhakrishnan, K. V. and Manojkumar, T. G. 2004. *Proceedings of the Second International Symposium on the management of large rivers for fisheries, vol 2. Sustaining Livelihoods and Biodiversity in the New Millennium,* 11 - 14 February 2003, Phnom Penh, Kingdom of Cambodia.

Leprieur, F., Beauchard, O., Blanchet, S., Oberdorff, T. and Brosse, S. 2008. Fish invasions in the world's river systems: When natural processes are blurred by human activities. *PloS Biol.,* 6: 404-410. https://doi.org/10.1371/journal.pbio.0060028.

Liu, C., Comte, L., Xian, W., Chen, Y. and Olden, J. D. 2019. Biological invasions are a primary threat to global biodiversity, supporting mounting calls for the development of early-warning systems to manage existing and emerging invaders. *Ecography*, 42: 2074-2083. doi: 10.1111/ecog.04665.

Lizarralde, D., Gaherty, J. B., Collins, J. A., Hirth, G. and Kim, S. 2004. Spreading-rate dependence of melt extraction at mid-ocean ridges from far-offset seismic data. *Nature*, 432: 744-747. https://doi.org/10.1038/nature03140.

Moyle, P. B. and Light, T. 1996. Fish invasions in California: Do abiotic factors determine success? *Ecology,* 77: 1666-1670. https://doi.org/10.2307/2265770.

Muirhead, J. R. and MacIsaac, H. J. 2005. Development of inland lakes as hubs in an invasion network. *J. Appl. Ecol.,* 42: 80-90. doi:10.1111/J.1365-2664.2004.00988.X.

Muniz, C. M., Ganassin, M. J. M., Agostinho, A. A. and Gomes L. C. 2020. Spatial and environmental factors predict the composition of non-native fish assemblages in Neotropical reservoirs. *Biol. Invasions*, 22: 499-508. https://doi.org/10.1007/s10530-019-02105-7.

Natarajan, A. V. and Jhingran, A. G. 1961. Index of preponderance-A method of grading the food elements in the stomach analysis of fishes. *Indian J. Fish*., 8(1): 54-59.

Nunes, A. L., Zengeya, T. A., Hoffman, A. C., Measey, G. J. and Weyl, O. L. F. 2017a. Distribution and establishment of the alien Australian redclaw crayfish, *Cherax quadricarinatus*, in South Africa and Swaziland. *Peer J.*, 5, e3135, https://doi.org/doi:10.7717/PEERJ.3135.

Ortega, J. C., Agostinho, A. A., Santos, N. C., Agostinho, K. D., Oda, F. H., Severi, W. and Bini, L. M. 2018. Similarities in correlates of native and introduced fish species richness distribution in Brazilian reservoirs. *Hydrobiologia,* 817: 167-177. https://doi.org/10.1007/s10750-018-3508-0.

Panikkar, P. and Khan, F. 2008. Comparative mass-balanced trophic models to assess the impact of environmental management measures in a tropical reservoir ecosystem. *Ecol. Model.,* 21: 280-291. https://doi.org/10.1016/j.*ecolmodel*.2007.10.029.

Pillai, P. M., Prasannan, K., Raj, S. and Kumar, A. B. 2016. Length-weight relationship and condition factor of the African catfish, *Clarias gariepinus* in Mattupetty Reservoir, Southern Western Ghats, Kerala, India. *J. Aquat. Biol. Fish.,* 4: 81-88.

Pinkas, L., Olipahnt, M. S. and Iverson, I. L. K. 1971. Food habits of albacore, bluefin tuna, and bonito in Californian waters. *Fish. Bull.*, 152: 1-105.

Radhakrishnan, K. V. and Kurup, B. M. 2010. Ichthyodiversity of Periyar Tiger Reserve, Kerala, India*. J. Threat. Taxa,* 2(10): 1192-1198.

Radhakrishnan, K. V., Lan, Z. J., Zhao, J., Qing, N. and Huang, X. L. 2011. Invasion of the African sharp-tooth catfish *Clarias gariepinus* (Burchell, 1822) in South China. *Biol. Invasions*, 13: 1723-1727. https://doi.org/10.1007/s10530-011-0004-0.

Raghavan, R. 2019. Impact of 2018 Kerala floods on aquatic biodiversity with special reference to single location endemic species. *Report submitted to the Kerala State Biodiversity Board*, Thiruvananthapuram, Kerala, India, 21 pp.

Reid, A. J., Carlson, A. K., Creed, I. F., Eliason, E. J., Gell, P. A., Johnson, P. T. J., Kidd, K. A., MacCormack, T. J., Olden, J. D., Ormerod, S. J., Smol, J. P., Taylor, W. W., Tockner, K.,Vermaire, J. C., Dudgeon, D. and Cooke, S. J. 2019. Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biol. Rev.,* 94: 849-873. https://doi.org/10.1111/brv.12480.

Ricciardi, A. 2001. Facilitative interactions among aquatic invaders: Is an "invasional meltdown" occurring in the Great Lakes? *Can. J. Fish. Aquat.,* 58(12): 2513-2525. https://doi.org/10.1139/cjfas-58-12-2513.

Saikia, S. K. and Das, D. N. 2008. Feeding ecology of common carp (*Cyprinus carpio* L.) in a rice–fish culture system of the Apatani plateau (Arunachal Pradesh, India). *Aquat. Ecol.,* 43(2): 559-568.

Sandilyan, S., Meenakumari, B., Biju Kumar, A. and Mandal, R. 2018. *A review on impacts of invasive alien species on Indian inland aquatic ecosystems*. National Biodiversity Authority, Chennai, Tamil Nadu, India.

Sarkar, U. K., Dubey, V. K., Singh, A. K., Gupta, B. K., Pandey. A., Sani, R. K. and Lakra, W. S. 2012. The recent occurrence of exotic freshwater fishes in the tributaries of river Ganga basin: Abundance, distribution, risk and conservation issues*. Environmentalist,* 32: 476-484.

Sarkar U. K., Sandhya K. M., Mishal, P., Karnatak, G., Lianthuamluaia, S. Kumari, Panikkar, P., Palaniswamy, R., Karthikeyan, M., Sibina Mol, S., Paul, T. T., Ramya, V. L., Rao, D. S. K., Feroz Khan, M., Panda, D. and Das, B. K. 2018. Status, prospects, threats, and the way forward for sustainable management and enhancement of the tropical Indian reservoir fisheries: An overview. *Rev. Fish. Sci. Aquac.*, 26: 155-175, https://doi.org/10.1080/23308249.2017.1373744.

Schoener, T. W. 1983. Field experiments on interspecific competition. *Am. Nat.,* 122(2): 240285. https://doi.org/10.1086/284133.

Simberloff, D. and Von Holle, B. 1999. Positive interactions of nonindigenous species: Invasional meltdown? *Biol. Invasions*, 1: 21-32.

Singh, A. K. 2014. Emerging alien species in Indian aquaculture: Prospects and threats. *J. Aquat. Biol. Fish.*, 2(1): 32-41.

Singh, A. K. and Lakra, W. S. 2006. Alien fish species in India: Impact and emerging scenario. *J. Ecophysiol. Occu. Health,* 6(3-4): 165-174.

Singh, A. K., Pathak, A. K. and Lakra, W. S. 2010. Invasion of an exotic fish - Common carp *Cyprinus carpio* L. (Actinopterygii: Cypriniformes: Cyprinidae) in the Ganga River, India and its impacts. *AIEP*, 40(1): 11-19.

Spataru, P., Viveen, W. J. A. R. and Gophen, M. 1987. Food composition of *Clarias gariepinus* (Cypriniformes, Clariidae) in Lake Kinneret, Israel. *Hydrobiologia*, 144: 77-82.

Sugunan, V. V. 1995. *Reservoir fisheries of India*. Food and Agriculture Organisation of the United Nations, Rome, Italy, 243 pp.

Sugunan, V. V. 2011. Reservoir fisheries. In: Trivedi, T. P. (Ed.), *Handbook of fisheries and aquaculture*, Indian Council of Agricultural Research, New Delhi, India, p. 239-274.

Thomas, J. 2012. *Channel characteristics of two upland river basins of contrasting climate: A study from Kerala.* Doctoral dissertation. University of Kerala, Thiruvananthapuram, Kerala, India.

Vitule, J. R. S., Freire, C. A. and Simberloff, D. 2009. Introduction of nonnative freshwater fish can certainly be bad. *Fish Fish.*, 10: 98-108. https://doi.org/10.1111/j.1467-2979.2008.00312.x.

Wakil, U. B., Haruna, A. B., Mohammed, G. A., Ndirmbita, W. L., Yachilla, B. K. M. and Kumai, M. U. 2014. Examinations of the stomach contents of two fish species (*Clarias gariepinus* and *Oreochromis niloticus*) in Lake Alau, North-Eastern Nigeria. *Agric. Forest. Fish.,* 3(5): 405-409.

Weber, M. J. and Brown, M. L. 2011. Relationships among invasive common carp, native fishes and physicochemical characteristics in upper Midwest (USA) lakes. *Ecol. Freshw. Fish.,* 20: 270-278. https://doi.org/10.1111/j.1600-0633.2011.00493.x.

Yalcin, S., Solak, K. and Akyurt, A. 2001. Certain reproductive characteristics of the catfish (*Clarias gariepinus*, Burchell, 1822) living in the river Asi, Turkey. *Turk. J. Zool.,* 25: 453-460.

Zacharias, V. J., Bhardwaj, A. K. and Jacob, P. C. 1996. Fish fauna of Periyar Tiger Reserve. *J. Bombay Nat. Hist. Soc.,* 93: 38-43.

Zhang, W. J. and Chen, B. 2011. Environment patterns and influential factors of biological invasions: A worldwide survey. *Proc. Int. Acad. Ecol. Env. Sci.,* 1(1): 1-14.

Date of Receipt : 02.07.2020

Date of Acceptance : 12.04.2021