Diet Spectrum and Microplastic Presence in the Gut Contents of Invasive Guppy, *Poecilia reticulata* (Peters, 1859), in the Southern Western Ghats, India

SUVARNA D. DEVI, ARCHANA D. SATHEESH, SMRITHY RAJ, APPUKUTTANNAIR BIJU KUMAR*

Department of Aquatic Biology & Fisheries, Faculty of Science, University of Kerala, Karyavattom, Thiruvananthapuram, Kerala 695581, India

E-ISSN: 2073-3720
https://doi.org/10.33997/j.afs.2026.39.2.004

*E-mail: bijukumar@keralauniversity.ac.in | Received: 06/05/2024; Accepted: 07/05/2026

Abstract

The guppy *Poecilia reticulata* (Peters, 1859), native to South America, is now an established invasive species in the ecologically sensitive Western Ghats biodiversity hotspot in India, yet its invasion biology in the region remains poorly understood. This study examines the dietary habits of invasive guppy populations in the Bonacaud Forest Range of the Peppara Wildlife Sanctuary, southern Western Ghats, India. A total of 130 individuals (38 males, 92 females; 10–37.6 mm in total length) were analysed. Their diet was dominated by midge fly larvae (34.18 %) and algae (32.15 %), followed by miscellaneous items including fibres, sand, and mud (11.95 %). Insect remains (Hemiptera, Coleoptera) accounted for 9.09 % of the diet, with smaller contributions from detritus (5.94 %), zooplankton (2.49 %), nereid larvae (2.03 %), fish remains (1.74 %), and arachnids (0.43 %). Frequency-of-occurrence analysis similarly identified Chironomidae larvae (27.53 %) and algae (25.87 %) as the most common food items. Feeding intensity assessments indicated that none of the fish had empty stomachs; most showed moderate (29 %) or good (28 %) fullness, with additional full (15 %), poor (17 %), and gorged (11 %) conditions. Larger individuals exhibited greater consumption, supported by gastrosomatic index values. Microplastics - primarily polyamide (PA) and polyethylene (PE) fibres - were detected in the gut, with a mean abundance of 1.03 ± 0.42 items per fish, and scanning electron microscopy confirmed evidence of microplastic degradation. These findings underscore the need for further research to evaluate the ecological impacts of invasive guppy populations on freshwater biodiversity in the Western Ghats across spatial and temporal scales.

Keywords: invasive species, stomach contents, feeding biology, omnivorous, Poeciliidae

Introduction

Invasive species, often transported by humans across natural geographic barriers, are major drivers of global environmental change and pose substantial threats to biodiversity (Essl et al., 2020; IPBES, 2019; Sage, 2020). Bioinvasions frequently result in habitat degradation, altered ecosystem functioning, and the displacement of endemic species (Clavero & García-Berthou, 2005). Freshwater ecosystems are particularly vulnerable (Clavero & García-Berthou, 2006), with aquatic invasive species (AIS) significantly impacting global freshwater biodiversity (Dudgeon et al., 2006; Reid et al., 2019). Their spread in inland waters is influenced by dispersal ability (Beisel, 2001), anthropogenic disturbance (Ross et al., 2001), and climatic suitability (Eaton & Scheller, 1996). Many AIS degrade water quality, outcompete native biota, and disrupt ecological communities through predation and hybridisation (Moyle & Light, 1996; Pimentel, 2002).

In India, one of the major pathways for the introduction of aquatic alien species is the release of larvivorous fishes for mosquito control (Kumar, 2000), which has contributed to the establishment of several non-native populations in the southern Western Ghats (Raj et al., 2021a), particularly following extreme climatic events or floods (Raj et al., 2021b). The guppy *Poecilia reticulata* (Peters, 1859), historically introduced worldwide for mosquito control and as aquarium fish, is now among the eight most widely translocated freshwater fishes (García-Berthou et al., 2005). In India, guppies were first introduced in 1908 for mosquito control (Deacon et al., 2019; Food and Agriculture Organization [FAO], 1997) and later through the aquarium trade (Chandra et al., 2008; Krishnakumar et al., 2009). Their exceptional adaptability has facilitated their spread from their native Caribbean-northern South American range to multiple regions globally (Deacon et al., 2011; Magurran, 2005), where they frequently become dominant (Walsh & Reznick, 2011). Today, guppies are listed as potential invasive species in the Global Invasive Species Database (2021) and the Centre of Agriculture and Biosciences International [CABI] database (2021).

Guppies possess a suite of physiological, behavioural, and life-history traits associated with high adaptability (Magurran, 2005) and invasion success (Hellmann et al., 2008). They adapt rapidly to environmental change (Reznick et al., 1997), establish in diverse habitats (Chervinski, 1984; Chung, 2001; Gibson & Hirst, 1955), and tolerate broad temperature (Chung, 2001; Reeve et al., 2014) and salinity ranges (Chervinski, 1984). Even introductions involving very few individuals can lead to thriving populations (Deacon et al., 2011). Their global distribution, including atypical habitats such as the Moscow sewage works (Zhuikov, 1993) and the River Lee in Essex, England (Wheeler, 1998), further demonstrates their ecological flexibility (Magurran, 2005).

Invasive guppies can negatively affect native fish assemblages through reduced fitness, competition, and disease transmission, as documented in Hawaii, where they halved native goby populations via invasive nematode transmission (Gagne et al., 2015). They can enhance primary productivity and alter nutrient regimes (Holitzki et al., 2013), and their tolerance to pollution (Ehlman et al., 2015; Kharat et al., 2003; Wagh & Ghate, 2003), short gestation periods, high reproductive output, and ability to store sperm for months (Evans & Magurran, 2000; Zane et al., 1999) enable rapid establishment and dispersal. Their impacts elsewhere include predation, competition, and acting as hosts for parasites (Courtenay & Meffe, 1989; Eldredge, 2000; Englund, 1999; Knight, 2010), with broad dietary spectra documented across multiple studies (Arthington, 1989; Dussault & Kramer, 1981; Ganassin et al., 2019; Lawal et al., 2012; Rodriguez, 1997; Winemiller, 1993).

In India, research on microplastic (MP) contamination in freshwater fishes remains limited, with only a few studies reporting MP presence (Anandhan et al., 2022; Boral et al., 2024; Devi et al., 2020; Nikki et al., 2021; Pandey et al., 2023). Although MP assessment was not originally planned for this species, the unexpected discovery of microplastics in an otherwise pristine stream prompted further investigation. Despite the establishment of guppy populations across aquatic systems in Kerala within the Western Ghats Biodiversity Hotspot (Raj et al., 2021a), little is known about their invasion biology in India. Similarly, studies on the feeding ecology of other non-native fishes in the region remain scarce, such as those on the red-bellied pacu (*Piaractus brachypomus*) (Anupama et al., 2021), common carp (*Cyprinus carpio*), and the African sharp-tooth catfish (*Clarias gariepinus*) (Raj et al., 2021c). This study, therefore, aims to document the food and feeding habits of the invasive guppy (*Poecilia reticulata*) that has established viable populations in the natural streams of Bonacaud, within the Peppara Wildlife Sanctuary, southern Western Ghats, Kerala, India.

Materials and Methods

Ethical approval

Current national regulations in India explicitly state that ethical clearance is not required for research involving invasive pest fish species. In this specific case, as the study was conducted inside a protected area, the collection and examination of *Poecilia reticulata* were initiated at the request of the government as part of ongoing efforts to remove invasive fish from forests rich in endemic species. Accordingly, Forests and Wildlife Department, Government of Kerala, gave permission to collect and study invasive guppies from the reserved forests (Order No. WL.10-6145/2017, dated 06/02/2017). Further, the fish was not used for any experimental work in this study.

Collection site

The invasive fish *Poecilia reticulata* was collected from a natural stream at the Bonacaud forest range (Thiruvananthapuram District), southern Western Ghats (WGs), Kerala. This pristine perennial stream (8°40'11.5"N; 77°10'10.6"E) (Fig. 1), which originates from the upper reaches of the Bonacaud region of the Western Ghats, has a width of 1–2 m and maintains a water level of about 300 mm in summer season and drains into the Peppara Reservoir located inside the Peppara Wildlife Sanctuary (8°34'30"N and 8°41'25"N latitude; 77°6'50"E and 77°14'5"E longitude), Thiruvananthapuram District, southern Western Ghats, Kerala, India. The stream is near human settlements near estates, where cardamom, coconut, pepper, and tea are grown.

Fish collection

The fish (n = 130; males: 38; females: 92; size range: 10-37.6 mm total length) were collected randomly from the natural stream of Bonacaud from its upper reaches during the 2019–2020 period using a mosquito net and scoop nets (Fig. 2). The captured fish were initially preserved in a 10 % buffered formalin solution and transported to the laboratory. Subsequently, each specimen's length (mm) and weight (g) were measured. Following this, each fish was dissected, and the length and weight of its gut were recorded. The gut contents were then preserved in 5 % formalin and examined using a stereomicroscope (EZ4D, Leica, Germany) and a compound microscope (BX43, Olympus, Japan). Various items within the gut contents were identified, and points were assigned accordingly.

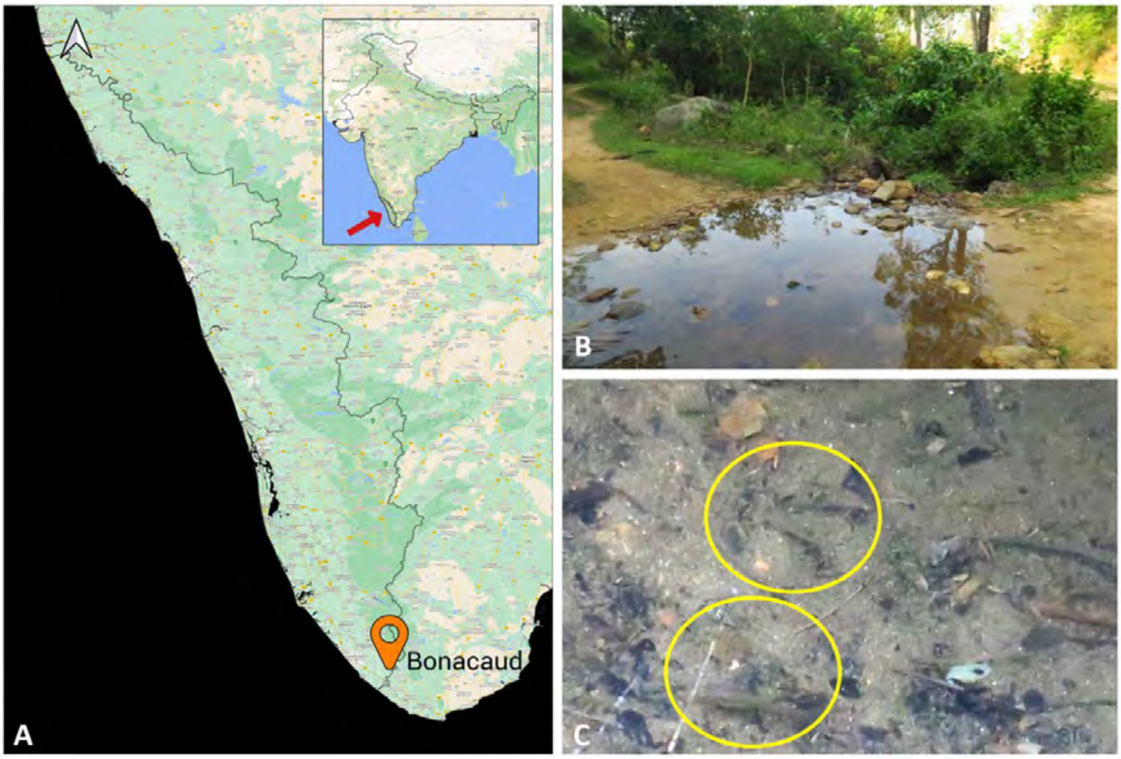

Fig. 1. A. Map of the collection site at Bonacaud forests, Thiruvananthapuram district, Kerala, India; B. Photograph of the natural stream at Bonacaud, Kerala, India; C. Guppy in the natural stream shown inside circles.

Fig. 2. Male (♂) and female (♀) specimens of *Poecilia reticulata* collected from Bonacaud forests, southern Western Ghats, Kerala, India (Total length male: 32 mm; female: 25 mm).

Gut content analysis

The method employed for this purpose was purely qualitative. The gut was examined and based upon the degree of distension, points were allotted, such as gorged, full, good, moderate, poor, and empty for estimation of feeding intensity and points were assigned separately for each food item as very abundant, plenty, common, few, little and rare by eye and the diet was analysed. The methods suggested by Hynes (1950), Pillay (1952), and Hyslop (1980) were used to study the determine the contribution by points and frequency of occurrence of each food item to the diet.

Depending upon the fullness of the stomach (Windel & Bowen, 1974) and for each prey item (Kow, 1950), points were allotted, and the percentage composition of the food items in the stomach for each prey item of fish was obtained (Points method). The percentage frequency of occurrence (%Oi) was calculated using the formula %Oi = Ni / N × 100, where Ni is the number of stomachs containing a specific prey item and N is the total number of stomachs containing food (Hyslop, 1980).

The relative gut length (RGL) was determined from the equation: RGL = GL/TL, where GL is the gut length, and TL is the total length following Al-Hussaini (1949). The gastrosomatic index (GaSI) was calculated as GaSI = Weight of gut / Weight of fish × 100 (Khan et al., 1998).

Analysis of microplastics in gut contents

Gut content analyses revealed several MP fibres, hence an additional sample of *P. reticulata* individuals (n = 50) was collected from the same stretch of river and transported to the laboratory in an ice box for microplastic analysis. Samples were thawed, cleaned thoroughly and rinsed with double-distilled water to remove debris. The total length and body weight (in mm and g, respectively) of each fish were measured, recorded, and their gastrointestinal tract (GIT) was extracted using sterile steel scissors and forceps, placed in different pre-cleaned glass containers for further analysis. The GIT was very small and was digested with 10 % KOH at 60 °C for 48 h, following the method of Dehaut et al. (2016), until the solutions became transparent.

Quality assurance

All protocols to minimise MP contamination were followed, which included meticulous cleaning of glassware and workplace with 75 % ethanol, using a cotton coat and nitrile gloves, and running procedural blanks (n = 5) (Gurjar et al., 2021, 2023) at the laboratory. The blanks were digested similarly to the samples, filtered and examined for MPs, but failed to find any. In order to preclude air-borne contamination, all procedures were carried out in a laminar flow hood.

Identification and characterisation of microplastics (MPs)

The clear digested material was filtered, dried, and examined under a stereomicroscope (Leica EZ4D, Germany), measured and micro-photographed using image-capturing software (Leica LAS EZ, Germany). These MP particles were classified as fibres (Free et al., 2014). Subsequently, these MPs were subjected to analysis using a spectrometer (Nicolet iS50 FTIR, ThermoFisher Scientific, USA) of resolution 4 cm^{-1}, with a scan range of 400–4000 cm^{-1}, for further confirmation of microplastic presence at the Central Laboratory for Instrumentation and Facilitation (CLIF) (https://kusicc.ac.in/), University of Kerala, India. The scans were compared with samples from the Bruker FTIR spectral library (Browne et al., 2011; Mecozzi et al., 2016; Rummel et al., 2016), and spectra with more than 75 % similarity are considered for the study (Rayhan et al., 2024). Finally, the surface morphology of the fibres was examined using a scanning electron microscope (Zeiss Evo 18, Carl Zeiss, Germany).

Results

The established guppy populations in Bonacaud, based on the colour patterns, may be considered as the wildtype, as the females are grey in body colour, while the males have splashes and stripes of orange and black spots surrounded by iridescent blue; smaller males with a short caudal fin. A total of 130 *P. reticulata*, comprising 38 males and 92 females, collected from the natural streams of Bonacaud forests of the Western Ghats, were examined for gut content analyses.

Percentage composition

After analysing the gut contents of *P. reticulata* (with total length ranging from 10 to 37.6 mm), it was found that their diet primarily consisted of insect larvae (Class: Insecta; Order: Diptera; Family: Chironomidae), predominantly midge fly larvae (34.18 %), and algae (32.15 %), including species such as *Oedogonium* sp., *Melosira* sp. (Protista), cyanobacteria, *Navicula* sp., *Nitzschia* sp., and *Pinnularia* sp. (Fig. 3A). Additionally, miscellaneous items (11.95 %) such as fibres, sand, and mud, insect remains (9.09 %) from the Order Hemiptera and Coleoptera, detritus (5.94 %), zooplankton (2.49 %) including Daphnia, nereid larvae (Class Polychaete; Order: Phyllodocida; Family: Nereididae) (2.03 %), fish remains (1.74 %) comprising scales and eggs, and *Hydrachna* (Class: Arachnida, ectoparasites of aquatic insects) (0.43 %) were also observed in the gut contents of the invasive guppy (Fig. 3A).

Similar results were obtained for different food items in the stomach of *P. reticulata* for the frequency of occurrence method with maximum percentage for midge fly larvae (Chironomidae) (27.53 %) and minimum with *Hydrachna* (Arachnida) (0.56 %) (Fig. 3B). Feeding intensity showed that even though a gorged stomach was noticed only for 11 % of the fish, none of them had an empty gut, and most of the fishes had moderate (29 %) and good (28 %) stomachs, followed by full (15 %) and poor (17 %) stomach fullness (Fig. 4A).

Regardless of size category, the primary dietary preference of the fish was midge fly larvae (Fig. 4B). In the larger size categories, where a higher percentage of midge fly larvae, and algal matter was present, miscellaneous items and fish remains were observed in smaller quantities, with other items being absent altogether, indicating a clear preference for midge fly larvae and algal matter in the natural habitat (Fig. 4B). Among the smaller-sized group fishes, various food

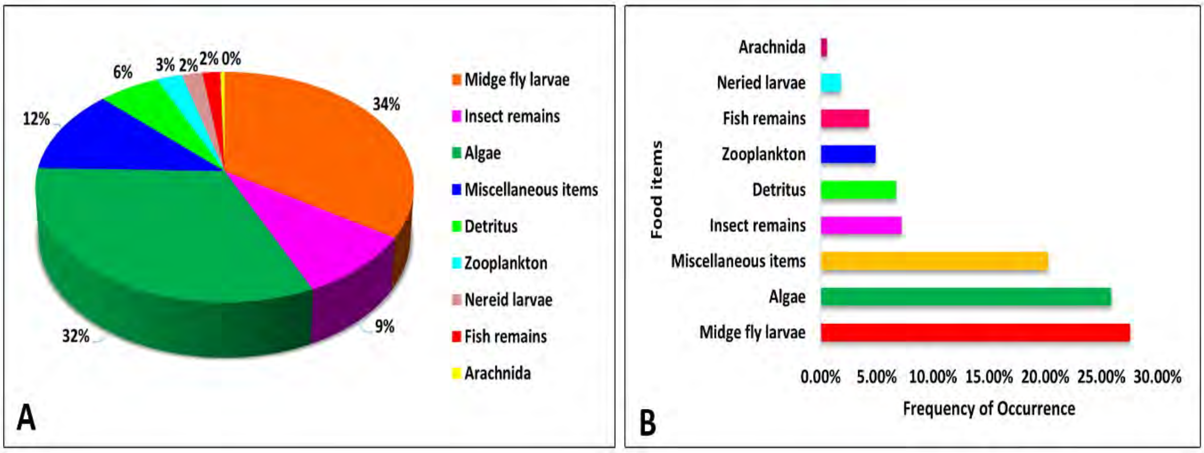

Fig. 3. A. Percentage composition of various food items in the gut of *Poecilia reticulata*; B. Frequency of occurrence of different food items in the gut of *P. reticulata* (n = 130).

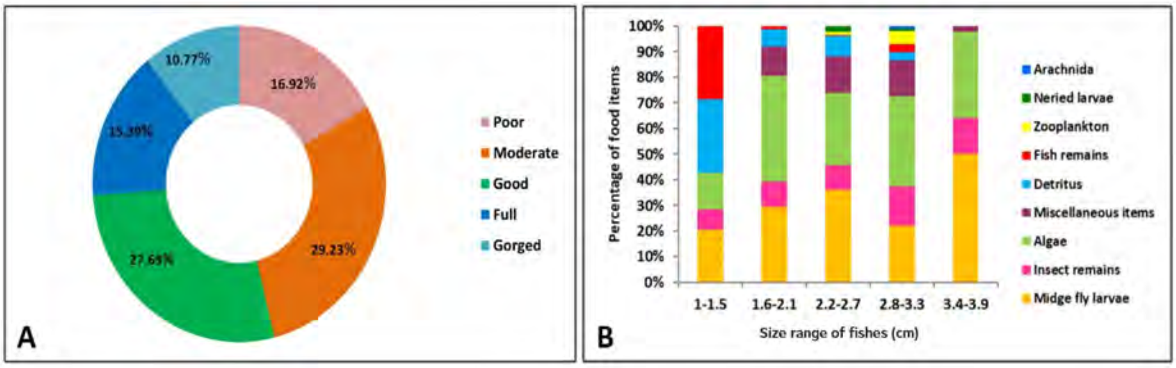

Fig. 4. A. Feeding intensity of *Poecilia reticulata* inhabiting the natural stream of Bonacaud; B. Percentage composition of various food items in the gut of *P. reticulata* based on different size ranges.

items were consumed in differing amounts, except for zooplankton and arachnids, but midge fly larvae remained the preferred food item. The other food items, such as fish remains, detritus, zooplankton, nereid larvae, and arachnids, were represented in varying proportions among the different size groups.

The relative gut length for different size ranges of fish showed an increase in length of the gut (Fig. 5A), which can be related to the increase in the size of the fish and cannot be related to the diet, as they consume both insect matter and algal matter almost in equal quantities. The GaSI of fish shows higher values for the larger size-grouped fishes, indicating that fully grown ones consumed more food (Fig. 5B).

Analyses of microplastics

Examination of gut contents of the species revealed the unexpected presence of microplastics in a forest stream within the Western Ghats. Out of the 50 fish analysed for MPs, ranging in total length from 18 to 32.4 mm, 42 MP fibres were obtained from the GIT. These fibres exhibited a variety of colours, including red, pink, blue, and black. The mean abundance of MPs in the guts was 1.03 ± 0.42 (SE) MPs.fish^{-1}. The mean fibre length was 2.06 mm (± 1.36), with a minimum length of 0.93 mm and a maximum length of 4.89 mm. Notably, these fibres were only observed in in the medium-sized length group and the larger size categories, as no plastic fibres were found in the GITs of fish measuring <21.5 mm.

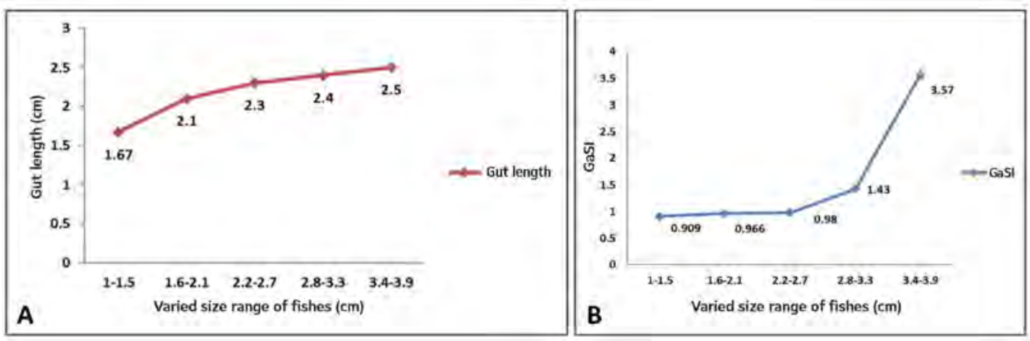

Fig. 5. A. Gut length of *Poecilia reticulata* based on different size groups (in cm); B. Gastro-somatic index (GaSI) of *Poecilia reticulata* for different size ranges (in cm).

Identification of polymer types of microplastics

Forty-two fibres in red (n = 22), pink (n = 13), blue (n = 5) and black (n = 2) colours were obtained from the gut contents of *P. reticulata* from the Bonacaud stream, and 28 of those could be identified to MP type (Fig. 6).

ATR-FTIR analyses revealed, polyamide (PA) as the predominant polymer type with 69.04 %, and polyethylene (PE) with 30.95 % (Fig. 7). The scanning electron micrographs (SEM) of microplastic fibres obtained from the GITs of *P. reticulata* revealed flakes, grooves and cracks due to severe environmental weathering process (Fig. 8).

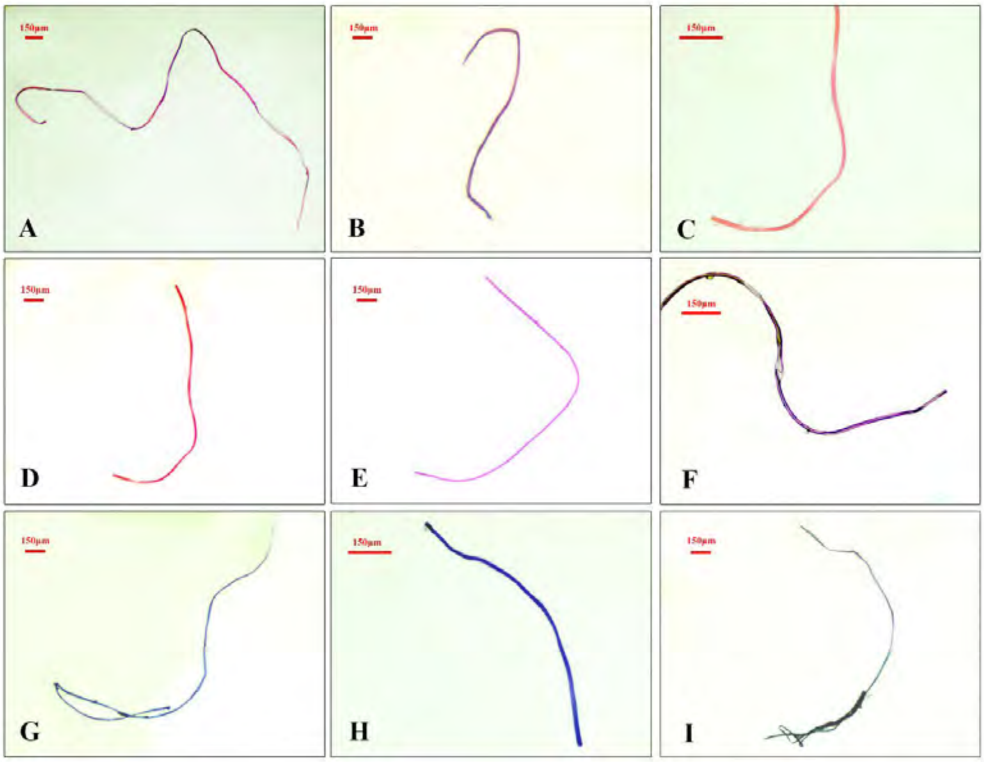

Fig. 6. Microplastics in varied colours retrieved from the gastrointestinal tract (GIT) of *Poecilia reticulata*.

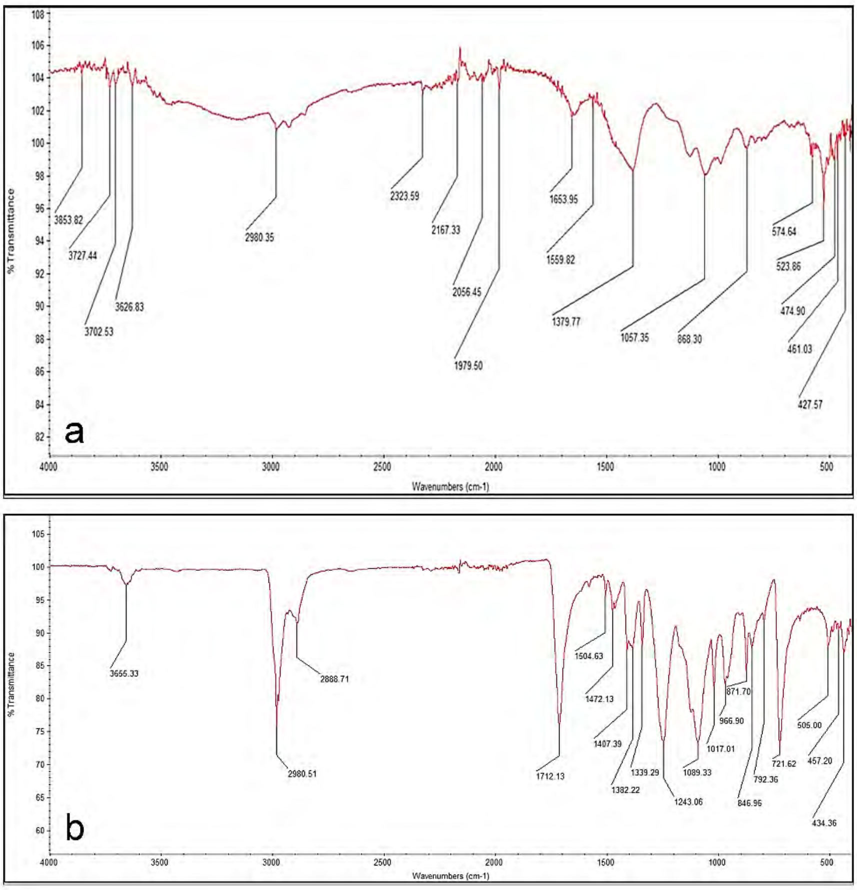

Fig. 7. ATR-FTIR spectra of the microplastic fibres: a. Polyamide (PA), b. Polyethylene (PE).

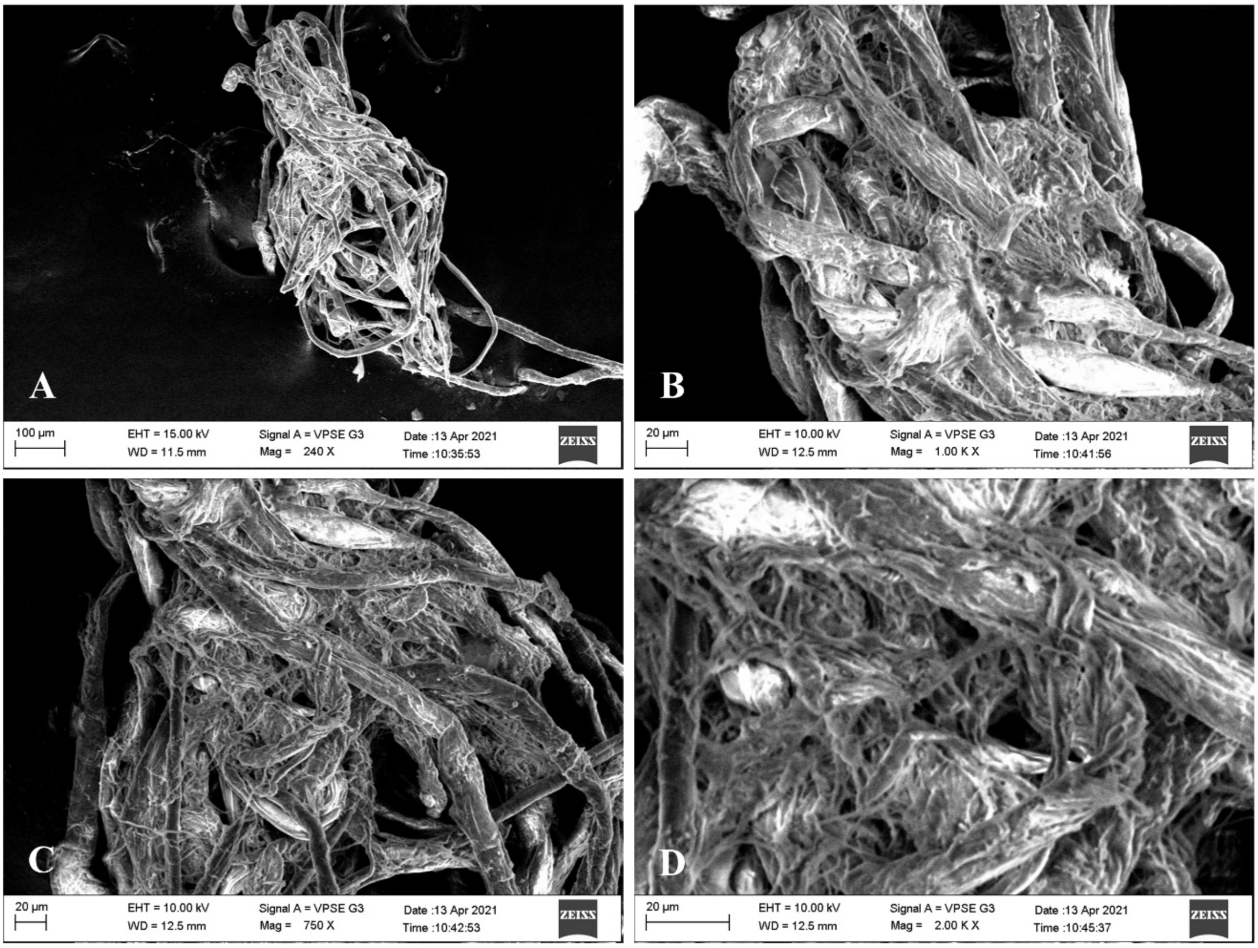

Fig. 8. A-D. SEM micrographs of fibres from gut contents of *Poecilia reticulata.*

Discussion

The primary purpose behind introducing *P. reticulata* into India's natural water bodies is to control mosquito larvae. Government-backed initiatives aimed at combating malaria and other mosquito-borne diseases often encourage the use of larvivorous fishes like guppies, which can be easily bred locally (Chandra et al., 2008; Ghosh et al., 2005; Suresh et al., 2021; World Health Organization [WHO], 2003). The presence of *P. reticulata* in the hill streams of Bonacaud, located in the southern Western Ghats, as reported in this study, may be attributed to their release from home aquariums, given the proximity of the collection site to settlements of tea estate workers in the region. Surveys conducted with local residents revealed that guppies are commonly kept as pets in their homes. Originally native to the inland waters of the Caribbean and northern South America, guppies are now widespread worldwide in temperate and tropical regions, introduced initially for mosquito control and later for the aquarium trade (Welcomme, 1988). Based on colour patterns, the established guppy populations in Bonacaud may be considered wild-type, as females exhibit a grey body colour. At the same time, males display splashes and stripes of orange and black spots surrounded by iridescent blue, with no long, colourful caudal fin (Gordon et al., 2011).

Understanding the basic feeding ecology is essential for properly utilising species for cultural, ornamental, and larvivorous purposes (Ndome & Victor, 2002). While most members of the family Poeciliidae are omnivores, feeding on invertebrates, detritus, algae, and vascular plants, some are piscivorous, and occasional cannibalism, such as consuming their young, may also occur (Meffe & Snelson, 1989; Shoemaker, 1944). The populations of *P. reticulata* from the wild stream are categorised as opportunistic benthopelagic feeders (Global Invasive Species Database [GISD], 2021). The gut contents primarily consisted of insect remains and midge fly larvae (Chironomidae), followed by a significant presence of various types of algae. Similar results were reported for wild guppies from Trinidad, which foraged benthically on algae and aquatic insect larvae and less frequently on material drifting in the water column or at the surface (Dussault & Kramer, 1981).

In this study, midge fly larvae were identified as the dominant food item in the stomachs of *P. reticulata*, consistent with observations by Zandona et al. (2011) and Ganassin et al. (2019), indicating a preference for chironomids despite the abundance of other insect orders in the environment. Coleopterans and hemipterans were also found in the gut contents, although midge fly larvae remained the preferred food item (Chironomidae). Due to the benthopelagic nature of the fish, small amounts of detritus, along with miscellaneous items such as sand and mud, were also found in the gut contents. Fishes occupying lower trophic levels in the food web can assimilate into the community, as detritus is abundant in aquatic environments (Gido & Franssen, 2007; Winemiller & Kelso-Winemiller, 2003). Additionally, detritivorous habits are considered a food strategy for exotic fishes (Gido & Franssen, 2007; Liew et al., 2016; Pazianoto et al., 2016). The perennial forest streams of the Western Ghats are rich in detritus derived from leaf litter, forming a principal food item for the fish fauna (Johnson & Arunachalam, 2012; Subramanian & Sivaramakrishnan, 2005). Reports of *P. reticulata* diet from natural water bodies in Australia include zooplankton, small insect larvae, and detritus (Arthington, 1989; Rodriguez, 1997). Other food items such as algae, small crustaceans, tubifex worms, fish eggs, and larvae, and various other items present in their habitat were also documented (Arthington, 1989).

No empty guts were recorded during this study, and most guts were in moderate condition, suggesting ample food resources in the forest streams of the Western Ghats where the fish were collected. Earlier research on the feeding ecology of fishes in the Kallada River found a diverse range of items in their gastrointestinal tracts, including chironomid larvae, filamentous algae, terrestrial insects, benthic microinvertebrates, insect larvae, adult insects, macrophytes, and water mites (Arun, 1992). Analysis of gut contents across different size groups revealed that all size-ranged fishes consumed more than 40 % midge fly larvae and smaller percentages of algae, miscellaneous items, and detritus. Larger size group fishes predominantly fed on the algal matter and midge fly larvae in roughly equal quantities, with miscellaneous items like sand and mud contributing only a small percentage. This guppy demonstrates dietary plasticity upon colonising and establishing in a new habitat (Ganassin et al., 2019).

The gastro-somatic index (GaSI) values reflected larger values for larger fish, indicating a moderate to good stomach condition. Additionally, the length of the gut increased slightly with the size of the fish. Despite the known predator pressure of *P. reticulata* invading Western Ghats streams, our study reveals a generalist feeding behaviour, with guppies consuming a range of food items. This behaviour may be attributed to guppies inhabiting streams under high predation pressure (Walsh & Reznick, 2008, 2009), showcasing the dietary plasticity of this invasive alien species in the natural forest streams of the Western Ghats.

The diet spectrum of wild guppies comprises primarily algal remains, diatoms, plant materials, insect larvae, and sand particles. They are opportunistic feeders, occasionally exhibiting cannibalistic behaviour, and their diet may vary based on habitat conditions and food availability (Dussault & Kramer, 1981). Competitive interactions among female guppies occur concerning defendable food resources in natural populations (Magurran & Seghers, 1991).

This study also documents the incidence of microplastics (MPs) in the gut contents of small invasive guppy *P. reticulata* residing in a natural stream for the first time. The mean abundance of MPs in *P. reticulata* was 1.03 ± 0.42 (SE).fish^{-1} in the current study, with PA and PE as polymers and red as the dominant colour; the reason could be that these MPs are consumed intentionally by being confused with food, especially with the chironomid larvae, which are red. The abundance of MPs in our study was higher than that recorded from smaller fishes of India (Pandey et al., 2023), with fibres as the common type and PE as the polymer.

The red-bellied Pacu or pirapitinga *Piaractus brachypomus*, an invasive alien fish from Vembanad Lake in Kerala India, carried MPs polymers of polyethylene (PE), nylon 6, polypropylene (PP), polyethylene terephthalate (PET) and polybutylene terephthalate (PBT), with fibres, foam and fragments as the most common type (Devi et al., 2020). MPs recovered from *P. reticulata* were all fibres made of PA (n = 29) and PE (n = 13), reaching the natural streams from the nearby human settlements, especially estates, in the Western Ghats. Polyvinyl chloride (PVC), polyethylene (PE), polypropylene (PP) and polyester were the polymers obtained from the spotted sea catfish *Arius maculatus*, green chromide *Etroplus suratensis* and orange chromide *E. maculatus* from Vembanad Lake, with fibre as the most abundant type with the highest load of (15 ± 13 particles.fish^{-1}) (Nikki et al., 2021).

A total of 15 MPs were isolated from 23 freshwater fishes comprising five species from rivers of Tamil Nadu, and fibres constituted the highest percentage (85.7 %) (Anandhan et al., 2022). Borah et al. (2024) recovered MPs from the fish of Loktak Lake, in Manipur northeast India; polymers such as polyamide (PA), polystyrene (PS), polycarbonate (PC) and carboxymethyl cellulose (CMC), along with heavy metals, were reported, with fragments being the most common type. In the present study, the MPs were photographed through SEM, which produced high-resolution images revealing the cracks, grooves and pits on their surface due to weathering and abrasion due to mechanical and oxidative weathering, demonstrating polymer ageing (Zbyszewski et al., 2014).

The invasion success of *P. reticulata* could be attributed to its naturally high reproductive potential and tolerance to changes in water quality. Researchers have questioned the utility of *P. reticulata* for mosquito larval control (see El-Sabaawi et al., 2016), suggesting the use of other indigenous larvivorous fish for larval control. Further, the suitability of guppies for mosquito control can only be established by studying their impacts on the endemic fauna and the mosquito larvae through gut content analysis (Paingankar & Dahanukar, 2013). Considering the ecosystem damages caused by non-native *P. reticulata* elsewhere and the challenges in managing invaded populations, preventive measures are necessary to prevent their entry into biodiverse natural water bodies through awareness and action plans. Furthermore, out of the 50 fish examined for MP contamination, 36 were found to ingest 42 MP fibres, indicating plastic contamination even within the forest streams of the Western Ghats. This underscores the need for an in-depth study on microplastic contamination in the fish fauna of the Western Ghats and the potential chemical contamination of fish through the ingestion of plastic debris.

Future research on the invasion biology of guppies in the Western Ghats biodiversity should focus on several key areas to enhance our understanding and management of this invasive species, including ecological impact assessment, habitat suitability and spread dynamics, genetic and phenotypic adaptations, climate change and invasive potential, and innovative methods for monitoring and management. By addressing these research needs, we can improve our understanding of guppy invasions in the Western Ghats and develop effective strategies to mitigate their ecological and socio-economic impacts while promoting the conservation of native biodiversity.

Conclusion

The invasive guppy (*Poecilia reticulata*) has successfully established self-sustaining populations in the ecologically sensitive streams of the southern Western Ghats, exhibiting an opportunistic feeding strategy dominated by chironomid larvae and algae. Its broad diet and dietary plasticity are likely to contribute to its invasion success in these natural freshwater ecosystems. The detection of degraded microplastic fibres in the digestive tracts of wild guppies from a forest stream further demonstrates that even relatively pristine habitats are not free from anthropogenic plastic contamination. Although the ecological consequences require further investigation, the combined evidence of successful establishment, flexible feeding behaviour, and microplastic ingestion highlights the need for long-term studies on the impacts of *P. reticulata* on native freshwater biodiversity and food webs, together with effective measures to prevent further spread of this invasive species.

Acknowledgements

We acknowledge the research services of the Central Laboratory for Instrumentation and Facilitation (CLIF) for SEM photographs. We are also thankful to the Forests and Wildlife Department, Government of Kerala, for permission to collect and study invasive guppies from the reserved forests (Order No. WL.10-6145/2017, dated 06/02/2017).

Conflict of interest: The authors declare that they have no conflict of interest.

Author contributions: Suvarna S. Devi: Conceptualisation, formal analysis, writing – original draft, writing – review & editing. Archana D. Satheesh: Investigation, formal analysis, writing – original draft, writing – review & editing. Smrithy Raj: Investigation, resources. Appukuttannair Biju Kumar: Funding acquisition, conceptualisation, formal analysis, writing – original draft, writing – review & editing.

References

Al-Hussaini, A. H. (1949). On the functional morphology of the alimentary tract of some fish in relation to differences in their feeding habits: Anatomy and histology. *Journal of Cell Science*, *3*(10), 109–139. https://doi.org/10.1242/jcs.s3-90.10.109

Anandhan, K., Tharini, K., Thangal, S. H., Yogeshwaran, A., & Muralisankar, T. (2022). Occurrence of microplastics in the gastrointestinal tracts of edible fishes from South Indian Rivers. *Bulletin of Environmental Contamination and Toxicology*, *109*(6), 1023–1028. https://doi.org/10.1007/s00128-022-03595-3

Anupama, V. S., Smrithy Raj, Suvarna, S. D., & Biju Kumar, A. (2021). Diet of exotic Pirapitinga *Piaractus brachypomus* (Cuvier, 1818) from Vembanad-Kole Wetland, India, as inferred from gut content analysis and DNA barcoding. *Asian Fisheries Science*, *34*, 47–55. https://doi.org/10.33997/j.afs.2021.34.1.005

Arthington, A. H. (1989). Diet of *Gambusia affinis holbrooki*, *Xiphophorus helleri*, *Xiphophorus maculatus* and *Poecilia reticulata* (Pisces: Poeciliidae) in streams of south-eastern Queensland, Australia. *Asian Fisheries Science*, *2*, 193–212. https://doi.org/10.33997/j.afs.1989.2.2.006

Arun, L. K. (1992). *Niche segregation in fish communities of a south Indian River* (Publication No. 196) [Doctoral dissertation, University of Kerala].

Beisel, J. N. (2001). The elusive model of a biological invasion process: Time to take differences among aquatic and terrestrial ecosystems into account? *Ethology Ecology & Evolution*, *13*, 193–195. https://doi.org/10.1080/08927014.2001.9522785

Borah, P., Kshiar, N., Reang, D., Nath, A. J., & Baruah, K. K. (2024). Incidence of microplastic contamination in fishes of the Ramsar Wetland, Loktak-The world's only floating lake from the Indian Himalayan region. *Journal of Environmental Management*, *358*, Article 120928. https://doi.org/10.1016/j.jenvman.2024.120928

Browne, M. A., Crump, P., Niven, S. J., Teuten, E., Tonkin, A., Galloway, T., & Thompson, R. (2011). Accumulation of microplastics on shorelines worldwide: Sources and sinks. *Environmental Science & Technology*, *45*, 9175–9179. https://doi.org/10.1021/es201811s

Centre of Agriculture and Biosciences International. (2021). *Poecilia reticulata*. In *Invasive Species Compendium*. CAB International. https://www.cabi.org/isc

Chandra, G., Bhattacharjee, I., Chatterjee, S. N., & Ghosh, A. (2008). Mosquito control by larvivorous fish. *Indian Journal of Medical Research*, *127*, 13–27. https://pubmed.ncbi.nlm.nih.gov/18316849/

Chervinski, J. (1984). Salinity tolerance of the guppy, *Poecilia reticulata* Peters. *Journal of Fish Biology*, *24*, 449–452. https://doi.org/10.1111/j.1095-8649.1984.tb04815.x

Chung, K. S. (2001). Critical thermal maxima and acclimation rate of the tropical guppy *Poecilia reticulata*. *Hydrobiologia*, *462*, 253–257. https://doi.org/10.1023/A:1013158904036

Clavero, M., & García-Berthou, E. (2005). Invasive species are a leading cause of animal extinctions. *Trends in Ecology & Evolution*, *20*, 110–119. https://doi.org/10.1016/j.tree.2005.01.003

Clavero, M., & García-Berthou, E. (2006). Homogenisation dynamics and introduction routes of invasive freshwater fish in the Iberian Peninsula. *Ecological Applications*, *6*, 2313–2324. https://doi.org/10.1890/1051-0761

Courtenay, W. R., Jr., & Meffe, G. K. (1989). Small fishes in strange places: A review of introduced poeciliids. In G. K. Meffe & F. F. Snelson Jr. (Eds.), *Ecology and evolution of livebearing fishes (Poeciliidae)* (pp. 319–331). Prentice-Hall.

Deacon, A. E., Ghosh, S. K., Bhat, A., & Magurran, A. E. (2019). Predatory behaviour of female guppies (*Poecilia reticulata*) in a mosquito control context: The importance of social and habitat factors. *Aquatic Invasions*, *14*(3), 478–489. https://doi.org/10.3391/ai.2019.14.3.07

Deacon, A. E., Ramnarine, I. W., & Magurran, A. E. (2011). How reproductive ecology contributes to the spread of a globally invasive fish. *PLoS ONE*, *6*, Article e24416. https://doi.org/10.1371/journal.pone.0024416

Dehaut, A., Cassone, A. L., Frere, L., Hermabessiere, L., Himber, C., Rinnert, E., & Paul-Pont, I. (2016). Microplastics in seafood: Benchmark protocol for their extraction and characterisation. *Environmental Pollution*, *215*, 223–233. https://doi.org/10.1016/j.envpol.2016.05.018

Devi, S. S., Sreedevi, A. V., & Kumar, A. B. (2020). First report of microplastic ingestion by the alien fish Pirapitinga (*Piaractus brachypomus*) in the Ramsar site Vembanad Lake, south India. *Marine Pollution Bulletin*, *160*, Article 111637. https://doi.org/10.1016/j.marpolbul.2020.111637

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z. I., Knowler, D. J., Leveque, C., Naiman, R. J., Prieur-Richard, A. H., Soto, D., Stiassny, M. L., & Sullivan, C. A. (2006). Freshwater biodiversity: Importance, threats, status and conservation challenges. *Biological Reviews*, *81*(2), 163–182. https://doi.org/10.1017/S1464793105006950

Dussault, G. V., & Kramer, D. L. (1981). Food and feeding behavior of the guppy, *Poecilia reticulata* (Pisces: Poeciliidae). *Canadian Journal of Zoology*, *59*, 684–701. https://doi.org/10.1139/z81-098

Eaton, J.G., & Scheller, R.M. (1996). Effects of climatic warming on fish thermal habitat in streams of the United States. *Limnology and Oceanography*, *41*, 1109–1115. https://doi.org/10.4319/lo.1996.41.5.1109

Ehlman, S. M., Sandkam, B. A., Breden, F., & Sih, A. (2015). Developmental plasticity in vision and behavior may help guppies overcome increased turbidity. *Journal of Comparative Physiology A*, *201*, 1125–1135. https://doi.org/10.1007/s00359-015-1041-4

Eldredge, L. G. (2000). Numbers of Hawaiian species. *Bishop Museum Occasional Papers*, *63*(5), 3–8.

El-Sabaawi, R. W., Frauendorf, T. C., Marques, P. S., Mackenzie, R. A., Manna, L. R., Mazzoni, R., Phillip, D. A. T., Warbanski, M. L., & Zandona, E. (2016). Biodiversity and ecosystem risks arising from using guppies to control mosquitoes. *Biology Letters*, *12*, Article 20160590. https://doi.org/10.1098/rsbl.2016.0590

Englund, R. A. (1999). The impacts of introduced poeciliid fish and Odonata on the endemic *Megalagrion* (Odonata) damselflies of Oahu Island, Hawaii. *Journal of Insect Conservation*, *3*, 225–243. https://doi.org/10.1023/A:1009651922486

Essl, F., Latombe, G., Lenzner, B., Pagad, S., Seebens, H., Smith, K., Wilson, J. R., & Genovesi, P. (2020). The Convention on Biological Diversity (CBD)'s Post-2020 target on invasive alien species-what should it include and how should it be monitored? *NeoBiota*, *62*, 99–121. https://doi.org/10.3897/neobiota.62.53972

Evans, J. P., & Magurran, A. E. (2000). Multiple benefits of multiple mating in guppies. *Proceedings of the National Academy of Sciences*, *97*(18), 10074–10076. https://doi.org/10.1073/pnas.180207297

Food and Agriculture Organization. (1997). *FAO database on introduced aquatic species*. FAO.

Free, C. M., Jensen, O. P., Mason, S. A., Eriksen, M., Williamson, N. J., & Boldgiv, B. (2014). High levels of microplastic pollution in a large, remote, mountain lake. *Marine Pollution Bulletin*, *85*, 156–163. https://doi.org/10.1016/j.marpolbul.2014.06.001

Gagne, R. B., Hogan, J. D., Pracheil, B. M., McIntyre, P. B., Hain, E. F., Gilliam, J. F., & Blum, M. J. (2015). Spread of an introduced parasite across the Hawaiian archipelago independent of its introduced host. *Freshwater Biology*, *60*, 311–322. https://doi.org/10.1111/fwb.12491

Ganassin, M. J. M., Frota, A., Muniz, C. M., Baumgartner, M. T., & Hahn, N. S. (2019). Urbanisation affects the diet and feeding selectivity of the invasive guppy *Poecilia reticulata*. *Ecology of Freshwater Fish*, *28*, 1–14. https://doi.org/10.1111/eff.12511

García-Berthou, E., Alcaraz, C., Pou-Rovira, Q., Zamora, L., Coenders, G., & Feo, C. (2005). Introduction pathways and establishment rates of invasive aquatic species in Europe. *Canadian Journal of Fisheries and Aquatic Sciences*, *62*(2), 453–463. https://doi.org/10.1139/f05-017

Ghosh, S. K., Tiwari, S. N., Sathyanarayan, T. S., Sampath, T. R. R., Sharma, V. P., Nanda, N., Joshi, H., Adak, T., & Subbarao, S. K. (2005). Larvivorous fish in wells target the malaria vector sibling species of the *Anopheles culicifacies* complex in villages in Karnataka, India. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, *99*, 101–105. https://doi.org/10.1016/j.trstmh.2004.03.009

Gibson, M. B., & Hirst, B. (1955). The effect of salinity and temperature on the pre-adult growth of guppies. *Copeia*, *1955*, 241–243. https://doi.org/10.2307/1440474

Gido, K. B., & Franssen, N. R. (2007). Invasions of stream fishes into low trophic positions. *Ecology of Freshwater Fish*, *16*, 457–464. https://doi.org/10.1111/j.1600-0633.2007.00235.x

Global Invasive Species Database. (2021). *Species profile: Poecilia reticulata*. http://www.iucngisd.org/gisd/species.php?sc=683

Gordon, S. P., Lopez-Sepulcre, A., & Reznick, D. N. (2011). Predation-associated differences in sex linkage of wild guppy coloration. *Evolution*, *66*, 912–918. https://doi.org/10.1111/j.1558-5646.2011.01495.x

Gurjar, U. R., Xavier, M., Nayak, B. B., Ramteke, K., Deshmukhe, G., Jaiswar, A. K., & Shukla, S. P. (2021). Microplastics in shrimps: A study from the trawling grounds of north eastern part of Arabian Sea. *Environmental Science and Pollution Research*, *28*(35), 48494–48504. https://doi.org/10.1007/s11356-021-14121-z

Gurjar, U. R., Xavier, K. M., Shukla, S. P., Takar, S., Jaiswar, A. K., Deshmukhe, G., & Nayak, B. B. (2023). Seasonal distribution and abundance of microplastics in the coastal sediments of north eastern Arabian Sea. *Marine Pollution Bulletin*, *187*, Article 114545. https://doi.org/10.1016/j.marpolbul.2022.114545

Hellmann, J. J., Byers, J. E., Bierwagen, B. G., & Dukes, J. S. (2008). Five potential consequences of climate change for invasive species. *Conservation Biology*, *22*, 534–543. https://doi.org/10.1111/j.1523-1739.2008.00951.x

Holitzki, T. M., MacKenzie, R. A., Wiegner, T. N., & McDermid, K. J. (2013). Differences in ecological structure, function, and native species abundance between native and invaded Hawaiian streams. *Ecological Applications*, *23*, 1367–1383. https://doi.org/10.1890/12-0529.1

Hynes, H. B. N. (1950). On the food of the freshwater sticklebacks, *Gasterosteus aculeatus* and *Pygosteus pungitius*, with a review of the methods used in the study of food fishes. *Journal of Animal Ecology*, *19*(1), 36–58. https://doi.org/10.2307/1570

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

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. (2019). *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (E. S. Brondizio, J. Settele, S. Díaz, & H. T. Ngo, Eds.). IPBES Secretariat.

Johnson, J. A., & Arunachalam, M. (2012). Feeding habit and food partitioning in a stream fish community of Western Ghats, India. *Environmental Biology of Fishes*, *93*, 51–60. https://doi.org/10.1007/s10641-011-9889-9

Khan, T. A., Wilson, M. E., & Khan, M. I. (1998). Evidence for invasive carp mediated trophic cascade in shallow lakes of western Victoria, Australia. *Hydrobiologia*, *506*, 465–472. https://doi.org/10.1023/B:HYDR.0000008558.48008.63

Kharat, S. S., Dahanukar, N., Raut, R., & Mahabaleshwarkar, M. (2003). Long term changes in the freshwater fish fauna in the Northern Western Ghats, Pune. *Current Science*, *84*, 816–820.

Knight, J. D. M. (2010). Invasive ornamental fish: A potential threat to aquatic biodiversity in peninsular India. *Journal of Threatened Taxa*, *2*(2), 700–704. https://doi.org/10.11609/JoTT.o2179.700-4

Kow, T. A. (1950). The food and feeding relationships of the fishes of Singapore Straits. *Colonial Office Fishery Publications*, *1*(1), 1–35.

Krishnakumar, K., Raghavan, R., Prasad, G., Kumar, A. B., Sekharan, M., Pereira, B., & Ali, A. (2009). When pets become pests - exotic aquarium fishes and biological invasions in Kerala, India. *Current Science*, *97*(4), 474–476.

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

Lawal, M. O., Edokpayi, C. A., & Osibona, C. A. (2012). Food and feeding habits of the Guppy, *Poecilia reticulata*, from drainage canal systems in Lagos, Southwestern Nigeria. *West African Journal of Applied Ecology*, *20*(2), 1–9.

Liew, J. H., Carrasco, L. R., Tan, H. H., & Yeo, D. C. (2016). Native richness and species level trophic traits predict establishment of alien freshwater fishes. *Biological Invasions*, *18*, 3495–3512. https://doi.org/10.1007/s10530-016-1241-z

Magurran, A. E. (2005). *Evolutionary ecology: The Trinidadian guppy*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780198527855.001.0001

Magurran, A. E., & Seghers, B. H. (1991). Variation in schooling and aggression amongst guppy (*Poecilia reticulata*) populations in Trinidad. *Behaviour*, *118*(3-4), 214–234. https://doi.org/10.1163/156853991X00292

Mecozzi, M., Pietroletti, M., & Monakhova, Y. B. (2016). FTIR spectroscopy supported by statistical techniques for the structural characterization of plastic debris in the marine environment: Application to monitoring studies. *Marine Pollution Bulletin*, *106*(1-2), 155–161. https://doi.org/10.1016/j.marpolbul.2016.03.012

Meffe, G. K., & Snelson, F. F., Jr. (1989). *Ecology and evolution of livebearing fishes (Poeciliidae).* Prentice Hall.

Moyle, P. B., & Light, T. (1996). Biological invasions of freshwater: Empirical rules and assembly theory. *Biological Conservation*, *78*(1-2), 149–161. https://doi.org/10.1016/0006-3207(96)00024-9

Ndome, C. B., & Victor, R. (2002). Food and feeding habits of *Epiplatys senegalensis* (Pisces: Cyprinodontiformes; Cyprinodontidae) in a black water pond in Benin City, Southern Nigeria. *West African Journal of Applied Ecology*, *3*(1), 105–117. https://doi.org/10.4314/wajae.v3i1.45574

Nikki, R., Jaleel, K. A., Ragesh, S., Shini, S., Saha, M., & Kumar, P. D. (2021). Abundance and characteristics of microplastics in commercially important bottom dwelling finfishes and shellfish of the Vembanad Lake, India. *Marine Pollution Bulletin*, *172*, Article 112803. https://doi.org/10.1016/j.marpolbul.2021.112803

Paingankar, M., & Dahanukar, N. (2013). Fishy Aliens: Invasive Introduced Fishes on the Forts of the Northern Western Ghats. *Min - Newsletter of the IUCN-SSC/WI Freshwater Fish Specialist Group - South Asia & the Freshwater Fish Conservation Network of South Asia*, (4), 1–3.

Pandey, N., Verma, R., Patnaik, S., & Anbumani, S. (2023). Abundance, characteristics, and risk assessment of microplastics in indigenous freshwater fishes of India. *Environmental Research*, *218*, Article 115011. https://doi.org/10.1016/j.envres.2022.115011

Pazianoto, L. H. R., Cionek, V. M., Fogaca, F. N. O., & Benedito, E. (2016). Feeding and body condition of an invasive fish species under different environmental conditions. *Neotropical Ichthyology*, *14*(1), e150164. https://doi.org/10.1590/1982-0224-20150164

Pillay, T. V. R. (1952). A critique of the methods of study of food of fishes. *Journal of the Zoological Society of India*, *4*, 185–200.

Pimentel, D. (Ed.). (2002). *Biological Invasions: Economic and environmental costs of alien plant, animal, and microbe species*. CRC Press. https://doi.org/10.1201/9781420041668

Raj, S., Pakash, P., Reghunath, R., Tharian, J. C., Raghavan, R., & Kumar, A. B. (2021a). Distribution of alien invasive species in aquatic ecosystems of the southern Western Ghats, India. *Aquatic Ecosystem Health & Management*, *24*(2), 58–69. https://doi.org/10.14321/aehm.024.02.09

Raj, S., Kumar, A. B., Tharian, J. C., & Raghavan, R. (2021b). Illegal and unmanaged aquaculture, unregulated fisheries and extreme climatic events combine to trigger invasions in a global biodiversity hotspot. *Biological Invasions*, *23*, 2399–2411. https://doi.org/10.1007/s10530-021-02525-4

Raj, S., Devi, S. S., Salam, S., & Kumar, A. B. (2021c). Food spectrum of two co-occurring invasive fish, *Cyprinus carpio* Linnaeus, 1758 and *Clarias gariepinus* (Burchell, 1822) in Mattupetty Reservoir, Kerala, India. *Indian Journal of Fisheries*, *68*(2), 65–73. https://doi.org/10.21077/ijf.2021.68.2.101875-05

Rayhan, A. B. M. S., Wang, J., Islam, M. M., Hossain, K. B., Chen, B., Ke, H., & Cai, M. (2024). Tidal variability and microplastics distribution: Source analysis in Dongshan Bay beach sediments, South China. *Journal of Oceanology and Limnology*, *42*, 1243–1256. https://doi.org/10.1007/s00343-024-4089-6

Reid, A. J., Carlson, A. K., Creed, I. F., Eliason, E. J., Gell, P. A., Johnson, P. T., Kidd, K. A., MacCormack, T. J., Olden, J. D., Ormerod, S. J., & Smol, J. P. (2019). Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews*, *94*(3), 849–873. https://doi.org/10.1111/brv.12480

Reeve, A., Ojanguren, A. F., Deacon, A. E., Shimadzu, H., Ramnarine, I. W., & Magurran, A. E. (2014). Interplay of temperature and light influences wild guppy (*Poecilia reticulata*) daily reproductive activity. *Biological Journal of the Linnean Society*, *111*(3), 511–520. https://doi.org/10.1111/bij.12217

Reznick, D. N., Shaw, F. H., Rodd, F. H., & Shaw, R.G. (1997). Evaluation of the rate of evolution in natural populations of guppies (*Poecilia reticulata*). *Science*, *275*(5308), 1934–1937. https://doi.org/10.1126/science.275.5308.1934

Rodriguez, C. M. (1997). Phylogenetic analysis of the tribe Poeciliini (Cyprinodontiformes: Poeciliidae). *Copeia*, *1997*(4), 663–679. https://doi.org/10.2307/1447285

Ross, R. M., Lellis, W. A., Bennett, R. M., & Johnson, C. S. (2001). Landscape determinants of nonindigenous fish invasions. *Biological Invasions*, *3*, 347–361. https://doi.org/10.1023/A:1015847305717

Rummel, C. D., Löder, M. G. J., Fricke, N. F., Lang, T., Griebeler, E. M., Janke, M., & Gerdts, G. (2016). Plastic ingestion by pelagic and demersal fish from the North Sea and Baltic Sea. *Marine Pollution Bulletin*, *102*(1), 134–141. https://doi.org/10.1016/j.marpolbul.2015.11.043

Sage, R. F. (2020). Global change biology: A primer. *Global Change Biology*, *26*(1), 3–30. https://doi.org/10.1111/gcb.14893

Shoemaker, H. H. (1944). A laboratory study of fish populations. *Transactions of the American Fisheries Society*, *74*(1), 350–359. https://doi.org/10.1577/1548-8659(1944)74[350:ALSOFP]2.0.CO;2

Subramanian, K. A., & Sivaramakrishnan, K. G. (2005). Habitat and microhabitat distribution of stream insect communities of the Western Ghats. *Current Science*, *89*(6), 976–987. https://www.jstor.org/stable/24110750

Suresh, A., Sreedhar, K. V., Mathew, J., Vijayakumar, K. N., Ajithlal, P. M., Saini, P., Kumar, N. P., & Kumar, A. (2021). Zero prevalence of dengue in urban and rural settings in Kerala, India. *Current Science*, *121*(2), 233–238. https://doi.org/10.18520/cs/v121/i2/233-238

Wagh, G. K., & Ghate, H. V. (2003). Freshwater fish fauna of the rivers Mula and Mutha, Pune, Maharashtra. *Zoos' Print Journal*, *18*(1), 977–981. https://doi.org/10.11609/JoTT.ZPJ.18.1.977-89

Walsh, M. R., & Reznick, D. N. (2008). Interactions between the direct and indirect effects of predators determine life history evolution in a killifish. *Proceedings of the National Academy of Sciences*, *105*(2), 594–599. https://doi.org/10.1073/pnas.0710051105

Walsh, M. R., & Reznick, D. N. (2009). Phenotypic diversification across an environmental gradient: A role for predators and resource availability on the evolution of life histories. *Evolution*, *63*(12), 3201–3213. https://doi.org/10.1111/j.1558-5646.2009.00785.x

Walsh, M. R., & Reznick, D. N. (2011). Experimentally induced life-history evolution in a killifish in response to the introduction of guppies. *Evolution*, *65*(4), 1021–1036. https://doi.org/10.1111/j.1558-5646.2010.01188.x

Welcomme, R. L. (1988). *International introductions of inland aquatic species* (FAO Fisheries Technical Paper No. 294). Food and Agriculture Organization.

Windel, V., & Bowen, K. (1974). Ornamental fish farming-successful small scale aqua business in India. *Aquaculture Asia*, *8*, 14–16.

Winemiller, K. O. (1993). Seasonality of reproduction by live-bearing fishes in tropical rainforest streams. *Oecologia*, *95*(2), 266–276. https://doi.org/10.1007/BF00323499

Winemiller, K. O., & Kelso-Winemiller, L. C. (2003). Food habits of tilapiine cichlids of the Upper Zambezi River and floodplain during the descending phase of the hydrologic cycle. *Journal of Fish Biology*, *63*(1), 120–128. https://doi.org/10.1046/j.1095-8649.2003.00134.x

World Health Organization. (2003). *Use of fish for mosquito control*. WHO Regional Office for the Eastern Mediterranean. https://apps.who.int/iris/handle/10665/116355

Wheeler, A. (1998). Ponds and fishes in Epping Forest, Essex. *London Naturalist*, *77*, 119–130.

Zandonà, E., Auer, S. K., Kilham, S. S., Howard, J. L., López-Sepulcre, A., O'Connor, M. P., Bassar, R. D., Osorio, A., Pringle, C. M., & Reznick, D. N. (2011). Diet quality and prey selectivity correlate with life histories and predation regime in Trinidadian guppies. *Functional Ecology*, *25*(5), 964–973. https://doi.org/10.1111/j.1365-2435.2011.01865.x

Zane, L., Nelson, W. S., Jones, A. G., & Avise, J. C. (1999). Microsatellite assessment of multiple paternity in natural populations of a live-bearing fish, *Gambusia holbrooki*. *Journal of Evolutionary Biology*, *12*(1), 61–69. https://doi.org/10.1046/j.1420-9101.1999.00006.x

Zbyszewski, M., Corcoran, P. L., & Hockin, A. (2014). Comparison of the distribution and degradation of plastic debris along shorelines of the Great Lakes, North America. *Journal of Great Lakes Research*, *40*(2), 288–299. https://doi.org/10.1016/j.jglr.2014.02.012

Zhuikov, A. Y. (1993). Avoidance learning and aggression in guppies. *Animal Behaviour*, *45*(4), 825–826. https://doi.org/10.1006/anbe.1993.1098