Poeciliid Research

Biological larvicide for the control of mosquito-borne diseases

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Abstract. This paper is a list of the most important fish species useful in the control of mosquito larvae. Some species of Poeciliidae, Cyprinidae, killifish and other fish species can often be effective for mosquito control. The effectiveness of fish species in mosquito control can vary depending on the specific environmental conditions and the types of mosquitoes present. Additionally, introducing non-native fish species into new environments should be done cautiously, considering potential ecological impacts. Local authorities, environmental agencies, and experts in mosquito control can provide guidance on the most suitable fish species for a particular region and ensure that any interventions are conducted responsibly.
Key Words: mosquito control, larvivorous, vectors, *Plasmodium*, *Culex*, *Anopheles*, *Aedes*, *Gambusia*.

Mosquito-borne diseases. Mosquitoes are known vectors for various diseases, and they can transmit pathogens to humans through their bites. In this paper, we propose to present a list of fish species useful in combating mosquito species that are vectors of human diseases, as well as to present the criteria for choosing these larvicidal species. Let's list these diseases, caused by parasites that use mosquitoes as vectors.

Malaria. Produced by the *Plasmodium* parasite and spred by *Anopheles* mosquitoes.

Dengue fever. Generated by the dengue virus and transmitted by *Aedes* mosquitoes.

Zika virus. Transmitted primarily by *Aedes* mosquitoes, Zika virus infection can lead to birth defects in infants born to infected mothers.

Yellow fever. Produced by the yellow fever virus and spred by *Aedes* and *Haemagogus* mosquitoes.

Chikungunya. Caused by the chikungunya virus and transmitted by *Aedes* mosquitoes.

West Nile virus. Transmitted by *Culex* mosquitoes, West Nile virus can cause flu-like symptoms and, in severe cases, neurological complications.

Japanese encephalitis. Caused by the Japanese encephalitis virus and transmitted by *Culex* mosquitoes, this viral infection can lead to inflammation of the brain.

Filariasis (elephantiasis). Caused by parasitic worms transmitted by various mosquito species, including *Culex* and *Anopheles*.

Malaria. Malaria remains a significant global health challenge, particularly in regions with tropical and subtropical climates (Moxon et al 2020; Nosten et al 2022).

Prevalence and impact. Malaria is triggered by *Plasmodium* parasites spread by the bite of infected female *Anopheles* mosquitos (Moxon et al 2020). Sub-Saharan Africa continues to bear the highest burden of malaria cases, with high transmission rates and severe health consequences. However, the disease also affects other parts of Asia, Latin America, and some regions in the Middle East (Figure 1).

Global progress. Over the past decade, there have been notable strides in malaria prevention and control (Daily et al 2022). Increased access to insecticide-treated bed nets, rapid diagnostic tests, and effective antimalarial drugs has contributed to a reduction in malaria cases and deaths in some areas (Nosten et al 2022; Dagen 2020).

Challenges. Despite progress, several challenges persist. Issues such as drug resistance, insecticide resistance in mosquitoes, and gaps in healthcare infrastructure hinder efforts to control and eliminate malaria (WHO 2020). The COVID-19 pandemic further strained health systems, potentially affecting malaria prevention and treatment services.

Innovations and research. Ongoing research and innovation are crucial components of the global malaria response. Efforts are focused on developing new tools, such as vaccines, and improving existing interventions. The development and deployment of new technologies play a pivotal role in the fight against malaria (WHO 2020).

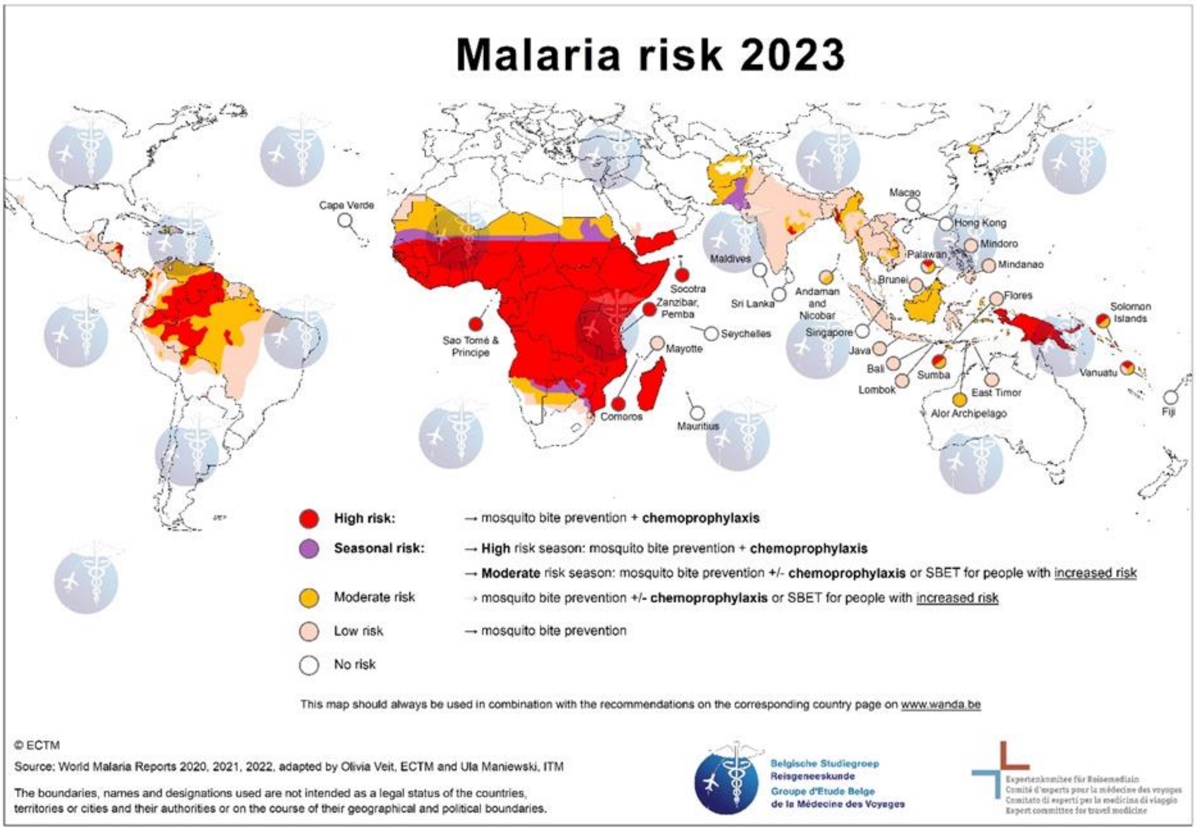

Figure 1. The map of malaria risk in the world. Source: World Malaria Reports 2020, 2021, 2022, adapted by Olivia Veit, ECTM and Ula Maniewski, ITM (www.wanda.be/en/a-z-index/malaria-world-map/).

Global initiatives. International organizations, including the World Health Organization, along with governments, non-governmental organizations, and private sector partners, collaborate on global initiatives to combat malaria (WHO 2020). The Roll Back Malaria Partnership and the Global Fund are among the key players working to reduce the burden of the disease.

Climate and environmental factors. Malaria transmission is influenced by environmental factors, including temperature and rainfall. Climate change and environmental modifications can impact the geographical distribution of malaria and introduce new challenges for control efforts (Dabaro et al 2021).

Community engagement. Community involvement and education are critical for the success of malaria control programs. Empowering local communities to participate in preventive measures, early diagnosis, and treatment is essential for sustainable progress (WHO 2020).

Biological larviciding for the control of mosquito-borne diseases. Certain species of fish are known for their efficiency in controlling mosquito larvae, including those responsible for spreading malaria. *Gambusia affinis* (Baird & Girard, 1853), commonly known as the western mosquitofish, is one of the most effective species for this purpose (Singh et al 2022). These small freshwater fish are voracious consumers of mosquito larvae and pupae. They are often introduced into water bodies, such as ponds or standing water, to help control mosquito populations and reduce the risk of diseases like malaria.

Larvivorous fish selection criteria. Selecting the right larvivorous fish for biological control of mosquito-borne diseases involves considering various criteria to ensure their effectiveness and compatibility with the local environment.

Prey preference. Choose larvivorous fish species that preferentially feed on mosquito larvae and pupae. Some common species include *G. affinis* (mosquito fish), *Aphanius* spp. and *Poecilia reticulata* Peters 1859 (guppy).

Adaptability. Select fish species that are adaptable to a variety of aquatic environments, including different water temperatures, pH levels, and salinity conditions.

Reproduction rate. Opt for fish species with a high reproductive rate to ensure a sustainable population capable of maintaining effective mosquito control.

Size. Consider the size of the larvivorous fish in relation to the size of mosquito larvae and pupae. The fish should be small enough to access mosquito breeding sites effectively.

Compatibility with native species. Ensure that the selected fish species are not invasive and won't harm native aquatic species. Introducing non-native species can have ecological consequences.

Survivability in the habitat. Evaluate the ability of the selected fish to survive in the local habitat, including factors such as water quality, vegetation, and other ecological conditions.

Behavior. Consider the behavior of the fish in terms of foraging activity and territoriality. Active foragers that cover a wide range are generally more effective in mosquito control.

Resistance to disease. Choose fish species that are resistant to common diseases to prevent potential health issues within the larvivorous fish population.

Ease of handling and transport. Select fish species that are easy to handle and transport to the target breeding sites. This ensures practicality in large-scale implementation.

Community acceptance. Involve the local community in the decision-making process and choose fish species that are culturally acceptable and well-received by the community.

Cost-effectiveness. Assess the cost-effectiveness of using larvivorous fish compared to other mosquito control methods. Consider the long-term sustainability and economic feasibility.

Regulatory compliance. Ensure compliance with local and international regulations regarding the introduction of non-native species and the use of biological control methods.

Efficacy. One of the key elements in assessing the larvivorous capacity is the mouth's position (Chandra et al 2008). We present below a categorization based strictly on their efficacy. The classification presented below (six categories) was proposed by Hora & Mukherjee (1938) and accepted by Chandra et al (2008).

1)Typical surface feeders. These are highly efficient larvivorous fish that primarily feed on mosquito larvae at the water's surface. Examples include *Aplochelius* spp. and *Gambusia* spp., which are known for their effectiveness in mosquito control (Hora & Mukherjee 1938).

2)Less efficient surface feeders. These fish also feed on the water's surface, but they may be less efficient compared to typical surface feeders. Examples include some genera such as *Oryzias*, *Poecilia*, *Aphanius*, and others (Chandra et al 2008).

3)Sub-surface feeders. These larvivorous fish feed just below the water's surface, targeting mosquito larvae in the upper water column. Eg. *Amblypharyngodon mola* (Hamilton, 1822) (mola carplet), *Danio* spp*., Rasbora* spp*.*, and others (Chandra et al 2008).

4)Column feeders. These fish actively search and feed in various depths of the water column, targeting mosquito larvae throughout the water body. Certain species of fish like *Puntius* spp., *Barbus* spp., *Puntigrus* spp., *Colisa* spp., *Fundulus* spp., *Gasterosteus* spp., *Trichogaster* spp., *Trichopodus* spp., *Chanda* spp., *Parambassis* spp., *Anabas* spp., *Macropodus* spp*.*, may fall into this category (Chandra et al 2008). They feed on mosquito larvae occasionally.

5)Fry of carps or mullets. Certain types of carp or mullet fry are also used for mosquito control. They may feed across different water layers and are employed in mosquito breeding habitats like ponds and lakes (Hora & Mukherjee 1938).

6)Predatory fish species. Predatory fishes like *Silurus* spp., *Perca* spp., *Ictalurus* spp., *Ameiurus* spp., *Sander* spp., *Wallago spp*., *Clarias* spp., *Channa* spp., *Notopterus* spp., *Lepomis* spp., and *Mystus* spp., whose fry may consume mosquito larvae but whose adults may predate upon other fish including larvicidal fish species (Chandra et al 2008).

Although, apparently, we would be tempted to choose larvivorous fish from the first two categories to populate the waters for the purpose of mosquito control, in reality the control plan is much more effective if we capitalize on the larvivorous potential by populating all levels of the water body with larvivorous fish. Moreover, fish monoculture is not as sustainable as polyculture, which provides the ecosystem with biodiversity, complexity and sustainability.

Fish against mosquitoes. In the followings, we will present some species frequently used in the control of mosquito larvae.

Gambusia affinis (Baird & Girard, 1853) (Mosquitofish)*.* Size: Max length: 5.1 cm total length for male or unsexed (Koutrakis & Tsikliras 2003); 7.0 cm total length for female; common length: 3.9 cm total length for male or unsexed (Hugg 1996); maximum reported age: 3 years (Beverton & Holt 1959). Distribution: North and Central America (in the Mississippi River basin) (Froese & Pauly 2023; Pyke 2005). One of the species with the widest range of introductions which acquired for itself a near pan-global distribution (Welcomme 1988). The mosquitofish is preferred for mosquito control programs due to its adaptability to various environmental conditions and its ability to thrive in both stagnant and flowing water. This species is the best known biological larvicidal agent. See field trials and studies in detail in Chandra et al (2008). However, it is essential to carefully consider the ecological impact of introducing non-native species into new environments, as they can sometimes have unintended consequences on local ecosystems (Iacob & Petrescu-Mag 2008; Mag et al 2009; Petrescu-Mag et al 2013; Oroian et al 2022). In some cases, native fish species may also contribute to mosquito larvae control. While *G. affinis* is one of the most widely used fish species for mosquito control, there are other fish species that have been successfully employed in malaria prevention efforts (Petrescu-Mag 2007ab, 2008; Chandra et al 2008). We list below other fish species known for their effectiveness in controlling mosquito larvae.

G. holbrooki (Girard, 1859) (Eastern mosquitofish). Maximum length: 4.7 cm total length for male or unsexed (Tarkan et al 2006); 8.0 cm total length for female; maximum reported age: 1 year (Nguyen et al 2021). This species, native to the southeastern United States, has also been introduced in various regions for mosquito control (Eagderi & Radkhah 2015; Mousavi-Sabet & Salehi 2018; Odagiu et al 2020; Mousavi-Sabet et al 2021). Established throughout southern Europe (Kottelat & Freyhof 2007). Introduced for mosquito control, but had rare to non-existing effects on mosquitoes, and negative to perhaps neutral impact on native fishes (Kottelat & Whitten 1996; Jawad 2021).

G. geiseri (Hubbs & Hubbs, 1957) (Largespring gambusia). It is a fish of about 2.5 cm, maximum 4.4 cm (Page & Burr 1991). Distribution: North America: San Marcos and Guadalupe River systems in Texas, USA (Froese & Pauly 2023). The Largespring gambusia plays a pivotal role in the biological control of mosquito-borne diseases. Employed as a natural predator of mosquito larvae, this species contributes to disrupting the mosquito life cycle and curtailing disease transmission. Known for its adaptability to various aquatic environments, including ponds and ditches, *G. geiseri* integrates seamlessly into ecosystems, showcasing environmental friendliness. Field trials and studies have explored the effectiveness of Largespring gambusia in controlling mosquito populations, emphasizing its potential as a sustainable and ecologically sound strategy for mitigating the impact of mosquito-borne diseases. Further research continues to refine our understanding of the interplay between *G. geiseri* and mosquito populations, offering valuable insights into the practical application of biological control measures for disease prevention.

G. gaigei (Hubbs, 1929) (The big bend gambusia). It is a fish of approximately 2.3 cm (Hugg 1996), maximum 5.4 cm (Page & Burr 1991). Distribution: North America, previously observed in Graham Ranch and Boquillas springs, Brewster County in Texas (Froese & Pauly 2023). Now restricted to an artificial spring-fed pond in Big Bend National Park in Texas, USA (Froese & Pauly 2023). The Big Bend gambusia emerges as a key player in the biological control of mosquito-borne diseases. Renowned for its efficacy as a natural predator of mosquito larvae, *G. gaigei* contributes significantly to interrupting the mosquito life cycle and thereby mitigating the spread of diseases. This species, adaptable to diverse aquatic environments such as ponds and ditches, seamlessly integrates into ecosystems without causing harm to the environment. Field studies and trials have substantiated the potential of Big Bend gambusia in controlling mosquito populations, underscoring its role as an environmentally friendly and sustainable solution to combat mosquito-borne diseases. Ongoing research further refines our comprehension of the dynamics between *G. gaigei* and mosquito populations, providing valuable insights for the practical implementation of biological control measures in disease prevention strategies.

***Poecilia reticulata* (Peters, 1859) (The guppy fish)**. Common length: 2.8 cm total length for male; 4.0-7.0 cm for female. Native to South America: Venezuela, Barbados, Trinidad, northern Brazil and the Guyanas (Mag et al 2006; Petrescu-Mag 2007c, 2009). Widely introduced and established elsewhere, mainly for mosquito control (Froese & Pauly 2023), but some authors reported that the species had rare to non-existing effects on mosquitoes, and negative to perhaps neutral effects on native fishes (Kottelat & Whitten 1996). These opinions that report bad results on mosquito control are not unanimously accepted. However, several countries reported adverse ecological impact after introduction (Froese & Pauly 2023). Guppy fish is a tropical species and cannot tolerate very low temperatures (Petrescu-Mag et al 2008; Păsărin et al 2007). This is a disadvantage for its use as a biological larvicidal agent in temperate or cold regions. *P. reticulata* is a prolific breeder in tropical waters and its optimal temperature is between 22 and 24°C (Chandra et al 2008). This species can be feed on artificial food, but prefers mosquito larvae (Chandra et al 2008). The guppy has been found to tolerate pollution more than *Gambusia* (Chandra et al 2008). These last two qualities make the guppy an excellent candidate for mosquito control programs in tropical regions. Laboratory trials: According to laboratory investigation (Chatterjee & Chandra 1997), an adult fish and a fingerling of *P. reticulata* can consume 32 and 18 IV stage *Anopheles subpictus* Grassi, 1899 larvae respectively in 24 hours. Field experiments in natural habitats: Menon & Rajagopalan (1978) studied the natural environment, predation rate and larvivorous capacity of 14 fish species from Puducherry (Chandra et al 2008). According to this study, guppy fish average predation per day was 53.1 larvae and range of consumption was 15-100 larvae. In the case of rice fields, Nalim & Tribuwono (1987) investigated the rice field breeding mosquito *Anopheles aconitus* Dönitz, 1902 in central Java (Indonesia) and their effective control using guppies through community participation (Chandra et al 2008). They also observed a steep decrease of the number of malarial cases after starting the effective control procedures with larvivorous fish species (Chandra et al 2008). Man-made habitats: Cisterns and washbasins. Sabatinelli et al (1991) showed that, in Grand Comore Island, *P. reticulata*, effectively suppressed larval and adult population of *Anopheles gambiae* Giles, 1902 in washbasins, and cisterns by 85% in a single year using a density of 3-5 fish per square meter of water surface (Chandra et al 2008). Experiments in containers: Gupta et al (1992) indicated that, in India, *P. reticulata* effectively decreased the breeding of *Anopheles stephensi* Liston, 1901 and *A. subpictus* population in containers, by 86% using a density of 5-10 fish per square meter of water surface (Chandra et al 2008). Drains: Saha et al (1986) investigated the quality of guppy as a possible biocontrol agent against mosquitoes. A team of researchers identified 20 surface waterways that served as breeding grounds for mosquitoes in Kolkata (India), out of which 10 were found to harbor both guppy fishes and mosquito larvae and the other 10 were utilized as reference value (Chandra et al 2008). Per dip larval and pupal densities of *Culex quinquefasciatus* Say, 1823 varied significantly compared to corresponding densities in the drains without guppies (Chandra et al 2008). Investigations in wells: The role of guppy in mosquito breeding biocontrol in Ghaziabad district villages (India, near Delhi) was analysed by Sharma & Gosh (1989). Natural reproduction of mosquitoes was found effectively controlled in wells provided the fish did not die or were not prevented from feeding on larvae due to debris (Chandra et al 2008). Guppies survived and multiplied in wells over the 22 weeks duration of the experiment (Sharma & Gosh 1989). Malaria was a serious issue in a sericulture area of Karnataka (southern part of India), where *Anopheles culicifacies* Giles, 1901 and *Anopheles fluviatilis* James, 1902 were known as principal vectors involved in malaria spread (Chandra et al 2008). Since 1998 (one year after release of *P. reticulata*) until 2003, no malaria cases were detected in the three villages where the waters were stocked with guppyfish (Gosh et al 2005). We have no data about the situation of malaria cases after the year 2003.

***Aphaniops dispar* (Rüppell, 1829) (Arabian pupfish)**. The species has a maximum length of 7.0 cm and it is native to Djibouti, Egypt, Ethiopia, Socotra Arch., Somalia, Sudan, Saudi Arabia and Yemen (Froese & Pauly 2023). It was introduced in Israel and Syria. *A. dispar* is a well-adapted larvivorous fish that lives in fresh and brackish waters. It is a sensitive species and difficult to transport (Chandra et al 2008). The species is suitable for drains and polluted water bodies and good for stagnant waters, cesspools and disused wells (Chandra et al 2008). Field trials: Natural habitats - shallow channels. Ataur-Rahim (1981) wrote about the natural occurrence of Arabian pupfish in shallow channels near Riyadh (Saudi Arabia) where it was reported to successfully control mosquito larvae. According to this observation, fish were stocked at about 3 specimens per square meter of water surface. Experiments using Arabian pupfish in man-made artificial containers have shown successful results (Chandra et al 2008). It has been shown that *A. dispar* is a suggested larvivorous fish for the control of vectors of Bancroftian filariasis namely *C. quinquefasciatus* in any kind of stagnant water containing organic pollution (NICD 1988). Louis & Albert (1988) indicated that in an urban area in Djibouti, *A. dispar* effectively suppressed the breeding of *Anopheles arabiensis* Patton, 1905 and *A. gambiae* breeding in cisterns, wells, barrels and containers by 97% (Chandra et al 2008). Further Fletcher et al (1992) reported that in an urban area in Ethiopia, the Arabian pupfish effectively suppressed *A. culicifacies adanensis* breeding in wells (fact indicated also by Chandra et al 2008). It is important to note that Aphaniidae were recently restructured by Freyhof & Yoğurtçuoğlu (2020) so many of the old reports on larvivorous potential of *A. dispar* (reviewed in Chandra et al 2008) may refer to other taxa, close related to *A. dispar*.

***Aplocheilus blockii* (Arnold, 1911) (Green panchax)**. This species of fish has a maximum length of 6.0 cm. It is native to India, Pakistan and Sri Lanka (Froese & Pauly 2023). The fish is a strictly fresh water species and inhabits stationary and sheltered waters of small streams, tanks and rivulets over grown with thick vegetation (Chandra et al 2008). The green panchax is suitable for ponds and impounded water bodies where carnivorous fish are present, wells and abounded water bodies (Chandra et al 2008). The species is also a good choice for introduction in overhead tanks, streambeds, ornamental pools, reservoirs and wells for malaria disease vector control (Chandra et al 2008). Field trials in natural habitats: Studies conducted by Kumar et al (1998) indicated that predation by green panchax reduced the larval population of *A. stephensi* by 75% along the coastal belt of Goa. Man made habitats: Green panchax is a potential larvivorous fish controlling the spread of chikungunya fever by controlling *Aedes albopictus* (Skuse, 1895) (NICD 1988). The investigation was conducted in tanks and big cisterns and barrels (NICD 1988).

***Aplocheilus lineatus* (Valenciennes, 1846) (Striped panchax)**. It is a fish of 7.0 cm, maximum 10.0 cm. It is native to India and Sri Lanka, and introduced to Hong Kong, Hawaii and Singapore (Froese & Pauly 2023). Common in tanks, canals, paddy fields, and tidal waters. Like other species of *Aplocheilus*, this one is suitable too for fishponds where carnivorous food fish are present and good for introduction in overhead tanks, artificial containers, fountains and cisterns to control urban malaria (Chandra et al 2008). As well, it is suitable for pools, streambeds, margins and marshes in rural areas (Chandra et al 2008). Field trials in man-made habitats: striped panchax is a potential biocontrol agent (Chandra et al 2008). It was reported to control dengue fever vector *Aedes aegypti* Linnaeus, 1762 (Ataur-Rahim 1981). The investigation was developed in the breeding habitats of *A. aegypti*, which included tanks of water storage, cisterns, and barrels (Ataur-Rahim 1981).

***Aplocheilus panchax* (Hamilton, 1822) (Blue panchax)**. It is a fish of about 5.0 cm. The maximum length is 9.0 cm. It is native to Andaman Is., Bangladesh, Cambodia, India, Indonesia, Malaysia, Myanmar, Nepal, Pakistan, Singapore, Sri Lanka, Thailand, Viet Nam, and introduced in Philippines and Timor-Leste (Froese & Pauly 2023). The species is very hardy and inhabits clear shallow fresh and brackish water at low altitudes

(Chandra et al 2008). The species is suitable for waters where carnivorous fish are present; also present in wells, marshes, lagoons and polluted storm water drains and any other stagnant water bodies containing organic pollutants. Effective in filariasis vector control (Chandra et al 2008). Field trials: The blue panchax is a potential larvivorous fish in controlling several vector species in different types of natural and man-made habitats (NICD 1988). The blue panchax controlled the mosquito *A. culicifacies* in breeding habitats like irrigation channels, rain water pools, sluggish streams with sandy margins and little vegetation, borrow pits, river bed pools, swimming pools, cemented tanks, freshly laid rice fields and so on (Chandra et al 2008). The vector *Anopheles sundaicus* (Rodenwaldt, 1925) was controlled in brackish waters full of algae, behind embankments protecting rice fields, tanks, ponds, cleared mangroves and lagoons, lakes and borrow pits in coastal areas (Chandra et al 2008). The blue panchax also controlled the species *C. quinquefasciatus* in cesspools, chocked severs, drains, storm water drains, polluted waterways, ponds, septic tanks, disused wells, manure pits, wells, and the vector *Culex vishnui* Theobald, 1901 in rice fields, ponds, marshes, pools, ditches, streams, borrow pits, irrigation channels, and field wells (Chandra et al 2008).

Nothobranchius guentheri (Pfeffer, 1893) (Redtail notho). Its maximum size is 3.5 cm standard length for males or unsexed individuals. Females are smaller, up to 3.2 cm standard length (Costa 2017). The species is endemic to Unguja Island, Zanzibar archipelago, eastern Tanzania (Costa 1017). Ecology: The redtail notho is a tropical, freshwater, benthopelagic and non-migratory fish (Riehl & Baensch 1991). The redtail notho is a fast-growing fish species, growing from egg to spawning adult in only four weeks (Chandra et al 2008). Throughout the duration of their lives, females lay between 20 and 100 eggs every day (Chandra et al 2008). Field trials in natural habitats: Vanderplank (1941) reported that the Redtail notho was the most suitable antimalarial fish species available for use when Panama Canal was under construction (Chandra et al 2008).

Oryzias melastigma (McClelland, 1839) (Estuarine ricefish). The Estuarine ricefish is a fish of up to 4.0 cm in total length (Menon 1999). The species is spread in Asia: Bangladesh, Sri Lanka and India (Froese & Pauly 2023). The Estuarine ricefish is a carnivorous, surface feeder found in both running waters and still water. The species is primarily estuarine and brackish water fish (it occurs in shallow lagoons and swamps among roots and mangroves along the margins of waters) (Menon 1999; Froese & Pauly 2023). However, the Estuarine ricefish can be found also in fresh waters such as ponds, rivers, lakes, canals and creeks, in significant numbers (Chandra et al 2008). Being highly resistant, it thrives in areas with shallow water, particularly in rice paddies where it can help manage mosquitoes that spread Japanese B encephalitis (Chandra et al 2008). Laboratory experiments: Predation potential of the Estuarine ricefish (measuring 2.4-2.5 cm) was tested in containers of glass, measuring 20x17x20 cm, against IV instar larvae of *Anopheles* sp. (Sharma & Ghosh 1989). Study on four subsequent days indicated that the Estuarine fish consumed 98 IV instar larvae of *Anopheles* per day (Sharma & Ghosh 1989). Field trials in natural habitats: *O. melastigma* has the ability to control the occurrence of Japanese B encephalitis due to the fact it restricts populations of *C. vishnui* Theobald, 1901 (Chandra et al 2008). This vector occurs in breeding habitats such as: marshes, rice fields, pools, ponds, ditches, streams, irrigation channels, field wells, borrow pits, rain water in fallow lands (Chandra et al 2008). A field-based investigation was developed to observe the efficacy of *O. melastigma* in controlling mosquito reproduction in rice fields rich in *Anopheles sp*. and *Culex sp.* (Sharma & Ghosh 1989). Percentage reduction in the density of pupa and larva was recorded. On the 6th day, the Estuarine ricefish lowered the density of III and IV instar larvae and pupae by 76.2% (Sharma & Ghosh 1989; Chandra et al 2008). On the following days the percentage reduction ranged from 98.3% to 100% (Sharma & Ghosh 1989). From the 12^{th} day onwards, 100% reduction in larval and pupal densities was reported (Sharma & Ghosh 1989; Chandra et al 2008).

***Trichogaster lalius* (Hamilton, 1822) (Dwarf gourami)**. Approximately 5.0 cm, maximum 9.5 cm in length. Native to Bangladesh, India and Pakistan. Introduced in Chinese Taipei, Singapore, USA and Colombia (Froese & Pauly 2023). It inhabits slow moving streams, rivulets and lakes with plenty of vegetation (Chandra et al 2008). Suitable for water bodies where carnivorous food fish are present (Chandra et al 2008). The dwarf gourami is a good choice for tanks and lakes (Chandra et al 2008). Field trials in natural habitats: The dwarf gourami is a good biocontrol agent. *T. lalius* has been shown to control the mosquito species *Anopheles annularis* van der Wulp, 1884 thereby preventing the spread of malaria disease to a significant extent (NICD 1988). Breeding habitat of the vector *A. annularis* include clear weed grown stagnant waters, tanks, margins of lakes, borrow pits, dead rivers, and rice field (NICD 1988).

Pseudosphromenus cupanus* (Cuvier, 1831) (Spiketail paradisefish).* The species has a maximum 7.5 cm in total length (Menon 1999). The species is spread in Asia: India, Bangladesh, Sri Lanka, Myanmar and Malaysia (Froese & Pauly 2023). Having an auxiliary organ for respiration, the Spiketail paradisefish is a facultative air-breathing (Froese & Pauly 2023). Therefore, it tolerates deficiency of oxygen in water (Chandra et al 2008). It breeds freely in stagnant waters. During reproduction, males build a bubble nest. The species can be found in ditches, paddy fields and shallow water not far from tidal influence (Rahman 1989). *P. cupanus* prefers stagnant or slow-flowing water with thick vegetation such as grasses, roots and floating plants (Rahman 1989). This species feeds on insects and zooplankton (Froese & Pauly 2023), being a good larvivorous fish (Chandra et al 2008). It thrives both in fresh and brackish waters of the low lands (Chandra et al 2008), but it also can be found in ditches, shallow waters and paddy fields (Chandra et al 2008). The spiketail paradisefish is also a good choice for brackish waters, lagoons, marshes, polluted canals and ditches. Laboratory experiments: A team developed research with *P. cupanus* collected from paddy fields (Mathayan et al 1980). The collected fish were split into three weight classes (570 mg, 270 mg, and 80 mg live weight) and kept in separate glass tanks (Mathayan et al 1980). They were acclimated to laboratory conditions (27±1°C) and fed ad libitum on the IV instar larvae of the species *Culex fatigans* (now *C. quinquefasciatus*) (Mathayan et al 1980). Prior to starting the nutrition trials, individuals of each group were denied food for 6, 9, 12, 24, or 48 hours in order to induce varying degrees of hunger (Mathayan et al 1980). The researchers concluded that, when deprived of food for equal duration, larger fish become hungrier than the smaller ones. Furthermore, the prey finding of larger individuals boost their appetite (Mathayan et al 1980). These findings improve our knowledge in terms of optimum fish stocking for maximizing the larvivorous effect.

Danio rerio* (Hamilton, 1822) (Zebrafish).* Maximum standard length of the Zebrafish is 3.8 cm for males (Menon 1999) and 5.0 cm for female. It is native to: India, Bangladesh, Myanmar, Bhutan, Nepal and Pakistan. It was introduced to: Japan, Philippines, Singapore, Sri Lanka, Martinique, USA and Colombia (Froese & Pauli 2023). Adult Zebrafishes populate streams, ditches, canals, ponds and beels (Rahman 1989). They occur in slow-moving to stagnant standing water bodies, particularly rice-fields (Talwar & Jhingran 1991); and lower reaches of streams (McClure et al 2006). *D. rerio* is common in rivulets at foot hills (Menon 1999). It is a surface feeder. It feeds on worms and small crustaceans and also on insect larvae (Froese & Pauly 2023). It breeds all year round (Spence et al 2007). It appears to be primarily an annual species in natural habitats, and the reproductive season starts just before the onset of the monsoon (Froese & Pauly 2023). Domesticated varieties of zebrafish live in aquaria on average 3.5 years, with oldest individuals surviving up to 5.5 years (Gerhard et al 2002). Laboratory experiments: A laboratory-based investigation on predatory potential of the Zebrafish (measuring 2.4-2.5 cm) in glass tanks of 20x17x20 cm against IV instar larvae of *Anopheles sp.* was performed (Sharma & Ghosh 1989; Chandra et al 2008). The trial was repeated on 4 subsequent days and the average number of larvae consumed per day by each Zebrafish was recorded (Sharma & Ghosh 1989). Study revealed that *D. rerio* consumed a number of 52 IV instar larvae of *Anopheles* per day (Sharma & Ghosh 1989).

Field experiments in natural habitats: A field-based research to evaluate the efficacy of Zebrafish in controlling mosquito reproduction in rice fields rich in two species of mosquitoes (*Culex* sp., and *Anopheles* sp.) was performed by Kumar et al (1998). On the 6th day, the Zebrafish reduced the density of III and IV instar larvae and pupae by 86.8%, and on subsequent days the percentage reduction ranged from 92.4% to 99.3%. From the 12th day onwards, 100% reduction in larval and pupal densities was noticed (Kumar et al 1998).

***Carassius auratus* (Linnaeus, 1758) (Goldfish)**. Maximum length: 48.0 cm total length for male/unsexed; common length: 10.0 cm total length for male/unsexed; maximum published weight: 1.6 kg; maximum reported age: 41 years (data collected from various sources by Froese & Pauly 2023). Goldfish is native to East Asia, China and Japan (Kailola et al 1993). It was introduced elsewhere throughout the world with reported adverse ecological impact after introduction (Froese & Pauly 2023). *C. auratus* is frequently used as aquarium fish or for stocking ornamental ponds. Laboratory experiments: Chatterjee et al (1997) reported the biocontrol efficacy of Goldfish under experimental conditions, created in laboratory. Under such conditions, one Goldfish was allowed to feed on 200 IV stage larvae of each of *A. subpictus, C. quinquefasciatus* and *Armigeres subalbatus* (Coquillett, 1898) in separate containers (Chatterjee et al 1997). The number of larvae consumed was 193, 188 and 132 per day respectively (Chatterjee et al 1997; Chandra et al 2008). Field trials/man-made habitats/unused reservoirs: Under field conditions, the Goldfish efficiently fed upon *A. subpictus* larvae in unused water reservoirs in Hooghly, West Bengal (Chatterjee et al 1997). There was a remarkable decreasing of the per dip density of *A. subpictus* larvae from 34.5 to 0.02 (Chatterjee et al 1997).

***Cyprinus carpio* (Linnaeus, 1758) (Common carp)**. Common carps are omnivores and generally feed on a variety of small aquatic organisms, including zooplankton, insects, and other invertebrates (Bud et al 2016). The species is one of large size. While they may consume mosquito larvae as part of their diet, the specific species of mosquito larvae targeted by common carp fry may vary.

***Oreochromis niloticus* (Linnaeus, 1758) (Nile tilapia)**. It is a fast-growing species with a special value for aquaculture. Maximum length: 60.0 cm standard length male/unsexed (Eccles 1992); maximum published weight: 4.3 kg (IGFA 2001); maximum reported age: 9 years (Noakes & Balon 1982; Froese & Pauly 2023). It is widespread in East Africa, West Africa and River Nile. It was widely introduced for aquacultural purposes on all continents. It does not tolerate waters with high salinity and needs warm temperatures. It is highly suitable for farming in tropical climate, in fresh waters and brackish waters (Chandra et al 2008). The lower lethal temperature is 12°C (Chandra et al 2008). *O. niloticus* is freshwater, brackish, benthopelagic, tropical and potamodromous (Riede 2004); Laboratory experiments: Ghosh et al (2006) performed laboratory investigations and established Nile tilapia as a strong larvicidal agent against mosquitoes. Field experiments in man-made habitats: Research under field conditions published by Ghosh et al (2006) and reviewed by Chandra et al (2008) indicated a significant reduction of per dip larval density at one month and half month after the introduction of Nile tilapia (Ghosh et al 2006). The larval density again increased significantly after removal of tilapias from mosquito breeding ground (Ghosh et al 2006). Once a number of 20 fish were subjected to natural environment conditions, the per dip larval population reduced from an initial population of 26.78 to 17.38 and 11.39 after 30 and 45 days, respectively. On the contrary, the density of larva increased to 21.2 and 24.37 at 30 and 45 days, respectively, after the removal of tilapias (Ghosh et al 2006).

***Oreochromis mossambicus* (Peters, 1852) (Mozambique tilapia)**. According to Froese & Pauly (2023), the size of this species is smaller than the size of Nile tilapia. Maximum length: 39.0 cm standard length for male/unsexed (Wohlfarth & Hulata 1983); common length: 35.0 cm total length for male/unsexed (Frimodt 1995); maximum published weight: 1.1 kg (IGFA 2001); maximum reported age: 11 years (Noakes & Balon 1982). It is spread in Africa: Lower Zambezi, Lower Shiré and coastal plains from Zambezi delta to Algoa Bay (Froese & Pauly 2023). Occurs southwards to the Brak River in the eastern Cape and in the Transvaal in the Limpopo system (de Moor & Bruton 1988; Froese & Pauly 2023). Widely introduced for aquaculture, but escaped and established itself in the wild in many countries, where it formed self-sustaining populations, often outcompeting local taxa (Kottelat & Whitten 1996). Several countries reported adverse ecological impact after Mozambique tilapia introduction (Froese & Pauly 2023). *O. mossambicus* grows fast and attains a maximum size in the wild. However, stunting is often observed in cultured populations (Chandra et al 2008). It reproduces under salinities of up to 35%. The lower lethal temperature for Mozambique tilapia is 10°C. *O. mossambicus* is suitable for hybridization if salinity tolerance is desired in the offspring generation (Chandra et al 2008). Field experiments in man-made habitats: *O. mossambicus* proved to be useful in suppressing mosquitoes in cow dung piles (Sharma & Ghosh 1989) when introduced against III and IV instar larvae and pupae *A. culicifacies* and *C. quinquefasciatus* at the rate of 5 fish per square meter of surface area (Sharma & Ghosh 1989; reviewed in Chandra et al 2008).

Chanda nama (Hamilton, 1822) (Elongate glass-perchlet). Maximum length: 11.0 cm total length for male/unsexed (Menon 1999). Distribution: India, Bangladesh, Nepal, Pakistan and Myanmar (Foroese & Pauly 2023). The Elongate glass-perchlet can be found in running and standing waters, clear streams, beels, canals, ponds, and inundated paddy fields (Froese & Pauly 2023), being abundant during the rainy season (Rahman 1989). This species could effectively be used in the control of guinea worms (Froese & Pauly 2023) and also for malarial control (Chandra et al 2008). It is suitable for consumption and for aquarium purposes (Arunachalam et al 2000). According to Chandra et al (2008), *C. nama* is a suitable and efficient larvicidal fish that can be used in waterways, reservoirs, drain canals, and vegetation infested areas for malaria vector control. Field experiments in natural habitats: *C. nama* has been shown to control the population of *A. culicifacies*, *Anopheles varuna* Iyengar, 1924, and *Anopheles balabacensis* Baisas, 1936, which are known malarial vectors inhabiting slow moving fresh water (Ataur-Rahim 1981).

Xenentodon cancila (Hamilton, 1822) (Freshwater garfish). Maximum length: 40.0 cm total length male/unsexed (Talwar & Jhingran 1991); common length: 30.0 cm total length for male/unsexed (Talwar & Jhingran 1991). Native to: Bhutan, Bangladesh, Cambodia, Indonesia, India, Laos, Malaysia, Myanmar, Nepal, Sri Lanka, Pakistan, Vietnam and Thailand. Introduced to: Hong Kong and Hawaii (Froese & Pauly 2023). *X. cancila* is a tropical, freshwater, brackish, pelagic-neritic, amphidromous fish species (Riede 2004). Laboratory experiments: Chatterjee & Chandra (1996) revealed the efficiency of *X. cancila* as a means of biocontrol to combat the IVth stage larval form of *A. subpictus*, *A. subalbatus*, and *C. quinquefasciatus* within experimental settings (Chandra et al 2008). Its average consumption rate during 24 hours period was significant. Three individuals of Freswater garfish separately consumed an average of 31, 28, 21 larvae of *A. subpictus, C. quinquefasciatus* and *A. subalbatus* respectively during the 24 hours of the experiment (Chatterjee & Chandra 1996).

Other larvicidal fish species. *Trichogaster fasciata* Bloch & Schneider, 1801 - Banded gourami, *Trichogaster chuna* (Hamilton, 1822) - Honey gourami, *Coptodon zillii* (Gervais, 1848) - Redbelly tilapia, *Epiplatys* spp. – Killifish, *Heterandria formosa* (Girard, 1859) - Least killifish, *Phalloceros* spp. - Toothcarps.

Conclusions. Some species of Poeciliidae, Cyprinidae, killifish and other fish species can often be effective for mosquito control. The effectiveness of fish species in mosquito control can vary depending on the specific environmental conditions and the types of mosquitoes present. Additionally, introducing non-native fish species into new environments should be done cautiously, considering potential ecological impacts. Local authorities, environmental agencies, and experts in mosquito control can provide guidance on the most suitable fish species for a particular region and ensure that any interventions are conducted responsibly.

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References

Arunachalam M., Johnson J. A., Sathyanarayanappa S. N., Sankaranarayanan A., Soranam R., 2000 Cultivable and ornamental fishes from Hemavathi and Ekachi rivers, South Karnataka. In: Endemic fish diversity of Western Ghats. Ponniah A. G., Gopalakrishnan A. (eds), pp. 226-227, NBFGR-NATP Publication, National Bureau of Fish Genetic Resources, Lucknow, U.P., India, 1, 347 p.

Ataur-Rahim M., 1981 Observations on *Aphanius dispar* (Ruppell, 1828), a mosquito larvivorous fish in Riyadh, Saudi Arabia. Annals of Tropical Medicine and Parasitology 75:359-62.

Beverton R. J. H., Holt S. J., 1959 A review of the lifespans and mortality rates of fish in nature, and their relation to growth and other physiological characteristics. In: The lifespan of animals. Wolstenholme G. E. W., O'Connor M. (eds), pp. 142-180, CIBA Foundation Colloquia on Ageing, Volume 5, J & A Churchill Ltd, London.

Bud I., Todoran L., Petrescu-Mag V. I., 2016 [Treatise on aquaculture and biodiversity, vol. 1]. Vatra Veche, Târgu-Mureș. [In Romanian].

Chandra G., Bhattacharjee I., Chatterjee S. N., Ghosh A., 2008 Mosquito control by larvivorous fish. Indian Journal of Medical Research 127(1):13-27.

Chatterjee S. N., Chandra G., 1996 Laboratory trials of the feeding pattern of *Anopheles subpictus*, *Culex quinquefasciatus* and *Armigeres subalbatus* by *Xenentodon cancila* fry. Environment and Ecology 14:173-174.

Chatterjee S. N., Chandra G., 1997 Feeding pattern of *Gambusia affinis* and *Lebistes reticulatus* on *Anopheles subpictus* larvae in the laboratory and field conditions. Journal of Applied Zoological Research 8:152-153.

Chatterjee S. N., Das S., Chandra G., 1997 Gold fish (*Carassius auratus*) as a strong larval predator of mosquito. Trans Zool Soc India 1:112-114.

Costa W. J. E. M., 2017 Taxonomic revision of the seasonal killifish genus *Nothobranchius* from Zanzibar, East Africa (Cyprinodontoidei: Aplocheilidae). Journal of Natural History 51(27/28):1-16.

Dabaro D., Birhanu Z., Negash A., Hawaria D., Yewhalaw D., 2021 Effects of rainfall, temperature and topography on malaria incidence in elimination targeted district of Ethiopia. Malaria Journal 20(1):1-10.

Dagen M., 2020 History of malaria and its treatment. In: Antimalarial agents. pp. 1-48, Elsevier.

Daily J. P., Minuti A., Khan N., 2022 Diagnosis, treatment, and prevention of malaria in the US: A review. JAMA 328(5):460-471.

de Moor I. J., Bruton M. N., 1988 Atlas of alien and translocated indigenous aquatic animals in southern Africa. A report of the Committee for Nature Conservation Research National Programme for Ecosystem Research. South African Scientific Programmes Report No. 144, Port Elizabeth, South Africa, 310 p.

Eagderi S., Radkhah A., 2015 Length-weight relationship and condition factor of Mosquitofish (*Gambusia holbrooki*) in three inland basins of Iran. Poec Res 5(1):39-43.

Eccles D. H., 1992 FAO species identification sheets for fishery purposes. Field guide to the freshwater fishes of Tanzania. Prepared and published with the support of the United Nations Development Programme (project URT/87/016). FAO, Rome, 145 p.

Fletcher M., Teklehaimanot A., Yemane G., 1992 Control of mosquito larvae in the port city of Assam by an indigenous larvivorous fish, *Aphanius dispar*. Acta Tropica 52:155-166.

Freyhof J., Yoğurtçuoğlu B., 2020 A proposal for a new generic structure of the killifish family Aphaniidae, with the description of *Aphaniops teimorii* (Teleostei: Cyprinodontiformes). Zootaxa 4810(3):421-451.

Frimodt C., 1995 Multilingual illustrated guide to the world's commercial warmwater fish. Fishing News Books, Osney Mead, Oxford, England, 215 p.
Froese R., Pauly D., 2023 FishBase. World Wide Web electronic publication. www.fishbase.org (10/2023).
Gerhard G. S., Kauffman E. J., Wang X., Stewart R., Moore J. L., Kasales C. J., Demidenko E., Cheng K. C., 2002 Life spans and senescent phenotypes of zebrafish (*Danio rerio*). Exp Gerontol 37:1055-1068.
Ghosh A., Bhattacharjee I., Chandra G., 2006 Biocontrol efficacy by *Oreochromis niloticus niloticus*. Journal of Applied Zoological Research 17:114-116.
Ghosh S. K., Tiwari S. N., Sathyanarayan T. S., Sampath T. R., Sharma V. P., Nanda N., et al, 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.
Gupta D. K., Bhatt R. M., Sharma R. C., Gautam A. S., 1992 Rajnikant. Intradomestic mosquito breeding sources and their management. Indian Journal of Malariology 29:41-46.
Hora S. L., Mukherjee D. D., 1938 The absence of millions, *Lebistes reticulatus* (Peters) in India. Malaria Bureau No.4, Health Bulletin No. 12, Delhi, pp. 1-49.
Hugg D. O., 1996 MAPFISH georeferenced mapping database. Freshwater and estuarine fishes of North America. Life Science Software. Dennis O., Hugg S., 1278 Turkey Point Road, Edgewater, Maryland, USA.
Iacob M., Petrescu-Mag I. V., 2008 [Inventory of non-native species of fish from fresh waters of Romania]. Bioflux, Cluj-Napoca, 89 p. [In Romanian].
Jawad L. A., 2021 The presence of gambusia fish in the Southern Marshes of Iraq: Bad or good. In: Southern Iraq's Marshes: Their environment and conservation. Springer International Publishing, Cham, pp. 285-294.
Kailola P. J., Williams M. J., Stewart P. C., Reichelt R. E., McNee A., Grieve C., 1993 Australian fisheries resources. Bureau of Resource Sciences, Canberra, Australia, 422 p.
Kottelat M., Freyhof J., 2007 Handbook of European freshwater fishes. Publications Kottelat, Cornol and Freyhof, Berlin, 646 p.
Kottelat M., Whitten T., 1996 Freshwater biodiversity in Asia, with special reference to fish. World Bank Technical Paper 343, 59 p.
Koutrakis E. T., Tsikliras A. C., 2003 Length-weight relationships of fishes from three northern Aegean estuarine systems (Greece). Journal of Applied Ichthyology 19:258-260.
Kumar A., Sharma V. P., Sumodan P. K., Thavaselvam D., 1998 Field trials of biolarvicide *Bacillus thuringiensis* var. israelensis strain 164 and the larvivorous fish *Aplocheilus blocki* against *Anopheles stephensi* for malaria control in Goa, India. Journal of the American Mosquito Control Association 14:457-462.
Louis J. P., Albert J. P., 1988 Malaria in the Republic of Djibouti. Strategy for control using a biological antilarval campaign: indigenous larvivorous fish (*Aphanius dispar*) and bacterial toxins. Med Trop 48:127-131.
Mag I. V., Bud I., Carșai T. C., 2009 [Feral ornamental fish species in Lake Pețea from Băile 1 Mai]. In: Neobiota din România. Rakosy L., Momeu L. (eds), pp. 184-195. [In Romanian].
Mag I. V., Petrescu R. M., Falka I., 2006 Long term treatment with estradiol valerate acts as endocrine disruptor in adult guppy females (*Poecilia reticulata* Peters, 1859). Scientific Papers Animal Sciences and Biotechnologies 39(1):83-88.
Mathayan S., Muthukrishnan J., Heleenal G. A., 1980 Studies on predation on mosquito larvae by the fish *Macropodus cupanus*. Hydrobiologia 75:255-258.
McClure M. M., McIntyre P. B., McCune A. R., 2006 Notes on the natural diet and habitat of eight danionin fishes, including the zebrafish *Danio rerio*. Journal of Fish Biology 69(2):553-570.
Menon A. G. K., 1999 Check list – fresh water fishes of India. Rec Zool Surv India, Misc Publ, Occcas Pap No. 117, 366 p.
Menon P. K. B., Rajagopalan P. K., 1978 Control of mosquito breeding in wells by using

Gambusia affinis and *Aplocheilus blochii* in Pondicherry town. Indian Journal of Medical Research 68:927-933.
Moxon C. A., Gibbins M. P., McGuinness D., Milner Jr D. A., Marti M., 2020 New insights into malaria pathogenesis. Annual Review of Pathology: Mechanisms of Disease 15:315-343.
Mousavi-Sabet H., Avani A., Sarpanah A., Hasanpoor S., 2021 Length-weight and length-length relationships of an established exotic *Gambusia holbrooki* population, from the Anzali Lagoon in the southern Caspian Sea basin. Poec Res 11(1):6-11.
Mousavi-Sabet H., Salehi M., 2018 Length-weight and length-length relationships of an established exotic mosquitofish population (*Gambusia holbrooki*), from Namak Lake basin in central Iran. Poec Res 8(1):27-32.
Nalim S., Tribuwono D., 1987 Control demonstration of the rice field breeding mosquito *Anopheles aconitus* Donitz in central Java, using *Poecilia reticulata* through community participation: 2. Culturing, distribution and use of fish in the field. Bull Penet Kesehatan 15:1-7.
Nguyen H., Bell J. D., Patil J. G., 2021 Daily ageing to delineate population dynamics of the invasive fish *Gambusia holbrooki*: implications for management and control. Biological Invasions 23(7):2261-2270.
NICD, 1988 Manual of entomological surveillance of vector-borne diseases. National Institute of Communicable Diseases, Delhi.
Noakes D. G. L., Balon E. K., 1982 Life histories of tilapias: an evolutionary perspective. p. 61-82. In: The biology and culture of tilapias. Pullin R. S. V., Lowe-McConnell R. H. (eds), ICLARM Conf Proc 7.
Nosten F., Richard-Lenoble D., Danis M., 2022 A brief history of malaria. La Presse Médicale 51(3):104130.
Odagiu A., Kovacs E., Nowak M., 2020 *Gambusia holbrooki* Girard, 1859 - Biology of the species and its history in Romania as an introduced taxon. Poec Res 10(1):24-35.
Oroian I., Balint C., Păpuc T., 2022 Genus *Phalloceros* Eigenmann, 1907: list of species and peculiarities. Poec Res 12(1):39-45.
Page L. M., Burr B. M., 1991 A field guide to freshwater fishes of North America north of Mexico. Houghton Mifflin Company, Boston, 432 p.
Păsărin B., Gorgan L., Bura M., Botha M., Petrescu-Mag I. V., 2007 The invasive potential of the exotic guppyfish (*Poecilia reticulata* Peters 1859) in temperate zone. Studia Ambientum 1-2:179-187.
Petrescu-Mag I. V., 2007a [Ecology of fishes of the family Poeciliidae and the importance of their research]. In: Ecologie aplicată. Petrescu-Mag I. V. (ed), AcademicPres, Cluj-Napoca, pp.303-319. [In Romanian].
Petrescu-Mag I. V., 2007b [Manipulation of the sexes in guppyculture]. AcademicPres, Cluj-Napoca. [In Romanian].
Petrescu-Mag I. V., 2007c [Current status and performances obtained in the field of world ornamental pisciculture]. AACL Bioflux Pilot :1-124. [In Romanian].
Petrescu-Mag I. V., 2008 [Biophysiological characterization of *Poecilia reticulata* and its particularities]. ABAH Bioflux Pilot (b):1-56. [In Romanian].
Petrescu-Mag I. V., 2009 Winge's sex-linked color patterns and SDL in the guppy: genes or gene complexes? AACL Bioflux 2(1):71-80.
Petrescu-Mag I. V., Boaru M. A., Harsan R., Petrescu-Mag R. M., 2008 Genetic basis of resistance to stress in fishes. Molecular and classical investigations in a few model organisms. AACL Bioflux 1(1):99-110.
Petrescu-Mag R. M., Păsărin B., Şonea C. G., Petrescu-Mag I. V., 2013 Customer preferences and trends for aquarium fish in Transylvania (Romania). North-West J Zool 9(1):166-171.
Pyke G. H., 2005 A review of the biology of *Gambusia affinis* and *G. holbrooki*. Reviews in Fish Biology and Fisheries 15:339-365.
Rahman A. K. A., 1989 Freshwater fishes of Bangladesh. Zoological Society of Bangladesh. Department of Zoology, University of Dhaka, 364 p.
Riede K., 2004 Global register of migratory species - from global to regional scales. Final Report of the R&D-Projekt 808 05 081. Federal Agency for Nature Conservation,

Bonn, Germany, 329 p.
Riehl R., Baensch H. A., 1991 [Aquarium Atlas. Volume 1. Melle: Mergus]. Verlag für Natur-und Heimtierkunde, Germany, 992 p. [In German].
Sabatinelli G., Blanchy S., Majori G., Papakay M., 1991 [Impact of the use of the larvivorous fish *Poecilia reticulata* on the transmission of malaria in RFI of the Comoros]. Ann Parasitol Hum Comp 66:84-88. [In French].
Saha D., Biswas D., Chatterjee K. K., Chandra G., Bhattacharya A., Bhattacharya S., et al, 1986 Guppy (*Poecilia reticulata*) as a natural predator of *Culex quinquefasciatus* larvae. Bull Cal Sch Med 34:1-4.
Sharma V. P., Ghosh A., 1989 Larvivorous fishes of inland ecosystems. In: Proceedings of the MRC-CICFRI Workshop, Malaria Research Centre (ICMR), Delhi, India.
Singh H., Gupta S. K., Vikram K., Saxena R., Srivastava A., Nagpal B. N., 2022 Sustainable control of malaria employing Gambusia fishes as biological control in Jalore and Barmer districts of Western Rajasthan. Journal of Vector Borne Diseases 59(1):91-97.
Spence R., Fatema M. K., Ellis S., Ahmed Z. F., Smitz C., 2007 Diet, growth and recruitment of wild zebrafish in Bangladesh. Journal of Fish Biology 71(1):304-309.
Talwar P. K., Jhingran A. G., 1991 Inland fishes of India and adjacent countries. Vol 1. A. A. Balkema, Rotterdam, The Netherlands.
Tarkan A. S., Gaygusuz O., Acipinar H., Gürsoy C., Ozulug M., 2006 Length-weight relationship of fishes from the Marmara region (NW-Turkey). Journal of Applied Ichthyology 22:271-273.
Vanderplank F. L., 1941 *Nothobranchius* and *Barbus* sp: Indigenous antimalarial fish in East Africa. East African Medical Journal 17:431-436.
Welcomme R. L., 1988 International introductions of inland aquatic species. FAO Fish. Tech. Paper no. 294, 318 p.
Wohlfarth G. W., Hulata G., 1983 Applied genetics of tilapias. ICLARM Stud Rev 6, 2nd edition, 26 p.
*** IGFA, 2001 Database of IGFA angling records until 2001. IGFA, Fort Lauderdale, USA.
*** WHO, World Health Organization, 2020 Malaria eradication: benefits, future scenarios and feasibility: a report of the Strategic Advisory Group on Malaria Eradication. https://iris.who.int/bitstream/handle/10665/331795/9789240003675-eng.pdf
*** World Malaria Reports 2020, 2021, 2022, adapted by Olivia Veit, ECTM and Ula Maniewski, ITM.
*** www.wanda.be/en/a-z-index/malaria-world-map/

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