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The Use of Larvivorous Fish Species to Control Malaria Transmission in Africa: A Review

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ABSTRACT: *Malaria is caused by the Plasmodium parasite, which is transmitted by female Anopheles mosquitoes. There are five Plasmodium species that cause disease in humans; however, the most important species in terms of disease burden are Plasmodium falciparum, which is prevalent in sub-Saharan Africa, and Plasmodium vivax, which is more common in Asia and South America. There were an estimated 219 million malaria cases and 435,000 deaths worldwide due to malaria in 2017; Sub-Saharan Africa carries a disproportionately high share of the malaria burden, with 92% of cases and 93% of malaria deaths in 2017. As well as direct effects on health, malaria is a major cause of poverty and underdevelopment in many countries, due to household and health system costs, absenteeism from school or work, reduced productivity, and premature death. The objectives of this review are to bring to the fore, "the use of larvivorous fish species (that is, fish that eats mosquito larvae, e.g. tilapias and others) to control malaria transmission in Africa. A handful of research works provide evidence that larvivorous fish species can decrease immature mosquito populations in defined water bodies altering mosquitos' metamorphosis. This is not surprising as we know a lot of fish species eat larvae, and this can reduce the proliferation of mosquitos' population and malaria occurrences. It is highly recommended that, the Federal Government of Nigeria (FGN) and the African Union (AU) should embark on a national and regional Malaria Control Using Biological Method (MCUBM) of Larvivorous Fish Species (especially Cichlids, they are found in almost every ecosystems). We all know that the Synthetic Drug Method of Controlling Malaria has not yielded much results, as millions of people (expectant mothers, infants, young ones, adults and the aged/olds) still die of malaria in Africa. Therefore, it is high time we applied this method just like the Kenyan Government tried it; believe me, it will work because mosquitos are always in the increase during the raining season and malaria patients are more during this period. The fish species will equally bridge the protein demand of some Africans in no distance time.*

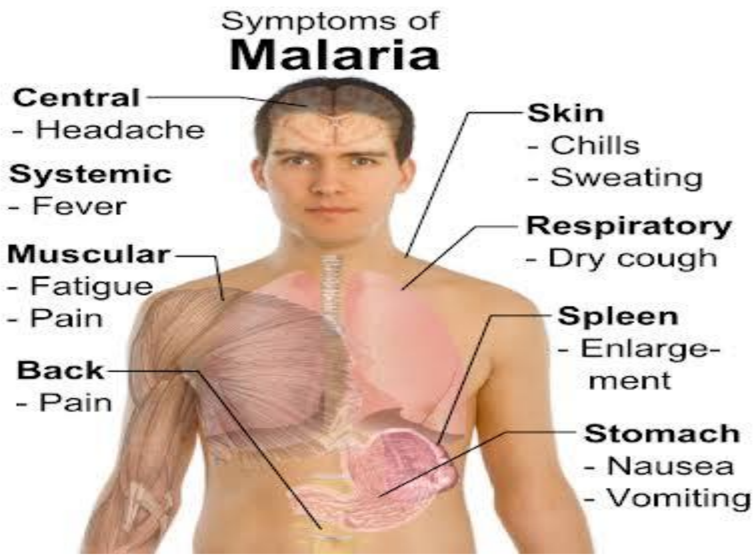
KEYWORDS: transmission, malaria, prevention, fish species, aquatic ecosystem, larvae

INTRODUCTION

Malaria is caused by the *Plasmodium* parasite, which is transmitted by female Anopheles mosquitoes. There are five (5) *Plasmodium* species that cause disease in humans; however, the most important species in terms of disease burden are *Plasmodium falciparum*, which is prevalent in sub-Saharan Africa, and *Plasmodium vivax*, which is more common in Asia and South America. There were an estimated 219 million malaria cases and 435,000 deaths worldwide due to malaria in 2017; Sub-Saharan Africa carries a disproportionately high share of the malaria burden, with 92% of cases and 93% of malaria deaths in 2017 (WHO. 2018). As well as direct effects on health, malaria is a major cause of poverty and underdevelopment in many countries, due to household and health system costs, absenteeism from school or work, reduced productivity, and premature death (Chima *et al*., 2008). Malaria-endemic countries are, on average, poorer by more than five-fold and have lower rates of economic growth than non-malaria endemic countries, with a mean growth of per-capita gross domestic product (GDP) of 0.4% per year versus 2.3% between 1965 and 1990 respectively (Sachs, 2002).

Vector control tools, such as long-lasting insecticidal nets (LLINs) and indoor residual spraying (IRS) of insecticides, play a major role in malaria control, alongside diagnosis and effective treatment of malaria cases, and chemoprevention in some population groups. Scale-up of vector control, diagnosis, and treatment averted 663 million clinical cases of malaria between 2000 and 2015 (Bhatt *et al*., 2015). However, progress against malaria is stalling and a high burden of morbidity and mortality still remains (WHO. 2017; WHO. 2018). The World Health Organization (WHO) set out ambitious targets in the Global Technical Strategy to eliminate malaria in at least 35 countries by 2030 (WHO. 2015a).

Figure 1: COMMON SYMPTOMS OF MALARIA PATIENTS



Source: (World Malaria Report, 2013)

Larviciding refers to the regular application of microbial or chemical insecticides to water bodies or water containers to kill the aquatic immature forms of the mosquito (the larvae and pupae) (Tusting, 2013). Malaria vectors lay their eggs in standing water and the eggs develop through a series of life stages (larvae and pupae) into adults. The type of standing water selected by ovipositing females depends on the species in question and can be natural or man-made, temporary or permanent (Bruce-Chwatt, 1985). For example, *Anopheles stephensi* prefers containers such as water tanks, some species prefer brackish habitats (*Anopheles aquasalis* in Latin America), while others prefer riceland habitats (*Anopheles arabiensis*). There are several different types of larvicide, including chemical larvicides (using conventional insecticides, such as temephos, or insect growth regulators, such as pyriproxyfen, methoprene, and diflubenzuron), microbial larvicides (such as Bacillus thuringiensis israeliensis (Bti) and Bacillus sphaericus (Bs)) and oils.

Larvivorous fish species have also been used as a form of malaria control. Larvicides have varying modes of action. For example, surface films, such as mineral oils and alcohol-based surface products, suffocate the mosquito larvae and pupae by covering the surface of a water body. This is different from synthetic organic chemicals, such as organophosphates, which inhibit cholinesterase and affect the central nervous system of the mosquito. Insect growth regulators interfere with insect metamorphosis and prevent adult emergence from the pupal stage. Microbial larvicides function by bacterial proteins binding to the larval gut, which cause the larvae to stop eating and dies (WHO. 2013).

Many of the principles behind vector control come from the theory of vectorial capacity developed by George Macdonald in the 1950s. Vectorial capacity describes the total number of potentially infectious bites that would eventually arise from all the mosquitoes biting a single perfectly infectious (i.e. all mosquito bites result in infection) human on a single day. Vectorial capacity can be linked to the basic reproduction ratio of a disease which is the estimated number of secondary infections potentially transmitted by a single infected individual in a totally susceptible population (Black, 1968; Macdonald, 1957). The basic reproduction number represents the theoretical estimate of the intensity of transmission. The George-Macdonald model shows that vectorial capacity is most sensitive to changes in adult mosquito survival, which led to the prioritization of IRS and LLINs as vector control tools in the 1950s. However, the vectorial capacity model does not adequately consider the aquatic stages of the vector and so the potential of larviciding is likely to have been underestimated (Brady *et al*., 2016). Models show that larval source management (LSM) reduces mosquito population density linearly with coverage if adult mosquitoes avoid laying eggs in treated habitats, but quadratically if eggs are laid in treated habitats and the effort is therefore wasted (Smith *et al*., 2013). This would mean that if the most productive habitats are targeted, larviciding could be highly effective even without extensive coverage. Larviciding may also operate against both indoor and outdoor (e.g. *Anarabiensis*) biting and resting mosquitoes, unlike LLINs and IRS. This is beneficial, since in some settings anthropophillic vectors are able to sustain transmission even with high coverage of LLINs or IRS, or both (Bayoh *et al*., 2010; Russell *et al*., 2010; Lwetoijera *et al.*, 2014), and several studies have also shown evidence of behavioural adaptation of vectors towards early evening biting which may reduce the effectiveness of indoor interventions (Gatton *et al*., 2013). Thus larviciding may be effective against 'residual malaria transmission', which is generally defined as transmission that exists despite universal coverage of LLINs or IRS to which vector populations are fully susceptible (Durnez and Coosemans, 2013; Killeen, 2014).

Stages of Adult Female Mosquitoes *Anopheles* Transmission Of Malaria

As adult female *Anopheles* mosquitoes transmit malaria, the intensity of transmission is partly dependent on the following:

- Whether *Anopheles* are infected with the *Plasmodium* sporozoite stage;
- How many *Anopheles* feed on humans during the transmission season or year.

The percentage of infected mosquitoes multiplied by the biting rate is a common parameter by which to estimate the force of infection, and is called the entomological inoculation rate (EIR).
Anopheles mosquitoes lay their eggs in water sources in which they develop into larvae and then pupae. *Anopheles* larvae are found in a wide range of habitats, including fresh or salt-water marshes; rice fields; mangrove swamps; edges of streams and rivers; grassy ditches; and small, temporary rain pools. Most species prefer clean, unpolluted water. Some mosquitoes may prefer specific sites in which to lay eggs, whilst others use a wide variety of larval habitats (such as temporary ground water pools, including footprints and ditches, as well as more permanent water sources, such as swamps and wells). The abundance of adult mosquitoes depends on a variety of factors, including the number and size of suitable oviposition sites and the density of the immature mosquito stages at these sites. Several other ecological and environmental factors may influence the adult anopheles population, such as temperature, rainfall patterns, and availability of blood meal sources.

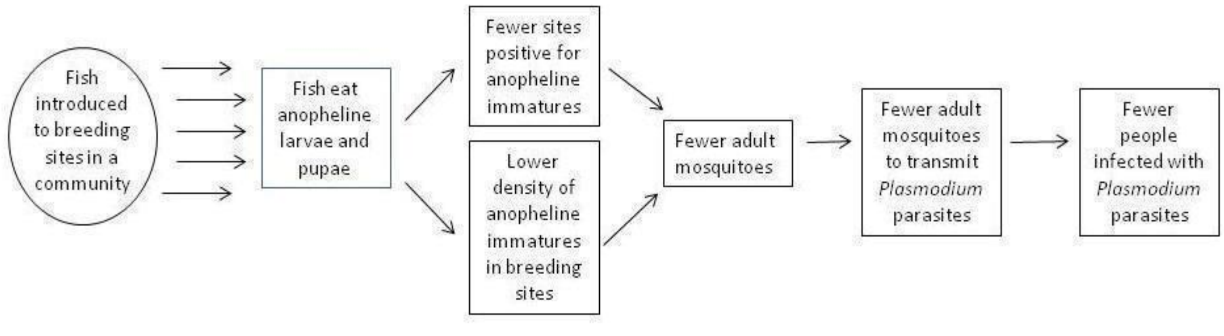


Figure 2: Larvivorous fish for preventing malaria transmission: conceptual framework.

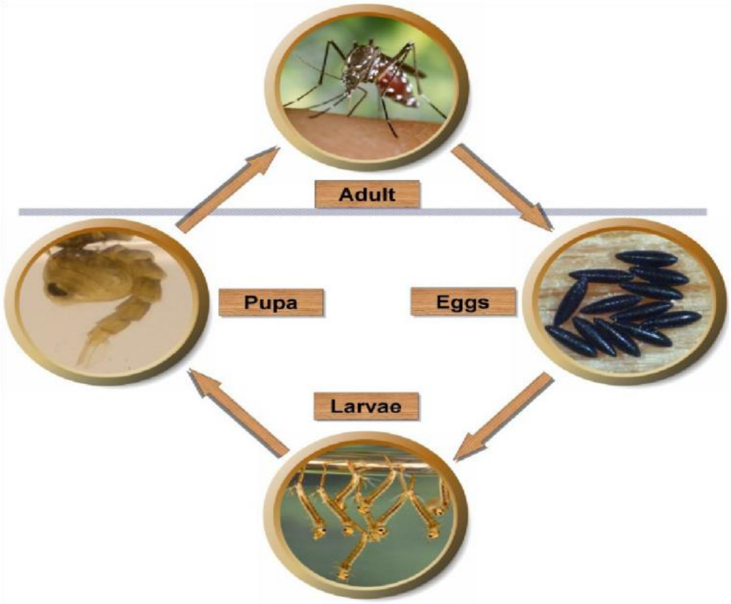


Figure 3: The life cycle of mosquitoes (Aymere and Laikemariam, 2006)

The larger the mosquito population, the greater the potential number of bites by vectors on humans, unless people take measures to avoid mosquito bites, such as sleeping under an LLIN. For a given sporozoite rate, increases in human-biting rate or mosquito density, or both, will result in higher inoculation rates and greater malaria transmission. If the size of the vector population is limited by interventions that reduce the number of larval habitats or the density of vector larvae per larval habitat, then malaria transmission to humans (with all other factors remaining the same) might potentially be reduced (Fig. 1). However, reducing the density of *anopheles* immature mosquitoes at a larval habitat might have little or no effect on adult numbers because adult numbers may be determined largely or entirely by other factors. Reductions in the density of immature vectors could result in larger, more robust, longer-lived adults through reduced competition between immature *Anopheles* for resources (density dependent effects), thereby minimizing the potential reduction in malaria transmission. However, Bond et al. (2005) demonstrated that *Anopheles pseudopunctipennis* larvae had significantly prolonged developmental times in the presence of (*Poecilia sphenops)* fish species and emerged as smaller adults. Smaller adult females can have reduced host-seeking responses, and may produce smaller egg batches (Lyimo and Takken, 1993; Takken *et al*., 1998).

AIM AND OBJECTIVES OF THE REVIEW

Aim

The work aims at reviewing recent data on the use of larvivorous fish species to control malaria transmission in Africa.

Objectives

The objectives of this review are to:

i. Identify larvivorous fish species in Africa;

ii. Consider how larvivorous fish species can control malaria transmission in Africa.

Another Way to Control Malaria Is Needed

There is a need for new tools in malaria vector control if the goals set by the WHO Global Technical Strategy are to be achieved (WHO. 2018). Malaria vector control currently relies largely on LLINs and IRS. Although the WHO recommends the use of LSM (including larviciding) as a supplementary control measure (WHO. 2013), larviciding is not widely used by malaria control programmes. This is despite historical and contemporary successes with the use of larviciding for vector control. Programmatic application of "Paris Green", an arsenic-based compound toxic to larvae, contributed to the elimination of species belonging to the *Anopheles gambiae* complex in Egypt and Brazil (Shousha, 1948). Larviciding is routinely practiced by mosquito control programmes in the USA and Europe (Becker, 1997; Floore, 2006). Larviciding has also been hugely successful against other vector-borne diseases; for example, Bti and temephos were used to control species of the *Simulium damnosum*, complex "vectors of *Onchocerciasis*" in Brazil and the continent of Africa as a supplement to mass drug administration (MDA) (Sékétéli, 2002; Gustavsen *et al*., 2011).

Larviciding has the potential to overcome several challenges currently facing malaria vector control. First, larviciding is able to target outdoor resting and biting mosquitoes that are less affected by LLINs and IRS. Second, it could be used to tackle residual foci of malaria where high coverage of LLINs and IRS is not sufficient to eliminate malaria. Last, larviciding could be used together with other interventions as part of an insecticide resistance management strategy. Insecticide resistance has been reported in all major malaria vectors and involves all classes of insecticide (but particularly pyrethroids) and may threaten the effectiveness of insecticide-based vector control (WHO. 2012a). The distribution and intensity of insecticide resistance has been increasing over time. Of 80 malaria-endemic countries reporting insecticide resistance monitoring data since 2010, 68 reported resistances to at least one insecticide class and 57 reported resistances to two or more insecticide classes (WHO. 2018). The WHO Global Plan for Insecticide Resistance Management recommends the use of insecticide-based and non-insecticide-based interventions targeting both immature and adult mosquitoes as an insecticide resistance management strategy (WHO. 2012a). This is also aligned with Integrated Vector Management (IVM), an adaptive, evidence-based, and multi-sectorial approach to vector control, which is recommended by the WHO for more effective, sustainable, and ecologically sound vector control (WHO. 2008).

Howard et al (2007) researched on malaria mosquito control using edible fish in western Kenya: preliminary findings of a controlled study. They reported a field trial data on Oreochromis niloticus for malaria mosquito control and shows that this species, already a popular food fish in western Kenya, is an apparently sustainable mosquito control tool which also offers a source of protein and income to people in rural areas. There should be no problem with acceptance of this malaria control method since the local communities already farm this fish species. Vatandoost (2021) researched on the use of larvivorous fishes for control of aquatic stage of mosquitoes, the vectors of diseases. He stated that one of the important environmental friendly malaria vector control is the use of biological control measure, using different species of larvivorous fishes. The artificial introduction of *Gambusia* (mosquito fish) into many countries beyond its native range has affected the natural dynamics of ecosystems. *Gambusia* successfully competes with native fish species and feeds on a wide range of organisms. Mosquito fish, due to their polyphagous nature, deplete the abundance of some invertebrate taxa including predatory insects and zooplankton. Reduction in the abundance of predatory insects consequently reduces the total intensity of their predation on mosquito larvae (Bence, 1988).

Goutam *et al*. (2013) researched on the use of larvivorous fish in biological and environmental control of disease vectors. They opined that the effective reduction of vector population and to minimize the incidence of vector-borne diseases, a holistic approach, incorporating larval and adult mosquito surveillance, environmental and human habitation modification, improved public health systems and health education and community participation is required. This will involve implementation of decentralized mosquito control at regional and national levels, increasing local capacity building, engaging civil society organizations and using the appropriate legislation (such as the application of civil bylaws, building construction act, environmental health act and environmental impact assessment laws). This will not be able to be achieved without the support of local research, inter-sectoral and regional cooperation.

Nwabor (2015) researched on anopheles mosquitoes and the malaria scourge. He observed that the use of Long Lasting Insecticide Treated Nets (LLITN) and Indoor Residual Sprays (IRS) are well established strategies with global recognition and currently ongoing in Africa. However, as a result of shortcomings in these major control measures, new strategies with hopes of blissful success are been sought after. Larviciding (abortion of metamorphosis) and constant and adequate environmental sanitation seems to be the next option available for use. This article therefore takes a look at the vector- anopheles mosquito, its ecology, productivity and distribution. It also considers malaria and the various control and preventive measures currently targeted at its eradication.

Tusting (2013) stated that WHO deliberations led to the recommendation of LSM as a supplementary malaria vector control intervention, and a WHO operational manual on LSM (WHO. 2012b; WHO. 2013). Although, all LSM interventions have the aim of reducing mosquito larvae, the ways they are carried out are very different and effectiveness is likely to differ. For example, habitat modification (a permanent alteration to the environment such as drainage of aquatic habitats) is different to regular application of chemical or microbial larvicides to a water body. Due to the diversity of forms of LSM, a new assessment of larviciding alone is justified, thus splitting the original Cochrane Review on LSM (Tusting, 2013).

Fish species belonging to 32 genera under seven families are used for mosquito control, and the family Cyprinodontidae contribute the highest number of genera (15) and species (300) (Goutam *et al*., 2013). Other promising species for mosquito control belong to the genera Aphanius, Valencia, Aplocheilus, Oryzias, Epiplatys, Aphyosemion, Roloffia, Nothobranchius, Pachypanchax, Rivulus, Fundulu and Cynolebias (Walton, 2007).

WHO recommendations from year 2012 stated that antilarval measures are likely to be cost-effective for control of malaria in areas where the larval habitats are limited in number, permanent, and easily found (that is, they are "fixed, finite and findable") (WHO-GMP. 2012). WHO stated that environmental factors that increase the likelihood that larval control will be effective include a short transmission season, cool temperatures that extend for the duration of the immature stages, and larval habitats that are manmade and homogeneous in nature? In Africa, larviciding is thought to have the best potential to be effective in urban and arid areas and possibly in the East African highlands (WHO-GMP. 2012). Indeed, the Cochrane Review of mosquito LSM indicated that the intervention often appeared to impact transmission when implemented in areas where it was feasible to do so (Tusting, 2013). Whether larvivorous fish are an option for LSM is the subject of this Cochrane Review. Since the 1970s, the WHO has promoted the use of larvivorous fish as an environmentally friendly alternative to insecticide-based interventions for malaria control. A WHO sponsored interregional conference on malaria control in 1974 reported that "the utilization of larvivorous fish, mainly *Gambusia* or suitable local species, is the only practical measure that can be recommended where applicable, as in lakes, ponds, pools, wells, rice fields" (WHO. 1974). The 2001 regional meeting in Kazakhstan recommended that more studies on larger numbers of local larvivorous and phytophagous fish be undertaken in different ecoepidemiological settings in that region, and that the search for effective larvivorous fish should continue (WHO-EURO. 2001).

More recently, momentum has gathered in efforts to eliminate malaria, resulting in the 2006-2015 WHO-EURO regional strategy (WHO-EURO. 2006) and the 2014-2020 WHO-EURO regional strategy (Ejov, 2014), which includes larval control by introduction of larvivorous fish preferentially over other forms of larviciding. However, in its current framework for malaria elimination, the WHO does not include larvivorous fish among the recommended vector control strategies for elimination of malaria (WHO 2017); someone may query that? WHO recommendations for larviciding as a general strategy are guarded and conditional, but the use of fish species are often included in listings of options, alongside clearly established effective measures such as LLINs. For example, the WHO integrated vector management plan to control malaria includes the "effective use of biologically-based agents such as bacterial larvicides and larvivorous fish" (HELI. 2005). Fish were one of the traditional means of malaria control in the ex-Soviet Republics of Central Asia, where their use continues (Kondrashin, *et al*., 2017; RTDC. 2008; Zvantsov, 2008). For example, the Global Fund provided funds for implementation of larvivorous fish against malaria in Tajikistan, although this investment appears modest (UNDP. 2013).

Thus, there appear to be differing views on whether introducing larvivorous fish is an effective larvicidal approach; some are strong advocates, whilst others question whether sufficient evidence exists to demonstrate its effectiveness, and whether the strategy can achieve the large reductions in larval numbers required to impact the size of the adult population. In addition, problems are associated with finding and treating all anopheles mosquito larval habitats within a specific area, and some larval habitats may be unsuitable for treatment.

Dissemination of larvivorous fish as a control strategy for malaria has the potential for adverse effects on local ecosystems by reducing or eliminating indigenous fish, amphibians, and invertebrates (Walton, 2007). Therefore, we carried out a systematic review of reliable research examining whether evidence shows that this form of larviciding has an impact on malaria. We also sought evidence of the potential to affect transmission, by summarizing studies on the effects of introducing fish on the density and presence of immature anopheles mosquitoes at potential larval habitats (Walshe, 2013).

Malaria Prevention and Control

Despite the huge investment and intensive research in the development of malaria vaccine, science is yet to record a breakthrough. However, a number of effective preventive methods are currently utilized to combat malaria. The policies and prevention strategies used are defined by the available resources and epidemiological setting of the diseases (Nejla, 2007). Environmentally, to prevent these diseases, the mosquito population must be kept at a low level at all times. The most effective way to control the mosquito population is to get rid of their breeding sources (National Environment Agency, 1995). As far as possible, stagnant waters should be removed permanently by good and regular housekeeping practices such as filling up ground depressions, disposing discarded containers properly and clearing choked drains and roof gutters. For those mosquito breeding habitats that cannot be removed permanently, a competent pest control operator should be engaged to look out for them within premises and treat them with insecticides to prevent breeding. Prevention of malaria encompasses a variety of measures that may protect against being bitten by the disease vector or against the development of disease in infected individuals (WHO. 1992). Full coverage and access to prevention methods is the means to reducing malaria incidence and eradicating the disease. There are three primary prevention strategies that are currently being utilized by 107 malarious countries. The first is drug treatment, the second is indoor residual spraying to eradicate mosquitoes, and the third, is mosquito nets to prevent bites (WHO. 2005).

Fig 1.3: A woman suffering from malaria

Source: (Alamy Stock Photo, 2011: Mabonto Health Clinic, Tonkolili, Sierra Leone).

Larval Control

Larval control is the foundation of most mosquito control programmes. Whereas adult mosquitoes are widespread in the environment, larvae must have water to develop. Control efforts therefore can be focused on aquatic habitats. Minimizing the number of adults that emerge is crucial to reducing the incidence and risk of disease. The three key components of larval control are environmental management, biological control, and chemical control. Larviciding is a general term for killing immature insects by applying agents, collectively called larvicides, to control larvae and/or pupae stages of these insects (FMC. 2009). This is an evolving control measure that targets the larva stage of the mosquito. Many people think that the best time to begin a mosquito control programme is when the numbers of biting female mosquitoes reach an intolerable level. Contrary to this believe, the best time to begin a mosquito management programme is before the adult mosquitoes emerge. Control efforts should begin immediately after the mosquito eggs have hatched, the breeding site should be inspected, and the numbers of larvae present quantified to determine whether or not the use of an insecticide is justified (CDC. 2004). Mosquitoes are most efficiently and economically destroyed when they are in the larval stage and are concentrated in their breeding site. Preventing the larvae from becoming adult mosquitoes minimizes the area that would have to be treated. It also prevents the development of an annoyance or health problem and it reduces the potential environmental impacts of the adult mosquito control programme (CDC. 2004). Larviciding can reduce overall insecticide use in a mosquito control programme by reducing or eliminating the need for ground or aerial application of insecticides to kill adult mosquitoes (CDC. 2004). Nandita *et al*. (2008) considered mosquitoes in the larval stage an attractive target for pesticides because they breed in water and, thus, are easy to deal with in this habitat whereas, Ubulom *et al*. (2012) opined that larviciding is a preferred option in vector control because larvae occur in specific areas and can thus be more easily controlled. Treatment of mosquito breeding sites provides control before the biting adults appear and disperse from such sites.

Chemical Larvicides

Chemical pesticides are rarely used to control mosquito larvae. Organophosphate larvicides are used infrequently because of their potential non-target effects and label restrictions. Temephos is currently the only organophosphate registered for use as a larvicide in California (CDPH. 2010). This product can be safely and effectively used to treat temporary water or highly polluted water where there are few non-target organisms and/or livestock are not allowed access. The efficacy of temephos may be up to 30 days depending on the formulation (CDPH. 2010).

Some Fish Species that Eats Mosquito Larvae

Goldfish

Goldfish are the most popular freshwater aquarium fish. This fish is often the first pet for many fish keepers because of their colorful appearance, hardiness, and easy maintenance. The common goldfish belong to the Cyprinidae family and are native to East Asia. They are a relatively small member of the carp family and are closely related to other ornamental fish like koi. There are over 200 goldfish species created through selective breeding. Most of these species consume mosquito larvae. *Comets* and *Shubunkin* goldfish eat mosquito larvae in abundance. Their dark coloration makes them easy to blend in with their surroundings to spot and eat the mosquito larvae. Also, smaller goldfish find it easy to maneuver in the pond and look out for the mosquito larvae hidden behind the plants and other hiding spots. Aquarists often feed mosquito larvae to their goldfish in captivity, which is healthy for their growth. Goldfish consume a lot of mosquito larvae in the early stages of their development (Haugen, 2023).

Plate 1: Goldfish

Guppies

Guppies, also known as millionfish and rainbow fish, belong to the Poeciliidae family. They originated from northeast South America, though most prevalent in Brazil and Guyana. Due to their vast distribution, guppies are now found worldwide, except in Antarctica. These fish are commonly kept in tanks and ponds. They are favorites among aquarists due to their stunning coloration and beautiful markings that can liven up any aquarium. One of the unique features of guppies is that they can consume nearly their body weight in mosquito larvae. Hence, they are considered a cheap and reliable option to control the mosquito larvae population. Besides mosquito larvae, guppies feed on algae, plant matter, diatoms, aquatic insect larvae, and tiny crustaceans. In captivity, you can feed your guppies a balanced and nutritious diet consisting of high-quality flakes, pellets, and green veggies. Live and frozen food such as bloodworms, brine shrimp, daphnia, etc. that are rich in proteins can also be given as occasional treats to guppies (Haugen, 2023).

Plate 2: Guppies

Zebra Danios

Zebra danios are another fish well known to eat mosquito larvae. They are one of the most popular tropical fish species in the world. These fish have a unique appearance, making them stand out from their counterparts. They have stripes along their body and fins. Their small size, usually less than 2.5 inches long, makes them ideal for a community tank. They do best when they are kept in groups of at least five or more. Zebra danios not only eat mosquito larvae but also consume mosquito pupae. Mosquito larvae are a good protein source for zebra danios. Aquarists often feed mosquito larvae to zebra danios as it helps enhance their color (Haugen, 2023).

Plate 3: Zebra Danios

Golden Orfe

Golden orfe is a freshwater fish belonging to the Cyprinidae family. They are found in rivers, lakes, and ponds across Asia and Northern Europe. They are long and slim with yellow-colored bodies and usually have small black spots across their backs. The golden orfe is a carnivorous fish that feeds mainly on invertebrates like insects, worms, mollusks, snails, and small fish in its natural environment. These fish also prey on aquatic pests such as mosquito larvae and water beetles. They are a great addition to a pond for controlling the mosquito larvae population along with large fish such as koi and goldfish (Haugen, 2023).

Plate 4: Golden Orfe

Koi

Koi are ornamental fish native to Japan. They are popular for their colorful patterns and bright colors. They are highly active fish that require plenty of space to swim around. Their large size makes them ideal for an outdoor pond. Koi do eat mosquito larvae but in moderation. They do not actively seek out mosquito larvae, unlike other fish. However, if there is an ample supply of mosquito larvae, then koi will happily devour them. Mosquito larvae are healthy for koi as they contain essential nutrients for the optimum growth of koi (Haugen, 2023).

Plate 5: Koi

Plecos

Plecos or suckermouth catfish is a tropical freshwater fish inhabiting tropical northeast South America. This fish is primarily found in northeastern Brazil, Guiana, and Trinidad and Tobago. Plecos are bottom-dwelling fish popular among aquarists for their unique ability to clean tank algae and debris. Just like koi, plecos also consume mosquito larvae in moderation. They are not a massive consumer of mosquito larvae and like to feed more on algae, plant matter, wood, and small insects. They are compatible with many other fish species of similar temperament. However, you should not house them with other plecos to avoid competition for space and food (Haugen, 2023).

Plate 6: Plecos

Mosquitofish

Mosquitofish, known by its generic name *Gambusia* fish species, is the most voracious consumer of mosquito larvae. These fish are very effective at controlling the mosquito larvae population as they have a huge appetite for mosquito eggs and larvae. Mosquitofish are native to southern parts of Indiana and Illinois throughout the Mississippi Basin and the northern Gulf of Mexico tributaries. These fish are tiny, having a dull grey body with rounded caudal and dorsal fins. They have a large abdomen and an upturned mouth. Mosquitofish are considered larvivorous. This is because they eat a lot of mosquito larvae and other aquatic insects, which can be a nuisance and spread diseases. A single mosquitofish is known to consume more than 100 mosquito larvae in a single day. It has been observed that these fish can consume mosquito larvae up to a maximum of 42% to 167% of their body weight. These fish feed on mosquito larvae throughout their life. They also feed on zooplankton, beetles, insect larvae, small insects, and detritus matter. Mosquitofish were introduced directly in many waterbodies worldwide as a biocontrol mechanism for the mosquito larvae population. This, in turn, affected other aquatic species negatively. Health departments across various states also used these fish widely to curb dreadful diseases like malaria and dengue (Haugen, 2023).

Plate 7: Mosquitofish

Bluegill Fish

Bluegill fish are freshwater fish native to North America. They inhabit the shallow waters of rivers, lakes, ponds, streams, and creeks. These fish have a highly compressed body. Another distinctive feature is their coloration. They have a deep blue and purple color on the gill and face, orange to yellow belly, and olive-colored bands on the side body. Bluegill fish can grow up to 12 inches in length and need a large tank of at least 75-gallon capacity to live peacefully. These fish are voracious predators and consume mosquito larvae in abundance. Apart from mosquito larvae, they feed on small fish, shrimp, snails, worms, small crustaceans, insects, aquatic plants, and algae in their natural environment (Haugen, 2023).

Plate 8: Bluegill Fish

Minnows

Minnow is a common name for a lot of small freshwater fish species belonging to the several genera of the Cyprinidae family. They are primarily found in North America. They have tight and slender bodies with dark brown color on top and green to dark olive sides. Minnows feed heavily on mosquito larvae and are an excellent choice to control their population. According to a study by the University of Wisconsin, minnows are considered a natural, biological, and long-term solution for controlling the mosquito population. They are also more economical and ecologically friendly than other chemical options to restrict mosquito breeding (Haugen, 2023).

Plate 9: Minnows

Bass Fish

Bass is a common name shared by many freshwater and marine species, many of which are native to North America and surrounding waters. There are many varieties of bass fish, and their appearance varies greatly depending on their habitat and size. These fish devour mosquito larvae as its preferred food. Other than mosquito larvae, bass fish feed on various food depending on their size and age. Young bass fish mainly feed on small crustaceans, aquatic insects, zooplankton, and other tiny organisms. On the other hand, adult bass fish eat small fish such as crayfish, shiners, minnows, sunfish, trout, etc., along with frogs and worms (Haugen, 2023).

Plate 10: Bass Fish

CONCLUSION

Malaria fever is a disease that is killing millions of people in the tropical and subtropical regions such as Sub-Saharan Africa, South and Southeast Asia, Pacific Islands, Central America and Northern South America. This sickness which you cannot get while in Europe and some parts of America is caused by mosquitoes. There are no mosquitoes in Europe and some parts of America because of their weather. Malaria fever comes with headache, general feeling of discomfort, nausea and vomiting, diarrhea, abdominal pains, high temperature; loss of appetite, weakness (fatigue), pale skin, muscular/joint pains, chills, rapid breathing and heart rate; cough, anemia and sometimes dizziness.

There are over one hundred (100) antimalarial drugs in Africa yet millions of persons are dying yearly because the chemical method is not effective; mosquito parasite is quick to gain immunity in the antimalarial drugs' potencies. Therefore, it is high time for us to try the larvivorous fish species (biological) control measure with the Kenyan researchers for the whole Africa. The photos of some of the fish species that consumes mosquitoes' larva in aquatic ecosystems may be far fetch in African aquatic ecosystem unlike cichlids that are found and can thrive in every African aquatic ecosystem as that of Nigeria that I see in gutters, creeks, ponds, rivers, lakes, bank of lagoons and estuaries.

Recommendations

World Health Organization currently recommends larviciding and other larval source management (LSM) interventions as a supplementary malaria control intervention: unlike insecticide-treated nets (ITNs) and indoor residual spraying (IRS) which target indoor vectors, LSM could potentially target outdoor as well as indoor transmission. As a result, many programmes in the elimination phase are now considering LSM including larviciding to tackle the remaining foci of malaria transmission but chemicals are unfriendly to aquatic life. This review strongly suggests the use of larvivorous fish species to eliminate mosquito population, thereafter solving the menace of malaria transmission to humans especially aquaculture workforce. A sick man can never be as productive as when healthy.

This review provides research evidence that larvivorous fish species can decrease immature mosquito populations in defined aquatic ecosystems. This is hardly surprising as we know fish eat larvae, and in itself sufficient evidence to support investing in the intervention as a policy without further scientific research. What is unclear is whether this method is ecologically friendly in the food web considering invasive species trophic level. Fish stocking is always going to be expensive but not with cichlids, and the effects almost inevitably will be marginal given the large numbers of water bodies usually present in areas where malaria-transmitting *Anopheles* lay eggs; of course, fisheries and hydrobiology experts will be involved.

If researchers judge that this is a potentially effective intervention, then well-designed experimental studies to examine the effects on malaria in humans or, at the very least, on the Larvivorous Fish Species Control method is necessary. It is important to note that researchers should carefully consider the design of the control method and should randomly allocate interventions to sites to minimize the risk of bias. In addition, researchers should undertake power calculations to decide the size of the action area for the programme.

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