Original Article

A narrative review of the control of mosquitoes by Larvivorous fish in Iran and the world

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Abstract
Background and purpose: Mosquitoes are responsible for the transmission of many pathogens such as malaria, yellow fever, dengue fever, and so on. The control of mosquitoes using chemical insecticides is not always a sensible approach, so, alternative biological control methods, especially the use of larvivorous fishes, can play a significant role in controlling of mosquito larvae.
Materials and Methods: In this narrative review study, papers and dissertations were collected without time and language limits from international electronic databases in Google Scholar, PubMed, ScienceDirect, Web of Science, Ovid, Medline and WHO site, and Iranian scientific databases including: Barakatkns, SID, Civilica, Magiran, and Medlib using appropriate keywords from 1937 to 2018. Finally, 55 sources were selected and criticized, interpreted, and analyzed.
Results: In the study, some of larvivorous fishes including *Aphanius dispar, Carassius auratus* (goldfish), *Gambusia affinis*, and *Poecilia reticulate* (guppy) have been investigated as important predators of mosquito larvae. Among these fish, *Gambusia*, *Aphanius dispar*, *Colisa Lalia*, *Danio rerio*, Goldfish, Guppy and *Oreochromis mossambica* are present in different regions of Iran.
Conclusion: Given the fact that malaria carriers are present in many regions of Iran and the climate of Iran is also potentially suitable for the transmission of malaria, it is recommended to use larvivorous fishes that are compatible with the environmental conditions of each area.

Key words: Mosquitoes; Biological Control; Larvivorous Fishes; Iran

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1. Introduction

Yearly more than one billion persons are infected or die from vector-borne diseases, of which mosquito-borne diseases make up a significant proportion (1). So, such diseases transmitted by mosquitoes in (almost) all tropical and subtropical countries are a major problem. Because these species are responsible for the transmission of important diseases including malaria, yellow fever, dengue fever, zika, chikungunya, filariasis, encephalitis, etc. It should be noted that the vector control plans have traditionally focused on killing mosquitoes using various pesticides including organophosphates, carbamates, and pyrethroids (2). Although the application of chemical pesticides is considered as an effective method, because of the adverse effects of chemical pesticides, especially on human health, non-target organisms, increasing the resistance of mosquitoes against these compounds and, consequently, the resumption of transmitted diseases has led to the prohibition of using most insecticides for mosquitoes or at least imposing severe restrictions on many of them by environmental protection agencies (3).

On the other hand, the financial burden of insecticide for the vector control programs is a fundamental constraint to widespread use (2). Therefore, the study and application of sustainable and safe methods, such as biological control is noteworthy in mosquito controlling (4). Biological control methods as a friendly way for the environment can be a suitable alternative to decrease the problems arising from the use of pesticides, such as selection pressure for insecticide resistance (2). Today, the use of biological methods in malaria control programs, especially in urban and rural areas, has been well-developed in different countries (5), because this method has the potential to be used with other control methods in the mosquito's integrative campaign (6). There is a wide range of living organisms that help regulate the population of mosquitoes through hunting, parasitism, and competition.

Natural organisms that kill mosquitoes have a various range including predators, parasitoids, entomopathogens, etc. (2). In the biological control of mosquitoes using predators, the role of larvivorous fish that consume the larval stage of mosquitoes is very important (2). Larvivorous fishes are one of the most important biological control agents for mosquitos' control, which began to be used widely in the world since the early 1900s and before the use of DDT (7). Many species of fishes have been used for the control of mosquito larvae as a biological control agent and the results indicated that they could be introduced as one of the best candidates for mosquitos' biological control programs (8, 9).

One of the most important species of larval fishes is *Gambusia affinis*, which has a high potential for larvae. This fish, as a native species in the southern regions of the United States, was transferred to the Hawaiian Islands, then to Spain, Italy, and 60 other countries to control malaria (10). Also from early 1908, the species of *Poecilia reticulata*, a native of South America, was introduced so as to control malaria in India, Britain, and many other countries (10). But the use of biological control methods was limited with the introduction of DDT to control malaria in the mid-1940s. Later, eradicating mosquitoes continued with other artificial insecticides, until the first resistances occurred against the insecticides, and again the use of biological methods was introduced (7). It should be said that natural enemies of mosquitoes, especially in aquatic ecosystems, can play an important role in reducing culicidae populations without making selective pressure (2).

In choosing biological control programs, it is important to select the biological agents. Although larvivorous fish has been demonstrated to be very effective at decreasing mosquito larval density in a variety of habitats (2), in the application of larvivorous fishes, considerations such as searching efficiency, hunting power, adapting to different climatic conditions, and interacting with predators is very important (11). As a result, this method is feasible if there is a proper knowledge of ecology and behavior of the larvivorous fishes and mosquito larvae (12). For example, larvivorous fishes feeding on immature mosquitoes should be small and resistant to drought. Also, they should have ability to live in shallow water among thick grasses, deep water, and various water reservoirs. At the same time, they must be resistant to touch and have the ability to be carried for long distances. They have a high reproduction in their life cycle and can be fed on water, and are interested in being fed from mosquito larvae even in the presence of other kinds of foods.

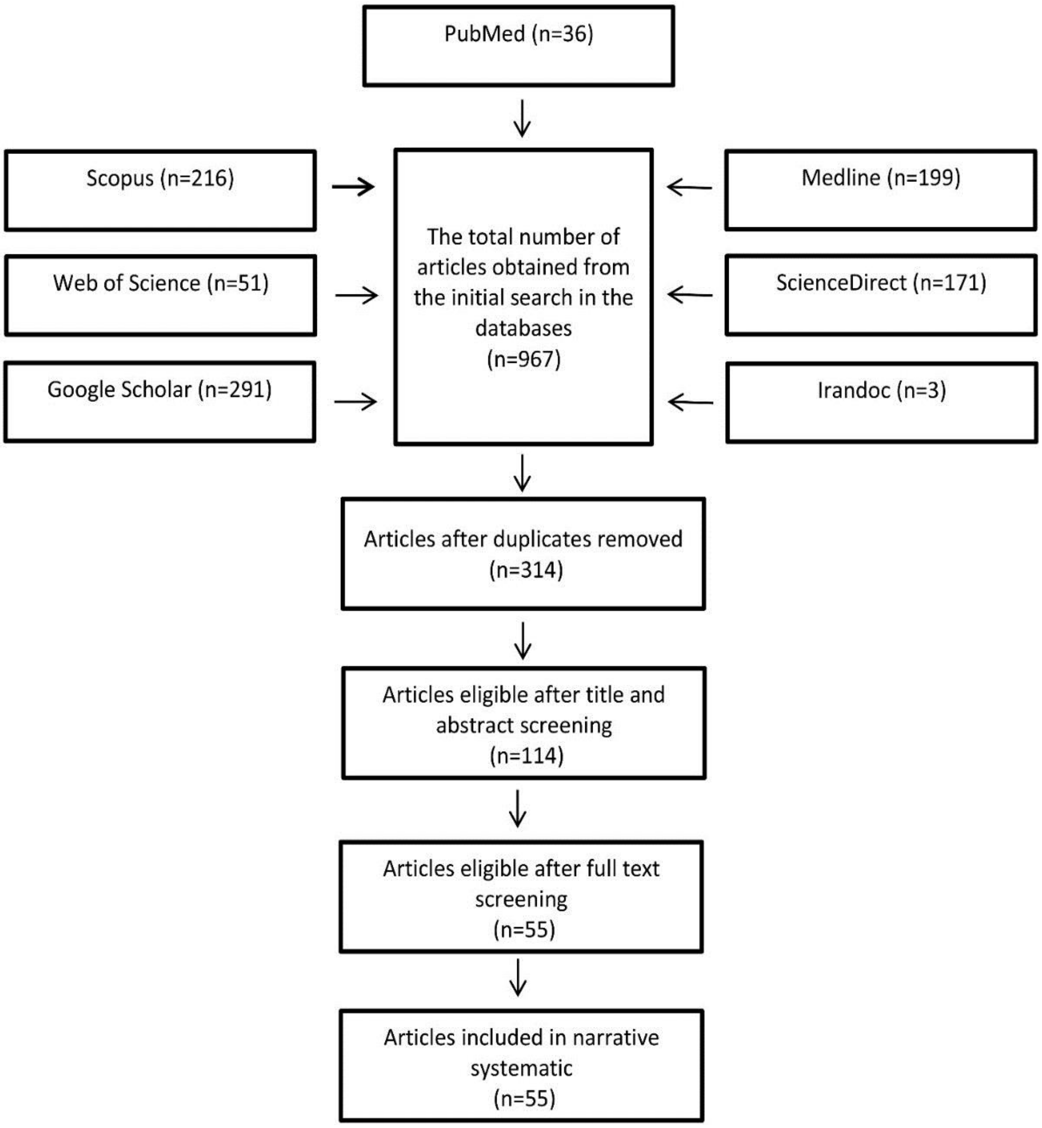
Another important criterion for larvivorous fishes is their appearance. They should not be colorful or attractive to be hunted by other species, and most importantly, they should not have any nutritional value for humans, so that people do not eliminate them by eating (13). It is of course certain that finding a type that has all of the above parameters is difficult, but possible. The classification of larval fishes is usually based on their feeding from the larval habitat. Some fishes, such as *Aplocheilus* and *Gambusia*, feed on the surface of water, and some of them such as Amblypharyngodon mola, *Danio* and *Rasbora*, feed on lower levels of water and some also feed on water depths, such as *Puntius* and *Colisa*. In the eradication program of malaria in Iran, the use of larvivorous fish varieties, especially *Gambusia*, was introduced as an auxiliary strategy along with other control methods of mosquito larvae (14). As in 1969, more than 1.5 million of the fish types were distributed in more than 3000 permanent water collections in Kermanshah (15). For example, after the release of fish in mosquito breeding sites, no population of larvae of *Anopheles* mosquitoes was found in stagnant waters around Kermanshah (15). Similarly, there was a significant decrease in larvae in Fars Province. In the village of Bahram Abad, Bushehr, in larval habitats where fish varieties were present, the larvae were not found, but there were numerous larvae in places where no larvivorous fish was present (15).

Therefore, based on the importance of the issue, the present study was a brief report of various types of larvivorous fish as a biological controller of mosquitoes in Iran and the world, which can provide interactions with prey/predator systems in aquatic ecosystems.

2. *Materials and Methods*

In this study, which was conducted as a non-systematic narrative review, keywords such as larvae, larvivorous fish, Gambusia, mosquito larvae and mosquito biological control were used. This study included an advanced searching in international scientific database including, Pub Med, Web of Science, Google

Scholar, Scopus, Elsevier, WHO and other internal scientific database including, Barakatkns, Sicentific Information Database (SID), Medical Libraries (Medlib), Magiran Database, civilizational reference. A total of 9 scientific sources were collected, including books, articles, theses and reports that were then translated into Persian and English in the period from 1937 to 2017. Unrelated sources and articles were deleted and the resources related to our review were studied. Finally, 55 articles and the scientific sources were selected by following flowchart (Figure 1). Then, they were analyzed according to the purpose of the study.



3. Result

Table 1. Introduction, function and distribution of important species of larvivorous fish based on ecological characteristics and target mosquitoes

Fish species	Dispersion	ecology	Field tests	Distribution in Iran	Mosquito species
Aphanius dispar	India-Pakistan-Sind-Ethiopia-Palestine-Stretches of the Red Sea coast	Salt and sweet water, sewage and contaminated water, stagnant water, sewage wells.	About 3 fish per square meter of surface water eliminates mosquito larvae (19) 97% reduction of *Anopheles arabiensis* and *An.gambiae* (20) Removing *An.culicifacies adanensis* in Ethiopian Urban Area Wells (21)	Balochistan-Hormozgan (22)	*Cx. quinquefasciatus* *An. arabiensis* *An. gambiae complex* *An. culicifacie*
Aplocheilus blockii	East Coast of India, Sri Lanka	Fresh water, dwelling, small streams and rivers with poor plant growth, reservoirs, pools, foam and rivers, wells and wetlands	Reduced populations of *An.stephensi* larvae to 75% in the coastal belt (23) Control of *Aedes albopictus skuse*, resulting in control of chikonugonia fever in tankers, large reservoirs and large barrels of water	was not observed	*An. stephensi* *Aedes albopictus*
Aplocheilus lineatus	Indian, Peninsula and Sri Lanka	Rice fields, aerial tanks, artificial vessels, reservoirs of pools, floor of rivers, marshes	*Ae. aegypti* Linnaeus, (Dengue Fever) (19)	was not observed	*Ae. aegypti*
Aplocheilus panchax	India and Bengal, Orissa, Assam, Punjab, Sri Lanka, Malaya, Myanmar, Thailand and Indonesia.	Quite durable and hardy and active Shallow water, sweet and salty water Wells, marshes, wetlands and contaminated drainage water, stagnant waters containing organic matter contamination	*An. culicifacies* control in irrigation channels, slow currents and low vegetation, river bed, rice fields *An. sundaicus* control in saline waters with algae, rice fields, reservoirs, wetlands, ponds, Control of *Cx. quinquefasciatus* in sewers, reservoirs, ponds, contaminated streams, *Cx. vishnui* control in rice fields, marshes, ponds, pools, streams, irrigation canals,	was not observed	*An. stephensi*
Colisa fasciatus	Myanmar, Punjab, Pakistan and across the peninsula of India	Rivers, lakes and rivers of fresh water Typically, the environment is covered with weeds	In the wells, complete removal of the larvae in one to two weeks after the arrival of 100 fish of the larvae (24)	was not observed	Carriers of filariasis and malaria
Colisa lalia	North India	Slow flows of rivers, lakes, reservoirs Rivers and pools with appropriate vegetation	Production habitats and carriers such as stagnant weeds, margins of pools, tanks, holes and rice fields	Available (25)	Malaria Carriers
Colisa sota	North India	Rivers, pools and among plants Muddy water, stagnant and fresh water	Reduces larvae of mosquitoes in weed water, stagnant waters, and margins of pools, reservoirs, dead rivers, pits and rice fields.	was not observed	Malaria Carriers
Chanda nama	India, Bangladesh and Burma (now Myanmar)	In freshly ground fresh vegetation Ponds, streams, streams, ponds	Suitable for controlling the variety of anopheles in sweet waters to control malaria	was not observed	Malaria Carriers
Oryzias melastigma	India	Freshwater and coastal waters, pools, pools, rivers, canals and rivers, rice fields	Control of Cx. vishnui in rice fields, wetlands, ponds, pools, irrigation canals (24) *Anopheles* sp. and *Culex* sp. In rice fields, the decline in population on the sixth day, to 76.2%, in the subsequent days decreased from 98.3 to 100%, and from the 12th day on, decreased by 100%.	was not observed	*An. culicifacies s.l.* *Cx. tritaeniorhynchus*
Danio rerio	North India, Bangladesh, Myanmar (Burma).	Slow flow, low-pitched wells, grass-clear transparent water,	In the rice farms, rich of *Anopheles* sp. and *Culex* sp. , On the sixth day, the reduction of larvae of age III, IV and IV by 86.8%, on the following days decreased from 92.4 to 99.3%, from the 12th day, decreased by 100% (24)	Available (Sanandaj-Golestan) (26)	*An. culicifacies s.l.* *Cx. tritaeniorhynchus*

Macropodus cupanus	East India, Sri Lanka, West Myanmar, Peninsula and Sumatra	In saline waters, contaminated canals, wetlands, shoals and shallow water, stagnant water, low food resistance or even lack of oxygen (27)	High level of hunting: Average hunting rate: 292.2 larvae per day	was not observed	*Culex quinquefasciatus*
Carassius auratus (goldfish)	China, Korea, Taiwan, Japan, Europe, Siberia, East Asia, India	Aquarium and decorative ponds	The number of larvae of *An. subpictus*, *Cx. quinquefasciatus* and Ar. subalbatus was 193,188 and 132 per day (28) Effectively, *An. subpictus* larvae in reservoirs reduced density from 34.5 to 99.8% (28)	Available (25)	*An. subpictus*
Gambusia affinis	Native US Coastal Waters from southern New Jersey, Italy, Thailand, India	Fresh water, salt water Feeding aquatic and terrestrial insects (fish preference to terrestrial insects)	Daily feeding were 48, 51 and 31 larvae of *An. subpictus*, *Cx. quinquefasciatus* and *Ar. subalbatus* (29) Mean hunting for each *Gambusia* fish is 7.65 *An. subpictus* larvae per day (30) Succeeding in the fight against malaria (15) Decreased *An. subpictus* to 96% (areas where fish have not been introduced, mosquito incidence increased from 55 to 92% (31) The best predator for *An. stephensi* larvae in air tanks (32) Introductions in rice fields have led to a sharp reduction in the density of *Anopheles* larvae (33)	Available (16)	*An. freeborni* *An. Pulcherrimus* *An. Stephensi* *An. Subpictus* *An. Superpictus* *Cx. tritaeniorhynchus*
Poecilia reticulata (guppy)	America, India, West of Venezuela, Guyana	Low temperature intolerance Resistant to contamination	Feeding 18 to 32 *An. subpictus* larvae within 24 hours (34) Reduction of *An. aconitus* mosquito production in rice fields (35) *An. gambiae* larvae control in wipes, using 3-5 fishes up to 85% (36)	Available (25)	*An. gambiae s.s.* *An.stephensi* *An.subpictus*
Nothobranchius guentheri	East Africa, Mambaas Pengani River in Tanzania	Fish growth very fast About 20-100 eggs a day	The most suitable fish for malaria control using the Panama Canal (37)	was not observed	*Cx. quinquefasciatus*
Xenentodon cancila	Pakistan, India, Bangladesh, Sri Lanka, Myanmar and Thailand	In clear streams and permanent streams	Control of the fourth instar larvae *An. subpictus*, *Cx. quinquefasciatus* and *Ar. subalbatus*, consumption of an average of 31, 28, 21 *An. subpictus*, *Cx. quinquefasciatus* and *Ar. subalbatus* during the 24-hour period (29)	was not observed	*An.subpictus* *Cx.quinquefasciatus* *Ar.subalbatus*
Oreochromis mossambica	East Africa, India, Pakistan, Sri Lanka and so on	Rapid growth in saline water The temperature of the die is less than 10^{o} Celsius	third and fourth stage of larvae *Cx. quinquefasciatus* and *An. culicifacies* with a rate of release of 5 fish per square meter (38)	Available (39)	*Cx.quinquefasciatus* *An.culicifacies*
Oreochromis niloticus niloticus	East Africa, West Africa, Nile River, Malaysia	Low salt tolerance (below c12) Suitable for agriculture in the tropical region	Introducing 20 fish in the field, reducing larval after 30 and 45 days, respectively. The removal of fish increased the larval congestion after 30 and 45 days (40)	was not observed	*An. gambiae* *An. Funestus* *An. stephensi*

Table 2. Examples of the use of a combination of two or more species of larvivorous fishes in the control of mosquito larvae

Species of larvivorous fish	Results in control of mosquito larvae
Moroco oxycephalus + Misgurnus anguillicaudatus	Control of *Anopheles sinensis* (41)
Melanotaenia duboulayi، Retropinna semoni, Pseudomugil signifer Hypseleotris galii, Hypseleotris compressa Ambassis marianus, Gambusia holbrooki	Control of *Cx. annulirostris*, most used by *M. dbulaii* (42)
Pseudotropheus, Betta splendens, Osphronemus goramy, Pterophyllum scalare	Control *Anopheles sinensis* Ranking: *P. tropheops*> *B. splendens*> *O. gorami*> *P. scalarae* Average daily feeding of larvae in 1 liter of water: 247, 238, 180 and 40 larva respectively (43)
P. reticulata - Ga. affinis	10 fish of *P. reticulata* and 5 fish of *Ga. Affinis* for feeding larvae of *Anopheles*, *Culex* and *Aedes* (40)
G. affinis - Lebistes reticulatus	Feeding on larva *An. subpictus*, the mean of feeding of larvae by *G. afinis* and *L. reticulatus* is 48 and 32, respectively (40)
C. carpio، Ctenopharyngodon idella, Oreochromis niloticus, Clarias gariepinus	Significant decrease in the fourth instar larvae *An. stephensi* in the 30 and 45 days after the arrival of the fish into the farm (44)
Pseudomugil signifer - Gambusia holbrooki	Nutrition from the age of four larvae *Cx. annulrostris* (45)
Aplocheilus lineatus - Oreochromis mossambicus	A reduction of 80-82% in the density of the *An. sinensis* larvae from the fifth week in the rice field (46)
G. affinis - Tilapia nilotica nilotica	Larva Control *An. freeborni* and *An. franciscanus* in the rice field (47)
Cyprinus carpio - Ctenopharyngodon idella - Tilapia	A reduction in *An. sinensis* during 150 to 170 days in rice fields and also reduction in the transmission of malaria (48)
Carassius auratus - C. carpio - G. affinis	The effectiveness of mosquito control in rice farms in northern Italy (49)
G. affinis , Lethrinus reticulatus	Larvae density of *An. Subpictus* in the presence of *G. affinis* and *L. reticulatus* was 25.7 to 0.36 and 23.7 to 0.5 (34)
Lepisosteus tropicus - Astyanax fasciatus -Brycon guatemalensis - Ictalurus meridionalis - Poecilia reticulata	Control of *Aedes aegypti* larvae in water storage tanks (50)
Cnesterodon decemmaculatus - Jenynsia multidentata	Control of fourth age of *Culex pipiens* (51)
P. reticulata - G. affinis	Control of *Cx. quinquefasciatus* larvae in drainage for about 3 months; reduction of larval congestion from 145 in each batch to 20 in each batch Control of 100% *An. culicifacies* and *An. stephensi* larvae (24)

4. Discussion

The use of biological control methods is expected to play an important role in future carrier management strategies. Unlike chemical pesticides, mosquito control results are unpredictable using biological agents. Therefore, developing and acquiring the necessary skills in this field is very necessary. Targeting interventions is essentially the most effective way to control vector-borne diseases, as most of the current efforts to develop new control tools are limited to laboratory scale (52).

In the application of larvivorous fish to control mosquitoes, two factors of fish adaptation and being native are very important. The most important adaptation of larvivorous fish in larval habitats is the ability to reproduce fish and feed the mosquito larvae. There are several factors that can influence the level of adaptation of larvivorous fish. For example, the use of a variety of pesticides and fertilizers can be harmful to fish used in irrigation fields (17). Aquatic plants, in turn, can also be effective in feeding fish, because it can hide mosquito larvae. Therefore, it is suggested that, before the release of larvivorous fish, an assessment of the effectiveness of one or more species of fish (especially native) is initially made (18). In this regard, fish behavior, the existence of minimum competition for food, proper water temperature, changes in water flow, suitable habitat for spawning, factors affecting species growth, such as diet, number of progenies per year, growth rate, body size, life span, and a lot of food have been introduced as the main factors promoting fish species creation.

On the other hand, it is important to note that introducing and releasing larvivorous fish as non-native species in a new ecosystem may have ecological hazards. Because accidental releases or deliberate releases of fishes may cause some animal species to fall out of their natural range. Also, unplanned releases of larvivorous fish can cause unwanted problems with native counterparts and consequently reduce the efficiency of the mosquito control programs. Therefore, the introduction of a new fish strategy can create a lot of ecosystem hazards. For example, the species *Pseudorasbora parva* is highly competing with other fishes for food, and is a slaughterer of eggs and young fishes (16). Also, *Gambusia* fish can be negatively affected when it is not planted in waters beyond its native range, as it is greedy and highly invasive, with native fish for food and space life compete. It also feeds algae, zooplankton, aquatic insects, as well as eggs, young fish, amphibians, and even diatoms (53). On the other hand, *Gambusia* indirectly causes environmental changes as it increases the pH of the phytoplankton, increases water temperature and dissolved organic phosphorus, and decreases water clarity (54).

In the mosquito control program using larvivorous fish, it should be determined whether larvivorous fish have the ability to live even in drinking water and other waters. The residents are also trained so as not to accidentally kill the fish. When fish are used in different places for controlling mosquitos larvae, periodic addition of fish is essential to maintain the population needed to suppress larval mosquitoes. At times, in order to help the effectiveness and efficiency of larvivorous fish, the need for another larval control agent may also be felt. For example, simultaneous use of larvivorous fish with one of the commercial products of *Bacillus* bacteria is very promising to control mosquitoes in sites where the fish cannot grow and reproduce sufficiently (55).

Considering that there are potential vectors of malaria in many regions of Iran and the climate of Iran has the potential to transmit the disease, it is suggested that, according to various ecological ecosystems of Iran, larvivorous fish that accept the environmental conditions of the area be used. In this regard, according to available findings, *Aphanius dispar* and *Danio rerio* can be used to control *Anopheles culicifacies* in areas, such as Sistan, South of Kerman, and Hormozgan. Also, *Gambusia affinis*, *Aplocheilus blochii*, *Aplocheilus panchax*, *Reiculate* (guppy) *Poecilia*, *Oreochromis niloticus* can be used to control *Anopheles stephensi* in southeast Iran. Finally, *Gambusia affinis* can be used to control *Anopheles superpictus* in the central plateau, mountainous regions of northern Iran and southern provinces of Iran.

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Conflict of interest

The authors also declare that they have no conflict of interest

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