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# Are Mosquitoes 'A Necessary Evil'?

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**Abstract**
There are around 3,500 species of mosquitoes all over the world, of which only a couple of hundred species are responsible for various diseases and deaths. However, the general perception in the society is that all mosquitoes are responsible for incalculable misery of human and animal life causing millions of death hindering social and economic development; mosquitoes should be eliminated from planet earth. On the other hand, mosquitoes are found to be important biotic components playing various ecological roles. They act as predator or prey in different food chains and play the role as pollinator and environmental filter. Mosquitoes might have some role as an indirect selection agent for population regulation. Mosquitoes' role must be evaluated in greater ecological and evolutionary perspectives before appreciating and adopting the policy of mosquito eradication programme, if any. A couple of hundred mosquito species is definitely 'evil' to humans, albeit rest of the members of the mosquito world might be 'necessary' in the nature. This review is an attempt to explore the ecological roles of mosquitoes and their importance in different ecosystems.

**Keywords:** Mosquitoes, necessary evil, ecological roles, mosquito eradication, bioethics

## Introduction
The oldest known mosquito with an anatomy similar to modern species was found in 79 million years old Canadian amber in the Cretaceous period [1]. An even older sister species with more primitive features was found in Burmese amber that is 90 to 100 million years old [2]. Genetic analysis indicates that the sub-families – Culicinae and Anophelinae under the family Culicidae may have diverged about 150 million years ago [3]. There are almost 3,500 species of mosquitoes all over the world [4], of which only a couple of hundreds (only female mosquitoes) are primary or secondary vectors. Interestingly all the female mosquito species in the world do not take blood. However, both male and female mosquitoes need sugar mostly from floral nectar, honey dew, fruits for nutrition and energy [5]. They live in almost every habitable continent except the permanently frozen areas and serve various functions in different ecological conditions.

Mosquito-borne diseases are responsible for significant human morbidity and mortality throughout the world [6]. Malaria is infecting 247 million people and killing one million people every year [7]. Mosquitoes cause immense medical and financial burden by spreading malaria, filariasis, yellow fever, dengue fever, Japanese Encephalitis, Rift Valley fever, Chikungunya virus and West Nile virus. In fact, the cause of the disease and death is the concerned virus/pathogen where mosquitoes are playing the role of vectors supporting and transmitting the disease causing agents. One common perception in the society is that mosquitoes are meant to cause disease, death, discomfort and they should be eliminated from planet earth. Now the question is surreptitiously arising that what would be the effect of the total extermination of mosquitoes? Every species is created through the process of natural selection and has its ecological role in the natural environment and mosquitoes are no exception to that. In spite of waging war against mosquitoes over hundred years through application of improvised tools and techniques, strategies and policies mosquitoes still survive and perpetuate. Today Dengue and West Nile virus are now becoming almost global. This can be interpreted to be some sort of affirmation that mosquitoes survived being the fittest through the process of natural selection and despite aggressive human campaign against them. Hence, an attempt has been made in this review to explore the ecological roles of mosquitoes and their importance in different ecosystems.

**Ecological perspective**

Each and every existing species on planet earth has some ecological role to play. If we consider 'Red Queen' hypothesis, where two groups of closely interacting organisms form evolutionary arms race such as prey-predator; the betterment of one group ultimately leads to the betterment of the interacting group and that is how evolution progresses. In words of Richard Dawkins, "Predators and prey are engaged in an evolutionary arms race, run in evolutionary time. The result has been steady escalation in the quantity of economic resources that animals, on both sides, spend on the arms race, at the expense of other departments of their bodily economy. Hunters and hunted alike get steadily better equipped to outrun (surprise, outwit, etc.) the other side" [8]. Darwin was aware of evolutionary 'arms race' concept, although he did not use the phrase. Improved equipment to outrun does not always lead to improved success in outrunning as the other side in the arms race is upgrading its equipment as well. This is just like as the Red Queen said to Alice, that they have to run fast as they can just to stay in the same place. Hence, prey and predator are two integral components of co-evolutionary dynamics. In various ecological habitats, either mosquito is someone's prey or it preys upon other organisms. Complete eradication of mosquito may halt the evolutionary process. Ecological processes disrupted by extinction or species decline may also lead to cascading and catastrophic coextinctions [9].

Moreover, the concept of 'keystone species' explains that apparently insignificant species, sometimes, might play a vital role in an ecological community, the complete absence of which may disturb the natural rhythm of ecosystem. So, comprehensive studies are needed in this context in order to find out their possible ecological role of mosquito hitherto unknown.

**Pollination by mosquitoes**

The male mosquito does not feed on blood. Instead, it survives on the sugar present in plant nectar. The primary sources of sugar consumed by mosquitoes are nectar from flowers and honeydew excreted by aphids. This feeding habit in return helps in pollination of plants [10]. Though mosquitoes are not considered as major pollinators, an exception exists in sub-arctic regions of Northern Canada and Russia, where they play a significant role in pollination. In other regions, the mosquitoes are outdone by bees and butterflies when it comes to pollination. Hence, the results of mosquito extinction might not be felt in all areas, but it would take a toll in subarctic regions where plants rely on them for pollination [11]. Although most pollination-reports for the cosmopolitan orchid genus *Habenaria* involve different kinds of moths and butterflies, [12] *Habenaria obtusata* is reportedly pollinated by mosquitoes [13, 14]. Orchid pollination by *Aedes* mosquitoes is also reported from Alaska [15]. Moreover, Mauer and Rowley (1999) showed that methylene chloride extract of flowers from four species of plants attract female northern house mosquitoes (*Culex pipiens pipiens*), which indirectly established the mosquitoes as a potential pollinator [16]. Just as eradicating biting midges of the family Ceratopogonidae will have detrimental effects on tropical crops such as cacao [17-19], complete eradication of mosquitoes may have similar effects on many species of plants, which depend on them for pollination.

**Impact of mosquitoes on migratory animals**

Eradication of mosquitoes might make the biggest ecological differences in the Arctic tundra, home to mosquito species like *Aedes impiger* and *Aedes nigripes*. From Northern Canada to Russia, there is a brief period during which they are extraordinarily abundant, forming thick clouds in some areas. The number of migratory birds that rest in the tundra region could drop by more than 50% without mosquitoes to eat.

Mosquitoes consume upto 300 ml of blood a day from each animal in a caribou herd, which are thought to select paths facing the wind to escape the swarm [7]. A small change in path can have major consequences in an Arctic valley through which thousands of caribou migrate, trampling the ground, eating lichens, transporting nutrients, feeding wolves and generally altering the ecology. Hence, it can be said that the complete absence of mosquitoes from the Arctic region will take a toll on the ecological balance of that area [7].

When birds migrate from south to north during summer season, they rely on the huge numbers of mosquitoes that swarm in certain areas. For example, in the Alaskan wilderness with its often inhospitable conditions where food is difficult to find, mosquitoes are a reliable source of food. Migrating birds rely on mosquitoes to fuel up on their way and thus mosquitoes may have an effect on migration path of birds.

**Mosquitoes as environmental filters**

Mosquitoes are important to the environment as a form of natural filter. Mosquito larvae grow in water and feed on detritus that floats and clogs the water surface, utilizing the detritus from choking off nitrogen and oxygen necessary for the survival of the plants below. Mosquito larvae feed on decaying leaves, organic detritus and microorganisms. They may filter-feed, graze microbial biofilms or even shred detritus [20]. In this sense, mosquitoes are an important component of functional wetland ecosystem, processing detritus and aquatic microbes, and eventually providing a link between aquatic and terrestrial systems when they emerge.

Mosquito larvae are important members of the tight-knit communities in the 25-100 ml pools inside the pitcher plants (*Sarracenia purpurea*) on the east coast of North America [21, 22]. A species of mosquitoes (*Wyeomyia smithii*) and midge (*Metriocnemus knabi*) are the only insects that live there, along with microorganisms such as rotifers, bacteria and protozoa. When other insects drown in the water, the midges chew up their carcasses and the mosquito larvae feed on waste products, making nutrients, such as nitrogen available for the plant. In this case, eliminating the mosquitoes might affect the plant growth. In 1974, ecologist John Addicott published his findings on the predator-prey relationship within the pitcher plants, where he observed more protozoan diversity in the presence of mosquito larvae [23]. He proposed that the feeding habit of mosquito larvae keeps down the numbers of dominant species of protozoa, letting others persist.

**Mosquitoes as prey/predator**

***Larvae***

Wide varieties of both permanent and temporary aquatic habitats are being used by the mosquitoes for larval development. In unpredictably flooded ephemeral habitats such as summer flood pools and storm-flooded salt marshes, there are a few predators that have been identified to rely principally on mosquito larvae as the source of food. The unreliable nature of mosquito larvae as prey in these habitats prevents the development of any close predator-prey relationship unless the predator shares diapausing strategies similar to those of floodwater mosquitoes. The only predators in these habitats that rely on mosquito larvae for prey are other

mosquito species. A few species of genus *Psorophora* mosquitoes have larvae that are predatory in late instar stages [24]. These species are generally found in summer flood pools. Although there are few predators that specialize on mosquito larvae in these habitats, generalist predators such as beetles (larvae and adults), backswimmers, and some odonates (damselflies and dragonflies) will take advantage of the temporary abundance of mosquitoes if the timing of arrival into the habitats coincides with the presence of mosquito larvae.

Some ephemeral aquatic habitats, however, have flooding regimes that are more predictable. In tree holes, *Toxorhynchites* sp. has evolved as predator of other tree hole dwelling mosquito larvae. Vernal pools in northen temperate regions periodically flood to their maximum extent in the early spring from rain and melting of snow, and this triggers the hatch of one or more species of *Ochlerotatus* mosquitoes. Hatching of mosquito larvae in vernal pools often occurs when water temperatures are still below 10°C, with few predators active in such cold environments. The predators present at this time of the year are generally those that share similar overwintering strategies with mosquitoes, such as cyclopoid copepods (viz. Macrocyclops) and a few species of beetles. Some species of predaceous driving beetles (family Dytiscidae) in the genus *Agabus* have evolved a diapausing strategy that closely resembles with *Ochlerotatus* mosquitoes. The beetle larvae are active in the cold water and appear to feed primarily on mosquito larvae and pupae [25, 26]. The predictable abundance of mosquitoes and general paucity of other potential prey species during the early spring in these pools has probably contributed to this specialization. Other predators in vernal pools will feed opportunistically on mosquito larvae. Some species of dragonflies and damselflies have also evolved drought-resistant and freeze-resistant eggs, but hatch later in spring. Colonizing species of backswimmers, water striders and water beetles will feed on late-instar mosquito larvae and pupae, but are considered generalist predators [27].

Mosquitoes require water for oviposition. Mosquitoes colonize in permanent to semi-permanent bodies of water, laying eggs on the surface. In many natural bodies of water, the larvae develop in the presence of diverse invertebrate predator community. The co-occurrence of mosquito larvae and predatory invertebrates is more predictable in these habitats, but the diversity of other potential prey species may prelude the development of specialized predator-prey relationship. Potential invertebrate predators in these habitats include: backswimmers, water striders, giant water bugs, water measurers, adult and larval beetles, many species of damselflies and dragonflies, phantom midge larvae and even copepods and flatworms. Although all of these predators can be considered generalists with regard to prey consumption, experimental evidences suggest that mosquito larvae, when available, are a preferred prey for some species [28-31].

Mosquitoes are reliable and necessary food resources for organisms ranging from insects to mammals. Many of these organisms have evolved along with mosquitoes and developed hunting techniques specifically designed to find and capture them. If mosquitoes no longer exist, these animals will be deprived of a vital source of nutrition and may suffer in nutritional deficiency.

In aquatic environment, mosquito larvae serve as a food source for fish as well [32]. In the absence of their larvae, hundreds of fish would lack a steady source of nutrition. The predatory fish, *Gambusia affinis* is competent in killing mosquito larvae. So, mosquito serves as their primary food source. The total destruction of mosquitoes may thus lead to nutritional deficiency of these fishes. Many species of insects, spider, salamander, lizard and frog would also loose a primary food source. In a study, researchers tracked insect-eating house martins at a park in Camargue, France, after the area was sprayed with a microbial mosquito-control agent [33]. They found that the birds produced on an average two chicks per nest after spraying, compared with three for birds at control sites. Bats feed on mosquitoes too. About 2% of their gut contents are found to be from mosquito source [34] Thus, complete absence of mosquitoes would affect the nutritional level of such bats.

**Adults**

Like other aquatic insects with terrestrial adult stages, mosquitoes provide a link between aquatic and terrestrial ecosystems as they convert detritus and aquatic microbial biomass into flying insect biomass. Most adult mosquitoes are relatively short lived. The probability of daily survival for adult mosquitoes, an important factor in disease transmission, varies among species and habitats. Daily survival probabilities usually range from 0.6-0.9, with much of the mortality coming from predation [35]. Mosquitoes are fed upon by a variety of invertebrate predators including spiders [36, 37] and odonates [38], although there are no known specialist predators that prey exclusively on mosquitoes. Vertebrate predators include insectivorous birds and bats [39], although mosquitoes account for only a small percentage of the total biomass consumed. Consumption of mosquitoes by the Indiana bat, *Myotis sodalis*, for example, accounted for upto 6.6% of the total diet [40].

**Biological control of pest and vector mosquitoes**

*Toxorhynchites* sp. mosquitoes are potentially ideal biological control agents. The adults do not feed blood and therefore cannot themselves act as vectors of disease; the larvae are predatory on other mosquito larvae and show 'pre-pupal killing' behaviour (before pupation they kill but do not consume large numbers of potential prey) and in addition, female *Toxorhynchites* sp. oviposit into pools of water which are not accessible to chemical control methods [41].

*Toxorhynchites* sp. mosquitoes offer an alternative form of biological control [41]. Their predatory larvae often feed upon the larvae of vector mosquito and hence, *Toxorhynchites* sp. adult females seek out these same aquatic habitats to lay their eggs. An additional tool in this respect might be the exploitation of oviposition cues for *Toxorhynchites* sp. They could be used to encourage released adult female *Toxorhynchites* sp. mosquitoes to remain in the target area, in addition to increase the efficiency since both predator and prey may be attracted to the same oviposition sites [42].

**Mosquito vectors as indirect selection agent**

The human malaria parasites are *Plasmodium falciparum, Plasmodium vivax*, *Plasmodium malariae* and *Plasmodium ovale*, which are causing millions of death every year [43]. Interestingly, sickle-cell anemia and glucose-6-phosphate dehydrogenase deficiency of human in certain endemic regions might be interpreted as an evolutionary process in the context of population regulation. These are examples of balanced polymorphism which counterbalances the high mortality rate caused by malaria parasites [44]. This sustained selection pressure controls the preservation of the beneficial genetic

attributes which could increase the chances of survival of the individuals in a population. The fitness of the individuals in the population group can be quantified in terms of its differential fertility and mortality [45]. Occurrence of sustained and frequent infection of the parasite facilitated by the mosquito vector in a population might possibly increases the propensity of these counterbalancing genetical attributes which in turn increases the survival fitness of the individuals and decreases the possible mortality rate of that population. Thus, mosquito might play an important role in natural selection as a potential indirect selection agent in those endemic areas. Every year millions of people die due to mosquito-borne diseases especially in the developing world [7]. Most of the mosquito-borne viral diseases are zoonotic in nature [46, 47]. Mosquitoes might have an influence in regulating animal population.

**Vector density and disease transmission**

Europe and Australia have anopheline mosquitoes, but are free from indigenous malaria. This has been possible mainly because of the elimination of malaria parasite from human population by using anti-malaria drugs as well as reducing the vector breeding sites through improvised agricultural practice and environment friendly development. Mosquito-borne diseases get transmitted only at a specific density of vector mosquitoes. So, by controlling the critical density of vector mosquitoes, transmission of pathogens can be prevented or kept under control.

**Discussion**

Mosquitoes are specially designed little flies. They have existed for over a hundred million years, which probably signifies that they have been favoured over other organisms by natural selection. Now a question is surreptitiously arising that what would happen if these dipterans were eradicated completely?

During the course of their existence, they have co-evolved with other organisms. Obliterating them completely could be detrimental – a predator would lack a prey and there would be no mosquito pollinators, which in turn may affect the continuity of certain plant species. Certain food chains would in turn be affected. A great deal of information has been accumulated on chromosome numbers and heterochromatin distribution as well as on genome size and gene functioning [48, 49] In fact, indiscriminate destruction of all mosquitoes may lead to loss of great genetic variability from nature. The unique genetic element of mosquitoes may be used in various ways for the benefit of the living world.

Thus, eradicating mosquitoes may not be a judicious and scientific notion. It can also be possible that some ecologically incompatible organisms may occupy the empty niche. Therefore, mosquitoes' role must be considered and evaluated in a greater ecological perspective before adopting the policy of mosquito eradication programme, if any.

Mosquitoes are found in diverse ecological niches both in terrestrial and aquatic environment and are linked with the food-chains. Hence, the micro-ecological changes as a result of disappearance of certain mosquito species or all the mosquito populations might not be visible initially; but with the passage of time, the cumulative effect of such changes may lead into macro-ecological disturbances.

Furthermore, a variety of parasites, pathogens and symbionts are dependent on mosquitoes for their survival [50, 51]. Mosquitoes not only act as vector/host of these organisms but also act as intermediate or definitive hosts in the life cycle of those parasites/pathogens. Eradication of mosquito from nature may have a great selection pressure on these organisms. Most of them may completely become extinct if their vectors/hosts are eradicated. Complete eradication of mosquitoes might result in the total destruction of the huge gene pool of mosquitoes along with the organisms dependent on mosquitoes. The genetic elements of these organisms may be used in various ways for the welfare of the living world. Hence, comprehensive studies are required to evaluate their ecological role and consequences of their absence before adopting any policy of eradication of mosquitoes from planet earth. Otherwise, man's war against nature and its organisms evolved through natural selection, will inevitably be a war against himself. Mother Nature is unbiased towards all her creations. Each and every creation of natural selection is no less important than others and has a role to play in nature and mosquito is no exception to that. Mosquito eradication doctrine may also raise a bioethical question – do humans have the right to decide which insect, a creation of organic evolution and an integral part of different ecosystems, deserve to live on planet earth? However, while appreciating the necessity of different groups of mosquitoes in different ecological conditions, the crusade against the 'evil' mosquitoes should continue till a mosquito-borne disease free world is attained.

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