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# SUSTAINABLE CONTROL OF ANOPHELES MOSQUITO POPULATION

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**Abstract:** Despite the widespread use of insecticides, community engagement programmes and preventive measures mosquito borne diseases are growing and new tools to prevent the spread of disease are urgently needed. An alternative control measure for the eradication of *Anopheles* mosquitoes is suggested by the use of a Sustainable Control Model, which demonstrates the capability of *Odonata*, a natural beneficial predator, to exercise control over *Anopheles* mosquitoes in less than 140 days.

**Keywords:** Anopheles mosquito, Odonato, population control, sustainability.

## 1. Introduction

According to Jaeger[1] the Mosquito is a Culicidae, which has several species, of which a few are harmless and useful to humanity, whilst others are harmful and constitute a nuisance to all living vertebrates and human beings. The female of several species of mosquitoes feed on blood and transmit extremely harmful vector-borne diseases like the canine heartworm (*Dirofilaria immitis)*[2] filariasis (*Wuchereria bancrofti, Brugia timori and Brugia malayi*)[3, 4] ,O'nyong-nyong fever[5], Brain

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tumour viruses [6] and Malaria [7], all of which present a major challenge to human health. Several strategies and control methods have been put in place to control the population of these vector borne diseases including insecticide-based control programs [8, 9], it is irrefutable that vector control is an essential economic requirement for developing nations, Goodman [10], Curtis *et al* [11]. However human health and the environment, Attaran *et al* [12], is exposed to greater risks due to the side effects of chemical pesticides and the harmful effect of prolonged use of synthetic insecticides. Mosquito resistance to insecticides is also a matter of concern as reported by Sina *et al* [13]; Rathburn, 1990 [14] has raised concerns over the rapid increase in the resistance of mosquitoes to traditional chemical pesticides and the growing concern about the potential health and environmental risks surrounding these chemical products. Kline [15], confirmed that there is growing concern among the operational mosquito-control personnel that effective insecticides may not be available in the near future due to the growing resistance of mosquitoes to most of the available adulticides, Rathburn [14]. Environmental management based on ecological principles provides an effective and expedient intervention methodology for vector control, WHO [16]; Ault [17]. Kitron & Spielman [18] and Marcia Anderson [19] suggested and demonstrated programmes based on environmental modification of pond and pool filling and several preventive measures based on mosquito breeding habitats. However, this programme and method requires considerable financial investment and time, which may be a determining factor to the success in curing the problem in question, as illustrated by Onwujekwe *et al* [20] on the challenge in using insecticide treated nets. Geissbühler *et al* [21] demonstrated the use of microbial larvicide application in rivers and mosquito breeding sites. This method was successful as it kills the larvae stage of aquatic breeding insects including mosquitoes, unfortunately it also kills the larva of natural *Anopheles* predators. Service [22], said vector population control can only be effective if the biology of the target species is understood. Bond J.G *et al* [23] proposed habitat manipulation to keep the population of the *Anopheles* mosquito under control. Despite the extensive effort and control strategies by governmental agencies, public and private non-governmental researchers and other relevant health agencies, malaria still persists in most endemic regions of the world.

As illustrated by Mugittu *et al* [24] the only way to control the spread of malaria and other known diseases transmitted by the bite of the mosquito is to control the *Anopheles* mosquito vector (plasmodium), which transmits malaria. This is a major public health problem as described by Sachs *et al* [25] among many African countries and Nigeria in particular. There is great urgency for the development and implementation of novel malaria vector control interventions. Oluwagbemi *et al* [26], expresses the importance of Mathematical models as a first step to asses control strategies and the efficacy of proposed methods prior to implementation. Lord [27], Axtell R [28], Wilensky [29] and Mc Kenzie [30] have developed mathematical models to show that it is a crucial element in developing optimised control techniques, especially to understand the *Anopheles* population and transmission dynamics to strategically control the disease vector.

The *Anopheles* mosquito is an important vector of *Plasmodium*, for which life cycle stages are widely distributed in Nigeria and some other regions of the world. So to deliver a lasting solution for the mosquito problem, it is important to identify the strains of mosquitoes in the affected environment [31].

To effectively control the *Anopheles* mosquito population, it is therefore imperative to create a Sustainable *Anopheles* Mosquito Control Model (SAMCM), which is based on the deployment of *Odonata* (dragonfly) a naturally beneficial predator of *Anopheles* mosquitoes. In this study, we demonstrate that SAMCM provides a unique opportunity for control of *Anopheles* mosquitoes. A concept based on the interaction between the population of *Anopheles* mosquitoes adults and its life cycle stages (egg, larvae and pupae) and the naturally beneficial predator *Odonata* (dragonfly) adult and its life cycle stages (egg, and nymph).

## 2. Materials, Methods and Model

A study was conducted in Epono 2, Nko autonomous community, which is located 5 kilometres from Ugep town, the local government headquarters, and 45 kilometres from the state capital, Calabar, Nigeria. A 1km$^2$ area in Epono 2, that was abandoned for several months was found to serve as an ideal breeding place for mosquitoes. Some images of the mosquitoes obtained were sent to the automatic pest detection and recognition system designed for the detection and recognition of all forms of pest images, Faithpraise *et al* [32], as shown in Fig. 1, the detection system processes and detects the images as illustrated in Fig. 2, and by optimal correlation, the recognition system identified and confirmed the presence of the *Anopheles* mosquito pest in question, no matter what its rotational distortion, as shown in Figures 3 and 4.

Figure 1. mosquito images from outdoor and indoor

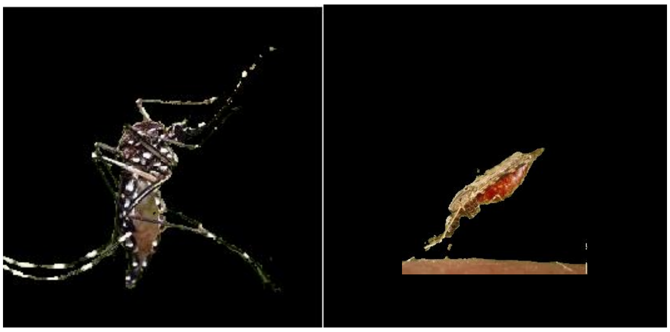

Figure 2. Results from the detection system

Figure 3. Orientation angle distortion of mosquito

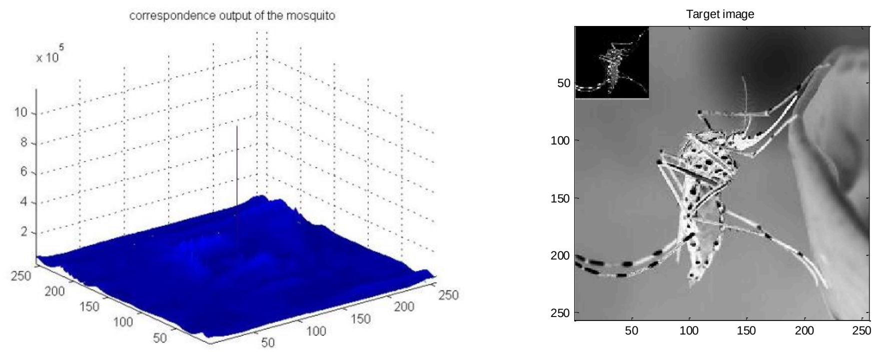


Figure 4. Recognition of mosquito image

A large population density of Anopheles mosquitoes and its life cycle stages were confirmed to be living in the Epono 2 environment and inside the houses located there. When a survey was conducted in the area, the people living in the area confirmed multiple bites from mosquitoes and how they have suffered from several diseases and malaria as a result of the mosquitoes. When further questions were asked about control measures, they expressed concern that the mosquitoes had developed resistance to the insecticide sprays, insecticide-treated nets and that it is very inconvenient to use an insecticide-treated net as they restrict ventilation, cause insecticide poisoning and are expensive - as confirmed by Onwujekwe *et al* [33]. To provide a lasting solution to the mosquito/malaria problem we propose the use of the natural predator *Odonata* (dragonfly) to control and eradicate the population of mosquitoes. *Odonat*a (dragonflies) are among the fastest flying insects in the world. They are important predators that eat small insects and mosquitoes. Just like mosquitoes they are found in ponds, streams, wetlands and their larvae are aquatic (Kalkman) [34]. *Odonata* have a life span of above a year, but very little of that life is actually spent as an adult dragonfly. It has three life cycle stages, the egg, the nymph (with up to 14 instars), and the adult dragonfly. Most of its life cycle is lived out in the nymph stage, during this stage it will eat large volumes of mosquito eggs, larva and pupa – once the nymph is fully grown it will crawl out of the water up the stem of a plant, shed its skin and become a young dragonfly [35]. As an adult dragonfly, it can eat anything and feed on mosquitoes, ants, termites, butterflies, gnats, bees and other insects. *Odonata* tend to hunt in groups when large colonies of ants or termites are spotted [36]. The *Odonata* nymph is very effective in reducing the mosquito population by eating the mosquito: eggs, larva and pupa. *Odonata* are very important predators and a valuable ally for humanity as they feed on mosquitoes, especially when their populations are in abundance. Breeding dragonfly is cost effective provided that the environment is free of pesticides and pollution. It is possible to control the mosquito population density in Nigeria using *Odonata*; as illustrated by Umarl *et al* [37], it is possible to collect *Odonata* species during the night using light traps. This is indeed a way of promoting integrated pest management (IPM) by restoring natural habitats, thereby discouraging in its totality the application of chemical pesticides as *Odonata* life stages only flourish in clean and healthy environments.

### 2.1. Model of interaction between the mosquitoes and predators

After sampling a 1km$^2$ area it was estimated that the density of mosquitoes was above two million, plus similar numbers of its life cycle stages. If four thousand dragonflies and it life cycle stages are introduced into the environment the effect of them on the mosquito population can be illustrated using the following non-linear simultaneous ordinary differential equations.

$$\frac{dN_m^e}{dt} = \beta_m N_m^h - \varepsilon_m N_m^e - aN_m^e N_d^n - m_m^e N_m^e \quad \text{Eqn. 1}$$

$$\frac{dN_m^l}{dt} = \varepsilon_m N_m^e - \lambda_m N_m^l - bN_m^l N_d^n - m_m^l N_m^l \quad \text{Eqn. 2}$$

$$\frac{dN_m^p}{dt} = \lambda_m N_m^l - \rho_m N_m^p - cN_m^p N_d^n - m_m^p N_m^p \quad \text{Eqn. 3}$$

$$\frac{dN_m^h}{dt} = \{\rho_m N_m^p - \zeta N_m^h N_d^h - m_m^h N_m^h\}\left[N_m^h\left(\frac{K_m^h - N_m^h}{K_m^h}\right)\right] \quad \text{Eqn. 4}$$

$$\frac{dN_d^e}{dt} = \beta_d N_d^h - \varepsilon_d N_d^e - m_d^e N_d^e \quad \text{Eqn. 5}$$

$$\frac{dN_d^n}{dt} = \varepsilon_d N_d^e - \mu_d N_d^n - m_d^n N_d^n - p^n N_d^n \quad \text{Eqn. 6}$$

$$\frac{dN_d^h}{dt} = \{\mu_d N_d^n - m_d^h N_d^h\}\left[N_d^h\left(\frac{K_d^h - N_d^h}{K_d^h}\right)\right] \quad \text{Eqn. 7}$$

where:

$N_m^h, N_m^e, N_m^l, N_m^p$ = Population density of mosquito: adult, egg, larvae and pupae - respectively

$N_d^h, N_d^e, N_d^n$ = Population density of dragonfly: adult, egg, nymph - respectively

$K_m^h, K_d^h$ = Population carrying capacity of the environment for adult: mosquito and dragonfly - respectively.

$m_m^h, m_m^e, m_m^l, m_m^p$ = Mosquito mortality rate: adult, egg, larvae and pupae - respectively.

$m_d^h, m_d^e, m_d^n$ = Dragonfly mortality rate: adult, egg and nymph - respectively.

$\zeta$ = Frequency with which an dragon fly adult finds and eats an adult mosquito.

$a, b, c$ = frequency with which a dragonfly nymph finds and eats a mosquito prey: eggs, larvae and pupae - respectively.

$p^n$ = Attrition of dragon fly nymphs by natural predators

$\beta_m, \beta_d$ = Number of eggs per day from: mosquito and dragon fly - respectively

$\varepsilon_m, \varepsilon_d$ = Fraction of eggs hatching into: mosquito larvae and dragonfly nymph - respectively

$\mu_d$ = Fraction of nymphs changing into dragonflies

$\lambda_m$ = Fraction of larvae changing to mosquito pupae

$\rho_m$ = Fraction of pupae turning into mosquitos

The proposed model consists of seven simultaneous non-linear, ordinary differential equations 1 to 7, which are solved using a 4$^{th}$ order Runge–Kutta method as described by Fehlberg, [38]; Dormand [39]; Butcher, [40]; and Schreiber [41] and using the average life span of all the insect life cycle stages and their mortality rates as displayed in Tables 1, 2 & 3.

Table 1: Mosquitoes life cycle as described by (Cross [42] and Choochote *et al* [43] )

| Mosquitoes ( *Anopheles* ) Life expectancy in days | |
|---|---|
| Maximum no of eggs per day | 50-100 singularly |
| Life expectancy of adult mosquito | 7-28 |
| Life expectancy of egg | 1-12 |
| Life expectancy of larva or (wigglers) | 2-29 |
| Life expectancy of pupa | 1-16 |

Table 2. Life cycle of the predators as reported by [44], [45]

| Dragonfly (*Odonata)* Life expectancy in days | |
|---|---|
| Maximum no of eggs per day | 50 |
| Life expectancy of egg | 12-16 |
| Life expectancy of nymph | 56-1516 |
| Life expectancy of adult | 14-60 |

It is important to note from Table 1 and Table 2, that the adult mosquitoes and its life cycle forms (egg, larvae and pupae) and the predator *Odonata* adult and life cycle forms have a unique death rate, which is already established from the literature and several research papers. The mortality rates were determined by the use of a distributive function as described by Chatfield [46], and Ostle *et al* [47], in their works on the Weibull probability distribution model. Hence, the mortality rate of the pest and predators are modelled using equations 8 to 11.

The Weibull distribution is a probability distribution function designed to describe failure rate. It has been established as the most popular model for describing failure times. For this reason, Faithpraise *et al* [48], used it in the determination on the mortality rates of parasitoid wasps and the diamondback moth. In the same manner we have estimated the mortality rates of all the classes of predators *(Odonata*) and the death rate of the mosquito and its offspring (*egg, larva and pupa*) by the use of the Weibull distribution probability model as given by equations 8 to 11. For a more detailed description on establishing mortality rates with a Weibull probability distribution model, please see Faithpraise *et al*, [48].

The life expectancy of the predators and mosquitoes can be represented by the Weibull distribution below:

$$X \sim W(\psi, \theta) \qquad \text{Eqn. 8}$$

So that

$$m = \frac{\psi}{\theta}\left(\frac{x}{\theta}\right)^{\psi-1} \qquad \text{Eqn. 9}$$

Where:

$m$ = mortality

$\psi$ = gradient of the least squares line of the Weibull probability plot. $\theta$ is the 63.2$^{th}$ quantile of a Weibull distribution. The intercept $= -\psi \ln(\theta)$, if we decide to calculate the least square line equation based on the plotted points $x_{(1)}$ .... $x_{(n)}$, then $b_1$ and $b_0$ will be estimates for $\psi$ and $-\psi \ln(\theta)$, such that $\psi \approx b_1$ and $\theta \approx e^{-\left(\frac{b_0}{b_1}\right)}$ where $b_0$ is the intercept point and $b_1$ is the slope Chatfield [46] and Ostle *et al*, [47].

To determine $\psi$ and θ, a graphical technique was used; this considers the age factor (x) and the probability distribution function *(y).* The variable *(x)* is estimated using the minimum and maximum life span of the insect lifecycle stage, $p_i$. The distributed data points are calculated from equation 11, while *y* the probability function is determined from eqn. 11, where *n* is the total number of data points.

$$p_i = \frac{i}{n+1} \qquad \text{Eqn. 10}$$

$$y_i = \ln\left[\ln\left(\frac{1}{1-p_i}\right)\right] \qquad \text{Eqn. 11}$$

The mortality rates of all the predators *Odonata* (egg, nymph and adult) and the *Anopheles* mosquito life cycle stages are estimated using equations 8 to 11 and the results are summarised in Table 3.

Table 3. Life expectancy of *Odonata* species and *Anopheles* mosquitoes species as obtained from the average life span using the Weibull probability distribution function

| Mortality | Life span *(x)* days | Average life span | *ln (x)* | $p_i$ $p_{ii}$ | Gradient $\psi$ | $\theta$ | $(b_0/b_1)$ | Mortality obtained |
|---|---|---|---|---|---|---|---|---|
| $m_m^e$ | 1-12 | 6.1 | 1.8083 | 0.333-0.666 | 0.5832 | 5.18 | -1.65 | 0.10 |
| $m_m^l$ | 2-29 | 15.5 | 2.7408 | 0.333-0.666 | 0.4879 | 12.75 | -2.55 | 0.035 |
| $m_m^p$ | 1-16 | 8.5 | 2.1401 | 0.333-0.666 | 0.4886 | 6.99 | -1.95 | 0.0632 |
| $m_m^a$ | 7-28 | 17.5 | 2.8622 | 0.333-0.666 | 1.0904 | 16.04 | -2.78 | 0.0685 |
| $m_d^e$ | 12-16 | 14 | 2.6391 | 0.333-0.666 | 10.2462 | 13.87 | -2.63 | 0.805 |
| $m_d^n$ | 56-1516 | 758 | 6.6307 | 0.333-0.666 | 0.3834 | 592.1 | -6.38 | 0.000055 |
| $m_d^a$ | 14-60 | 37 | 3.6109 | 0.333-0.666 | 1.0280 | 33.73 | -3.52 | 0.0306 |

## 3. Performance Reliability and Results

After the confirmation of the presence of the *Anopheles* mosquito by the people of the Epono 2 community, our goal is to find a permanent and lasting solution for the control of *Anopheles* mosquitoes, which has transmitted life threating diseases to mankind in many regions of the world. In this simulation experiment the population of *Anopheles* mosquitoes (*adult, egg, larvae and pupae*) was modelled with each female mosquito laying an average of 85 eggs per day. In the absence of any control measure or predators, the result of Fig. 5 was obtained for a period of 30 days.

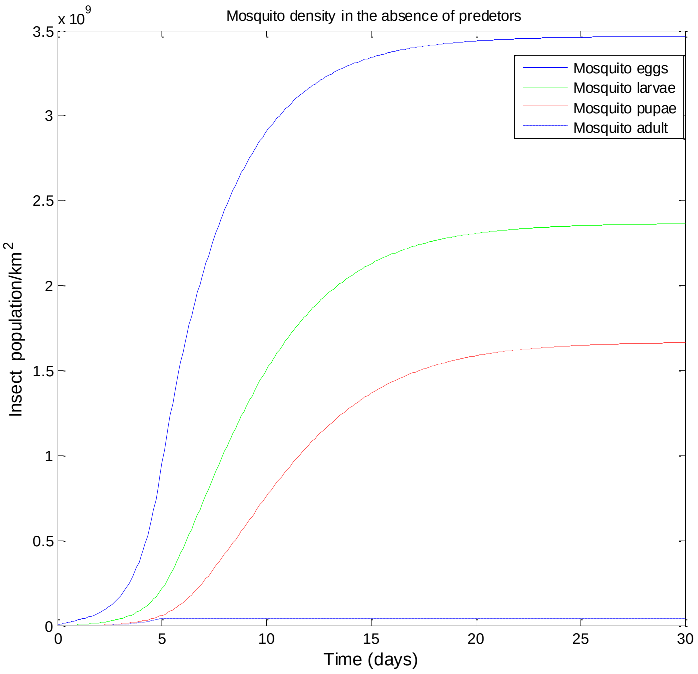


Figure 5. Mosquito density in the absence of any control measures

The result of Fig. 5, shows a tremendous increase in the population densities of the mosquitoes to a value of $3.4x10^9$ for the egg, $2.3\ x10^9$ for larvae and $1.6\ x10^9$ for pupae, and $4x10^7$ for the adult. The adult mosquito reached its environmental carrying capacity within six days, since there are no control measures to check its population growth. The multiplication rate of the population of mosquito has raised great concerns over the years as the only available solution so far has been insecticide spray, for which the mosquito has developed resistance.

## 4. Exploring the Control Possibilities

After conducting many simulation experiments with varying densities of the *Odonata*, see Fig. 6. It was found that the best control method was with the deployment of the three life cycle stages (egg, larvae and adult) of the dragonfly as illustrated by Fig. 7.

Figure 6. Nigerian *Odonata* (*source: adult[49] and nymph[50] & eggs (source Jay[51] & clip art[52])*

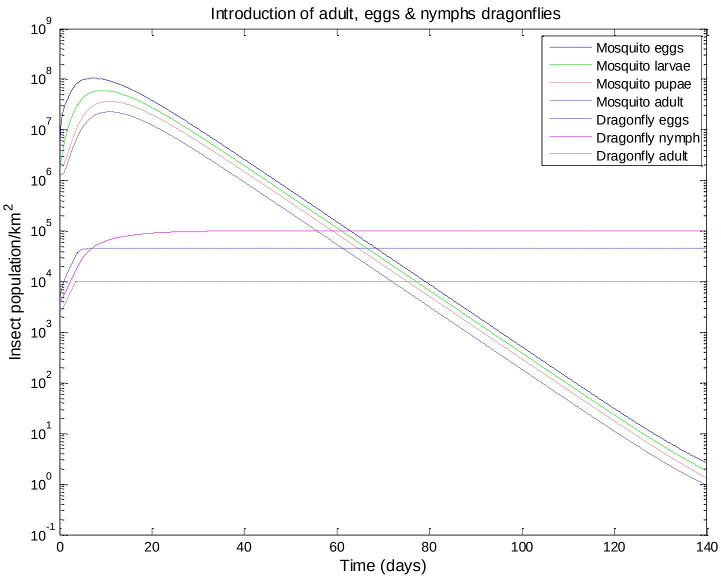


Figure 7. Deployment of *Odonata* species against the mosquito population

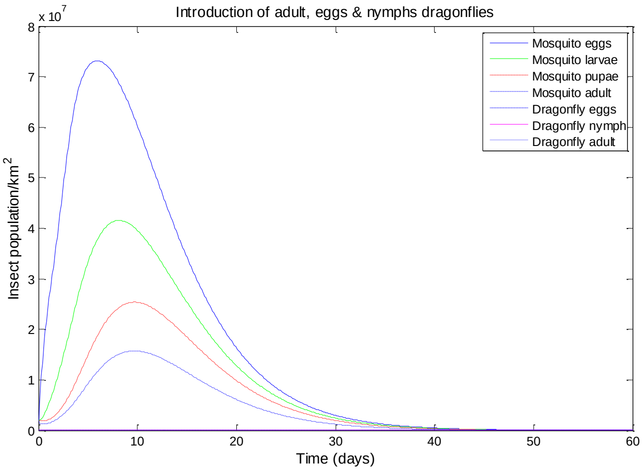


Figure 8. Deployment of *Odonata* species against the mosquito population

The result of Fig. 7, illustrates the semilog view of the plot of Fig. 8, which shows the control capability that the *Odonata* adults and nymphs have over the mosquito population in less than 120 days. The first 30 days shows that the mosquito population growth peaks at a height greater than 1.5 x $10^7$ per $km^2$. As the population of the *Odonato* species increases from the initial population of 4000 (egg, nymph adult) dragonflies, it was possible to cause the population of the mosquito species to fall to 37 for the egg, 26 for the larvae, 17 for the pupae and 12 for the adult in 120 days. Due to its longevity, the *Odonata* nymph grows to a population of $9.5x10^4$, it has the greatest effect in culling the mosquito by eating its eggs larva and pupa, its population is limited by the environmental carrying capacity for the adult dragonfly. The *Odonata* adult population grows to $10^4$, and has a big impact in culling adult mosquitoes. The *Odonata* egg population grows to $4.5x10^4$.

After 140 days the dragonflies were able to reduce the population of the mosquito (adults, eggs, larvae, and nymphs) to < 5. Fig. 7 shows complete stability in the population of the mosquito pest as their population drops to almost zero, indicating almost complete eradication of the species in the environment as the population of dragonflies and nymphs becomes stable.

## 5. Results Analysis

The result of Fig. 2 confirmed the existence of *Anopheles*, the malaria carrying vector, a danger signal for the human population, this result is in line with the findings of Hallem *et al* [53], which states that female mosquitoes will always hunt to get a blood meal in order to reproduce. The female mosquito is attracted to its host due to its carbon-dioxide emissions, octenol and other compounds that make up body odour . The result of Fig. 5, shows that as long as the mosquito has a blood meal, it will keep on reproducing, thereby increasing its population density and only being limited by the environmental carrying capacity. The results of Fig. 7 show that the effect of predators on the pest population takes time. When predators are deployed it is not possible to obtain a pest free environment in one day, we need to exercise patience as it will take a number of days to obtain favourable and lasting results. Insecticide sprays can be used to kill *Anopheles* mosquitoes rapidly in a local area, for instance a person's house but this is only a short term solution as the mosquitos will soon reinvade the house. Whilst the dragonfly adult eats great quantities of mosquitoes it is the dragonfly nymph that is most effective in limiting the population of the mosquitoes, and it is the nymph that is most vulnerable to pollution and pesticides. The result of Fig. 7 shows that, it is possible to obtain a pest free environment when the population of beneficial insects becomes stable. SAMCM demonstrates what is required to control the population of mosquitoes within a five month time period.

## 6. Conclusion

Sustainable Control of the *Anopheles* Mosquito Population Model (SAMCM) demonstrates an effective methodology to cure the long term problem of mosquitoes that have overwhelmed several solutions for many years. This model demonstrates how to permanently reduce to the lowest value the parasitic diseases called malaria caused by various species of *plasmodium*, carried by mosquitoes of the genus *Anopheles* through the continuous application of the *Odonato* predators.

The simulation results encourage the restoration of natural habitats by every home, to enable a clean and healthy environment that will attract naturally beneficial organisms to keep the population of all kinds of pest under control. These results absolutely discourage the application of pesticides with either minor or major effect, both short term and long term. It is very important to understand that larvicides will kill dragonfly nymphs, which is very counterproductive; this study demonstrates that *Odonato* nymphs make the greatest contribution in controlling the mosquito population by natural means. To solve the mosquito problem, we need to encourage the global breeding of dragonflies in our environment and for success we need a cleaner insecticide free environment.

## Conflict of Interests

The author declares that there is no conflict of interests.

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