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On the Range of Action of Adult *Culex pipiens s.l.*

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Abstract

Mosquitoes are an interesting topic due to their medical importance, as they play an active role in the transmission of many pathogens and parasites, acting as vectors for various pathologies that are deadly to humans, such as dengue, yellow fever, chikungunya, West Nile virus, encephalitis and malaria, among many others that are less common. In terms of morbidity and mortality caused by vector-borne diseases, mosquitoes are the most dangerous animals for humanity and, although they also play a role in the ecosystem as a food source for other organisms, their importance for public health cannot be overlooked. As highly efficient vectors, they put more than three billion people at risk, mainly in tropical and subtropical regions as well as in Europe, since heat waves and flooding are becoming more frequent and severe, and summers are getting longer and warmer, accelerating mosquito development, biting rates, and the incubation of the pathogens within their bodies. Female mosquitoes bite to acquire proteins for the development of their ovaries and eggs and, in the process, acquire pathogens and/or parasites from one vertebrate host and transmit them to another, usually after a short period of replication. Three of their four life stages are lived in still freshwater, so it is crucial to understand their range of action when they reach adulthood and leave the water, in order to plan and implement local prevention measures. A set of georeferenced abundance data collected in mainland Portugal over seven years was linked to cartographed water bodies in a geographic information system to estimate the distances at which *Culex pipiens s.l.* had a significant presence, with criteria based on the size of the catches. The result allows for an estimate of the fly range of those mosquitoes, which can be used to focus countermeasures.

Keywords

Mosquito Fly Distance, Vector-Borne Diseases, *Culex pipiens s.l.*,

Geographic Information Systems

1. Introduction

There are more than 3,500 species of mosquitoes known in the world. All species go through four life stages with different characteristics—egg, larva, pupa and adult. In the first three stages, which typically last five to fourteen days, they live in still water. Each species has different times for each stage, which in turn are largely influenced by the environmental temperature [1]. When they leave the aquatic environment as adults, gender and weather conditions will both influence their lifespan, which can vary from a week to several months. In some species, adults can even spend the winter in diapause [2].

Normally, the males live for five to seven days, feeding on nectar and other plant juices. In the wild, females do not live more than one to two weeks, depending on the temperature, humidity, and their ability to avoid predators or be killed by the host while looking for a blood meal. The females rest for a few days after obtaining a blood meal, while the eggs develop. In tropical regions, this process usually takes two to three days. The female then lays the eggs and resumes hunting for a new host, eventually picking up a new variety of different bacteria, viruses, or parasites. Mosquitoes have the capacity to transmit diseases without ever being infected, which means that they continue to spread all the pathogens throughout their entire lifespan without being affected themselves [3].

The distance mosquitoes can fly depends on the species, and most species will only fly around 1,500 to 5,000 m around the area from where they hatched. Both *Aedes aegypti* (Linnaeus, 1762) and *Aedes albopictus* (Skuse, 1894) mosquitoes, renowned for its role as Zika and Dengue-spreading vectors, only fly a few tens of meters from their breeding area, while *Anopheles* mosquitoes, malaria vectors, can fly for up to four hours at one to two km/h [4], traveling up to 12 km in one night. On the other hand, *Culex* mosquitoes do not fly long distances but have been known to fly up to 3.2 km [5].

The problem with mosquitoes in general is that they are avid travelers, using any means of transport available—the adults can travel by plane, in the cabin or in luggage, the eggs can travel in any small puddle of water on a ship or truck and in their cargo. The eggs have the advantage that, if the puddle of water dries up, they can survive drying out for up to 8 months [6].

While mosquitoes occupy natural containers in natural and eventually remote locations, such as the hollow of a trunk or the base of a curled leaf, they are much less likely to pick up and transmit pathogens from human to human, even if they are infected. The problem increases as artificial water containers in residential areas become breeding sites, where the probability of human contact is much higher [3] [6].

Female mosquitoes hunt for their blood meal by looking for substances such as carbon dioxide produced by the host and using visual recognition. Among humans, mosquito preferences generally go to those who breathe heavily, have type O blood, have a high level of body heat or are pregnant women [7] [8]. It has also been found [9] that there is a hereditary and genetically controlled component to mosquito attractiveness.

Mosquito females consume human blood but prefer the blood of other vertebrates such as mammals or birds linked to human presence whose interactions have led to an increase in the transmission routes of pathogens from animals to humans [10].

During blood-sucking mosquitoes inject saliva into the bodies of their hosts which acts as an anticoagulant and is the main route by which eventual pathogens access the hosts' bloodstream. Mosquitoes' degree of activity (biting) is a function of temperature, humidity, and light conditions changes throughout the year, with three major activity patterns: day-active, night-active, and dawn and dusk active individuals [11]. Moreover, species host preference (ornithophilic species such as *Culex pipiens* or mammalphilic as *Aedes* spp) affects the distance and direction of mosquito dispersal [12].

The *Culex pipiens* complex is the most prevalent mosquito in Portugal [13] and in general in the northern hemisphere. Its survival is associated with water-based habitats containing high amounts of organic matter [14]. As vector borne pathogen transmission is highly influenced by the ecology of the vector [10], it is evident that *Cx. pipiens* adaptability to human-made environments led to its global distribution as a vector.

With the available abundance data set, it was possible to quantify the density of mosquito presence as a function of distance from the water where they presumably began their lives, thus providing an estimate of the species' flight range. The flight range of mosquitoes in general shows great variability in the literature [12] and the dispersal capacity of *Culex pipiens* is considered strong, so the opportunity to combine field data with the exact location of the water in a geographic information system (GIS) seemed relevant to obtain a solid result for this species complex.

2. Material and Methods

Using a 7-year set of abundance data for the *Culex pipiens s.l.* complex, acquired in mainland Portugal between 2006 and 2012, we used various criteria to establish a range that reflects the species' flight distance when it reaches the adult stage. The initial data consisted of the georeferenced dataset, containing 2.181 records concerning the captures of 37.094 *Cx pipiens* females, captured by trapping carried out from May through October, with CDC type traps staying on site for one night, hanging from a tree branch (**Table 1**). The locations, as well as the periodicity of the sampling, were selected by the regions, having as main criteria: proximity to the human population, the history of the presence of mosquitoes, the impact in human activities, the presence of potential breeding sites and entry points for exotic/invasive species [13].

Table 1. The dataset: number of traps and average capture of females by month.

Month	*# traps*	*Average*
May	203	2.8
June	289	17.8
July	406	37.1
August	440	12.3
September	437	19.4
October	406	6.0

This dataset was cross-referenced with several layers of thematic cartography focused on the water bodies referenced in the country in a geographic information system, ArcGiS (from ESRI). The mapped bodies of water include dams, lagoons, marshes, estuaries, and rivers which, although they are not standing water, are important in this context because their banks often have a significant amount of stagnant water associated with them, encouraging the creation of large ponds, that serve as nurseries [15] [16].

The information concerning cartographed water was available online from *Serviço Nacional de Informação de Recursos Hídricos* [17]. Different layers contain the water bodies and have elements of three different types: polygonal (dams' reservoirs, lagoons, and estuaries), linear (rivers) and punctual (marshes). All the shapefiles were reprojected to the system ETRS 1989-TM06.

The average of the overall data set is 17.0 *Culex pipiens* females per trap and night. Working in intervals of 1000 m (according to the criteria indicated above), three benchmarks were used to compare the captures with the distance to water, to establish a suitability discrimination:

i) the average captures for the interval considered,

ii) the distribution of above-average captures, and

iii) the percentage of captures above 50 females.

The reason for choosing these criteria was the progressive aggregation we were able to observe in the data and their discriminatory potential, which was not observed with other parameterizations tested.

3. Results

The distribution of the average capture to the nearest body of water, based on the minimum Euclidean distance and using 1000 m intervals, shows an overall downward trend (**Figure 1**), with the average catch showing a clear decrease at distances greater than 3 km.

The distribution of above-average captures (captures with more than 17.0 females, the global average of the dataset) shows that 81% of all above-average catches were made at less than 1 km from water, and 16.7% in the next range, but still less than 2 km from the water. A minority of these catches (2.3%) occurred more than 2 km away and none were recorded after the 3 km mark (**Figure 2**).

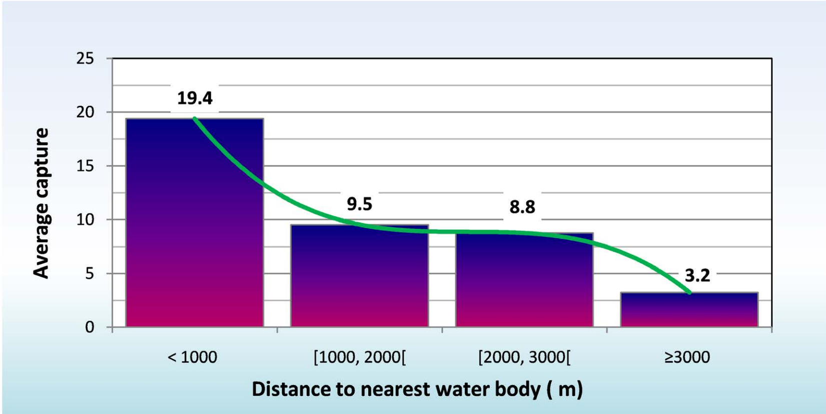

Figure 1. Average capture at each distance from a water body, using minimum Euclidean distance.

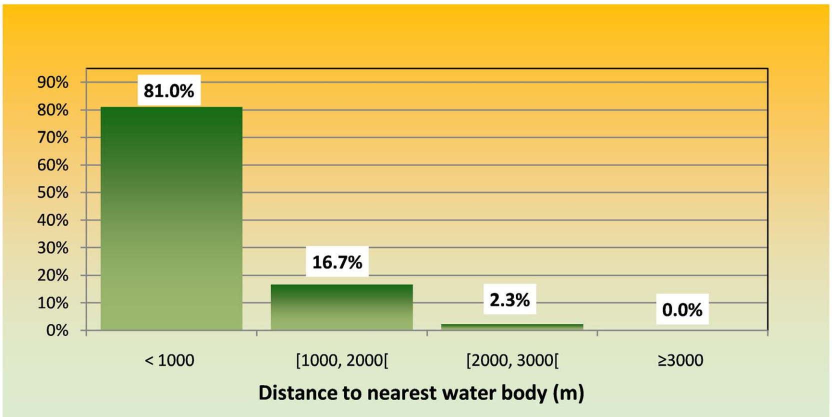

Figure 2. Distribution of above-average captures by distance from a water body.

Considering the captures of more than 50 individuals, which is the case for 140 of the 2,181 records, the majority are in the first interval: 85.7% of these catches occur less than 1,000 m from the water, 12.1% in the next interval, and only 2.1% were made more than 2,000 m away; none took place more than 3 km away (**Figure 3**).

The highest capture efficiency, calculated as the number of female mosquitoes per trap in all the data set, is associated with swampy marshes (21.0), rivers have a value of 17.1, dams' reservoirs 8.9 and lagoons only 2.7 (**Figure 4**).

The evolution of distance from water was analysed according to the months of the so-called "mosquito season", which in Portugal runs from May to October. **Figure 5** shows a significant presence of *Culex pipiens* females further away from the water bodies considered. July, along with August, are usually the two months with higher mean air temperatures. Maxima air temperatures begin to rise in May, remaining consistently above 20 degree Celsius during June, July and August.

The first interval, from 0 up to 1000 m, is the one with the largest average catches, and is above average in June, July and September.

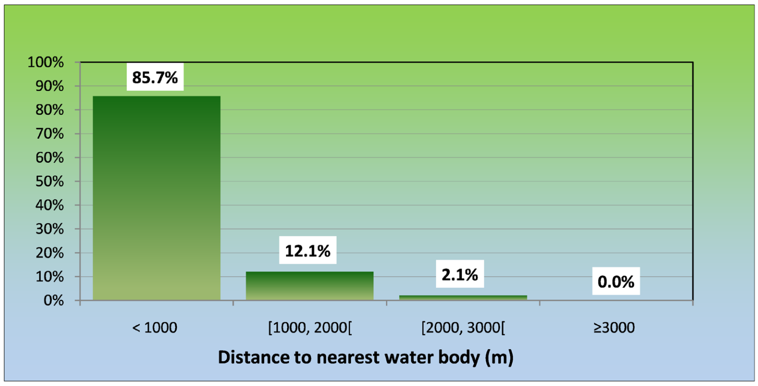

Figure 3. Distribution of captures above 50 females by distance from a water body.

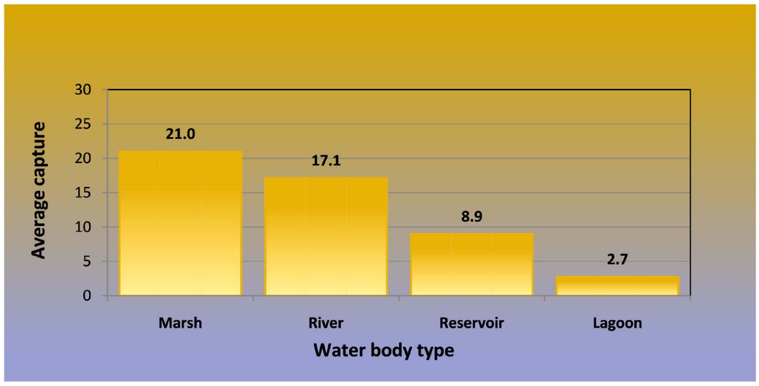

Figure 4. Average capture by nearest water body type.

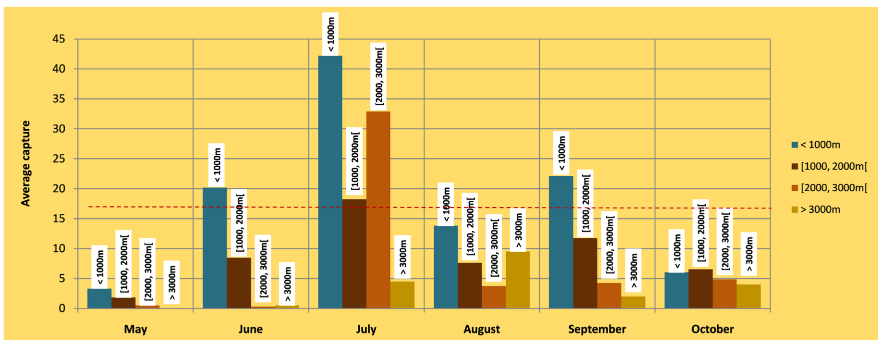

Figure 5. Evolution of the average catch according to month, for each distance-to-water interval considered. The dashed red line identifies the overall average of the data set, 17.0 females.

4. Discussion

Culex pipiens s.l. depend on the presence of water to complete the life cycle, and disease transmission requires the completion of at least one gonotrophic cycle before pathogen transfer occurs [18] as the transmission is a collateral effect of the blood meal needed for the oviposition. Their preference seems to go for standing water with large amounts of organic content, which turns out to be the case for most spots of standing water. The water bodies' cartographed are indicative of the presence of the standing water needed, but there are many small water containers, natural and man-made, which are not possible to referencing without exhaustive fieldwork, impossible to realize at nationwide scale. So, we worked with the set of layers previously mentioned (dam reservoirs, lagoons, estuaries, marshes, and rivers) establishing the minimum Euclidean distance to the nearest water body. These layers were the only digital information available at national scale that could be directly related to the initial life cycles of the mosquitoes.

The global trends with intervals of 1000 m shows a clear decrease at distances greater than 3 km, for both the distribution of average captures and the percent of above-average catches, leading to the conclusion that the mark of 3000 m is a reasonable estimate for the *Culex pipiens* usual flight range. Epidemiologically, the mosquito population is a relevant component of vectorial capacity [19] that, along with human presence, will determine the rate of pathogen transmission by host contact and therefore the probability of human infection in the area.

The highest capture efficiency associated with swampy marshes corroborates the *C. pipiens* demand for waters with a high organic content, which can provide food for the larvae. Lagoons shown the lowest captures, which can be explained by the fact that most of the mapped lagoons end up being opened to ocean salt water at least once a year.

It should be highlighted that variations in trapping intensity across the country and some fluctuations in environmental conditions over the 7 years of monitoring may have caused some bias in the data set and must be addressed in the future.

5. Conclusions

Considering the three results, we suggest an action range limited by the 3000 m mark for the *Culex pipiens*, estimated from an abundance dataset of females.

This methodology helps to identify the area where *Culex pipiens* have a high probability of presence near their birthplaces (mainly swampy marshes) and can therefore be used to target only the areas where the mosquito population becomes critical, using the mosquito's flight range to focus the necessary countermeasures and so avoiding excessive environmental contamination due to insecticide application in larger areas that present very low risk.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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