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Climatic and Physiographic Variables to Evaluate *Culex pipiens s.l.* Risk and Habitat

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Abstract

Using a geographic information system (GIS), the relations between a georeferenced data set of *Culex pipiens s.l.* collected in Portugal mainland during seven years (2006-2012) and meteorological and physiographic parameters are evaluated. This work is one of the results of a long-term surveillance program of pernicious insects that act as vectors of various diseases; its focus is on the possibility of prevention that can be achieved with abundance data. The focus on *Culex pipiens* is justified by its abundance and its competence as a vector for numerous health issues. The cumulative distribution of monthly captures by each meteorological parameter allows to compute thresholds corresponding to mosquito massive presence related to 90% of the captures. Using the weather parameters measured in the network of weather stations across the country, a monthly average of each parameter of interest (temperature, humidity, etc.) is computed and an interpolation of the results is made to produce raster maps corresponding to each month. The previously obtained thresholds are applied to each map, producing spatial masks with the relevant zones for each parameter. The intersection of the various masks for each month shows the most densely populated area of Culex, and the ensemble allows us to observe the evolution of mosquito presence through the critical season, which is from May to October at these latitudes. In parallel, mosquito abundance data are related to physiographic parameters. The relative distribution of female mosquitoes across land cover types in each month allows identifying which classes and seasons are most relevant. Orthometric altitude related to the presence of 90% of the catches shows the limits reached by mosquitoes in each month. The results are applied to the previously obtained climate envelopes, delimiting critical areas where the level of risk of transmission of the pathogens for which Culex pipiens is a competent vector is high and countermeasures should be concentrated, allowing its planning, and targeting on a monthly basis. The described procedure can be used with other relevant vectors in any region of the world, whenever abundance data is available.

Keywords

Vector-Borne Diseases, Transmission Risk, *Culex pipiens s.l.*, GIS, Global Changes

1. Introduction

The mosquito species most abundant in Portugal mainland is the complex *Culex pipiens s.l.*, included in a long-term surveillance nationwide program rolling since 2006. These mosquitoes are among the competent vectors to transmit many pathogens of medical importance such as West Nile virus (Hamer et al., 2008; Ozdenerol, Bialkowska-Jelinska, & Taff, 2008), iridoviruses, rheoviruses, and parvoviruses (Vinogradova, 2000). Like in many other mosquito species, females need a blood meal to get the protein enzymes to develop the eggs while males do not bite. Both total and females' mosquito records were detailed in the data set, but we focus on females, which gonotrophic cycle mate-bloodmeal-oviposition is responsible for the virus transmission (Bentley & Day, 1989) and its abundance is the key to delimit areas of higher transmission risk for the planning of local prophylactic countermeasures. We used seven years (2006-2012) of the data set to characterize the areas with a suitable environment for *Culex pipiens s.l.* using its abundance as a proxy to relate with meteorological and environmental factors—several works in this research topic can be found (Kalluri, Gilruth, Rogers, & Szczur, 2007; Beck, Lobitz, & Wood, 2000). The same methodology can be applied to other vectors, whenever surveillance data is available—the distribution of most vectors of zoonoses is linked to the environment determinants ensuring survival conditions (Brownstein et al., 2002). A raster-based abundance map enables a more efficient monitoring in any arboviral surveillance program aiming at control (Barker, Eldridge, & Reisen, 2010) and is the baseline to evaluate disease transmission risk (Tachiiri, Klinkenberg, Mak, & Kazmi, 2006) and identify areas with future higher probability of infection. The procedure presented can be used with abundance data instead of disease occurrences, being part of any surveillance program already in place and contributing to focus prevention measures. The use of open-source data, such as altitude and land use/land cover data, puts this methodology within the reach of various official services such as municipalities, to save human labor and avoid the use of toxic products over large regions. This methodology can be applied anywhere with other vectors, since weather and thematic cartography is worldwide available (Hay, Tatem, Graham, Goetz, & Rogers, 2006), a few options of open-source GIS are offered, and the computational requirements are the usual find in a current laptop.

2. Materials and Methods

The data base was collected from May to October all over Portugal mainland, and *Culex pipiens* is noticed in 2181 georeferenced bulletins, containing records of 37,094 female mosquitoes, with a global average of 17.0 females per trap per night. All the traps stayed for one night on the site chosen. Four baiting options were contemplated, namely CO_2, dry ice, BG attractant and no bait at all.

The mosquito + pathogen dynamic depends on multiple factors, and the weather conditions are crucial since mosquitoes are ectothermic organisms, and the development of the virus inside its body is initially dependent on temperature specific thresholds. Also, mosquito survival and pathogen development and maintenance are strongly affected by the variability of external conditions and suitability of environment. Driven by this reasoning, we used air temperatures since minima and maxima temperature control most *Cx. pipiens* biological rates (Paz & Albersheim, 2008) including blood feeding, reproduction, and larval development, as well as the viruses' dynamics and survival inside the mosquito.

Considering that humidity influences both the survival and flight performance of mosquitoes, contributing to increase the frequency of host contact, we use maxima and minima values for air relative humidity. Occurrence records and climatic data from the network of 136 weather stations are exactly from the same period. A preliminary analysis of the data shows well marked trends for minima and maxima temperatures of the air and minima relative air humidity, whereas the value of minima relative humidity of the air seems to be less important. Using the whole dataset, we can evaluate the distribution of captures above and below average (**Figure 1**) and anticipate that the favourable interval for more significant captures will occur when the minima temperatures reach circa 11˚ Celsius, and the maxima is above 22˚ Celsius.

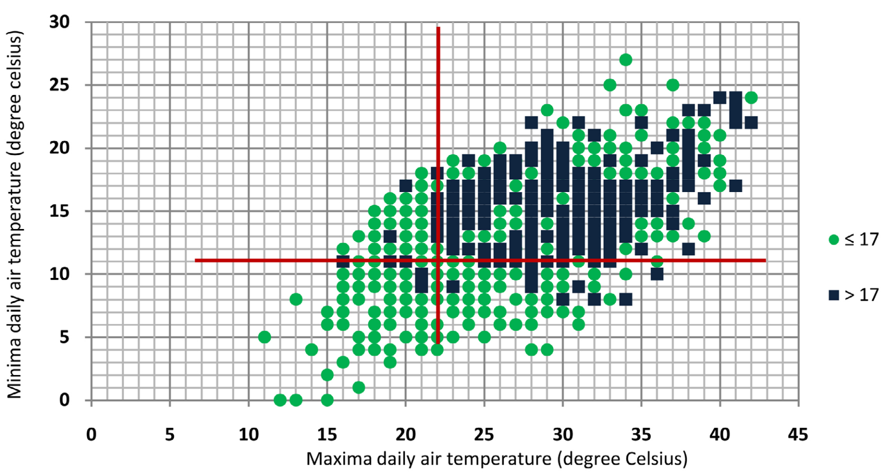

Figure 1. Female captures higher than the average of 17.0 (black square) occur more often when minima and maxima daily temperatures are respectively greater than 11 and 22 degrees Celsius.

The cumulative distribution function (CDF) (Gabbiani & Cox 2010) is used to find the threshold of relevant abundancy for each meteorological parameter, corresponding to the value where the CDF reaches 10%. Exemplifying with temperatures (**Figure 2**), the cumulative distribution function of captures for each month with minima and maxima temperatures is computed and the value of temperature corresponding to 10% of the CDF is interpolated in Matlab environment.

3. Results and Discussion

Temperatures from the network of meteorological stations were monthly averaged and interpolated using the method of inverse distance weight in the GIS, resulting in rasters of minima and maxima temperatures for each month. The thresholds previously determined were applied, segmenting the raster and producing a binary mask where the value one is assigned to the area of interest and zero to its complement. When all the meteorological parameters were evaluated for one month, the respective masks were multiplied to find its intersection (**Figure 3**), that delimits the area satisfying simultaneously all the climatic conditions required according to the abundance of *Culex pipiens*.

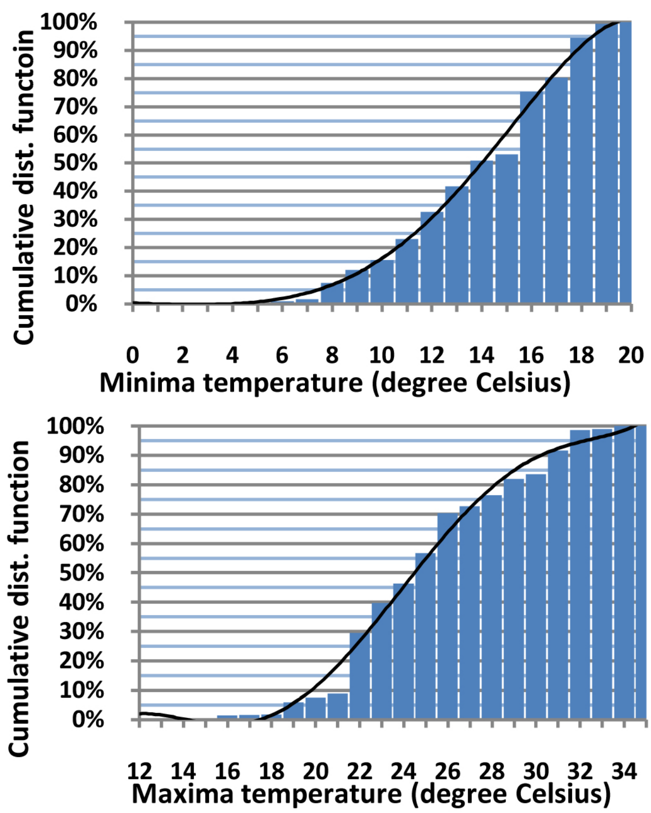

Figure 2. Example of the cumulative distribution function of captures with minima (left) and maxima (right) temperatures for one month (October): the value of temperature corresponding to breaking 10% - 90% of the CDF is interpolated and will be the threshold for that month.

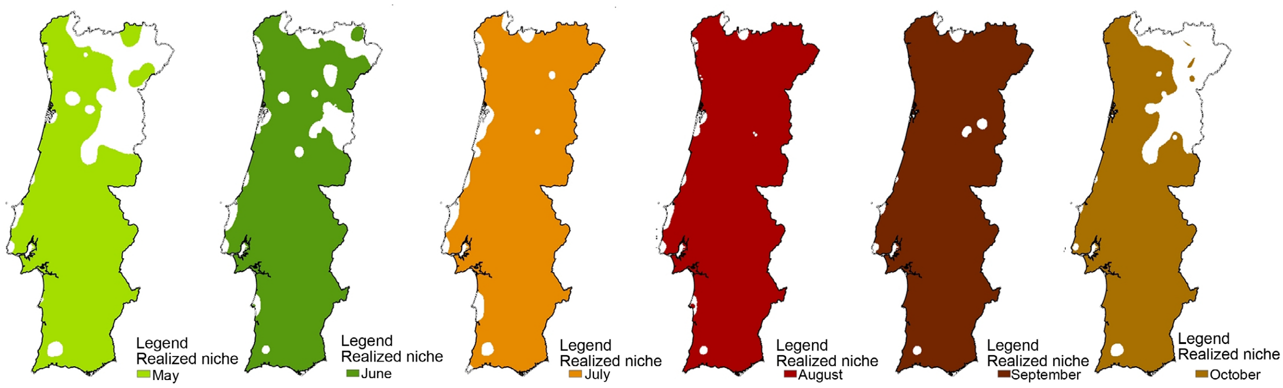

Figure 3. Climatic envelopes (from left to right, May to October) obtained considering 90% of the cumulative distribution of captures for each month, considering air temperatures and air relative humidity (minima and maxima for both).

These results were refined considering the distribution of *Culex* by pertinent physiographic parameters. *Culex pipiens s.l.*, as a peridomestic species, is peculiar in what concerns its breeding places, from where it would never be very distant: any recipient with standing water will do, natural or man-made, preference with high organic content (Paz & Albersheim, 2008). Marshes, lagoons, dam reservoirs or any other cartographic information regarding the hydrographic network is not particularly relevant, as mosquitoes thrive in any water spot left by the rain or an irrigation system.

Mosquitoes need to live near vegetation cover that can provide shelter, carbo-hydrate resources, and the essential meal of blood for reproduction (Brownstein et al., 2002). Using the Corine Land Cover from 2006 (Bütner, Kosztra, Maucha, & Pataki, 2012) and regrouping the hierarchical legend of 44 classes in 10 aggregated classes with biologic meaning in the context of mosquitoes, we evaluate the relative abundance among these classes for each month (**Table 1**).

We can conclude that the 5 classes more relevant during May, June, September, and October are heterogeneous cultures, human presence, forest, small vegetation, and temporary wetlands. In July the biggest concentration is in heterogeneous cultures, and in August water bodies became also important. The most relevant classes for each month were spatially aggregated producing a new binary mask, corresponding to the area where the presence of mosquitoes is most noticeable in each month.

Considering the altitude at which we found the Culex complex, the cumulative distribution function of catches by orthometric altitude (extracted from a digital elevation model) gives the values related to a massive presence of mosquitoes in each month. From May to October, these altitudes are respectively 137.0, 164.3, 263.1, 352.7, 261.3 and 157.5 m. They present an obvious symmetry; in August, with hot weather, mosquitoes go up to fresher areas, and descend when the weather get cold again. This can be translated to a spatial condition in the DEM, masking the areas that satisfy the thresholds for each month, as shown in **Figure 4**.

Table 1. Relative abundance of *Culex pipiens* females by aggregate class of land use/land cover.

	May	June	July	August	September	October
Heterogeneous cultures	**22.2%**	**66.8%**	**61.3%**	**31.0%**	**39.5%**	**24.7%**
Human presence	**17.0%**	**20.2%**	**22.3%**	**27.8%**	**21.0%**	**41.9%**
Forest	**36.3%**	**5.7%**	**5.6%**	**7.0%**	**26.7%**	**9.3%**
Small vegetation	**12.2%**	**3.6%**	**9.2%**	**20.0%**	**7.4%**	**19.5%**
Temporary wetlands	**10.2%**	**3.1%**	1.2%	**7.8%**	**3.8%**	**3.9%**
Water bodies	0.4%	0.2%	0.0%	**4.3%**	0.2%	0.0%
Permanent cultures	1.8%	0.3%	0.4%	2.0%	1.3%	0.4%
Coastal wetlands	0.0%	0.0%	0.0%	0.1%	0.0%	0.2%
Natural wetlands	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Urban uninhabited	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

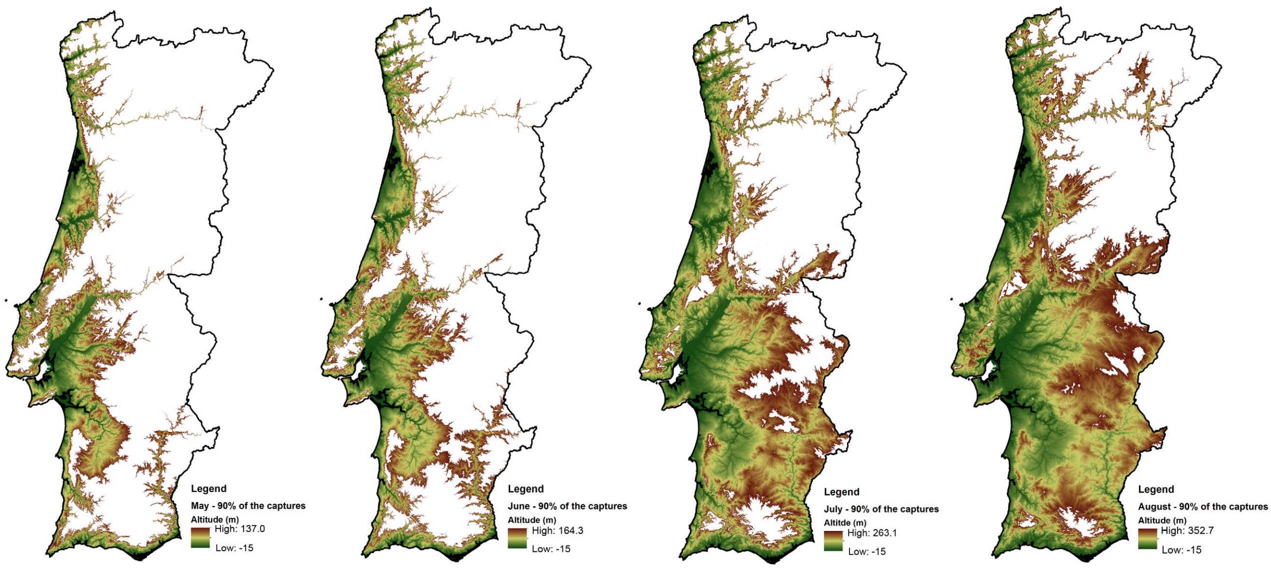

Figure 4. Regions of the DEM corresponding to the altitudes where the majority of *Culex pipiens* females were captured in the months of May, June, July and August (from left to right).

The intersection of climatic and physiographic conditions in each month (Figure 5) limits the realized niche of *Culex pipiens s.l.*

Epidemiologically, mosquito population size is an important component of vectorial capacity (Reisen et al., 2008) that with local human density, would determine the possible rate of pathogen transmission by host contact and therefore the risk of human infection in the area.

4. Conclusion

With a vector species abundance dataset as a starting point, we were able to map the areas where the probability of transmission for the vector-borne diseases

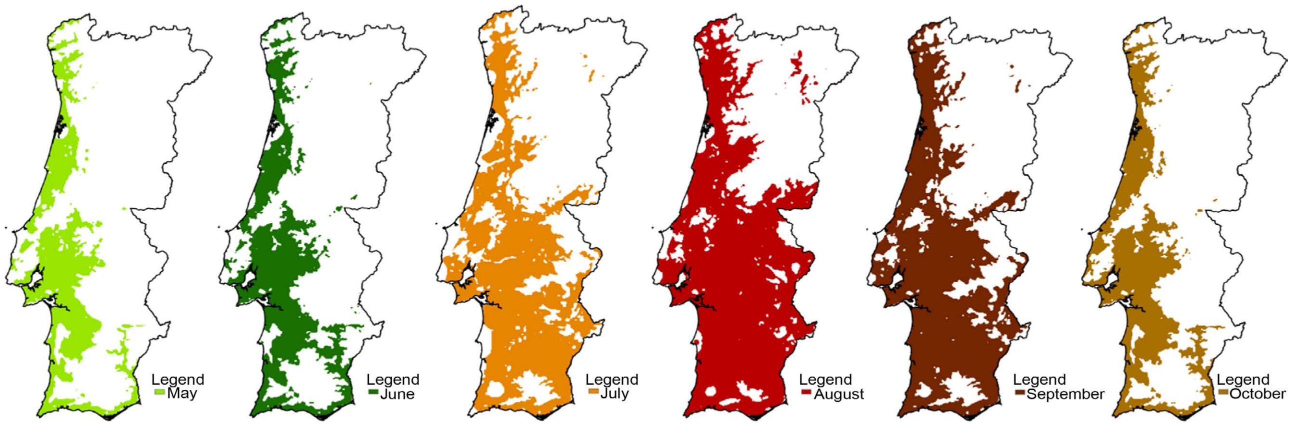

Figure 5. Areas where the risk of transmission is high due to abundance of *Culex pipiens* for each month, determined using air temperature and relative humidity values, land cover and altitude.

associated with that vector was significant. The same methodology can be used with other vectors if abundance data is available, at any scale, and the resulting maps can be used to target prophylactic countermeasures to mitigate costs and avoid extensive chemical applications, while helping to minimize risk to human health and protect the environment.

The ability to anticipate the planning of mitigation measures can be capital for outbreaks of vector-borne diseases with severe outcomes, especially due to the strong dependence of transmitted pathogens on temperatures, which are increasing rapidly with global change. This particular methodology is within the reach of many official services, such as city councils, which are now often equipped with GIS for other reasons (cadastre, road network, etc.) and can have field work done locally, being able to map problematic areas and plan local interventions.

Based on current work, future research directions will focus on using multiple vectors simultaneously to establish areas of higher risk to be cross-referenced with demographic data. Mitigation measures must also be categorized, to ensure the best cost/benefit ratio between the environmental disturbance and the required outcomes.

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Conflicts of Interest

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

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