Ports and Airports: Gateways to Vector-Borne Diseases in Portugal Mainland

Maria C. Proença, Maria T. Rebelo, Maria J. Alves, Sofia Cunha

***Abstract*—**Vector-borne diseases are transmitted to humans by mosquitos, sandflies, bugs, ticks, and other vectors. Some are re-transmitted between vectors, if the infected human has a new contact when his levels of infection are high. The vector is infected for lifetime and can transmit infectious diseases not only between humans but also from animals to humans. Some vector borne diseases are very disabling and globally account for more than one million deaths worldwide. The mosquitoes from the complex *Culex pipiens* sl. are the most abundant in Portugal, and we dispose in this moment of a data set from the surveillance program that has been carried on since 2006 across the country. All mosquitos' species are included, but the large coverage of *Culex pipiens* sl. and its importance for public health make this vector an interesting candidate to assess risk of disease amplification. This work focus on ports and airports identified as key areas of high density of vectors. Mosquitoes being ectothermic organisms, the main factor for vector survival and pathogen development is temperature. Minima and maxima local air temperatures for each area of interest are averaged by month from data gathered on a daily basis at the national network of meteorological stations, and interpolated in a geographic information system (GIS). The range of temperatures ideal for several pathogens are known and this work shows how to use it with the meteorological data in each port and airport facility, to focus an efficient implementation of countermeasures and reduce simultaneously risk transmission and mitigation costs. The results show an increased alert with decreasing latitude, which corresponds to higher minimum and maximum temperatures and a lower amplitude range of the daily temperature.

***Keywords*—**Human health, risk assessment, risk management, vector-borne diseases.

I. Introduction

A mosquito abundance data set of *Culex pipiens* sl., species of major medical importance, was collected in Portugal mainland during nine years (2006-2014) and allows identifying ports and airport zones as areas of high density of vectors. Epidemiologically, mosquito population size is an important component of vectorial capacity that determines the frequency of host contact, the rate of pathogen transmission and therefore the risk of human infection.

Culex pipiens, as well as other mosquitoes, have the ability to feed across zoological class lines, acting as bridge vectors and transmitting zoonotic pathogens to humans [1], [2].

The viability of an infectious agent transported by humans to survive in a new environment and be transmitted by the waiting vectors is mainly a function of temperature. Temperature is related to the life-cycle dynamics of both the vector species and the pathogenic organisms [3]. As the vectors are ectothermic organisms, they are highly susceptible to positive gradients of air temperature, which will increase their reproduction rates and number of blood meals, and prolongs their breeding season [4]. The maturation of the virus – rates of development and reproduction - is directly proportional to the temperature in a given range specific to each virus, and higher temperatures within that range will reduce the extrinsic incubation period [5], defined as the time interval between acquisition of an infectious agent by a vector and the vector's ability to transmit the agent to other susceptible hosts [6], thereby increasing transmission risk.

Once the virus is introduced, it has the potential to establish itself and spread rapidly, since mosquito species with knowing competence for hosting and transmitting do exist in Portugal – we use *Culex pipiens* sl. as a surrogate for estimating the potential risk, as it is the most widespread and abundant mosquito in the country and is a competent vector for more than 22 virus, including West Nile virus (the most widely distributed arbovirus in the world, occurring on all continents except Antarctica [7]) and St Louis encephalitis virus, arboviruses, iridoviruses, rheoviruses and parvoviruses [8]. Adults live for four to five weeks and females in Europe can hibernate during winter [9], carrying the pathogens to the next season.

Ports and airports are locals of circulation in two directions – people are coming and leaving the country; the first carry the viruses to the local community of vectors, while the very same vectors have the opportunity of final contact with those leaving, which will carry away the pathogens acquired, spreading those for which humans are not dead end hosts. Not only a mosquito population of relatively high size is present in these areas, but also the density of human population ensures the possibility of a high frequency of host contact.

This work demonstrates that the temporal limits corresponding to the critical range of temperatures identified in each international airport location and in the port facilities with larger traffic can be used by the local authorities to plan prevention and mitigation measures, focusing where and when the countermeasures should be applied on a monthly basis.

II. Data and Methodology

The georeferenced data set of *Culex pipiens* used were collected during the mosquito season – from May to October in Portugal mainland, during nine years, from 2006 to 2014,

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under a long term vector surveillance program called REVIVE (*REde de VIgilância de VEctores)*, implemented by the Health Ministry and local health authorities.

The capture of adult mosquitoes occurred from May to October, using CDC-like traps installed, once a week, in the early evening and collected the morning of the following day.

The data from these nine years consists in 3,714 georeferenced registers of captures georeferenced, covering the country from north to south, with a mean catch of 12.36 female mosquitoes per trap per night. Females are the only that do bite, as they need a blood meal to get the protein enzymes to develop the eggs [10]. It is when the female mosquito ingests the blood of an infected host that it acquires the pathogens and becomes infected for lifetime, so only females play an active role in disease transmission. Mosquito abundance hereafter refers to *Culex pipiens* sl. adult females' abundance.

The nine-year period covered by the data is simultaneously sufficiently long to include variation in environmental conditions [11], and short enough to reduce the influence of long-term trends in mosquito abundance.

The two measures used to evaluate the tendencies in the data set were the mean catch and the relative proportion of catches above average, defined as the percentage of catches above average in the total number of catches registered for the site or characteristic considered. These criteria allow the identification of Ports and Airports as one of the land use classes with large number of above average captures (Fig. 1), with a percentage more significant than the sites in the neighborhood of animals (including domestic husbandry, equines and kennel) and urban areas.

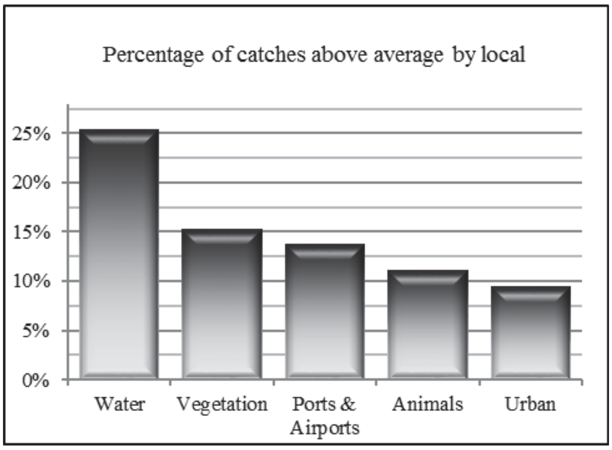
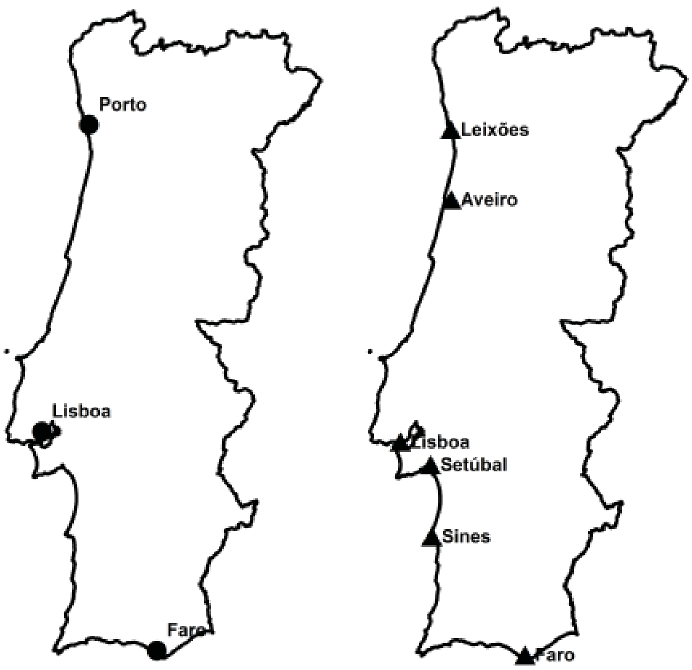


Fig. 1 Percentage of above average catches by typified land use class

The three international airport locations are Oporto, Lisboa and Faro (Fig. 2 (a)), which recorded together 32.6 million in passenger traffic in 2013 [12].

The five port facilities with larger traffic, that accounts for a total of more than 14,200 ships in 2013, including 1.2 million passengers in cruise lines [12], are Leixões, Aveiro, Lisboa, Setúbal and Sines (Fig. 2 (b)), all belonging to the main port system. The commercial port of Faro, although does not register large traffic, is used often for a weekly shipment of cement to Madeira island, where in 2012 a dengue outbreak occurred (1,898 recorded cases) [13], and for the reception of big trunks of exotic wood from tropical origin.

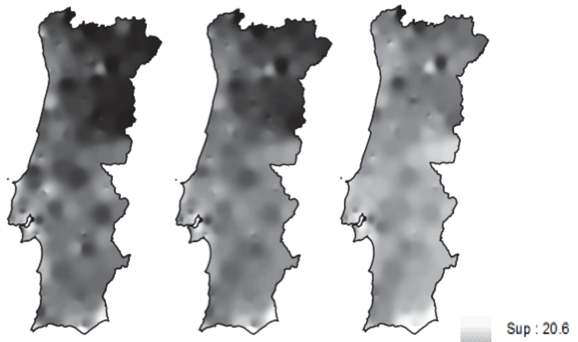


(a) (b)

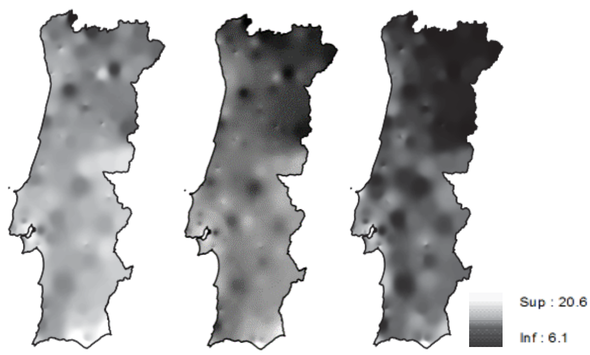
Fig. 2 (a) Airports location from north to south: Aeroporto Sá Carneiro at Porto, Aeroporto da Portela at Lisboa and Aeroporto de Faro; (b) Location of the six port facilities considered of interest

To characterize the range of temperatures at these locations during the mosquito season in terms of minima and maxima local air temperatures, we use data gathered on a daily basis at the national network of meteorological stations that comprises 136 weather stations (Fig. 3) exactly from the same years.

Fig. 3 Deployment of the 136 locations of the meteorological stations of the national network



(a)



(b)

Fig. 4 Series of air minima temperature maps from left to right: (a) May, June and July; (b) August, September and October. Temperature range: from 6.1 (black) to 20.6 (white) degrees Celsius.

Temperatures were averaged by month and interpolated using an inverse distance weight method in a geographic information system (ArcGIS 10.1 from ESRI). The maps obtained are two series (May to October) of minima and maxima air temperatures, where each month is computed with the mean values of minima (or maxima) temperatures from the data recorded in the meteorological stations exactly at the same period and interpolated to form a raster (Fig. 4).

Minima temperatures vary between 6.1 degrees Celsius (ºC) and 20.6 ºC, the higher values being recorded only in the south, in the eastern half of the Algarve region during July and August. May and October recorded the lowest minima in mountainous regions in the north and Serra da Estrela at Northeast, which features the higher point in Portugal mainland (1,993 m).

Maxima temperatures stay in the range 14.5 ºC to 35.7 ºC, with higher values registered in July and August at Alentejo, a province in the center of the country near the border with Spain.

III. Results and Discussion

The limits of transmissibility for vector-borne diseases are generally admitted to be 14 ºC and 18º ºC to the lower limit and 35 ºC and 40 ºC to the upper limit [14]; the vectors itself also have short tolerance to high temperatures.

Some specific pathogen temperature requirements are already known, like West Nile virus (18-30 ºC) [15], the malaria agents *Plasmodium falciparum* (15.4-35 ºC) [16] and *Plasmodium vivax* (14.5-35 ºC) transmitted by *Anopheles* spp., which occurrence in Portugal is known [17], [18], yellow fever virus (16.5-35 ºC) [19] and dengue virus (11.9-37 ºC) [20], [21], both flavivirus transmitted by *Aedes* spp. mosquitoes already established in Madeira [22], where a recent dengue outbreak occurred [13]. The large range of temperatures associated with dengue virus is a major concern in Portugal, due to the significant communities of natives from Cabo Verde and Brazil, both countries where dengue is a public health problem.

The risk from air traffic based in Porto (Fig. 5) is small - the minima and maxima temperatures during the mosquito season could demand for surveillance only for dengue and malaria and associated vectors, as the minima temperature stays in between 12.4 ºC and 15.6 ºC, while the maxima vary from 20.5 ºC to 25 ºC. The same apply to the Leixões port facilities, in a short distance from Porto.

The minima average temperatures concerning Lisboa airport are higher than Porto, as the two airports present a difference of 2.5 decimal degrees in latitude.

In Lisboa airport (Fig. 6) minima temperatures ranges from 14.3 ºC to 18.6 ºC and maxima averages vary from 23.6 to 29.8 ºC. This window of opportunity includes all viruses and protozoa previously mentioned after June; the exception is West Nile virus that requires a minimum of 18 ºC to develop inside the vector, and that condition only occurs during July (18.0 ºC) and August (18.6 ºC). The minima of 14.3 ºC in May only demands surveillance focused in dengue virus and its vectors, and October, with an average minimum temperature of 15.3 ºC, needs also surveillance in malaria agents and possible existence of local vectors.

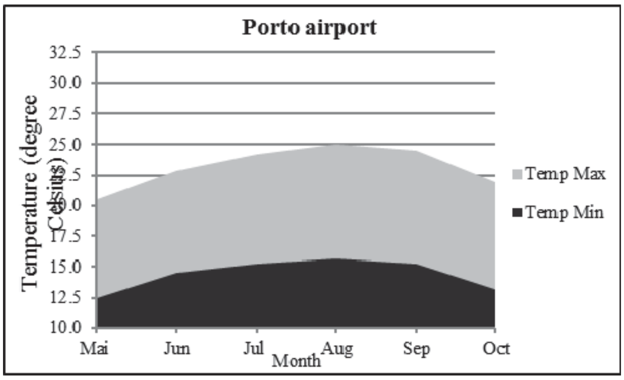


Fig. 5 Air temperature monthly average for Porto airport, from May to October

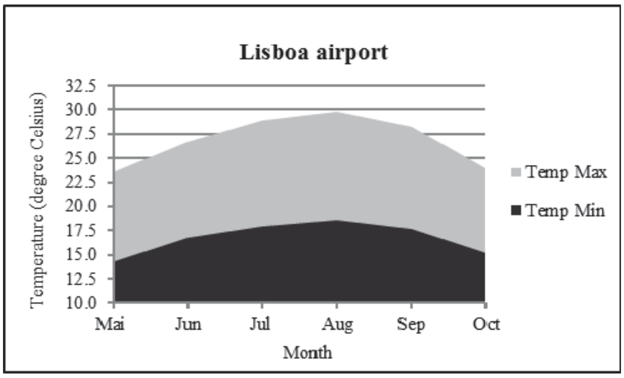


Fig. 6 Air temperature averages for Lisboa airport, from May to October. Compared to Porto airport (Fig. 5), there is an obvious increment in minima and maxima temperatures as latitude decrease (Porto airport latitude: 41º14'27", Lisboa airport latitude: 38º46'30")

The third international airport is at the south, located in Faro and has averaged minima temperatures between 15.4 ºC and 20.3 ºC, and maxima ranging from 23.9 ºC to 29.9 ºC (Fig. 7). This is the most critical entry point in the country because during four of the six months that are the "mosquito season" in Portugal (May to October) the minima temperatures are above 18 ºC, enabling the development of all the previously mentioned viruses; and also because – the temperature being the cause or not – this is one of the areas known [23] to be populated by a large variety of vectors. The maxima temperatures remain below 29.9 ºC, never increasing to the values that will endanger vectors survival or viruses' development.

In Faro, the minima averaged temperatures occurred in May (15.4 ºC) and October (16.3 ºC), still allowing for the eventual development of dengue and malaria agents, if vectors are present. In the other four months, minima temperatures in the range 18.0 ºC to 20.3 ºC and maxima temperatures below 30 ºC ensures the conditions for West Nile virus development in a region with a large population of *Culex pipiens* spp., where the birds species acting as primary reservoirs do exist, as well as animal husbandry (pigs, horses, sheep and chicken) that can act as amplification hosts. It is worth noting that a case in humans has been reported in Algarve (Loulé municipality) in 2015 [24].

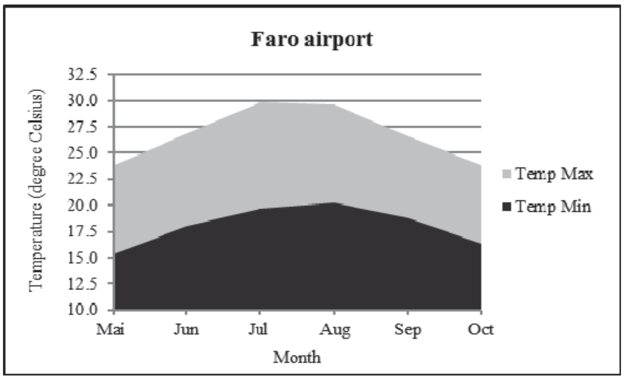


Fig. 7 Air temperature averages for Faro airport, at the south of Portugal, through the mosquito season: from May to October

Concerning the remaining port facilities, from north to south, the Port of Aveiro (Fig. 8) presents minima temperatures between 13.5 ºC and 16.1 ºC, enabling all but West Nile and yellow fever agent's development. Maxima temperatures amplitude stays in the range 21.0 ºC to 24.3 ºC.

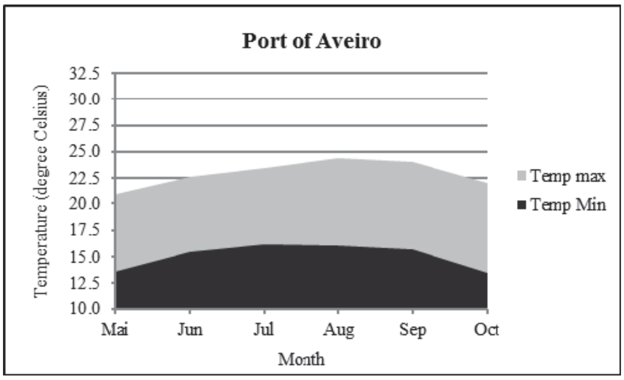


Fig. 8 Air temperature monthly averaged at port of Aveiro facilities

The Port of Lisboa features a profile of temperatures similar to Lisboa Airport; more to the south, Setúbal Port facilities have a larger dynamic range, the minima temperatures varying from 14.6 ºC to 18.4 ºC and the maxima from 25.1 ºC to 30.2 ºC (Fig. 9). It is only in July and August, usually the warmest months of the Portuguese summer that the minima average temperatures are above 18 ºC.

The conditions for development of the dengue virus are present throughout the entire summer and the cement industry near the port has a weekly shipment to Madeira. If the vectors are transported within the ships, they will find the appropriate conditions at Setúbal.

More to the south and facing west, the port facilities in Sines have a different profile for minima and maxima temperatures (Fig. 10), with less amplitude than the port of Setúbal and a constant difference between both.

Similarity with the other port facing west, Aveiro, is obvious comparing Figs. 8 and 10. The port of Sines serves mainly the oil terminals so, although it is responsible for a large volume of traffic, but traffic in tons, not so much in number of people. The origin and destination of the large oil tankers are not public domain information, so it cannot be related to zones with dangerous known species of vectors and agents.

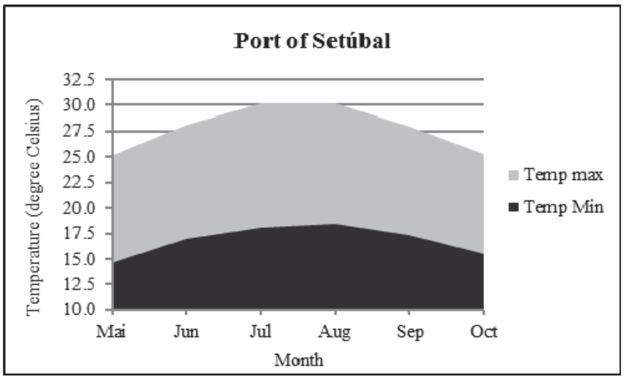


Fig. 9 Air temperature averages for Setúbal port facilities, situated on the west coast, facing south

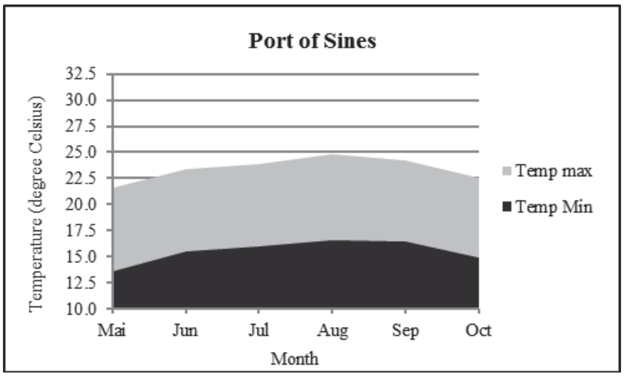


Fig. 10 Air temperature averages for Sines port facilities, situated on the west coast, facing west

The smaller port of Faro, on the south coast of Portugal, is a commercial port where two interesting kinds of shipments are frequent – cargo in a round trip to the autonomous region of Madeira and the arrival of large trunks of exotic woods with origin in tropical regions around the globe, where these kinds of trees are native.

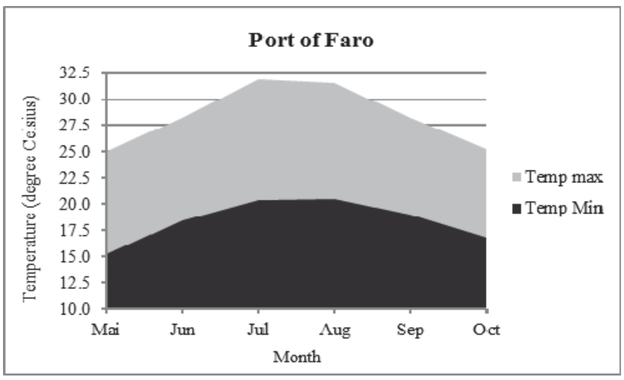


Fig. 11 Air temperature averages at Faro Port facilities, situated on the south coast.

From June to September, the averages of minima temperatures are above 18.5ºC, enabling the development of all the viruses considered in a favorable environment, including West Nile virus. The minimum average temperature in May (15.2 ºC) and October (16.9 ºC) still let some concerns about a dengue and malaria transmissibility scenario, since this port is a location where all the conditions for transport and introduction of novel agents and vectors are fulfilled and became a real possibility.

III. Conclusions

Combined assessment of potential introduction gateways and local climatic zones may form an evidence base for planning efficient mitigation strategies against epidemiologically aggressive invaders.

In this context, airports and ports vector control can help identify potential targets and enable major policy decisions, so effective action can be taken – with precise targets located in space and time. This work is a baseline, where the *Culex pipiens* spp. is used as a surrogate for the large mosquito population that does exist. The data for the transmissibility windows of pathogen agents is exemplified with the values available in the literature for West Nile, dengue, yellow fever viruses and malaria protozoa, the best studied in this moment, but there are many ongoing research projects in this field.

New strategies for prevention and control of vector-borne diseases are emphasizing "Integrated Vector Management" as a multi-sectorial approach that reinforces linkages between health and environment, providing stakeholders with a complete tool for improving decision capacity.

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