

Mosquito Abundance as a Proxy to Assess Vector-Borne Disease Risk

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Abstract

This work characterizes the most suitable Mediterranean environment for *Culex pipiens s.l.*, using 7 years of data collected in Portugal from May to October each year. *Culex pipiens s.l.* is the most common mosquito complex with a Holarctic distribution and medical importance, being the vector of more than 20 virus species. Female mosquito abundance data is used with environmental factors in a geographic information system to characterize their habitat, using land use/cover data, distance to mapped bodies of water and altitude. The distribution of mosquitoes by each factor shows mosquito preferences and identifies thresholds between zones of higher/lower abundance for i) altitude at 100 m intervals and ii) distance to water at 1000 m intervals; in the case of land use/land cover, subsets of more/less populated classes are identified and aggregated. These thresholds allow the corresponding maps to be segmented, with their intersection being the common area where all the environmental factors considered favor the presence of mosquitoes, thus constituting areas of significant risk for disease transmission. The above-average catches of the entire data set have made it possible to identify three categories of increased risk, where countermeasures should be focused in detailed mitigation planning. This methodology can be used for any other vector of medical importance, whenever abundance data is available, helping to reduce costs, human labor and the adverse side effects of insecticide application.

Keywords: *vector-borne diseases, transmission risk, Culex pipiens s.l., GIS, mosquitos.*

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Introduction

This case study characterizes the environment of *Culex pipiens s.l.* in mainland Portugal using its abundance as a proxy, with a set of data collected over seven years (2006-2012) from May to October throughout the territory, because from November to April the activity of *Culex pipiens* is negligible in the latitudes of Portugal, ranging from 36° 57' N to 42° 9' N. The specimens collected were identified and separated into females and males, allowing to work out the abundances of each sex.

Although the data base includes many other mosquitoes, the focus of interest in the *Culex pipiens* complex is justified by its abundance (Gomes et al, 2012) and medical importance as vectors of arbovirus of concern to human health, like West Nile virus (Hamer et al., 2008) iridoviruses, rheoviruses and

parvoviruses (Vinogradova, 2000). The *Culex pipiens s.l.* disease transmission requires the completion of at least one gonotrophic cycle before pathogen transfer occurs (Bentley & Day, 1989) as the transmission is a collateral effect of the blood meal needed for the oviposition. This species complex prefers standing water with a high organic content (Paz & Albersheim, 2008), as can be seen in most long-lasting pools of water. The dataset consists of 2,181 bulletins, containing records of 37,094 female mosquitoes linked to environmental factors in a geographic information system (GIS). A few works in this area of research can be found (Beck et al, 2000, Kalluri et al, 2007), and the bases of the methodologies, although quite diverse, have also been inventoried (Dale et al, 1998).

The environmental factors used here to characterize the vector habitat are land use/land cover (LU/LC), distance to cartographed water bodies, and altitude. Focus is on mosquito females, which gonotrophic cycle mate-bloodmeal-oviposition is responsible for the virus transmission (Ghakanyuy et al, 2022) since its abundance is the key for the planning of prophylactic countermeasures in delimited areas of disease transmission risk and to focus mitigation measures to avoid outbreaks of vector-borne diseases. Both total and females' figures were detailed in the data set.

The same methodology can be applied to other vectors whenever abundance data is available as the cartography is worldwide available (Hay et al, 2006) and the computational requirements are the usually found in a regular laptop.

Materials and Methods

The data set is issued from a long-term vector surveillance program implemented by the Health Ministry, with the local labor of five regional administrations of health (ARS). Sampling was carried out from May through October, with modified CDC-traps staying on site for one night. The average capture is defined as the number of females captured divided by the number of traps used in one night, at each place.

Two criteria were used to compare the environmental parameters associated with catches and establish a breakdown: the average catch in each interval considered (or LU/LC class), which made it possible to find a threshold to discriminate areas where abundance is relevant, and the distribution of catches above the average, which allowed for greater refinement in the areas of interest. The average of the overall data set is 17.0 *Culex pipiens* females per trap and night. To ensure that a threshold or a subset of classes was the best, we compared the two large groups resulting from the splitting using statistical Levene's test for variances and the appropriate test for means at a 95% confidence level.

Land Use/land Cover

The land use/land cover information used is part of the data base issued from the CORINE Programme Co-ordination of Information on the Environment). Basically, it is an inventory of land cover with a hierarchical nomenclature of 44 classes: a program of the European Union aiming to build a uniform data base at a scale 1:100 000, with a minimum unity cartographed of 25 ha. From 1985 to 1990, the European Commission implemented the CORINE Programme, and now is under the European Environment Agency (EEA) responsibility.

We use the data base from 2006, Corine Land Cover 2006 (CLC2006). Two kinds of satellites provided imagery for CLC2006 project (Bütner, 2012):

- French SPOT-4/5 (60 km swath width, 20 m pixels; VIS, NIR and SWIR bands).
- Indian IRS P6 LISS III (141 km swath width, 23 m pixels; VIS, NIR and SWIR bands).

The original 44 classes of land use/cover data were aggregated to establish the relationship between mosquito activity and their habitat preferences. This aggregation was achieved by merging several Corine



Land Cover (CLC) classes into 11 classes, synthesizing the common interest of each subset for mosquitoes: Forest, Heterogeneous cultures, Permanent cultures, Small vegetation, Human presence, Human uninhabited, Temporary, Coastal and Natural wetlands, Bare soil and Water bodies. This spatial aggregation was carried out in a geographic information system (GIS) (ESRI's ArcMap). The result (Figure 1) is a consolidated thematic map, with significant differences in detail.

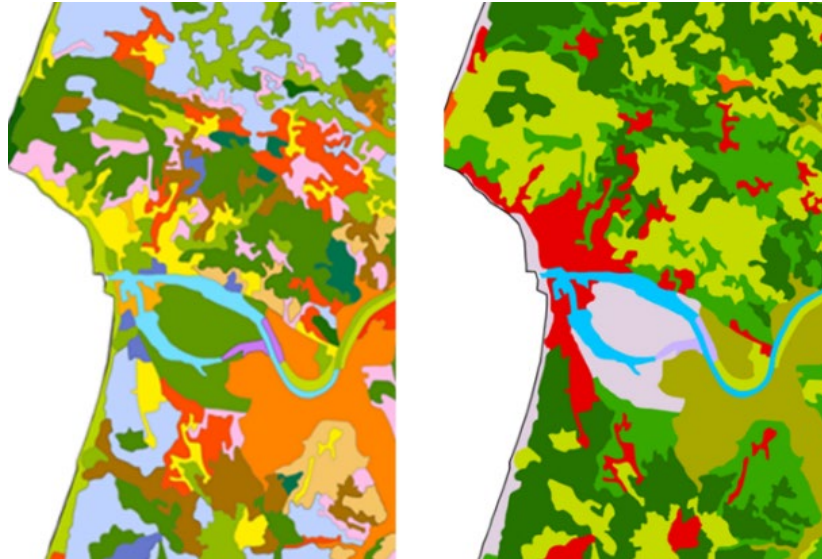


Figure 1. Illustration of the Difference Corresponding to the Original Corine Land Cover with 44 Possible Classes (left) Versus the Same Area with the Aggregation to 11 Classes (right)

The Bare soil class has no associated records, so only 10 aggregate classes were used.

Altitude

The altimetry came from the digital elevation data (DEM) obtained by the Shuttle Radar Topography Mission (SRTM), an international project spearheaded by the U.S. National Geospatial-Intelligence Agency (NGA) and the U.S. National Aeronautics and Space Administration (NASA) that has covered more than 80% of the Earth's solid surface during a 11-day mission of the Space Shuttle Endeavour in February 2000. The SRTM data is available as 3 arc second (approx. 90 m ground resolution) and has a vertical error reported to be less than 16 m (USGS EROS Archive, n.d.). We had access to a version made available by University of Porto, which has been projected to ETRS89 PT-TM06 and resampled to a ground resolution of 80 m (DEM, n.d.).

Water Proximity

The information concerning cartographed water was available online from Serviço Nacional de Informação de Recursos Hídricos (Serviço Nacional de Informação de Recursos Hídricos, n.d.), the national service of water resources. The fact that it is standing water that provides breeding grounds for mosquitoes led to the selection of layers containing ponds, swamps, reservoirs and, finally, rivers, as they favor large pools of standing water along the banks and in the estuaries. These digital layers have elements of three different types: polygonal (reservoirs of dams, lagoons, and estuaries), linear (rivers) and punctual (marshes).



Analysis of Average Captures by Parameter

The average capture for each ARS, from North to South, is shown in Figure 2. Only at Alentejo and Algarve regions the records are higher than the overall average value of the data set (17.0 females).

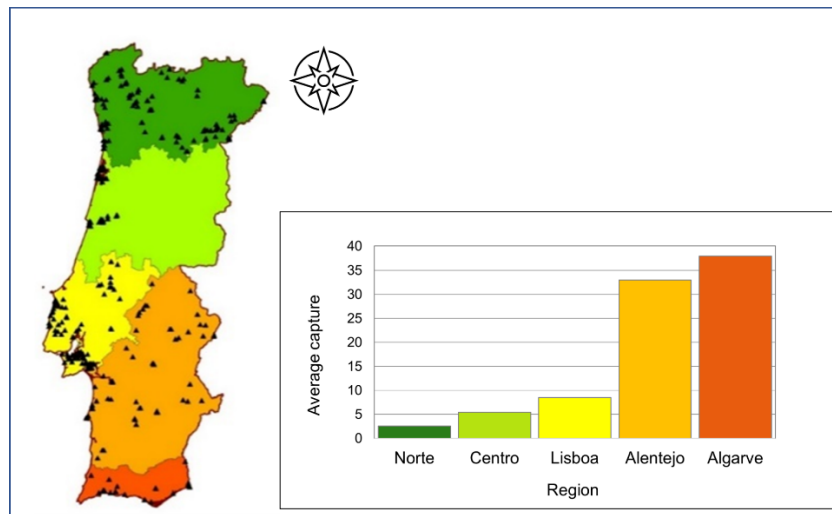


Figure 2. Left, Portugal Mainland with Capture Sites (black triangles) in the Five Regional Administrations of Health (ARS) and Right, the Average Capture in Each Region Coded in the Same Colors

Considering the average capture by land use/land cover, the score of the ten LU/LC aggregated classes shown in Figure 3, highlights that Heterogeneous cultures, Forest and Small vegetation has an average capture higher than the overall average, although three more classes have meaningful scores compared to the four less representative ones, which are Permanent cultures, Coastal and Natural wetlands and Urban uninhabited, all with an average capture below 2.5 individuals.

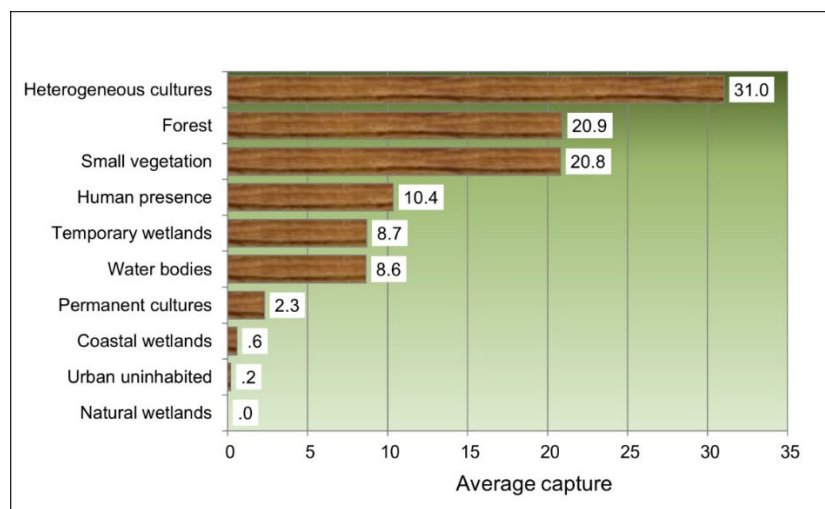


Figure 3. *Culex pipiens* Female Average Capture by Land Use/Land Cover Aggregated Class



For the altitude data, the orthometric altitude of each record was extracted and interpolated at each capture point. In the range found in the data [-15 m, + 941 m] we consider intervals of 100 m between 100 and 900 m and average the captures for each interval (Figure 4); the 400 m mark is a threshold for the mosquito abundance.

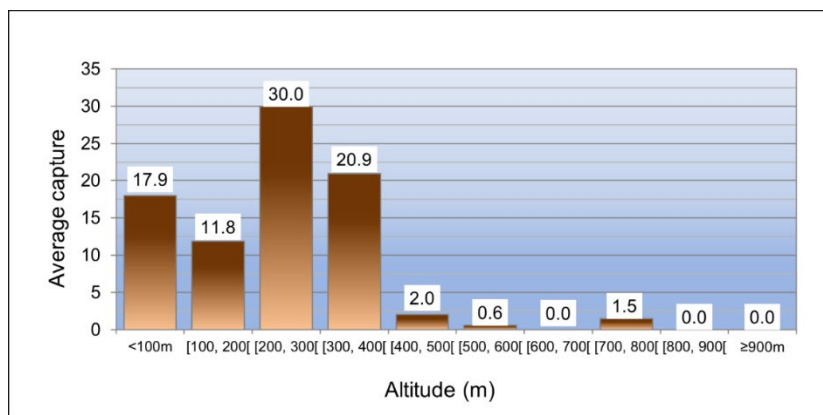


Figure 4. *Culex pipiens* Female Average Capture Size by Interval of Altitude

Regarding proximity to water, although the mapped bodies of water are indicative of the presence of standing water, there are also other small containers of water, both natural and artificial, which cannot be referenced. Thus, we worked with the set of layers mentioned above, establishing the minimum Euclidean distance to the nearest body of water at intervals of 1000 m, and we could see (Figure 5) a clear decrease in the average catch at distances of more than 3000 m.

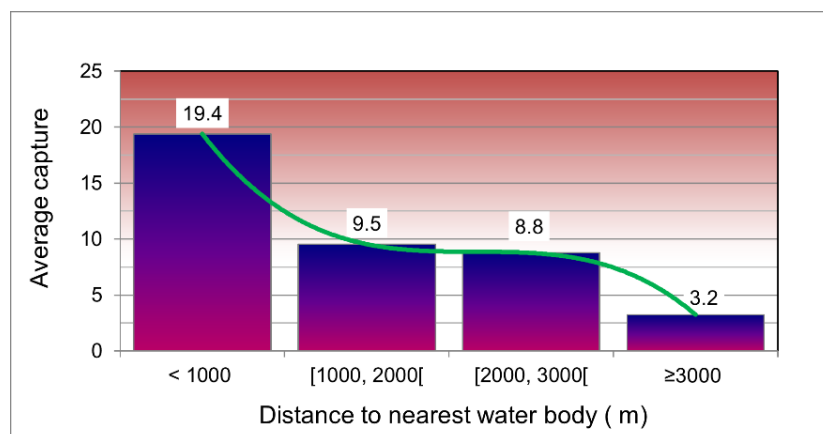


Figure 5. *Culex pipiens* Female Average Capture and Distance to a Cartographed Water Body

Analysis of Above Average Captures

Using the same methodology described above and the distribution of the 342 above-average catches instead of the 2,181 records (which contain around 5% of catches with zero individuals), we targeted only the areas where the mosquito population becomes critical, which allowed us to refine the area of greatest risk of transmission using the same environmental parameters. The procedure is illustrated with



the distribution of above-average catches by distance from a body of water (Figure 6), showing that 81% of all above-average catches occurred less than 1 km from a body of water, and 16.7% in the next interval, 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.

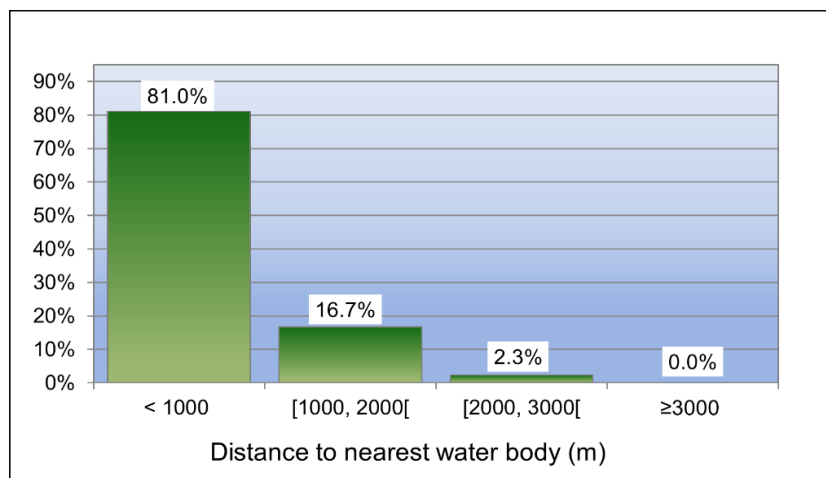


Figure 6. *Culex pipiens* Female Distribution of Above Average Captures per Water Body Distance

The same reasoning was used for the other two factors, altitude, and land use/land cover.

Results

The thresholds obtained by analyzing the average catches of female mosquitoes were applied to segment the thematic layers in the geographic information system, producing binary masks to delimit the areas with the required characteristics. Three masks were produced:

- the 6-land use/land cover classes with major abundance were aggregated in one mask.
- for the altitude, the 400 m threshold was applied to the raster DEM, separating the higher altitudes, that in the case of Portugal are mainly at the north.
- the distance of 3000 m from the water is represented by a buffer contouring all the cartographed water bodies. The water distance was processed separately for rivers and the set of lagoons, reservoir dams, marshes, and estuaries because of its nature in a GIS, as mentioned: rivers are the only linear feature among the water layers.

The crossing of these 3 spatial conditions gives the area where the abundance of the vector is most noticeable (Figure 7).

In this area identified by the abundance of *Culex pipiens*, which therefore has a high probability of vector presence and, inherently, a high risk of transmission to humans (Reisen et al, 2008), the distribution of catches above the average was used to discriminate three sets of conditions that express risk categories. These three categories were characterized by:



1 – Minimum risk: distance to water bodies < 3000 m, altitude < 300 m, and LU/LC classes included Heterogeneous cultures, Small vegetation, Forest, Temporary wetlands, Human presence and Water bodies.

2 – Medium risk: distance to water bodies < 2000 m, altitude < 200 m, and LU/LC classes included Heterogeneous cultures, Small vegetation, Forest and Temporary wetlands.

3 – High risk: distance to water bodies < 1000 m, altitude < 100 m, and LU/LC classes included: Heterogeneous cultures and Small vegetation.

The three risk categories are shown superposed in Figure 8.



Figure 7. Area of Higher Probability of *Culex pipiens* s.l. Presence in Portugal

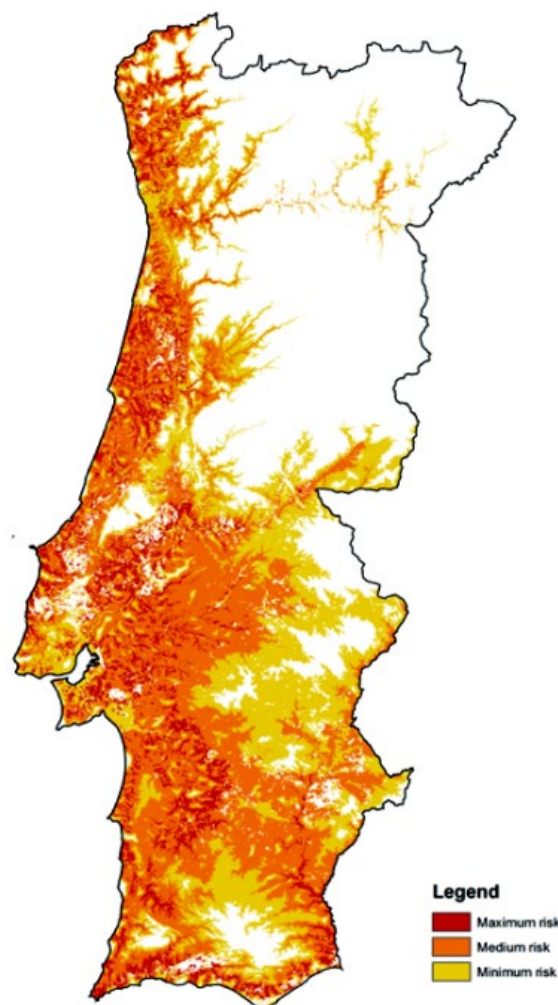


Figure 8. The Three Areas of Increased Risk Using *Culex pipiens* Female Abundance as a Proxy

The area of greatest risk is small and can be perfectly localized, as can the other two. The advantage of a GIS is that these results can be translated into maps, overlaying the areas of interest defined by the masks on conventional cartography, as can be seen in Figure 9, and disseminated to stakeholders so that they can direct the level of countermeasures required at each location.



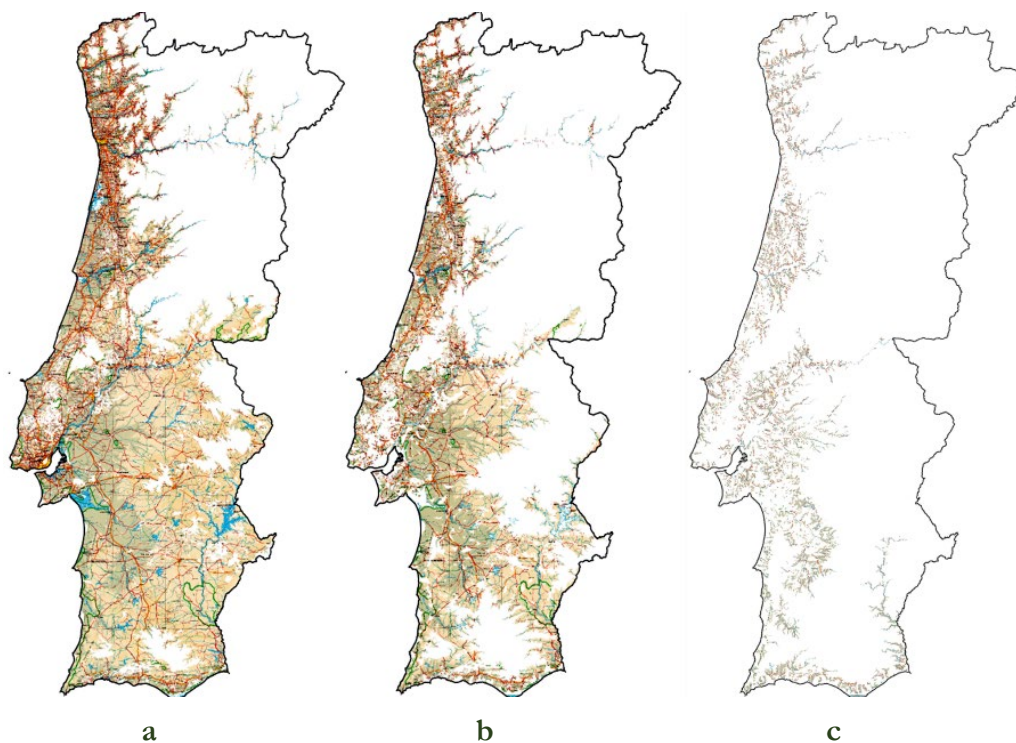


Figure 9. The Three Areas of Increased Risk Overlapped to Conventional Cartography:
a) Minimum Risk, b) Medium Risk and c) Maximum Risk

Discussion

This case study presents a methodology developed using *Culex pipiens s.l.* abundance data as a proxy, which can be used with any vector to assess its ecological niche and establish the boundaries of the areas most at risk of human contact and, consequently, most at risk of transmitting vector-borne diseases. In this work we have used environmental data, but many other parameters can be considered, according to our knowledge of the habits and characteristics of the vector species, and/or the conditions of survival and replication of the pathogens, whenever these are known.

Conclusion

Being simple, this approach can be easily implemented in town halls, which today are often equipped with GIS capabilities, requiring minimal mathematical and computational skills to produce a useful map that can be used in the field by technical staff. Applying this methodology to a large area makes it possible to plan and detail different levels of countermeasures according to the local scale of the problem.

The added value of risk categorization can help stakeholders target the toughest countermeasures, reducing the use of chemical control and minimizing secondary effects on the environment and non-target species, saving human labor and reducing costs, and allowing more efficient mitigation measures to be planned in the long term.



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Conflict of interests

No conflict of interest.

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