Determining the difference in the geographic overlap of the potential distribution of the green and ocellated lizards at continental and regional extents in the Mediterranean Basin

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by

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Abstract

This research focuses on determine the differences on the potential geographic overlap areas resulting from models fitted at continental and at regional extents for seven reptile species in the Mediterranean Basin. The maximum entropy method (MaxEnt) was used to perform the potential distribution of the target species.

The green lizards (*Lacerta agilis*, *Lacerta bilineata–viridis*, *Lacerta trilineata*, and *Lacerta schreiberi*) and the ocellated lizards (*Timon lepidus*, *Timon tangitanus* and *Timon pater*) were include as target species.

The potential geographic overlap areas were derived from modelling the potential spatial distribution of the target species at continental extent using only climate predictor variables. Based on these results, four zones were selected to analyze the differences with the outcomes modelled at regional extent.

In the selected zones, the potential geographic overlap areas were determined for pairs of species based on models fitted at regional extent using only climate predictor variables and another adding variables related to land cover, topography and NDVI. By comparing the performed of the models fitted, six out of eight of the models do not significantly improve the area under the curve (AUC) values by adding variables related to land cover, topography and NDVI.

The resulting potential geographic overlap areas modelled at continental extent were zoomed in on the selected zones and compared by visual interpretation and statistical tests with the results at regional extent. Based on the comparison, the potential geographic overlap areas significantly change depending on the extent at which the potential distribution models of the species are fitted. The potential geographic overlap areas derived from models fitted at regional extent reduced considerably in comparison with the potential geographic overlap areas from models fitted at continental extent. On the other hand, the potential geographic overlap areas do not significantly change depending on the type of predictor variables use to model the potential spatial distribution of the species at regional extent.

The environmental predictor variables related to radiation and temperature appear to be the most important in explaining the potential spatial distribution of the target species at continental and at regional extents.

Keywords: *MaxENT, green lizards, ocellated lizards, continental extent, regional extent, potential geographic overlap.*

Acknowledgements

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1. Introduction

1.1 Background and significance

Habitat loss and degradation, invasive species, environmental pollution and climate change are some of the reasons which cause the global decline of reptiles (Gibbons et al., 2000). Therefore, the identification of factors that explain the distribution patterns of reptiles is an essential objective to increase our knowledge about the biodiversity and environmental conditions of this species.

The application of Species Distribution Models (SDM) permitted to understand the relationship between species and its environment (Franklin, 2009). SDMs are empirical techniques which relate known occurrences of species to environmental predictors using statistically derived response curves that aim the best reflect the species' environmental tolerances (Guisan et al., 2007). Moreover, SDMs can be used to quantify and understand relationships between species (Guisan et al., 2000). This understanding gives us knowledge to recognize the fundamental factors that influence the distribution of the organisms on the planet.

The study of the spatial distribution of species allows defining the influences of specific ecological factors that limit the rage of species in space and time. These ecological factors are categorized as being abiotic versus biotic (Lomolino et al., 2010). Abiotic factors include climate, soil conditions, and topography among others (Lomolino, et al., 2010). While biotic factors include competition, predation, parasitism and the limits of the range of prays (Wiens, 2011).

Relationships between species matters when individuals of one species suffer by resource exploitation or interference by individuals of another species (Begon et al., 2005). These interactions may be defined spatially by analysing the contact zones of the spatial distribution of species (Anderson et al., 2002). In this context, the contact zones of the spatial distribution were considered as the spatial overlap areas. Taking into account that these areas were derived from models of the potential spatial distribution of the species, in this research the areas where two species potentially interact is referred as the potential geographic overlap areas.

1.1.1 Scale and extent in species distribution models

One of the most relevant considerations in species distribution models is related to the scale at which a model is performed. Scale usually depends on two aspects resolution (grain size) and extent (Guisan et al., 2005).

Resolution is defined by the size of the sampling unit at which the data are recorded (Austin, 2007). The resolution or grain size directly describes the properties of the predictor variables (cell size) and the spatial accuracy of the species occurrence records (Elith et al., 2009).

Extent describes the size of the study area and the area over which a model is used to extrapolate from data (Franklin, 2009). It reflects the purpose of the analysis and it can goes from global, continental and regional among others (Elith & Leathwick, 2009).

In this research the analysis and models were carried out at two areas of different sizes or at two extents. Continental extent corresponds to the totality of the study area described in section 2.1. While regional extent is referred to small subsets of the study area name as selected zones which are described in section 3.3.

1.2 Research problem

This research focuses on determine and studying the differences on the potential geographic overlap areas resulting from models fitted at continental and at regional extents for seven reptile species in the Mediterranean Basin.

The potential geographic overlap areas were determined based on modelling the potential spatial distribution of the target species at continental extent using only climate predictor variables. Also in four selected zones, the potential geographic overlap areas were determined for pairs of species based on models fitted at regional extent using only climate predictor variables and another adding variables related to land cover, topography and NDVI.

The changes on the potential geographic overlap areas were analysing based on the effect of modelling the potential distribution of the target species at different extents and by using different variables than climate ones. The differences were determine by zooming in on each selected zone and compare the potential geographic overlap areas derived from the models at continental and at regional extents. In addition, differences related to the variable importance from the models at different extents were studied as well.

The target species are part of the two most important groups of big lizards existing in the Mediterranean Basin. The green lizards including: *Lacerta agilis*, *Lacerta bilineata–viridis*, *Lacerta trilineata*, and *Lacerta schreiberi*. And the ocellated lizards including: *Timon lepidus*, *Timon tangitanus* and *Timon pater*.

1.3 Research objectives

1.3.1 General objective

Determine and analyze the differences in the potential geographic overlap areas between reptile species by fitting models of their potential spatial distribution at continental and regional extents in the Mediterranean Basin.

1.3.2 Specific objectives

- To model the potential spatial distribution of the target species at continental extent based on climate predictor variables.

- To define the potential geographic overlap areas between the species which share their potential spatial distribution at continental extent.

- To select specific zones based on the resulting potential geographic overlap areas at continental extent to zoom in and performed the analysis at regional extent.

- To model the potential spatial distribution of pairs of species at regional extent in specific selected zones fitting one model based on a) only climate predictor variables and b) adding variables related to land cover, topography and normalized difference vegetation index (NDVI).

- To analyze the differences of the potential geographic overlap areas based on models fitted at continental and at regional extents.

- To analyze the differences of predictor variables importance between the models at continental and at regional extents.

1.4 Research questions

1) Considering the models at regional extent, is the accuracy of estimations improving by adding variables related to land cover, topography and NDVI compared to the models based only on climate predictor variables?

2) Do the potential geographic overlap areas change depending on the extent at which the potential distribution models are fitted?

3) Do the potential geographic overlap areas change depending on the type of predictor variables use to model the potential spatial distribution of the species at regional extent?

4) Which of the selected predictor variables are the most important for modelling the potential spatial distribution of reptile species at continental and at regional extents?

1.5 Research hypothesis

From research question 1:

Hypothesis a:

H_0: There is no significant difference in the AUC values of the models based on only climate predictor variables and the models that also includes variables related to land cover, topography and NDVI as predictor variables.

H_1: There is significant difference in the AUC values of the models based on only climate predictor variables and the models that also includes variables related to land cover, topography and NDVI as predictor variables.

From research question 2:

Hypothesis b:

H_0: There is no significant difference on the potential geographic overlap areas depending on the extent at which the potential distribution models are fitted.

H_1: There is significant difference on the potential geographic overlap areas depending on the extent at which the potential distribution models are fitted.

From research question 3

Hypothesis c

H_0: There is no significant difference on the potential geographic overlap areas depending on the type of predictor variables use to model the potential spatial distribution of the species at regional extent.

H_1: There is significant difference on the potential geographic overlap areas depending on the type of predictor variables use to model the potential spatial distribution of the species at regional extent.

1.6 Research approach

The research approach applied included three main stages: 1) modelling the potential spatial distribution and determination of the potential geographic overlap areas between the target species at continental extent, 2) modelling the potential spatial distribution and determination of the potential geographic overlap areas at regional extent of pairs of species in four selected zones and 3) determine and analyze the differences observed on a) the potential geographic overlap areas and b) the variable importance from the results of the models performed at continental and at regional extents. Figure 1-1 illustrates in a general way the research approach of this study. Section 2 dedicated to Materials and Methods describes in detail the different steps fallowed on this research.

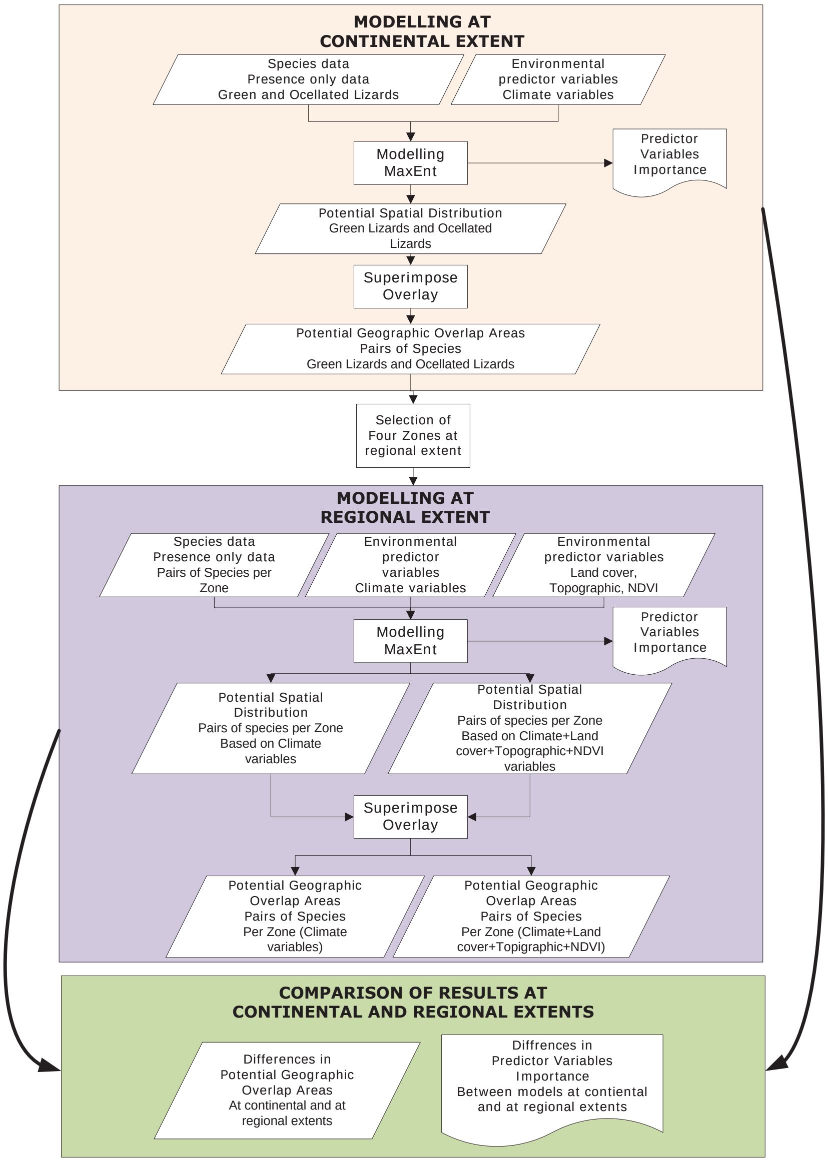


Figure 1-1: Workflow research approach.

2. Materials and Methods

2.1 Study area

The study area of this research consist of all the territories including the Mediterranean Basin, north of Europe, part of north Africa and part of west Asia or Anatolia (Longitude 54° North – 25° North; Latitude 18°West – 54 East). Basically, the area extends to all the lands surrounding the Mediterranean Sea, Black Sea and Caspian Sea. In total the study area represents 13 094 105 km^2 (Figure 2-1).

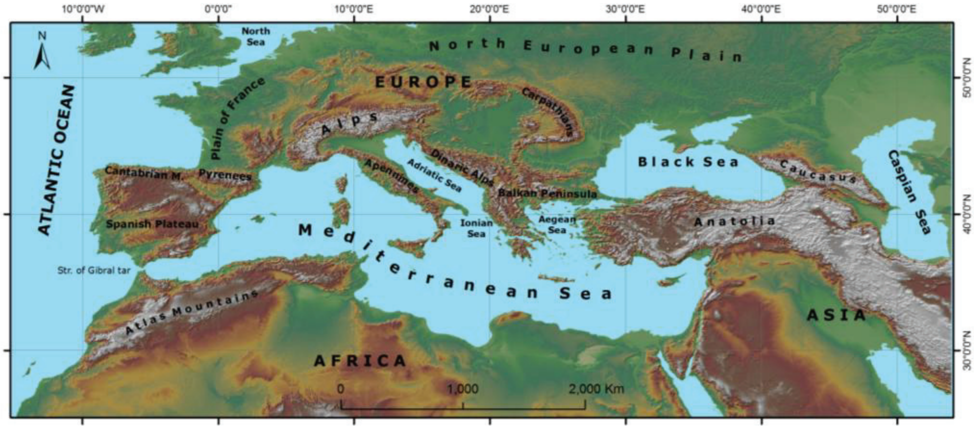


Figure 2-1: Map of the study area.

The Mediterranean Basin stretches west to east from Portugal to Jordan and north to south from northern Italy to Morocco. Surrounding the Mediterranean Sea include parts of Spain, France, the Balkan states, Greece, Turkey, Tunisia and Algeria. The location of the basin is at the intersection of two major land masses Eurasia and Africa. The climate is dominated by cool wet winters and hot dry summers, and rainfall ranges from 100 to 3000 millimetres (CI, 2012). This area is well known as a glacial refugia for reptiles (Gómez et al., 2007) and in particular considering the species which were included in this research.

The Anatolia is a western Asia geographic region limited by the Aegean, the Mediterranean and the Black Sea to the west, south and north respectively, while to the northeast and the east by the Caucasus and the Armenian highlands (Kornilios et al., 2011). The Anatolia includes territories of Turkey, Greece, the Asian Aegean and Mediterranean cost. In terms of species and taxonomic diversity of reptiles, this area contain the most remarkable reptile fauna within the Western Palaearctic region (Sindaco et al., 2000).

2.2 Target species

2.2.1 Green Lizards, Lacerta spp.

There are eight species of green lizards (*Lacerta sensus strict*) inhabiting a large area from Western Europe to Central Asia (Godinho et al., 2005). They are distributed in a cyclical pattern in the north part of the Mediterranean Basin from the Iberian Peninsula until Turkey. Most of the species are restricted to the southern European peninsulas with the exception of *Lacerta agilis* (Godinho, et al., 2005).

For the purpose of this research five of *Lacerta* species were considered: *Lacerta agilis, Lacerta bilineata, Lacerta schreiberi, Lacerta trilineata* and *Lacerta viridis*.

a) *Lacerta agilis*

b) *Lacerta bilineata-viridis*

c) *Lacerta schreiberi*

d) *Lacerta trilineata*

Figure 2-2: Pictures of green lizards.

a) ***Lacerta agilis*** **(Sand Lizard)**

It is widely distributed, to the north until England, south of Sweden and Russia, while to the south it is found in the eastern Pyrenees, the Alps, the Balkans, northeaster part of Anatolia, Caucasus and Transcaucasia and northern Greece (Sindaco et al., 2006). This species can be found in different types of habitats including meadows, grassland, woodland, agricultural lands and sandy semi desert areas among others (IUCN, 2012) (Figure 2-2a).

b) *Lacerta bilineata* (Western Green Lizard) – *Lacerta viridis* (Green lizard)

This two reptile species due to their similarities are consider as a single species (E.N. Arnold, 2002). Therefore, in this study *L. bilineata* and *L. viridis* were treated as one species. This species expand its distribution from the northern of Spain, most of France and Italy, the south eastern and western part of Germany, southern Switzerland, Austria, Czech Republic, Slovenia, Slovakia, Croatia, Hungary, Romania, Moldova, southern Ukraine, Croatia, Bosnia-Herzegobina, Serbia, Montenegro, Macedonia, Albania, Greece and in Turkey along the Black Sea coastal region (IUCN, 2012). In general this species prefers bushy vegetation, woodland, forested areas, shrubland and cultivated areas (Valakos et al., 2008) (Figure 2-2b).

c) *Lacerta schreiberi* (Schreiber´s Green Lizard)

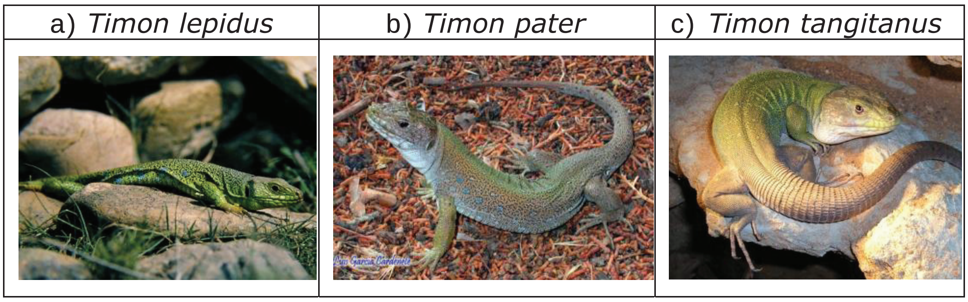
L. schreiberi is endemic from the Iberian Peninsula where is mainly distributed in the northwester side, including an isolated population in the south of the Peninsula (Brito, Godinho, et al., 1999). Basically, it occurs from sea level up to 2100 m but more usual in mountainous regions (Brito, Crespo, et al., 1999). It can be found next to streams because its preference of high humidity areas (Brito et al., 1998) (Figure 2-2c).

d) *Lacerta trilineata* (Balkan Green Lizard)

The range of this species includes territories of the Balkan Peninsula, Asiatic Turkey and Greece including Crete, the Aegean and Ionian Islands (Pafilis et al., 2008). The habitat preferences of *L. trilineata* include dry areas, dense vegetation such as bushes, meadows, woodland, sand dunes, as well as abandoned cultivated land (Valakos, et al., 2008) (Figure 2-2c).

2.2.2 Ocellated Lizards, Timon spp.

The ocellated lizards group include three species *Timon lepidus*, *Timon pater* and *Timon tangitanus* (E. N. Arnold et al., 2007). This group of lizards are distributed around the western Mediterranean basin (E.N. Arnold, 2002). It includes European territories of most of the Iberian Peninsula, southern France and northwestern Italy and Morocco, northern Algeria and Tunisia in North Africa (Paulo et al., 2008).



a) *Timon lepidus* b) *Timon pater* c) *Timon tangitanus*

Figure 2-3: Pictures of ocellated lizards.

a) *Timon lepidus* (Ocellated Lizard)

This species is widely distributed in Portugal and Spain and as isolated population in the southern and western France, and in extreme north western Italy (IUCN, 2012). *T. Lepidus* is found in habitats than include dry as well as humid areas, woodland, shrubland, olive groves, vineyards and sandy or rocky sites (IUCN, 2012) (Figure 2-3a).

b) *Timon pater* (North African Ocellated Lizard)

T. pater occupies territories along the north Mediterranean costs of Algeria and Tunisia including some islands of this country (IUCN, 2012). This lizard can be found in Mediterranean forests, open areas, meadows, shrubland, woodland, coastal areas, rocky sites on stone walls and old olives groves (IUCN, 2012) (Figure 2-3b).

c) *Timon tangitanus* (Atlas Ocellated Lizard)

This species basically occurred in much of Morocco and northwestern Algeria (IUCN, 2012). In Morocco, where most of its distribution is extended, it is possible to find in the northern part and in the Atlas Mountains (Perera et al., 2010). These lizards occur in Mediterranean scrubby habitats and middle elevation mountain forests (IUCN, 2012) (Figure 2-3c).

2.3 Species occurrence data

The objective of the data collection, considering the large extent of the study area, was to cover most of the actual range of each target species. Therefore, data from different sources were integrated. It is important to mention that presence only data were used in this study, based on the purpose and the applied modelling technique (Section 2.5.2).

The main sources of the occurrence data collected in this research were biological atlases. These databases records observed presence of species in cells, and divide the landscape in regular grids (Bierman et al., 2010). The area covers by these atlases ranges from less than 100 km^2 to more than 10 million km^2 with different grid sizes from 1 x 1 km to 100 x 100 km (Franklin, 2009).

For most of the target species atlases at national scale (4 x 4 km, 5 x 5 km, 10 x 10 km, and 11.5 x 11.5 km) were possible to collect. In addition, data at broader scales (30 x 30 km, 50 x 50 km) was used for those species with no available data in certain zones of the study area.

The atlas data collected were grid maps in digital vector format and scanned maps with species locations symbolized as points. For the maps in digital format, only the grids identified as presence were converted to points in order to extract the central point of each grid. The scanned maps first were georeferenced and then each location was digitalized as one point in vector format.

Another collected data were points in vector format. These points correspond to observation records collected in different countries. This data was checked to avoid spatial errors.

Table 2-1 summarises the data according to country, format, grid size and the source of the data which were collected for this study.

Table 2-1: Species occurrence data collected.

Country	Format and Grid size (km)	Source
Austria	Vector grid (5x5)	(Cabela et al., 2001)
Belgium	Vector grid (4x4)	(Parent, 1984)
Bulgaria	Vector grid (10x10)	
Germany	Vector grid (11.5x11.5)	(Günther, 1996)
Italy	Vector grid (10x10)	(Sindaco & ... 2006)
Poland	Vector grid (10x10)	(Głowacinski et al., 2003)
Portugal	Vector grid (5x5)	(Malkmus, 2004)
Spain	Vector grid (10x10)	(Pleguezuelos et al., 2002)
France	Scanned map (30x30)	(Castanet et al., 1989)
Hungary	Scanned map (10x10)	(Puky et al., 2005)
Netherlands	Scanned map (5x5)	(RAVON, 2011)
Europe	Scanned map points	(Gasc et al., 1997)
Greece	Vector points	Natural History Museum of Crete
Morocco	Vector points	(Harris et al., 2008); Observation points West Sahara and Morocco
Switzerland	Vector points	(NAGON. et al., 2001)
Ukraine	Vector points	(Kypnjehko et al., 1999)
Algeria	Vector points	(Harris, et al., 2008); Observation points West Sahara and Morocco
Algeria	Scanned map points	(Mateo, 1990)
Russia	Scanned map points	(Bahhnkob et al., 1971)
Tunisia	Scanned map points	(Mateo, 1990); Toxopeus fieldwork guides (unpublished)
Turkey	Scanned map points	(Sindaco, et al., 2000)
United Kingdom	Scanned map points	(NBN, 2012)

Once all the collected data were converted into vector points representing the presence of a species, it was necessary to homogenise the spatial reference system. Therefore, the data were reprojected to Alberts Equal Area Central Meridian 18° East (AEA18E). Then, the different layers with presence points were merged in unique layers per each reptile species (Figure 2-4).

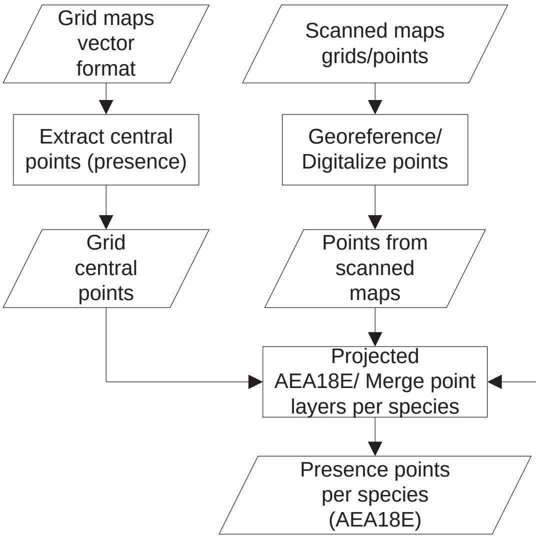


Figure 2-4: Approach to obtain the collected species occurrence data.

The presence points per species were intersected in a layer with regular grids of 10 by 10 km previously created. The result was a vector layer of regular grids including in the database attribute fields per each reptile species with the presence locations mark as 1. Next, the grid´s central points with presence information per each species were extracted to establish the databases of presence points to be used to model the potential distribution (Figure 2-5).

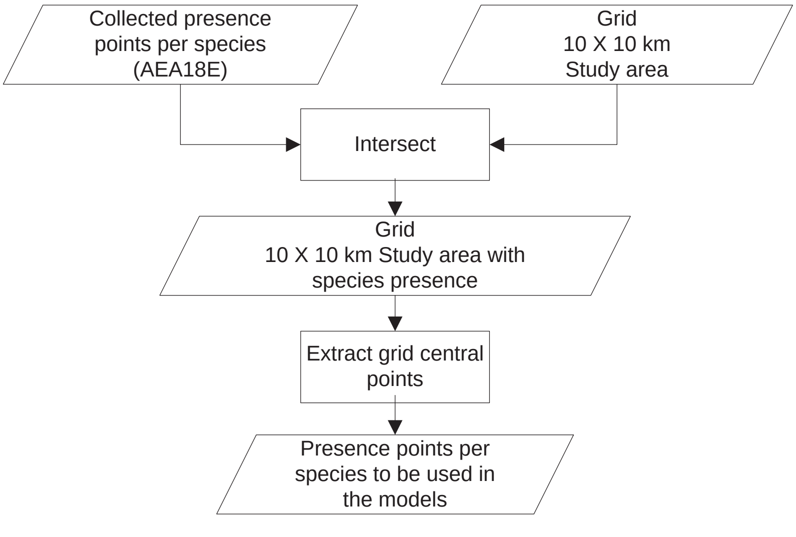


Figure 2-5: Approach to obtain the presence points per species to be used in the models.

Figure 2.6 shows the presence occurrence points to be used in the models on the green and ocellated lizards.

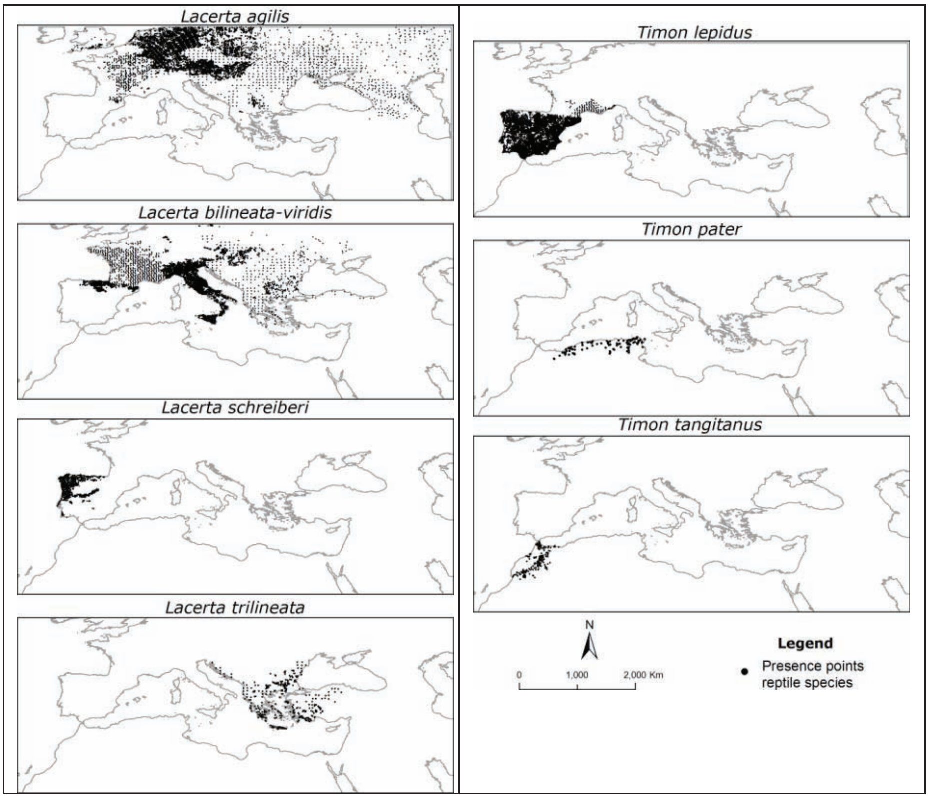


Figure 2-6: Presence occurrence points of green and ocellated lizards.

One consequence of collecting data from different sources and scales for the large study area was the unequal distribution of points in certain zones. This problem is observed from figure 2-6 in the databases of two species *L. agilis* and *L. bilineata-viridis.* Considering that the number of observations is less important than species observations well distributed throughout the environmental space that it occupies (Franklin, 2009). It was necessary to balance the distribution of the presence points by applying a spatial filter. The procedure was performed with the sampling tools of the Hawth´s analysis tools for ArcGIS. First, a layer with regular grids of 500 x 500 km covering the study area was created. Then in the grids where less dense sample points were observed, the average number of presence points was calculated. After that, within each 500x500 km grid presence points were randomly selected based on the average number of points previously calculated. The random selection was performed repeatedly until obtain ten sets of presence points for each of the two species. For the other five species the distribution of presence points were acceptable and the data were ready to be used in the modelling stage (Figure 2-7).

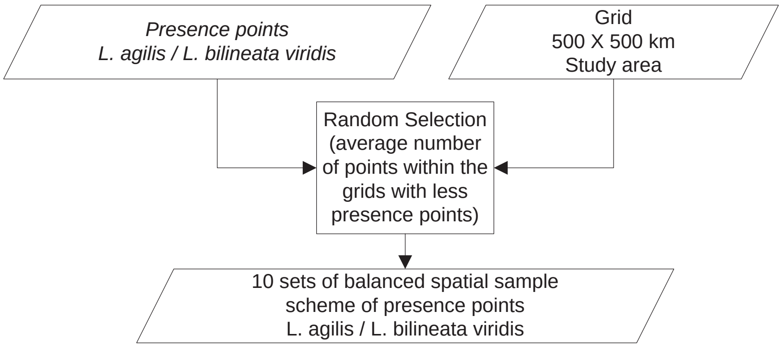


Figure 2-7: Approach to balance the spatial sample scheme of presence points for *L. agilis* and *L. bilineata-viridis*.

2.4 Predictor variables

The environmental predictor variables used to model the potential distribution of the target species at continental and regional extent include five groups: Climate, Topographic, Land cover and the normalized difference vegetation index (NDVI) (Table 2-2). All were in raster format at spatial resolution of 1 km (cell size). The layers were defined in the same spatial reference system as the occurrence data (Alberts Equal Area Central Meridian 18° East).

Only the groups of Climate variables were used to be included in the models at continental extent.

The four groups of variables were used to generate the models in the selecting regional extent zones. Therefore, it was necessary to subset all layers depending on the boundaries of the selected zones.

2.4.1 Climate variables

The climate variables include predictors which consider temperature, precipitation and radiation.

The variables related to temperature and precipitation was downloaded from the WorldClim – Global Climate online database. The layers are interpolated climate surfaces for global land areas at spatial resolution of 1 km. The database include 19 layers about monthly precipitation and mean, minimum and maximum temperatures generated by integrating records from the 1950 to 2000 period (Hijmans et al., 2005).

Seasonal means and extremes of precipitation and temperature are more strongly related to species distribution than annual averages (Franklin, 2009). Therefore, 14 climate variables related to mean of quarters (wettest, driest, warmest, and coldest) of the year, seasonality and maximums and minimums of extreme months (warmest, coldest, wettest, and driest) were initially selected.

The radiation variables were available through the European Solar Radiation Atlas (ESRA). The data corresponds to the averages of monthly means of daily sums of radiation in watt hour per square meter (Wh/m^2) for ten year period (1981 – 1990) (Scharmer et al., 2000). The database includes layers per months as well as the mean annual radiation. The mean global annual radiation layer was considered for the models.

2.4.2 Topographic variables

The topographic variables were derived from the Shuttle Radar Topographic Mission (SRTM). The SRTM obtained data of elevation at global scale for the Earth surface. It was based on a modified radar system installed onboard of the Space Shuttle Endeavour during a 11 day mission in February 2000 (van Zyl, 2001). Elevation, Aspect (north expose and east expose) as well as Slope variables was produced from this data.

Aspect and Slope were created using the surface analysis tools of spatial analyst extension in ArcGIS. The aspect layer originally was in decimal degrees (0° to 360°). This surface was transformed in radians in order to produce the north expose and the east expose by calculation the cosine and sine respectably. The results were two surfaces representing the north expose and east expose with values ranging from 1 (north / east expose) to –1 (south / west expose). The slope surface was created in decimal degrees to be included in the modelling stage.

2.4.3 Land cover variable

The ECOCLIMAP is the source of the land cover variable used in this study, which is a result of a combination of land cover maps, climate and satellite data (Masson et al., 2003).

2.4.4 Normalized difference vegetation index

A common parameter to quantify productivity and above ground biomass of ecosystems is the Normalized Difference Vegetation Index (NDVI) (Niamir et al., 2011). The average NDVI for the decade 1998 to 2008 were calculated based on 10 day composite NDVI images at

1 km resolution. The NDVI images from the SPOT 4 and SPOT5 vegetation sensor were downloaded from the http://www.vgt.vito.be.

Table 2-2: Preselected predictor variables.

Group	Predictor variable (units)	Source
Climate	Temperature seasonality (°C)	WORLDCLIM
	Maximum temperature of warmest month (°C)	
	Minimum temperature of coldest month (°C)	
	Mean temperature of wettest quarter (°C)	
	Mean temperature of driest quarter (°C)	
	Mean temperature warmest quarter (°C)	
	Mean temperature of coldest quarter (°C)	
	Precipitation of wettest month (mm)	
	Precipitation of driest month (mm)	
	Precipitation seasonality (coefficient of variation)	
	Precipitation of wettest quarter (mm)	
	Precipitation of driest quarter (mm)	
	Precipitation of warmest quarter (mm)	
	Precipitation of coldest quarter (mm)	
	Mean annual global radiation (Wh/m^2)	ESRA
Topographic	Altitude (m)	SRTM
	Aspect (North expose) (1=north;-1=south)	
	Aspect (East expose) (1=east; -1=(west)	
	Degree of Slope (degrees rise)	
Land cover	Land cover	ECOCLIMAP
NDVI	NDVI average (1998-2008) (Scaled 1-255)	10 day SPOT 4–5

2.5 Modelling and analysis

The first step was to model the potential spatial distribution of the target species at continental extent. These permitted to analyse three basic aspects in the study area: 1) to study the potential distribution of the species and the environmental climatic factors that limits their distribution, 2) to define the geographic potential overlap areas between species 3) to select specific zones where the analysis at regional extent was conducted.

The fact that climate controls the thermal, moisture and light conditions that determine the species range limits at large scales is widely acknowledged (Franklin, 2009). In addition, annual measures of radiation have also been used as predictor variables (Elith et al., 2006). Therefore, at continental extent the selection of the predictor variables only include climatic ones.

The second step was to model the potential spatial distribution at regional extent. These models were carried out in specific zones where potential geographic overlap areas were identified based on the results at continental extent. More typically land cover and topographic derived variables are applied in species distribution models at smallest scales and extents (Elith & Leathwick, 2009; Franklin, 2009). In this case, topographic, land cover and NDVI predictors were considered in addition to climate variables.

2.5.1 Multicollinearity analysis

A high degree of collinearity between the predictor variables can have important and detrimental effects on the estimated regression parameters (Keough et al., 2002). The most important problem is that the standard deviation of the regression coefficients is disproportionally large resulting in Type I error. Consequently, the calculation of the coefficients becomes unstable (ITC handouts, 2011). One way to detect multicollinearity is by checking the tolerance value of each predictor variable. This can be done by performing separate regression analysis per each variable. Tolerance can be expressed as the variance inflation factor (VIF) which is the inverse of the tolerance (Keough & Quinn, 2002). Equation 1 shows how VIF is calculated.

$$VIFi = \frac{1}{1 - \mathrm{Ri}^2} \quad \text{Equation 1}$$

Where Ri^2 is the coefficient of determination of the regression model of variable i. This procedure has to be performed for all the predictor variables and calculated VIFs for all of them. VIF values greater than ten suggest strong collinearity (Keough & Quinn, 2002).

The spatial structure of the preselected predictor variables (Table 2-2) was studied. The test was conducted in R software by applying a linear model to each predictor and VIFs were calculated. In each run the predictor with VIF value bigger than ten were removed. Several runs were performed until only the significant predictor variables remain. It is important to take into account that previously four groups of environmental predictor variables were preselected in the basis of ecological relevance for the reptile species included in this research.

Separate tests were conducted to the predictor variables depending on the study area at continental and regional extent.

Figure 2-8 presents the approach applied to select the predictor variables to be used at continental extent based on the multicollinearity analysis.

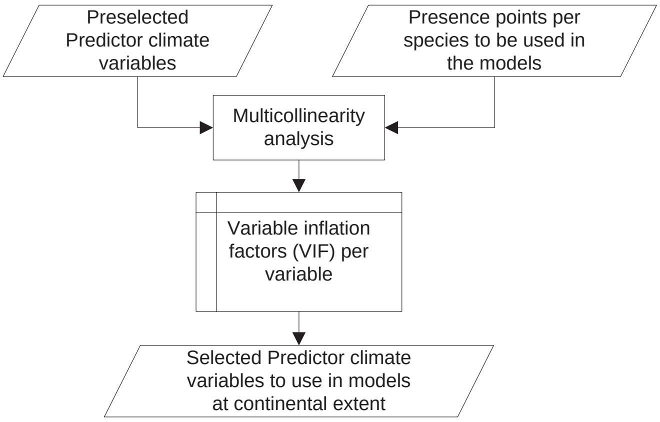


Figure 2-8: Approach to select the predictor climatic variables to use in the models at continental extent.

Table 2-3 shows the predictor variables which passed the multicollinearity analysis for the models at continental extent.

Table 2-3: Result of multicollinearity analysis predictor variables at continental extent.

Group	Predictor variable	VIF
Climate	Maximum temperature of warmest month	3.10
	Minimum temperature of coldest month	2.59
	Mean temperature of driest quarter	3.80
	Precipitation of driest month	5.18
	Precipitation seasonality	3.04
	Mean annual global radiation	3.04

At regional extent two models were fitted a) one including the same climate predictor variables as the models at continental extent and b) adding variables related to topography, land cover and NDVI to the climate ones. Just for the latter models multicollinearity test was performed for the predictors in each of the four selected zones. The same procedure previously describe was carried out and the variables with VIF value bigger than ten were remove. Appendix 1 shows the results of the multicollinearity test and the predictor variables selected for the models in each of the four zones. Figure 2-9 presents the approach followed to select the predictor variables included in the models at regional extent.

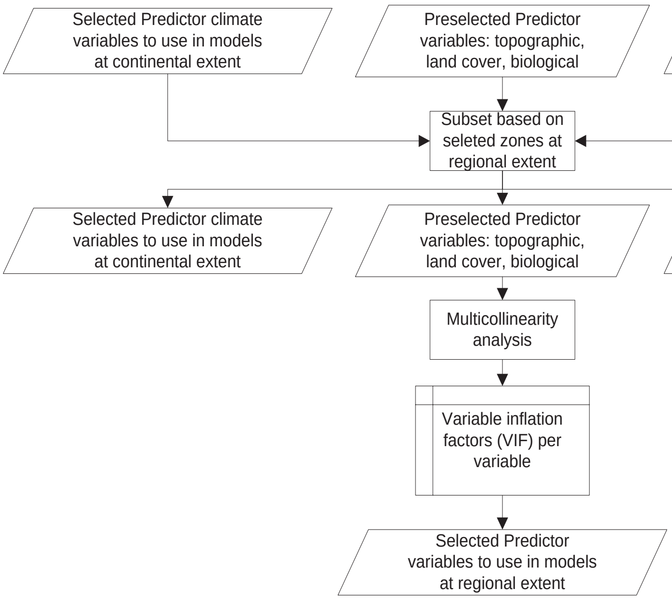


Figure 2-9: Approach to select the predictor variables to use in the models at regional extent.

2.5.2 Modelling with Maximum Entropy (MaxEnt)

MaxEnt is a general-purpose method for making predictions or inferences from incomplete information (Phillips et al., 2006). The idea of the method is to estimate a target probability distribution by finding the probability distribution of maximum entropy (i.e. that is the most spread out, or closest to uniform), subject to a set of constrains that represent the incomplete information about the target distribution (Phillips, et al., 2006). The constrains are defined by the expected value of the distribution, which is estimated from a set of species presence observations (Franklin, 2009). MaxEnt produces a continuous raster coverage where on each pixel of the study area a probability distribution is defined (Phillips, et al., 2006). This is performed based on the pixels with known species occurrence records, which constitute the sample points and the environmental predictors (climate, elevation, topography, land cover) (Phillips, et al., 2006).

MaxEnt is a species distribution modelling technique designed to use presence only sets of data. In addition, it has been used for large-scale biodiversity mapping applications (Elith et al., 2011). In comparison with other methods, it has shown higher predictive accuracy when applied to presence only data (Elith, et al., 2006).

Based on these considerations, MaxEnt software was suitable for the purpose of this research. Therefore, MaxEnt version 3.3.3e was selected to model the potential spatial distribution of the seven reptile species at continental and at regional extent in the selected areas.

Maxent output format includes different options such as raw, cumulative and logistic. The logistic format estimates the probability of presence. Considering the feasibility to interpret, the logistic format was preferred among the others.

In order to model the potential spatial distribution of the target species some requirements need to be fulfilled to the species presence point data as well as the predictor variables. The presence points per each species were necessary to covert to CSV (comma separated values) including the longitude as well as latitude coordinates (X, Y) of each point. The predictor variables previously selected (see section 2.5.1) were exported to ASCII format.

2.5.3 Potential spatial distribution at continental extent

At continental extent the selected predictors were the climate variables which were considered adequate after the multicollinearity analysis (Table 2-3). All the predictor variables were set as continuous in the software.

Ten iterative models were created for those species which were not necessary to balance the spatial distribution of the presence points (*L. schreiberi*, *L. trilineata*, *T. Lepidus*, *T. pater* and *T. tangitanus*). Additionally the software was set to use a maximum of 10000 background points. Bootstrap replicate type with random seed and 30% random test percentage was set in MaxEnt. These options allowed in each of the ten replicates to split 70% of the total presence records to used for training the models and 30% for testing the models. In order to define the importance of the different variables involved, the Jackknife test option was selected. From this test, the regularized training gain was used as a measure of variable importance for each model. In addition, the response curves where calculated and interpreted for each of the predictor variables included.

At the end of the ten runs the average results were consider in order to get the best estimate model.

The sample schemes of *L. agilis* and *L. bilineata-viridis* needed to be balanced by applying a spatial filter. Based on that, ten sets of randomly selected presence points were created. Therefore, it was not necessary to apply any replicate run type. In this case, one model with each set of data was performed. As previously, the presence records were spitted 70% for training the model and 30% for testing the model. At the end, ten models for each species were created and averaged them using the raster calculator in ArcGIS. In addition, all the other statistical results were averaged as well in order to have the best estimations.

Figure 2-10 summarizes the steps followed to model the potential spatial distribution at continental extent of the seven reptile species. It includes the four main outputs, the Probability maps of each species as well as the predictor variables importance, the response curves and the measure of the Area Under the Curve (AUC) of the Receiver Operating Characteristics (ROC).

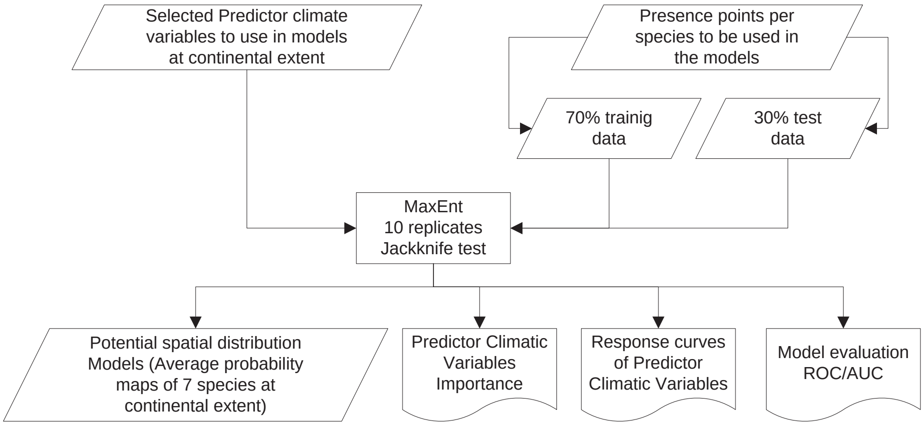


Figure 2-10: Approach to model the potential spatial distribution of the target species at continental extent.

2.5.4 Potential spatial distribution at regional extent

In order to analyse the difference of the potential geographic overlap areas derived from models performed at continental and at regional extents, four specific zones were selected within the study area. These selected zones were chosen based on two criteria: 1) potential geographic overlap areas were predicted at continental extent and 2) the presence points of the species were spatially balanced.

The models at regional extent were fitted for the pair of species depending on the selected zone: Zone 1 *L. agilis* and *L. bilineata-viridis*; Zone 2 *L. bilineata-viridis* and *L. trilineata*; Zone 3 *T. Lepidus* and *T. tangitanus*; and Zone 4 *T. pater* and *T. tangitanus*. The presence points as well as the predictor variables were subset based on the boundaries of each of these zones.

For the species involve in each zone two models were fitted. The first model includes the same climate predictor variables used in the models at continental extent. The second model included land cover, aspect north expose, aspect east expose, slope and NDVI additionally to the climate predictor variables.

Ten iterative models were created for the pair of species involve in each selected zone. Additionally the software was set to use a maximum of 10000 background points. Bootstrap replicate type with random seed and 30% random test percentage was set in MaxEnt. In each of the ten replicates the presence points were spitted 70% for training the models and 30% for testing the models. In order to define the importance of the different variables involved the regularized training gain was used from Jackknife test.

At the end of the ten runs the average results were consider in order to get the best estimate models.

Figure 2-11 shows the approach applied to model the potential spatial distribution of the species involve in each of the selected zones. In total sixteen models at regional extent were fitted including all the resulting outputs possible to obtain with MaxEnt.

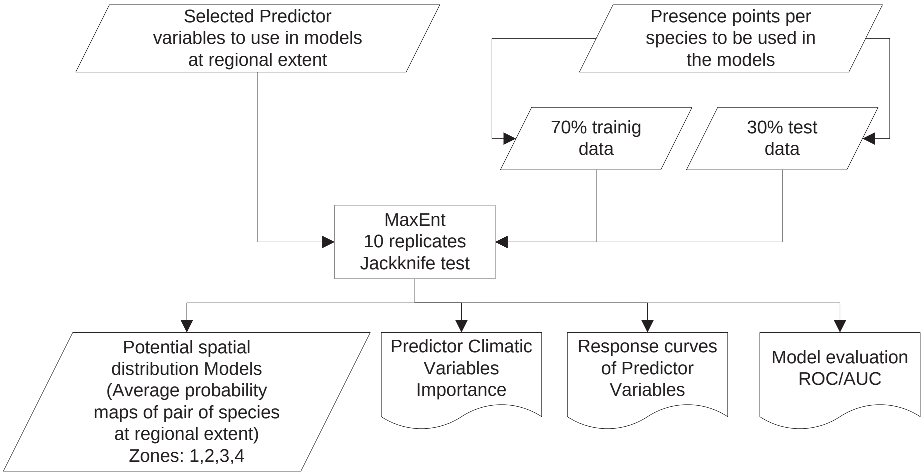


Figure 2-11: Approach to model the potential spatial distribution of the target species at regional extent.

2.6 Potential geographic overlap areas

The potential geographic overlap areas were the result of superimposing the presence/absence maps of the potential spatial distribution models between pairs of species.

The first aspect to consider was to define the threshold to be applied to the average probability maps. The equal sensitivity and specificity threshold was chosen. It determines the optimal threshold by minimising the absolute difference between computed sensitivity and specificity. The average value of the equal training sensitivity and specificity logistic threshold calculated from the ten models processed for each species in MaxEnt was used.

Then the average probability maps of each species were reclassified in presence (1) and absence (0) based on the threshold value. This procedure was performed using the Spatial Analyst tools available in ArcGIS. Finally, the presence/absence (1/0) maps were multiplied between two species in order to define the areas which are potentially suitable for both species.

This procedure was carried out at continental extent between all the seven target species. At regional extent this procedure were made between the pairs of species included in each of the four selected zones. Figure 2-12 shows the general approach applied to find the potential geographic overlap areas at continental and regional extent.

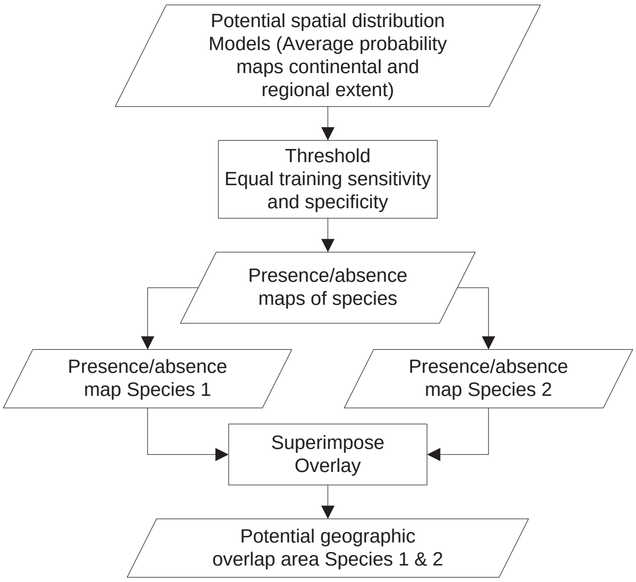


Figure 2-12: Approach to define the potential geographic overlap areas between target species at continental and regional extent.

2.7 Model evaluation and threshold sensitivity analysis

2.7.1 Threshold independent and threshold dependent evaluation

Generally the measures of accuracy in species distribution models (SDM) can be divided into two groups: threshold independent and threshold dependent evaluations (Liu et al., 2011). For the purpose of this research the resulting model outputs at continental and regional extents were evaluated based on the two approaches. The threshold independent approach was applied to evaluate the continuous predictions in other words to the probability maps. The threshold dependent approach was used to evaluate the presence-absence maps, because of its influence in defining the potential geographic overlap areas.

The area under the receiver operating characteristic curve (AUC/ROC) was used as accuracy measure of the threshold independence results. It is one of the most widely used accuracy measure in ecology (Liu, et al., 2011). The AUC of a model is equivalent to the probability that the model will rank a randomly chosen species presence site higher than a randomly chosen absence site (Pearce et al., 2000). The curve is a graphical representation of the trade off between the false negative and the false positive rates for every possible probability threshold (Zarri et al., 2008). In order to evaluate the models performed in MaxEnt a bootstrap iterative type was used and 10 replicated were performed to evaluate the average behaviour of the models based on the 30% of the data. The AUC were reported considering a value equals to 0.5 as the model result does not differ from a chance.

The Cohen´s kappa statistics were selected to the evaluate results which were produced dependent on a threshold. This measure is widely used in assessing species distribution models (Liu, et al., 2011). It measures the extent to which the agreement between the observed and predicted is higher than expected by chance alone (Liu, et al., 2011). The kappa coefficient value is calculated based on the followed equation.

$$Kappa = \frac{\mathrm{P(A)} - \mathrm{P(E)}}{1 - \mathrm{P(E)}}$$

Where P(A) is the proportion of times that the rasters agree (prediction and observed) and P(E) is the proportion of times that we would expect them to agree by chance. When there is no agreement other than that would be expected by chance Kappa is zero. When there is total agreement kappa is 1.

To evaluate the presence absence maps of each species, confusion matrixes were performed and the kappa coefficients calculated in SPSS software. The 30% presence points used for testing the models were used. The absent points were extracted based on the 10x10 km grids originally used to define the occurrence data. The central points from the cells with values mark as absences (0) were extracted for each species. Then a similar number as presence points were randomly selected from the absence points depending on the species. This procedure was applied for the ten replicates model of each species at continental and regional extent.

Additionally for the models fitted at regional extent a statistical t-test were carried out to determine if there is significant difference in the AUC values of the models based on only climate predictor variables and the models that also includes variables related to land cover, topography and NDVI as predictor variables (Hypothesis a).

2.7.2 Threshold sensitivity analysis

A sensitivity analysis determines how highly correlated the model result is to the value of a given input component (Smith et al., 2007). It compares changes in the simulated values against changes in the model components (Smith & Smith, 2007).

The equal sensitivity and specificity threshold value was applied to create the presence-absence maps and by combining them determine the potential geographic overlap areas between pairs of species. In order to observe if changes in the threshold value cause a significant change in the resulting presence-absence maps and in the potential geographic overlap areas a sensitivity analysis was performed. This analysis was carried out to the results from the models performed at continental extent.

The procedure consisted in changing the original threshold values applied to create the presence-absence maps of the seven species by ±10%. Based on that it was possible to analyse two aspects 1) how much area difference was observed in the presence and absence units of the original maps of the seven species and 2) how much area difference was observed in the potential geographic overlap areas between pairs of species by changing the threshold. All the procedures were executed using the Spatial Analysis tools available in ArcGIS.

2.8 Comparison at continental and at regional extents

2.8.1 Differences in the potential geographic overlap areas

To study and analyze the differences in the potential geographic overlap areas determined from models fitted at continental and regional extents visual interpretation as well as a statistical test was performed.

The potential geographic overlap areas between pairs of species at continental extent were zoomed in and subset depending on the boundaries of each of the four selected zones. Maps with the result at continental and at regional extents were made in order to visually interpret the differences.

Additionally, the sum of pixels classified as potential overlap was extracted from each result within each of the four selected zones. Based on that, a paired samples t-test to compare which two means are significantly different from each other were carried out. This permitted to test if there is significant difference on the potential geographic overlap areas depending on the extent (Hypothesis b). And if there is significance difference on the potential geographic overlap areas depending on type of predictor variables use to model the potential spatial distribution of the species at regional extent (Hypothesis c). All the statistical tests were performed in SPSS software.

3. Results

3.1 Modelling at continental extent

3.1.1 Model evaluation

Table 3-1 presents the evaluation results of the ten models run and their averages for the reptile species of the green lizards group. Considering the threshold independence evaluation based on the area under the receiver operating characteristic curve (AUC/ROC) all the ten iterative models was modelled better than a random prediction. This based on a value of AUC equals to 0.5 been a model which does not differ from a chance prediction. The average model for *L. agilis* presents the lowest accurate estimation with 0.822 AUC value. On the other hand, the average AUC of the models for *L. schreiberi* is the highest with 0.964.

Kappa coefficient was used to evaluate the models based on a threshold dependence approach (equal sensitivity and specificity threshold). The results of the evaluation show that all the values are higher than 0 when there is no agreement other than that would be expected by chance. The model for *L. agilis* (average value) got a kappa coefficient lower than 0.5 (0.493). For the other models the kappa values are higher than 0.5. The highest kappa coefficient is 0.885 for the average of *L. schreiberi* models.

Table 3-1: Evaluation results of the models at continental extent of the green lizards group. AUC values and Kappa coefficients (equal sensitivity and specificity threshold).

	L. agilis		***L. bilineata-viridis***		***L. schreiberi***		***L. trilineata***	
Model	**AUC**	**Kappa**	**AUC**	**Kappa**	**AUC**	**Kappa**	**AUC**	**Kappa**
1	0.816	0.494	0.886	0.654	0.962	0.837	0.943	0.733
2	0.826	0.471	0.891	0.602	0.962	0.860	0.949	0.720
3	0.829	0.498	0.873	0.590	0.966	0.916	0.953	0.815
4	0.818	0.523	0.888	0.657	0.965	0.886	0.964	0.785
5	0.825	0.513	0.879	0.623	0.963	0.882	0.966	0.853
6	0.825	0.469	0.885	0.643	0.966	0.943	0.951	0.827
7	0.816	0.517	0.884	0.645	0.961	0.868	0.955	0.726
8	0.825	0.484	0.891	0.635	0.965	0.908	0.953	0.794
9	0.817	0.462	0.889	0.643	0.966	0.917	0.955	0.824
10	0.822	0.498	0.887	0.670	0.961	0.829	0.966	0.863
Avg.	**0.822**	**0.493**	**0.885**	**0.636**	**0.964**	**0.885**	**0.955**	**0.794**

The evaluation results of the models performed for the species included in the ocellated lizards group is described in Table 3-2. The threshold independent evaluation results (AUC/ROC) shows that all the models predict better than chance. The highest AUC value was got by the models of *T. pater* and *T. tangitanus* with 0.971 and 0.981 respectively.

The kappa coefficients show that the models performed better than chance. The models for the three species get kappa coefficients higher than 0.7.

Table 3-2: Evaluation results of the models at continental extent of the ocellated lizards group. AUC values and Kappa coefficients (equal sensitivity and specificity threshold).

	T. lepidus		***T. pater***		***T. tangitanus***	
Model	**AUC**	**Kappa**	**AUC**	**Kappa**	**AUC**	**Kappa**
1	0.867	0.760	0.970	1.000	0.984	0.897
2	0.869	0.768	0.970	0.808	0.984	0.914
3	0.873	0.753	0.968	0.641	0.984	0.931
4	0.873	0.777	0.975	0.885	0.983	0.913
5	0.869	0.734	0.973	0.769	0.979	0.828
6	0.868	0.753	0.969	0.808	0.984	0.930
7	0.871	0.767	0.972	0.731	0.975	0.826
8	0.868	0.759	0.972	0.846	0.982	0.845
9	0.867	0.733	0.976	0.885	0.977	0.862
10	0.864	0.727	0.966	0.846	0.984	0.897
Avg.	**0.869**	**0.753**	**0.971**	**0.822**	**0.981**	**0.884**

3.1.2 Climate predictor variables

Table 3-3 shows the variable importance of the models for the green lizards at continental extent. For each variable it is presented the average of the ten iterative models of the regularized gain value on train data when each variable is used in isolation. The variable with the highest value appear to have the most useful information by itself.

The mean annual global radiation is the variable which has the highest importance for *L. agilis* and *L. trilineata*. For *L. bilineata-viridis* and *L. schreiberi* is the third and second in importance respectively. The variable related to precipitation of the driest month is important for *L. bilineata-viridis* and *L. agilis*. For *L. schreiberi* the mean temperature of the driest quarter has the highest importance and the second for *L. trilineata*. In general the variables of minimum temperature of coldest month and precipitation seasonality are the less important for all of the species in the green lizard group.

Table 3-3: Variable importance of models for green lizards at continental extent based on regularized train gain values. The number inside parenthesis is the order of importance of the predictor variable in each model.

Predictor Variable	***Lacerta agilis***	***Lacerta bilineata-viridis***	***Lacerta schreiberi***	***Lacerta trilineata***
Maximum Temperature of Warmest Month	0.651(**4**)	0.654(**2**)	0.705(**3**)	0.701(**3**)
Minimum Temperature of Coldest Month	0.561(**6**)	0.262(**6**)	0.375(**6**)	0.379(**5**)
Mean Temperature of Driest Quarter	0.755(**3**)	0.516(**4**)	1.387(**1**)	0.734(**2**)
Precipitation of Driest Month	0.767(**2**)	0.681(**1**)	0.694(**4**)	0.496(**4**)
Precipitation Seasonality	0.597(**5**)	0.387(**5**)	0.618(**5**)	0.090(**6**)
Mean annual global radiation	0.776(**1**)	0.627(**3**)	1.074(**2**)	1.033(**1**)

The profiles of the response curves of the models for the green lizards are presented in Appendix 2.

As was mention before, the variables related to radiation and temperature are the most relevant ones for the species. The mean annual global radiation for *L. agilis* reaches the highest probability of occurrence in the range between 2600 and 4200 Wh/m^2. This species is the one that seems to support the coldest temperatures. From the mean temperature of the driest quarter its optimum range of occurrence is between -7°C until 12°C. And for the minimum temperature of the coldest month is between -17°C until 1°C.

In the case of *L. bilineata-viridis* the response curve of the precipitation of the driest month variable shows that the highest range of occurrence is between 25 mm until 60 mm. The maximum temperature of warmest moth indicates that as the temperature increases the occurrence decreases. According to the mean global annual radiation the highest range of occurrence is from 3000 until 4600 Wh/m^2. The mean temperature of the driest quarter indicates the this species increase its occurrence as the temperature increases from 0° C up to 35°C.

For *L. schreiberi* the response curve of the mean temperature of driest quarter presents its highest probability of occurrence in a range between 5°C and 22°C. The range related to the mean annual global radiation goes from 3300 until 4700 Wh/m^2 approximately. The profile of the maximum temperature of the warmest month shows that the highest occurrence ranges from 20°C to 35°C. For the precipitation of the driest month the curve shows that the highest probability of occurrence goes from 5 mm to 60 mm.

L. trilineata presented a high range of probability of occurrence related to the mean global annual radiation from 3500 to 4500 Wh/m^2. For the mean temperature of the driest quarter the curve shows that increasing from 2°C the occurrence increase up to 25°C. The profile of the maximum temperature of the warmest month established low probability of occurrence in general.

Table 3-4 presents the variables importance of the ocellated lizards models. It can be observed that the most important variable for the three species of ocellated lizards is the mean annual global radiation. Mean temperature of driest quarter and precipitation of driest month variables are the second in importance for this reptile species. Again the least important variables are precipitation seasonality and minimum temperature of coldest month.

Table 3-4: Variable importance of models for ocellated lizards at continental extent based on regularized train gain values. The number inside parenthesis is the order of importance of the predictor variable in each model.

Predictor Variable	***Timon lepidus***	***Timon pater***	***Timon tangitanus***
Maximum Temperature of Warmest Month	0.376(**4**)	0.880(**5**)	0.756(**5**)
Minimum Temperature of Coldest Month	0.355(**5**)	0.463(**6**)	0.261(**6**)
Mean Temperature of Driest Quarter	0.584(**2**)	1.231(**3**)	1.003(**3**)
Precipitation of Driest Month	0.467(**3**)	1.630(**2**)	1.122(**2**)
Precipitation Seasonality	0.269(**6**)	0.572(**4**)	0.802(**4**)
Mean annual global radiation	0.882(**1**)	1.719(**1**)	1.548(**1**)

The response curves related to the models of the ocellated lizards are shown in Appendix 3.

As it was expected, this group of lizards presented highest probability of occurrence at highest values of radiation and temperature because of its geographical distribution. That is why from the variable related to radiation is observed that *T. lepidus* got a range from 3500 to 4800 Wh/m^2, *T. pater* from 4300 to 5200 Wh/m^2 and *T. tangitanus* from 4600 to 5300 Wh/m^2. For the mean temperature of the driest quarter profile, *T. Lepidus* and *T. pater* optimum range goes from 0°C to 25°C, and for *T. tangitanus* from -5°C to 25°C. Considering the maximum temperature of the warmest month, the range for *T. lepidus* goes from 22°C to 35°C, *T. pater* from 25°C to 35°C and *T. tangitanus* from 25°C to 40°C. For this group of lizards the variable related to the precipitation of the driest month is important and the ranges for *T. lepidus* goes from 0 to 40 mm, *T. pater* from 0 to 10 mm and *T. tangitanus* from 0 to 15 mm.

3.1.3 Potential spatial distribution models

Figure 3-1 presents the models of the potential spatial distribution of the four species from the group of green lizards. In general from the models it is possible to observe that all of the species extent their highly probability distribution on the northern parts of the study area.

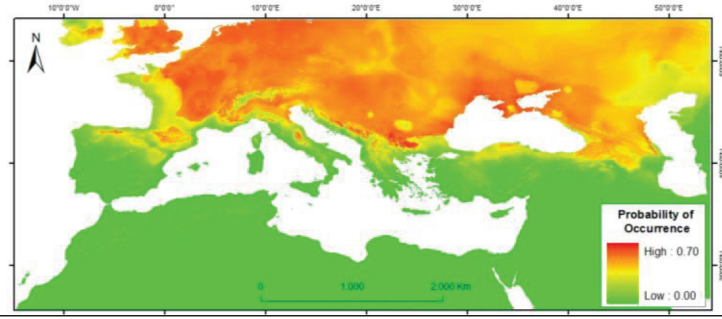
The model for *L. agilis* (Figure 3-1a) shows that this species is the most widely extent in terms of probability of occurrence. The suitable areas in the west side limit the northern extreme of Spain and in the east until the costal zones of the Caspian Sea. It extends from the north part which includes all the north European Plain until the latitudinal central part of the study area in the south including areas in the Balkan Peninsula, and along the southern cost of the Black Sea. It is possible to observe that the territories in the Alps, Apennines and Dinaric Alps were modelled as not suitable for the species.

The suitable areas for *L. bilineata-viridis* (Figure 3-1b) extent west to east from the extreme north of Spain until the costal zones of the Black Sea and small areas in the southern cost of the Caspian Sea. In the north it extents until the south of the North European Plain and in the south include areas in the north of Portugal and Spain, Italy, the south cost of the Black and Caspian Sea. The Alps, Dinaric Alps, Carpathians Mountains and Caucasus were modelled as not suitable.

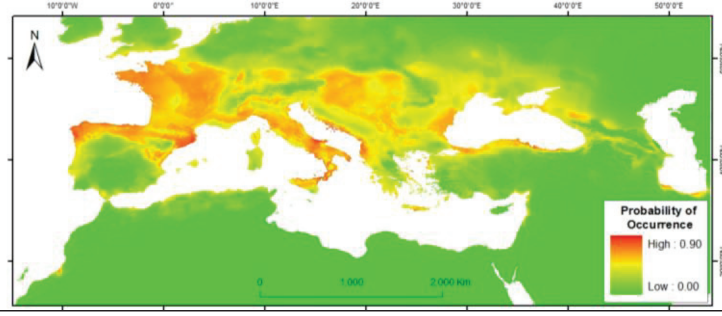
The model for *L. schreiberi* (Figure 3-1c) shows that suitable areas of this species basically is located in the north western cost of Portugal and Spain, and it extends along the Cantabrian Mountains and Sierra de Gredos and Guadarrama in Spain.

L. trilineata model (Figure 3-1d) shows that the highly probability of occurrence areas are located in the costal lands of the Ionian and Aegean Seas, the Balkan Peninsula and the western and southern part of Turkey (Anatolia) in the cost of the Mediterranean Sea. Some areas of lower probability can be observed at the north of Spain, western cost of Italy, some areas at the south west of the Carpathians and along the cost of the Black and Caspian Seas.

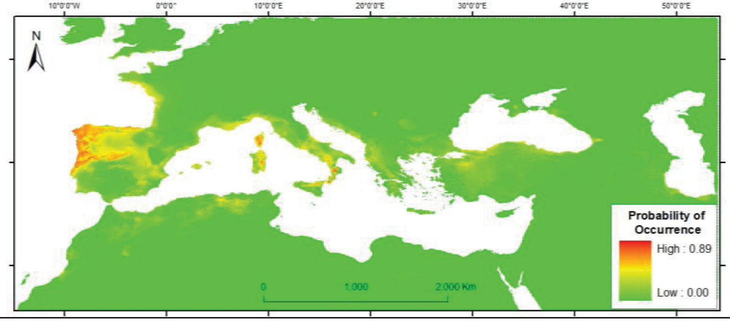
a) Probability map *Lacerta agilis*



b) Probability map *Lacerta bilineata-viridis*



c) Probability map *Lacerta schreiberi*



d) Probability map *Lacerta trilineata*

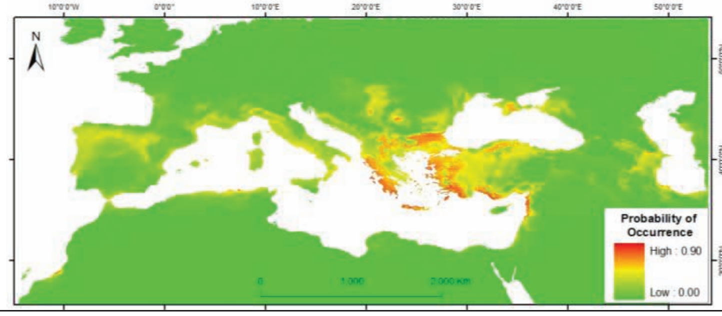
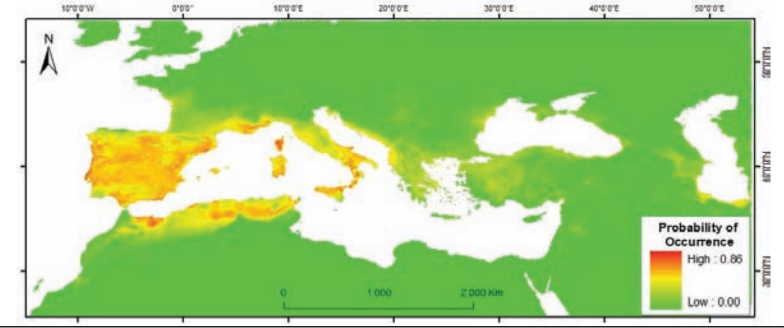


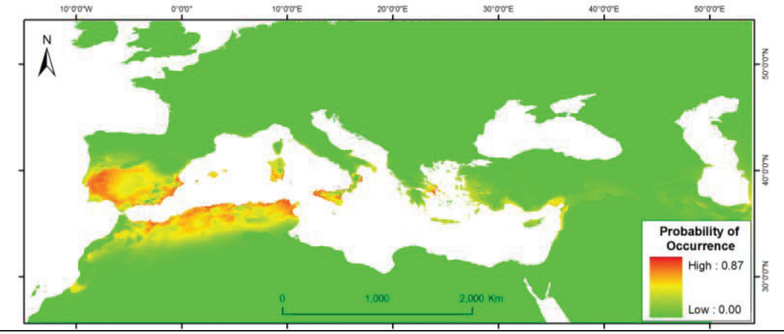
Figure 3-1: Potential spatial distribution at continental extent of green lizards.

Figure 3-1 presents the results of the models performed for the group of ocellated lizards. As it is possible to observe, the models shows that the three reptile species of this group expand their probability of occurrence from the south western part of Europe until the north western part of Africa.

a) Probability map *Timon lepidus*



b) Probability map *Timon pater*



c) Probability map *Timon tangitanus*

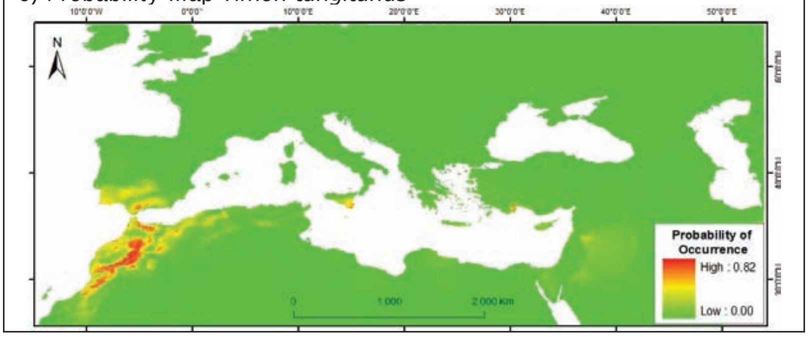


Figure 3-2: Potential spatial distribution at continental extent of ocellated lizards.

The model for *T. lepidus* (Figure 3-2a) predicted probability of occurrence areas mainly in Portugal and Spain and the extreme north cost of France and the north of Italy. In addition, it is observed suitable areas in the north sides of Morocco, Algeria and Tunisia along the southern costs of the Mediterranean Sea and limited by the Atlas Mountains in the south.

The model prediction for *T. pater* (Figure 3-2b) shows that the highly probability areas extend in the north eastern parts of Morocco, the northern part of Algeria and Tunisia along the Mediterranean costs. In addition, the model predicted some areas in the southern part of Portugal and Spain and some areas in the islands of Sardinia and Sicily.

The model for *T. tangitanus* (Figure 3-2c) predicted the most suitable areas of occurrence in the central part of Morocco from south to north, along the Atlas Mountains. There are some suitable areas in the eastern part of Algeria along the Valley of Moulouya River. In addition, there are some suitable areas in the southern part of the Spanish Plateau as well as in the south side of the island of Sicily.

3.2 Potential geographic overlap at continental extent

3.2.1 Potential geographic overlap areas

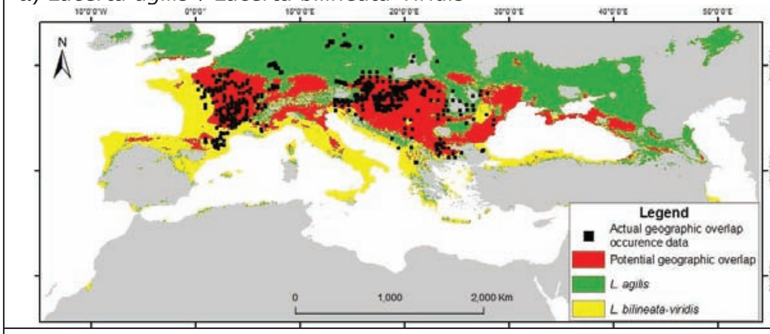
The potential geographic overlap areas were revealed after superimpose the presence-absence maps between pairs of species.

Figure 3-3 presents the resulting potential geographic overlap areas of the species included in the group of green lizards. It is observed in all cases that the potential geographic overlap areas include zones where locations of actual geographic overlap are not possible to identify. In addition, locations with actual overlap were not defined as potential overlap. This is interpreted from Figure 3-3 a, b and d.

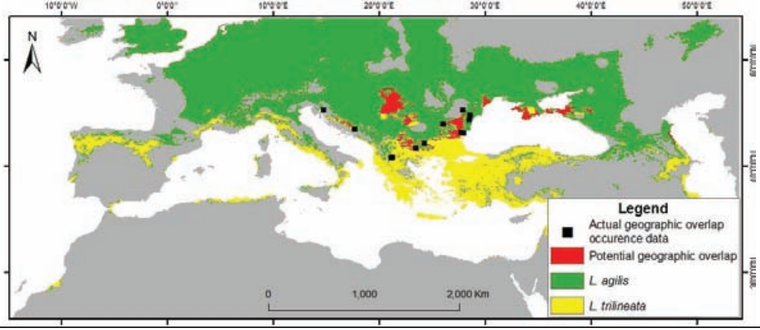
The largest potential geographic overlap area is between *L. agilis* and *L. bilineata-viridis* (Figure 3-3a). The area extends along the south of the potential distribution of *L.* agilis and the north part of *L. bilineata-viridis*. The potential geographic overlap area extends on the north and southern part of the Alps Mountains. However, actual geographic overlap locations are not identified in those areas.

The second more representative potential overlap area is observed between *L. bilineata-viridis* and *L. trilineata* (Figure 3-3b).

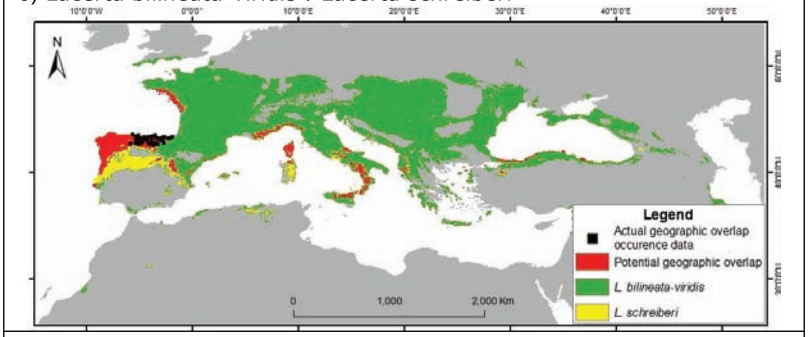
a) *Lacerta agilis* / *Lacerta bilineata-viridis*



b) *Lacerta agilis* / *Lacerta trilineata*



c) *Lacerta bilineata-viridis* / *Lacerta schreiberi*



d) *Lacerta bilineata-viridis* / *Lacerta trilineata*

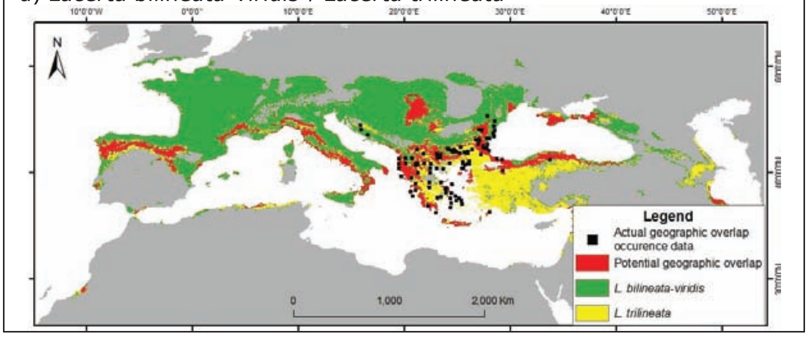
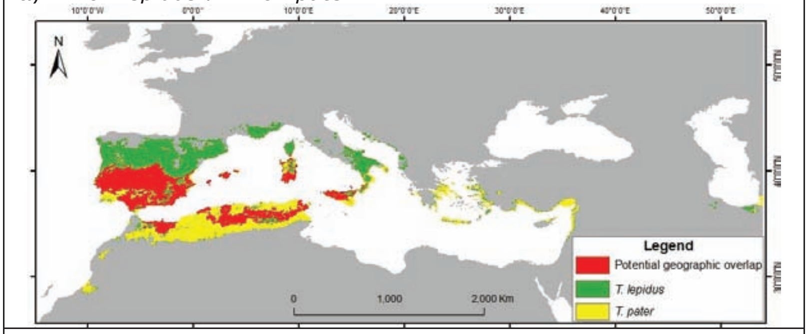


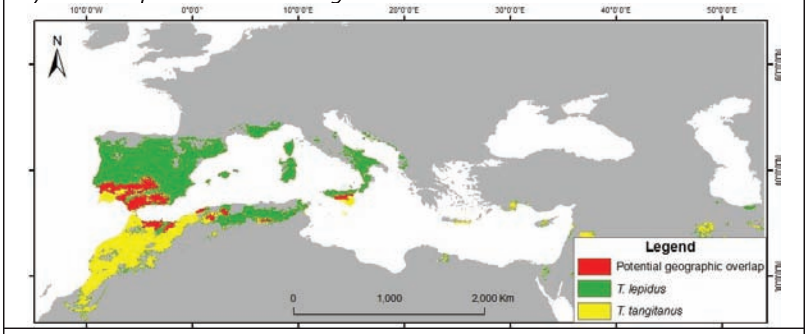
Figure 3-3: Potential geographic overlap areas between species of green lizards.

Figure 3-4 presents the results of the potential geographic overlap areas between the species of ocellated lizards. Contrary to the other group of lizards, these species do not have locations with actual geographic overlap. However, areas of potential geographic overlap are observed between the three species.

a) *Timon lepidus / Timon pater*



b) *Timon lepidus / Timon tangitanus*



c) *Timon pater / Timon tangitanus*

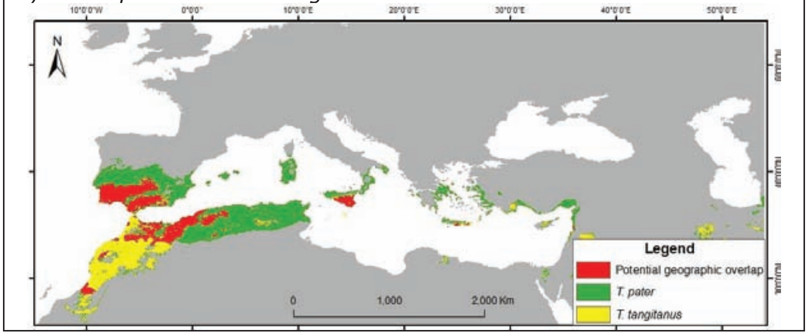
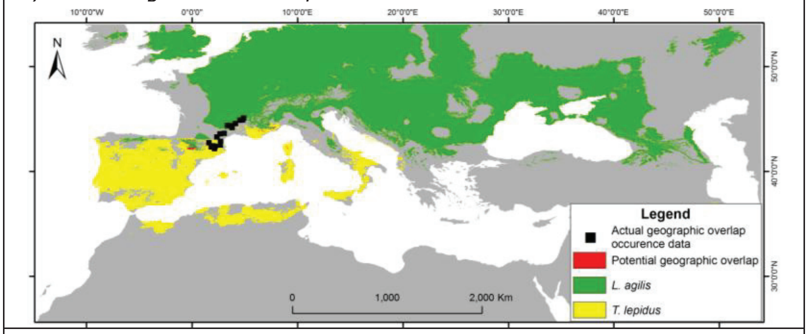


Figure 3-4: Potential geographic overlap areas between species of ocellated lizards.

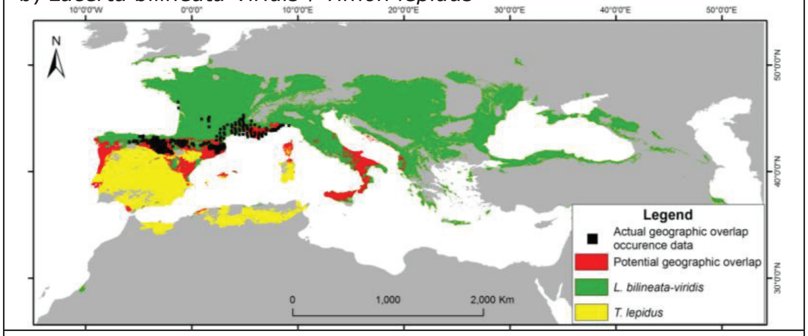
In Figure 3-5 is presented the results between the species of the two groups of lizards with locations with actual geographic overlap. As in the previews results the potential overlap areas extend in zones far from the locations of actual overlap. From the result of *L. agilis* and *T.*

lepidus (Figure 3-5a) is observed that most of the location of actual overlap were not define as potential geographic overlap area.

a) *Lacerta agilis / Timon lepidus*



b) *Lacerta bilineata-viridis / Timon lepidus*



c) *Lacerta schreiberi / Timon lepidus*

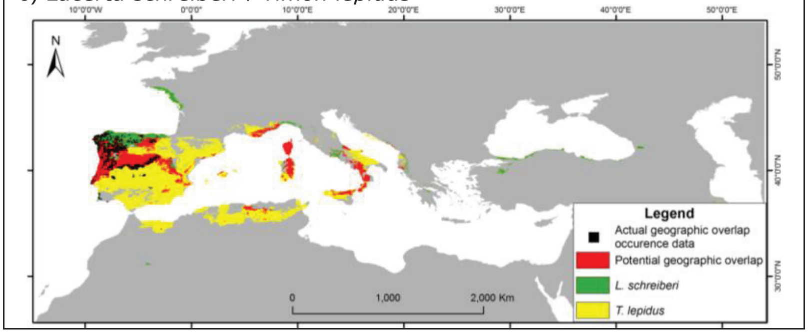


Figure 3-5: Potential geographic overlap areas between species of green and ocellated lizards.

The zones to zoom in and analyze the difference at regional extent were selected based on the resulting potential geographic overlap areas between *L. agilis* and *L. bilineata-viridis* (Figure 3-3a), *L. bilineata-viridis* and *L. trilineata* (Figure 3-3d), *T. lepidus* and *T. tangitanus* (Figure 3-4b), *T. pater* and *T. tangitanus* (Figure 3-4c).

3.2.2 Threshold sensitivity analysis

The potential geographic overlap areas are the result of overlaying the presence-absence maps. Consequently, the threshold values applied influence directly these outcomes. Therefore, a sensitivity analysis was performed by change the original threshold values (equal sensitivity and specificity) in ±10%.

From figure 3-6, bars represent the percentage that the presence area changes by increasing or decreasing the original threshold value. The presence-absence maps of *L. agilis* and *T. lepidus* are the most sensitive to threshold alterations. On the other hand, the maps of *T. pater* and *T. tangitanus* were the less sensitive.

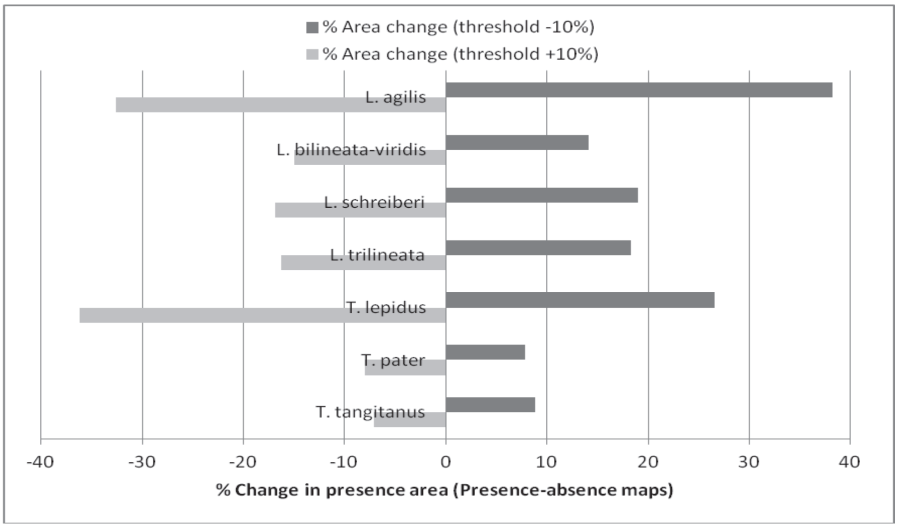


Figure 3-6: Threshold sensitivity analysis: % change in presence-absence maps.

Figure 3-7 shows the variation in the potential geographic overlap areas between pairs of species by shifting the original threshold value (equal sensitivity and specificity) applied to the probability maps in ±10%.

It is possible to infer that the greatest change was observed in the overlap area based on the models for *L. agilis* and *T. Lepidus*. However, in this case the proportion of change is highly influence because of the small potential geographic overlap between these two species. The models for *T. pater* and *T. tangitanus* are the less sensitive to variations of the threshold values. Therefore, the resulting potential geographic overlap area presents a small variation among the others.

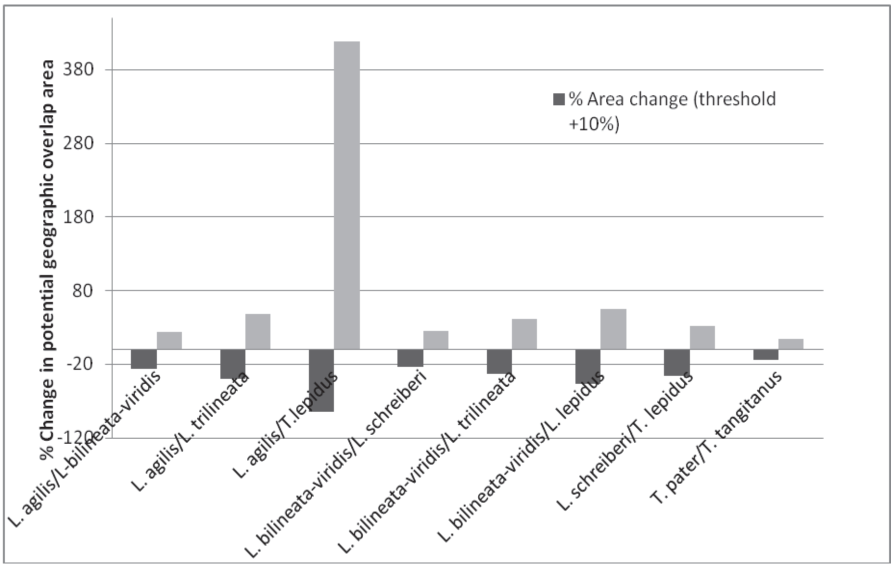


Figure 3-7: Threshold sensitivity analysis: % change in potential geographic overlap areas.

It is important to mention that the scaling of the positive and negative changes shown in the figures are not comparables, because negative changes are bounded by -100% while positive changes can be multitudes of this. However, the graphic is used to understand how sensitive a model is by increasing or decreasing the threshold, and how these changes propagate to the resulting potential geographic overlap areas.

3.3 Modelling at regional extent

In order to analyze the difference of the potential geographic overlap areas derived from models fitted at continental and at regional extents, four specific zones were selected within the study area (Figure 3-8). These selected zones were chosen based on two criteria: 1) potential geographic overlap areas were predicted at continental extent and 2) the presence points of the species were spatially balanced.

Zone 1 is located in the north western part of the study area, between Italy, Switzerland, Austria and France crossed by the Alps Mountains. Zone 2 is in the central part of the study area in the Balkan Peninsula including territories of Greece, Bulgaria and Turkey. Zone 3 is in the western part, where the Strait of Gibraltar separated Europe from Africa including territories of Portugal, Spain and Morocco. Zone 4 is located in the western of the study area including territories of Morocco, Algeria and Tunisia.

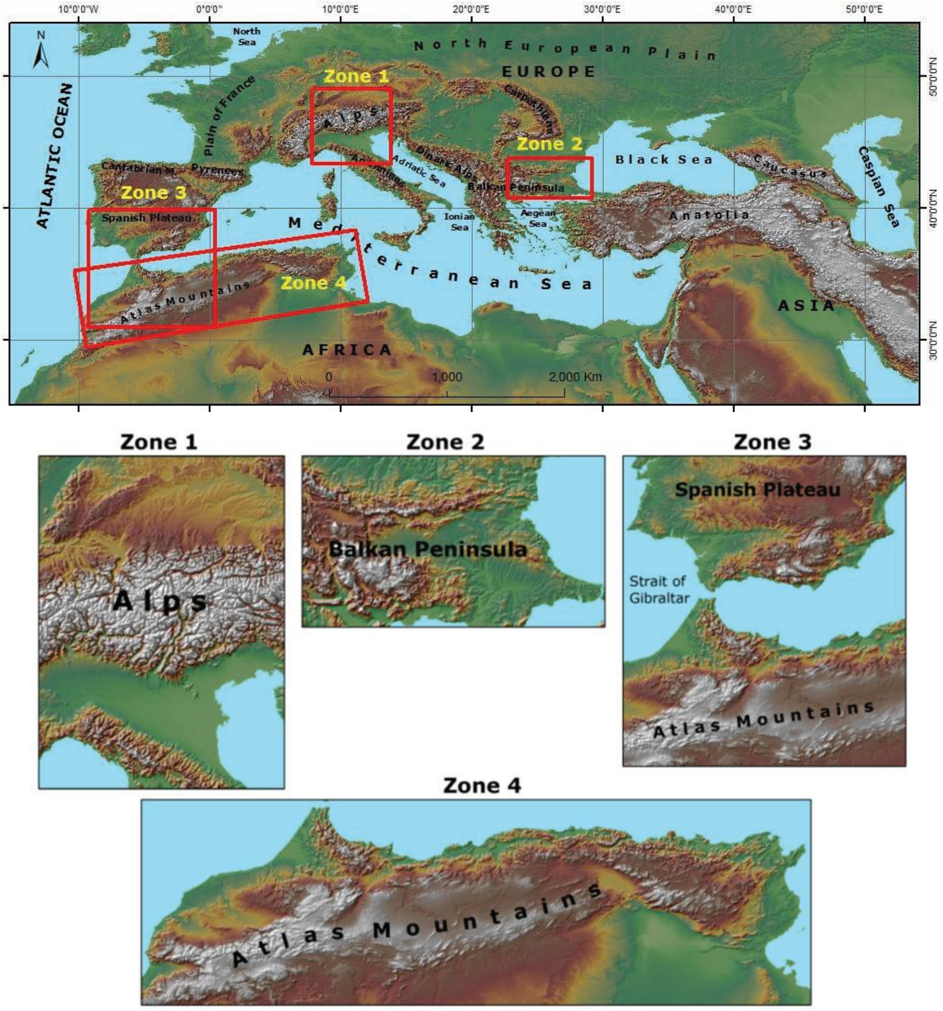


Figure 3-8: Maps of the selected zones for analysis at regional extent.

3.3.1 Model evaluation and comparison

Table 3-3 displays the average AUC and Kappa coefficients of the 10 models run for each species per selected zone. The models got average AUC values higher than 0.5. Therefore, the predictive models differ from a prediction by chance. Based on the threshold dependence evaluation, the average kappa coefficients are larger than zero. However, the models for *L. bilineata-viridis* and *L. trilineata* in zone 2 got values of kappa less than 0.4.

Table 3-5: Evaluation results of the models at regional extent in Zones 1, 2, 3 and 4. AUC values and Kappa coefficients (equal sensitivity and specificity threshold).

	Climate variables		**Climate+Land Cover+Aspect (north/east)+Slope+NDVI**	
	AUC	**Kappa**	**AUC**	**Kappa**
Zone 1				
L. agilis	0.789	0.489	0.791	0.446
L. bilineata-viridis	0.781	0.575	0.798	0.557
Zone 2				
L. bilineata-viridis	0.680	0.249	0.712	0.358
L. trilineata	0.741	0.380	0.768	0.442
Zone 3				
T. lepidus	0.747	0.506	0.773	0.541
T. tangitanus	0.878	0.650	0.910	0.652
Zone 4				
T. pater	0.880	0.600	0.891	0.573
T. tangitanus	0.918	0.661	0.919	0.660

Regarding research question one a paired-sample t test was carried out. This permitted to test if there is significant difference in the average AUC values of the models with only climate variables and those which include land cover, aspect north expose, aspect east expose, degree of slope, NDVI and climate variables. Table 3-6 shows the p-values of the t-test.

From the results in Zone 1 the t-test showed significant difference between the models fitted for *L. bilineata-viridis* by adding other variables to the climate ones, but no significant difference for those for *L. agilis*.

In the case of the models for *L. bilineata-viridis* and *L. trilineata* fitted in Zone 2, the t-test showed no significant difference between the models performed with climate variables and the ones including land cover, slope, aspect and NDVI.

In Zone 3 the t-test showed significant difference between the models for *T. lepidus*. However, the models for *T. tangitanus* were not significantly different.

In Zone 4 the t-test showed no significant difference between the models for *T. pater*. For the models for *T. tangitanus* the t-test showed no significant difference.

Table 3-6: Results of paired-sample t test of the two models developed per species in each selected Zone at regional extent. * significant at 0.05 level.

	P-value
Zone 1	
L. agilis	0.687
L. bilineata-viridis	0.004*
Zone 2	
L. bilineata-viridis	0.157
L. trilineata	0.092
Zone 3	
T. lepidus	0.00000454*
T. tangitanus	0.079
Zone 4	
T. pater	0.174
T. tangitanus	0.834

3.3.2 Potential spatial distribution models

Figure 3-9 presents the results of the models for *L. agilis* and *L. bilineata-viridis* performed in Zone 1. a) and c) are the results of the models including only climate variables. b) and d) are the models using land cover, aspect north expose, aspect east expose, slope and NDVI.

For *L. agilis* the models predicted areas of potential distribution in the north side of the Zone at the north of the Alps Mountains. It is possible to observe some suitable areas at the south limit of the Alps Mountains.

In the case of *L bilineata-viridis* the models predicted in the south of Zone 1 the highest probability of occurrence for this species. It is possible to identify some suitable areas in the southern part of the Alps Mountains.

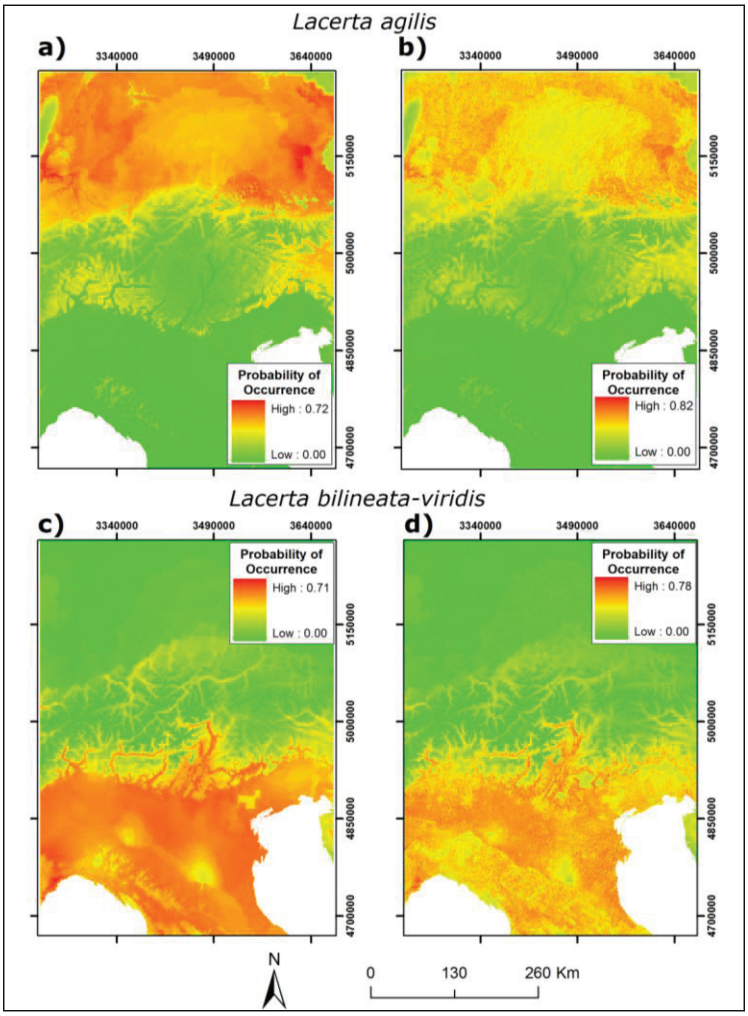


Figure 3-9: Potential spatial distribution modelled with climate variables only (a, c) and with land cover, aspect north/east expose, slope, NDVI and climate variables (b, d) at regional extent for *L. agilis* and *L. bilineata-viridis* in Zone 1.

Figure 3-10 presents the results of the models for *L. bilineata-viridis* and *L. trilineata* performed in Zone 2. a) and c) are the results of the models including only climate variables. b) and d) are the models using land cover, aspect north expose, aspect east expose, slope and NDVI.

Models predicted for *L. bilineata-viridis* suitable areas of occurrence in the central eastern and in the western parts of Zone 2. However, it is evident that the model using only climate variables predicted more areas with high probability of occurrence than the other model.

For *L. trilineata* the models predicted suitable areas in the west, central south and in the south east of Zone 2. The same difference is observed between the two models, more suitable areas were predicted by the model using only climate variables.

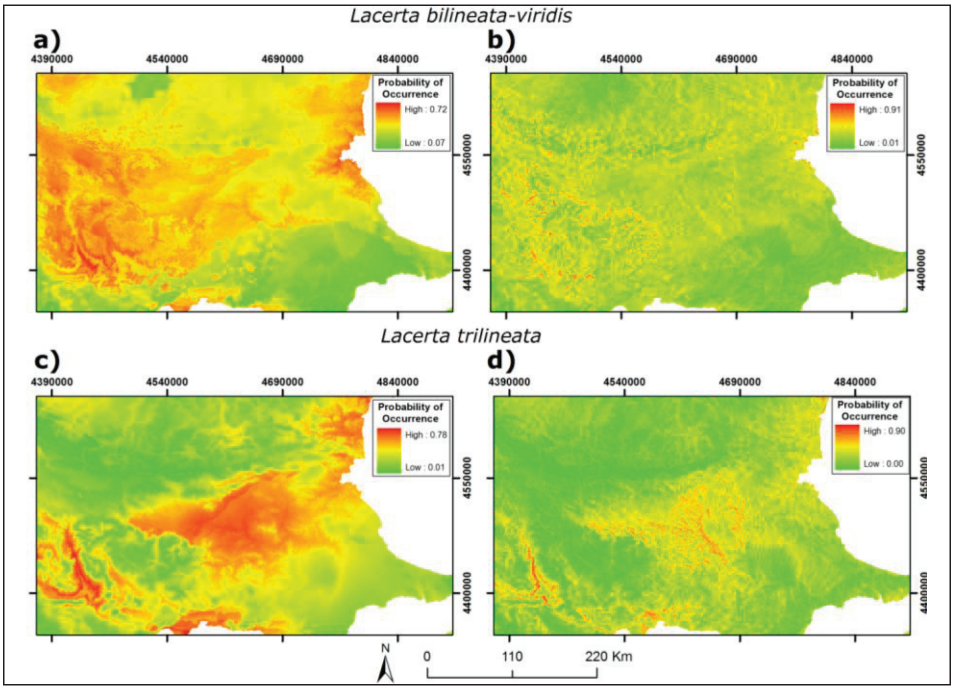


Figure 3-10: Potential spatial distribution modelled with climate variables (a, c) and with land cover, aspect north/east expose, slope, NDVI and climate variables (b, d) at regional extent for *L. bilineata-viridis* and *L. trilineata* in Zone 2.

Figure 3-11 shows the results of the models for *T. lepidus* and *T. tangitanus* performed in Zone 3. a) and c) are the results of the models including only climate variables. b) and d) are the models using land cover, aspect north expose, aspect east expose, slope and NDVI.

From Figure 3-11a of *T. lepidus* the model predicted suitable areas in most of the north part and some areas in the south part. The results from the model which includes other variables than the climate ones do not predict most of the areas in the southern part of Zone 3.

The models for *T. tangitanus* predicted most of the highly suitable areas in the south western part of Zone 3. It is possible to observe from the result of the model with only climate variables some suitable areas in the north which were not predicted by the other model.

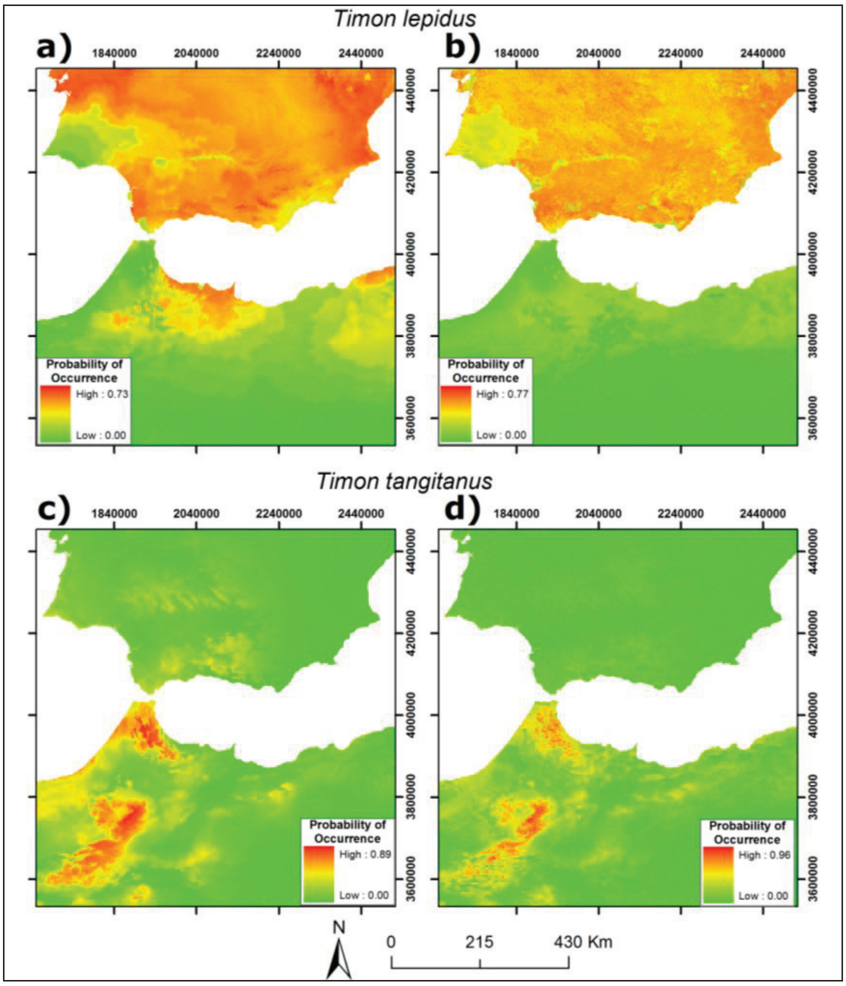


Figure 3-11: Potential spatial distribution modelled with climate variables (a, c) and with land cover, aspect north/east expose, slope, NDVI and climate variables (b, d) at regional extent for *T. lepidus* and *T. tangitanus* in Zone 3.

Figure 3-12 shows the results of the models for *T. pater* and *T. tangitanus* performed in Zone 4. a) and c) are the results of the models including only climate variables. b) and d) are the models using land cover, aspect north expose, aspect east expose, slope and NDVI.

From the models for *T. pater*, the most suitable areas were predicted in the north part of Zone 4, in the costs of the Mediterranean Sea. The suitable areas were predicted in major proportion from the model with climate variables than the other.

The models for *T. tangitanus* predicted the areas with high probability of occurrence in the western part of Zone 4. The model with climate variables increases the predictions of highly suitable areas than the other model.

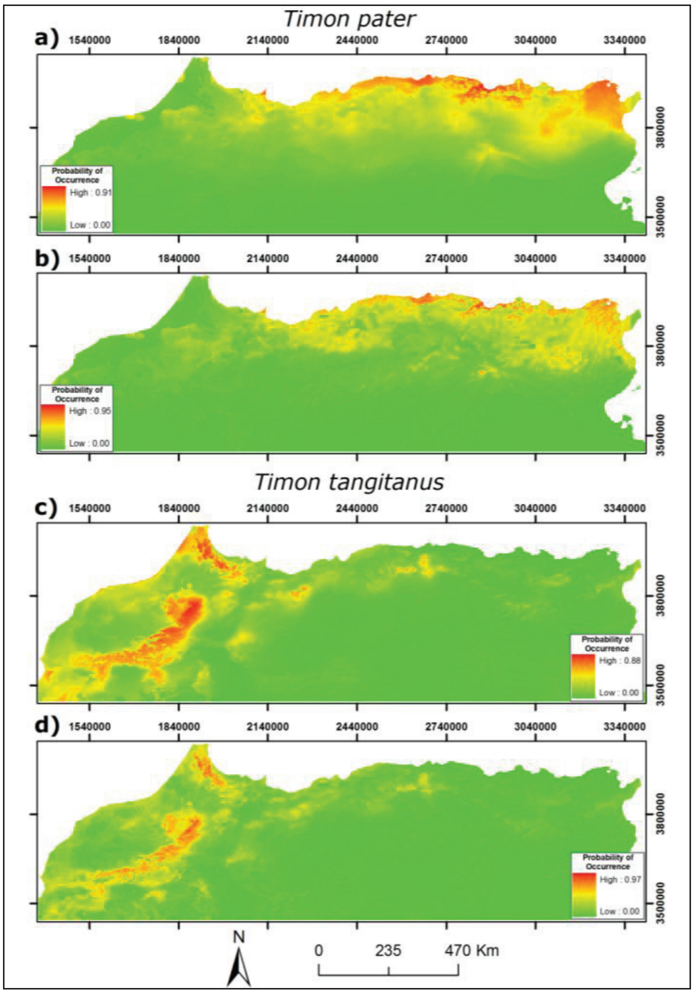


Figure 3-12: Potential spatial distribution modelled with climate variables (a, c) and with land cover, aspect north/east expose, slope, NDVI and climate variables (b, d) at regional extent for *T. pater* and *T. tangitanus* in Zone 4.

3.4 Comparison at continental and at regional extents

3.4.1 Differences in potential geographic overlap areas

In all the following figures three maps are showing the potential geographic overlap areas resulting from the models at continental and at regional extents and one map presenting the presence points of the species in each zone. Map a) is a zoom in on the resulting potential geographic overlap areas based on models at continental extent. Map b) presents the potential geographic overlap areas derived from the models performed at regional extent using the same climate predictor variables as the models at continental extent. Map c) shows the potential geographic overlap areas revealed by the models at regional extent using climate, land cover, aspect north expose, aspect east expose, slope and NDVI. Map d) the presence points of the two species in the zone.

Figure 3-13 presents the results in Zone 1 between *L. agilis* and *L. bilineata-viridis*. Based on visual interpretation it is clear to observe that the potential geographic overlap areas revealed by the models at continental extent totally disappeared by the models performed at regional extent. From Map d) it can be observed in the central eastern part of the zone that the presence points of *L. agilis* and *L. bilineata-viridis* actually overlap.

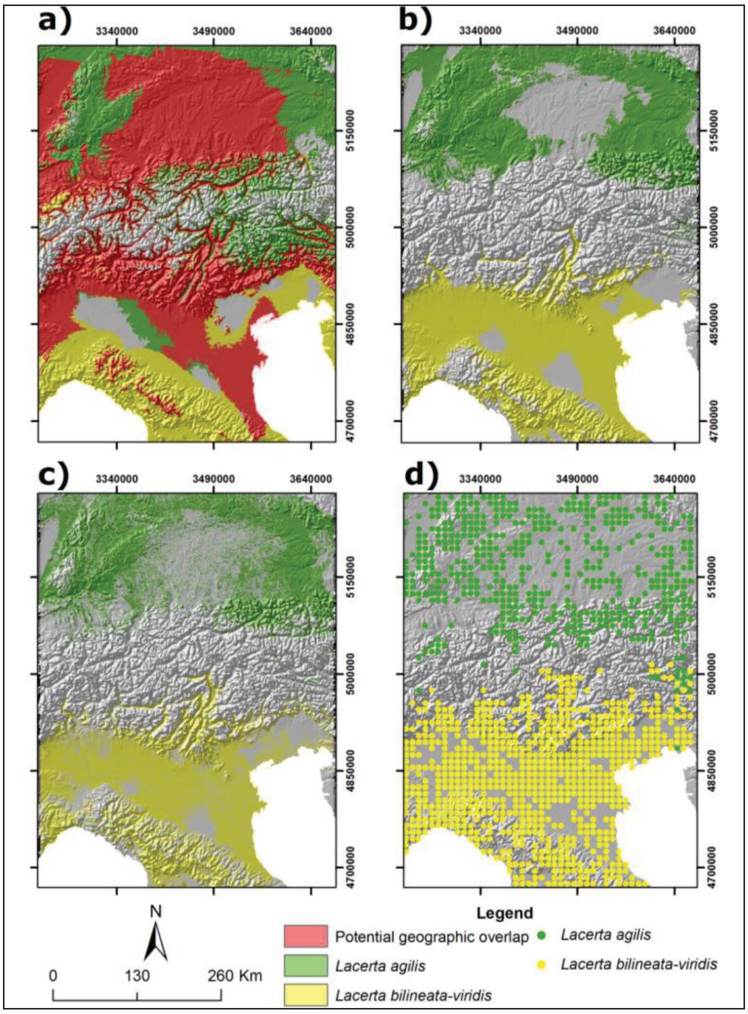


Figure 3-13: Potential geographic overlap areas at continental and regional extents modelled with climate variables only (a, b) and with land cover, aspect north/east expose, slope, NDVI and climate variables (c). Presence points of *L. agilis* and *L. bilineata-viridis* (d). Zone1.

Figure 3-14 presents the results of Zone 2 between *L. bilineata-viridis* and *L. trilineata*. In the three maps a), b) and c) it is possible to identify potential geographic overlap areas. It is clear that the overlap areas decrease in the maps at regional extents in comparison with the results at continental extent. In map d) the presence points of *L. bilineata-viridis* and *L. trilineata* actually overlap in the eastern part as well as in the central and southern western part of the zone. Specifically in the central part the results from the model at continental extent did not predicted this areas as potential overlap.

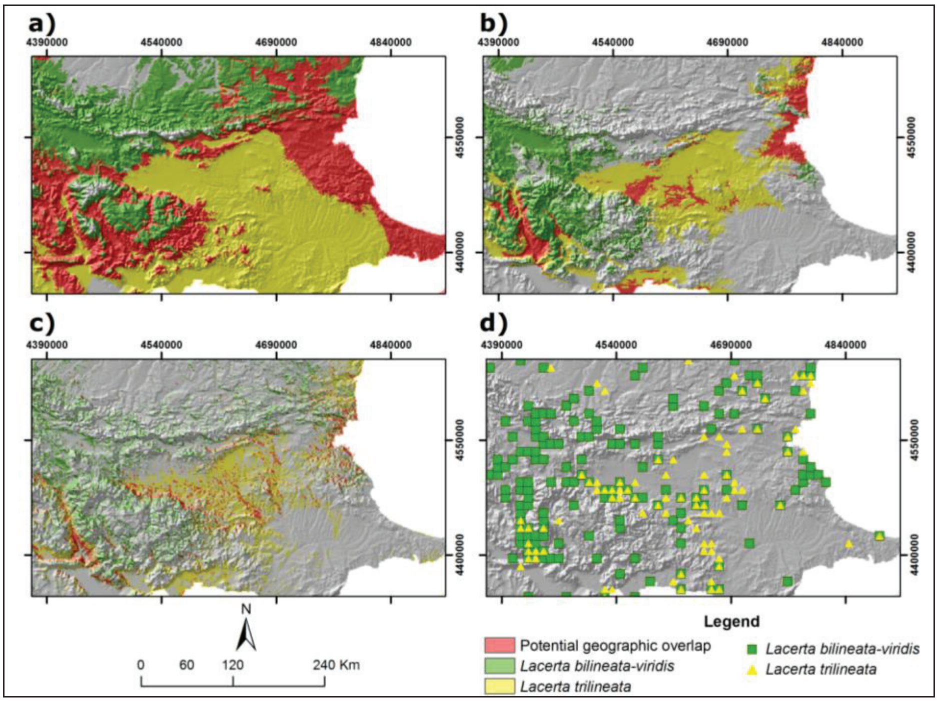


Figure 3-14: Potential geographic overlap areas at continental and regional extents modelled with climate variables only (a, b) and with land cover, aspect north/east expose, slope, NDVI and climate variables (c). Presence points of *L. bilineata-viridis* and *L. trilineata* (d). Zone 2.

Figure 3-15 shows the results in Zone 3 between *T. Lepidus* and *T. tangiatnus*. In Map a) the potential geographic overlap areas extend in the north part as well as in some parts of the south part of the Zone. In Map b) the potential overlap areas in the south completely disappear, but some small areas can be observed in the northern part. In Map c) there is not areas classified as potential overlap. The presence points of *T. lepidus* and *T. tangitanus* in Map d) are located in different parts of the zone and did not actually overlap.

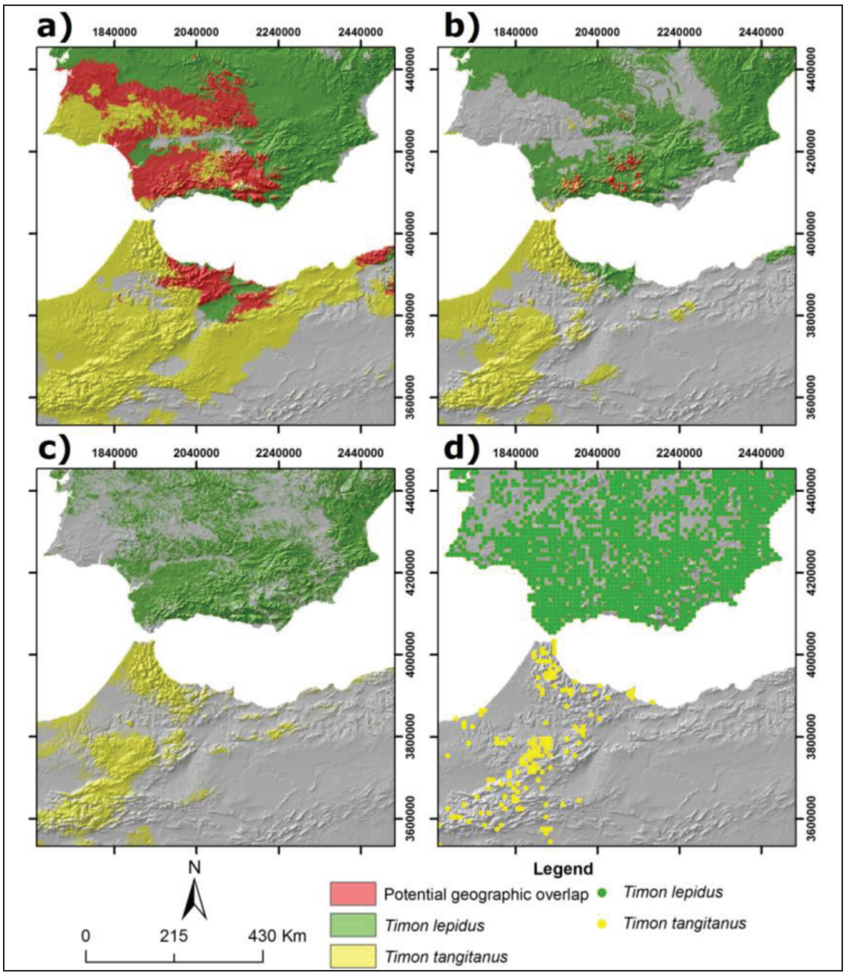


Figure 3-15: Potential geographic overlap areas at continental and regional extents modelled with climate variables only (a, b) and with land cover, aspect north/east expose, slope, NDVI and climate variables (c). Presence points of *T. lepidus* and *T. tangitanus* (d). Zone 3.

Figure 3-16 presents the results in Zone 4 between *T. pater* and *T. tangitanus*. In this Zone it is possible to observed potential overlap areas from the three maps a), b) and c). In Map a) the potential overlap areas extends in the north central part of the zone. However, from the results at regional extent (Maps b) and Map c)) the potential overlap areas significantly diminished. The presence points of both species occur in different parts of the zone and it is not possible to find locations where they actually overlap.

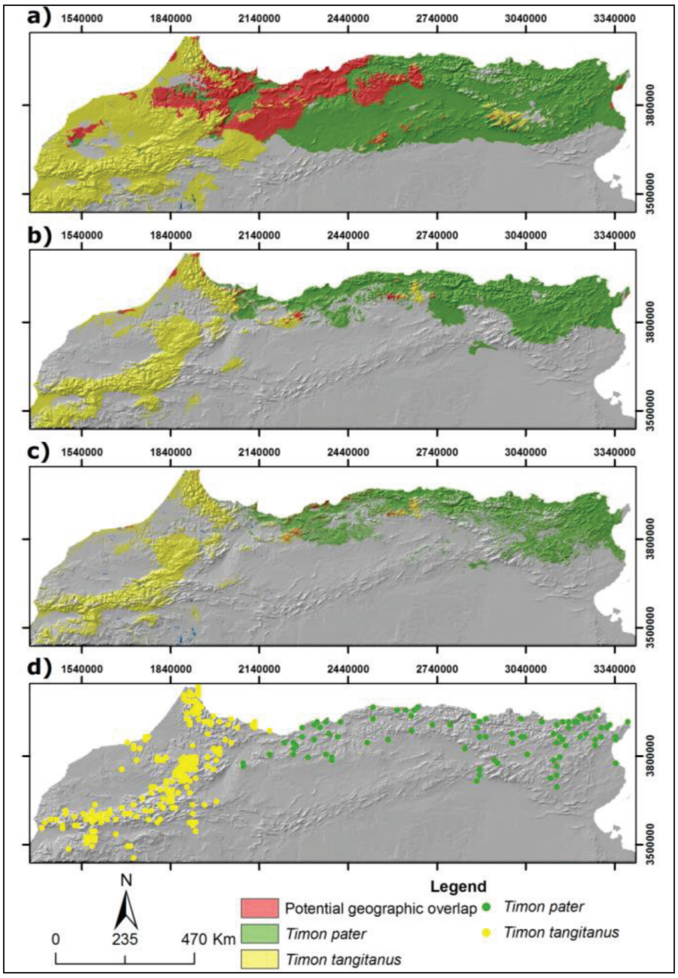


Figure 3-16: Potential geographic overlap areas at continental and regional extents modelled with climate variables only (a, b) and with land cover, aspect north/east expose, slope, NDVI and climate variables (c). Presence points of *T. pater* and *T. tangitanus* (d). Zone 4.

From the results performed in the four selected zones between pairs of species. It was observed that the potential geographic overlap areas considerably change depending on the extent at which the models were performed. In addition, between the models at regional extents small changes in the potential geographic overlap areas were detected depending on the environmental predictor variables used.

3.4.2 Statistical test to determine changes in potential geographic overlap areas

Table 3-7 presents the sum of pixels classified as potential geographic overlap in each of the four selected Zones depending on the extent and predictor variables used to fit the models between pairs of species.

Table 3-7: Sum of pixels classified as potential overlap in each of the four selected Zones derived from the models fitted at different extents and predictor variables.

	Continental extent	**Regional extent**	
	Climate variables	**Climate variables**	**Climate+Land cover+Aspect (north/east)+Slope+NDVI**
Zone 1	113853	0	0
Zone 2	41416	8685	5556
Zone 3	89742	3860	41
Zone 4	97085	3972	3498

Regarding research question two a paired sample t-test was performed to determine changes in the potential geographic overlap areas resulting from models at continental and regional extents.

As it possible to observed from the P-values of Table 3-8 in both cases there is significant changes on the potential geographic overlap areas depending on the extent at which the potential distribution models were fitted.

Table 3-8: Results of paired-sample t test of the sum of pixels classified as potential overlap in each selected zone. * significant at 0.05 level.

	P-value
Continental extent / regional extent (climate variables)	0.018*
Continental extent / regional extent (Climate+Land cover+Aspect(north/east)+slope+NDVI)	0.015*

In order to answer research question three a t-test was performed to determine changes in the potential geographic overlap areas resulting from the models at regional extents using different type of predictor variables. Table 3-9 shows the p-values of the t-test.

In this case the P-values shows that there is not significant changes in the geographical overlap areas depending on the type of predictor variables used to model the potential spatial distribution of the species at regional extent.

Table 3-9: Results of paired-sample t test of the sum of pixels classified as potential overlap at regional extent from models using only climate variables and models with land cover, aspect (north/east expose), NDVI and climate variables in each selected Zones. * significant at 0.05 level.

	P-value
Regional extent models Only climate variables / Climate+Land cover+Aspect(north/east)+slope+NDVI	0.146

Based on these results it is possible to conclude that the potential geographic overlap areas change depending on the extent at which the models of the potential spatial distribution of the species involve were performed. On the other hand, the potential geographic overlap derived from the models at regional extent which used different environmental predictor variables do not significantly change.

3.4.3 Differences in predictor variable importance

Research question 4 refers to the predictor variable importance depending on models at continental and at regional extents. To answer this question the results obtained in Zone 1 (*L. agilis* and *L. bilineata-viridis*) and Zone 4 (*T. pater* and *T. tangitanus*) were considered because the three models fitted used the same climate predictor variables as the models at continental extent.

From the model at continental extent (Model a) for *L. agilis* the most important variable is the mean annual global radiation, but for the models at regional extent (Models b and c) the most important one is the maximum temperature of the warmest month. The second in importance of Model a is the precipitation of the driest quarter which in the models at regional extent is rank as the 6 and 7 in importance. At regional extent the second in importance is the mean annual global radiation variable. The three models coincide that the mean temperature of the driest quarter is the third in importance. It is important to observe that for Model c the three most important variables are the climate ones.

From the models for *L. bilineata-viridis* at continental extent the most important variable is the precipitation of the driest month. At regional extent the most important ones are temperature of the driest quarter and land cover for models b and c respectively. The maximum temperature of the warmest month is the second in importance at continental extent and at regional extent in model c. But for model b at regional extent is the mean annual global radiation. The third in importance from the models at continental and at regional extent in is the mean annual global radiation variable.

Table 3-10: Comparison of variables importance between models at continental and regional extents with climate variables only (a, b) and with land cover, aspect north/east expose, slope, NDVI and climate variables (c) in Zone1. The number inside parenthesis is the order of importance of the predictor variable.

	L. agilis			***L. bilineata-viridis***		
Predictor Variable	**Model a**	**Model b**	**Model c**	**Model a**	**Model b**	**Model c**
Maximum Temperature of Warmest Month	0.651(**4**)	0.425(**1**)	0.425(**1**)	0.654(**2**)	0.388(**1**)	0.374(**2**)
Minimum Temperature of Coldest Month	0.561(**6**)	0.248(**4**)	0.240(**5**)	0.262(**6**)	0.319(**3**)	0.299(**4**)
Mean Temperature of Driest Quarter	0.755(**3**)	0.328(**3**)	0.329(**3**)	0.516(**4**)	0.281(**4**)	0.268(**5**)
Precipitation of Driest Month	0.767(**2**)	0.089(**5**)	0.077(**7**)	0.681(**1**)	0.098(**5**)	0.106(**6**)
Precipitation Seasonality	0.597(**5**)	0.070(**6**)	0.076(**8**)	0.387(**5**)	0.084(**6**)	0.077(**8**)
Mean annual global radiation	0.776(**1**)	0.383(**2**)	0.387(**2**)	0.627(**3**)	0.336(**2**)	0.337(**3**)
Degree of slope			0.102(**6**)			0.081(**7**)
Aspect north expose			0.027(**10**)			0.024(**10**)
Aspect east expose			0.015(**11**)			0.015(**11**)
Land cover			0.300(**4**)			0.398(**1**)
NDVI			0.059(**9**)			0.073(**9**)

In table 3-11 from the models for *T. pater*, the most important variable at continental and at regional extents is the mean annual global radiation. The precipitation of the driest month is rank as the second in importance at continental extent. But for Model b the second is the maximum temperature of the warmest month and for Model c at regional extent is NDVI. Models a and b coincide that mean temperature of the driest quarter is rank as the third at continental and at regional extents. In Model c the third most important variables is land cover.

For *T. tangitanus* the most important variable in the model at continental extent is the mean annual global radiation. For both models b and c at regional extent the most important predictor is the mean temperature of the driest quarter which is the third at continental extent. The precipitation of the driest month is the second in importance for the model at continental extent and the mean temperature of the driest quarter for the models at regional extent. Precipitation seasonality for model b and degree of slope in model c is the third in importance.

Table 3-11: Comparison of variables importance between models at continental and regional extents with climate variables only (a, b) and with land cover, aspect north/east expose, slope, NDVI and climate variables (c) in Zone 4. The number inside parenthesis is the order of importance of the predictor variable.

	T. pater			***T. tangitanus***		
Predictor Variable	**Model a**	**Model b**	**Model c**	**Model a**	**Model b**	**Model c**
Maximum Temperature of Warmest Month	0.880(**4**)	0.367(**2**)	0.356(**4**)	0.756(**5**)	0.344(**4**)	0.329(**7**)
Minimum Temperature of Coldest Month	0.463(**6**)	0.189(**5**)	0.197(**7**)	0.261(**6**)	0.533(**2**)	0.484(**2**)
Mean Temperature of Driest Quarter	1.231(**3**)	0.275(**3**)	0.263(**5**)	1.003(**3**)	0.663(**1**)	0.633(**1**)
Precipitation of Driest Month	1.630(**2**)	0.217(**4**)	0.229(**6**)	1.122(**2**)	0.065(**6**)	0.043(**11**)
Precipitation Seasonality	0.572(**5**)	0.083(**6**)	0.085(**10**)	0.802(**4**)	0.397(**3**)	0.387(**6**)
Mean annual global radiation	1.719(**1**)	0.901(**1**)	0.809(**1**)	1.548(**1**)	0.156(**5**)	0.163(**8**)
Degree of slope			0.155(**8**)			0.469(**3**)
Aspect north expose			0.103(**9**)			0.052(**9**)
Aspect east expose			0.079(**11**)			0.050(**10**)
Land cover			0.665(**3**)			0.460(**4**)
NDVI			0.684(**2**)			0.444(**5**)

4. Discussion

4.1 Effect of extent in the potential geographic overlap areas

In all of the four selected zones where the comparison between the results modelled at continental and at regional extents the potential geographic overlap areas significantly decreased.

In Zone 1 (Figure 3-13) there is important potential geographic overlap areas between *L. agilis* and *L. bilineata-viridis* from the model fitted at continental extent. Nevertheless, the potential overlap is not predicted from the models at regional extent. Even in the results derived from the model at regional extent which used the same climate variables as the model at continent extent there is not potential overlap.

The same pattern is observed in selected Zone 2 (Figure 4-14). However, in this case potential geographic overlap areas were detected from the models fitted at different extents for *L. bilineata-viridis* and *L. trilineata*. It is important to consider that looking at the presence points of both species location with actual overlap occurred.

In Zone 3 (Figure 3-15) between *T. lepidus* and *T. tangitanus* potential geographic overlap areas were determined by the models fitted at continental and at regional extents. Nonetheless, the potential geographic overlap areas drastically diminished from the models at regional extent. This pattern is more evident in the result derived from the models that used other variables than the climate ones.

Similar effect is observed in Zone 4 (Figure 3-16) in the potential geographic overlap areas between *T. pater* and *T. tangitanus*. At continental extent the combination of the models determined a large potential geographic overlap area. Contrary, at regional extent the resulting potential geographic overlap areas reduced considerably.

From the visual interpretation the potential geographic overlap areas considerably change depending on the extent at which the potential distribution models were fitted.

This asseveration is confirmed by testing the significance of change of the potential geographic overlap areas between the results at different extents (Section 3.4.2). The comparison was based on performing a sample t-test between the sum of pixels classified as potential overlap from the models fitted at continental and regional extents in the four selected zones. The results of the test (Table 3-8) determined that there is significant change in the potential geographic overlap areas depending on the extent at which the models were fitted.

Additionally, a t-test were conducted to the results at regional extent in order to determine if significant change in the potential geographic overlap areas depend on the type of variables used to modelled the potential distribution of this species. The results (Table 3-9) confirmed that there is no significance change in the potential geographic overlap areas.

Based on these results it seems that the changes in the potential geographic overlap areas is more dependent on the extent than on the type of predictor variables used to model the potential distribution of the species.

5. Conclusions

1) At regional extent six out of eight of the potential spatial distribution of species modelled using variables related to land cover, topography and NDVI do not improve the AUC values in comparison to the models based on only climate predictor variables. Only for *L. bilineata-viridis* and *T. lepidus* the models including other variables than the climate ones significantly improve the accuracy estimations.

2) The potential geographic overlap areas between pairs of species significantly change depending on the extent at which the potential distribution models are fitted. The potential geographic overlap areas derived from models fitted at regional extent reduced considerably in comparison with the results derived from models fitted at continental extent.

3) The potential geographic overlap areas between pairs of species do not significantly change depending on the type of predictor variables use to model the potential spatial distribution of the species at regional extent.

4) The environmental predictor variables related to radiation and temperature appear to be the most important in explaining the potential spatial distribution of the target species at continental and at regional extents.

6. Recommendations

1) In this research, at continental extent the resulting potential geographic overlap areas between pairs of species were derived from models performed with only climate predictor variables. Therefore, in future studies it could be important to analyze the potential overlap between models which use more detailed environmental predictor variables.

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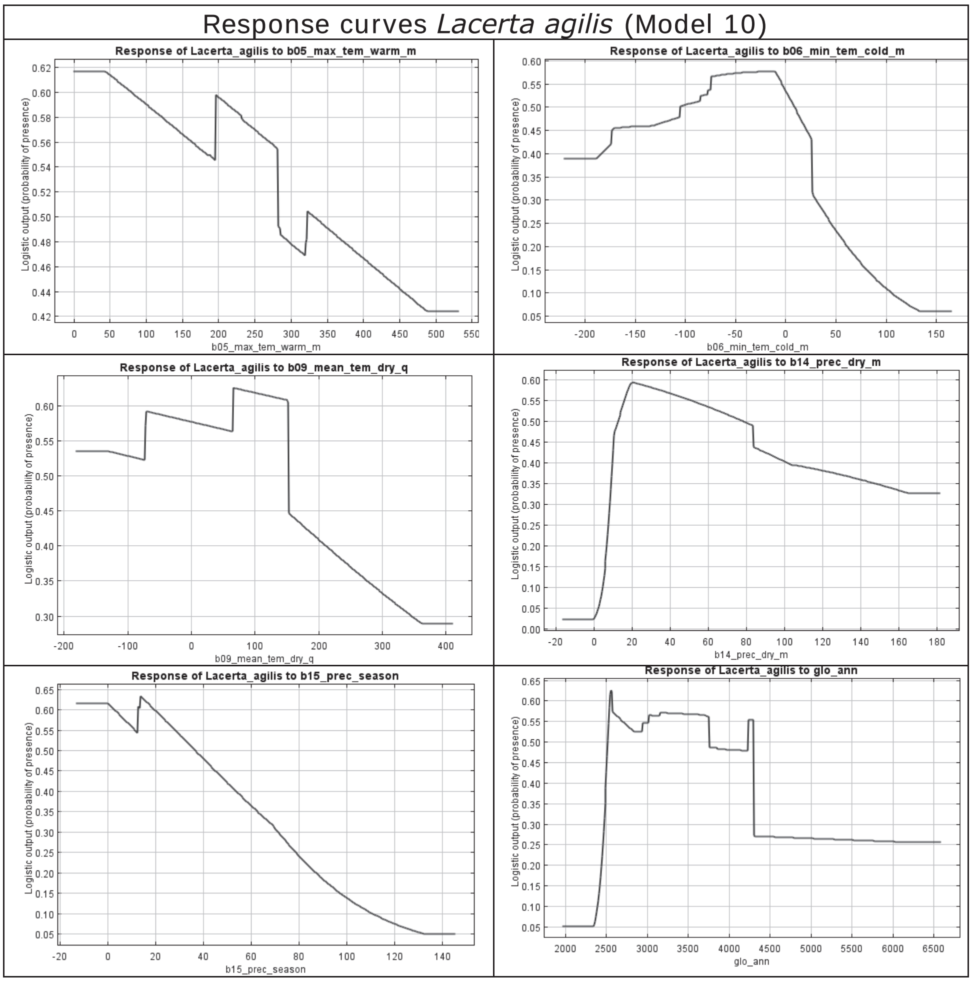
Appendix

Appendix 1: VIF values of the multicollinearity tests performed to the predictor variables included in the models at regional extent in the four selected zones using climate, land cover, topographic and NDVI variables. The variable related to land cover was not included in the test of multicollinearity because is a discrete variable. The symbol X means that the VIF value is higher than 10 and the variable was not consider in the models.

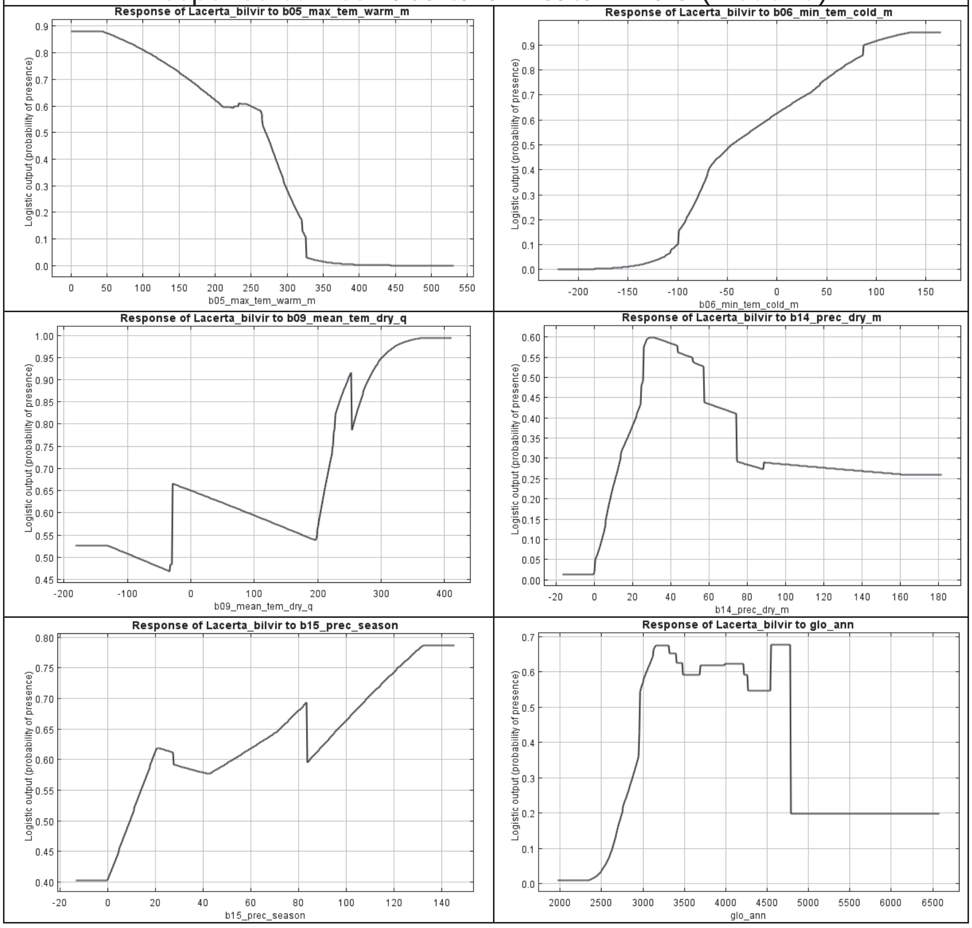
Predictor Variable	Zone 1	Zone 2	Zone 3	Zone 4
Maximum Temperature of Warmest Month	3.54	4.52	2.69	3.30
Minimum Temperature of Coldest Month	5.81	6.06	3.61	9.35
Mean Temperature of Driest Quarter	2.86	2.33	3.05	6.02
Precipitation of Driest Month	2.16	X	X	8.55
Precipitation Seasonality	3.00	1.55	4.65	4.63
Mean annual global radiation	2.17	2.11	2.65	4.48
Degree of slope	2.04	1.84	1.24	1.39
Aspect north expose	1.07	1.08	1.01	1.07
Aspect east expose	1.02	1.06	1.01	1.01
NDVI	1.21	1.18	1.22	2.49
Land cover	-	-	-	-

Appendix 2: Response curves of the models fitted at continental extents for the reptile species of the green lizards group. The values of the predictor variables related to temperature are multiplied by 10.

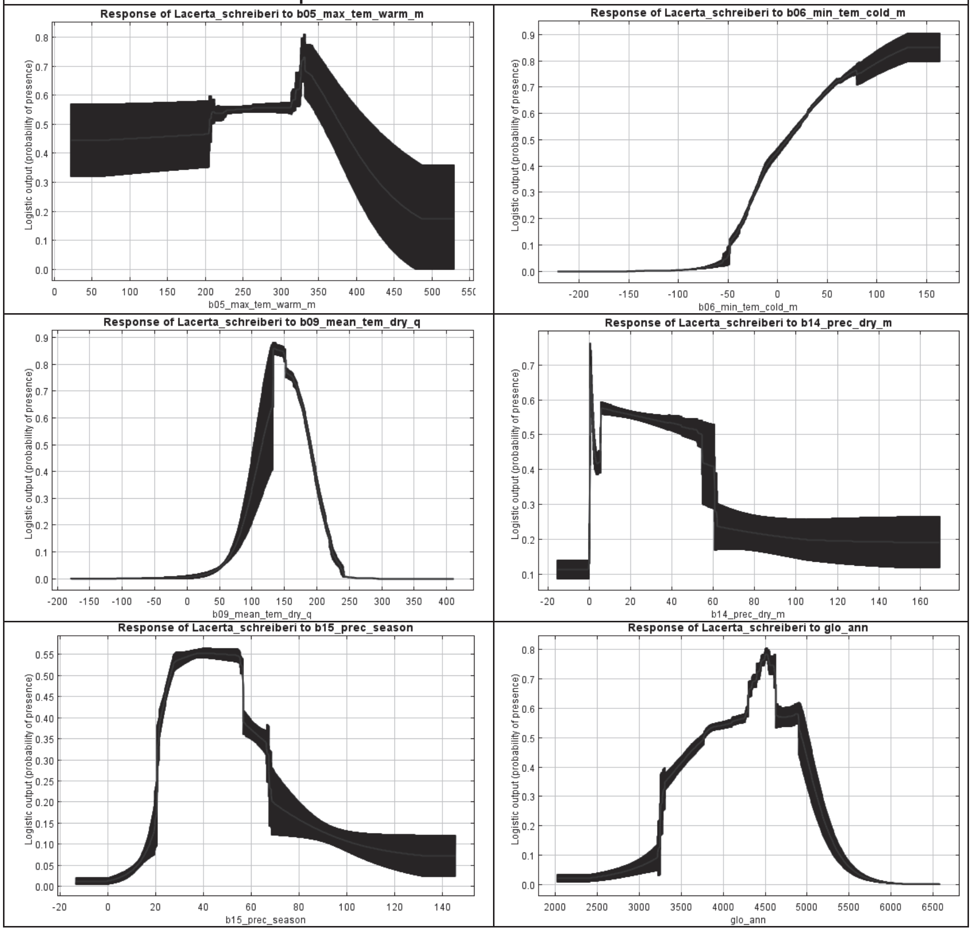
Response curves *Lacerta agilis* (Model 10)

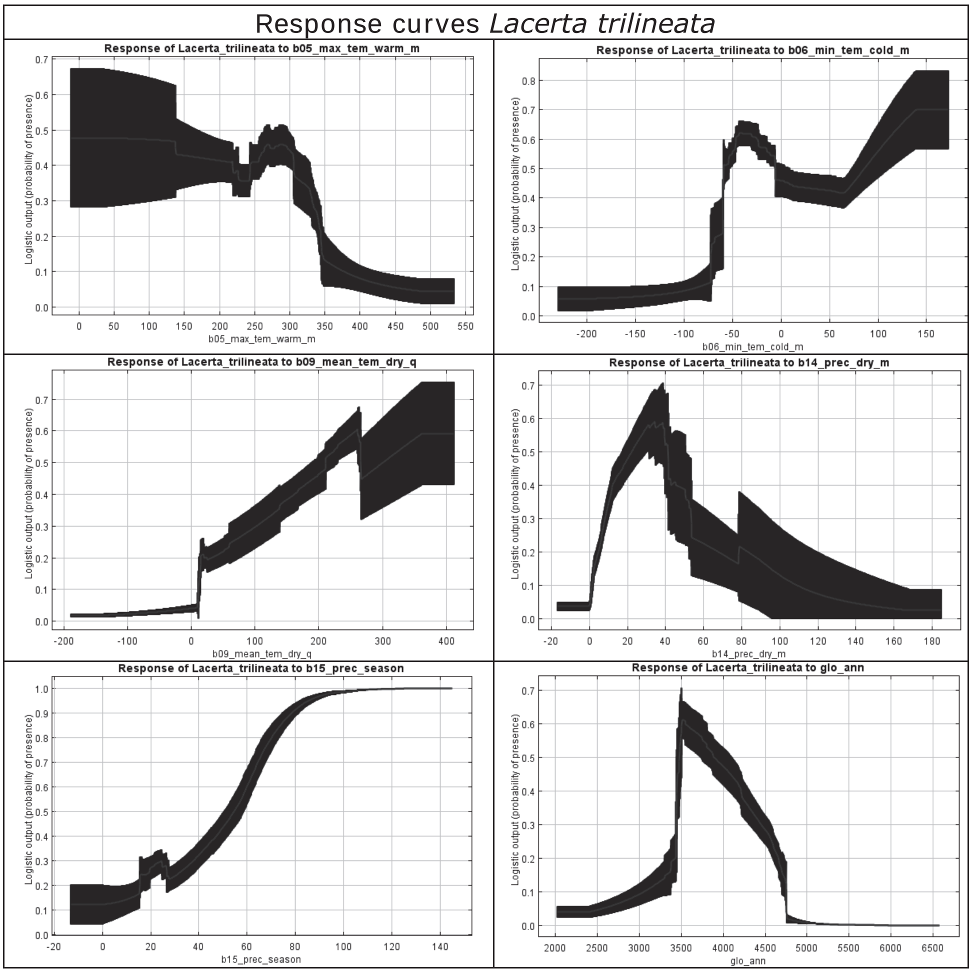


Response curves *Lacerta bilineata-viridis* (Model 6)



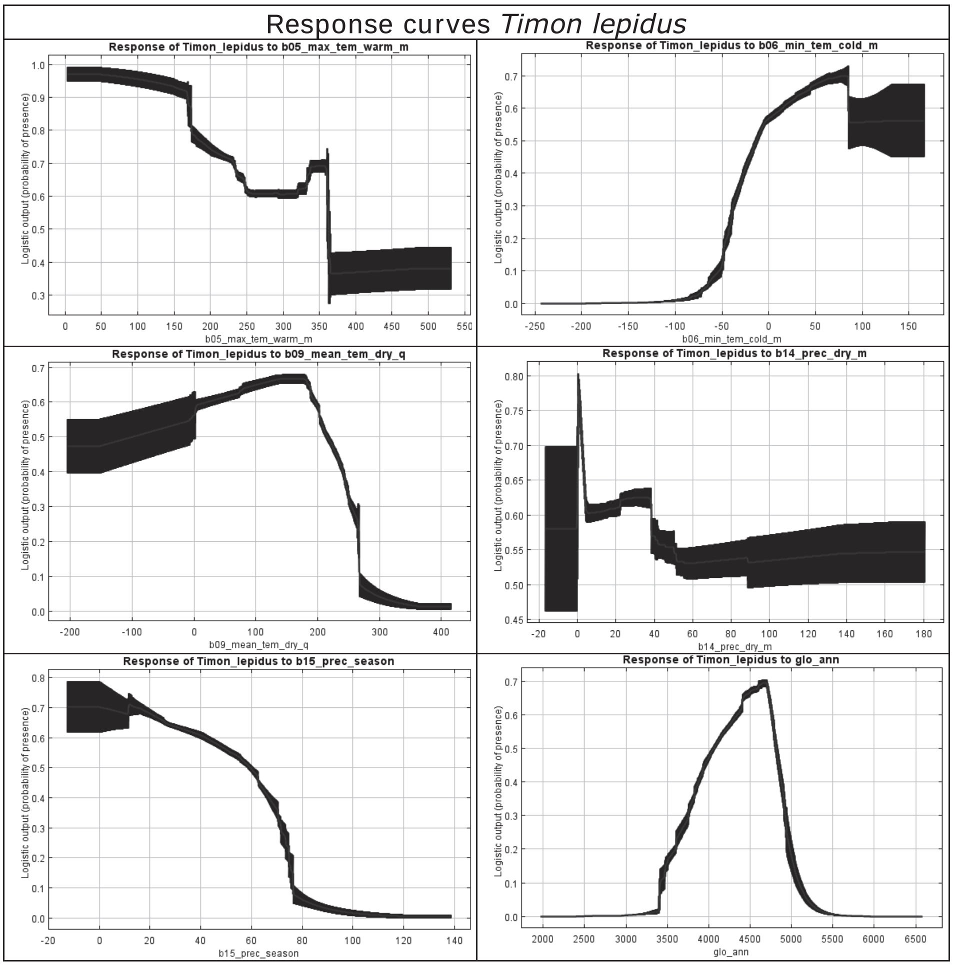
Response curves *Lacerta schreiberi*





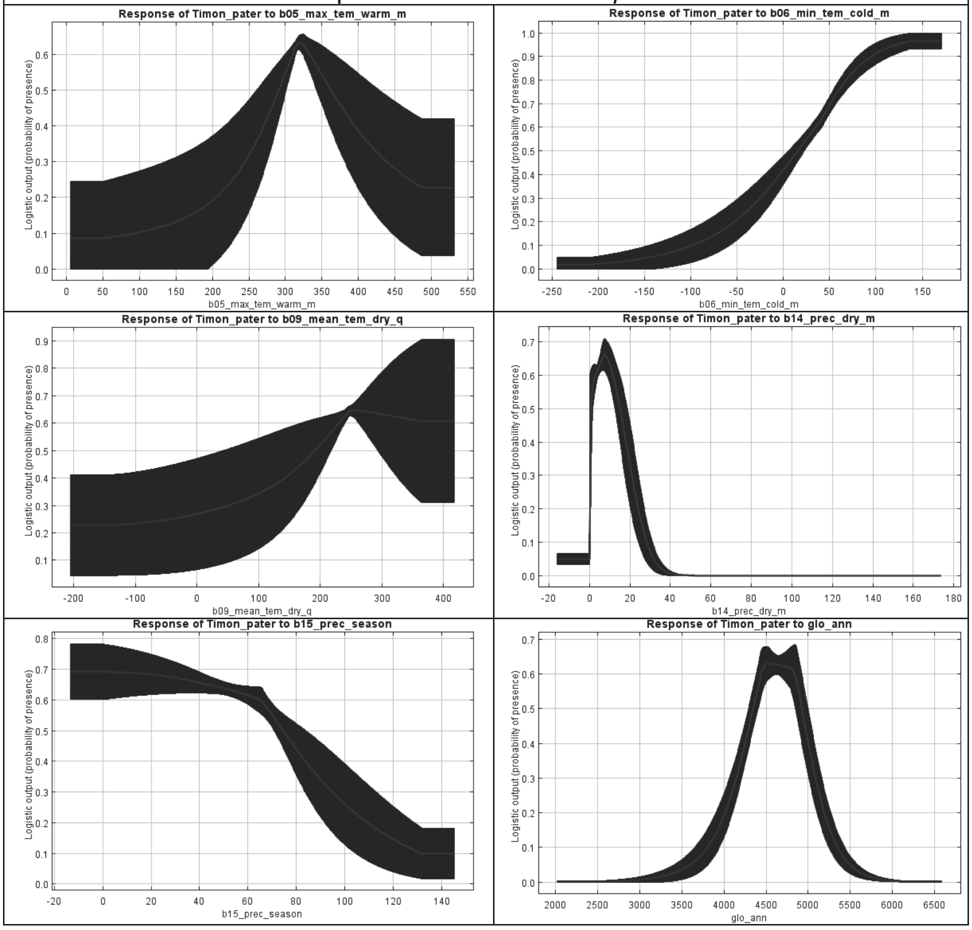
Response curves *Lacerta trilineata*

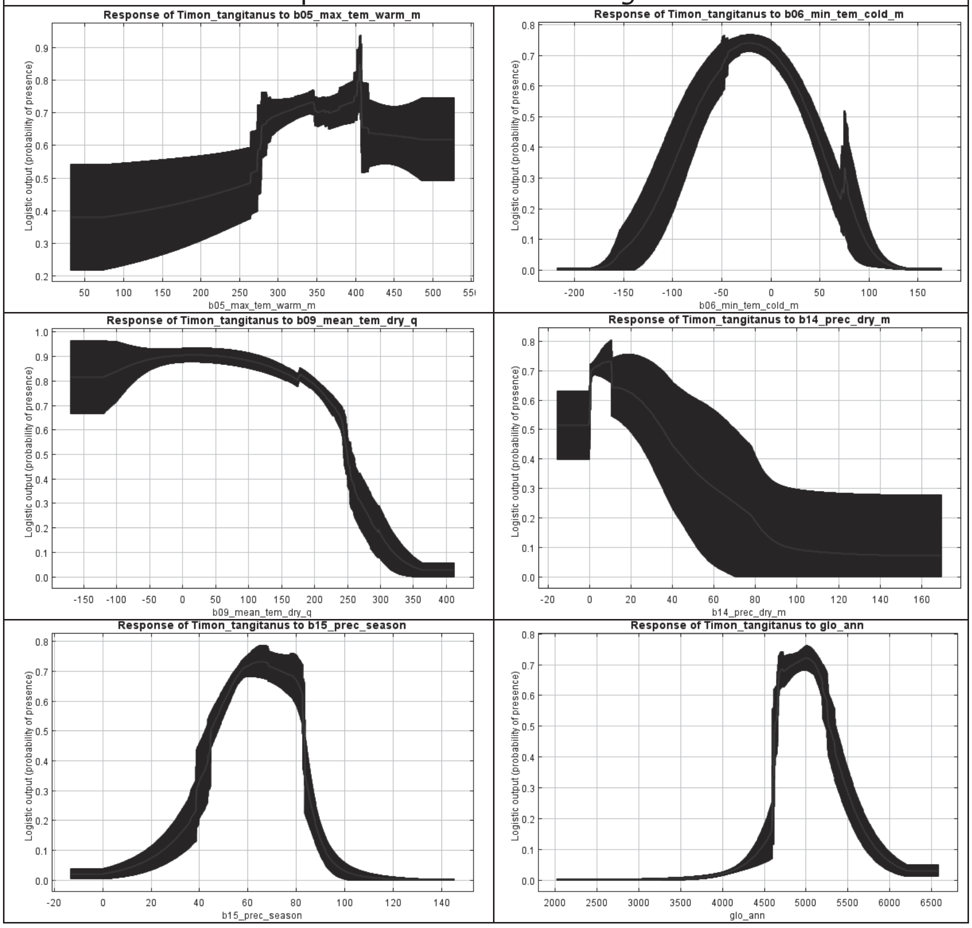
Appendix 3: Response curves of the models fitted at continental extents for the reptile species of the Ocellated lizards group. The values of the predictor variables related to temperature are multiplied by 10.



Response curves *Timon lepidus*

Response curves *Timon pater*





Response curves *Timon tangitanus*

Response of Timon_tangitanus to b05_max_tem_warm_m

Response of Timon_tangitanus to b06_min_tem_cold_m

Response of Timon_tangitanus to b09_mean_tem_dry_q

Response of Timon_tangitanus to b14_prec_dry_m

Response of Timon_tangitanus to b15_prec_season

Response of Timon_tangitanus to glo_ann