Environmental niche modeling; present and future potential distribution of garter snakes species from the Trans-Mexican Volcanic Belt

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Land-use and climate change are affecting the abundance and distribution of species. The Trans-Mexican Volcanic Belt (TMVB) is a very diverse region due to geological history, geographic position and climate, however, is one of the most disturbed regions in Mexico. Reptiles are particularly sensitive to environmental changes due to their low dispersal capacity and thermal ecology. In this study, we define the environmental niche (a part of it; considering climatic, topographic and land use variables) and potential distribution (present and future) of the five *Thamnophis* species present in TMVB. To do so, we used the maximum entropy modelling software (MAXENT). First, we modeled to select the most important variables to explain the distribution of each species, then we modeled again only with the most important variables and projected these models to the future (year 2050) considering a middle-moderate climate change scenario (rcp45) and the land use and vegetation variables for year 2050, generated with Land Change Modeler based on the land use change occurred between years 2002 and 2011. We also calculated niche overlap between species in environmental space for the present and the future. Percentage of arid vegetation was a negative important variable for all the species and minimum temperature of the coldest month was selected as an important variable in four of the five species. Distance to *Abies* forest had a high percentage of contribution for *T. scalaris* and *T. scaliger* distribution. We found that all *Thamnophis* species will experience reductions in their distribution ranges in the TMVB in the future, however, for the whole country, the distribution of *T. melanogaster* seems to increase in the future. *T. scalaris* is the species that will suffer the biggest reduction in its distribution; the fact that this species is limited by high temperatures and that cannot shift its distribution upward, as it is already distributed in the highest elevations, can be the cause of this dramatic decline. We found a reduction in niche overlap between species in the future, which means a reduction in the

range of suitable combination of variables for the species.

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Running title: Niche modeling of TMVB garter snakes.

Abstract:

Land-use and climate change are affecting the abundance and distribution of species. The Trans-Mexican Volcanic Belt (TMVB) is a very diverse region due to geological history, geographic position and climate, however, is one of the most disturbed regions in Mexico. Reptiles are particularly sensitive to environmental changes due to their low dispersal capacity and thermal ecology. In this study, we define the environmental niche (a part of it; considering climatic, topographic and land use variables) and potential distribution (present and future) of the five *Thamnophis* species present in TMVB. To do so, we used the maximum entropy modelling software (MAXENT). First, we modeled to select the most important variables to explain the distribution of each species, then we modeled again only with the most important variables and projected these models to the future (year 2050) considering a middle-moderate climate change scenario (rcp45) and the land use and vegetation variables for year 2050, generated with Land Change Modeler based on the land use change occurred between years 2002 and 2011. We also calculated niche overlap between species in environmental space for the present and the future. Percentage of arid vegetation was a negative important variable for all the species and minimum temperature of the coldest month was selected as an important variable in four of the five species. Distance to *Abies* forest had a high percentage of contribution for *T. scalaris* and *T. scaliger* distribution. We found that all *Thamnophis* species will experience reductions in their distribution ranges in the TMVB in the future, however, for the whole country, the distribution of *T. melanogaster* seems to increase in the future. *T. scalaris* is the species that will suffer the biggest reduction in its distribution; the fact that this species is limited by high temperatures and that cannot shift its distribution upward, as it is already distributed in the highest elevations, can be the cause of this dramatic decline. We found a reduction in niche overlap between species in the future, which means a reduction in the range of suitable combination of variables for the species.

Key Words: *potential distribution; environmental niche models; climate change; land-use change; Thamnophis.*

Introduction

Land-use and climate change are affecting the abundance and distribution of species, altering biological communities, ecosystems, and their associated services to humans (Parmesan & Yohe, 2003; Cardinale et al., 2012; Kortsch et al., 2015; Nadeau, Urban & Bridle, 2017). Both factors are the main contributors to the global decline of reptiles (Ribeiro et al., 2009; Schneider-Maunoury et al., 2016; Sunny, González-Fernández & D'Addario, 2017), in fact, some studies indicate that between 15 and 44% of the world's reptile species are threatened (Böhm et al., 2013; Ceballos et al., 2015) because they are particularly sensitive to environmental changes due to their low dispersal capacity and thermal ecology (Huey, 1982; Castellano & Valone, 2006; Ribeiro et al., 2009; Russildi et al., 2016). Studies predicting biological responses to land use and climate change are therefore necessary in order to assess the potential impacts of these changes and develop management decisions and conservation strategies (Jiménez-Valverde & Lobo, 2007; Nadeau, Urban & Bridle, 2017). Information concerning species distributions is essential in these cases (Liu, White & Newell, 2013). Through species occurrence data and environmental information, we can generate environmental niche models that can be projected to geographic space, showing particular areas where environmental conditions are favorable for the species presence (Suárez-Atilano, 2015).

The TMVB is a set of mountain ranges and volcanoes of different ages, aligned on a strip that crosses the Mexican territory from the west, on the Pacific coast, to the east, on the Gulf of Mexico. It is a transition area between Neartic and Neotropical regions which leads to an overlap of biotas from both regions (Suárez-Atilano, 2015). Its geological history and geographic position make it a very complex area with 30 different climatic types and different types of vegetation like coniferous forests, oaks, mesophyll forests, alpine pastures, subalpine scrub and riparian vegetation (Espinoza & Ocegueda, 2007). For these reasons, the TMVB is a biogeographic zone with high species richness and endemism; it is the second biogeographic zone with the highest herpetological richness and the most important region in endemic amphibian and reptile species (Flores-Villela & Canseco-Márquez, 2007; Sunny, González-Fernández & D'Addario, 2017). Due to the complex characteristics of the TMVB, the montane taxa of this region have been exposed to a sky-island dynamic through climate fluctuations (Mastretta-Yanes, 2015), consequently, the high-altitude adapted species could be vulnerable to climate change as they may be limited by future rising temperatures (Sunny, González-Fernández & D'Addario, 2017). Moreover, the TMVB is one of the most disturbed regions in the country as it contains the biggest metropolitan areas of Mexico (CONAPO, 2010; Sunny, González-Fernández & D'Addario, 2017).

Garter snakes are among the most abundant snake species in North America (Rossman, Ford & Seigel, 1996; de Queiroz, Lawson & Lemos-Espinal, 2002), they are distributed from

Canada to Costa Rica, but only the northern populations have been well studied (Rossman, Ford & Seigel, 1996; Manjarrez, 1998; de Queiroz, Lawson & Lemos-Espinal, 2002) and we lack information on the ecology of Mexican *Thamnophis* (Manjarrez, Venegas-Barrera & García-Guadarrama, 2007). From an evolutionary perspective, the group as a whole is singular for its radiation into diverse ecological niches (de Queiroz, Lawson & Lemos-Espinal, 2002); some species are generalists and others are specialists in their diets and habitats (Rossman, Ford & Seigel, 1996), therefore some species are particularly sensitive to land-use and climate change. For this study, we chose the garter snake species that are distributed in the TMVB. Our hypothesis was that land use and climate change will decrease the future distribution range of these species. Therefore, the aim of the study was to define the environmental niche (a part of it; considering climatic, topographic and land use variables) and the present and future potential distribution, for the whole country, of the five *Thamnophis* species present in TMVB.

Materials and methods

We modeled the distribution of the *Thamnophis* species that occur in the Trans-Mexican Volcanic Belt (*T. cyrtopsis*, *T. eques*, *T. melanogaster*, *T. scalaris* and *T. scaliger*). Occurrence data were obtained from fieldwork (60% of records or more; Table S1) and online databases, namely the Global Biodiversity Information Facility (GBIF and iNaturalist). We selected for the analysis only the records from the last 20 years. Maps of occurrence data for the five species were produced to check for obvious errors. We also filtered these data to obtain only one record per km^2 to reduce spatial autocorrelation (Boria et al., 2014). We defined a polygon for each species which represents the accessibility area (Suárez-Atilano et al., 2014; Suárez-Atilano et al., 2017; Sunny, González-Fernández & D'Addario, 2017). These polygons were generated considering biogeographic regions with geographical records or records near its borders (Sunny, González-Fernández & D'Addario, 2017). We obtained bioclimatic variables from WorldClim (Hijmans et al., 2005), topographic and land cover variables were obtained from the National Institute of Statistics and Geography based on satellite images series V, 1:250 000 with a pixel resolution of 120 meters (Landsat TM5) during the period 2011 to 2013 (INEGI, 2013). Land cover variables were converted to raster and transformed from categorical to continuous using a resample method that averages the value of the surrounding pixels to assign a new value to each pixel. For raster processing we used ARC GIS 10.5 and the packages RASTER (Hijmans, 2016) and RGDAL (Bivand, Keitt & Rowlingson, 2017) for R software (version 3.4.0; R. Development

Core Team, 2017). After a bibliographic review and correlation analysis to discard highly correlated variables (Pearson coefficient higher than 0.8, Suárez-Atilano, 2015) we selected the following variables: elevation, natural grasslands percentage, induced grasslands percentage, percentage of arid vegetation, *Pinus* forest percentage, distance to *Pinus* forest, *Quercus* forest percentage, distance to *Quercus* forest, distance to water sources, agriculture percentage, *Abies* forest percentage, distance to *Abies* forest, minimum temperature of the coldest month, maximum temperature of the warmest month, precipitation of the wettest month and precipitation of the driest month.

We used the maximum entropy modelling software (MAXENT; Phillips, Anderson & Schapire, 2006) which estimates species distributions by finding the distribution of maximum entropy (the most spread out, or closest to uniform) subject to constraints imposed by a known distribution of the species, and by the environmental conditions across the study area (Anderson & González, 2011). First, we ran the model for each species in MAXENT with 10 replicates and we selected the most important variables in explaining the distribution of each species (Anderson, Lew & Peterson, 2003; Chefaoui, Hortal & Lobo, 2005; Suárez-Atilano et al., 2017). All analyses were performed with a convergence threshold of 1 X 10^{-5} with 500 iterations (Pearson et al., 2007; Suarez-Atilano, 2015). We modeled again only with the most important variables (Guisan and Zimmerman, 2000; Guisan and Thuiller, 2005; Araújo and Guisan, 2006) for each species and projected these models to the future. We obtained the future bioclimatic variables CCSM4 for the year 2050 considering the climate change scenario rcp45 (middle-moderate) from WorldClim. Land use and vegetation variables for year 2050 were generated using the software LAND CHANGE MODELER FOR ECOLOGICAL SUSTAINABILITY in IDRISI SELVA 17.0 software (Clark Labs, 2012) and the land cover and vegetation layers from years 2002 and 2011 (series III and V; INEGI 2005, 2013). We also used elevation, slope (obtained from the elevation layer) and distance to urban settlements, for a better prediction of land use change. We established present urban areas, of the present distribution maps, and future urban areas, of the future distribution maps, as areas of zero habitat suitability. We did not include distance to urban areas as a variable in the models because there is usually a bias with it, as these areas are more easily accessed by recorders (Araujo & Guisan, 2006). To evaluate model performance, we used partial-ROC graphics and we used null distributions of expectations to assess the statistical significance of the partial-ROC graphics (Peterson, Papes & Soberón, 2008; Osorio-Olvera et al., 2016) as recommended based on AUC criticisms (Lobo, Jiménez-Valverde & Real, 2008; Peterson, Papes & Soberón, 2008). While AUC evaluates only the environmental niche model (under the omission-commission framework) performance, partial-ROC allows for statistical significance from the AUC itself, based on a null distribution of expectations created via bootstrapping replacement of 50% of the total available points and 1,000 resampling replicates (Suárez-Atilano, 2015). One-tailed significance of the difference between AUC and the null expectations was assessed by fitting a standard normal variate (the z-statistic) and calculating the probability that the mean AUC ratio was ≤ 1. We used 75% of occurrence localities for model training and 25% for model testing (Suarez-Atilano, 2015). We used the platform NICHE TOOLBOX for partial-ROC calculations (Osorio-Olvera et al., 2016). We generated the species distribution binary maps using Max SSS threshold (Liu, White & Newell, 2013), a threshold selection method based on maximizing the sum of sensitivity and specificity. This is considered an adequate method to use when reliable absence data are unavailable (Liu, White & Newell, 2013). We used these binary maps to calculate the area of high suitability for the present and for the future (Suárez-Atilano, 2015), for the whole Mexico and only TMVB for each species, in order to see if the distribution of each species will decrease or increase in the future in both areas. We also calculated niche overlap between species in environmental space using D (Schoener metric; Rödder & Engler, 2011) and Hellinger's I metrics (Warren, Glor & Turelli, 2008) for the present and the future in order to assess if the overlap between niches will increase or decrease in the future. For environmental niche calculations, we used the package ECOSPAT (Di Cola et al., 2017) for R.

Results

After depuration, we worked with 267 records of *T. cyrtopsis*, 274 of *T. eques*, 103 of T. *melanogaster*, 186 of *T. scalaris* and 76 of *T. scaliger*. The most important variables for each *Thamnophis* species are summarized in the Table 1. For *T. cyrtopsis* were (Fig. 1A): minimum temperature of the coldest month (33.7% contribution), arid vegetation (26.4%), distance to *Quercus* forest (8.5%) and maximum temperature of the warmest month (5.2%). These variables, together, explained 73.8% of the species potential distribution. Habitat suitability decreased when minimum temperatures were lower than 5°C and steadily decreased when maximum temperatures increased. Arid vegetation had a negative effect on habitat suitability for this species, and also distance to *Quercus* forests, therefore proximity to *Quercus* forests was positive for the species. For *T. eques*: (Fig. 1B) elevation (28.4% contribution), minimum temperature of the coldest month (19.2%), arid vegetation (15.6%) and agriculture (9.6%). These variables, together, explained 72.8% of *T. eques* potential distribution. Habitat suitability for this species had an optimum near 2500 m.a.s.l. but it dropped to zero with minimum temperatures lower than -7°C. Arid vegetation had a negative effect on this species and agriculture was positive at low values of this variable, however, it became negative at higher values (above 30%). For *T. melanogaster*: (Fig. 1C) elevation (27.3% contribution), agriculture (12.9%), arid vegetation (11.5%) and minimum temperature of the coldest month (11.3%). These variables, together, explained 63% of *T. melanogaster* potential distribution. Elevation was a positive variable. Habitat suitability dropped to 0 with minimum temperatures lower than -7°C. Arid vegetation had a negative effect on this species and agriculture was positive at low values of this variable, however, it became negative at higher values (above 20%). For *T. scalaris:* (Fig. 1D) distance to *Abies* forest (44.9% contribution), maximum temperature of the warmest month (36%) and arid vegetation (4.9%). These variables, together, explained 85.8 % of the species potential distribution. Arid vegetation and distance to *Abies* forests had negative effects on this species, therefore, proximity to *Abies* forests was positive for the species. Habitat suitability steadily decreased when maximum temperatures increased. For *T. scaliger*: (Fig. 1E): distance to *Abies* forest (40.6% contribution), minimum temperature of the coldest month (26.5%) and arid vegetation (5.3%). These variables, together, explained 72.4 % of the species potential distribution. Arid vegetation and distance to *Abies* forests had a negative effect on this species. Habitat suitability dropped to 0 with minimum temperatures lower than -3°C. It is important to notice that arid zones had a percentage of importance in all the models and minimum temperature of the coldest month resulted important in four of the five models (Table 1).

Between 2002 and 2011, we can observe an increase of almost 16000 km^2 in agriculture extension and an increase of about 5000 km^2 in urban areas. There is also a smaller increase in induced grasslands. We can observe an important reduction in arid vegetation and natural grasslands mainly because of its conversion to agriculture lands. There is also a reduction in *Pinus* and *Quercus* forests, meanwhile *Abies* forest seems to keep its extension (Fig. 2). For the year 2050, an increase of 20,391.64 km^2 in urban areas is expected according to the model, the main increase will take place in the surroundings of Toluca city. Agriculture will increase 82,865 km^2 and induced grasslands will increase 24,796.05 km^2 (Fig. 3). We generated present and future potential distribution maps for each species, modeled using only the most important variables (Fig. 4). We preferred to show the continuous maps because binary outputs can obscure important biological detail (Liu, White & Newell, 2013). Partial-ROC bootstrap tests showed significant ratio values of empirical AUC over null expectations (*T. cyrtopsis* =1.49695, P <0.001; *T. Eques*

= 1.682837, P <0.001; *T. Melanogaster* = 1.758803, P <0.001; *T. scalaris* = 1.846627, P <0.001; *T. scaliger* = 1.875488, P <0.001) Fig. S1.

According to high suitability area calculations for the present and the future, all *Thamnophis* species will experience reductions in their distribution in the TMVB and in the whole country. Only *T. melanogaster* will increase its distribution in the future. *T. scalaris* is the species that will suffer the biggest reduction in its distribution (reductions of 54.08% for the TMVB and 54.30% for the whole country, Table 2; Fig. 4). We can observe a reduction in niche overlap between species in the future in all cases (Table 3; Fig. 5).

Discussion

Environmental niche

Although our records and literature support that grasslands and water sources are essential for *Thamnophis* species in México (Jones, 1990; Manjarrez and Drummond, 1996; Venegas-Barrera and Manjarrez, 2011), these variables were not selected by the model as important to explain the distribution of the species. This can be explained because both variables are more related with the microhabitat of the species and we are modelling the macrohabitat; although most of the records are in grasslands or near water sources, we can find water sources (seasonal or permanent) and grasslands through most of the country, also where the species is not present, therefore, these variables are not limiting the species at a macro level. Anyway, percentage of arid vegetation (which can be interpreted as the opposite of water sources) was a negative limiting factor for all the species (Table 1). Distances to forests were more important to explain the presence of *Thamnophis* species than the percentage of these forests. This is especially important for *T. scalaris* and *T. scaliger* as distance to *Abies* forest is one of the most important variables determining their probability of presence. These results are consistent with our fieldwork observations, as we found only a few individuals inside forests, the majority were found in grasslands near coniferous forests. This may be because coniferous forests favor moisture (annual precipitation between 1000 and 3800 mm) and a cold microclimate (2-24°C; Sáenz-Romero et al., 2012; Sunny, González-Fernández & D'Addario, 2017) preferred by *Thamnophis* species (Manjarrez & Drummond, 1996). Therefore, microclimatic conditions of grasslands surrounded by forests and large extents of grasslands without forest may be different and grasslands surrounded by forests will offer the climatic benefits of forests and the food benefits of grasslands due to the small preys that live there (Bastos, Araújo & Silva, 2005; Mociño–Deloya et al., 2009; Reinert et al., 2011; Wittenberg, 2012; Mociño-Deloya, Setser & Pérez-Ramos, 2014).

Low agriculture percentages were positive for *T. eques* and *T. melanogaster*, but high percentages were negative for both species. This may be because agriculture is a tradeoff for many reptile species, especially snakes, because at the same time that provides benefits for them, like prey availability, also let them exposed to human interactions (i. e., people kill them for fear although *Thamnophis* species are not dangerous for humans; Sunny et al., 2015). Moreover, the stuck practice of crop burning and the use of roller-chopping may also affect their populations (Mullin & Seigel, 2009).

Maximum temperature of the warmest month was one of the most important variables explaining *T. scalaris* potential distribution, however, for all other species the minimum temperature of the coldest month was more important. This can be explained because *T. scalaris* is the species occurring at highest elevation and, consequently, is adapted to a colder climate. Therefore, while other species are more limited by lower temperatures, *T. scalaris* is more limited by higher temperatures, which will make this species more vulnerable to climate change. This scenario is consistent with the future distribution model for this species as *T. scalaris* suffers the biggest distribution range reduction. The fact that its distribution already includes the existing areas with the highest altitude implies that, as climate change takes hold, this species will be limited in its ability to shift its distribution upward, increasing the possibility of becoming extinct (Sunny, González-Fernández & D'Addario, 2017). According to the IUCN *T. Scalaris* is considered of Least Concern (Canseco-Márquez & Mendoza-Quijano, 2007), however, our results suggest that this risk category is probably going to change in the future. The reduction in niche overlap between species in the future means a reduction in the range of suitable combination of variables for the species.

Present and future potential distribution

We are surprised by the fact that the distribution range of *T. melanogaster* resulted to increase in the future considering the whole country, as this species is the most threatened of the five ones, according to the IUCN (Endangered, Vasquez-Díaz & Quintero-Díaz, 2007). We have some possible explanations for that; temperature increases may have positive effects on *T. melanogaster* presence, however in the TMVB, where the conversion to agriculture is higher (CONAPO, 2010; Sunny, González-Fernández & D'Addario, 2017), this species will reduce its distribution. Another possible explanation, more feasible, can be that this species is more aquatic than the others (Manjarrez & Drummond, 1996) so, an approach considering both macrohabitat and microhabitat variables (like water sources quality) will be necessary for a better prediction of *T. melanogaster* distribution.

Conservation implications

The preservation of *Abies* forests in the TMVB is key for the conservation of many species (Figueroa-Rangel, Willis & Olvera-Vargas, 2010; Vargas-Rodriguez et al., 2010; Ponce-Reyes et al., 2012; Bryson et al., 2014), like *T. scalaris* and *T. scaliger*, as the TMVB has the highest amount of *Abies* forests (91.143%) of the country (Sunny, González-Fernández & D'Addario, 2017). However, *Abies* forest only represents the 1.1% of TMBV area (Sunny, González-Fernández & D'Addario, 2017). Unfortunately, governmental laws have recently changed the protection status of some areas of the TMVB, like the Nevado de Toluca Volcano (DOF, 2013). This change could lead to logging and to changes in land use (Mastretta–Yanes et al., 2014). *Abies* forest has keep a constant extension from 2002 to 2011 (Fig. 2) and we are afraid this may change as a consequence of this protection status variation, affecting *Thamnophis* populations and the populations of many other species of amphibians and reptiles of the TMVB. Also, *Thamnophis* species may face the potential effects of climate change. Environmental temperature is important to ectothermic species like garter snakes because they are more active when they can maintain a body temperature above approximately 22°C (Manjarrez & Drummond, 1996). Environmental temperatures increases may lead *Thamnophis* to a physiological stress that will result in a fitness reduction (Peterson, Gibson & Dorcas 1993), this will be especially important for *T. scalaris* as this species cannot shift its distribution upward as we mentioned before. Moreover, land-use changes are expected to accelerate due to climate change (Maclean & Wilson, 2011; Urban, 2015; Nadeau, Urban & Bridle, 2017) so garter snakes could suffer the synergic effect of both factors.

Conclusions

Percentage of arid vegetation was a negative important variable in all species and minimum temperature of the coldest month was selected as an important variable in four of the five species. Distance to *Abies* forest was very important to explain *T. scalaris* and *T. scaliger* distribution (with a contribution over 40% for both species). All *Thamnophis* species will experience reductions in their distributions in the TMVB, as we predicted, however, for the whole country, *T. melanogaster* seems to increase its distribution in the future. We consider that more studies should be done to evaluate *T. melanogaster* distribution and abundances. These studies should consider microhabitat variables like water quality. We also consider essential to carry out studies about *T. scalaris* abundance, as this species will suffer the biggest reduction in its distribution according to our results. Therefore, current abundance data of this species will be key to decide if a change in its conservation status is needed. Climate change reversion involve government decisions and the predominant economical system in the world, so we can say little about this here. However, we consider *Abies* forests of great importance for *T. scalaris* and *T. scaliger* conservation. Moreover, in the short term, we think it is essential to implement environmental education activities, in order to avoid snake killing, the use of the roller chopping and crop burning practices.

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Figure 1

Graphics of the most important variables for each *Thamnophis* species: (A) *T. cyrtopsis*, (B) *T. eques*, (C) *T. melanogaster*, (D) *T. scalaris* and (E) *T. scaliger*.

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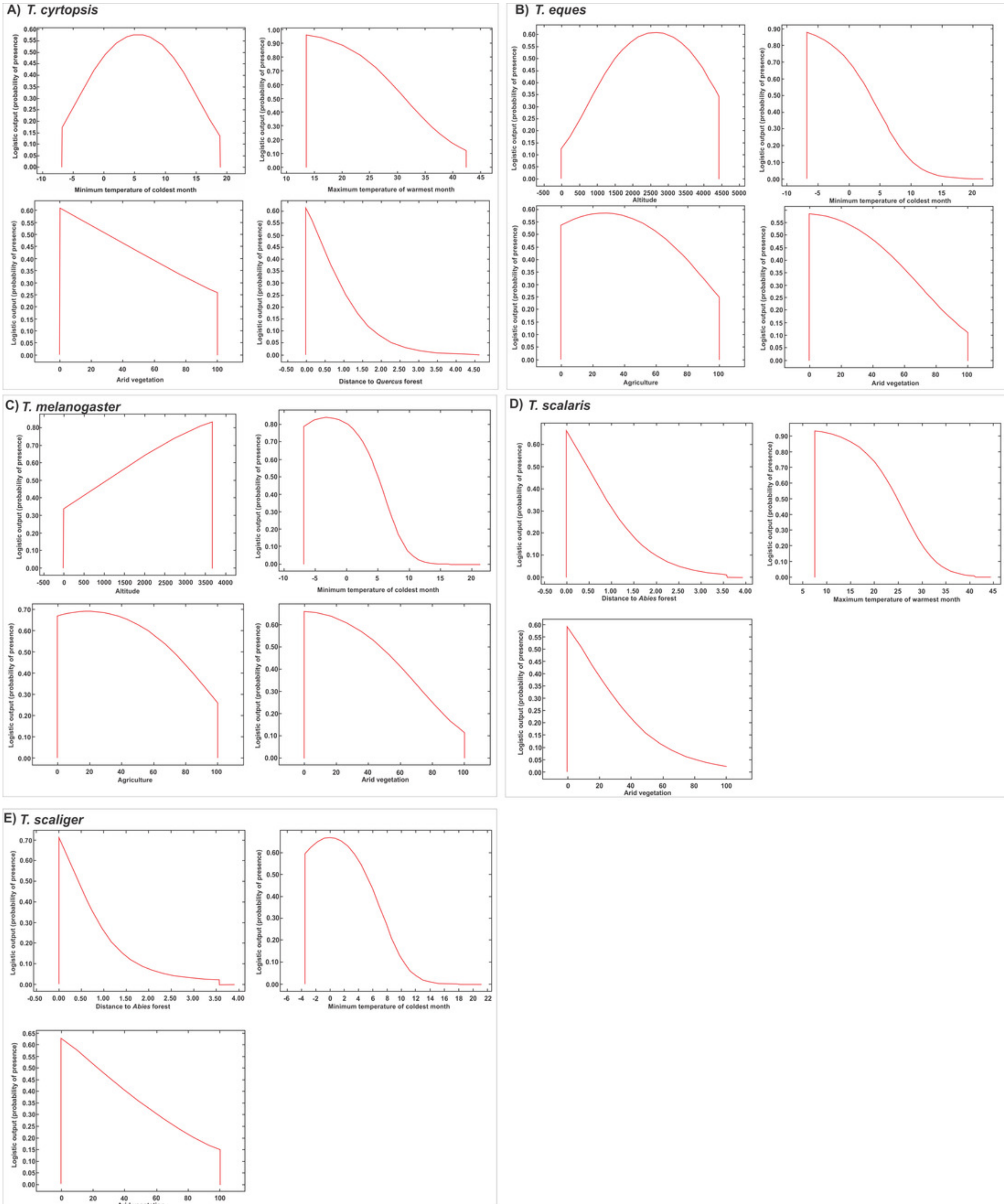
A) T. cyrtopsis
Logistic output (probability of presence)
Minimum temperature of coldest month
Maximum temperature of warmest month
Arid vegetation
Distance to Quercus forest
B) T. eques
Altitude
Minimum temperature of coldest month
Agriculture
Arid vegetation
C) T. melanogaster
Altitude
Minimum temperature of coldest month
Agriculture
Arid vegetation
D) T. scalaris
Distance to Abies forest
Maximum temperature of warmest month
Arid vegetation
E) T. scaliger
Distance to Abies forest
Minimum temperature of coldest month
Arid vegetation

Figure 2

Land use change by category (in Km^2) between years 2002 and 2011.

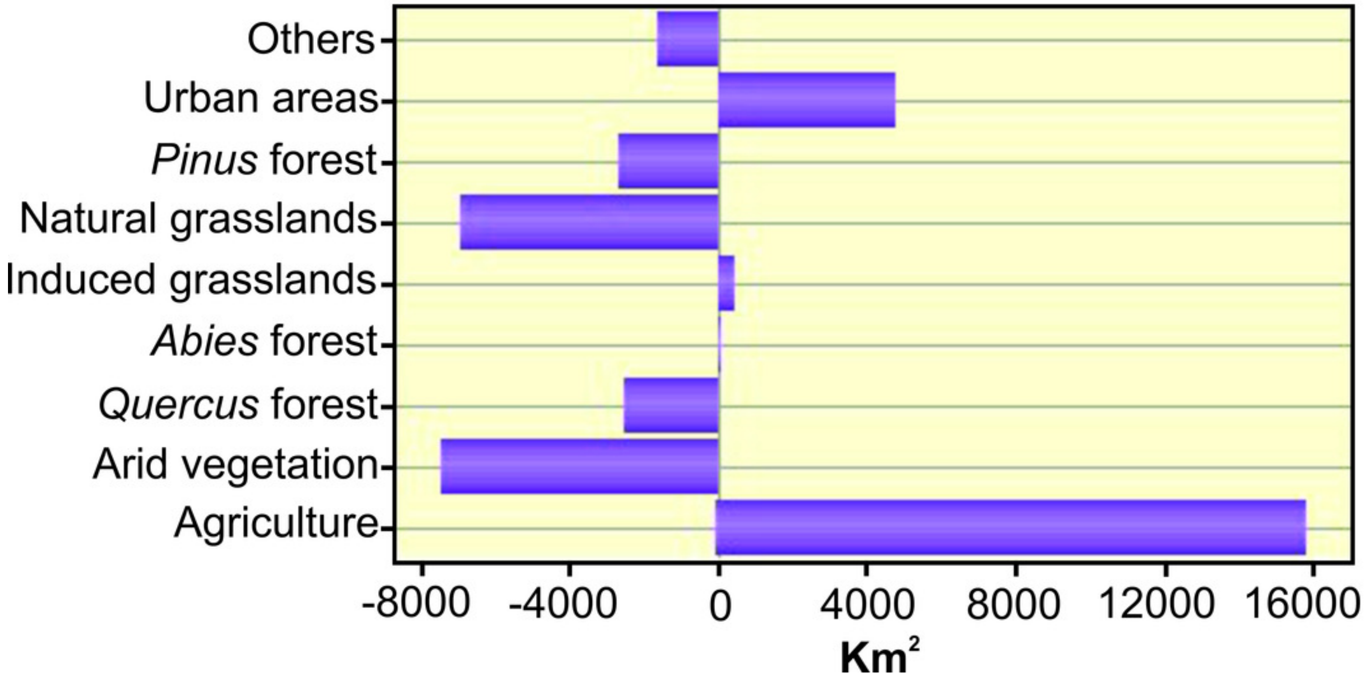

Figure 3

Present (2011) and future (2050) maps of agriculture, induced grasslands and urban areas.

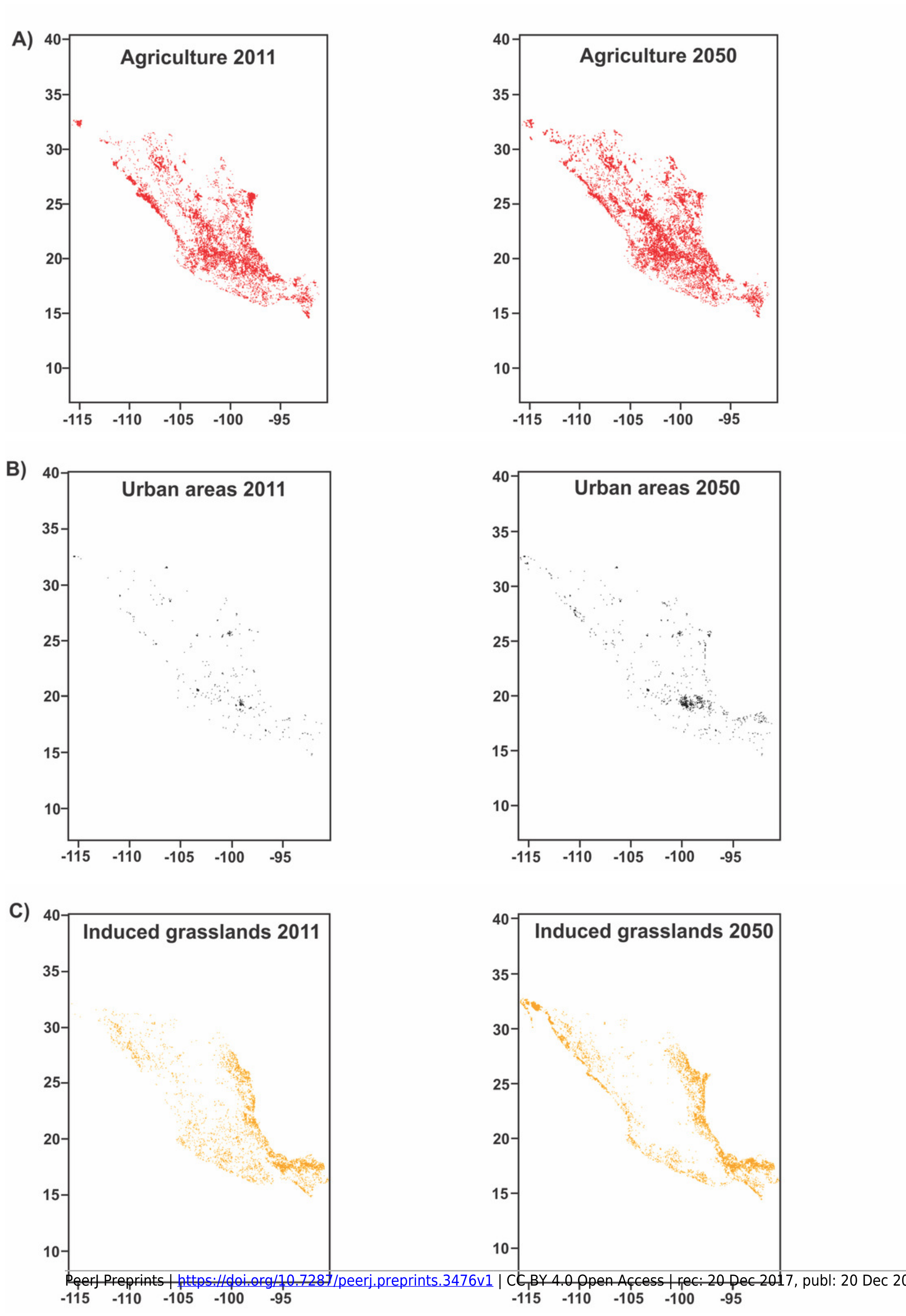
A)
Agriculture 2011
Agriculture 2050
B)
Urban areas 2011
Urban areas 2050
C)
Induced grasslands 2011
Induced grasslands 2050
40
35
30
25
20
15
10
-115
-110
-105
-100
-95

Figure 4

Present (2011) and future (2050) potential distribution maps for each *Thamnophis* species: (A) *T. cyrtopsis*, (B) *T. eques*, (C) *T. melanogaster*, (D) *T. scalaris* and (E) *T. scaliger*.

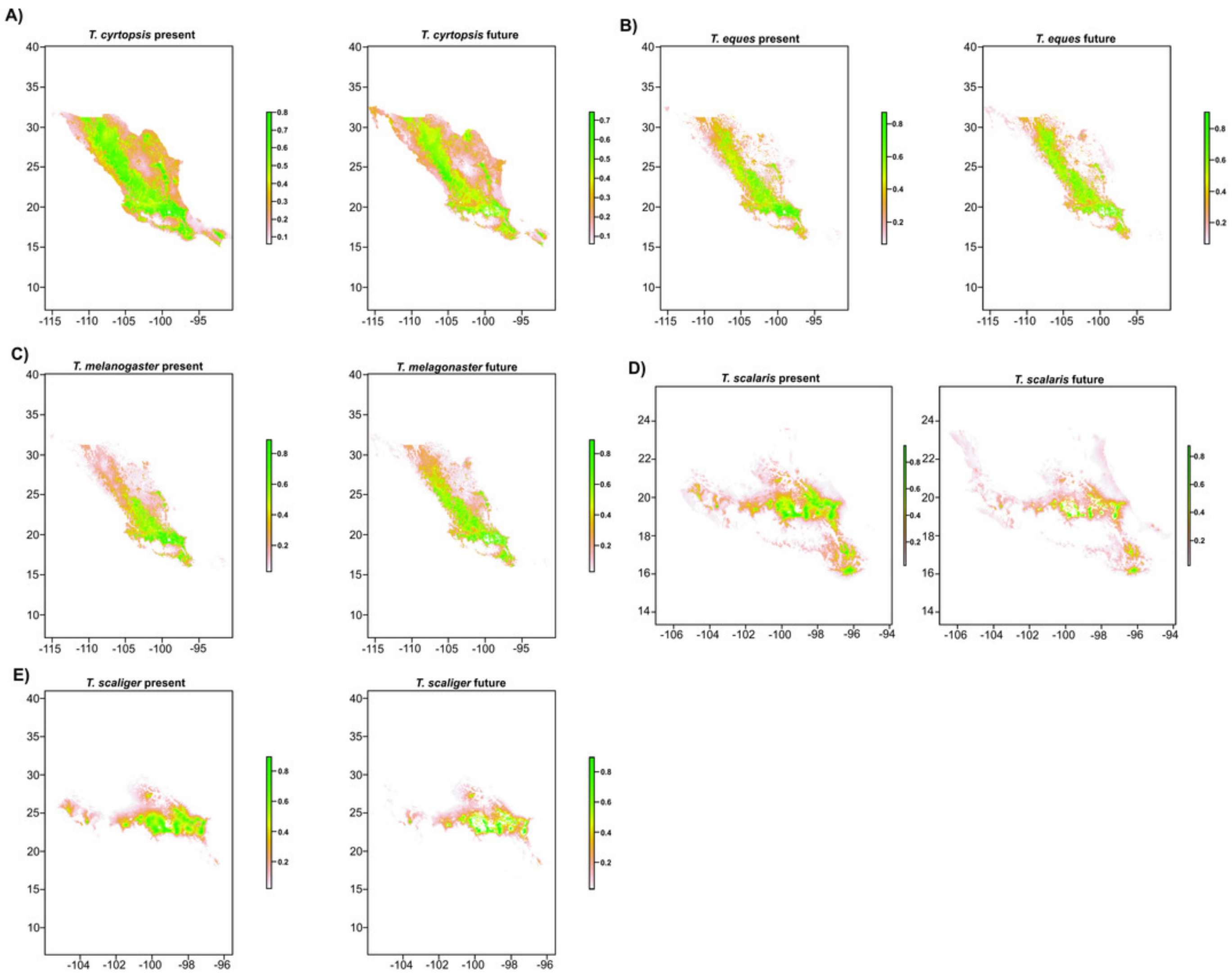

Figure 5

Present (2011) and future (2050) environmental niches for each species.

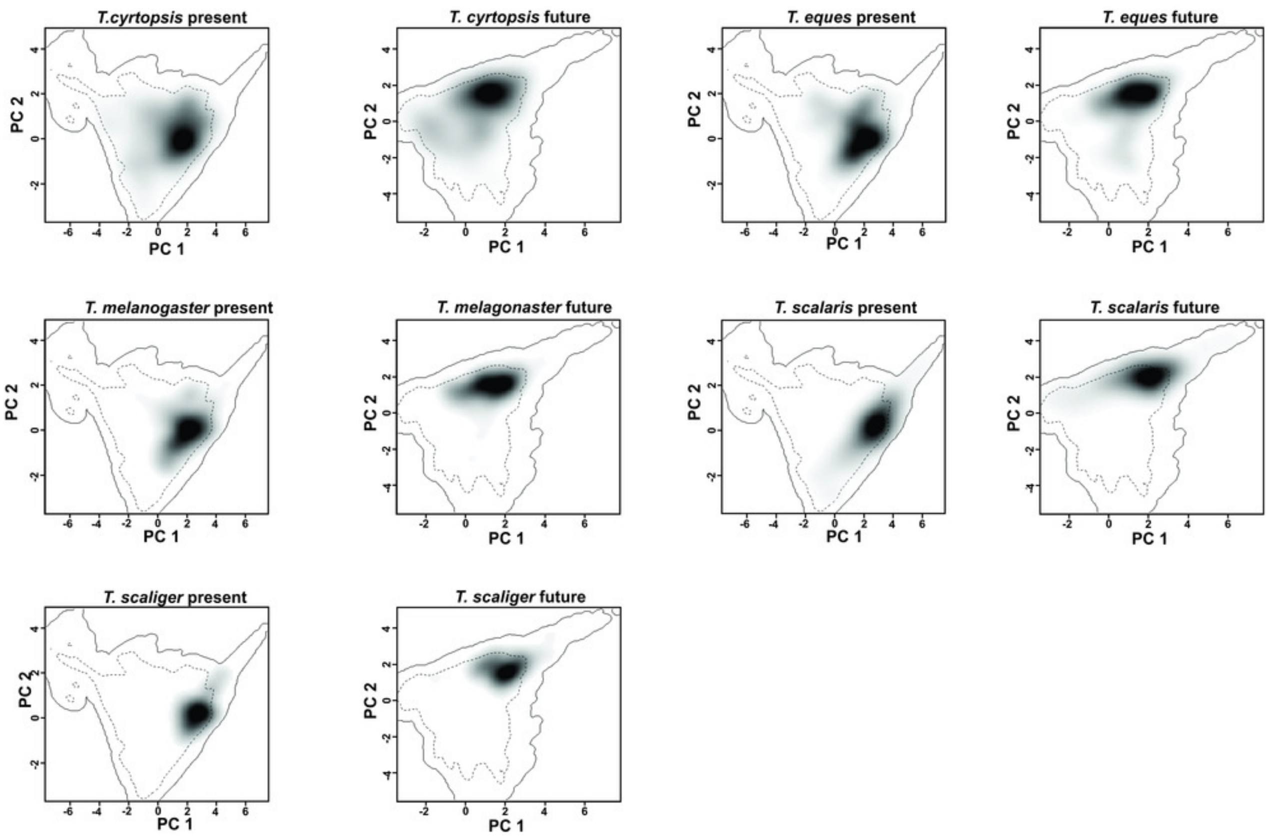

Table 1(on next page)

Percentages of the most important variables that explain the distribution of each *Thamnophis* species.

Variables	*T. cyrtopsis*	*T. eques*	*T. melanogaster*	*T. scalaris*	*T. scaliger*
Minimum temperature of the coldest month	33.7	19.2	11.3	-	26.5
Maximum temperature of the warmest month	5.2	-	-	36	
Elevation		28.4	27.3	-	-
Arid vegetation	26.4	15.6	11.5	4.9	5.3
Agriculture		9.6	12.9	-	-
Distance to *Quercus* forest	8.5	-	-	-	-
Distance to *Abies* forest				44.9	40.6
Total	73.8	72.8	63	85.8	72.4

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Table 2(on next page)

Present and future high suitability area (in Km^2) and percentage of reductions in these areas for each *Thamnophis* species in Mexico and the TMVB.

	MEXICO			TMVB		
	Present distribution (Km^2)	**Future distribution (Km^2)**	**Reduction (%)**	**Present distribution (Km^2)**	**Future distribution (Km^2)**	**Reduction (%)**
T. cyrtopsis	661888.53	387393.67	41.47	103190.15	56172.18	45.56
T. eques	583936.04	554336.36	5.07	102001.64	88928.44	12.82
T. melanogaster	255647.78	317411.39	-24.16	83237.55	67581.46	18.81
T. scalaris	110441.63	50474.08	54.30	54057.65	24825.27	54.08
T. scaliger	58682.16	37278.67	36.47	42804.76	26617.94	37.82

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Table 3(on next page)

Pair-wise niche overlap indices Schoener´s D and Hellinger´s I. Above the diagonal the present niche overlap, below the diagonal the future niche overlap.

Schoener´s D	***T. cyrtopsis***	***T. eques***	***T. melanogaster***	***T. scalaris***	***T. scaliger***
T. cyrtopsis	-	0.601	0.512	0.375	0.429
T. eques	0.073	-	0.855	0.410	0.757
T. melanogaster	0.033	0.580	-	0.341	0.803
T. scalaris	0.446	0.064	0.029	-	0.361
T. scaliger	0.0438	0.500	0.403	0.063	-

Hellinger´s I	***T. cyrtopsis***	***T. eques***	***T. melanogaster***	***T. scalaris***	***T. scaliger***
T. cyrtopsis	-	0.747	0.651	0.544	0.547
T. eques	0.264	-	0.924	0.630	0.869
T. melanogaster	0.174	0.748	-	0.581	0.867
T. scalaris	0.538	0.235	0.161	-	0.596
T. scaliger	0.161	0.593	0.581	0.241	-

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