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Potential distribution of medium-sized felines in Morelos: climate suitability and coverage in protected natural areas

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The presence of the six species of felids distributed throughout Mexico has been documented in the state of Morelos. These species face serious threats from habitat loss and fragmentation driven by human activities. Some, particularly medium-sized felines, such as margay, jaguarundi, ocelot, and bobcat, remain poorly studied. Our objective was to identify their potential distribution areas within Morelos, assess the impact of human activities on these areas, and evaluate the role of Protected Natural Areas (PNAs) in conserving their potential habitats. We used the Maximum Entropy algorithm to model the ecological niches of the four species and generate potential distribution maps using bioclimatic variables from WorldClim. We estimated the potential distribution areas for each species and identified zones suitable for the coexistence of all four felines. These models were superimposed on digital maps of human settlements, agricultural fields, and bare soil to quantify anthropogenic impacts and to assess the effectiveness of PNAs in protecting these habitats. Our results indicate that human activities reduce the potential distribution areas of the four species by an average 42%, and only 880.56 km^2 (18%) of the area with primary or secondary vegetation is protected by any PNAs. Although we identified areas with high climate suitability for these species, no research has yet confirmed their presence. We therefore propose targeted monitoring of these areas to gather critical data that can inform conservation strategies for medium-sized felines and their habitats in Morelos.

Keywords: Agriculture, ecological niche model, *Herpailurus yagouaroundi, Leopardus pardalis*, *Leopardus wiedii*, *Lynx rufus*, urbanization.

En el estado de Morelos se ha reportado la presencia de las seis especies de félidos que se distribuyen en México, estas se encuentran gravemente amenazadas por la pérdida y fragmentación de su hábitat provocadas por las actividades humanas. Algunas de estas especies han sido poco estudiadas, particularmente los felinos medianos (tigrillo, jaguarundi, ocelote y gato montés), por lo que nuestro objetivo fue identificar las áreas de distribución potencial dentro de Morelos, evaluar los efectos que tienen los impactos antropogénicos sobre las áreas estimadas y analizar la importancia de las ANP estatales en la protección de las áreas potenciales de distribución de estas especies. Se utilizó el algoritmo de Máxima Entropía para modelar el nicho ecológico de las cuatro especies y poder obtener mapas de distribución potencial considerando las variables bioclimáticas disponibles en WorldClim. Se estimaron las áreas de distribución potencial para cada especie y se identificaron áreas idóneas para la coexistencia de los cuatro felinos. Los modelos fueron superpuestos sobre mapas digitales de asentamientos humanos, áreas agrícolas, suelo desnudo, para cuantificar los efectos que tienen estas actividades sobre las áreas de distribución estimadas y analizar la importancia que tienen las ANP en la protección de estos felinos. Nuestros resultados indican que las actividades humanas reducen en promedio un 42% las áreas de distribución potencial de las cuatro especies y solo 880.56 km^2 (18%) del área con vegetación primaria o secundaria está protegida por algún ANP. Identificamos áreas de alta idoneidad climática para estas especies, sin embargo, no existen trabajos que comprueben su presencia, por lo que proponemos el monitoreo en las zonas con el fin de obtener información relevante que nos pueda ayudar a desarrollar estrategias de conservación para los felinos medianos y su hábitat en Morelos.

Palabras clave: Agricultura, *Herpailurus yagouaroundi, Leopardus pardalis*, *Leopardus wiedii, Lynx rufus*, modelado de nicho ecológico, urbanización.

Habitat loss and fragmentation are among the main factors threatening biodiversity (Crooks and Sanjayan 2006; Ryser *et al.* 2019). The first reduces the habitat area, potentially affecting species richness (Fahrig 2003; Galán-Acedo *et al.* 2023), while the second divides the habitat into increasingly smaller patches, exposing species to external threats. Additionally, the distance between patches complicates the displacement of individuals, influencing gene flow between populations (Fahrig 2003; Holderegger and Di Giulio 2010). The creation of Natural Protected Areas (PNAs) is an essential strategy to counteract the effects of habitat loss and fragmentation and preserve biodiversity (Gray *et al.* 2016). However, this strategy has been insufficient, as the effects of habitat fragmentation are still evident within the PNAs. On the other hand, the distance between PNAs contributes to the isolation of animal populations, mainly due to habitat transformation outside them (Santiago-Ramos and Feria-Toribio 2021; Yuan *et al.* 2024).

Felids are particularly vulnerable to habitat loss and fragmentation (Crooks *et al.* 2011; Zanin *et al.* 2015; Butti *et al.* 2022). Six felids are distributed in Mexico (Ceballos and Oliva 2005): *Leopardus wiedii* (margay), *Herpailurus yagouaroundi* (jaguarundi), *Leopardus pardalis* (ocelot), *Lynx rufus* (bobcat or red lynx), *Puma concolor* (puma), and *Panthera onca* (jaguar). There has been a considerable reduction in the distribution areas of these felids in recent years, mainly due to the loss and fragmentation of their habitat as a result of anthropogenic activities such as the expansion of crop fields and urban areas, which compromises survival and puts felid populations at risk (Carrillo-Reyes and Rioja- Paradela 2014; Dirzo *et al.* 2014; SEMARNAT 2018; Solari *et al.* 2018). Furthermore, these species are hunted or captured for trade or due to the growing conflicts between wildlife and humans, as wild felids are considered a threat to domestic animals or humans (Inskip and Zimmermann 2009; CITES 2010; Solari *et al.* 2018). Therefore, at the national and international levels, wild felids have been listed in some risk category — Endangered, Threatened, or Near Threatened — although some species, such as the bobcat and the puma, are not yet listed in a risk category (IUCN 2010; SEMARNAT 2010).

Felid conservation is essential for the integrity of ecosystems, as they regulate the population sizes of other species, influencing the dynamics and structure of natural communities, which is why they are considered indicators of habitat quality (Miller *et al.* 2001; Nagy-Reis *et al.* 2017; Tossens *et al.* 2024). In addition, these mammals require extensive areas with little human intervention for their survival, so the area allocated for felid conservation can potentially serve for the protection of other species and in territorial planning through the establishment of protected areas and to support conservation-related decision-making (Ceballos *et al.* 2002; Nuñez *et al.* 2002; Carrillo-Reyes and Rioja- Paradela 2014; Ashrafzadeh *et al.* 2020; Vega and Farías 2021)

The state of Morelos is home to the six felid species present in Mexico (Guerrero *et al.* 2020; Valenzuela *et al.* 2020). Four of these species are medium-sized felines that weigh between 101 g and 10 kg (Ceballos and Oliva 2005; Cervantes and Riveros Lara 2012). Information on the distribution of medium-sized felines in Morelos is limited to presence records in some localities and PNAs (Vargas *et al.* 1992; Valenzuela *et al.* 2013; Aranda *et al.* 2014; Aranda and Valenzuela 2015; Valenzuela *et al.* 2015; Vera-García *et al.* 2023). Although the potential distribution of these felines in Mexico has been modeled (Monroy-Vilchis *et al.* 2019), the models were developed at the biogeographic province level. This implies that areas with a suitable climate in Morelos have not been specifically identified, which is crucial for the conservation of these felines in the state. Therefore, it is necessary to identify potential areas where medium-sized felines can live in the state of Morelos, to support the development of conservation strategies that help prevent and mitigate the risks threatening their populations and habitats.

Our objectives were the following: a) identify the potential distribution areas for medium-sized felines in the state of Morelos using ecological niche models; b) analyze the extent to which the Natural Protected Areas in Morelos protect the potential distribution areas; and c) identify unprotected areas that could facilitate the connectivity of the populations of these species.

Materials and methods

Study area. The state of Morelos is located in central Mexico, between coordinates 18°20′, 19°07′ N and 98°37′, 99°30′ W. It covers an area of 4893 km^2, representing 0.25% of Mexico's territory (INEGI 2021a). Morelos includes five types of climates, ranging from cold subhumid to warm subhumid. The mean annual temperature is 21.5 °C and the mean annual precipitation is 900 mm, with summer rainfall (INEGI 2021a). The state is divided into three ecological regions: a) the northern mountainous region, represented by primary temperate forests, b) the intermontane valley dominated by crops and some disturbed patches of low deciduous forest, and c) the southern mountainous region, characterized by the largest extension of low deciduous forest in the state (Monroy and Colín 1991).

Fourteen PNAs have been established in Morelos (Figure 1) — five federal, seven state, and two municipal — which together comprise an area of 1196.9 km^2 (Table 1). These PNAs seek to protect and conserve biological diversity and natural resources in the state. Some have patches of habitat for different mammals, while others are corridors that maintain structural connectivity for populations of several species (González-Flores and Contreras-MacBeath 2020).

Ecological niche model. Ecological niche models (ENM) were used to identify potential distribution areas of the four medium-sized felines in Morelos. These models are tools for exploring the relationship between presence records and the associated environmental variables to construct potential or actual species distribution models (SDMs) (Guisan and Zimmermann 2000; Phillips *et al.* 2006; Peterson and Soberón 2012). The ENMs and SDMs for each species were generated using the MaxEnt algorithm version 3.4.4 (Philips *et al.* 2006). This is one of the most widely used algorithms for modelling ecological niches due to its high predictive power. In addition, the results allow predicting the availability of suitable areas for each species, generating a geographical representation of this information (Elith *et al.* 2006; Phillips *et al.* 2006; Kumar and Stohlgren 2009; Merow *et al.* 2013).

Species records were obtained from the scientific literature published between 2005 and 2020. A database was constructed from the geographic coordinates of occurrence records of the four medium-sized felines at the national and state levels, supplemented with records from the online database of the Global Biodiversity Information Facility (GBIF). Records of subspecies distributed in Mexico that could be present in Morelos were downloaded. Duplicate records, those without geographic coordinates, and those outside of Mexico were excluded. In total, 568 records of margay, 252 of jaguarundi, 1029 of ocelot, and 1819 of bobcat were obtained countrywide.

An ENM was generated for each feline species using its presence records in Mexico and coverage information on 19 climatic variables obtained from WorldClim that have been previously used for feline ENMs (Martínez-Calderas *et al.* 2015, 2016; Pérez-Irineo *et al.* 2019; Morales-Delgado *et al.*

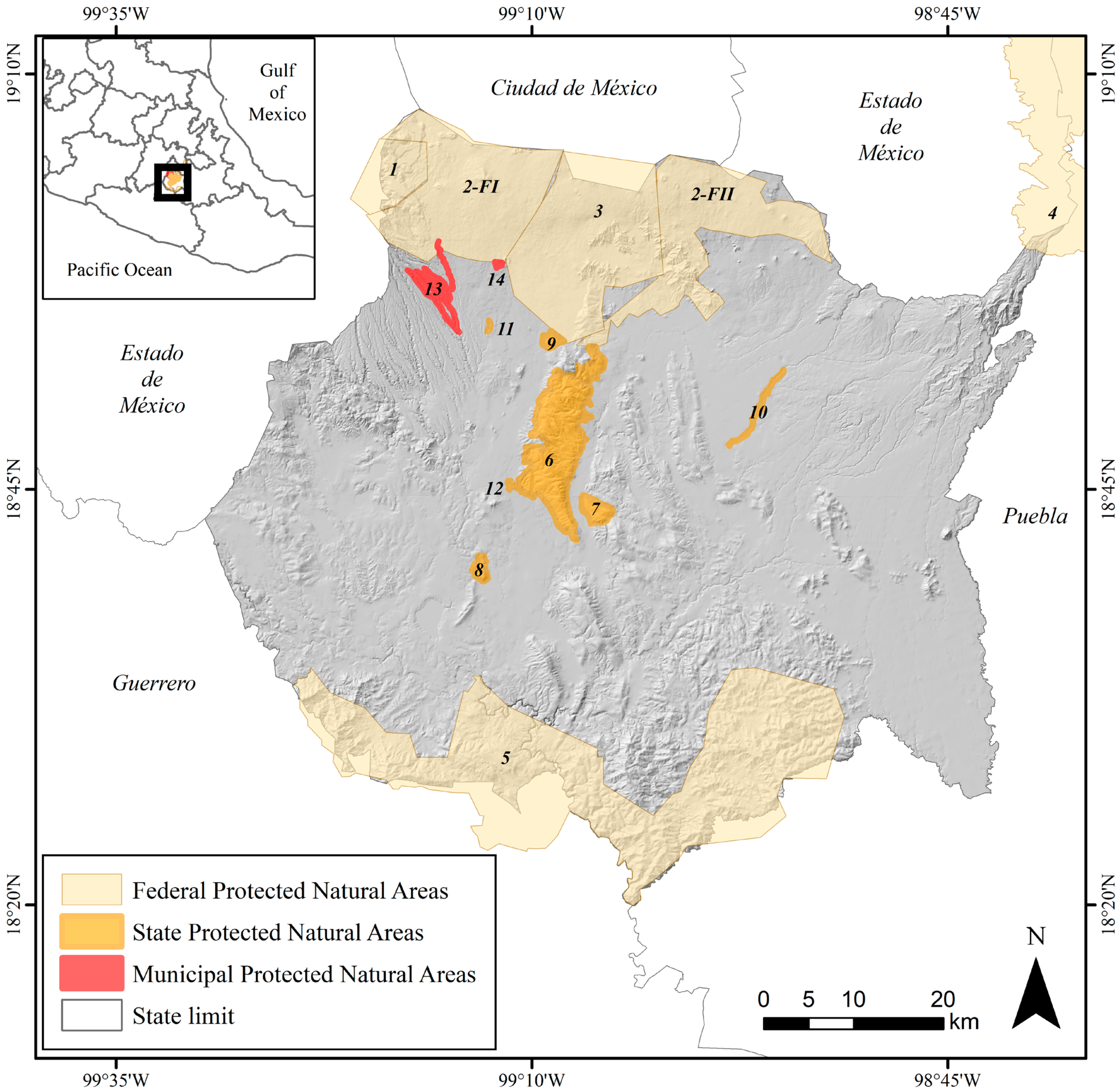

Figure 1. Map of the state of Morelos and its PNAs (acronyms after the name in Spanish). 1. Lagunas de Zempoala National Park (PNLZ), 2. Chichinautzin Biological Corridor Flora and Fauna Protection Area (APFFCBC), 3. El Tepozteco National Park (PNET), 4. Iztaccíhuatl-Popocatepetl National Park (PNIP), 5. Sierra de Huautla Biosphere Reserve (REBIOSH), 6. Sierra de Monte Negro State Reserve (RESMN), 7. Las Estacas State Reserve (RELE), 8. Cerro de la Tortuga State Park (PECT), 9. El Texcal State Park (PEET), 10. Los Sabinos, Santa Rosa, San Cristóbal Ecological Conservation Zone (ZSCESSS), 11. Barranca de Chapultepec Urban State Park (PEUBC), 12. Cueva El Salitre Wildlife Refuge (RVSCS), 13. Barrancas Urbanas de Cuernavaca Protected Natural Zone (ZNPBUC), 14. Bosque Mirador Protected Natural Area (ANPBM).

2021). Climate data were limited to the period 1970–2000 and had a spatial resolution of 1 km. The accessible area (*M*-area) was delimited (Soberón *et al.* 2017) by selecting the global terrestrial ecoregions reported by Olson *et al.* (2001) that coincided with the location of records for each species and with the country area. The resulting areas were used to delimit the set of bioclimatic layers for each species.

Based on records obtained via spatial filtering, the values of the 19 bioclimatic layers were extracted for each species, and a correlation test was performed to remove redundant information (Zurell *et al.* 2020; Passos *et al.* 2024). Layers with a Pearson correlation coefficient greater than 85% were considered correlated variables (Dorman *et al.* 2013; Passos *et al.* 2024). Based on these results, we selected the layers with simpler interpretations and a direct effect on the biology of the four species.

Initially, all records for each species were included in the niche models, with the climate variables selected after the correlation analysis. To avoid overrepresentation of records without affecting model fitness, spatial filtering was

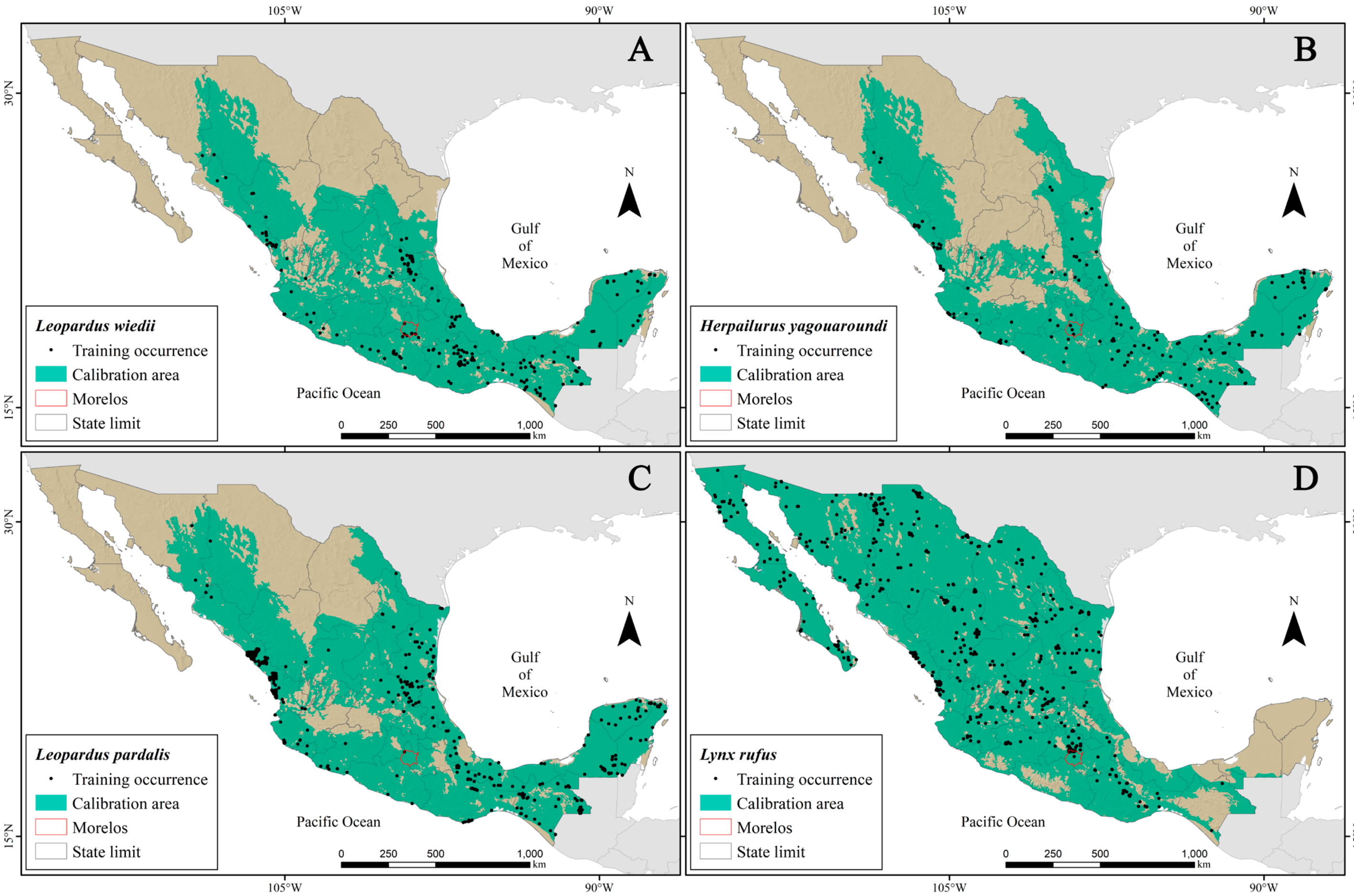

Figure 2. Maps of calibration areas and records of each medium-sized feline species in Mexico.

performed at different distances from presence records. The 1 km distance produced the best response. The 1km spatial filtering produced 302 records for margay, 240 for jaguarundi, 643 for ocelot, and 804 for the bobcat (Figure 2). Of the total records obtained, 70% were randomly selected to calibrate the ENM and 30% to validate the SDM using the partial ROC method available in the *ntbox* package in R (Osorio-Olvera *et al.* 2020).

Since using a large number of bioclimatic layers in models can lead to prediction errors (Peterson and Nakazawa 2008), these were reduced based on three reliable criteria in the MaxEnt output: 1) Jackknife plots, which evaluate the relative importance of environmental variables. For all species, the variables maintained in the models were those with the highest contribution and those that most affected the model (Phillips 2010; Merrow *et al.* 2013; Golden *et al.* 2022). 2) The table of the percentage contribution and importance of the permutation of the variables to each model (Phillips 2010). 3) The final model was the one with the lowest number of climatic variables with an AUC value greater than 0.70.

Species distribution model. The SDM models were created from ENMs and validated with the partial ROC method available in the *ntbox* package in R (Osorio-Olvera *et al.* 2020). The bootstrap technique was used, selecting 50% of the validation records for each of the 500 iterations performed.

The potential distribution of the four felines in the state of Morelos was spatially represented using binary models. The presence-absence cut-off threshold was set at the 10th percentile of the training presence method because there were no data on actual absence (Brito *et al.* 2009) and because it is a good threshold that accurately recovers the distribution of mammals (Escalante *et al.* 2013). This threshold was also selected based on the model with the smallest predicted area, with the lowest omission and commission rates.

Considering that 11 records were obtained for margay, 4 for jaguarundi, 2 for ocelot, and 27 for bobcat in Morelos, the cut-off threshold by species was set to include most of these records; only one record for ocelot was not predicted. After defining the cut-off threshold, binary climate suitability (CS) maps were generated in the calibration area. Subsequently, the CS areas for each species in Morelos were delimited, and a consensus was derived by superimposing these areas to identify the potential distribution range of the four species in the state of Morelos.

Contrast with human activities and Natural Protected Areas. Exclusion zones for the distribution of the four felines were delimited on the generated binary DMs, assigning a suitability value of 0 (zero) to areas that do not correspond to primary vegetation, secondary tree vegetation, and secondary shrub vegetation. According to the land use and vegetation layer series VII (INEGI 2021b),

Table 1. Protected Natural Areas in the state of Morelos. The names of the PNAs are presented along with their category. The numbering corresponds to that in Figure 1. The acronyms used in the text are indicated in parentheses.

Protected Natural Area	Jurisdiction*	Area in Morelos (km²) *	Vegetation types*	Primary vegetation (km²) **	Secondary tree vegetation (km²) **	Secondary shrub vegetation (km²) **	Medium-sized felines reported in Morelos***
1. Lagunas de Zempoala National Park (PNLZ)	Federal	30.04	Aquatic, pine-fir forest, alpine grassland	28.67	0	0	Bobcat and ocelot
2. Chichinautzin Biological Corridor Flora and Fauna Protection Area (APFFCBC)	Federal	369.87	Pine, pine-oak, fir, and mountain cloud forest, oak forest, low deciduous forest, and crasicaule shrub	160.92	32.43	45.71	Bobcat and margay
3. El Tepozteco National Park (PNET)	Federal	209.54	Pine, pine-oak, fir, mountain cloud forest, and low deciduous forest	40.61	52.42	51.26	Bobcat
4. Iztaccíhuatl-Popocatépetl National Park (PNIP)	Federal	4.44	Pine-fir forest, alpine moorland and grasslands	3.89	0	0	No report
5. Sierra de Huautla Biosphere Reserve (RBSH)	Federal	488	Low deciduous forest	40.97	41.17	298.98	Bobcat and margay
6. Sierra de Monte Negro State Reserve (RESM)	Estatal	77.25	Low deciduous forest	0	41.68	30.46	Margay
7. Las Estacas State Reserve (RELE)	State	6.52	Low deciduous forest, riparian forest, and aquatic and underwater vegetation	0	0	5.52	No report
8. Cerro de la Tortuga State Park (PECT)	State	3.10	Low deciduous forest	0	0	2.93	No report
9. El Texcal State Park (PEET)	State	2.6	Low deciduous forest	0	2.42	0	No report
10. Los Sabinos Santa Rosa San Cristóbal Zone Subjected to Ecological Conservation (ZSCESSS)	State	1.52	Aquatic and riparian forest	0	0	0	No report
11. Barranca de Chapultepec Urban State Park (PEUBC)	State	0.13	Aquatic and riparian forest	0	0	0	No report
12. Cueva El Salitre Wildlife Refuge (RVSCS)	State	0.0003	Low deciduous forest	0	0	0	No report
13. Barrancas Urbanas de Cuernavaca Protected Natural Zone (ZNPBUC)	Municipal	3.7	Aquatic and riparian forest	0.84	0	0	No report
14. Bosque Mirador Protected Natural Area (ANPBM)	Municipal	0.22	Pine-oak forest	0	0	0.16	No report
Total surface area		**1196.93**		**275.90**	**170.12**	**435.03**	

*Data from González-Flores and Contreras-MacBeath 2020.
**Cover according to the land use and vegetation layer, series VII of INEGI (2021b).
***Records obtained from GBIF, Valenzuela et al. (2013), Aranda and Valenzuela (2015), and Vera-García et al. (2023).

the primary vegetation covers an area of 332.48 km²; the secondary tree vegetation, 318.12 km²; and the secondary shrub vegetation, 1184.62 km². In the resulting SDMs, we quantified the potential distribution areas for each species. The SDMs of each species were superimposed to estimate the areas of medium-sized feline richness in Morelos. Finally, the federal, state, and municipal PNAs were superimposed, and, according to the CS, the number of medium-sized feline species that each PNA could potentially host and the potential distribution area of each species protected by the PNAs were counted.

Results

The final ENMs were calibrated with 212 records for margay, 168 for jaguarundi, 403 for ocelot, and 563 for bobcat, using a combination of variables associated with the presence records for each species (Table 2). According to the contribution and permutation values and the Jackknife method, the minimum temperature of the coldest month is the most important variable for margay, jaguarundi, and ocelot, while the seasonality of precipitation is the key variable for bobcat. The second most important variable differed among species: annual temperature range for

Table 2. Importance of climatic variables and evaluation of models with the partial ROC method, according to the Jackknife output. An asterisk indicates that the variable produces a better model fit; two asterisks indicate that the absence of the variable reduces the model fit.

Species	Climatic variable	Percentage contribution	Percentage permutation	Mean AUC ratios (partial ROC)	*p*-value for the partial ROC analysis
Margay	Bio6 (minimum temperature of the coldest month) **	53.8	53.6	1.36	<0.00001
	Bio7 (annual temperature range) *	36.4	34.3		
	Bio15 (precipitation seasonality)	6.4	7.3		
	Bio10 (mean temperature of the warmest quarter)	3.4	4.7		
Jaguarundi	Bio6 (minimum temperature of the coldest month) */**	77.9	13.1	1.28	<0.00001
	Bio4 (temperature seasonality)	13.3	23.1		
	Bio10 (mean temperature of the warmest quarter)	5.5	33.4		
	Bio7 (annual temperature range)	3.3	30.4		
Ocelot	Bio6 (minimum temperature of the coldest month) *	74.2	20.2	1.25	<0.00001
	Bio1 (mean annual temperature) **	16.1	47.2		
	Bio7 (annual temperature range)	9.8	32.6		
Bobcat	Bio15 (precipitation seasonality) */**	36.8	25.8	1.12	<0.00001
	Bio10 (mean temperature of the warmest quarter)	26.8	33.8		
	Bio6 (minimum temperature of the coldest month)	14	6		
	Bio19 (precipitation of the coldest quarter)	12.3	14.5		
	Bio3 (isothermality)	10.1	20		

margay, temperature seasonality for jaguarundi, mean annual temperature for ocelot, and mean temperature of the warmest quarter for bobcat (Table 2).

Based on the MaxEnt response curves (Philips *et al.* 2006) and information on environmental variables associated with the records, we described the relationships between the climatic variables and the records of the four species. The minimum temperature of the coldest month was used for all four species, which showed a positive relationship between 0 °C and 22 °C for margay, jaguarundi, and ocelot, but a negative relationship between -6 °C and 20 °C for bobcat. The temperature of the warmest quarter was used in three species, revealing a positive relationship for jaguarundi (between 14 °C and 30 °C) and ocelot (between 12 °C and 30 °C), and a negative relationship for bobcat (between 8 °C and 33 °C). The annual temperature range was relevant for margay, jaguarundi, and ocelot, with a negative relationship between 10 °C and 34 °C. Precipitation seasonality was considered for the bobcat only, with a negative relationship and coefficients of variation ranging from 47 to 140.

The partial ROC evaluation of the SDMs indicates that the predicted potential distribution of the species is greater than expected by chance, with average values of AUC ratios of 1.36 ($p < 0.0001$) for the margay, 1.28 ($p < 0.0001$) for the jaguarundi, 1.25 ($p < 0.0001$) for the ocelot, and 1.22 ($p < 0.0001$) for the bobcat (Table 2). Binary SDMs predict an area with CS of 4327.28 km^2 for margay, 3564.6 km^2 for jaguarundi, 3280.2 km^2 for ocelot, and 2926 km^2 for bobcat. Of these areas, 20% correspond to water bodies, induced grasslands, induced palm forest, bare soil, and devoid of vegetation; 9%, to human settlements; and 33%, to agricultural areas. By reducing these binary model areas, the area with CS decreases to 38% (± 0.74) for each species (Table 3, Figure 3).

Of the total area considered potentially viable, 7% corresponds to primary vegetation, an additional 7% to secondary tree vegetation, and 24% to secondary shrub vegetation. In terms of extension, most of the potential distribution of neotropical felines (ocelot, jaguarundi, and ocelot) is concentrated in the central and southern regions of the state, although the models also consider regions to the north for the ocelot. For bobcat, a large part of its potential distribution is concentrated in the north and center of the state, largely coinciding with that of margay (Figure 3).

Considering the reduction of SDMs associated with the absence of primary or secondary vegetation, the area that

Table 3. Potential distribution area for the four medium-sized felines present in the State of Morelos. Estimates of the area with climate suitability (CS) that coincides with primary and secondary vegetation (tree and shrub) are shown, as well as the area within and outside protected natural areas.

Species	CS area (km^2)	CS area with vegetation cover (km^2)	CS area with vegetation cover within PNAs (km^2)	CS area with vegetation cover outside PNAs (km^2)
Margay	4327.28	1646.21	726.36	919.85
Jaguarundi	3564.56	1352.99	487.07	865.92
Ocelot	3280.16	1298.02	490.78	807.24
Bobcat	2926.04	1125.85	514.50	611.35

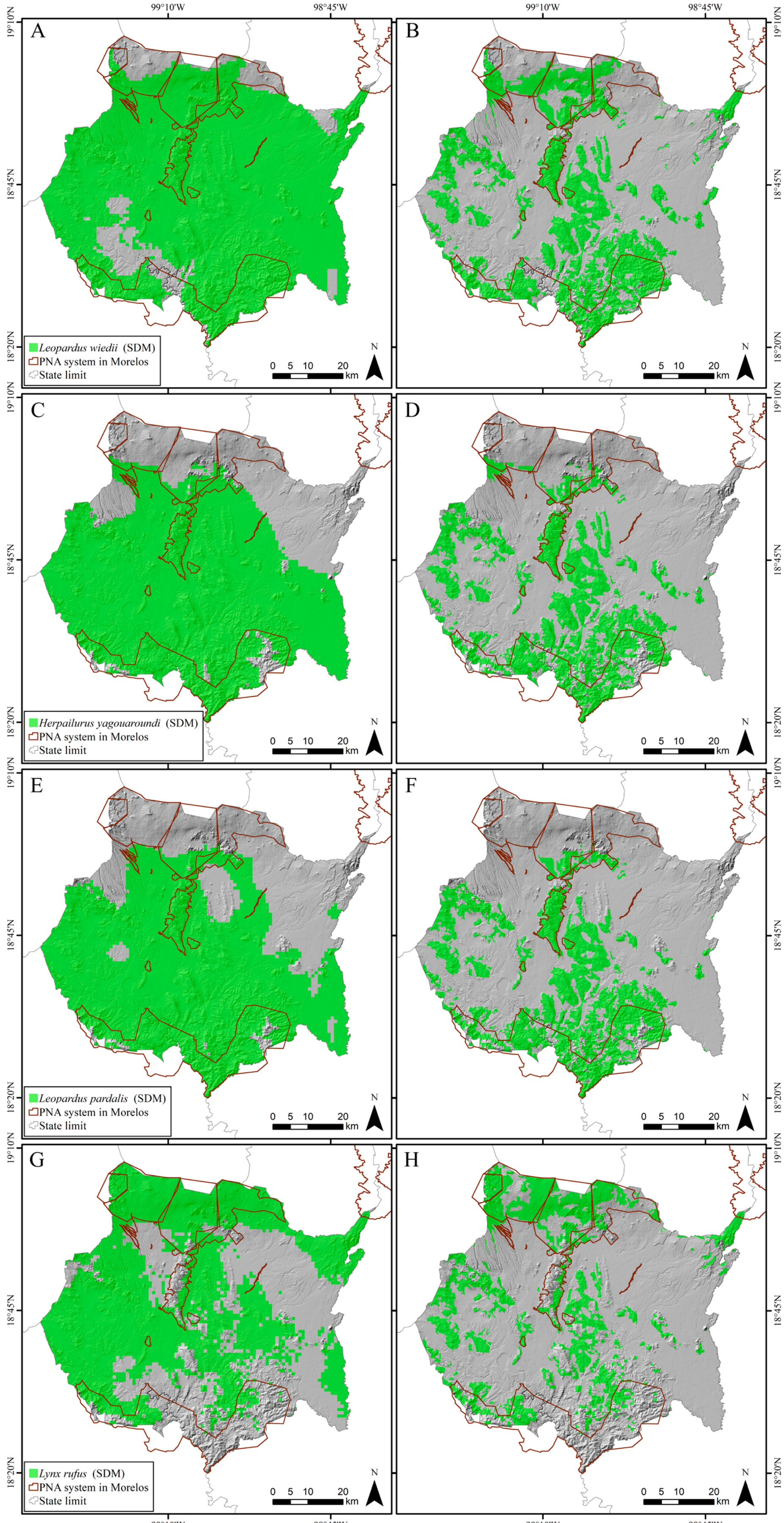

Figure 3. Potential distribution of the four medium-sized felines in the state of Morelos. Sections A, C, E, and G depict the models obtained from MaxEnt. Subparagraphs B, D, F, and H correspond to areas with climate suitability that coincide with primary vegetation, secondary tree vegetation, and secondary shrub vegetation (INEGI 2021b).

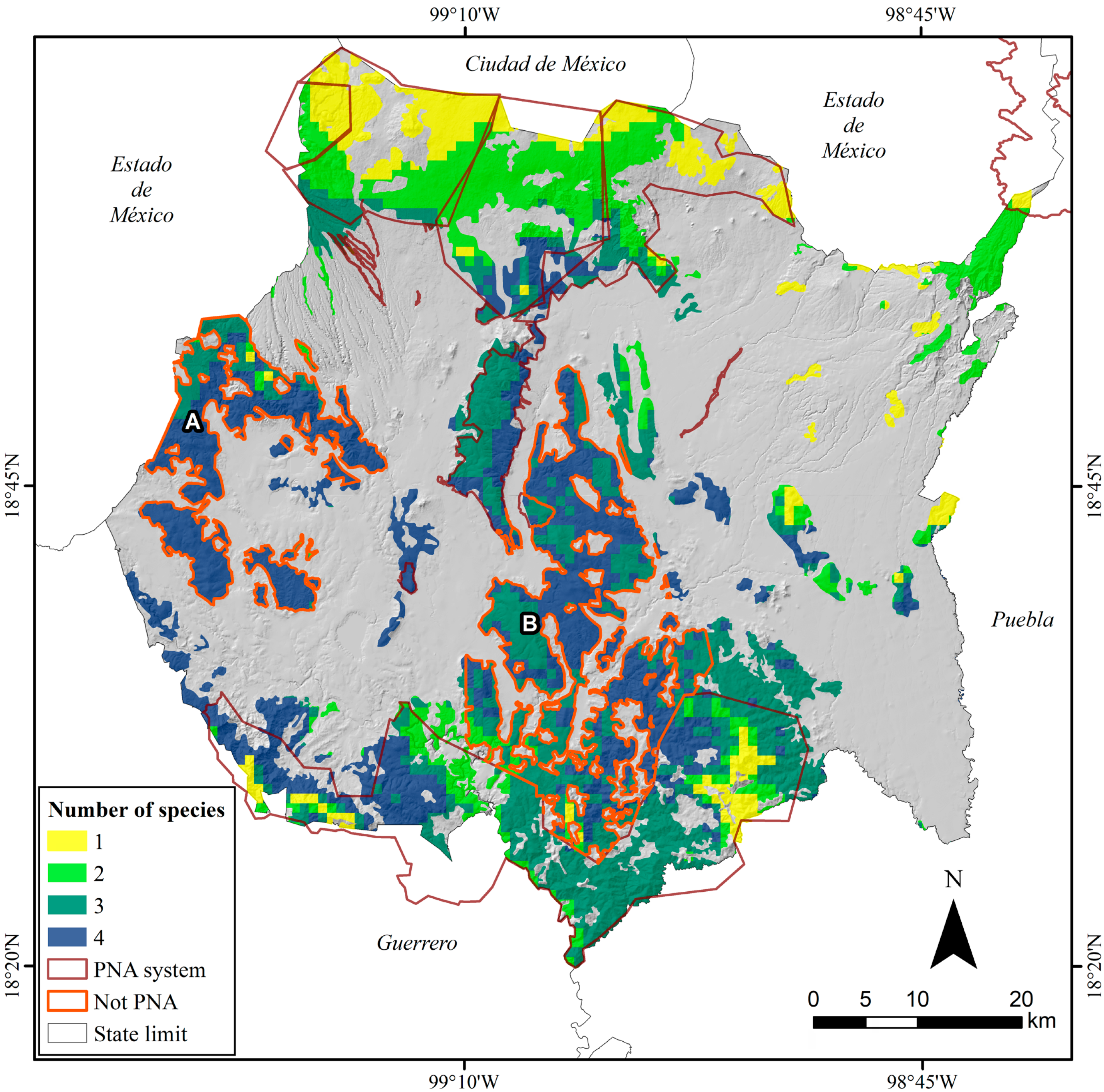

Figure 4. Richness model of the potential distribution of the four feline species in the state of Morelos. Blue shades indicate areas where the four species of medium-sized felines are potentially distributed. A) Region with a continuous area with climate suitability for four species in the west of the state; B) region with a continuous area with climate suitability for four species between RELE and RBSH.

can potentially host one feline species is 189.70 km^2; two species, 360.43 km^2; three species, 625.92 km^2; and the area with CS and vegetation cover in which the four species could potentially be present is 658.69 km^2, with region A (208 km^2) and region B (404 km^2) in Figure 4 being the largest.

By superimposing the PNAs on the richness areas model, the PNAs showing CS and vegetation cover for four species are APFFCBC FII, PNET, RBSH, RESMN, RELE, PEET, PECT, and ZPNBUC; it is worth mentioning that the last four have an area of less than 7 km^2 (Figure 4). The PNAs that show CS and vegetation cover for three species are APFFCBC FI and ANPBM, the latter with an area of only 0.22 km^2, but contiguous to APFFCBC FI (Figure 4). Finally, the PNAs with CS and vegetation cover for two species are PNIP and PNLZ, in which the potential distributions of margay and bobcat overlap (Figure 4).

Discussion

ENMs show climatic segregation, consistent with the Neotropical and Nearctic affinities reported for these felines (Sunquist and Sunquist 2002; Solari *et al.* 2018). The presence records of margay, jaguarundi, and ocelot are associated with warm and temperate climates, which prevail in the study area and favor a large CS area in Morelos for these species. On the other hand, bobcat presence records are associated with low temperatures, which explains the availability of CS areas in the north of the state.

The SDMs show that, despite differences in the importance of climate variables, their combination predicts potential overlapping distribution ranges for the four species. However, it is worth noting that only 38% of the CS area has native vegetation cover, with 24% being secondary shrub vegetation. Therefore, factors such as habitat patch size and conservation status could limit the use of CS areas, as they are not sufficiently large and conserved to support populations of the four felines (Fahrig 2003; Lawrence *et al.* 2018; Cudney-Valenzuela *et al.* 2021).

When SDMs were superposed, two CS areas for the potential distribution of a single species were predicted, covering 3.9% of the area of Morelos. The first is located in the northern part of the state, corresponding to a large part of the potential distribution of the bobcat; the second corresponds to part of the potential distribution of the margay and is located in the southeast and northeast of the state (Figure 4).

The area where the potential distribution ranges of two feline species overlap is equivalent to 7.4% of the state (Figure 4). The combinations predicted are as follows: bobcat and margay in the north of the state, margay and jaguarundi in the center, and ocelot and jaguarundi in the south of the state. The area potentially inhabited by three feline species covers 12.8% of the state, resulting from the intersection of the CS areas of margay, ocelot, and jaguarundi, mainly in the central and southern regions of the state. Intersections of potential ranges of bobcat with margay and ocelot, and with jaguarundi and ocelot, and with jaguarundi and margay were also found, but in a smaller proportion. Finally, the results showed that the potential area where the four species could be found is equivalent to 13.5% of the state area, mainly in the west (region A, Figure 4) and the center-south of the state (region B, Figure 4).

Although our results show areas in Morelos where all four species could be found, interactions between these felines should also be considered, as these may also limit the presence of a given species. Previous studies indicate that the medium-sized felines studied could compete for similar resources, hampering their coexistence (Hutchinson 1957; Jacksic and Marone 2007). However, they could display spatial or temporal segregation mechanisms that could favor sympatry (Núñez *et al.* 2002; Di Bitetti *et al.* 2010; Bianchi *et al.* 2014; Carrera *et al.* 2018).

The constant spatial and demographic growth of urban areas or the expansion of the agricultural frontier have contributed to the transformation and degradation of natural systems, with a negative impact on biodiversity, limiting resources, and the ability to establish populations for some species (Monroy and Velázquez 2002; Sierra 2012; Newbold *et al.* 2015). This effect is evident in the 42% reduction in CS areas for felines in the state. However, it should be noted that 33% of the potential distribution range of medium-sized felines corresponds to agricultural areas, which are considered the productive base of the primary sector (Monroy and Colín 1991; Escandón *et al.* 2018). Therefore, habitat conservation strategies for medium-sized felines should be designed considering these activities.

Our findings show that the PNA complex in the north of the state (PNLZ, APFFCBC, PNET, and PEET) mainly protects CS areas for bobcat and margay and, to a lesser extent, for ocelot and jaguarundi. RESMN and REBIOSH, located in the center and south of the state, respectively, have climatic conditions and primary, secondary tree, and secondary shrub vegetation that are ideal for the potential distribution of the four species. According to previous reports, APFFCBC, PNET, and REBIOSH have high CS for the distribution of margay (Morales-Delgado *et al.* 2021), which is consistent with our results.

The protected areas are supplemented by smaller PNAs that have CS for at least one species (ZNPBUC, ANPBM, PEET, PECT, and RELE). However, due to their extension, they cannot house or conserve a population of felines, as their area is smaller than the home ranges reported in Mexico for bobcat, ocelot, and jaguarundi (Elizalde-Arellano *et al.* 2012; Caso 2013; Giordano 2016). Nonetheless, some small PNAs are located adjacent to larger PNAs, and others, such as RELE, are part of large areas outside PNAs that are covered by vegetation and have ideal climatic conditions for the establishment of feline populations (region B in Figure 4). In addition, small PNAs could serve as stepping stones to facilitate the movement of individuals between PNAs (Dueñas-López *et al.* 2015; Herrera *et al.* 2017; Luja *et al.* 2017). However, to favor the role of these small PNAs as stepping stones, the design of structural corridors connecting them to larger PNAs or to regions A and B is required (Figure 4).

Although our results suggest that at least 11 of the 14 PNAs in Morelos have a high CS for the four medium-sized felines, records of these species in PNAs are scarce, and their presence has only been reported in five of them. The first record of the ocelot was reported in PNLZ in 2014. The presence of ocelot has also been confirmed in APFFCBC, REBIOSH (Valenzuela *et al.* 2013; Aranda Valenzuela 2015), and recently in RESMN (Vera-García *et al.* 2023). There are several records of bobcat in PNLZ, APFFCBC, and PNET (Monroy and Velázquez 2002; Uriostegui-Velarde *et al.* 2015), and, to a lesser extent, in RBSH (Valenzuela *et al.* 2013). There are no published records of jaguarundi confirming its presence in PNAs of Morelos, although there are anecdotal records that await confirmation.

This work also identified areas outside of the PNAs with primary, secondary tree, and secondary shrub vegetation that have CS for the potential distribution of the four medium-sized felines. One such area is region A (Figure

4), which, according to the richness model, covers 208.01 km^2 and is mainly composed of low deciduous forest (INEGI 2010a; Miranda-González *et al.* 2011). In this region, Álvarez *et al.* (2009) reported the presence of jaguarundi, ocelot, and bobcat in the community of Paredón, municipality of Miacatlán. Another important area is region B (Figure 4), located between RESMN-RELE and REBIOSH, covering 404.25 km^2 of low deciduous forest (INEGI 2010b; INEGI 2010c) with CS for the four felines.

Studies in regions A and B addressing the local fauna are scarce. Therefore, it is recommended to implement systematic monitoring to evaluate the conservation status, potential threats, and the presence of key or indicator species, such as felines. On the other hand, although there are remnants of relatively conserved vegetation, no measures have been put in place to protect and conserve them in these regions. Consequently, evaluations should be conducted to incorporate these areas into the Morelos protected natural areas system.

The results of the present study highlight the importance of designing monitoring programs to confirm the presence of the studied feline species in the different Morelos localities where their presence has not yet been substantiated. In addition, we suggest supplementing the programs with restoration actions, as between 40% and 58% of the final areas predicted by the models correspond to secondary shrub vegetation, which would restrict their viability. On the other hand, the potential distribution of these four felines should be considered in the State Urban Development Program and the Ecological Land-Use Planning Program to prevent further degradation of their habitat. It is therefore necessary to conserve and protect the areas that contribute to the structural connectivity between the PNAs. With this information and with the participation of different sectors of society, comprehensive conservation strategies can be established that guarantee the protection and restoration of the areas potentially inhabited by medium-sized felines in the state of Morelos.

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