 doi:10.20944/preprints202211.0024.v1

Article

Threatened habitats of carnivores: identifying conservation areas in Michoacán, México

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Abstract: The present study contributes to bridging the gap on research related to the presence and distribution patterns of carnivore mammals in the western state of Michoacán, highlighting the importance and need to increase efforts aimed at the study and monitoring of wildlife present in this region.
The distribution of carnivore in western Mexico was modeled through the application a two-scale approach: a large, modeled region, corresponding to the western part of the country, for which models were obtained that represent the distribution potential of the species, and, the second modeled study area that includes only the western portion of the state of Michoacán, in which models of the current distribution of the species for this region were proposed.
A series of predictive models were generated on the current distribution of 11 species of carnivore species (*Canis latrans*, *Urocyon cinereoargenteus*, *Herpailurus yagouaroundi*, *Leopardus pardalis*, *Leopardus wiedii*, *Puma concolor*, *Panthera onca*, *Conepatus leuconotus*, *Bassariscus astutus*, *Nasua narica*, *Procyon lotor*), from which, prioritization exercises were carried out on important areas for the conservation of these species, as well as the comparison and analysis of the existing natural protected areas (NPA) in the study area.
The different exercises for prioritizing areas for conservation yielded similar results and show the potential percentages of the landscape that can be subjected to protection and conservation programs.

Keywords: carnivore species; western Michoacán; actual species distribution; prioritization; conservation areas.

1. Introduction

1.1. Michoacán's mammals

The state of Michoacán is located in the central-western part of Mexico and includes a variety of physiographic regions (Figure 1). These regions' climate is also diverse: tropical humid and subhumid (*Costas del Sur*, *Cordillera Costera del Sur*, *Depresiones del Balsas* and *Escarpa Limítrofe Sur*); temperate (*Sierras y Bajíos Michoacanos, Mil Cumbres*, *Neovolcánica Tarasca*); dry-hot at the lower and middle parts of *Depresión del Balsas* and *Tepalcatepec* [1, 2]. Such heterogeneity in climate, physiography and lithology promotes ecological conditions which allow for the presence of a wide variety of vegetation

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communities [3] associated with an also high fauna diversity. A high diversity of vertebrate species is found in the transition zones between physiographic regions in the state of Michoacan [4].

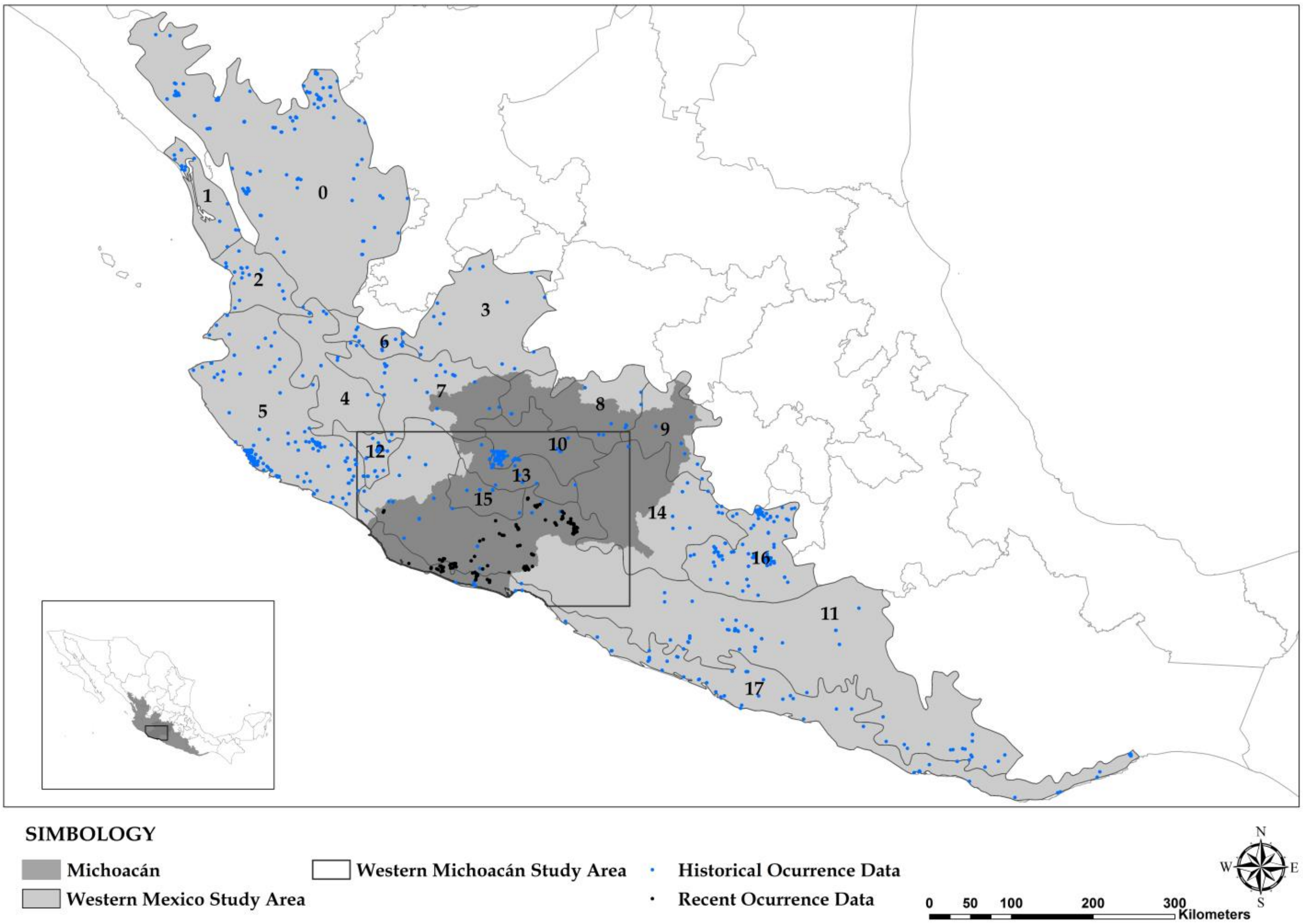

Figure 1. Study areas' location, physiographic provinces and records of 11 carnivore species distributed in western México. (0) *Mesetas y Cañadas del Sur*, (1) *Delta del Río Grande de Santiago*, (2) *Sierras Neovolcánicas Nayaritas*, (3) *Altos de Jalisco*, (4) *Sierra de Jalisco*, (5) *Sierras de la Costa de Jalisco y Colima*, (6) *Guadalajara*, (7) *Chapala*, (8) *Sierras y Bajíos Michoacanos*, (9) *Mil Cumbres*, (10) *Neovolcánica Tarasca*, (11) *Cordillera Costera del Sur*, (12) *Volcanes de Colima*, (13) *Escarpa Limítrofe del Sur*, (14) *Depresión del Balsas*, (15) *Depresión de Tepalcatepec*, (16) *Sierras y Valles Guerrerenses*, y (17) *Costas del Sur*.

A wide variety of mammal species have been reported for the state of Michoacán, from rodents [5], shrews [6] and bats [7]; middle size mammals such as *Tamandua mexicana*, *Leopardus wiedii*, *Leopardus pardalis*, *Spilogale pygmaea* and *Herpailurus yagouaroundi*, to large size mammals such as *Panthera onca* and *Puma concolor* [8-10].

There are 161 mammal species reported in the state of Michoacán, which represent 32% of the species at the national level; the most represented order in the state is Chiroptera with 74 species, while Carnivora has 18 species [10].

1.2. Carnivores and biodiversity indicators

Carnivores play an important ecological role; these can belong to many trophic levels due to variance in size, their separation between temporal and spatial niches, and their food habits [11, 12]. Their presence and population conditions represent valuable ecological metrics because this is a group indicator of the conservation status in different ecosystems. Species of carnivores are considered umbrella species since conservation of their distribution aids in protecting many other species inhabiting the same habitats [11]. Being large predators, carnivores control their prey populations, affecting the trophic web dynamics and therefore the ecosystem's energy flows [13]. Sergio *et al.* [14] have proposed several factors describing the presence of carnivores in high biodiversity areas: (1) the density of carnivores may be related to high productivity estimates; (2) being strict predators they may be affected by environmental disturbances such as pollution, habitat degradation and fragmentation; (3) carnivores prefer vegetation and topographic complex habitats; and (4) most predators have a diet compounded by both main and secondary lists of prey.

Issues related to global conservation of carnivores are widely documented. Their specific food habits, their need for large areas and their low tolerance to human presence, make carnivores highly vulnerable to extinction processes [15]. The strongest threats are the destruction and fragmentation of habitat and the intense hunting of them and their prey [16].

1.3. Species distribution models

Analyzing patterns of species distributions during the last decades has been a research tool used in important fields such as conservation planning. Therefore, species distribution modeling has developed algorithms and procedures aimed to improve the prediction of such models [17]; such is the case for the application of geographic information systems (GIS) and the development of statistic and machine learning algorithms oriented to generate robust species distribution models [18-30]. Considering the wide assortment of algorithms [31], an ensemble of consensus of models has been proposed as an approach to generate more robust species distribution predictions [32].

The most common strategy to estimate a species actual or potential distribution consists in characterizing the suitable environmental conditions and subsequently identifying the spatial distribution of such conditions [33]. This characterization may be developed as a mechanistic and correlative approach [34]. A mechanistic model includes those processes of physiological limitations by which a species tolerates environmental conditions. On the other hand, the correlative approach assumes the observed distribution of a species provides useful information about the species environmental requirements. This approach is based on the association of a species' occurrence records with environmental conditions that reasonably affect the physiology and the species' persistence likelihood [33, 34].

For some authors ecological niche modeling (ENM) is not synonymous with species distribution modeling (SDM) [35]. However, the niche concept is key to differentiating between potential and actual distribution models. Peterson and Soberón [36] recommend being careful to distinguish between the potential distribution models generated under the ENM approach and their existing or realized manifestations; the reconstructed distributions should necessarily consider the historical landscape transformations to obtain models of the species actual distributions.

1.4. Conservation areas

Historically, the establishment of natural protected areas has been based on opportunity ad-hoc criteria, different from systematic biodiversity knowledge [37, 38]. However, nowadays species distribution models are used as key input for identifying and selecting natural areas with maximum representation of species richness, so that computing methods have been developed for selection of natural areas [39-42]. Such methods have focused on three quantitative approaches [43, 44]: (a) identification of hot spots in species richness, (b) selection of areas with rare species, and (c) complementarity of natural areas. Systematic conservation planning requires setting clear objectives from which it is possible to propose measurable and explicit conservation goals [45]. Conservation goals consist of explicitly quantifying a minimum amount of biodiversity elements, such as species distributions and vegetation types, which may be protected at local, regional, or continental scales [46].

There exist several natural protected areas in western Michoacán, Mexico, covering approximately 328,000 ha, comprised mostly of the Zincuirán-Infiernillo biosphere reserve [4, 47]. There also exist several proposals to protect this region´s natural areas: Terrestrial Priority Regions (TPR) [48], Important Areas for Bird Conservation (IABC) [49], and Priority Terrestrial Sites for Biodiversity Conservation (PTSC) [50], at the country scale (Figure 2), and Priority Areas for Conservation in Michoacán (PACM) [51] and Conservation Areas System in Michoacán (CASM) [52], at the state scale.

1.5. Statement of the problem

Elaborating national schemes for prioritizing mammal conservation in México has made evident the need for generating reliable species distribution models at a detailed scale [53]. Most of the studies on Michoacán's mammals have focused on estimating species richness [8, 10, 54-59]. These studies suggest the region is crucial for the connectivity of populations. Western Michoacán is representative of western Mexico's biodiversity and endemism. The *Faja Transvolcánica* and *Sierra Madre del Sur* are identified as relevant regions because of their high concentrations of endemic plants and animals [60]. There are various aspects explaining this region's research and biodiversity conservation challenges: 1) it is a region representative of the whole biodiversity in the western Mexico's slope; 2) there is a lack of information about the regional patterns of biodiversity; 3) the biosphere reserve Zicuirán-Infiernillo (ZIBR) is the only large natural protected area, the remaining areas are not significant in terms of size and care; 4) There are several proposed areas defined as priority for conservation, some of them comprising very large areas; 5) there is data about the presence of various species of carnivores and other mammals.

This study aims to determine the level of correspondence between natural protected areas (NPA) and proposed areas for conservation with actual hot spot areas identified based on the distribution of carnivore species. One research question relates to the ZIBR's role for protecting areas with high carnivore richness and what are the specific priority sites within the large regions proposed for conservation.

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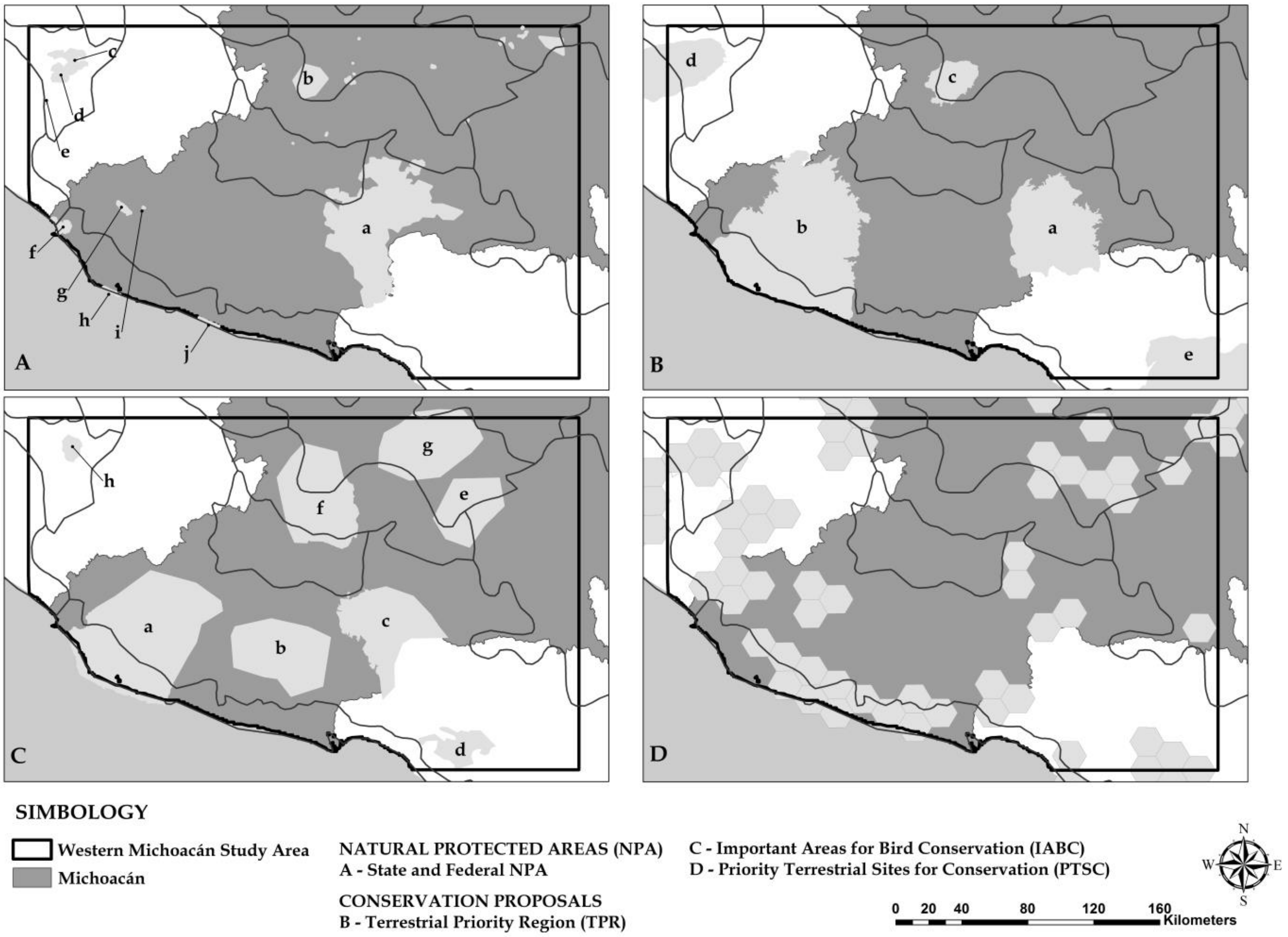

Figure 2. Natural protected areas (NPA) and existing proposed conservation regions and sites in western Michoacán, México. (A) NPA: (a) Zicuirán-Infiernillo Biosphere Reserve (ZIBR), (b) Pico de Tancintaro, (c) Volcán Nevado de Colima, (d) El Jabalí, (e) Las Huertas, (f) Lagunas Costeras y Serranias aledañas de la Costa de Michoacán, (g) El Barrancón de las Guacamayas, (h) Santuario Playa Maruata y Colola, (i) La Chichihua, (j) Santuario Playa Mexiquillo. (B) Terrestrial Priority Regions (TPR): (a) Infiernillo, (b) Sierra Coalcomán, (c) Tancíntaro, (d) Manantlán - Volcán de Colima, (e) Sierra Madre del Sur de Guerrero. (C) Important Areas for Bird Conservation (IABC): (a) Coalcomán-Pomaro, (b) Tumbiscatio, (c) Cuenca Baja del Balsas, (d) Vallecitos de Zaragoza, (e) Tacambaro, (f) Tancíntaro, (g) Patzcuaro, (h) Nevado de Colima. (D) Priority Terrestrial Sites for Biodiversity Conservation (PTSC).

This study considers a group of carnivores as a biodiversity indicator whose spatial patterns of richness and rareness would suggest the location of areas priority for conservation. This analysis or selection of areas also includes vulnerability conditions resulting from deforestation and fragmentation processes.

1.6. Objectives

1. To propose models of actual distribution of carnivore species in western Michoacán, México, generated from potential distribution models corresponding to western México.
2. To obtain estimates of vulnerability in areas where carnivore species are distributed, due to deforestation and fragmentation processes (i.e., land use/land cover changes).

3. To identify important areas for conservation, by applying systematic conservation planning tools (e.g., prioritization and complementarity), based on the actual distribution of carnivore species and the potential transformation in the land cover.

2. Materials and Methods

Occurrence data of carnivore species in western Michoacan was obtained from field work carried out during the years 2010-2014 which is part of a project named "Jaguar Conservation". These data were collected by a photo tramp system as shown in Figure 1. On the other hand, occurrence data of carnivore species in western Mexico was acquired from accessing different databases: Global Biodiversity Information Facility (GBIF), Mammal Networked Information System (MaNIS), Unidad de Informática para la Biodiversidad UNAM (UNIBIO), and Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO). These databases were cleaned and integrated into a single database, avoiding duplicates and records without complete taxonomic and georeferenced data.

2.1. Carnivore species

A preliminary species list of carnivores in Michoacán [10] and the recorded species by Nuñez (unpublished data) were used to verify their taxonomic status following Ramirez-Pulido et al. [64, 65] and supported by the work of Ceballos et al. [66, 67], and CONABIO. Eleven species were finally included in this study as shown in Table 1.

2.2. Species distribution modeling

Species distribution models were generated by applying a consensus approach [32]. The software MODECO [68] was used to run different prediction algorithms: Support Vector Machine (SVM), Generalized Linear Model (GLM) and Artificial Neural Networks (ANN). The MaxEnt (Maximum Entropy) was also applied, but it was run independently because its software provides more integral analysis.

2.3. Prediction variables

Variables for predicting the species potential distributions in western Mexico, included topography (elevation, aspect, and topographic position) and 19 bioclimatic variables from the WorldClim project [69] (https://www.worldclim.org/). This data set was used to generate preliminary distribution models, allowing the selection of more significant prediction variables. Selected variables differed in number and composition for each species, and they accounted for ≥95% of the total percentage. All these environmental variables have 1x1 km spatial resolution.

Table 1. Carnivore species, conservation status and record number by species in two databases, wMex (western Mexico) and wMich (western Michoacán). Taxonomy according to Ramírez-Pulido

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et al. [65]. UICN: NT= close to threatened, EN= endangered. NOM-059-SEMARNAT-2010: P= endangered, A= threatened.

Family	Species	Conservation status			Number of records	
		SEMARNAT	CITES	IUCN	wMex	wMich
CANIDAE	*Canis latrans Say, 1823*				216	25
	Urocyon cinereoargenteus (Schreber, 1775)				366	20
FELIDAE	*Herpailurus yagouaroundi (Lacépède, 1809)*	A	I	EN	91	6
	Leopardus pardalis (Linnaeus, 1758)	P	I	EN	127	43
	Leopartus wiedii (Schinz, 1821)	P	I	NT	77	11
	Puma concolor (Linnaeus, 1771)				97	33
	Panthera onca (Linnaeus, 1758)	P		NT	84	18
MEPHITIDAE	*Conepatus leuconotus (Lichtenstein, 1832)*				231	6
PROCYONIDAE	*Bassariscus astutus (Lichtenstein, 1830)*				239	6
	Nasua narica (Linnaeus, 1766)		III		376	81
	Procyon lotor (Linnaeus, 1758)				242	14
TOTAL RECORDS					2,146	263

2.4. Potential distribution models

Maxent was the algorithm applied to generate potential distribution models, using the complete set of climate and topography prediction variables. The selected prediction variables are shown in Table 2 and were defined based on their importance value and other species' ecological aspects, such as habitat preferences, water requirements, resources availability, environmental tolerance, etc. These selected variables were then used to run four different prediction algorithms per species (MaxEnt, Support Vector Machine, Generalized Linear Model and Artificial Neural Networks).

A consensus approach [32] was applied so that the median was the representative statistic for combining four prediction models for each species.

2.5. Actual distribution models

Considering that occurrence data for the carnivore species distributed in western Michoacán, were collected recently (2010 – 2014), generalized linear models (GLM) were run to estimate habitat associations, analysis that required pseudo absence data. These data for each carnivore species were generated from those potential distribution models obtained for western Mexico. By applying this approach, it was expected to reduce the risk of generating pseudo absences in places potentially suitable for the species, in contrast with the random approach often suggested [70, 71]. The use of preliminary habitat suitability maps as a spatial guide for generating pseudo absences is an efficient means to reduce the possibility for obtaining false negatives [71, 72].

GLM are an extension of linear models and allow to manage data sets that lack normal error distributions and constant variances. Binary response variables, such as presence/absence data, show such characteristics so that the association between carnivore species occurrence and habitat types in western Michoacan was described by GLM run in the software R (R Core Team, 2013). The independent variables consisted of land use/ land cover data obtained for the years 2013-2014 (INEGI-Serie V) [73, 74] and the topographic position index [75].

The significance of variables in the GLM was obtained by applying Akaike information criterion. However, an independent evaluation of each model was carried out by the partial Receiving Operating Characteristic (ROC) [76].

Actual distribution models for western Michoacan were obtained from adjusting the potential distribution models for western Mexico, by using the species/ habitat association (probability) models obtained from the GLM analysis. A weighted sum of both types of models -potential distribution and habitat associations- was conducted, assigning a weight of 2 to the former and 1 to the latter, then the models were re-scaled to a 0 – 1 range of values. The results yielded continuous models representing estimates of probability of the actual species occurrence in western Michoacan, determined not only by climate and topography, but also by the land cover conditions at the time when the species occurrence data were gathered in the field.

2.6. Model Validation

Evaluation of models consisted in applying the partial ROC test (Receiver Operating Characteristic) [76] which provides the partial value area under the curve (AUC), among other statistics. The application of partial ROC was carried out employing the NicheToolBox [77] (http://shiny.conabio.gob.mx:3838/nichetoolb2/), using 20% training records with 500 iterations and calculating the AUC average [76].

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Table 2. Prediction variables used in the elaboration of potential distribution models for carnivore species in western Mexico. Selected variables per species represented ≥95% in prediction importance. Topo=Topographic, asp= aspect, ele= elevation. Bioclimatic Variables: 1 = Annual Mean Temperature; 2 = Mean Diurnal Range (Mean of monthly (max temp - min temp); 3 = Isothermality (2/7) (×100); 4 = Temperature Seasonality (standard deviation ×100); 5 = Max Temperature of Warmest Month; 6 = Min Temperature of Coldest Month; 6 = Min Temperature of Coldest Month; 7 = Temperature Annual Range (5-6); 8 = Mean Temperature of Wettest Quarter; 9 = Mean Temperature of Driest Quarter; 10 = Mean Temperature of Warmest Quarter; 11 = Mean Temperature of Coldest Quarter; 12 = Annual Precipitation; 13 = Precipitation of Wettest Month; 14 = Precipitation of Driest Month; 15 = Precipitation Seasonality (Coefficient of Variation); 16 = Precipitation of Wettest Quarter; 17 = Precipitation of Driest Quarter; 18 = Precipitation of Warmest Quarter; 19 = Precipitation of Coldest Quarter.

Species (order Carnivora)	Prediction Variables																				
	Bioclimatic Variables																			Topo	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	asp	ele
Canis latrans Say, 1823		X		X	X	X						X	X	X				X	X	X	X
Urocyon cinereoargenteus (Schreber, 1775)				X			X	X	X			X		X		X	X		X		X
Herpailurus yagouaroundi (Lacépède, 1809)		X				X	X							X		X	X		X	X	X
Leopardus pardalis (Linnaeus, 1758)		X	X	X		X	X				X	X									X
Leopartus wiedii (Schinz, 1821)		X	X	X			X						X				X				
Puma concolor (Linnaeus, 1771)			X	X								X					X	X	X	X	
Panthera onca (Linnaeus, 1758)			X	X			X										X	X		X	X
Conepatus leuconotus (Lichtenstein, 1832)		X		X		X	X	X	X					X			X	X			
Bassariscus astutus (Lichtenstein, 1830)		X	X		X				X			X	X	X	X			X			X
Nasua narica (Linnaeus, 1766)	X	X				X	X	X	X		X	X		X			X	X			X
Procyon lotor (Linnaeus, 1758)		X						X	X			X		X					X	X	

2.7. Land use/ land cover change

A land use/land cover modeling exercise was conducted to obtain deforestation vulnerability estimates (i.e., deforestation likelihood) to be incorporated into the identification of priority areas for conservation of carnivore species in western Michoacán. Vector coverages 1: 250,000 scale, generated by the Mexican government (Instituto Nacional de Estadística y Geografía, INEGI), known as Serie II [78] and Serie V (INEGI, 2013) were used as two different dates to determine change in the region's land use/land cover. Indeed, Serie II was created using Landsat TM images gathered in 1993, while Serie V was elaborated based on SPOT images gathered in 2012-13.

The Land Change Modeller module in the IDRISI Selva software was used to generate probability transition models related to three main submodels: *Deforestation* (change from conserved temperate and tropical forests to cropland and introduced grassland); *Regeneration* (change from cropland and introduced grassland to conserved and secondary temperate and tropical forests); *Disturbance* (change from conserved temperate and tropical forests to secondary forests). This study focused on the transition probability estimates corresponding to the Deforestation submodel, because these estimates of deforestation vulnerability were included as key variables in the identification of priority areas for conservation of 11 carnivore species in western Michoacan. Given the nature of the transition probability output, it was necessary to calculate the inverse and to rescale values from a 0 - <1.0 range to 0 – 1.0, so that the model represented the probability of persistence of the different land cover/ land use types.

2.8. Identification of priority areas for conservation

Individual actual distribution models by species were summated to identify areas with species concentration or richness. Continuous models were converted to binary models (i.e., presence/ absence) based on the application of a prediction threshold. In this case, such a threshold consisted in the sensibility/specificity maximization criteria [80].

The software Zonation [81] was used to prioritize the analysis of conservation areas. Zonation is based on the complementarity of areas and serves as a balance to rank conservation priorities across the landscape through iterative elimination of cells or planning units to direct at a minimum aggregated loss of conservation values. The cell elimination order depends on an elimination rule which can be selected according to conservation objectives [81-83].

The actual distribution models (continuous) for each species and the inverse deforestation model were used as inputs while the Additive Benefit Function (ABF) and the Core Areas Zonification (CAZ) were applied as removal rules. In general terms, the ABF rule prioritizes exclusively high richness areas, whereas the CAZ rule determines important high richness areas while at the same time identifies areas with unique biodiversity elements (e.g., rareness areas).

Different weights were assigned to each species, depending on their conservation status (see Table 3) and different modeling parameters were used. Smoothing and Boundary Length Penalty (BLP) are two aggregation methods that generate solutions relatively more compactly. The former conserves well-connected areas and the latter is the most frequently used method. Additionally, BLP does not consider situations like species fragmentation, but rather penalizes the boundary length to produce more compact conservation areas. Different conservation priorities are classified in the resulting conservation models allowing for the specification of different thresholds in the percentage of landscape. For instance, here 15% of the landscape was chosen as a threshold to describe the conservation areas identified.

Table 3. Assigned weights to each species in prioritization of conservation areas (Zonation). NOM059= legal conservation status by the Mexican government [84]; EN=endangered, T= threatened

SPECIES	Conservation Status (NOM059)	Weight
Canis latrans Say, 1823	-	1
Urocyon cinereoargenteus (Schreber, 1775)	-	1
Herpailurus yagouaroundi (Lacépède, 1809)	T	2
Leopardus pardalis (Linnaeus, 1758)	EN	3
Leopartus wiedii (Schinz, 1821)	EN	3
Puma concolor (Linnaeus, 1771)	-	1
Panthera onca (Linnaeus, 1758)	EN	3
Conepatus leuconotus (Lichtenstein, 1832)	-	1
Bassariscus astutus (Lichtenstein, 1830)	-	1
Nasua narica (Linnaeus, 1766)	-	1
Procyon lotor (Linnaeus, 1758)	-	1

2.9. Comparing identified and already proposed priority areas

The conservation areas identified in this study were compared (overlap) with other existing areas that have been proposed for conservation. Particular attention is paid to a recent version of priority terrestrial conservation areas (RTP) proposed by CONABIO [50] (Priority Terrestrial Sites for Biodiversity Conservation (PTSC); see Figure 2), which consist of 256 km^2 hexagons distributed across the country and with a ranked priority level (medium, high and very high).

3. Results

3.1. Carnivore species occurrence data

This study used a total of 263 occurrence records belonging to 11 carnivore species found in western Michoacan during the years 2010 – 2014. *Nasua narica* was the species with the highest number of records (81) while *Bassariscus astutus*, *Conepatus leuconotus* and *Herpailurus yagouaroundi* had the lowest with six records. On the other hand, a total of 2,146 historic occurrence records, for the same 11 carnivore species but across western Mexico, were integrated from querying public databases. The highest number of records belonged to *Nasua narica* (376) while the lowest was *Leopardus wiedii* with 77 records (Table 1).

3.2. Potential distribution models

Four models for each species, for a total of 44 potential distribution models, were constructed by applying the algorithms MaxEnt, Support Vector Machine, Generalized

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Linear Model and Artificial Neural Networks. Afterwards, a consensus approach was applied to generate a potential distribution model per species, as a continuous of occurrence probability estimates.

The most important prediction variables varied among species (Table 2): 13 variables predicted 5 – 8 species and 8 variables predicted <5 species (see Table 2). The b10 variable (Mean Temperature of Warmest Quarter) was not important for any species while b2 (Mean Diurnal Range (Mean of monthly (max temp - min temp)) was important for 8 species.

3.3. Associations species/ habitat types

Table 4 shows a summary of the estimated association probability between habitat types and each species presence (GLM analysis) in western Michoacán. All models had an AUC value above 1.2 which indicates good-fitting models.

Results indicate that the lowest probability areas for all species correspond to bare soil and cropland areas. Some species also showed low occurrence probabilities in other land cover types; for instance, *Urocyon cinereoargenteus*, *Herpailurus yagouaroundi* and *Leopardus pardalis* in temperate forests, and *Conepatus leuconotus* and *Bassariscus astutus* in tropical semi-evergreen forest (Figure A1).

High occurrence probability areas for *Urocyon cinereoargenteus*, *Leopardus pardalis* y *Nasua narica* consisted of almost exclusively tropical semi-evergreen forest, for the species *Canis latrans*, *Leopardus wiedii* and *Procyon lotor* the highest presence probability were areas with tropical semi-evergreen forest and temperate forests whereas *Panthera onca* was highly associated with tropical semi-evergreen forest and tropical dry forest. Temperate forests are areas where *Conepatus leuconotus* and *Bassariscus astutus* had the highest occurrence probability, while tropical dry forest was the land cover type with the probability for *Herpailurus yagouaroundi* and *Puma concolor* (See Figure 3).

Table 4. GLM results summary

SPECIES (ORDER CARNIVORA)	Dispersion parameters							
	Presence/ Absence records	Significant variables	Deviance null	Deviance residual	Deviance (D²)	AIC	Z value	P value
Canis latrans Say, 1823	25/ 25	TPI	205.1	143.2	30.1%	171.2	1.841	0.0656
Urocyon cinereoargenteus (Schreber, 1775)	20/ 20	TPI / Oak Forest	213.4	164.9	22.7%	190.9	3.142	0.00168 / 0.092
Herpailurus yagouaroundi (Lacépède, 1809)	6/ 6	(-)	30.4	22.7	25.5%	38.7	(-)	(-)
Leopardus pardalis (Linnaeus, 1758)	43/ 43	TPI	155.2	105.7	31.8%	137.7	2.365	0.018
Leopartus wiedii (Schinz, 1821)	11/ 11	TPI	72.0	34.3	52.3%	60.3	1.942	0.0522
Puma concolor (Linnaeus, 1771)	33/ 33	TPI	130.3	44.8	65.5%	78.8	3.231	0.00123
Panthera onca (Linnaeus, 1758)	18/ 18	TPI	55.4	20.6	62.6%	42.6	1.719	0.0855
Conepatus leuconotus (Lichtenstein, 1832)	6/ 6	(-)	63.7	36.7	42.4%	60.7	(-)	(-)
Bassariscus astutus (Lichtenstein, 1830)	6/ 6	(-)	77.6	39.9	48.5%	65.9	(-)	(-)
Nasua narica (Linnaeus, 1766)	81/ 81	TPI	291.1	179.2	38.4%	215.2	2.942	0.00327
Procyon lotor (Linnaeus, 1758)	14/ 14	(-)	88.7	57.4	35.2%	85.4	(-)	(-)

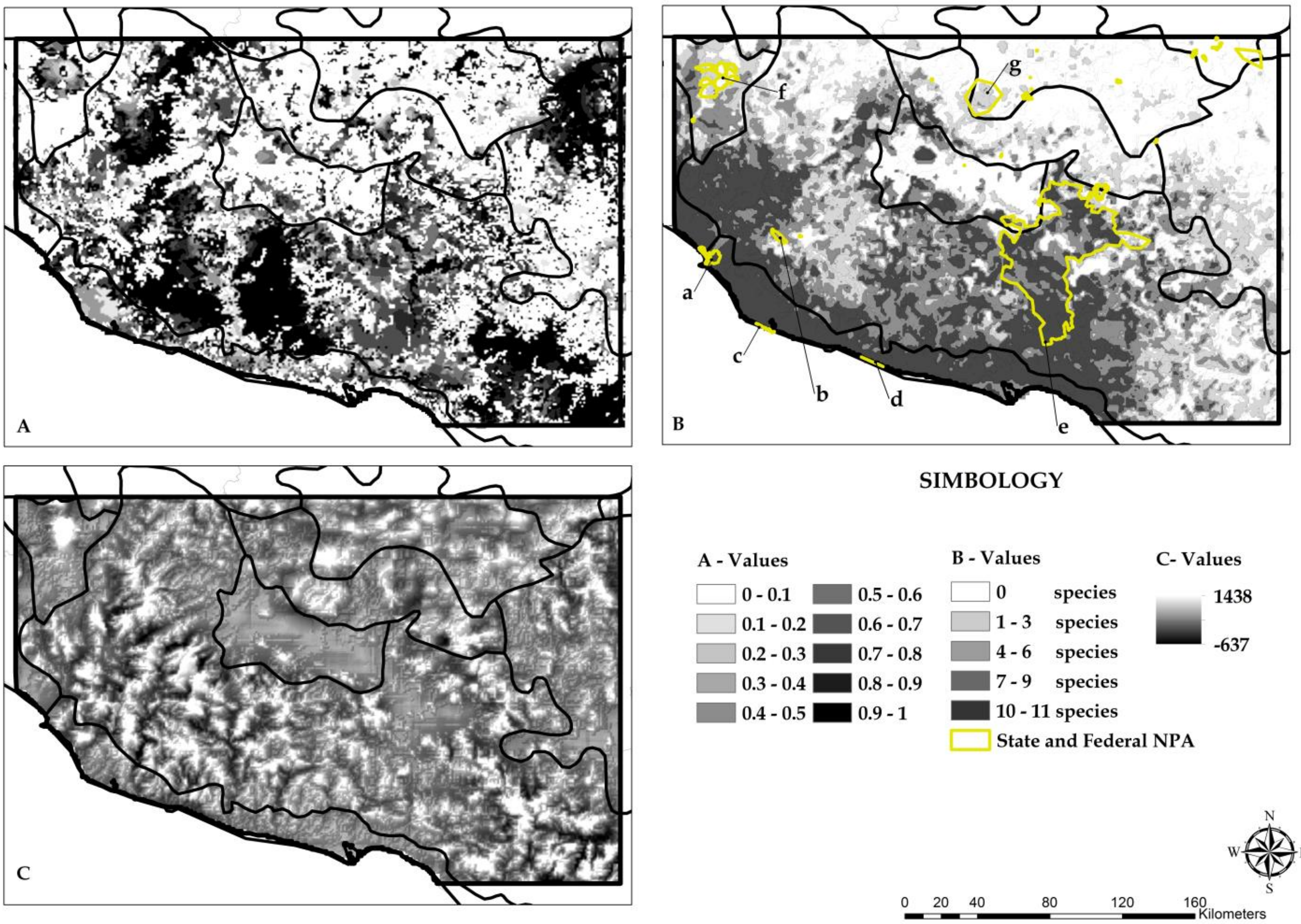

Figure 3. (A) Inverted deforestation, (B)species richness , and (C) Topographic Position Index (TPI) models. (a) Lagunas Costeras y Serranías Aledañas de la Costa Norte de Michoacán, (b) El Barrancón de las Guacamayas, (c) Santuario Playa Maruata y Colola, (d) Santuario Playa Mexiquillo, (e) Zicuirán-Infiernillo biosphere reserve, (f) Volcán Nevado de Colima, (g) Pico de Tancíntaro.

Regarding the GLM statistical model, the topographic position index (TPI) was the independent variable with significative influence predicting the presence of seven species: *Canis latrans* (p= 0.065), *Leopardus pardalis* (p=0.018), *Leopardus wiedii* (p=0.052), *Puma concolor* (p=0.0012), *Panthera onca* (p=0.085), *Nasua narica* (p=0.0032) and *Urocyon cinereoargenteus* (p= 0.0016). This last species also showed a low p-value (0.092) for the variable "oak forest", but with a negative relationship (Estimate = -2.432), which indicates the occurrence probability increases as the species locate the farthest.

3.4. Actual distribution models

The actual distribution models for each species were obtained by the weighted sum of potential distribution models for western Mexico and habitat/species associations models for western Michoacan. Seven species (*Urocyon cinereoargenteus*, *Herpailurus yagouaroundi*, *Leopardus pardalis*, *Panthera onca*, *Conepatus leuconotus*, *Nasua narica* and *Procyon lotor*) showed an actual distribution almost exclusively in the Michoacan coast region, corresponding to the *Costas del Sur* physiographic province, including counties ("municipios") such as Aquila, Coahuayana, Chinicuila, Lázaro Cárdenas, Coalcomán and

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Arteaga, zones covered by tropical dry forest and tropical semi-evergreen forest (Figure A2).

The actual distribution of these seven species is partially included in: small natural protected areas (NPA) such as "Lagunas Costeras y Serranias Aledañas a la Costa Norte de Michoacán", "Playa Maruata y Colola" and "Playa Mexiquillo" sanctuaries; the Terrestrial Priority Region (TPR) "Sierra de Coalcomán"; the Important Area for Bird Conservation (IABC) "Coalcomán-Pomaro"; polygon 6 in the Priority Areas for Conservation in Michoacan (PACM); and areas 01 and 02 in the Conservation Areas System in Michoacán (CASM). Nevertheless, there exist recent records for most species within the "Zicuirán Infiernillo" Biosphere Reserve (ZIBR); only *Panthera onca* y *Puma concolor* showed high occurrence probability within this area (Figure A2).

The other four species (*Canis latrans*, *Leopardus wiedii*, *Puma concolor* and *Bassariscus astutus*) showed an actual distribution expanding from the coastal region towards inland Michoacan, including the *Costas del Sur* and *Cordillera Costera del Sur* physiographic provinces (Figure A2). Temperate forest is the main vegetation type in this latter province. *Bassariscus astutus* is the species showing the most restricted actual distribution in western Michoacan; small areas with high occurrence probability are found in the *Cordillera Costera del Sur* province (Figure A2), within the Coalcomán and Aguililla counties. On the other hand, Puma concolor was the species with the most widespread actual distribution. It is important to mention that the *Depresión del Tepalcatepec* province did not include species with high occurrence probability because it is largely covered by cropland.

Each of the actual distribution models were validated using the test Partial ROC; estimates of partial values in the AUC (area under the curve) ratio were above 1.2 which indicates good model performance (above 1.0 means that model improves as compared with random).

3.5. Land use/land cover change

The deforestation model generated contains the probability (i.e., 0 – 1.0 range of values) of change from conserved forests to cropland and introduced grassland; high values represented high probability of change. Because this study's objective was to assign conservation values for identifying priority areas, the deforestation model was inverted so that high values represented areas with low probability of change (high persistence) and low values represented high deforestation or low persistence probabilities (Figure 3A).

Highest values in the inverted deforestation model correspond to temperate forest areas while the lower values are associated with tropical forest areas. Apparently, temperate forests in western Michoacan have been transformed at lower rates than tropical formations within the time-period 1993 – 2014. Inference can be made that tropical forests have higher vulnerability to deforestation processes occurring in western Michoacan.

3.6. Identification of conservation priority areas

A species richness model was created by adding the individual binary actual distribution models for western Michoacan. This richness model shows that more species (e.g., 10 – 11 species) co-occur in the *Costas del Sur* physiographic province, involving the counties of Coahuayana, Aquila and Lázaro Cárdenas. However, there are small high-richness areas scattered across the region. The *Cordillera Costera del Sur* province included 7 – 9 richness values while the *Depresión de Tepalcatepec* province included mainly low richness values (1 – 3 species; Figure 3B).

One small NPA ("Lagunas Costeras y Serranías Aledañas de la Costa Norte de Michoacán") and two sanctuaries had spatial correspondence with highest richness areas within the *Costas del Sur* province. The ZIBR, located in the *Cordillera Costera del Sur* province, also included high species richness areas (7 – 9 species).

A variety of tests were performed to locate priority conservation areas (zonation), generating a total of 18 models. The objective was to identify model differences determined by varying modeling parameters such as: two cell elimination rules, aggregation method, species' conservation status, deforestation model. In general, each of the generated models located the most important conservation areas within western Michoacán coastal region. However, models generated by applying the CAZ (core areas zoning) identified small highest priority areas towards inland and northern the study area (Figure A3).

The models generated in this study allow for flexibility in selecting different landscape area threshold percentages for conservation. For example, as shown in Figure A3, a 15% threshold percentage corresponds to the area in yellow, pink, cherry and red; a 5% threshold percentage corresponds to the areas in pink, cherry, and red, and finally, a 2% threshold percentage is represented by the areas in red (Figure A2).

The two aggregation methods in the study resulted in small homogeneity differences in the models. In general, the BLP method tends to generalize and slightly increase the size of priority areas, reducing fragmentation, independently of the elimination rule. On the other hand, the Smoothing method does not seem to significantly affect the priority areas spatial configuration (Figure A4).

Weights on species, depending on their conservation status, seem to have an apparent effect on the priority areas connection. Assigning a species' weight generates a continuum in the coastal region, independently of the aggregation method and reduces the size of priority areas (CAZ rule) located north of the study area (Figure A4).

The inclusion of the deforestation model does not significantly affect the identification of priority areas. The only apparent effect is the presence of a set of priority areas located in the northeastern study area (Figure A3a-c).

Despite these variations among models, we found all models show a concentration of high priority areas in the coastal region, which coincides with the species richness model, in other words, similar spatial patterns. These areas correspond to tropical forest formations which show high vulnerability to degradation and fragmentation processes occurring in the region.

Currently proposed priority areas and regions for conservation have not been actualized due to issues of size (exceptionally large or exceedingly small). Thus, important portions of the TPR "Sierra de Coalcomán" and the IABC "Coalcomán-Pomaro", as well as polygon 6 in PACM, areas 01 y 02 in CASM, sanctuaries "Playa de Maruata y Colola" y "Playa Mexiquillo", and a small area of NPA "Lagunas Costeras y Serranías Aledañas de la Costa Norte de Michoacán", all show spatial correspondence with high priority conservation areas identified by the 18 priority models. The southern portion of ZIBR also included high priority areas. To a lesser extent, other areas also contain identified priority

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areas such as the NPA "Pico de Tancíntaro", "El Jabalí", "Volcán Nevado de Colima", "Las Huertas", "Bosque Mesófilo Nevado de Colima", and the TPR and IABC "Tancíntaro". CONABIO *et al*. [50] identified 54 conservation priority hexagons (256 km² each) within the study area, 10 are considered high priority and six as extreme priority. Eight hexagons of high and extreme priority are distributed along the Michoacán coast, in correspondence with the high conservation priority areas identified by this study (2 – 15% percentage of landscape) (Figure 4).

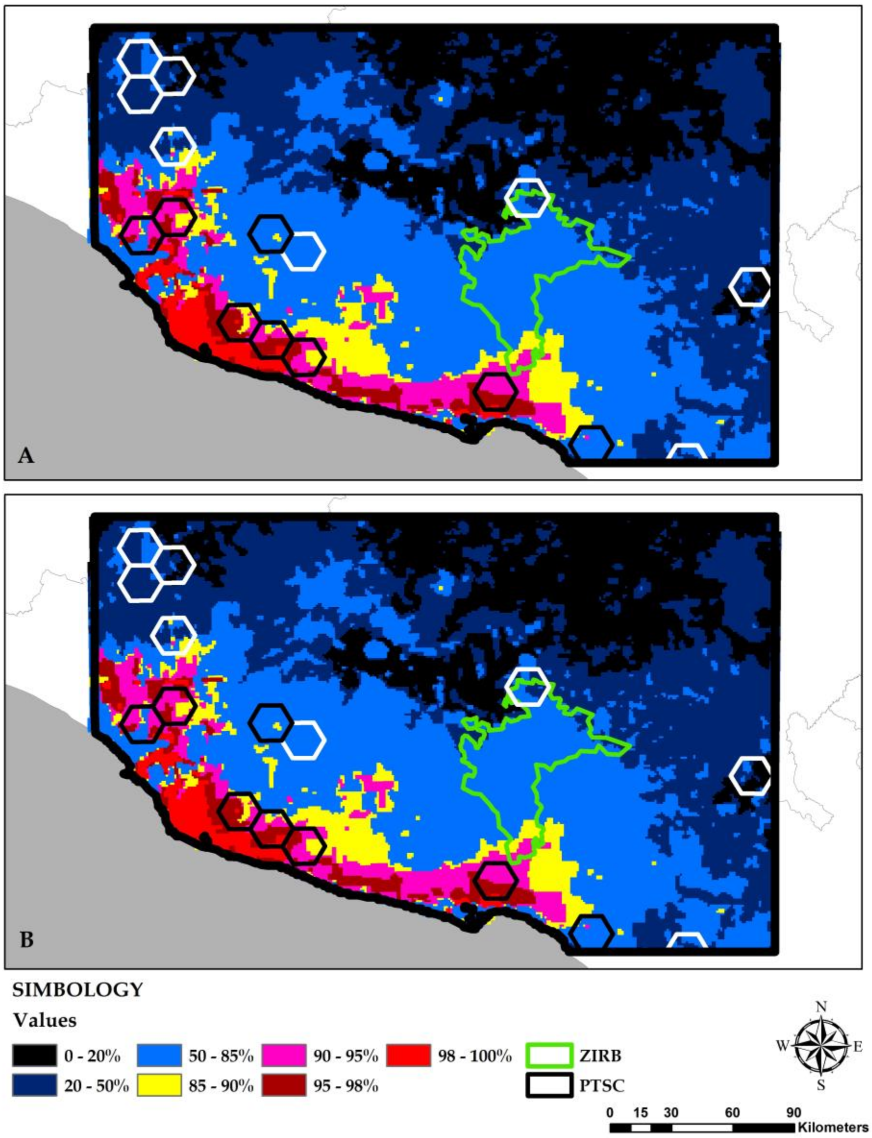

Figure 4. Spatial correspondence between prioritization models and existing proposed priority terrestrial sites (PTSC; CONABIO et al., 2007) shown as hexagons. (A): Prioritization model obtained by applying the Additive Benefit Function (ABF), weighted species, the Boundary Length Penalty (BLP), and the inverted deforestation model. (B) Prioritization model obtained by applying the Core Area Zonation (CAZ) elimination rule and the same parameters as in model (A).

4. Discussion

4.1. Modeling scales

The definition of the geographic extent is a fundamental step in the process of modeling species distributions because such extension will determine extrapolations based on statistical associations between biological occurrence data and the complete set of environmental conditions on which the prediction is developed [17]. This study carries out a two-scale approach for modeling the actual distribution of carnivore species in western Michoacán.

The large scale corresponded to western Mexico that includes temperate and tropical biomes, main habitats where many carnivore species are distributed. The modeling of such a region was based on using climate prediction variables following the hypothesis that species distributions are primarily determined by this type of environmental factors at regional scales [85, 86, 87]. These models represent potential species distribution models because climate and topography variables are used to build fundamental species ecological niches which are projected to a geographic space [88].

The second scale consisted of western Michoacán; an area centered in the larger region which is 1/5 in size of the latter. This smaller area allowed for collection of current carnivore species occurrence data by means of applying a photo camera sampling method, and to perform land use/land cover change modeling. These data are necessary for generating actual species distribution models and applying analytical procedures for conservation planning and NPA networks design [88, 89].

This study proposes actual distribution models of carnivore species in western Michoacán, generated from combining potential distribution models for western Mexico with habitat/species association models which correspond to actual landscape conditions in western Michoacán.

4.2. Species actual distribution models

Previous studies have attempted to generate species current distribution models from refining potential distribution models in the field of conservation planning [88, 90-94]; these have consisted in using a digitally documented suitable habitat map to intersect a potential distribution model. In this study, such a spatial cookie-cutting procedure is replaced by using a habitat/species associations model to restrict a potential distribution model. This model combination makes it possible to include the landscape's habitat transformations in the climate/topography predicted model at local scales [62].

Indeed, the use of species/habitat type associations, particularly on mammal species, has been supported in research on use and selection of habitat widely abundant in ecological studies. Such studies apply statistical tests (e.g., logistic regression) to determine levels of associations between species occurrence and habitat types [9, 95-97]. However, these studies are conducted at local scales, limiting their application to conservation goals [98].

In this study the application of GLM consisted in using a digital land use/land cover map, with a 250x250 m spatial resolution, corresponding to the dates when the species occurrence data were collected, along with a topographic position model. The pseudo absence data were obtained from potential distribution models for western Mexico [71, 72], different from a random approach [70, 71].

The GLM results showed that seven species had a significant variable predicting species occurrences. Such species occurrence probability is an objective and quantitative means to determine the levels of habitat suitability for each of the carnivore species. Four species that did not have significant predicting variables had the smallest occurrence sample size, which would be the first factor explaining the GLM model performance [99-101].

Identification of suitable habitats where species are likely to occur has demonstrated being a powerful conservation tool [102-106]. Moreover, such information is considered as measurements of biodiversity units that are inputs for applying algorithms and geographic information systems (GIS) to identify priority conservation areas [93, 107].

Efforts for prioritizing conservation areas in Mexico have revealed the need to generate species distribution models at more reliable and finer scales [53]. Most of the research on Michoacán's mammals refers to species richness [8, 10, 54-59], however, mammal distribution studies in Michoacán suggest this region as key for population connectivity. As in the case of the jaguar which occurs along the Pacific coast, making possible its distribution not only towards the south and north along the coast, but also to the country's inland [58, 108].

The geographic description of most of this study's carnivore species' actual distribution models show similar spatial patterns as those described in the literature previously cited. On the other hand, this study's actual distribution models contrast with those potential distribution models proposed in studies with a national scope such as "Project DS006 Modeling mammal species distributions in México, a GAP approach" [109]; the former are significantly more restricted than the latter. For instance, even though *Bassariscus astutus* is reported to occur in most of Michoacán [110], and there exist some historic records [5, 111, 112], very few individuals have been recorded in the last two decades [59, 113]. *Bassariscus astutus* model was the most restricted actual distribution among the 11 species (see Figure A2).

The restricted nature of the actual distribution models previously referred to is closely related to the land cover/land use changes observed across the region [114]. A significant number of historic records related to Michoacán's carnivore species are currently located in sites with agricultural and human settlement land uses (106].

4.3. Species distributions and natural protected areas (NPA)/ proposed priority areas

The current NPA and the proposed priority areas (IABC, TPR, PACM, CASM) show gaps, including highest species richness values (10 – 11 species), which are mainly distributed in the *Costas del Sur* and *Cordillera Costera del Sur* provinces. Lower species richness values (7 – 9 species) are included in the ZIBR and other existing proposed areas located inland Michoacán. Indeed, the lowest richness occurs in areas such as *Depresión del Tepalcatepec* which currently is characterized by extensive cropland. Other NPA such as "Pico de Tancíntaro" (northern), "Volcán Nevado de Colima" and "El Jabalí" (northeastern) include middle richness values (4 – 6 species; see Figure 3B).

4.4. Selection of conservation priority areas

Different characteristics of biodiversity elements and application of modeling tools and parameters affect the results in prioritization exercises for selection and complementarity of conservation areas [82, 115]. This study did not generate drastic changes when varying zonation's modeling parameters to identify conservation priority areas. There was a

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consensus for locating priority areas mainly in the *Costas del Sur* province and *Cordillera Costera del Sur* to a lesser extent. One important difference consisted in locating priority areas in the study area's northern portion; when the prioritization applied rule is CAZ and with no species conservation status weighting, high priority areas appeared in "Pico de Tancítaro" and "Volcán Nevado de Colima" NPA (Figure A3a-c).

There exists a spatial correspondence between middle priority importance areas (50 – 85%) with current NPA (ZIBR, "Pico de Tancítaro" and "Volcán Nevado de Colima"). However, there are two sanctuaries, "Playa de Maruata y Colola" and "Playa Mexiquillo", which contain the highest priority importance areas (95 – 100%). These sanctuaries are very reduced areas (220 and 74 ha, respectively), originally defined with the goal of protecting three species of marine turtles (*Lepidochelys olivacea*, *Dermochelys coriacea*, and *Chelonia agassizii*) [116, 117]. Although these sanctuaries are basically marine NPA, they can serve as a geographic reference from which expand or include inland areas for biodiversity conservation.

The ZIBR raises particular interest because of its location, biological diversity, endemism, size (265,000 ha) and legal status. The ZIBR is one of the largest biosphere reserves in Mexico and was created in 2007. This NPA is occupied by high species richness (7 – 9 species) but does not include the highest conservation importance priority. However, this study's results were obtained from a reduced number of species, and it is likely that other wider taxonomic groups would produce higher prioritization estimates within the ZIBR, based on maximization of its biodiversity. This study used a group of umbrella species as indicators of biodiversity and could be considered a preliminary approach for evaluating conservation priority areas [11, 12].

In relation to the deforestation model, this was inverted so that it meant the probability of natural areas to persist with their native land cover type (Figure 3). Therefore, the prioritization procedure selected, as high prioritization importance, conserved areas of tropical dry forest, tropical semi-evergreen forest, and temperate forest. However, the prioritization procedure without the deforestation model resulted in the same selection of areas. This could be since both, high species richness areas coincide with areas of land cover types with high probability of persistence, given the land cover/land use changes occurring between 1993 – 2014.

A comprehensive Marxan proposed prioritization study [50] was compared to this study's results. Such a comprehensive study consisted in applying an optimization analysis of 1,450 biodiversity elements across México, including critical vegetation types, plant species under risk, richness of plants and vertebrate species, resident birds, reptiles, amphibia, and mammals, along with 19 layers of threatening factors [50]. Despite the different scopes applied in each study, there were coincidences in the location of priority sites and areas: Our study included half of CONABIO's high conservation priority sites, included within the study area (Figure 4). In other words, both studies identify the Costas del Sur province in western Michoacán as an important region for conservation of biodiversity. This kind of concurrence supports the idea that a small group of umbrella species may be used as biodiversity indicators, as biodiversity units are useful for prioritizing biodiversity conservation areas.

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5. Conclusions

This study proposes the identification of conservation areas for 11 carnivore species distributed in western Michoacán, México, which represent the basis for further research on: (1) suitable sites to conduct species monitoring across the region; (2) conservation of Michoacán's coastal region, mainly corresponding to Aquila and Lázaro Cárdenas counties; (3) issues about the extent of current proposed regions for biodiversity conservation, given their larger sizes and location; (4) connectivity of areas identified as priority for biodiversity conservation; and (5) comparison of prioritization and complementarity exercises based on analyzing multiple taxonomic groups, including animal and plant taxa of different taxonomic hierarchy and functional groups, such as key and umbrella species.

Author Contributions: Conceptualization, Marisol del Moral, Miguel Ortega, Rodrigo Nuñez; methodology, Marisol del Moral, Miguel Ortega, Rodrigo Nuñez; software, Marisol del Moral, Miguel Ortega; validation, Marisol del Moral, Miguel Ortega; formal analysis, Marisol del Moral, Miguel Ortega; investigation, Marisol del Moral, Miguel Ortega, Rodrigo Nuñez; resources, Marisol del Moral, Miguel Ortega, Rodrigo Nuñez; data curation, Marisol del Moral; writing—original draft preparation, Marisol del Moral, Miguel Ortega; writing—review and editing, Miguel Ortega; visualization, Marisol del Moral, Miguel Ortega; supervision, Miguel Ortega; project administration, Marisol del Moral, Miguel Ortega; funding acquisition, Marisol del Moral. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding

Data Availability Statement: The collection records of carnivores in western Michoacán belong to Rodrigo Nuñez. The rest of the data is public and held by Marisol del Moral.

Acknowledgments: We thank Livia S. León P., Victor M. Sánchez-Cordero D., Enrique Martínez M., Melanie Kolb, Francisco J. Botello L., Fernando A. Cervantes R., who gave important comments and suggestions to previous drafts. Our appreciation to Karla K. Kral for advising the written English. Thanks also to CONACyT (Consejo Nacional de Ciencia y Tecnolgía) for the scholarship given to Marisol del Moral, and the Posgrado en Ciencias Biológicas, Instituto de Biología, UNAM.

Conflicts of Interest: The authors declare no conflict of interest, The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Appendix A

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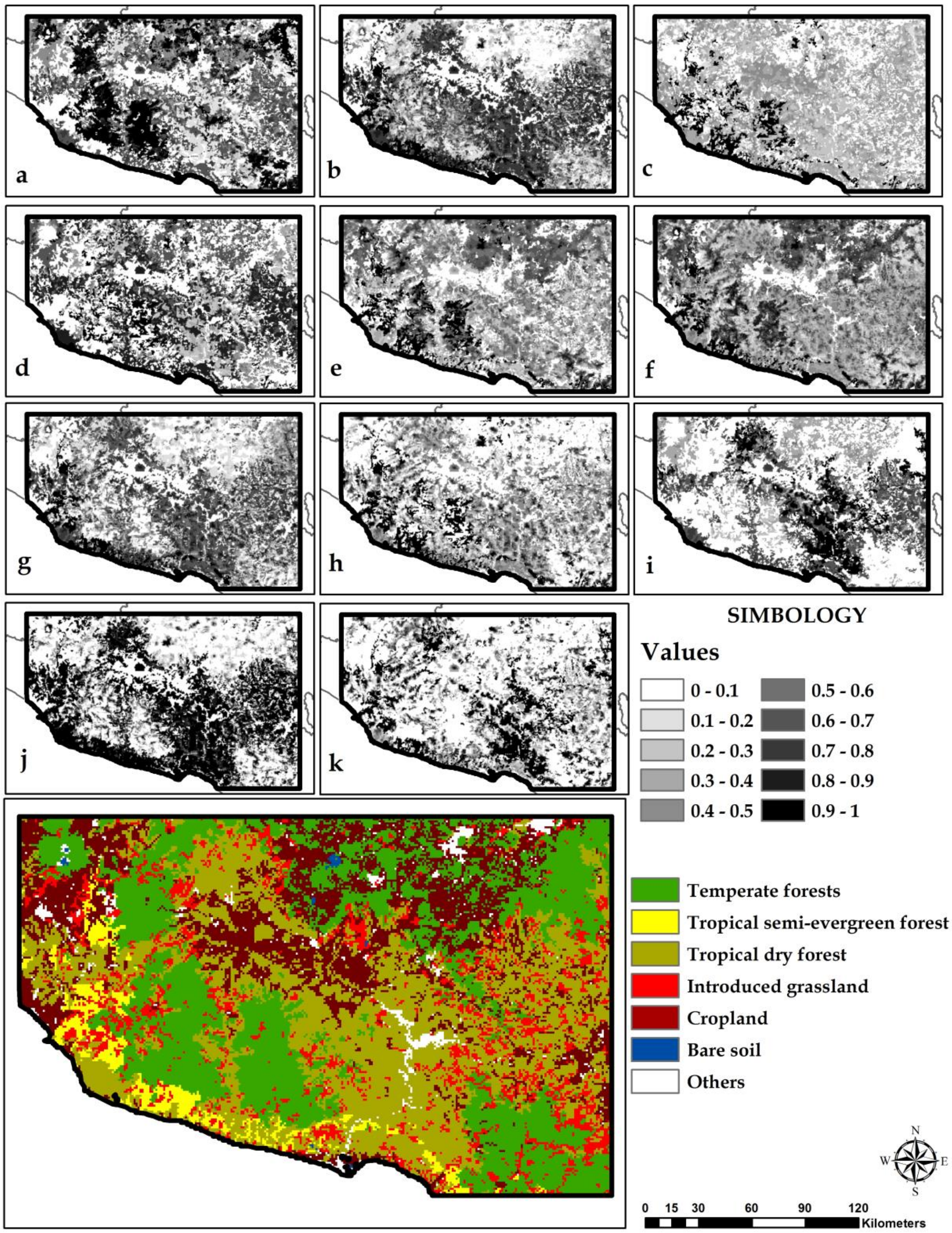

Figure A1. Generalized Linear Models (GLM) for 11 carnivore species and vegetation types in western Michoacán. (a) *Bassariscus astutus*, (b) *Nasua narica*, (c) *Procyon lotor*, (d) *Conepatus leuconotus*, (e) *Canis latrans*, (f) *Urocyon cinereoargenteus*, (g) *Leopardus pardalis*, (h) *Leopardus wiedii*, (i) *Herpailurus yagouaroundi*, (j) *Puma concolor*, (k) *Panthera onca*.

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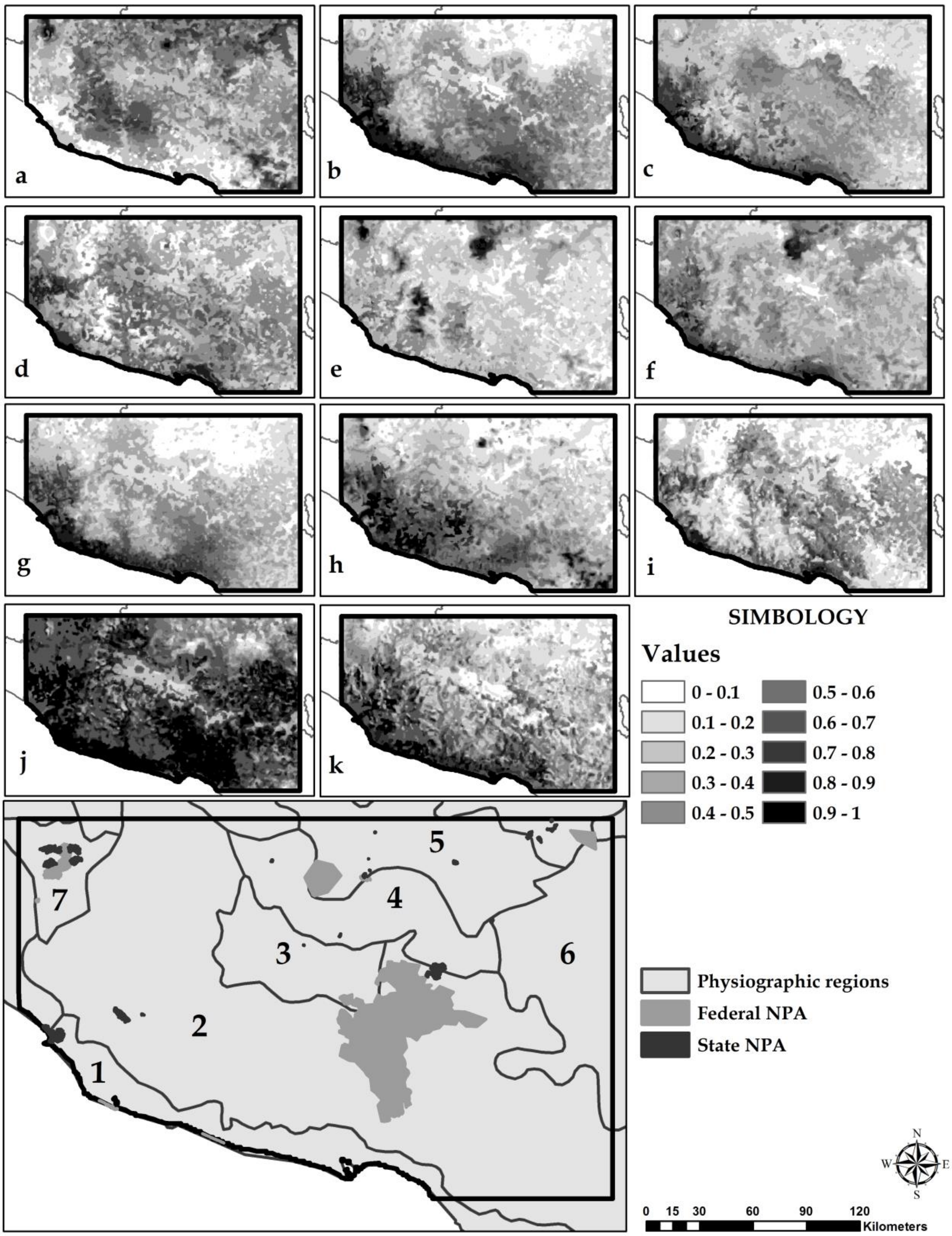

Figure A2. Actual distribution models for 11 carnivore species. (a) *Bassariscus astutus*, (b) *Nasua narica*, (c) *Procyon lotor*, (d) *Conepatus leuconotus*, (e) *Canis latrans*, (f) *Urocyon cinereoargenteus*, (g) *Leopardus pardalis*, (h) *Leopardus wiedii*, (i) *Herpailurus yagouaroundi*, (j) *Puma concolor*, (k) *Panthera onca*. Physiographic provinces: (1) *Costas del Sur*, (2) *Cordillera Costera del Sur*, (3) *Depresión de Tepalcatepec*, (4) *Escarpa Limítrofe del Sur*, (5) *Neovolcánica Tarasca*, (6) *Depresión del Balsas*, y (7) *Chapala*.

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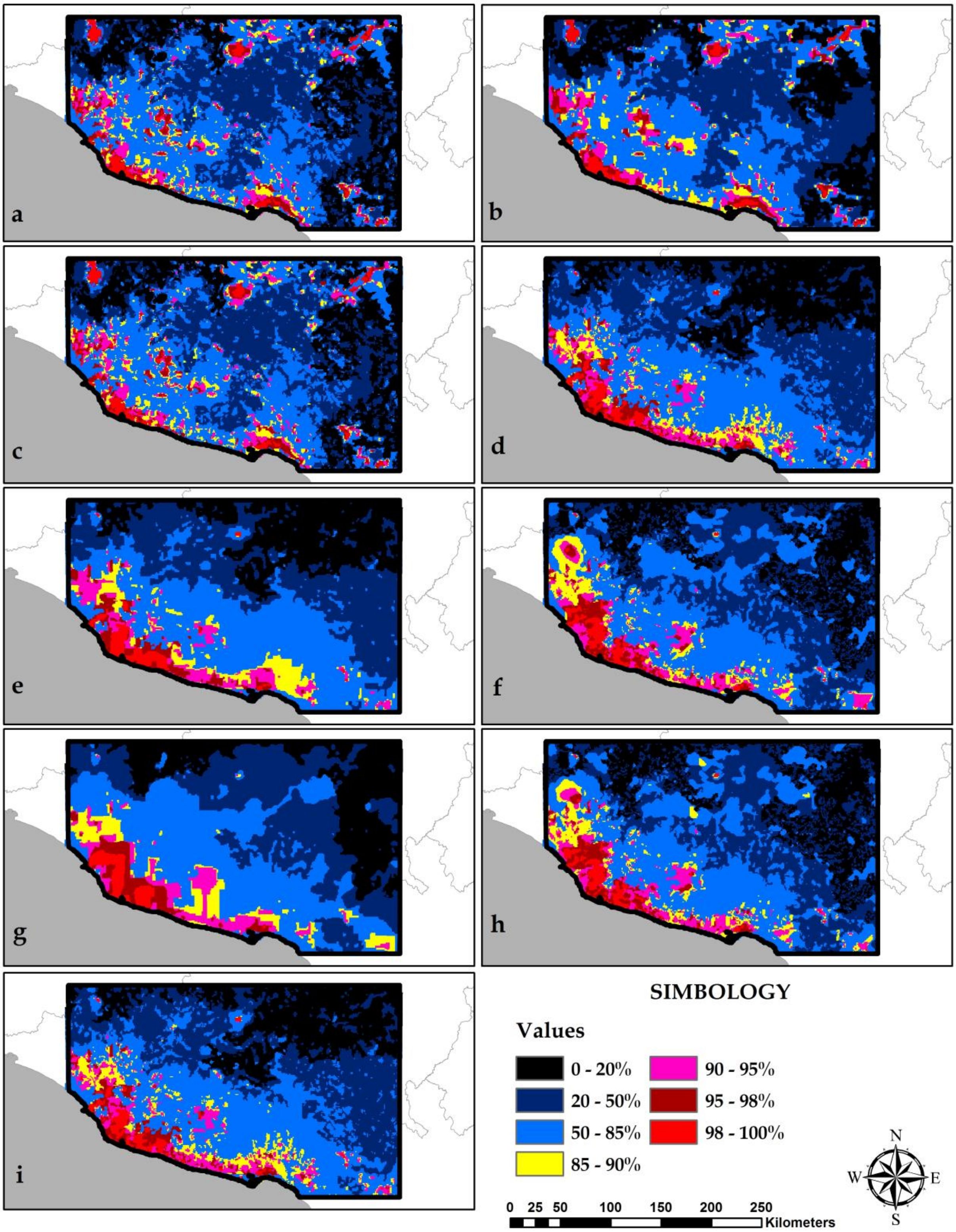

Figure A3. Prioritization (zonation) models, applying the Core Area Zonation (CAZ) elimination rule. (a) Only CAZ, (b) CAZ and BLP (Boundary Length Penalty), (c) CAZ - Smoothed function, (d) CAZ - species Weights, (e) CAZ - species Weights - BLP, (f) CAZ - species weights - inverted deforestation, (g) CAZ - species Weights - inverted deforestation - BLP, (h) CAZ - species Weights - inverted deforestation - Smoothed function, (i) CAZ- species Weights - Smoothed function.

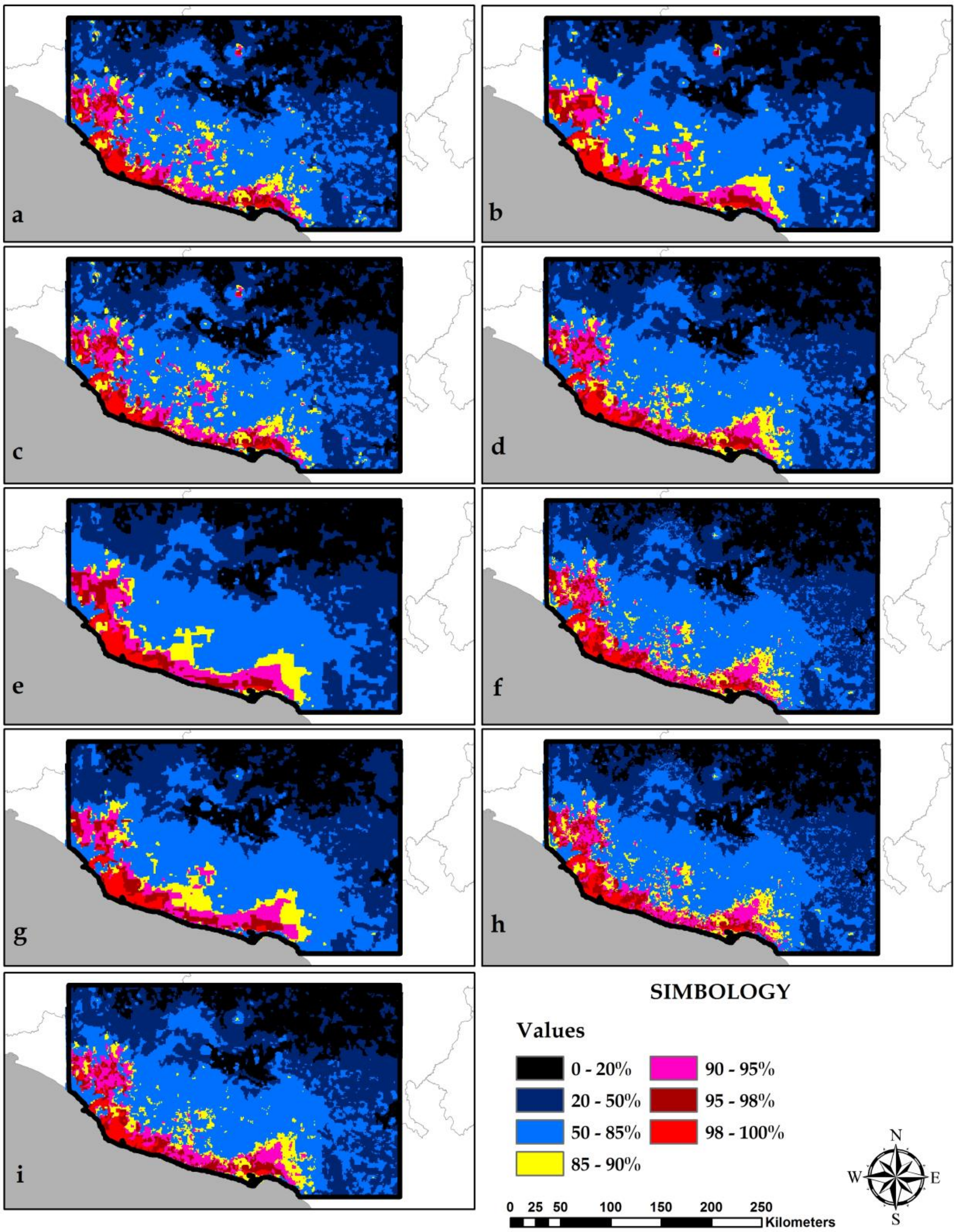

Figure A4. Prioritization (zonation) models, applying the Additive Benefit Function (ABF) elimination rule. (a) Only ABF, (b) ABF and BLP (Boundary Length Penalty), (c) ABF - Smoothed function, (d) ABF - species Weights, (e) ABF - species Weights - BLP, (f) ABF - species weights - inverted deforestation, (g) ABF - species Weights - inverted deforestation - BLP, (h) ABF - species Weights - inverted deforestation - Smoothed function, (i) CAZ- species Weights - Smoothed function.

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