ECOLOGICAL NICHE MODELING AND WILDLIFE MANAGEMENT UNITS (UMAS): AN APPLICATION TO DEER IN CAMPECHE, MÉXICO

[MODELAMIENTO DE NICHO ECOLÓGICO Y UNIDADES DE MANEJO PARA LA CONSERVACIÓN DE LA VIDA SILVESTRE: UNA APLICACIÓN A CIERVOS EN CAMPECHE, MÉXICO]

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SUMMARY

The Units for the Conservation, Management and Sustainable Use of Wildlife (UMAs) are instruments of conservation and management of specific species in Mexico. UMAs represent in southeastern Mexico an important way for deer management, but they have major problems related to the monitoring of species. In this paper, we propose a methodology based on the use of a 'niche centroid approach' for estimating ecological distances to the niche centroid in order to produce distribution maps containing information on the potential relative abundance of species to evaluate the capability of UMAs to maintain populations of deers. We modeled the abundance for *Mazama temama*, *M. pandora* and *Odocoileus virginianus* on the state of Campeche, Mexico. Our predictions of areas with most abundance of deer coincided with reports from literature. We identified the UMAs "Ik Balam" and "Ejido Carlos Cano Cruz" as areas with high proportion of suitable environment, while UMAs "Betito y Lupita", "El Huanal", "Puh", "Refugio faunístico Jalotum", "Ría Lagartos-Ría Celestun" and "Yocol Cab Balam" have not environmental conditions adequate to maintain deer populations. Although this is a preliminary study, it can be a starting point to establish institutional standards for the management of species.

Keywords: Abundance; distribution; Euclidean distance; GARP; mammals.

RESUMEN

Las Unidades de manejo para la conservación de la vida silvestre (UMAs) son instrumentos de conservación y manejo de especies particulares en México. Las UMAs representan en el sureste de México, un mecanismo importante para el manejo de los ciervos, pero tienen problemas importantes relacionados con el monitoreo de las especies. En este artículo, proponemos una metodología basada en el uso de una 'aproximación al centroide del nicho' para estimar las distancias ecológicas al centroide del nicho con la finalidad de producir mapas de distribución que contengan información sobre la abundancia relativa potencial de las especies, para evaluar la capacidad de las UMAs para mantener poblaciones de ciervos. Modelamos la abundancia de *Mazama temama*, *M. pandora* y *Odocoileus virginianus* en el estado de Campeche, México. Nuestras predicciones de las áreas con mayor abundancia de ciervos coincidieron con reportes de literatura. Identificamos las UMAs "Ik Balam" y "Ejido Carlos Cano Cruz" como áreas con alta proporción de hábitat adecuado, mientras que las UMAs "Betito y Lupita", "El Huanal", "Puh", "Refugio faunístico Jalotum", "Ría Lagartos-Ría Celestun" y "Yocol Cab Balam" no tienen condiciones ambientales adecuadas para mantener poblaciones de ciervos. Aunque éste es un estudio preliminar, se considera como un punto de inicio para establecer estándares institucionales para el manejo de especies.

Palabras clave: Abundancia; distribución; distancia Euclideana; GARP; mamíferos.

INTRODUCTION

The Units for the Conservation, Management and Sustainable Use of Wildlife (UMAs, from its Spanish name) are instruments of conservation and management of specific flora and fauna species in Mexico (Secretaría de Medio Ambiente, Recursos Naturales y Pesca, 1997; Diario Oficial de la Federación, 2000). UMAs are either wild or managed lands (extensive UMAs), or enclosures or greenhouses (intensive UMAs) registered to operate in accordance to an approved management plan to harvest individuals of one or more species for which there is a continuous monitoring of habitat and populations/individuals (Diario Oficial de la Federación, 2000). In the extensive UMAs, species are managed in wild conditions (*in situ*), therefore population numbers are estimated from field sampling. The UMAs system is much more developed in northern Mexico, holding more than 80% of all UMAs in the country (see March *et al.*, 2009). In southeastern Mexico, the state of Campeche holds the largest number of UMAs (Secretaría de Medio Ambiente y Recursos Naturales, 2011), where almost all of them (99%) are extensive UMAs (García-Marmolejo, 2005). However, few studies have being carried out to characterize UMAs and evaluate their effectiveness for conservation (González Marín *et al.*, 2003; García-Marmolejo *et al.*, 2008; Mandujano and González-Zamora, 2009).

A major operative problem in the extensive UMAs is to maintain reliable technical assistance and monitoring of species and to avoid illegal harvest of non-target species (March *et al.*, 2009). Estimating populations of most hunting species is especially difficult in the humid tropics (e.g., Campeche) (Weber *et al.*, 2006), and because authorization for the extraction quota depends on such estimations, it would be very useful to have a methodological approach to produce baseline data on the expected abundance of target species to serve as a reference for determining whether the numbers reported by field technicians are realistic or not.

In recent years, ecological niche modeling has developed and established as a robust approach for mapping species' geographic distributions via the characterization of suitable areas based upon occurrence records and a suite of environmental variables that are known or assumed as distributional conditionals. This approach has been broadly tested for many species of basically all groups, with generally reliable results for predicting species' distributions (see Elith and Leathwick, 2009). Although it is controversial about what is the best algorithm for modeling (Pearson *et al.*, 2006; Elith *et al.*, 2006; Guisan *et al.*, 2007; Tsoar *et al*., 2007; see Pliscoff and Fuentes-Castillo, 2011), the Genetic Algorithm for Rule-set Production (GARP; Stockwell and Noble, 1992; Stockwell, 1999) is maintained as a good option for modeling (for example: Haverkost *et al.*, 2010; Ray *et al.*, 2011; Kumara and Suganthasakthivel, 2011; Marín-Togo *et al.*, 2012).

Although some authors have found that high quality habitat are not necessarily directly related with the density of species (Van Horne, 1983); in previous works, Díaz-Porras (2006) and Martínez-Meyer *et al.* (2013) demonstrated that abundance distributional patterns hold a strong inverse relationship with the distance to the ecological niche centroid in several species of birds, mammals and a reptile. In other words, the abundance of a species in a specific locality is determined by the niche conditions therein (Brown, 1995) and optimal conditions are around the niche centroid in ecological space, thus the closer a locality is to the niche centroid the higher its abundance (Maguire, 1973; Yañez-Arenas *et al.*, 2012).

In this paper we use the 'niche centroid approach' for estimating ecological distances to the niche centroid for three species of ungulates with the aim to produce distribution maps containing information on the potential relative abundance of species based on the ecological characteristics of the landscape, and evaluate the capability of UMAs to maintain populations of these mammals in Campeche, Mexico, as a management tool for authorities and decision makers.

MATERIAL AND METHODS

We analyzed three species of deer (Artiodactyla: Cervidae): *Mazama temama* (South American red brocket), *M. pandora* (Yucatan brown brocket), and *Odocoileus virginianus* (white-tailed deer), which have been authorized to be managed in UMAs in Campeche since 1999 to date. For these species, we obtained occurrence data points for modeling for the whole Yucatán Peninsula from Escalante *et al.* (2002), Sánchez-Cordero (2003), El Colegio de la Frontera Sur (Unidad Chetumal), and collections in Global Biodiversity Information Facility (http://www.gbif.org/), Mammal Networked Information System (MaNIS) (MaNIS, 2008), REMIB (Conabio, 2008), and Unidad de Informática para la Biodiversidad (Instituto de Biología, UNAM, 2008). The collections consulted are: Colección Mastozoológica, El Colegio de la Frontera Sur, Unidad San Cristóbal de las Casas; Colección Nacional de Mamíferos, Instituto de Biología, UNAM; Lousiana State University Museum of Natural Science; Mammal collection, The Museum of Vertebrate Zoology at Berkeley; Museo de Zoología, El Colegio de la Frontera Sur, Unidad Chetumal; Museo de Zoología, Facultad de Ciencias, UNAM; Museum of Comparative Zoology, Harvard University; Natural History Museum, University of Kansas; and The Field Museum.

Ecological niche models (ENM) were developed in GARP (Stockwell and Noble, 1992; Stockwell, 1999) with 15 environmental layers. We used an average of monthly Normalized Difference Vegetation Index (NDVI; following Pettorelli *et al.*, 2009) obtained from MODIS (Moderate Resolution Imaging Spectroradiometer) sensor for all the Yucatán Peninsula for years 2001 and 2002, and three topographic layers: elevation data, slope and compound topographic index (USGS, 2008), all of them at cell size of 0.0028 degrees.

For *M. pandora* (less than 20 localities) we modeled with all points. For the other species, we used 75% of points for training and 25% for testing. For each species, we performed 100 individual models using all rules, and from them we selected the ten models that minimized omission and commission errors (Anderson *et al.*, 2003). Best subset models were summed to obtain a consensus map, which got values 0-10, where 0 represents the areas where all models coincided to predict the absence of the species, 1 is where 1 out of 10 models predicted the presence of the species, and so forth until 10, representing the maximum consensus areas. i.e., where all models predicted the presence of the species. Consensus maps were then clipped to the boundaries of state of Campeche (CONABIO, 2003), at scale 1:250 000.

In order to estimate the geographic distribution of relative abundance of each species, we obtained as a proxy a map representing the Euclidean distance of each pixel of the distribution to the ecological centroid. Euclidean distances were calculated as follows: (1) in a GIS, we combined the maximum consensus values of a species distribution map with the 15 environmental layers that we used to model the distribution, to obtain a matrix in which columns contained the values of each environmental variable, and rows the pixels where the species was predicted present; (2) environmental variables were *z*-standardized, thus the mean value of each variable equals zero, being this multidimensional point the niche centroid; and (3) distances to the centroid were calculated with the formula:

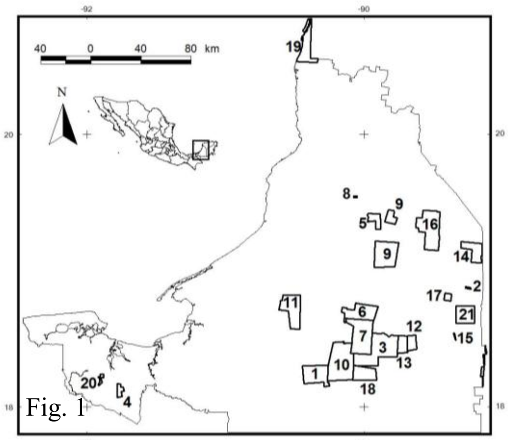
$$Dc = \sqrt{\sum(\bar{\mu}_i - a_{ij})^2}$$

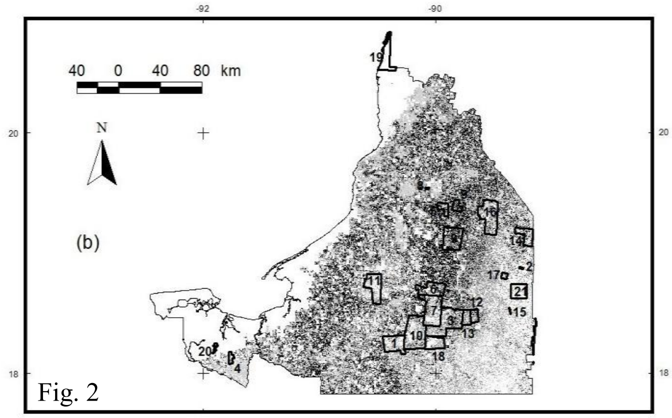
where Dc is the distance to the ecological niche centroid, $\bar{\mu}_i$ is the mean of variable *j* and a_{ij} is the value of the variable *j* in population *i*. Euclidean distances were projected back to the landscape to generate a map which was then overlapped with the UMA polygons map (Secretaría de Medio Ambiente y Recursos Naturales, 2005). Distance values were classified in quartiles in order to identify the places of shorter distances to the centroid (i.e., higher expected abundance), which are more suitable for species management. We considered that the best conditions for species, and the higher values of abundance, will be in the first quartile, which we used for proposing some recommendations for UMA managers.

Because most UMAs have not up-to-date abundance data (needed to validate our models), we used the data of Weber (2005) for Nuevo Becal "ejido" (communal land) (polygon 21 in Fig. 1) for the three species of deer. For this polygon, we averaged the Euclidean distance values of all pixels where each species was predicted present, and compared to the abundance estimation of Weber (2005); also, we calculated the number of pixels belonging to the first quartile. Finally, we calculated the number of pixels in the first quartile of each species for all UMAs in Campeche and compared them with Nuevo Becal "ejido".

RESULTS

We obtained 59 occurrence data points for *Mazama temama*, 15 for *M. pandora* and 87 for *Odocoileus virginianus*. There are 20 UMAs in the digital map of Secretaría de Medio Ambiente y Recursos Naturales (Secretaría de Medio Ambiente y Recursos Naturales, 2005) in Campeche for mammals (Fig. 1). However, Nuevo Becal is not in that map (Fig. 1, drawn by us). Data of abundance for the three species of deer in Nuevo Becal (Weber, 2005), and results of distance are shown in Table 1. Results of validation of models are in Table 2 and the percentage of pixels for each species into each UMA is shown in Table 3. Weber (2005) found that density (deer/km^2) of *Mazama* (both species together) is higher than that of *Odocoileus* in Nuevo Becal, but for both species, the relative abundance and density in Nuevo Becal is lower than that reported elsewhere in the Neotropics. Interestingly, our results coincide with this information: although *Mazama* includes two species, we found that *Mazama* occupies a more extensive area than *O. virginianus* in Nuevo Becal, but this polygon is not the area with the highest habitat quality for the three species in Campeche. On the other hand, UMAs "Ik Balam" and "Ejido Carlos Cano Cruz" have proportionally more high-quality area within their polygons. However, there are some differences for *M. temama, M. pandora* and *O. virginianus*: in "Ejido Carlos Cano Cruz", while *O. virginianus* may be more abundant, *M. pandora* may be less abundant than the white-tailed deer. Following those two UMAs, are "Ejido Constitución" and "Macanguas".





Figures 1 and 2; Units for the Conservation, Management and Sustainable Use of Wildlife (UMAs) and Nuevo Becal Ejido in Campeche, Mexico (names of UMA are in Table 3; Secretaría de Medio Ambiente y Recursos Naturales 2005). Ecological niche model (ENM) for *Mazama temama* showing pixels with Euclidean distance (gray tones indicate nearness to the centroid niche). Polygons are UMAs (see Table 3).

Table 1. Abundance and Euclidean distance for three species of deer in Nuevo Becal polygon.

Deer	Abundance deer/km^2 (permanent transects of Weber, 2005)	Number of pixels with prediction* (percentage of pixels with prediction)	Euclidean distance average	First quartile value (considering all Campeche)	Number of pixels with distance in the first quartile* (percentage)
Mazama temama	0.90±0.72	743 (34.44%)	4.31	2.7393	4 (0.18%)
Mazama pandora		458 (21.23%)	4.42	2.9331	2 (0.09%)
Odocoileus virginianus	0.021	590 (27.35%)	4.47	2.7252	1 (0.04%)

*The total number of pixels in the polygon of Nuevo Becal is 2157. Each pixel size: 0.09 km^2.

Table 2. Results of validation of models by species. We show the range of the omission errors and chi-square values (x^2) for the ten best models.

Species	Omission error	x^2
Mazama temama	0-6.66	0.019-4.95
*Mazama pandora**	-	-
Odocoileus virginiana	0-4.54	0.89-3.39

*Validation was not possible for *M. pandora* because all 15 occurrence data were used for model calibration.

Habitat suitability is not equal for the three species. The largest high-quality areas in the state are for *Mazama temama*, followed by *Odocoileus virginianus*, and finally for *M. pandora*. It is interesting to observe that the two closely related *Mazama* species show contrasting results, and this has important implications for the management of the two species, since in the field the tracks of both species are hard to separate them apart (Weber, 2005) even via direct observations.

Table 3. UMA in Campeche, Mexico: area in km^2 and percentage of number of pixels with prediction in the first quartile of distance for three species of deer.

No.	UMA	*Mazama temama* km² (%)	*Mazama pandora* km² (%)	*Odocoileus virginiana* km² (%)
1	Ampliación forestal Luna	8.46 (3.16)	7.65 (2.85)	2.34 (0.87)
2	Betito y Lupita	0 (0)	0 (0)	0 (0)
3	Campamento Los Jaguares	44.73 (8.59)	45.18 (8.68)	16.70 (3.21)
4	Campo Laguna Blanca	1.17 (2.95)	0 (0)	4.14 (10.45)
5	Ejido Carlos Cano Cruz	24.84 (30.23)	14.13 (17.19)	32.76 (39.86)
6	Ejido Constitución	63.81 (23.63)	43.83 (16.23)	41.76 (15.46)
7	Ejido Xbonil	44.46 (10.30)	40.68 (9.43)	26.55 (6.15)
8	El Huanal	0 (0)	0 (0)	0 (0)
9	Ik Balam	174.33 (43.16)	119.07 (29.48)	179.55 (44.46)
10	Jaguar (*Panthera onca goldmani*) Chilam Balam	14.94 (2.81)	7.74 (1.45)	4.86 (0.91)
11	Laguna Mocu	5.58 (1.89)	6.12 (2.07)	1.8 (0.61)
12	Las Codornices	8.01 (10.11)	6.12 (7.72)	4.77 (6.02)
13	Los Pumas	5.58 (5.53)	7.47 (7.41)	1.62 (1.60)
14	Macanguas	31.5 (19.01)	21.42 (12.92)	32.31 (19.50)
15	Puh	0 (0)	0 (0)	0 (0)
16	Pool Hayin	42.84 (10.11)	23.64 (5.58)	39.06 (9.21)
17	Refugio Faunístico Jalotum	0.09 (0.32)	0.27 (0.98)	0.09 (0.32)
18	Reserva ecológica y cinegética Itzamna	4.68 (2.54)	5.4 (2.93)	1.08 (0.58)
19	Ría Lagartos-Ría Celestún	0 (0)	0 (0)	2.7 (1.59)
20	Yocol Cab Balam Ceh	0 (0)	0 (0)	0.45 (2.5)
21	Nuevo Becal	0.36 (0.18)	0.18 (0.09)	0.09 (0.04)

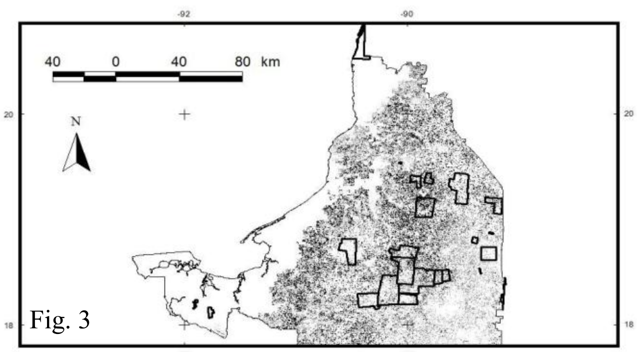
DISCUSSION

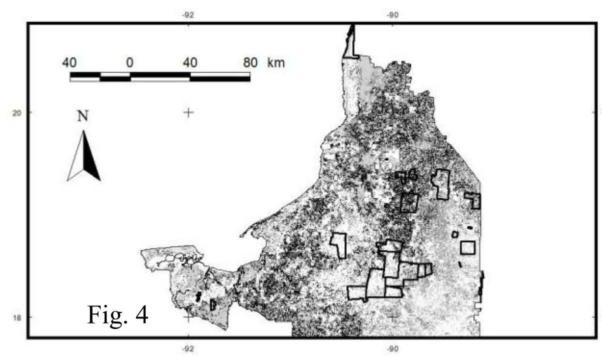
Many problems have been detected in the UMAs of southeastern Mexico, including poor population estimations, introduction of exotic species, overexploitation for gaming and subsistence hunting, etc. (Weber *et al.*, 2006). The first problem is very relevant to extractive activities, because extraction permits are given based on population estimations, and in many cases these are not reliable. The approach presented here aims to alleviate somehow this problem, producing spatially specific estimations of suitable areas for safe extraction without demising populations.

Mandujano and González-Zamora (2009) evaluated the UMAs and other conservation instruments to maintain viable populations of *O. virginianus* on the basis of minimum critical area for the whole country, and they found that UMAs are generally unsuitable to maintain viable populations. For *O. virginianus*, it is necessary a minimum critical area of 1,667 to 50,000 ha to support a minimum viable population of 500 deer, or 16,670 (16.67 km^2) to 500,000 ha (5,000 km^2) for long-term viability of 5,000 deer, depending on regional deer density (Mandujano and González-Zamora, 2009). Because the minimum critical area increased in a non-lineal trend as the population density diminished (Mandujano and González-Zamora, 2009), for *O. virginianus* in Nuevo Becal, with density of 0.021 deer/km^2, the minimum critical area (500 deer) will be 23,809 km^2, that means, areas extremely large. However, for species of *Mazama* with density of 0.90 deer/km^2, the minimum critical area will be 555 km^2. The total surface of Nuevo Becal is 520 km^2, just enough to maintain a minimum viable population of *Mazama*, but evidently low for *O. virginianus*.

For the other UMAs in Campeche, it should be assessed the density of deer, but even using the densities of Nuevo Becal, many of them have not the enough area to maintain minimum viable populations. For example, “Betito y Lupita”, “El Huanal” and “Puh”, hold 56, 27 and 39 km^2, respectively, and none of them have pixels of the first quartile. However, other bigger UMAs, like “Refugio faunístico Jalotum”, “Ría Lagartos-Ría Celestun” and “Yocol Cab Balam Ceh” (305, 1,884 and 200 km^2, respectively), despite being considerably larger, do not have environmental conditions adequate to maintain populations of deer. So, the size of the UMAs is not sufficient to sustain a certain number of deer for a sustainable exploitation, but depends on the density and adequate environmental conditions.

In Yucatán (a state contiguous to Campeche), *O. virginianus*, *Cuniculus paca* and *Pecari tajacu* are the species more managed in intensive UMAs, which are a modality more similar to breeding as they raise those species in confined spaces, because they are the most demanded by consumers (González-Marín *et al.*, 2003). These authors pointed that the information about of extensive UMA is insufficient to know if they are working as a useful tool for conservation. Few efforts have focused on UMAs of Campeche. García-Marmolejo *et al.*, (2008) developed a multicriterion framework to evaluate performance and sustainability of 6 UMAs in Campeche, considering environment, economy, social development, and laws and rules. They found that the quality of technical studies to support extraction rates (including, for example, transects to estimates population densities) was generally low. Moreover, although extractive rates were generally below the allowed rates, these were derived from unreliable sampling.





Figures 3 and 4; ENM for *M. pandora* showing pixels with Euclidean distance (gray tones indicate neareness to the centroid niche). Polygons are UMAs (see Table 3). ENM for *Odocoileus virginianus* showing pixels with Euclidean distance (gray tones indicate nearness to the centroid niche). Polygons are UMAs (see Table 3).

CONCLUSIONS

The use of this methodology will help authorities to make decisions using additional information. We propose a protocol with six steps: (1) obtain data of known presence of taxa and area of study, (2) model the ecological niche of taxa, (3) model the abundance using the Euclidean distance and map this measures, (4) test the model of abundance using field data, (5) overlap the map of abundance and UMAs and quantify areas, and (6) make decision about new UMAs, permissions to existent UMAs and evaluation of reports of UMAs for past periods.

The strategy presented here can be used to validate the technical reports of UMAs, and can be used to estimate the rates of extraction allowed by period. Following the proposal of Weber *et al.* (2006), this work can be a starting point to establish institutional standards, and a network of regional centers for management of UMAs can be the mechanism to apply the methodology proposed here.

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