UNIVERSIDAD AUTÓNOMA DEL ESTADO DE MÉXICO

MAESTRÍA Y DOCTORADO EN CIENCIAS AGROPECUARIAS Y RECURSOS NATURALES

EVALUACIÓN DE LAS PRINCIPALES AMENAZAS DE *Heloderma horridum*: PROPUESTAS PARA SU CONSERVACIÓN

TESIS

QUE PARA OBTENER EL GRADO DE DOCTOR EN CIENCIAS AGROPECUARIAS Y RECURSOS NATURALES

PRESENTA:

HUBLESTER DOMÍNGUEZ VEGA

El Cerrillo Piedras Blancas, Toluca, Estado de México. Abril 2014

UNIVERSIDAD AUTÓNOMA DEL ESTADO DE MÉXICO

MAESTRÍA Y DOCTORADO EN CIENCIAS AGROPECUARIAS Y RECURSOS NATURALES

EVALUACIÓN DE LAS PRINCIPALES AMENAZAS DE *Heloderma horridum*: PROPUESTAS PARA SU CONSERVACIÓN

TESIS

QUE PARA OBTENER EL GRADO DE DOCTOR EN CIENCIAS AGROPECUARIAS Y RECURSOS NATURALES

PRESENTA:

HUBLESTER DOMÍNGUEZ VEGA

COMITÉ DE TUTORES:

Dr. F. Javier Manjarrez Silva

Dr. Octavio Monroy Vilchis

Dr. Carlos J. Balderas Valdivia

El Cerrillo Piedras Blancas, Toluca, Estado de México. Abril 2014

A Emilano Atecaltzin

RESUMEN

Los escorpiones (Squamata: Helodermatidae) componen un grupo de saurios de cinco especies con varias características distintivas. Entre sus particularidades destaca la presencia de un sistema bien desarrollado para la producción e inoculación de veneno, una apariencia tosca y coloración generalmente llamativa. Sus características han despertado el interés de las personas desde la época prehispánica y debido a ello son parte importante del folclor mexicano. Sin embargo, actualmente existe un conflicto entre humanos y estos reptiles que amenaza su persistencia. Los escorpiones se distribuyen en las selvas bajas de la vertiente del pacífico mexicano desde el estado de Sonora hasta Chiapas, sin embargo, se consideran especies de ocurrencia rara debido a la baja densidad de sus poblaciones y su limitada actividad superficial. Además, sus requerimientos de clima y alimento indican que se restringen a ambientes conservados para sobrevivir, lo que les confiere importancia como especies indicadoras de la calidad del hábitat. Igual que muchas otras especies, los escorpiones están amenazados por la reducción y fragmentación de su hábitat pero además, este grupo es víctima de cacería aversiva y comercio ilegal. Debido a su condición de rareza y los gastos que implican su estudio, las investigaciones sobre estos animales han sido escasas y el conocimiento sobre su biología limitado. El desarrollo de herramientas de análisis de datos como los sistemas de información geográfica, estadística multivariada y teorías como el nicho ecológico permiten el estudio de especies con escasa información biológica, donde se pueden aprovechar al máximo los registros reunidos de varias fuentes y a través de periodos temporales relativamente largos como es el caso de los escorpiones. En este estudio se presentan aportes al conocimiento de la ecología de los escorpiones que incluyen la identificación de su área de distribución potencial, el análisis de los efectos de

las perturbaciones sobre su hábitat en relación a la selección de sitios de ocurrencia, la cuantificación de la frecuencia de cacería aversiva y las perspectivas de persistencia de sus poblaciones con base en las tendencias de modificación de la vegetación nativa en su área de distribución. Los escorpiones son un grupo expuesto a serias presiones antropogénicas y escasa protección, que además es sensible a la perturbación de su hábitat; por lo que se requiere de un plan de conservación donde se incluya el manejo de la estructura de la vegetación y educación ambiental además de la creación de áreas naturales protegidas en las zonas de alta calidad de hábitat y con posibilidades de persistencia para garantizar su conservación a largo plazo.

ABSTRACT

The Beaded Lizards (Squamata: Helodermatidae) compose a saurian group of five species presenting several distinctive characteristics. Among its particularities, we found a well-developed system for production and inoculation of venom, a rough aspect and striking coloration. Its characteristics have awakening the human interest since pre-hispanic times and that is why beaded lizards are included in Mexican folklore. Nonetheless, nowadays a strong conflict exists between these reptiles and people that threat its persistence. Beaded lizards are found in Mexican tropical dry forests of the pacific slope from Sonora State to Chiapas; however they are considered rare species due to the low density of their populations and their low activity rates. Besides, it's climatic and food requirements suggest that they are restricted to well-preserved environments which confer them relevance as key species of habitat quality. As many other species, beaded lizards are threatened by habitat reduction and fragmentation but besides, they are victims of aversive hunting and illegal trade. Due to its conditions as rare species and the expensive implications of their study, investigation on these animals has been scarce and the knowledge on its biology restricted. The development of some tools for data analysis as the geographic information systems, multivariate statistics and niche theory allow us to study species as the beaded lizards that present scarce biological information and exploit the records gathered from several sources and across a relative large time period. In this study we present some contributions to the ecological knowledge of beaded lizards that include the identification of its potential distribution area, the analysis of the effects of habitat perturbations on site selection, aversive hunting estimation and the perspectives of persistence for their populations based on land change tendencies. The beaded lizards are

exposed to strong anthropogenic pressures and scarce protection; moreover they are habitat perturbation´s sensitive species. It is proposed that a conservation strategy is needed where the structure of vegetation can be controlled and environmental education can be included, besides, the creation of natural protected areas are also recommended in areas of high habitat quality and persistence to assure the long span conservation of beaded lizards.

AGRADECIMIENTOS

A CONACYT por la beca otorgada durante tres años y medio para la realización de esta tesis. A mis tutores: Javier, Octavio y Carlos por su apoyo y consejos para desarrollar y terminar esta tesis y sobre todo por compartir sus experiencias académicas. A los revisores de esta tesis: Ulises Aguilera, Carmen Zepeda, Víctor Fajardo y Hermilo Sánchez. A la UAEMex., por ser un espacio agradable para mi aprendizaje y formación por 16 años. A mis compañeros de laboratorio por su apoyo en el trabajo de campo, recomendaciones académicas a lo largo del desarrollo de este trabajo y por su amistad. En especial a Edgar, Víctor y Jesús. A las personas que contribuyeron con su conocimiento sobre los escorpiones en las distintas localidades de trabajo. También a quienes además ayudaron a contactar a estas personas: Bernabé Vega, Don Margarito, Raunel, Margarito, Sirino, Don Alfredo, Don Adán, Don Quino y Sergio Pedrero. A mis amigos y colegas: Yuriana, Tamara, Leroy, Víctor, Clarita y Claudia por su invaluable apoyo, compañía y consejos que ayudaron a mejorar y terminar esta tesis. A todos los demás amigos cuya compañía y alegría alimenta y ameniza cualquier trabajo.

A mi familia por su apoyo incondicional y consejos.

En la tierra hay suficiente para satisfacer las necesidades de todos, pero no tanto para satisfacer la avaricia de algunos…

Gandhi

CONTENIDO

LISTA DE TABLAS

LISTA DE FIGURAS

INTRODUCCIÓN GENERAL

"El escorpión: un lagarto poco conocido"

Hublester Domínguez-Vega[1], Octavio Monroy-Vilchis[1] y Carlos J. Balderas-Valdivia[2]

Artículo de divulgación

[1]Universidad Autónoma del estado de México. Centro de investigación en recursos bióticos. Calle Instituto literario # 100 Col. Centro, Toluca Estado de México.

hdvar83@gmail.com

[2]Universidad Nacional Autónoma de México, Laboratorio de Biodiversidad, Dirección General de Divulgación de la Ciencia, Zona Cultural de Cd. Universitaria, Coyoacán, D. F., CP 04510, México. Tel. 56 22 75 05, e-mail: cjbv@servidor.unam.mx

El escorpión: un lagarto poco conocido

Escorpión, Acaltetepon o niño dormido son algunos de los nombres comunes del lagarto *Heloderma horridum* (del griego *helos* = tachuela, perno, cabeza de clavo; *dermis* = piel; y del latín *horridum* = áspero o rudo; "entachuelado de la piel áspero"), y que junto con su famosa especie hermana el "monstruo de Gila" *(Heloderma suspectum),* son los únicos integrantes de la familia Helodermatidae. Estos lagartos exclusivos de norte y centro América presentan características únicas entre los reptiles y hasta nuestros días ha permanecido como uno de los grupos menos estudiados, aun cuando paradójicamente se puede considerar entre los más famosos. Sus parientes vivos más cercanos son los varanos, y en conjunto, están emparentados más próximamente con las serpientes que con el resto de los lagartos. Por esta razón, presentan características como una lengua bífida para detectar olores, rituales de combate entre machos durante la época de apareamiento y capacidad de ingerir grandes cantidades de alimento.

Los escorpiones

Desde la primera descripción del escorpión en 1615, estos animales han permanecido desconocidos para el mundo científico. En el ambiente popular, por otro lado, los escorpiones son muy famosos a pesar de que sus avistamientos son poco frecuentes para las personas. Esta fama es debida a la característica más conocida de los escorpiones, "que poseen veneno". De hecho, hasta 2006 se pensaba que los helodermátidos eran los únicos lagartos venenosos, lo que ha inspirado muchas leyendas a su alrededor y a últimas fechas ha despertado el interés y la curiosidad de algunos científicos. Actualmente se ha comprobado que varias otras lagartijas tienen toxinas en su saliva, pero se sigue considerando que el escorpión y el monstruo de gila son los únicos con un sistema bien desarrollado para la producción e inoculación de veneno. Este sistema incluye glándulas especializadas para producir el veneno, conductos de secreción del mismo hacia dientes acanalados que dirigen y escurren el veneno en la victima con una mordida tenaz y dolorosa (de acuerdo a lo narrado por las escasas víctimas humanas conocidas).

Es bien conocido que existen muchas serpientes venenosas. Entonces, ¿por qué es atractivo el veneno de los escorpiones como objeto de estudio científico? Una de las principales razones es que es muy diferente al que presentan las serpientes. Esta diferencia consiste en que en las serpientes, el veneno se almacena en la mandíbula superior mientras que en los escorpiones se almacena en la inferior. Además, las serpientes utilizan el veneno para cazar sus presas e incluso les ayuda a digerirlas, mientras que en los escorpiones, el veneno funciona como defensa contra sus posibles depredadores. Por lo tanto, es de esperarse que presente diferentes propiedades al de sus parientes. Al igual que la mayoría de los aspectos biológicos de los helodermátidos, su veneno ha sido poco estudiado. Sin embargo, el interés en esta área ha ido en aumento poco a poco, principalmente debido a las aplicaciones médicas recientemente descubiertas, entre las que se incluyen el tratamiento de la diabetes y el cáncer.

Otra de las peculiaridades más notables de los escorpiones es que presentan escamas modificadas en la región dorsal de su cuerpo, patas y cola. Las cuales son conocidas como osteodermos. Estas estructuras poseen hueso debajo de una capa endurecida de piel y son muy semejantes en forma, tamaño y textura a las cuentas de chaquira. Por esta razón, también son conocidos como “lagartos enchaquirados”. Además de adornar a los escorpiones, los osteodermos les sirven como protección, al crear una especie de armadura semirígida. Los patrones de coloración de estos animales completan su aspecto singular y muy atractivo para los amantes de los animales extraños. Sin embargo, como discutiremos más adelante, las personas que comparten el mismo sitio con los escorpiones tienen una opinión diferente de ellos.

Otros rasgos distintivos, son que poseen una cola robusta en la cual almacenan nutrimentos en forma de grasas, y que son utilizados de manera gradual durante un prolongado periodo de letargo (inactividad semejante al sueño, en este caso de cuatro a cinco meses). Además, su cola es semiprensil y les ayuda a trepar por los árboles en busca de su alimento. Su cabeza y cuerpo son robustos y a primera vista se asemejan a los de la iguana negra. Sus patas son cortas en relación a su cuerpo y esta característica los obliga a desplazarse con lentitud aun cuando se vean amenazados. Todas estas características hacen de los escorpiones unos animales muy diferentes a los que normalmente observamos, y probablemente debido a ello han inspirado muchas leyendas y mitos a lo largo de su distribución.

El hogar del escorpión y sus amenazas

Estas rarezas vivientes habitan casi exclusivamente en México, su distribución se extiende cercana a la costa del Océano Pacífico desde el sur de Sonora hasta Chiapas. Se incluye también una porción importante del centro del país en la región conocida como Depresión del Río Balsas, la cual abarca parte de los estados de Michoacán, Guerrero, México, Morelos, Puebla y Oaxaca. Su población más sureña (la única fuera de nuestro país y además al borde de la extinción), se encuentra en una región conocida como valle Motagua en Guatemala. La distribución conocida de los escorpiones se ha determinado poco a poco con los escasos reportes de avistamientos acumulados a lo largo de casi 400 años. Sin embargo, hasta la fecha se considera que pueden existir en lugares no reportados, así como lugares donde sus poblaciones se han extinguido. Como ejemplo de ello, en los últimos 10 años se documentó esta especie para el estado de México, Puebla y Durango. A lo largo de toda su distribución, el escorpión coincide casi exclusivamente con un ecosistema conocido como selva baja caducifolia. Además, este ecosistema ha sido reconocido como el más amenazado a nivel mundial, lo que implica que los escorpiones también se encuentran gravemente amenazados. De hecho, la pérdida de su hábitat constituye la principal amenaza para estos y muchos otros animales. Sus otras dos grandes amenazas son la cacería indiscriminada causada por las creencias equivocadas y el comercio ilegal, principalmente como mascotas y como rituales. Por si fuera poco, los escorpiones tienen que enfrentar la adversidad de su medio natural, pues no solo deben soportar hasta cinco meses de fuertes sequías; sino además, desde que nacen y sin que nadie les enseñe o ayude a defenderse, a muchos depredadores. Entre los enemigos naturales más temidos para estos lagartos están las serpientes, los coyotes, aves de presa y otros vertebrados.

Debido a lo anterior, esta especie es considerada por las leyes mexicanas y normas internacionales como “amenazada”, con excepción de la subespecie *Heloderma horridum charlesbogerti* que vive en Guatemala que está en verdadero peligro de extinción. A pesar de estos peligros, la falta de estudios sobre su reproducción, supervivencia y otras características biológicas ha impedido que se establezcan planes apropiados para su conservación. Sin embargo, es necesario reconocer que en nuestro país se encuentra la gran mayoría de su hábitat por lo que es urgente actuar para garantizar que los escorpiones no desaparezcan.

Mitos y verdades

La carencia de información sobre la biología de los helodermatidos, en particular sobre *Heloderma horridum*, está directamente relacionada con dos características propias de la especie. En primer lugar, es bien sabido que los escorpiones son animales de poca actividad. Se ha estimado que pueden pasar más del 90% de su vida en sus refugios. En segundo lugar, se cree que las poblaciones de escorpiones mantienen bajas densidades de manera natural. Debido a esto, los registros de escorpiones son poco frecuentes, y los que se tienen han sido en su mayoría encuentros casuales. De hecho, debido al gran esfuerzo de búsqueda necesario para encontrar a un escorpión, se ha calculado en 500 horas/hombre por individuo. Los estudios sobre esta especie sólo se han realizado en dos localidades: Chamela, Jalisco y en el valle Motagua, Guatemala. Donde se ha determinado que su dieta se compone de huevos de aves y reptiles así como de crías de aves y mamíferos. Un aspecto importante es que los escorpiones pueden consumir hasta un tercio de su peso en un solo alimento. Además, se ha comprobado que su metabolismo es muy lento cuando están en reposo. Es decir, tardan mucho en digerir su alimento, por lo que pueden mantenerse sin alimentarse por largos periodos. Sin embargo, para encontrar su alimento deben moverse continuamente y pueden llegar a cubrir un espacio de hasta 24 hectáreas, o sea 22 canchas de futbol, lo que resulta impresionante para un animal de su tamaño.

Desafortunadamente debido a su veneno y su apariencia, estos animales son considerados agresivos y muy peligrosos en todo su territorio. Lo que ha propiciado que se genere una gran cantidad de mitos sobre ellos. Es impresionante como las personas a través de estas historias populares les han conferido poderes casi mágicos, entre ellos, matar rápidamente a cualquier persona que se cruce con ellos. Tal vez, las más populares sean las que cuentan cómo las personas mueren envenenadas si se tiene contacto con la sombra de un escorpión. Entonces, aparecerá la imagen del escorpión como un tatuaje en el pecho de la víctima e indudablemente morirá. Estas historias han generado un conflicto grave entre las personas y los escorpiones, y han llevado esta relación al caso extremo de que cuando un escorpión es localizado casi invariablemente resulta muerto. La realidad sobre los escorpiones es que son animales muy discretos y poco agresivos, que prefieren evadir el contacto con los humanos. En su caso, utilizarán la huida como primer método de defensa, si ésta no funciona, emplearán varios métodos de intimidación y dejaran el ataque como recurso final y desesperado.

Las historias de escorpiones que atacan y matan personas son muy comunes en comunidades pequeñas, incluso algunas han llegado a aparecer en reportes médicos formales. De estas últimas sin embargo, la gran mayoría son muy antiguas y dudosas. Los casos confirmados de estos accidentes son muy raros y de estos se ha obtenido que los síntomas del envenenamiento varíen debido a diversos factores como el peso del animal y de la persona. Pero entre los más comunes se puede mencionar sangrado abundante, dolor intenso, edema (acumulación de líquido), debilidad y nauseas. Es importante mencionar que la mayoría de los casos de mordeduras confirmadas son debidos a la imprudencia, ignorancia o errores cuando se manipulan animales, ya sean cautivos como mascotas o en zoológicos, o uno que otro caso rural. A pesar de estos desafortunados accidentes, es un hecho que en condiciones de cautiverio, muchos individuos pueden volverse muy dóciles.

Donde sus experimentadores o cuidadores pueden cargarlos y acariciarlos con las manos; esto, sin que represente riesgo alguno y en porcentajes muy elevados y confiables. Tanto, que en algunos zoológicos y museos incluso los niños pueden los pueden tocar durante una emocionante visita.

Después de casi 400 años de la primera descripción de un escorpión, se han logrado avances significativos en la comprensión de la biología de una de las especies de reptiles más evasivas de nuestro país. Sin embargo, es mucho lo que hace falta por conocer, por ejemplo sobre sus aspectos reproductivos y conducta. Como primer paso para avanzar en el conocimiento de los escorpiones es necesario iniciar un cambio radical en la manera en la que las personas ven a estos animales, y promover estudios sobre su biología para poder conservar uno de los animales más peculiares y emblemáticos de la basta diversidad de reptiles de México.

JUSTIFICACIÓN

Debido a las características biológicas y ecológicas de los Helodermátidos de la selva baja, el conocimiento científico desarrollado a su alrededor es limitado. Sin embargo, los escasos estudios en vida libre, junto con los realizados en laboratorio, han permitido evidenciar la importancia de los escorpiones en diferentes aspectos que incluyen la conservación de ambientes amenazados, evolución de los reptiles, salud humana, sociología, etc. Por lo que es importante conservar estas especies y conocer sus características biológicas con el fin de mantener y manejar apropiadamente un recurso con relevancia biológica y cultural. Por otra parte, a pesar de que se conocen las amenazas para su persistencia, se ignora su efecto actual sobre estos animales así como el estado de conservación de sus poblaciones; por lo que no se pueden aplicar estrategias apropiadas para su conservación. Por lo tanto, es necesario determinar las características básicas sobre la ocurrencia de estos animales como sus límites de distribución, el estado de su hábitat y la intensidad y efecto de las actividades que se consideran sus principales amenazas. Con base en ello se podrá iniciar con un plan de conservación apropiado para garantizar la persistencia de los escorpiones a largo plazo.

OBJETIVOS

Determinar la distribución potencial de los escorpiones así como las características ambientales que restringen su ocurrencia y el grado de protección de estas especies en áreas naturales protegidas.

Determinar y cuantificar el efecto de las perturbaciones del hábitat sobre los patrones de selección de hábitat y amplitud de nicho espacial de los escorpiones.

Identificar las variables estructurales y de composición de la vegetación asociadas a la capacidad de respuesta de los escorpiones en ambientes perturbados.

Cuantificar la frecuencia de avistamientos y cacería aversiva sobre los escorpiones y analizar su relación con la estructura de la vegetación.

Identificar las zonas con mejores condiciones ambientales para la ocurrencia de los escorpiones y analizar su viabilidad a mediano plazo como áreas de protección mediante un escenario de cambio de la cobertura vegetal.

RESULTADOS

Capítulo I. Predicting de Potential Distribution of beaded lizard and identification of priority areas for conservation.

Hublester Domíguez-Vega[a], Octavio Monroy-Vilchis[a*], Carlos J. Balderas-Valdivia[b], C.M. Gienger[c] and Daniel Ariano-Sánchez[d]. **Publicado en: Journal for Nature Conservation. 2012**

[a] Estación Biológica Sierra Nanchititla, Facultad de Ciencias. Universidad Autónoma del Estado de México. Instituto literario # 100. Colonia Centro. Toluca, Estado de México. CP 50000

[b] Laboratorio de Biodiversidad, Dirección General de Divulgación de la Ciencia, Universidad Nacional Autónoma México. Zona Cultural de Cd. Universitaria, Coyoacán, D. F., CP 04510, México

[c] School of Environmental and Life Sciences, Charles Darwin University. Darwin, NT 0909, Australia.

[d] Organización Zootropic, 12 calle 1-25, zona 10, Geminis 10, Torre Sur Nivel 18, 0f. 1801, Guatemala.

* Correspondence: Octavio Monroy-Vilchis, Estación Biológica Sierra Nanchititla, Facultad de Ciencias. Universidad Autónoma del Estado de México. Instituto literario # 100. Colonia Centro. Toluca, Estado de México. CP 50000. E-mail: omv@uaemex.mx, tavomonroyvilchis@gmail.com

ABSTRACT

The beaded lizard (*Heloderma horridum*) is a threatened species. Scientific research has been limited to two sites within its range (Chamela and Valle Motagua) while most presence records are casual or unverified sightings, as consequence its actual distribution and associated environmental factors are unknown. We propose an ensemble model (EM) of the potential distribution for *H. horridum* in México and Guatemala and identify priority areas for conservation. We used nine presence-only modeling methods, and select three to generate our EM. We used the EM to evaluate the efficacy of the existing Protected Natural Areas (PNA´s) in Mexico and Guatemala for *H.horridum*. Also we used the best individual predictive model (Maxent) to obtain the most important factors for *H. horridum* presence and used them to analyze the habitat use; finally we used our predictive model to calculate niche breath for the species. The estimated potential distribution of *H. horridum* is 370,474 km^2; within we identified 9 zones based on continuity and natural barriers. About 1.5% of the species distribution is under protection in the PNA´s. The five most important factors for the presence of this species explained 78.2% of the generated model and are related to seasonality and soil cover, and these are used selectively. This species is strongly specialist according to niche breath analysis. *H. horridum* is primarily restricted to tropical deciduous forest and is scarcely protected in both Mexico and Guatemala. Our results clearly show the necessity of a protection plan for this species.

Key words: Ensemble Model, Habitat Suitability, Heloderma, Niche Model

INTRODUCTION

It is estimated that the main threats to species persistence are anthropogenic, such as loss and fragmentation of habitat, as well as illegal trade and hunting (Brown and Carmony, 1999; Casas-Andreu, 2000; Beck, 2005). In addition to natural threats, as demonstrated for Balderas-Valdivia and Ramírez-Bautista (2005), there are several predators that also put pressure on the survival of *Heloderma horridum* (Wiegmann, 1829) in its range. Therefore is listed as threatened in Mexico (SEMARNAT, 2008). While in the international arena is considered a species of least concern (IUCN, 2010) also found in Appendix II of CITES (CITES, 2007).

The historical distribution of beaded lizards is restricted to the Pacific slope of North America from southern Sonora, Mexico to Guatemala (Beck, 2005). *H. horridum* is found primarily in tropical deciduous forests, but have also been recorded in foothill thornscrub habitats, and in high elevation pine-oak woodlands (Bogert and Martín del Campo, 1956; Lemos-Espinal et al., 2003; Monroy-Vilchis et al., 2005). In Mexico, potential habitats include parts of the Sierra Madre Occidental, the Sierra Madre del Sur and trans-Mexican volcanic belt, which are three of the most biologically important mountain ranges of México (Conservancy, 2007). In Guatemala, beaded lizards are thought to be restricted to the Motagua Valley in the southeast (Campbell and Vannini, 1988), which is one of eight highest priority conservation areas in northern Mesoamerica (Ariano-Sánchez, 2003; Ariano-Sánchez and Cotí, 2007).

This historical distribution of *H. horridum* has previously been estimated from records collected from 1577 to present day (Bogert and Martín del Campo, 1956; Beck 2005), however, most reports have consisted of casual or unverified sightings. Thus, there is a high likelihood that many important areas in the occurrence of the species have yet to be identified. As a result, it is unknown whether the historical distribution accurately reflects the current distribution, and how environmental features may potentially restrict the distribution of *H. horridum*.

Habitat suitability models are commonly used to predict the potential distribution of species based on the inter-relationships between habitat variables (Guisan and Zimmermann, 2000; Rushton et al., 2004; Guisan and Thuiller, 2005; Hernandez et al., 2006; McPherson and Jetz, 2007; Rodríguez- Soto et al., 2011). We developed spatial models of habitat suitability for *H. horridum* in its historical range (Mexico and Guatemala) using geographic, biological, and climatic habitat attributes (Hirzel and Arlettaz, 2003; Segurado and Araújo, 2004; Phillips et al., 2005; Elith et al., 2006, Papes and Gaubert 2007; Marmion et al., 2009a). The objectives of this study are to: (1) use habitat suitability models to determine the potential current distribution of *H. horridum*; (2) determine the most important habitat features for predicting the presence of *H. horridum*, in order to estimate habitat use and spatial niche breadth and (3) to compare the predicted distribution with the current system of protected natural areas in Mexico and Guatemala.

METHODS

México is a large (~2 million km^2) and biologically diverse country with a varied geological composition, topography and climate (CONABIO, 1998). Mexico is considered one of the seven most biologically diverse countries in the world and ranks third in importance for conservation because it is home to between 8 and 12% of the world's species (Challenger, 1998). Mexico further stands out as having the world’s greatest richness of herpetofauna (Flores-Villela, 1993; Llorente-Bousquets and Ocegueda, 2008). In Guatemala, the mountains from the north and south are separated by the Motagua valley, characterized by thorn scrub vegetation (Ariano-Sánchez, 2003). The Montagua valley is one of the driest areas of Central America (Hastenrath, 1967) and structurally resembles the tropical deciduous forests in Mexico. Because of its location and biogeography, Guatemala is also recognized as a global area of extreme biodiversity (Loening and Markussen, 2003; Nations et al. 1988).

We obtained specific locality information for *H. horridum* in two ways: 1) by reviewing databases of herpetological collections and published scientific literature, and 2) by field surveys at five locations in México and one in Guatemala. Field locations included Los Alamos (Sonora), the Chamela-Cuixmala Biosphere Reserve (Jalisco), Arcelia (Guerrero), the Sierra Nanchititla Nature Reserve (México), Malinalco (México), and the Motagua Valley (Guatemala). Fieldwork was conducted in different years (1998 to 2009) at the different sites, but all work involved visual encounter surveys to locate *H. horridum* while they were active above-ground. Activity of *H. horridum* throughout the foraging and breeding season is primarily crepuscular (Beck and Lowe, 1991), and we typically hiked foot trails in search of active lizards between 0700 and 1000 h, and again between 1700 and 2100 h. When lizards were observed, we recorded general habitat notes, date, location, and geographical coordinates (GPS). Because there were significant changes in land use and vegetation cover in Mexico between 1970 and 1990 (FAO, 2001), we only used the historic records from databases and published literature from the years 1990 to 2010.

Data for environmental variables used to predict habitat suitability were obtained through online databases of elevation, topography, temperature, precipitation, and vegetation cover (Global Land Cover Facility, Hydro1k and WorldClim). We chose 15 biologically relevant habitat and climate variables (Table 1) to generate models, and processed digital coverage at a resolution of 1 km^2 using ArcView 3.2, Arc GIS, and Idrisi Andes. Considering the scope of the study area (Mexico and Guatemala), and the space that is typically used by individual lizards (mean home range = 0.216 km^2) according to Beck and Lowe (1991), a 1 km^2 resolution is appropriate to examine the effect of selected habitat variables on the potential distribution of *H. horridum*.

→ Table 1

We applied nine different modeling techniques that have been widely used to delimit the potential distribution of several species of terrestrial vertebrates (Carpenter et al., 1993; Guisan and Zimmermann, 2000; Hirzel and Arlettaz, 2003; Peterson et al., 2003; Raxworthy et al., 2003; Engler et al., 2004; Segurado and Araújo, 2004,; Guisan and Thuiller, 2005; Elith et al., 2006; García, 2006; Hernandez et al., 2006; Ochoa and Flores-Villela, 2006; Ficetola et al., 2007; Papes and Gaubert, 2007; Thorn et al., 2009; Urbina-Cardona and Flores-Villela, 2010). We used: 1) Artificial neural networks, 2) Bioclim, 3) Climate model space, 4) Ecological niche factor analysis (ENFA), 5) Envelope scores, 6) Environmental distance, 7) Garp, 8) Maxent, and 9) Support vector machines. Theses models were implemented in three software packages: Open modeller 1.0.8 (Sutton et al., 2007) Biomapper 4.0 (Hirzel and Le Lay, 2008), and Maxent 3.3 (Phillips et al., 2005).

Locality records were randomly divided so that 75% of observations were used to generate predictive habitat models and 25% were used for model evaluation. Evaluation of the nine models was performed using receiver operating characteristic (ROC) plots and area under the curve (AUC) calculations, which have been shown to be robust indicators of model performance (Fielding and Bell, 1997; Jiménez-Valverde and Lobo, 2007). The three models with the highest AUC values were then combined to create an ensemble model, and we used the AUC as a weight for each model, as recommended by Marmion et al., (2009b). By combining the weighted single-models, the predictive uncertainty of the consensus model is lower than when considering the models individually (Araújo et al., 2005; Marmion et al., 2009b,; Rodriguez-Soto et al., 2011).

The weighted average (WA) ensemble model was generated using IDRISI Andes and the formula:

$$WA_i = \frac{\sum_j (AUC_{mj_i} \times mj_i)}{\sum_j AUC_{mj_i}}$$

where, mj_i is the probability of occurrence for *H. horridum* in a grid cell in the jth individual model. The ensemble model was considered the best estimate of the potential distribution of *H. horridum*. To facilitate interpretation of the final model, we reclassified the predictions from continuous probabilities (where probabilities of occurrence ranged from 0 to 1) into two suitability classes: low suitability (value less than the weighted mean probability of 0.332) and high suitability (values above the mean; Liu et al., 2005; Jiménez-Valverde and Lobo, 2007).

To evaluate the extent that current reserve systems contribute to the protection and conservation of the species, the reclassified ensemble model output was superimposed on the Protected Natural Areas (PNA's) in Mexico and Guatemala.

We identified the habitat and climate variables that were most important in predicting the distribution of *H. horridum* using the best performing (highest AUC) single-technique model. Using the potential distribution, we then divided the range of each habitat and climate variable into ten classes considering the greatest possible value for each one. Then all records were assigned to one of the categories of each of the evaluated variables. The method suggested by Neu et al., (1974) was followed to determinate which habitat types were used more or less frequently than expected. This method compares the frequency of the observed with the expected (poisson distribution) values in each habitat type. The Neu´s method usually includes a chi-square statistic. In the present study, the likelihood ratio test (G-test) was used since the test is recommended for comparison of more than 2 classes (e. g. categories of habitat types) by Sokal and Rohlf, (2001). The frequency expected was based on habitat type availability like suggested by Krebs, (1999). Finally, all values subtracted of each category were added and the habitat use index (HUI) for each variable was obtained.

In order to quantify the specialization of *H. horridum*, we applied an analysis of niche breadth. The niche breadth is measured by observing the distribution of individual organisms within a set of resources states. We reclassified the ensemble model into four habitat suitability classes based on the probability of occurrence of the species: (1) unsuitable, (2) low suitability, (3) medium suitability and (4) high suitability. These habitat types were considered for analysis and were applied using Hurlbert's niche breadth index (Krebs, 1999). This index were used since allows for the fact that some resources (in this case habitat suitability classes) are more abundant than others.

RESULTS

We obtained 288 locality records for *H. horridum* (all years), and retained 101 records collected between 1990 and 2010 to develop models.

The three models used to generate our ensemble model (highest AUC) were: Maxent, Support Vector Machines, and Environmental Distance. Subsequently, we evaluated the ensemble model and the results show that it has greater predictive ability than the individual models (Table 2).

→Table 2

The potential distribution of *H. horridum* is 370,474 km ^{2} and the species is limited in México to the states of Sonora, Chihuahua, Sinaloa, Durango, Nayarit, Jalisco, Colima, Zacatecas, Aguascalientes, Guanajuato, Michoacan, Guerrero, México, Morelos, Puebla, Oaxaca and Chiapas. In Guatemala, the potential distribution includes the department of Huehuetenango in the east and the departments of Quiché, Chimaltenango, Baja Verapaz, Guatemala, Progreso, Jalapa, Zacapa, Chiquimula and Jutiapa in the southeast (Figure 1).

→Figure 1

The distribution of *H. horridum* occurs in several zones with differing degrees of fragmentation. Based on this fragmentation and the presence of geographic barriers (mountains), we identified the following areas of importance in the distribution of this species. In northern México there is a continuous area extending south along the west slope of the Sierra Madre Occidental from Sonora to northern Nayarit (1). In southern Nayarit habitats are substantially fragmented, and the fragmented habitat areas extend through Jalisco and include small portions of Zacatecas, Aguas Calientes, Guanajuato and Michoacan (2). In the coast of Jalisco begins an area that continues through Colima and a small portion of Michoacan (3). In the center of the country, the potential distribution largely matches the Balsas River depression and includes parts of Jalisco, Michoacan, Guerrero, México, Morelos, Puebla and northwest Oaxaca (4). In southern

Mexico, the potential distribution extends along the coast of Guerrero (5) and the west coast of Oaxaca (6). From the central coast of Oaxaca the potential distribution continues through central Chiapas and ends in Guatemala (7). In southeastern Puebla and northern Oaxaca, there is a small area of potential distribution where the species has not yet been reported (8). The potential south most distribution areas for *H. horridum* (9) fall within the Motagua Valley (Figure 2).

→ Figure 2

The range of *H. horridum* found within the natural protected areas in Mexico and Guatemala (Figure 3) is 5,576 km ^{2}. This area is distributed in 15 PNA's in Mexico and 16 in Guatemala, which together protects 1.5% of the potential distribution of *H. horridum.*

→ Figure 3

The most important variables in determining habitat suitability of *H. horridum* were: bare soil coverage, percentage of annual precipitation occurring in the dry season, perennial vegetation cover, percentage of annual precipitation occurring in the rainy season, and minimum precipitation of the rainy season. Together these variables accounted for 78% of the explained variation in the model (Table 3).

→ Table 3

The habitat use index shows that *H. horridum* makes selective use of some classes of habitat features. However, differences are only significant for the variables: percentage of annual precipitation occurring in the dry season (G = 81. 418), percentage of annual precipitation occurring in the rainy season (G = 97. 026) and minimum precipitation in the rainy season (G = 53. 944; p <0.05, df = 9 for all). In the variable rainfall in the dry season, there is a preference for class 3 (4.4-6.1%) and 8 (12.9-14.6%). At the same variable shows a strong avoidance by the class 2 (2.7-4.4%) and a slight evasion class 4 (6.1-7.8%). In the variable rainfall in the rainy season provides a preference for class 3 (62.2-69.3%) and minimum precipitation in the rainy *H. horridum* select the Class 5 (189-237mm). In the two variables were obtained that the other classes are used in proportion to their disposition. Standardized niche breadth obtained (Hurlbert's niche breadth index) was 0.001 indicating that *H. horridum* is highly specialist.

DISCUSSION

Validation tests suggest that the ensemble model has greater predictive ability than the individual models (Table 2). As a result, the proposed distribution of *H. horridum* should more accurately reflect the actual distribution of the species. In comparing the potential distribution of *H. horridum* determined in this study (Figure 1) with the distribution presented by Beck, (2005), we can see that there are four important differences: 1) the potential range of *H. horridum* in the north (Sonora) is larger, 2) the potential range along the coastline is about 25% lower. 3) the potential range in the center of the country is larger, and mainly restricted the Balsas Basin. 4) the estimated distribution presented here suggests that there is an area of species occurrence (Figure 2) that has yet to be confirmed.

Historic observations proposed that the northern limit of the distribution of *H. horridum* is in southern Sonora, near the border with Sinaloa (excluding the states of Chihuahua and Durango). Our study suggests that potential habitat in this area is wider than previously thought, such that it includes much of southern Sonora and areas in southwestern Chihuahua and western Durango. Recent sightings in those states (Lemos-Espinal, 2007; Muñiz-Martínez and Rojas-Perez, 2009) support this possibility, and the occurrence of *H. horridum* in northern México is potentially broader than previously thought.

In Nayarit and Jalisco, the potential habitat area also appears to be larger than suggested by historical observations. However, in this region the potential habitat is quite fragmented (Trejo and Dirzo, 2000) and extends toward the center of the country to parts of Zacatecas, where the presence of *H. horridum* was only recently reported (Avila-Villegas, 2007). *H. horridum* likely also still exists in isolated fragments of Aguascalientes and Guanajuato. In Michoacan, Guerrero, Mexico, Morelos, Puebla and Oaxaca, there are larger and more continuous areas adjacent to the Balsas Basin. As for the continuity of the distribution along the coast, the potential habitat appears to be very scarce on the coast of Oaxaca and any populations there are likely to be quite isolated.

The potential distribution of *H. horridum* in Guatemala appears to be similar to the distribution described by Beck, (2005). Both historical observations (Campbell and Vannini, 1988) and our model predictions agree that the species distribution in Guatemala is likely limited to the Motagua Valley. This population is the only completely geographically isolated population of *H. horridum*. One of the most plausible hypotheses suggests that *H. horridum* first colonized the region when forest cover was more extensive and had a continuous distribution between México and Central America (Campbell and Vannini, 1988). The population then likely became isolated during the formation of volcanic mountain ranges in southeastern Guatemala (Graham and Dilcher, 1995).

Eastern Puebla and northern Oaxaca (Figure 2) is the only area where the potential distribution proposed by this study has not yet been confirmed by the occurrence of *H. horridum*. These areas are isolated by the presence of two major mountain ranges; the Neovolcanic Belt and the northern portion of the Sierra Madre del Sur (Conabio, 2007). However, *H. horridum* has recently been documented in western Puebla (García-Vázquez et al., 2006). The potential barriers to the dispersal of *H. horridum* include altitude and vegetation type. The altitudinal limit of this species has not been well defined, but some accounts report presence in higher altitude habitats (1861 m in pine-oak woodland; Monroy-Vilchis et al., 2005). It is unlikely that high elevation environments can maintain viable populations of *H. horridum*, however, individuals are likely able to disperse through high elevations in order to colonize new lowland areas.

Only 5,576 km^2 (1.5%) of potential habitat for *H. horridum* is within PNA's (Figure 3). This shows the low representation of this species in the protection equemas and their potential vulnerability to extinction. This situation has been reported in general for the biodiversity of Mexico (Sánchez-Cordero and Figueroa, 2007), and for the herpetofauna (Urbina-Cardona and Flores-Villela, 2010). The model developed in this study identifies important areas for conservation of *H. horridum*, but more detailed studies are needed in order to incorporate relevant aspects of the species ecology into the selection of appropriate sites for protection.

The potential habitat of *H. horridum* in Mexico appears to largely coincide with the distribution of tropical deciduous forest in México (Trejo, 2005). In Guatemala, vegetation in the areas *H. horridum* occurrence is similar to tropical deciduous forest in México, being forested environments having a marked seasonality (Murphy and Lugo 1995). These settings match the tropical sub-humid ecological zone proposed by Challenger, (1998) for Mexico, which includes thorn scrub, lowland tropical forests, and low elevation pine-oak woodlands.

Tropical deciduous forests are one of the most threatened environments worldwide (Janzen, 1988), and among the largest remaining fragments of this vegetation type in America are located in central and western Mexico (Ceballos, 1995). Tropical deciduous forests in México are extremely biologically important and they contain around 67% of endemic vertebrates in the country (Conservancy, 2007), but occupy only about 15% of the land area (Trejo, 2005). Because the distribution of *H. horridum* largely coincides with tropical dry forests, this species could be used to propose protection areas for this ecosystem but it is necessary a more detailed study to determine which characteristics of the tropical dry forest (i. e. species richness, vegetation quality) could be favored. So, it is proposed that the areas for the protection of this species are located in the main areas identified as potential distribution (Figure 2). The exact location and size of areas to protect these animals must be identified in local studies on populations of *H. horridum*.

Beck and Lowe, (1991) and Ariano-Sánchez, (2003) describe the general features of habitats used by *H. horridum*, however, no study has yet looked at habitat selection (habitat use in relation to habitat availability) of this species. We identified five environmental variables as the primary determinants of the presence of *H. horridum*. The results indicate that areas where bare soil is from 0 to 10% are suitable for the species. The second significant variable was rainfall in the dry season. The results show that *H. horridum* occurs in areas with low rainfall at this time between 0 and 10% of the total. This provides quantitative data and strengthens the hypothesis that seasonality is important for this species (Beck, 2005; Lovich and Beaman, 2007), particulary seasonally dry conditions, and might provide important cues for reproductive events, such as ovulation, spermiogenesis (Goldberg and Beck, 2001), and timing of hatching (Gienger et al., 2005).

The third variable in importance was the absence in perennial vegetation cover, confirming the preference of the species in the tropical deciduous forest. Although it can be found in pine and oak, this coverage is seldom used (Beck, 2005; Monroy-Vilchis et al., 2005). The fourth and fifth most important variables were related to rainfall in the rainy season and the results show that at the sites of occurrence of the species precipitation during this period is very high (75-90% of total). These variables are indicators of environmental seasonality and can say that this feature is essential for *H. horridum*.

H. horridum is presented in two environments, the subspecies northerly distributed (*H. h. exasperatum and H. h. horridum*) inhabit environments with more marked seasonality than those occupied by the subspecies that are distributed to the south (*H. h. alvarezi and H. h. charlesbogerti*). The environmental seasonality seems to be the major limiting distribution of helodermatids. However, we also found that bare soil cover is an important variable for these animals and suggest that conserved environments may be more appropriate for beaded lizards.

Indices of habitat use identified important ranges of the environmental variables used by the species. Statistically significant results were only present in the three variables related to environmental seasonality (percentage of annual precipitation occurring in the dry season, percentage of annual precipitation occurring in the rainy season, and minimum precipitation of the rainy season). For precipitation in the dry season, the results show that the species prefers classes 3 (4.4-6.1%) and 8 (12.9-14.6%), corresponding with sites of low and high rainfall respectively. In the same variable, it appears that there is avoidance for the class 2 (2.7-4.4%) and other classes were used in proportion to their availability.

In the variables of percentage of annual precipitation occurring in the rainy season, and minimum precipitation of the rainy season, the results suggest that this species prefers areas with a very narrow range of variation. These results coincide with that obtained by the niche breadth index, which indicates that *H. horridum* is highly specialist (0001). It is likely that the validity of these two tests is debatable if one considers the distribution of records, but this study lays the foundations for future work on the use of habitat by these animals. It is therefore suggested to perform this analysis on a smaller scale to confirm these results more accurately.

Acknowledgments

We thank the Mexican people for financing this study through the Autonomous University of the State of Mexicowhit projects FEO 12/ 2007, 2578/2007, FEO51/2008. Two anonymous reviewers made important observations. The State Commission of Natural Parks of Fauna gave permissions to work in Parque Natural Sierra Nanchititla. We also thank to all the people from Sierra Nanchititla for sharing their knowledge as well as the students who participate with field work.

References

Araújo, M.B., Whittaker, R.J., Ladle, R.J. & Erhard, M. (2005). Reducing uncertainty in projections of extinction risk from climate change. *Global Ecolology and Biogeography*. 14, 529–538.

Ariano-Sánchez, D. (2003). *Distribución e historia natural del escorpión, Heloderma horridum charlesbogerti Campbell y Vannini, (Sauria: Helodermatidae) en Zacapa, Guatemala y caracterización de su veneno*. Tesis de licenciatura, Universidad del valle de Guatemala.

Ariano-Sánchez, D. & Cotí, P. (2007). *Priorización de áreas de conservación en el matorral espinoso del valle Montagua, utilizando como indicadores a las especies endémicas lagarto escorpión, Heloderma horridum charlesbogerti y la iguana garroba, Ctenosaura palearis*. Guatemala. Zootropic / The Nature Conservancy.

Avila-Villegas, H. (2007). Heloderma horridum horridum (Mexican Beaded Lizard). *Herpetological Review*. 38, 218.

Balderas-Valdivia, C. J. & Ramírez-Bautista, A. (2005). Aversive behavior of beaded lizard Heloderma horridum to sympatric and allopatric predator snakes. *Southwestern Naturalist*. 50, 24-31.

Beck, D. D. (2005). *Biology of Gila Monsters and Beaded Lizards*. Berkeley: University of California Press.

Beck, D. D. & Lowe, C.H. (1991). Ecology of the beaded lizard, Heloderma horridum, in a tropical dry forest in Jalisco, México. *Journal of herpetology*. 25, 395-406.

Bogert, C. M. & Martín del Campo, R. (1956). The Gila monster and its allies. *Bulletin of the American museum of natural history*. 109, 1-238.

Brown, D. E. & Carmony, N.B. (1999). *Gila monster: Facts and Folklore of America´s Aztec Lizard*. Salt Lake City: University of Utah Press.

Campbell, J. A. & Vannini, J.P. (1988). A new subspecies of beaded lizard, Heloderma horridum, from the Motagua Valley of Guatemala. *Journal of herpetology*. 22, 457-468.

Carpenter, G., Gillison, A.N. & Winter, J. (1993). DOMAIN: a flexible modelling procedure for mapping potential distributions of plants and animals. *Biodiversity and conservation*. 2, 667-680.

Casas-Andreu, G. (2000). Mitos, leyendas y realidades de los reptiles en México. *Ciencia Ergo Sum*. 7, 286-291.

Ceballos, G. (1995). Vertebrate diversity, ecology and conservation in neotropical dry forest. In: S.H. Bullock, H. A. Mooney & E. Medina (Eds.), *Seasonally Dry Tropical Forests* pp. 195-220. Cambridge: Cambridge University Press.

CITES. (2007). Apéndices I, II y III. Convención sobre el comercio internacional de especies amenazadas de fauna y flora silvestres. CITES.

Conabio. (1998). *La diversidad biológica de México: estudio de país*. México: Comisión nacional para el conocimiento y uso de la biodiversidad.

Conabio. (2007). *Estrategias estatales para la conservación y uso sustentable de la biodiversidad*. México: Comisión nacional para el conocimiento y uso de la biodiversidad.

Conservancy. (2007). *Biodiversidad del centro y occidente de México Planeación ecorregional: Avances y próximos pasos*. México: USAID.

Challenger, A. (1998). *Utilización y conservación de los ecosistemas terrestres de México, pasado, presente y futuro*. México: Conabio-Instituto de Biología-Sierra Madre.

Elith J., C. H. Graham, R. P. Anderson, M. Dudík, S. Ferrier, A. Guisan, R. J. Hijmans, F. Huettmann, J. R. Leathwick, A. Lehmann, J. Li, L. G. Lohmann, B. A. Loiselle, G. Manion, C. Moritz, M. Nakamura, Y. Nakazawa, J. M. Overton, A. T. Peterson, S. J. Phillips, K. Richardson, R. Scachetti-Pereira, R. E. Schapire, J. Soberón, S. Williams, M. S. Wisz & N. E. Zimmermann. (2006). Novel methods improve prediction of species´ distributions from occurrence data. *Ecography*. 29, 129-151.

Engler, R., Guisan, A. & Rechsteiner, L. (2004). An improved approach for predicting the distribution of rare and endangered species from occurrence and pseudo-absence data. *Journal of applied ecology*. 41, 263-274.

FAO. (2001). *The State of World´s Forests*. 4. FAO.

Ficetola, G. F., Thuiller, W. & Miaud. C. (2007). Prediction and validation of the potential global distribution of a problematic alien invasive species - the American bullfrog. *Diversity and distributions*. 13, 476-485.

Fielding, A.H. & Bell, J.F. (1997). A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environmental Conservation*. 24, 38-49.

Flores-Villela, O. (1993) Herpetofauna of México: Distribution and endemism. In: Ramamoorthy, R. Bye, A. Lot & J. Fa (Eds.), *Biological Diversity of México: Origins and Distribution* pp. 253-280. Oxford: Oxford University Press.

García A. (2006). Using ecological niche modelling to identify diversity hotspots for the herpetofauna of Pacific lowlands and adjacent interior valleys of Mexico. *Biological Conservation*. 130, 25-46.

García-Vazquez, U., Canseco-Márquez, L.,. Aguilar-López, J.L, Hernández-Jiménez, C.A., Maceda-Cruz, J., Gutiérrez-Mayen, M.G. & Melgarejo-Velez, E.Y. (2006). Análisis de la distribución de la herpetofauna en la región Mixteca de Puebla, México. In: A. Ramirez-Bautista, L. Canseco-Márquez & F. Mendoza-Quijano (Eds.), *Inventarios herpetofaunísticos de México: Avances en el conocimiento de su biodiversidad* pp. 152-169. México: Publicaciones de la Sociedad Herpetológica Mexicana.

Gienger, C.M., Johnson, G.W., McMillan, M., Sheldon, S., & Tracy, C.R. (2005). Timing of hatching in beaded lizards (Heloderma horridum). *Sonoran Herpetologist* 18, 93-94.

Goldberg, S.R. & Beck, D.D. (2001). Heloderma horridum (Beaded Lizard) Reproduction. *Herpetological Review*. 32, 255-256.

Graham, A. & Dilcher, D. (1995). The cenozoic record of tropical dry forest in northern Latin America and the southern United States. In: S.H Bullock., H. A. Mooney & E. Medina (Eds.), *Seasonally Dry Tropical Forests* pp. 195-220. Cambridge: Cambridge University Press.

Guisan, A. & Thuiller, W. (2005). Predicting species distribution: offering more than simple habitat models. *Ecology letters*. 8, 993-1009.

Guisan, A. & Zimmermann, N.E. (2000). Predictive habitat distribution models in ecology. *Ecological modelling*. 135, 147-186.

Hastenrath, S. (1967). Rainfall distribution and regime in Central America. *Theoretical and applied climatology*. 15, 201-241.

Hernandez, P. A., Graham, C.H. Master, L.L. & Albert, D.L. (2006). The effect of sample size and species characteristics on performance of different species distribution modeling methods. *Ecography*, 29, 773-785.

Hirzel, A. H. & Arlettaz, R. (2003). Modeling habitat suitability for complex species distributions by enviromental-distance geometric mean. *Enviromental management*. 32, 614-623.

Hirzel, A. H. & Le Lay, G. (2008). Habitat suitability modelling and niche theory. *Journal of applied ecology*. 45, 1372-1381.

IUCN. (2010). *Categorías y criterios de la lista roja de la UICN: versión 3.1*. Gland, Suiza y Cambridge, Reino Unido: Comisión de supervivencia de especies de la UICN.

Janzen, D. H. (1988). Tropical dry forests: the most endangered major tropical ecosystem. In: E.O. Wilson (Ed.), *Biodiversity* pp. 130-137. Washington, DC: National Academy Press.

Jiménez-Valverde, A. & Lobo, J.M. (2007). Threshold criteria for conversion of probability of species presence to either-or presence-absence. *Acta Oecologica*. 31, 361-369.

Krebs, C. J. (1999). *Ecological Methodology*. California: Benjamin/Cummings.

Lemos-Espinal, J.A., Chiszar, D. & Smith, H.M. (2003). Presence of the Río Fuerte beaded lizard (Heloderma horridum exasperatum) in western Chihuahua. *Bulletin of the Md. Herpetological Society*. 39, 47-51.

Lemos-Espinal, J. A. (2007). *Anfibios y reptiles del estado de Chihuahua México*. México: CONABIO.

Liu, C., Berry, P.M., Dawson, T.P. & Pearson, R.G. (2005). Selecting thresholds of occurrence in the prediction of species distributions. *Ecography*. 28, 385-393.

Llorente-Bousquets, J. & Ocegueda, S. (2008). *Estado del conocimiento de la biota de México, capital natural de México: Conocimiento Actual de la Biodiversidad*. México: Conabio.

Loening, L. J. & Markussen, M. (2003). Pobreza, deforestación y sus eventuales implicaciones para la biodiversidad en Guatemala. *Economía, Sociedad y Territorio*, 4, 279-315.

Lovich, J. E. & Beaman, K.R. (2007). A history of Gila monster (Heloderma suspectum cinctum) records from California with comments of factors affecting their distribution. *Bulletin of Southern California Academy of Sciences*, 106, 39-58.

Marmion, M., Hjort, J., Thuiller, W., & Luoto, M. (2009). Statistical consensus methods for improving predictive geomorphology maps. *Computers and Geosciences*, 35, 615-625.

Marmion, M., Parviainen, M., Luoto, M., Heikkinen, R.K. & Thuiller, W. (2009). Evaluation of consensus methods in predictive species distribution modelling. *Diversity and Distributions*. 5, 59-69.

McPherson, J.M. & Jetz, W. (2007). Effects of species´ ecology on the accuracy of distribution models. *Ecography*, 30, 135-151.

Monroy-Vilchis, O., Hernández-Gallegos, O. & Rodríguez-Romero, F. (2005). Heloderma horridum horridum (mexican beaded lizard), unusual habitat. *Herpetological Review*. 36, 450.

Monroy-Vilchis, O., Soto-Rodriguez, C., Zarco-González, M. & Urios, V. (2009). Cougar and jaguar habitat use and activity patterns in central México. *Animal Biology*. 59, 145-157.

Muñiz-Martínez, R. & Rojas-Pérez, M.A. (2009). Registro nuevo del escorpión mexicano Heloderma horridum (Reptilia: Helodermatidae) en Durango, México. *Revista Mexicana de Biodiversidad*. 80, 871-873.

Murphy, P.G. & Lugo, A.E. (1995). Dry forest of Central America and the Caribbean. In: S.H. Bullock, H. A. Mooney and E. Medina (Eds.), *Seasonally Dry Tropical Forests* pp. 9-34. Cambridge: Cambridge University Press.

Nations, J., B. Houseal, I. Ponciano, B. Billy, J. C. Godoy, F. Castro, G. Miller, D. Rose, M. Rey Rosa, & C. Azurdia. (1988). *Biodiversity in Guatemala*. Washington, DC: Center for International Development and Environment, World Resources Institute.

Neu, C., Byers, C. & Peek, J. (1974). A technique for analysis of utilization-availability data. *Journal of wildlife management*. 38, 431-438.

Ochoa, L. M. & Flores-Villela, O. (2006). *Áreas de diversidad y endemismo de la herpetofauna mexicana*. México: UNAM-CONABIO.

Papes, M. & Gaubert, P. (2007). Modeling ecological niches from low numbers of occurrences: assessment of the conservation status of poorly known viverrids (Mammalia, Carnivora) across two continents. *Diversity and distributions*. 13, 890-902.

Peterson, A. T., Papes, M. & Kluza, D.A. (2003). Predicting the potential invasive distributions of four alien plant species in North America. *Weed Science*. 51, 863-868.

Phillips, S. J., Anderson, R.P., & Schapire, R.E. (2005). Maximum entropy modeling of species geographic distributions. *Ecological modelling*. 190, 231-259.

Raxworthy, C. J., Martinez-Meyer, E., Horning, N., Nussbaum, R.A., Schneider, G.E., Ortega-Huerta, M. & Peterson, A.T. (2003). Predicting distributions of known and unknown reptile species in Madagascar. *Nature*, 426, 837-841.

Rodríguez-Soto, C., Monroy-Vilchis, O., Maiorano, L., Boitani, L., Faller, J.C., Briones, M.A., Nuñez, R., Rosas-Rosas, O., Ceballos, G. & Fallcucci, A. (2011). Predicting potential distribution of the jaguar (Panthera onca) in México: identification of priority areas for conservation. *Diversity and distributions*. 17, 350-361.

Rushton, S.P., Ormerod, S.J. & Kerby, G. (2004). New paradigms for modelling species distributions? *Journal of applied ecology*. 41, 193-200.

Sánchez-Cordero, V. & Figueroa, F. (2007). La efectividad de las reservas de la biosfera en México para contener procesos de cambio en el uso del suelo y la vegetación. In: G. Halfter, & S. Guevara (Eds.), *Hacia una Cultura de Conservaciòn de la Diversidad Biológica* pp. 161-171. Zaragoza: Sociedad Entomológica Aragonesa, Conabio, Conanp, Conacyt, Instituto de Ecología, A. C., MAB-UNESCO, Ministerio de Medio Ambiente-Gobierno de España.

Segurado, P. & Araújo, M.B. (2004). An evaluation of methods for modelling species distributions. *Journal of biogeography*. 31, 1555-1568.

SEMARNAT. (2008). *Norma oficial mexicana NOM-059-ECOL-2001, protección ambiental-especies nativas de México de flora y fauna silvestres-categorias de riesgo y especificaciones para su inclusión, exclusión o cambio-lista de especies*. México: Diario oficial.

Sokal, R. R. & Rohlf F. J. (2001). *Biometry*. New York: W. H. Freeman and company.

Sutton, T., de Giovanni, R. & Ferreira, M. (2007). Introducing openModeller: A fundamental niche modelling framework. *OSGeo Journal*, 1, 1-6.

Thorn, J.S., Nijman, V., Smith, D. & Nekaris, K.A.I. (2009). Ecological niche modelling as a technique for assessing threats and setting conservation priorities for Asian slow lorises (Primates: Nycticebus). *Diversity and distributions*. 15, 289-298.

Trejo, I. (2005). Análisis de la diversidad de la selva baja en México. In: J. Halffter, Soberón, P. Koleff & A. Melic (Eds.), *Sobre Diversidad Biológica: el Significado de las diversidades alfa, beta y gamma* pp. 111-122. Zaragoza: SEA-CONABIO-Grupo DIVERSITAS-CONACYT.

Trejo, I. & R. Dirzo (2000). Deforestation of seasonally dry forest: a national and local analysis in Mexico. *Biological conservation*. 94, 133-142.

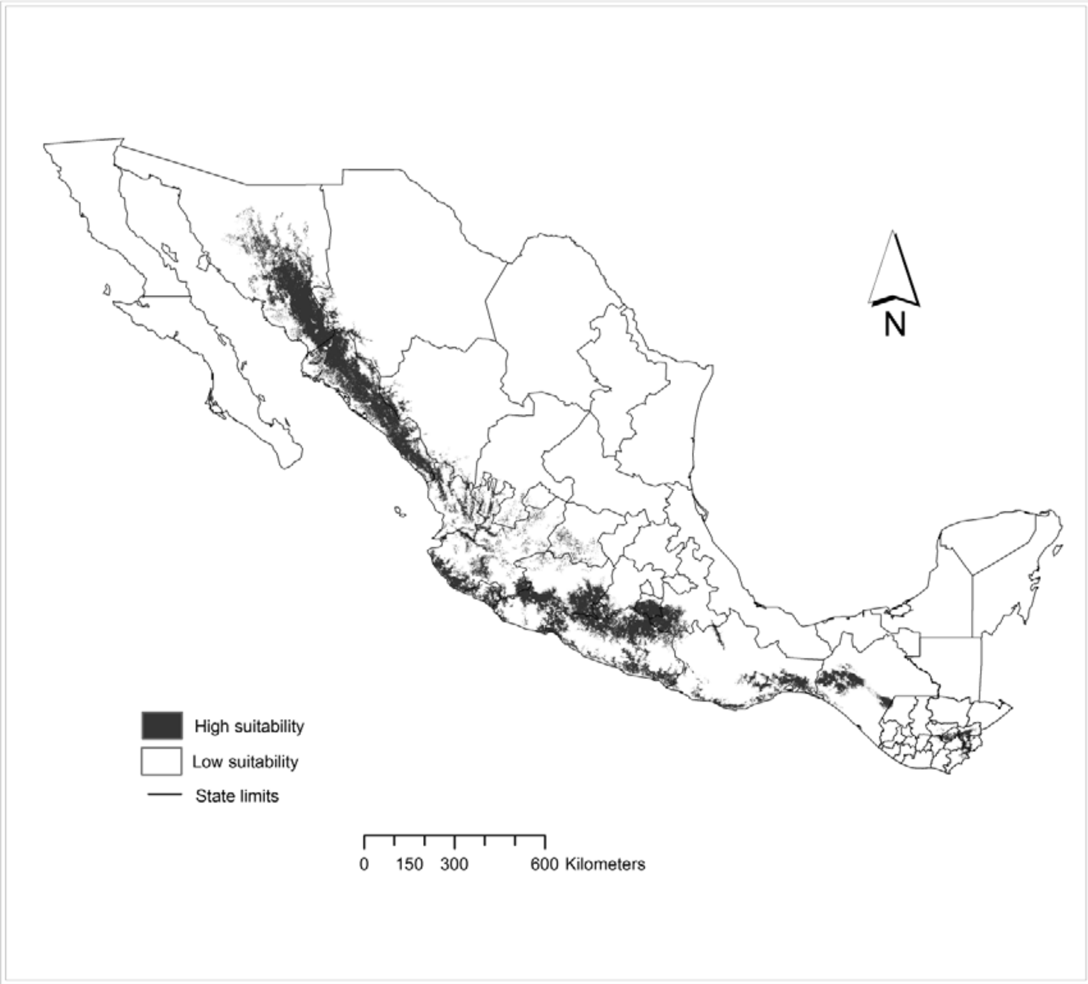
Urbina-Cardona, J.N. & Flores-Villela, O. (2010). Ecological-niche modeling and prioritization of conservation-area networks for Méxican herpetofauna. *Conservation biology*. 24, 1031-1041.

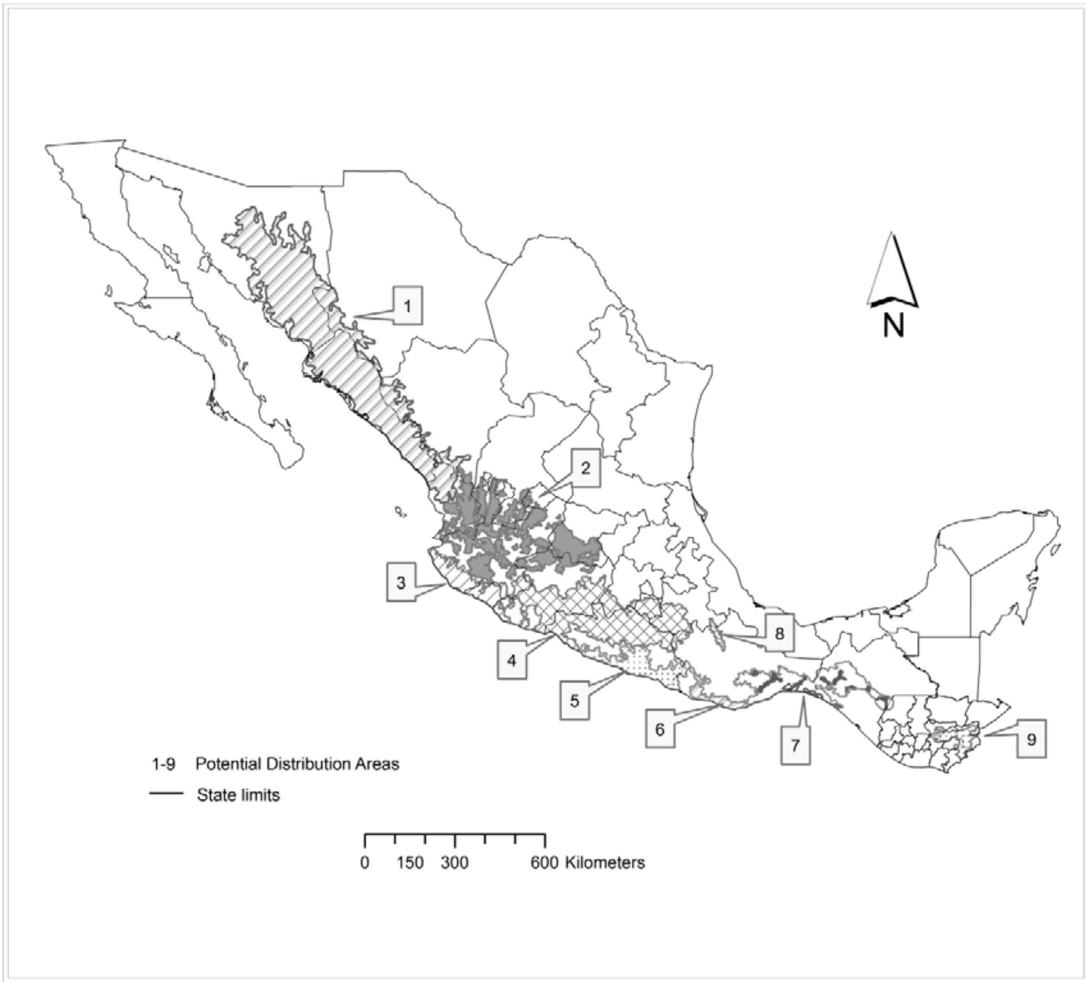
Figures:

Figure 1. Potential distribution of *H. horridum.*

Figure 2. Zones of potential distribution of *H. horridum.* See meaning of the initials in the text.

Figure 3. Potential distribution of *H. horridum* included in Protected Natural Areas (PNA's).


N
High suitability
Low suitability
State limits
0 150 300 600 Kilometers


1
2
3
4
5
6
7
8
9
N
1-9 Potential Distribution Areas
State limits
0 150 300 600 Kilometers

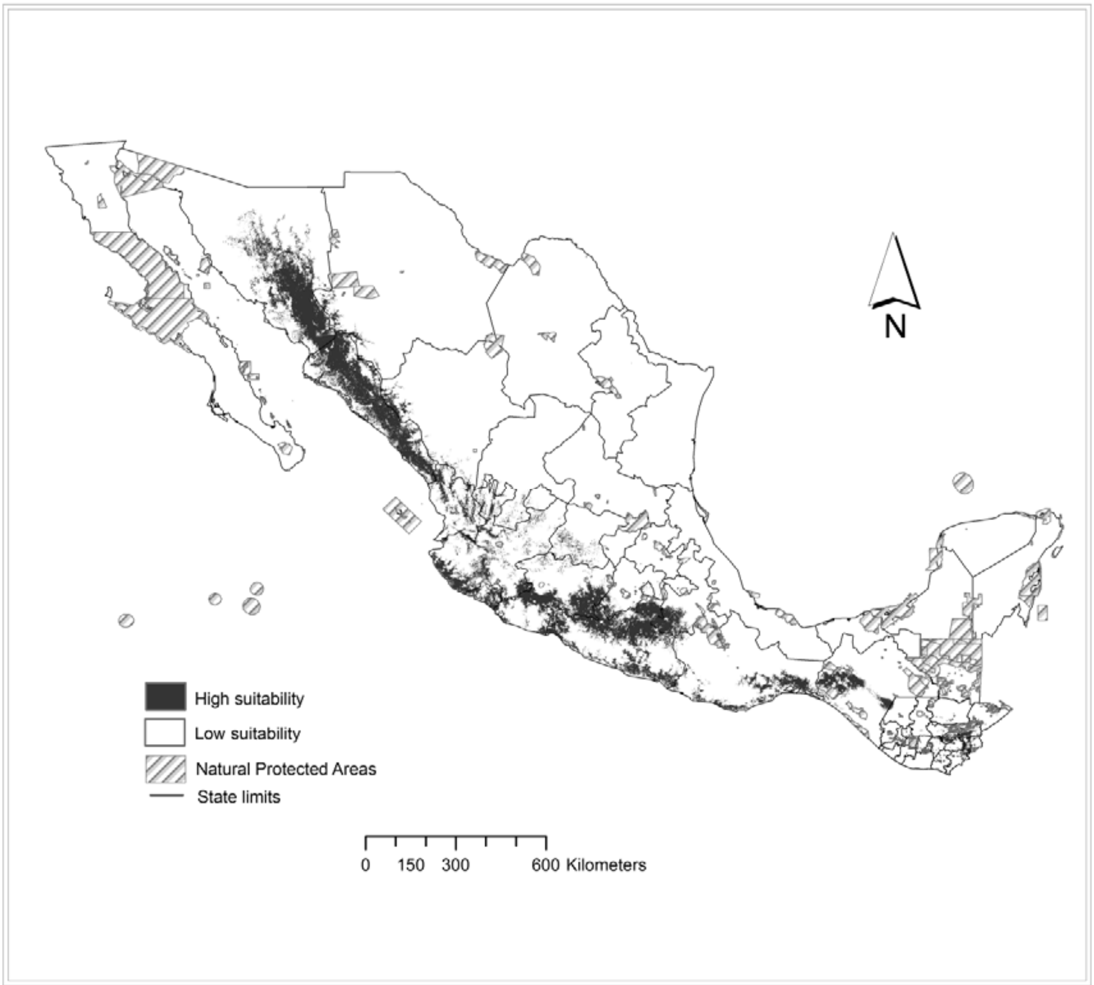

N
High suitability
Low suitability
Natural Protected Areas
State limits
0 150 300 600 Kilometers

Table 1. Environmental variables included in the ensemble model of *H. horridum* (variables 1-9; from WorldClim, Hydro 1k and Global Land Cover Facility, 10-15, derived from temperature and precipitation)

Number	Variable
1	Elevation (DEM)
2	Slope
3	Tree Cover (%)
4	Herbaceous Cover (%)
5	Conifer Cover (%)
6	Hardwood Cover (%)
7	Perrenial Plant Cover (%)
8	Deciduous Cover (%)
9	Bare Soil (%)
10	Anual Rainy Season Precipitation (%)
11	Anual Dry Season Precipitation (%)
12	Maximum Precipitation (Dry Season)
13	Minimum Precipitation (Rainy Season)
14	Anual Maximum Temperature
15	Anual Minimum Temperature

Table 2. Area under the curve (AUC) values for each model used to predict the distribution of *H. horridum*. The three models with the highest AUC (*) were weighted and combined to create a consensus model.

Model	AUC
Bioclim	0.854
Envelope Scores	0.863
ENFA	0.899
GARP	0.920
Artificial Neural Networks	0.948
Climate Space	0.959
*Enviromental Distance	0.965
*Support Vector Machines	0.973
*Maxent	0.976
Ensemble Model	0.989

Table 3. Important variables and intervals in which it is expected the presence of *H. horridum* based on the Maxent model. Together the variables explain 78.2% of the variation in the species distribution.

Variable	Contribution to the Model (%)	Interval of *H. Horridum* Occurrence
Bare Soil Cover	19.8	0-10 %
Anual Dry Season Precipitation (%)	19.6	0-10 %
Perennial Vegetation Cover	17.4	0 %
Anual Rainy Season Precipitation (%)	13.1	70-100 %
Minimum Rainy Season Precipitation	8.3	90-300 mm

Capítulo II. Environmental factors associated to sightings and aversive hunting of Beaded lizards (Squamata: Helodermatidae) in Mexico

Hublester Domínguez-Vega[1], Octavio Monroy-Vilchis[2] and Javier Manjarrez[3]. **En revisión: Tropical Conservation Science**

Centro de Investigación en Recursos Bióticos. Universidad Autónoma del Estado de México. Instituto Literario N. 100. Col. Centro, Toluca, México

[1] hublester.dvega@gmail.com

[2] tavomonroyvilchis@gmail.com

[3] jsilva@ecologia.unam.mx

Corresponding author: Octavio Monroy Vilchis

E-mail address of corresponding author: tavomonroyvilchis@gmail.com

ABSTRACT

Wildlife hunting is one of the main threats for biodiversity because of its intensity and synergistic effects with other anthropogenic activities. Lethal control is a type of hunting realized over species considered threats to human health or goods that exerts high negative impacts on wildlife populations or even on ecosystems stability. We quantify sighting and hunting frequency of Helodermatids (Beaded lizards); a reptile group of rare occurrence that is scarcely included in natural protected areas. We analyze sighting and hunting relationships with habitat structure and perturbation trough digital habitat layers. We applied 136 interviews in rural areas on the central and southern range of Helodermatids in Mexico. Our results were analyzed using simple Spearman´s correlation tests and discriminant function analysis. We recorded 225 sightings realized in conserved vegetation sites; hunting frequency was closed to 50% and justified on the potential direct threat of these species. Sighting and hunting frequency was not explained by individual relations with vegetation type, topography, perturbation or rockiness; sightings are explained by a group of variables related to habitat structure whilst hunting was not explained by environment characteristics. Our study exposes that negative impact on Helodermatids is high and that an education plan is required to decrease it. Moreover, our study shows that an effective strategy of conservation for this group most include habitat structure management.

Key words: Conservation, habitat perturbations, human-wildlife conflict

RESUMEN

La caería de fauna silvestre es una de las principales amenazas de la biodiversidad debido a su intensidad y sinergia con actividades antrópicas. El control letal, es un tipo de cacería sobre especies consideradas amenazas a la salud o los bienes humanos que ejerce un impacto elevado sobre las poblaciones silvestres e incluso sobre la estabilidad de los ecosistemas. En este estudio se cuantifica la frecuencia de avistamientos y de cacería sobre Helodermátidos; un grupo de reptiles de ocurrencia rara escasamente incluido en áreas naturales. Además, se analiza la relación entre los avistamientos y cacería con la estructura y perturbación del hábitat a través de superficies digitales. Se aplicaron 136 entrevistas en zonas rurales en la distribución centro y sur de los Helodermátidos en México. Los resultados se analizaron con correlaciones de Spearman y con análisis de funciones discriminantes. Se registraron 225 avistamientos en zonas con cobertura vegetal conservada; la frecuencia de cacería fue cercana al 50% y justificada en la amenaza potencial de estos animales. La frecuencia de avistamiento o cacería no se explica a través de relaciones individuales con las variables analizadas; pero los avistamientos si se explican por un conjunto de variables relacionadas con la estructura de la vegetación. Este estudio evidencia que el impacto negativo sobre los Helodermátidos es elevado y que es necesario un plan de educación para disminuirlo. Además muestra que una estrategia de conservación efectiva para este grupo debe incluir el manejo de la estructura de la vegetación.

Palabras clave: Conservación, conflicto humano-fauna silvestre, perturbaciones del hábitat.

INTRODUCTION

Wildlife hunting and management are considered critical factors in early human society development and continue in contemporary rural communities; it constitutes an impportant source to cover basic needs like food and medicine. Nonetheless, subsistence and comercial hunting represents one of the most important biodiversity threats because of its intensity and synergistic effects with anthropic activities like farming and ranching [1-3]. Otherwise, aversive hunting or “lethal control” is a traditional activity justified on the protection of human health or economic goods that is increasing worldwide because of anthropic expansion [4-6]. The targeted species in this activity are those considered direct or indirect threats for humans, and as its aim is erradication, the impact on wild populations is high [5-8]. Several experiences mainly related to large carnivores like wolf in Northamerica or felids in Africa have shown that lethal control can drastically affect ecosystem stability, although some good examples also include other key species like prairie dog [4, 6]. The effects of hunting can vary acording to the intensity and span or risilence of wild populations [3, 6]. However, in adition to environmental perturbations like habitat fragmentation, negative effects can be enhanced leading to local extintions [3, 9]. Recently, the study on biodiversity hunting and trade has been favored because of human concern on long term suply of natural resources and the search for sustentable management [10]. Nonetheless, hunting impact on most species populations remain unknown specially for those of rare occurence [3, 11].

Mexican tropical dry forests contain three of five species of the family Helodermatidae commonly known as Beaded lizards (*Heloderma exasperatum, H. horridum and H. alvarezi*); a group recognized for its well-developed venomous system. All are considered rare species restricted to well conserved environments [12-15]. Moreover, these species are included in a rich folklore in which they are considered extremely dangerous [16, 17], so aversive hunting is common for the group, although intensity are unknown. Helodermatid´s potential distribution is largely outside of recognized natural protected areas and therefore anthropic activities may play an important role in its population's persistence or decline [13]. Helodermatids are also include in national and international protection lists [18-20], but as negative impacts over its populations and habitat are increasing [12], an estimation of hunting impact is necessary to generate an effective strategy for its protection.

We analyzed sightings and hunting frequency on Mexican Helodermatids in seven localities of its distribution. Our objectives were to: 1) quantify sightings and hunting frequency and 2) analyze the relation among sightings and hunting frequency and habitat structure using fragmentation indicators.

METHODS

We applied interviews to estimate sightings and hunting frequency in seven localities. Our study area includes the center and south portion of Helodermatids distribution in Mexico (Fig 1). We collected information to: (1) verify correct species identification, (2) locate sightings as precisely as possible, (3) determinate general landscape environmental characteristics as vegetation type, topographic characteristics of sighting locality (on streams, on hill base, on hill slope, on hill top), perturbation degree (only native vegetation, half native vegetation-half crops, only crops) and rockiness (presence or absence) and (4) determinate hunting reasons. The interviewed population was restricted to inhabitants of rural agricultural communities that were older than 30 years of age and had been natives or residents for more than 10 years. We restricted questions to those for sightings within a one year period prior to the interview. Before each interview, we exposed the aims, and methods of our study to each potential informant and we ask them for their willingness to participate on it. We also declared to the participants that they will have no economic benefits for their information. Our results were analyzed using a detailed description of sightings and hunting events within and among localities, we also analyzed sight and hunt frequency relation using a Spearman´s simple correlation.

#Figure 1, approximately here#

To analyze the importance of habitat structure (fragmentation), we used geographic coordinates for each sight based on locality description from interviews, using “Google earth 7.1” with an approximated precision of $1km^2$. Occurrences were mapped over a digital layer of vegetation types and land use for Mexico [21]; no referenced sightings were discarted from this analysis. In each locality, we generated a minimum convex polygon using referenced sightings and we estimated habitat structure using fragmentation indicators (crops distance, mean patch edge, mean patch size, number of patches,) and the “Patch analyst” extension for ArcView 3.3. Moreover, we included a human population density and a road distance layer as habitat perturabtion indicators and then extracted relate habitat information for each sight record. These variables were compiled to generate a base for all studied localities and then we performed correlation tests using sighting and hunting frequency as dependent variables against structural and perturbation indicators. In order to identify environmental differences associated to locations of different intensity of sightings or hunting, we also applied discriminant function analysis using sighting and hunting frequencies as grouping variables (5 groups in each analysis) and the habitat structure variables as dependent. Finally, a correspondance analysis was performed to identify environmental variables determining differences in sighting and hunting.

RESULTS

We conducted 136 interviews and acquired 225 Helodermatid´s sightings from seven localities (Table 1). Even though these species are considered rare due to few presence rocords in scientific collections or the major sampling effort necessary to obtain a record in field [22], inhabitants identified them effectively (95%) and show a high aversion to them as the hunting frequency was close to 50% of sightings (Table 1). Sighting frequency showed inter-locality variation; Malinalco stands out as it presented the highest mean sightings per person (2.41) and before this study there was scarce knoledge of the precence of this group in the region [13]. Tuxtla Gutierrez, showed the lowest sighting frequency and the highest urban development (Table 1). Spearman test showed a positive and significant relation between sightings and hunting ($r=0.52$; $p<0.05$), highlighting the generalized aversion to Helodermatids in the study area. According to interviews, the environmetal characteristics associated to sightings were abundant native vegetation and rocks coverage (71%). Most sightings occured in the hills (53%) but an important portion occurred near streams (27%). Potential threat of these animals to human were the only reported justification for hunting, which demostrate the lack of knowledge regarding Helodermatid´s biology for peole in the study area.

Table 1 approximately here#

We did not find significant relationship between sighting frequency and hunt frequency (Spearman´s correlation index from -0.021 to 0.28; $p>0.05$); hunting events are not restricted by landscape characteristics or perturbation indicators and occured wherever the animals were seen. Discriminant function analysis showed a significant environmental difference between sighting locations (Table 2), and the most impportant characteristics accounting for sightings, are related to habitat structure (patch numer, mean edge). Sighting frequency is negatively related to those variables suggesting a highest frequency in homogeneous environments. Discriminant function analysis for hunting frequency did not find significant differences among locations, supporting the hypothesis that this activity uccured wherever Helodermatids were found.

Table 2 approximately here#

DISSCUSION

Our records of 225 sightings in three years was higer than expected, given that in museums and scientific literature there are only approximately 150 well referenced records for the last 23 years [12, 13]. Results show an impportant variation in per-person sightings (Table 1), this may be is related to habitat suitability or availability (ecological niche and degree of urbanization respectively). The studied locations are included in Helodermatid´s potential distribution area; therefore, a relatively similar habitat suitability is expected [23]. Nonetheless, inter-population differences in habitat requirements and habitat suitability may restrict species occurrence [24]. Moreover, urbanization is related to habitat degradation and several species occurrences; therefore, we expect sighting frequency to be negatively related to urbanization [3]. Our results support this idea as more urbanized locations presented the lowest sighting frequency and the locations were vegetation was conserved present the highest sighting frequency (Table 1).

Field studies on Helodermatid´s biology in Mexico are restricted to one locality in Jalisco state [25-27] and another in Sonora state [28], but most of field knowledge has been collected from haphazard encounters. Therefore, there is an impportant lack of biological information on this group, even though it is a widely occuring group [13]. The remarcable difference in presence records between literature and this study exposes the limited field work on this group and we proppose rural inhabitants as an impportant potential source of information to increase capture rates and therefore knowledge of Helodermatids.

Hunting frequency was relatively constant among locations (Table 1) showing an homogeneous aversion to Helodermatids. Interviewed people mencioned potential threats to humans as the only justification for hunting and this is related to folklore surrounding these animals (pers. Obs.). Despite the fact that Helodermatids can truly cause serious injury in humans, its disposition to attack and its capabilities to do so seem to be limited. In fact, reported bites from Helodermatids are scarce and restricted almost exclusively to captive breeders or people attempting to handle them in field (Pers. Obs).

We found a 44% hunting frecuency, but the effect of this activity on wild populations is unknown; nonetheless, the synergy between low reproductive potential [29-31] and continued habitat perturbations may enhance negative effects and threaten several Helodermatid´s population persistence [3]. Besides, we found a positive correlation between sighting and hunting frequency suggesting that suitable environments are more impacted. We evaluated central and southern distribution portion of Mexican Helodermatids; however it is known that these animals are considered dangerous in every site where they are found [16, 17], there fore we think the impact on northern populations is quite similar to our findings.

Sighting events mainly accur in dense vegetation areas and where the presence of rocks is evident. Helodermatids relation to vegetation density has been suggested previously and seems to be related to food availability and refugia [26]. Otherwise, the importance or use of rocky habitats has not been reported (to our knowledge) but is possible and plays a valuable role as refugia during activity period in some areas. The predominant use of high hilly areas adjacent to streams coincides with reports from Beck and Lowe [26] who showed they are used as refuges during periods of inactivity in *H. horridum*.

Spearman correlation tests did not show significant relations between sighting or hunting frequency and structural or perturbation indicators of habitat, suggesting a non restriction of any of them on those events. It has been shown that habitat structure affects several biological characteristics such as reproduction and activity [32, 33]. However, these effects have been related to a combination of several habitat attributes [34, 35]. Discriminant analysis supports this idea as it showed environmental differences between locations with different sighting frequency associated to an specific group of variables (Table 2). Correspondance analysis showed the Helodermatids evasion of heterogeneous habitats through a negative relation between sightings-patch number and sightings-edge, which supports the group’s prefence for well preserved environments [13]. Crop distance was also an important variable in the correspondence analysis and its relation to sighting frequency was positive; we think, this is an effect of the activity of interviewed people, since farming inceases sightings in near crop areas. Discriminant analysis for hunting frequency did not find significant differences among locations, supporting the idea that they are determined by cultural rather than environmental factors.

Our results show that hunting impact can be a main threat to the presistence of the populations of Helodermatids and confirms that these animals avoid structurally heterogeneous environments. It is accepted that human impacts on tropical environments are directed by government politics on development, subsistence needs of the people, and by economic objectives of companies; this has generated fragmented landscapes dominated by humans [3]. The value of forest patches for conservation is also recognized, however because human activities influence on these communities is faster than natural proceses, it is necessary to understand the negative effects on wild populations before conservation strategies can be applied [3, 6]. Therefore, we propose that an effective conservation strategy for Helodermatids must include an education plan for people sharing the habitat with them and a vegetation management that account for structurally homogeneous vegetation.

Implications for conservation

Our results have clear implications for conservation of Helodermatids inhabiting tropical dry forest in two aspects: in the first place, they show that hunting impact is high because they are seen as direct threats to human health. It is a true that they have real potential to cause serious injuries to humans, but the beliefs of people exaggerate the capabilities of the lizards, and are the real culprits of hunting. This information shows that diffusion of behavior and mainly of venom characteristics and injury capabilities of this group may decrease negative on their populations. In the second place, the identified relationship between sightings and habitat structure confirms that Helodermatids are associated with conserved vegetation areas and show that is necessary to retain specific habitat characteristics that determine conservation value as surrogates of habitat quality.

ACKNOWLEDGEMENTS

We are grateful to the people from interviewed localities for their support, we also thank to Edgar Reyes, Jesús Rodríguez and Víctor Muñoz for their help in field work. Christopher Gienger revised the english translation. The first autor also thanks to CONACYT for the doctoral scolarship.

REFERENCES

[1] Peres, C. A. 2001. Synergistic effects of subsistence hunting and habitat fragmentation on Amazonian forest vertebrates. Conservation Biology 15:1490-1505.

[2] Redford, K. H. 1992. The empty forest. Bioscience 42:412-422.

[3] Robinson, J. G. Hunting wildlife in forest patches: An ephemeral resource. 1996. In: Forest patches in tropical landscapes. Schelhas, J. and Greenberg, R. (Eds.), pp.111-130. Island Press, Washington

[4] Distefano, E. 2005. Human-wildlife conflict worldwide: A collection of case studies, analysis of management strategies and good practices. FAO, Rome

[5] Treves, A., Wallace, R., Naughton-Treves, L. and Morales, A. 2006. Co-managing human-wildlife conflicts: A review. Human Dimensions of Wildlife: An international Journal 11:383-396.

[6] Woodroffe, R., Thirgood, S. and Rabinowitz, A. Eds. 2005. People and wildlife: conflict or coexistence? Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, Sao Paulo: Cambridge University Press.

[7] Conover, M. 2002. Resolving human-wildlife conflicts: The science of wildlife managment. Lewis publishers, USA

[8] Inskip, C. and Zimmermann, A. 2009. Human-felid conflict: a review of patterns and priorities worldwide. Orix 43:18-34.

[9] Fa, J. E., Ryan, S. F. and Bell, D. J. 2005. Hunting vulnerability, ecological characteristics and harvets rates of bushmeat species in afrotropical forests. Biological conservation 12:167-176.

[10] Nóbrega, R. R. and Lucena, I. Eds. 2013. Animals in traditional folk medicine: Implications for conservation. Berlin: Springer.

[11] Sterner, R. T. The economics of threatened species conservation: a review and analysis. 2009. In: Handbook of nature conservation. Aronoff, J. B. (Eds.), Nova Science Publishers,

[12] Beck, D. D. 2005. Biology of gila monsters and beaded lizards. University of California press, California

[13] Domínguez-Vega, H., Monroy-Vilchis, O., Balderas-Valdivia, C. J., Gienger, C. M. and Ariano-Sánchez, D. 2012. Predicting the potential distribution of the beaded lizard and identification of priority areas for conservation. Journal for Nature Conservation 20:247-253.

[14] Fry, B. G., Vidal, N., Norman, J. A., Vonk, F. J., Scheib, H., Ramjan, S. F. R., Kuruppu, S., Fung, K., Hedges, S. B., Richardson, M., Hodgson, W. C., Ignjatovic, V., Summerhayes, R. and Kochva, E. 2006. Early evolution of the venom system in lizards and snakes. Nature 439:584-588.

[15] Reiserer, R. S., Schuett, G. W. and Beck, D. D. 2013. Taxonomic reassessment and conservation status of the beaded lizard, Heloderma horridum (Squamata: Helodermatidae). Amphibian & Reptile Conservation 7:74-96.

[16] Brown, D. E. and Carmony, N. B. 1999. Gila monster: Facts and folklore of america´s aztec lizard. University of Utah press, Salt lake city

[17] Casas-Andreu, G. 2000. Mitos, leyendas y realidades de los reptiles en México. Ciencia ergo sum 7:286-291.

[18] CITES 2007. Apéndices I, II y III. Convención sobre el comercio internacional de especies amenazadas de fauna y flora silvestres,

[19] SEMARNAT 2008. Norma oficial mexicana NOM-059-ECOL-2001, protección ambiental-especies nativas de México de flora y fauna silvestres- categorias de riesgo y especificaciones para su inclusión, exclusión o cambio-lista de especies. Diario oficial 1-85.

[20] IUCN 2013. IUCN red list of threatened species. Version 2013.2. <www. uicnredlist.org>. Downloaded on 08 december 2013.

[21] INEGI 2005. Carta de uso actual del suelo y vegetación serie IV. INEGI, México D. F.

[22] Ariano-Sánchez, D. 2003. Distribución e historia natural del escorpión, *Heloderma horridum charlesbogerti* Campbell y Vannini, (Sauria: Helodermatidae) en Zacapa, Guatemala y caracterización de su veneno. Facultad de ciencias y humanidades. Universidad del valle de Guatemala. Biólogo.

[23] Hirzel, A. H. and Le Lay, G. 2008. Habitat suitability modelling and niche theory. Journal of applied ecology 45:1372-1381.

[24] Gaston, K. J. 2003. The structure and dynamics of geographic ranges. Oxford University Press, Oxford

[25] Balderas-Valdivia, C. J. and Ramirez-Bautista, A. 2005. Aversive behavior of beaded lizard, *Heloderma horridum*, to sympatric and allopatric predator snakes. The southwestern naturalist 50:24-31.

[26] Beck, D. D. and Lowe, C. H. 1991. Ecology of the beaded lizard, *Heloderma horridum,* in a tropical dry forest in Jalisco, México. Journal of herpetology 25:395-406.

[27] Beck, D. D. and Ramirez-Bautista, A. 1991. Combat behavior of the beaded lizard *Heloderma h. horridum*, in Jalisco, México. Journal of herpetology 25:481-484.

[28] Gienger, C. M., Johnson, G. W., McMillan, M., Sheldon, S. and Tracy, R. C. 2005. Timing of hatching in beaded lizards (*Heloderma horridum*). Sonoran herpetologist 18:93-94.

[29] Ariano-Sánchez, D. and Salazar, G. 2013. Heloderma horridum charlesbogerti (Guatemalan beaded lizard). Wild reproductive ecology. Herpetological Review 44:324.

[30] Golberg, S. R. and Beck, D. D. 2001. *Heloderma horridum* (beaded lizard) reproduction. Herpetological review 32:255-256.

[31] Gonzalez-Ruiz, A., Godinez-Cano, E. and Rojas-Gonzalez, I. 1996. Captive reproduction of the mexican acaltetepon, *Heloderma horridum*. Herpetological review 27:192.

[32] Cardozo, G. and Chiaraviglio, M. 2008. Landscape changes influece the reproductive behaviour of a key "capital breeder" snake (Boa constrictor occidentalis) in the Gran Chaco region, Argentina. Biological conservation 141:3050-3058.

[33] Trzcinski, M. K., Fahring, L. and Merriam, G. 1999. Independent effects of forest cover and fragmentation on the distribution of forest breeding birds. Ecological applications 92:586-593.

[34] Attum, O., Eason, P., Cobbs, G. and Baha El Din, S. M. 2006. Rresponse of a desert lizard community to habitat degradation: Do ideas about habitat specialist/generalist hold? Biological conservation 133:52-62.

[35] Blevins, E. and With, K. A. 2011. Landscape context matters: local habitat and landscape effects on the abundance and patch occupancy of collared lizards in managed grasslands. Landscape Ecology 26:837-850.

Tables

Locality	Number of interviews	Number of sightings	Sighting mean	Sightings proportion of total sightings	Number of hunt events	Hunting mean
Arcelia	8	10	1.25	0.04	5	50
Malinalco	29	70	2.41	0.30	35	50
Nanchititla	34	56	1.64	0.24	27	48
Tetecala	21	46	2.19	0.20	14	30
Tuxtla	10	19	1.9	0.08	6	31
Villa Flores	30	20	0.66	0.08	11	55
Yautepec	4	5	1.25	0.02	2	40
Total	136	226	-	-	100	-
Mean	19.42	32.28	-	-	14.28	44

Table 1. Sighting and hunting frequency of Helodermatids

	Discriminant funtion analysis			Canonic correspondence analysis	
Variables	p	Wilks´	F	Root 1	Root 2
Variables included in the discriminant model					
Number of patches	<0.01	0.50	4.87	-0.44	0.48
Edge mean	<0.05	0.47	2.96	-0.30	0.39
Crops distance	<0.05	0.46	2.42	0.40	0.06
Road distance	0.24	0.44	1.34	0.04	-0.19
Variables not included in the discriminant model					
Population density	0.99	<0.01	<0.05	-	-
Mean patch size	1	<0.01	<0.01	-	-
Explained Variation	-			66.44%	83.62%

Table 2. Environmental differences between locations (discriminant analysis) and important characteristics that define these differences (correspondence analysis)

Figures

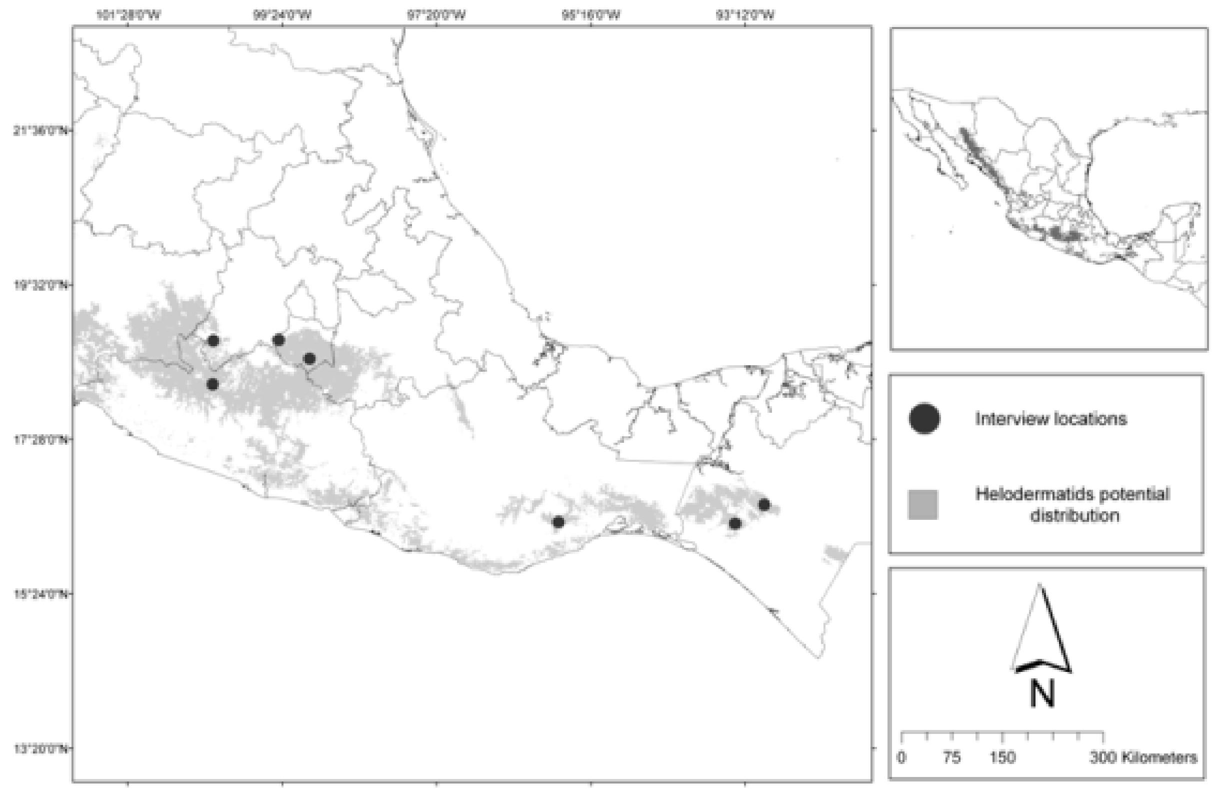


Figure 1. Interviewed localities on the distribution of Helodermatids

Capítulo III . Habitat loss and fragmentation affects niche breadth and habitat selection in Mexican Helodermatids

Hublester Domínguez-Vega[a], Octavio Monroy-Vilchis[a] and Carlos J. Balderas-Valdivia[b]

En revisión: Herpetological Journal

[a]Estación Biológica Sierra Nanchititla, Facultad de Ciencias, Universidad Autónoma del Estado de México. Instituto literario #100. Col. Centro, Toluca, Mexico

[b]Dirección General de Divulgación de la Ciencia, Universidad Nacional Autónoma de México, Zona Cultural de Cd. Universitaria, Coyoacán, D.F., CP 04510, México

Corresponding autor: Octavio Monroy-VIlchis, tavomonroyvilchis@gmail.com

Habitat perturbation effects on Helodermatids

ABSTRACT

Habitat loss and fragmentation are the main biodiversity threats, understanding their effects is essential to develop conservation strategies. Behavioral adaptive responses of biodiversity to these perturbations are scarcely known. We analyzed the response of Mexican Helodermatids using habitat selection and niche breadth. These species are mainly threaten by environmental perturbations and its requirements restrict them to well preserved areas. Our objectives were to: determine habitat selection and niche breadth responses to habitat loss and fragmentation and identify the associated factors. The study area was the potential distribution of these species. We used presence records and vegetation layers to characterize habitat. The species response was evaluated in environments with different perturbation degree using clustering analysis. We used discriminant analysis to identify habitat use and niche breadth differences and the associated environmental factors. Habitat loss restricts habitat selection as perturbation increases whereas fragmentation allows wider environmental use. Niche breadth analysis also showed a stronger response capability in habitat fragmentation. This behavior shows a mechanism that allows the persistence of populations in fragmented areas and restricts them in habitat loss. Our study contributes information on mechanisms explaining negative effects of habitat loss and effects of habitat fragmentation on biodiversity.

Key words: Beaded lizards, conservation, ecological responses, habitat perturbations, Helodermatidae, landscape, tropical dry forest.

INTRODUCTION

Habitat loss and fragmentation (HL&F) are the main biodiversity threats; hence understanding species response to these disturbances is essential to define conservation strategies(Saunders et al., 1991; Andrén, 1997; Gibbons et al., 2000; Fahring, 2002; Hoffmeister et al., 2005; Cushman, 2006). Nonetheless, the studies on this subject have shown controversial results that have cuestioned the ecological applicability of these concepts (Fahring, 2003; Ewers & Didham, 2006; Lindenmayer & Fischer, 2006; Ewers & Didham, 2007). Fahring (2003) proposed that an independent evaluation of habitat loss (a reduction of area available for one species) and fragmentation (structural rearrangement of the available area) is necessary to correctly identify the positive and negative effects on biodiversity. By this way she proved that habitat reduction, strongly affects biodiversity whilst its rearrangement promotes low intensity or null effects on numeric parameters. However Blouin-Demers & Weatherhead (2001) considered that fragmentation can have an impportant role on ecological interactions (behavioral parameters) but the evidences on this idea are insufficient and its role to habitat disturbances remain unknown.

Habitat selection and niche breadth constitute appropiated parameters to evaluate the responses of species in face of habitat changes as HL&F, because through them, we can quantify and compare the relationship between resources use and their availability and also to indentify changes on use intensity (specialization). This kind of knwoledge allows to infer habitat characteristics related to the species fitness and is considered a leading evidence of each resource importence (Krebs, 1999; Thomas & Taylor, 2006).

We analized HL&F effects on habitat selection and niche breadth using presence records of three Helodermatid species: *Heloderma exasperatum, H. horridum and H. alvarezi* (Reiserer et al., 2013) distributed throughout mexican tropical dry forest. Despite its relative large distribution area, these species are considered to be rare. Moreover it has been estimated that its populatios are scarcely included in natural protected areas, supporting the idea that these species are mainly threatened by habitat perturbation (Domínguez-Vega et al., 2012). Besides, the low activity rate of these species and its trophic specialization confirm they require a preserved habitat to survive (Beck & Lowe, 1991; Beck, 2005), and made Helodermatids an appropiated model to analize behavioral response role in face of HL&F. Our objectives were to: (1) determine and quantify the effect of HL&F on habitat selection and niche breadth, (2) identify the variables associated to the behavioral response and (3) determine the effect of HL&F interaction on the species behavioral response.

We used the potential distribution area of mexican Helodermatids reported by Domínguez-Vega et al. (2012). This area includes most of the western tropical dry forest in Mexico, an ecosystem covering an area of almost 15 degrees of latitude from north to south and an impportant area in central Mexico known as Balsas Basin gathering more than 25 million hectares. This large area and its complex phisiography shelters 67% of the reported vertebrates in the country which make it extremely important in conservation (Conservancy 2007). At the same time, some of the biggest cities and urban areas are foud in here which represent an immportant threat for biodiversity manly due to land use change and hunting.

MATERIAL AND METHODS

The study area (Fig. 1), was difined based on the potential distribution of the three species (Domínguez-Vega et al., 2012), we considered native vegetation as the species habitat. This area is dominated by tropical dry forest and transition zones with several vegetation types. In Mexico there has been a prolonged process of soil use change that continues afecting a great portion of the country. In tropical dry forests this process were particuary strong in the midle 70´s (Ceballos et al., 2010) and dramaticly changed its structure and composition; so, we adopted 1980 as a threshold point to relate species occurrences to habitat characteristics.

Helodermatid presence records were colected from museum data bases and scientific literature. We selected those records with geographic cordenates or a precise drescription of the record locality and colecting year. We obtained geographic coordinates using Google Earth ver. 6.1.0.5001 at an approximate accuracy of 1km^2 for records needed. The presence records were overlaid on a digital layer of soil use and vegetation types (S&V) depending on the collecting year. We used two layers that were generated for all the country at an accuracy of 1 km^2 in different years, one of them correspond to our threshold point and it were applied for those records acquired before 1980 (INEGI, 1993). The second layer was used for those records acquired after 1980 (INEGI, 2005). Surrounding each point, we generated a buffer area of approximately 11km^2, based on *Heloderma horridum* home range, and we considered it could home 50 individuals (Beck & Lowe, 1991). In each buffer we quantify native and disturbed vegetation cover. Habitat fragmentation was estimated using Patch Analyst (Elkie et al., 1999), this is an ArcGIS extension that allows to infer an area vegetation structure using several indicators; we used those related to shape, isolation and environmental heterogeneity (Table 1). Habitat loss was evaluated in the same way but we used three variables related to native vegetation cover (Table 1).

To independtly evaluate loss and fragmentation effects, we used the clasification variables (Table 1) to cluster buffers using the K-means algorithm. This way we generated groups of similar habitat loss or fragmentation (controls; CG). Afterwards another cluster was applied in each CG; this process allowed us to identify sub-groups were habitat loss or fragmentation effects were evaluated (response groups; RG). The number of groups were determined looking for differences to be maximized; we used as many groups as possible holding significat differences in all variables, and a minimum group size of 20 elements. This analisys desing enabled us to indepently evaluate each perturbation (loss or fragmentation) effect on habitat selection among a relative constant environment of the other perturbation (Fig. 2).

The species response was evaluated using nine environmental variables (Table 1); we selected indicators of vegetation cover suitability, human perturbation and moisture based on the hypothesis that Helodermatids prefer well preserved vegetation areas. We also included topographic variables because they can be related to some resources availability as food and refugia (Beck & Lowe, 1991; Beck & Jennings, 2003; Beck, 2005). A discriminant analysis was applied to evaluated habitat selection; the response group was set as the clasification variable and the nine variables as independents. Besides, we used Mahalanobis distance to determinate inter-group diference degree, and canonic correspondance analysis to identify the most important variables determinating group differences in habitat selection.

Niche breadth was estimated for each response group and for all variables using Levin´s standarized index (Krebs, 1999). Use intensity was calculated from presence records using ArcGIS 10. We considered that resources in the 11 km^2 buffers were available for individuals because even when its home range is relatively small (21 ha) its linear movement can be high (Beck & Lowe, 1991). Afterwards, the formula propposed by Krebs (1999), was applied and niche breadth variations were analyzed for control and response groups. Finally, a bootstrap analysis with 10,000 iteractions was used to obtain confidence intervals of niche breadth in response groups.

RESULTS

We used 242 Helodermatid presence records (Fig. 1); 136 of them were related to the first vegetation layer (1950-1979) and 106 to the second one (1980-2010). Throughout this time antropic activities has modified vegetation in Helodermatids distribution area and nowadays is a complex mosaic of native primary vegetation patches (36%), native-introduced vegetation patches (28%) and diverse soil use patches (36%).

Effects of habitat loss

Cluster analysis identified three CG (same intra-group fragmentation conditions), where CG1 presents the lowest fragmentation and the CG3 the highest. Response groups (different inter-groups habitat loss conditions) for CG1 don´t were obtained because it presents no habitat loss and its elements were analized with those of CG2; from now on, these will be referd as GA and GB respectively (Table 2).

Discriminant analysis identified significant differences ($p<0.01$) in habitat slection in GA and GB (Table 3). Besides, Mahalanobis distance shows a inter RG difference increment as habitat loss intensity increases (Table 4), i. e. habitat use in RG are increasingly different according habitat loss. Habitat selection differences ($P<0.05$) in GA are determined by stream distance, slope, conserved vegetation distance and native vegetation distance (Table 3). In GB the important variables were seasonal crops distance, native vegetation distance, altitude and moisture (Table 3). These results clearly evidence a change in habitat selection as response to habitat availability and sugest a switch of main habitat characteristics from topographic variables to cover vegetation variables.

Niche breadth analysis for GA showed a specialist habitat use (B´<0.5) at low, medium and high habitat loss (66, 77 and 66% of response variables) that became marked in half of response variables as habitat availability decrease, whilst the rest showed a generalist tendency. GB showed a similar but stronger specialist pattern at low, medium and high habitat loss (88, 77 and 88% of response variables) and a weaker generalist tendency (33% of the variables). Nonetheless, specialization values are extremely small in most variables indicating a low response hability in high disturbed habitat (Table 5). Confidence intervals in bootstrap analysis support that helodermatids are habitat specialists and that specialization are stronger in more disturbed habitat suggesting a sinergetic effect between habitat loss and fragmentation (Table 5).

Effects of Habitat Fragmentation

Cluster analysis identified three CG (same intra group habitat loss conditions), where GC presents the lowest loss folowed by GD and GE the highest (Table 2). RG (different inter-group fragmentation conditions) were analized in the same way as in habitat loss effects.

Discriminant analysis showed significant differences ($p<0.01$) in habitat selection for GC, GD and GE (Table 3). Mahalanobis distance showed a inter-RG increment as fragmentation increase for GC and GD (Table 4). Canonic correspondance analysis yielded stream distance, altitude and dry forest distance as the determinating variables ($p<0.05$) for GC (Table 3). For GD the important variables were conserved vegetation distance, permanent crops distance and stream distance (Table 3). Correspondance analysis in GE was not performed because data from discriminant analysis were insuficient, therefore important variables were not identified. These results showed a behavioral response similar to that from habitat loss because prove a change in habitat use leaded by habitat perturbations; and also a switch of important variables from topographic to vegetation cover.

Helodermatids present a specialist habitat use in GC ($B´<0.5$) in low (55%); medium (88%) and hihg fragmented habitat (66% of response variables) this behavior became marked as fragmentation increase for 77% of response variables proving a strong change in niche breadth as response to this perturbation (Table 5). GD showed the same specialist pattern in low, medium and high fragmentation (77, 88 and 88 % of response variables) in conjuction with and espicialist tendency of 77% of response variables as the perturbation increase. In GE the specialization was the strongest but as fragmentation increase, habitat use showed a slight tendency to become generalist; however specialization in this group in near minimum indicating that in low habitat availability environments, Helodermatids realized a extremely specialist use of most environment characteristics and perhaps showing a treshold in its response capabilities. Bootstrap analysis proved these tendencies as stables, suggesting a synergistic effect between habitat loss and fragmentation that is observed as habitat breadth reduction between control groups (Table 5).

DISCUSSION

Altough several studies propose reptiles as the most threatened group of vertebrates to environmental disturbances (White et al., 1997; Gibbons et al., 2000), habitat changes effects on them has been scarcely evaluated (Gardner et al., 2007). We analized the behavioral response role in face of HL&F using spatial and trophic specialist reptiles. Our results showed that Helodermatids occur in environmentaly different areas when its habitat decrease or change structuraly (Table 3). Moreover, these differences increase proportionally to habitat perturbations (Table 4). These behavioral pattern suggest that both habitat loss and fragmentation promote a strong change in habitat selection that could be related to movement capability. It has benn proved that habitat loss constraint movement more than fragmentation (Fahring & Merriam, 1994; Fahring, 1997), and our results indicate that habitat selection can be afected by this restriction. Moreover, if selection capability decrease, some individuals would be restricted to low suitability areas where survival (Hokit & Branch, 2003) and reproduction (Cardozo & Chiaraviglio, 2008) will also be negatively affected, indicating habitat fragmentation allows selection of appropiated characteristics whilst habitat loss restricts populations to homogeneous environments by isolation.

We identified several environment characteristics as important for Helodermatids occurences, but it seems to be a pattern of selection leaded by topographic variables in low distrurbed areas and by vegetation cover variables in those of high perturbation (Table 3).

Variation in responses to habitat perturbations has been documented for reptiles, and among principal factors we can found intrinsic needs as home range and trophic breadth (Fischer et al., 2005; Rizkalla & Swihart, 2006; Suazo-Ortuño et al., 2008) or those related to termorregulation needs affected by reproduction (Blouin-Demers & Weatherhead, 2001). Beck and Lowe (1991) observed that dense native vegetation areas are more frecuently occupied by *H. horridum*. Besides, there is evidence proving refugia availability and microenvironmental quality are crucial in *H. suspectum* occurrence and may also be the same for *H. horridum* (Beck & Jennings, 2003). HL&F strongly affect these factors, nonetheless the interaction between vegetation cover characteristics (kind and quality) and topography may result in multiple convinations offering similar habitat quality and hence resulting in the variety of conditions selected by Helodermatids.

Niche breadth analysis showed a diferent intensity response in perturbations. Habitat loss displayed a low strength response with tendencies to both specialization and generalization indicating a difuse response (Table 5). Instead, Habitat fragmentation showed a more consistent patern in the response. In face of habitat structure changes, Helodermatids clearly modify its habitat specialization in a negative relation (Table 5). However, in GE we observed a change in Helodermatids response indicating a treshold in behaviour (Table 5). These kind of changes has been proposed in relation to decreases in richness and abundance (With & King, 1999; Drinnan, 2005; Lindenmayer et al., 2005) and respresent environmental conditions in wich species exhibit a drastic reduction on these characteristics. In our study, a treshold could indicate the point at wich Helodermatids loss its capability of selecting appropiated environmental characteristics due to movement limitations.

Besides, we observed a progresive specialization patern between RG in both habitat loss and fragmentation wich suggest a sinergic effect among these perturbations (Table 5). Such idea agrees with that proposed by Fahring (2003) on the misinterpretation of HL&F effects when these perturbations are not evaluated independently. Most published studies on HL&F, suggest habitat loss as the determinant factor on biodiversity negative effects whilst fragmentation has been considered of low relevance (Fahring, 2003). Our results showed that behavioural response is mainly affected by fragmentation whilst habitat loss do not produce or likely limits noticeable changes in habitat selection and niche breadth offering a posible explanation for the absence of biodiversity numeric response to fragmetation trought plasticity in habitat selection and niche breadth.

Negative effects on biodiversity leads conservation strategies in many areas and focus work on ecological restoration and resources use reduction (Fahring, 1997). However, even when this strategy maybe the most effective, human needs frecuently obstruct its appliaction (Vandermer & Perfecto, 2007). Trough our results, a more flexible conservation strategy can be proposed where social and biodiversity needs can be included taking habitat structure as the cornerstone.

Conservation strategies in Mexican tropical dry forest are scarce despite its recognized biodiversity. The main reason include intensity of human activities as farming and ranching. Our results clearly show that habitat structure management can provide species space needs and at the same time allow human economic activities. An important issue is that movement constraints are different for each secies and even populations and conectivity requirements should be estimate at least for those considered as keystones in each area before management strategies are established.

CONCLUSIONS

Helodermatids and may be other animals modify their ecological parameters as a strategy to endure habitat perturbations. The main response to habitat loss and fragmentation is specialization of ecological parameters related to movement. Fragmentation allows a stronger response in ecological parameters related to animal movement, may be through movement facilities across suitable habitat patches. Habitat loss restricts movement and hence the response capability of Helodermatids to use suitable habitat.

ACKNOWLEDGEMENTS

We thank to all the people from Sierra Nanchititla and Arcelia Guerrero who helped us in field work and to CEPANAF for provide permits to work at Sierra Nanchititla Natural Park. We also thank to the working group from the Museo Nacional de Anfibios y Reptiles (UNAM) and to GBIF for the records provided. The first autor also thanks to CONACYT for the doctoral scolarship.

REFERENCES

Andrén, H. (1997). Habitat fragmentation and changes in biodiversity. *Ecological Bulletins*, 171-181.

Beck, D. D. (2005). *Biology of gila monsters and beaded lizards*. California: University of California press.

Beck, D. D. & Jennings, R. (2003). Habitat use by gila monsters: the importance of shelters. *Herpetological monographs*, *17*, 111-129.

Beck, D. D. & Lowe, C. H. (1991). Ecology of the beaded lizard, *Heloderma horridum*, in a tropical dry forest in Jalisco, México. *Journal of herpetology, 25*, 395-406.

Blouin-Demers, G. & Weatherhead, P. J. (2001). Habitat use by black rat snakes (Elaphe obsoleta obsoleta) in fragmented forests. *Ecology, 82*, 2882-2896.

Cardozo, G. & Chiaraviglio, M. (2008). Landscape changes influence the reproductive behaviour of a key "capital breeder" snake (Boa constrictor occidentalis) in the gran chaco region, Argentina. *Biological conservation, 141*, 3050-3058.

Ceballos, G., Martínez, L., García, A., Espinoza, E., Bezaury Creel, J. & Dirzo, R. (2010). *Diversidad, amenazas y áreas prioritarias para la conservación de las selvas secas del Pacífico de México*. México, D. F.: CONABIO/FCE.

Cushman, S. A. (2006). Effects of habitat loss and fragmentation on amphibians: A review and prospectus. *Biological conservation, 128*, 231-240.

Domínguez-Vega, H., Monroy-Vilchis, O., Balderas-Valdivia, C. J., Gienger, C. M. & Ariano, D. (2012). Predicting the potential distribution of the beaded lizard and identification of priority areas for conservation. *Journal for nature conservation, 20*, 247-253.

Drinnan, I. N. (2005). The search for fragmentation thresholds in a southern Sydney suburb. *Biological conservation, 124*, 339-349.

Elkie, P. C., Rempel, R. S. & Carr, A. P. (1999). Patch analyst user´s manual. 1-22.

Ewers, R. M. & Didham, R. K. (2006). Confounding factors in the detection of species responses to habitat fragmentation. *Biological reviews, 81*, 117-142.

Ewers, R. M. & Didham, R. K. (2007). Habitat fragmentation: pancherston or paradigm? *Trends in ecology and evolution, 22*, 511.

Fahring, L. (1997). Relative effects of habitat loss and fragmentation on population extinction. *The Journal of Wildlife management, 61*, 603-610.

Fahring, L. (2002). Effect of habitat fragmentation on the extinction threshold: A synthesis. *Ecological applications, 12*, 346-353.

Fahring, L. (2003). Effects of habitat fragmentation on biodiversity. *Annual review of ecology, evolution, and systematics, 34,* 487-515.

Fahring, L. & Merriam, G. (1994). Conservation of fragmented populations. *Conservation biology, 8*, 50-59.

Fischer, J., Lindenmayer, D. B., Barry, S. & Flowers, E. (2005). Lizard distribution patterns in the Tumut fragmentation "Natural experiment" in south-eastern Australia. *Biological conservation, 123*, 301-315.

Gardner, T. A., Barlow, J. & Peres, C. A. (2007). Paradox, presumption and pitfalls in conservation biology: The importance of habitat change for amphibians and reptiles. *Biological conservation, 138*, 166-179.

Gibbons, J. W., Scott, D. E., Ryan, T. J., Buhlmann, K. A., Tuberville, T. D., Metts, B. S., Greene, J. L., Mills, T., Leiden, Y., Poppy, S. & Winne, C. T. (2000). The global decline of reptiles, déjà vu amphibians. *BioScience, 50*, 653-666.

Hoffmeister, T. S., Vet, L. E., Biere, A., Holsinger, K. & Filser, J. (2005). Ecological and evolutionary consequences of biological invasion and habitat fragmentation. *Ecosystems, 8*, 657-667.

Hokit, D. G. & Branch, L. C. (2003). Habitat patch size affects demographics of the Florida scrub lizard (*Sceloporus woodi*). *Journal of herpetology, 37*, 257-265.

INEGI. (1993). *Carta de uso actual del suelo y vegetación serie II*. México, D. F.: INEGI.

INEGI. (2005). *Carta de uso actual del suelo y vegetación serie IV*. México D. F.: INEGI.

Krebs, C. J. (1999). *Ecological methodology* (2 ed.). Menlo Park, CA: Benjamin/Cummings.

Lindenmayer, D. B. & Fischer, J. (2006). Tackling the habitat fragmentation pancherston. *Trends in ecology and evolution, 22*, 127-132.

Lindenmayer, D. B., Fischer, J. & Cunningham, R. B. (2005). Native vegetation cover thresholds associated with species responses. *Biological conservation, 124*, 311-316.

Reiserer, R. S., Schuett, G. W. & Beck, D. D. (2013). Taxonomic reassessment and conservation status of beaded lizard, *Heloderma horridum* (Squamata: Helodermatidae). *Amphibian & Reptile Conservation*, *7*, 74-96.

Rizkalla, C. E. & Swihart, R. K. (2006). Community structure and differential responses of aquatic turtles to agriculturally induced habitat fragmentation. *Landscape ecology, 21*, 1361-1375.

Saunders, D. A., Hobbs, R. J. & Margules, C. (1991). Biological consequences of ecosystem fragmentation: A review. *Conservation biology*, *5*, 18-32.

Suazo-Ortuño, I., Alvarado-Díaz, J. & Martínez-Ramos, M. (2008). Effects of conversion of dry tropical forest to agricultural mosaic on herpetofaunal assemblages. *Conservation biology, 22*, 362-374.

Thomas, D. L. & Taylor, E. J. (2006). Study desings and tests for comparing resource use and availability II. *Journal of wildlife management*, *70*, 324-336.

Vandermer, J. & Perfecto, I. (2007). The agricultural matrix and a future paradigm for conservation. *Conservation biology, 21*, 274-277.

White, D., Minotti, P. G., Barczak, M. J., Sifneos, J. C., E., F. K., V., S. M., F., S. C., R., K. A. & M., P. E. (1997). Assesing risk to biodiversity from future landscape change. *Conservation biology*, *11*, 349-360.

With, K. A. & King, A. W. (1999). Extinction thresholds for species in fractal landscapes. *Conservation biology*, *13*, 314-32.

Table 1. Variables used to evaluate Helodermatid response to habitat perturbations

	Clasification Variables	Response variables
Habitat fragmentation variables	Number of patches	Native vegetation distance
	Median patch size	Conserved vegetation distance
	Total edge	Temporal cultives distance
	Edge density	Permanent cultives distance
	Mean patch edge	Tropical dry forest distance
	Area Weighted mean patch fractal dimension	Stream distance
	Mean patch-area ratio	Altitude
	Vegetation types	Slope
Habitat loss variables	Native vegetation percent	Humidity index
	Conserved vegetation percent	
	Urban use percent	

Table 2. Control and response groups used in discriminant analysis

Fragmentation effect		Loss effect	
Control group	Response group	Control group	Response group
Low loss (80)	Fragmentation 1 (25)	Low fragmentation (119)	Loss 1 (30)
	Fragmentation 2 (23)		Loss 2 (63)
	Fragmentation 3 (32)		Loss 3 (26)
Medium loss (110)	Fragmentation 1 (29)	High fragmentation (123)	Loss 1 (64)
	Fragmentation 2 (32)		Loss 2 (36)
	Fragmentation 3 (49)		Loss 3 (23)
High loss (52)	Fragmentation 1 (26)		
	Fragmentation 2 (26)		

Table 3. Significant differences in habitat selection

Habitat selection differences (*) indicates significant differences, (+) indicates the most important variables according to correspondence analysis.

Variables	Loss		Fragmentation		
	p (GA)	p (GB)	p (GC)	p (GD)	p (GE)
Altitud	0.1311	0.0016*$^{+}$	0.0009*$^{+}$	0.8454	0.8976
Stream distance	0.0050*$^{+}$	0.7052	0.1314^{+}	0.0005*$^{+}$	0.7770
Permanent crops distance	0.5694	0.0846	0.3457	0.0004*$^{+}$	0.2264
Temporal crops distance	0.7474	0.0003*$^{+}$	0.5874	0.0148*	0.0241*
Dry forest distance	0.4362	0.6630	0.0178*$^{+}$	0.7241	0.6625
Native vegetation distance	0.0177*$^{+}$	0.0272*$^{+}$	0.2432	0.2974	0.3597
Conserved vegetation distance	0.0005*$^{+}$	0.3485	0.9854	0.0210*$^{+}$	0.6583
Humidity index	0.0739	0.0131*	0.8921	0.1891	0.0096*
Slope	0.0001*$^{+}$	0.9500	0.3163	0.7820	0.5839

Table 4. Difference degree for response groups estimated with Mahalanobis distance

The Mahalanobis distance value increases as differences become stronger, all groups are significantly different ($p<0.01$).

Pérdida de hábitat							
GR-A				GR-B			
	GR1	GR2	Gr3		GR1	GR2	Gr3
GR1	0	1.2094	2.9275	GR1	0	2.2569	3.4719
GR2		0	2.5091	GR2		0	1.5359
GR3			0	GR3			0
Fragmentación del hábitat							
GR-C				GR-D			
	GR1	GR2	Gr3		GR1	GR2	GR3
GR1	0	2.0184	3.6475	GR1	0	1.2113	1.9580
GR2		0	1.7756	GR2		0	2.7458
GR3			0	GR3			0

GR-E		
	GR1	GR2
GR1	0	2.4064
GR2		0

Table 5. Niche breadth changes in face of habitat perturbations

Niche breadth values ranges from 0 (completely specialist) to 1 (completely generalist)

Variable	Niche Breath Index (Habitat loss)						Niche Breath Index (Habitat Fragmentation)							
	RG-A			RG-B			RG-C			RG-D			RG-E	
Altitude	0.25	0.47	0.55	0.77	0.37	0.24	0.22	0.48	0.83	0.37	0.20	0.61	0.36	0.40
Stream distance	0.61	0.35	0.13	0.12	0.23	0.15	0.68	0.42	0.11	0.29	0.22	0.08	0.08	0.16
Temporal Farming Distance	0.90	0.88	0.15	0.42	0.02	0.07	0.64	0.82	0.58	0.38	0.07	0.15	0.12	0.19
Permanent Farming Distance	0.69	0.60	0.27	0.22	0.58	0.37	0.67	0.42	0.27	0.71	0.67	0.18	0.23	0.53
Tropical Dry Forest Distance	0.38	0.13	0.22	0.09	0.00	0.11	0.45	0.23	0.09	0.10	0.00	0.05	0.14	0.20
Conserved Vegetation Distance	0.34	0.29	0.37	0.13	0.02	0.18	0.43	0.27	0.20	0.16	0.01	0.13	0.25	0.26
Native Vegetation Distance	0.45	0.14	0.47	0.03	0.00	0.11	0.61	0.23	0.03	0.07	0.00	0.03	0.23	0.36
Humidity Index	0.44	0.47	0.67	0.38	0.51	0.52	0.38	0.31	0.27	0.54	0.38	0.43	0.75	0.49
Slope	0.17	0.27	0.06	0.46	0.13	0.02	0.16	0.25	0.74	0.16	0.18	0.25	0.01	0.09
	0.32-	0.25	0.17	0.14	0.03	0.11-	0.33	0.25	0.136-	0.15	0.05	0.09	0.08-	0.19-
Bootstrap	0.48	-	-	-	-	0.23	-	-	0.44	-0-	-	-	0.39	0.37
		0.43	0.39	0.32	0.30		0.59	0.27		34	0.19	0.25		

Figure 1. Potential distribution of Mexican Helodermatids.

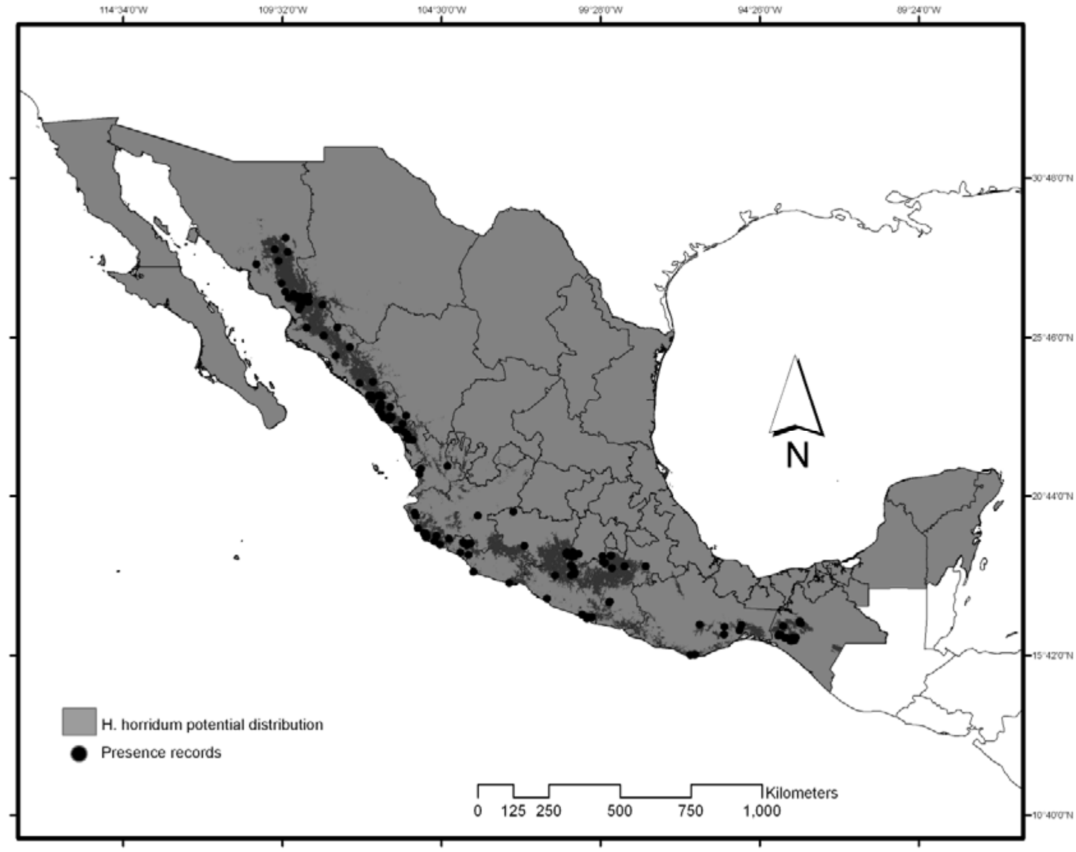
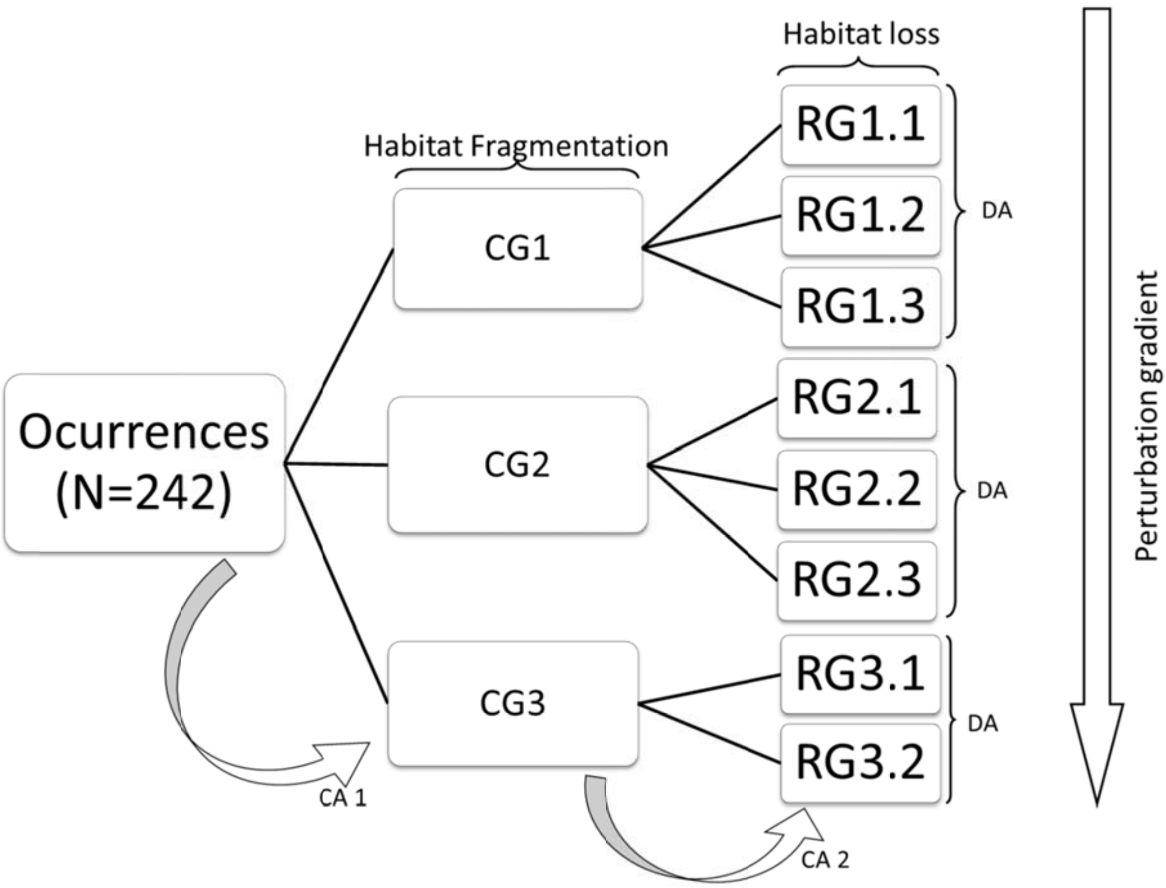


Figure 2. Analysis design used to independently evaluate habitat perturbation effects



Capítulo IV . Perspectivas de conservación de los escorpiones (Squamata:Helodermatidae) en México

Hublester Domínguez-Vega[a,c], Octavio Monroy-Vilchis[a], Carlos J. Balderas-Valdivia[b] y Javier Manjarrez-Silva[c]. **En preparación**

[a]Estación Biológica Sierra Nanchititla, Facultad de Ciencias, Universidad Autónoma del Estado de México. Instituto literario #100. Col. Centro, Toluca, Mexico

[b]Dirección General de Divulgación de la Ciencia, Universidad Nacional Autónoma de México, Zona Cultural de Cd. Universitaria, Coyoacán, D.F., CP 04510, México

[c]Centro de investigación en recursos bióticos. Facultad de Ciencias, Universidad Autónoma del Estado de México. Instituto literario #100. Col. Centro, Toluca, Mexico

INTRODUCCIÓN

La familia Helodermatidae se compone de un género y cinco especies (Reiserer et al., 2013), aunque de manera informal se reconocen solo dos grupos. Los monstruos de Gila (Heloderma suspectum) que están asociados a las zonas desérticas del suroeste de Estados Unidos y noroeste de México y los escorpiones (H. exasperatum, H. horridum, H. alvarezi y H. charlesbogerti) que se distribuyen en la selva baja de la vertiente del pacífico mexicano y en Guatemala (Beck, 2005). Las lagartijas de esta familia presentan características morfológicas y ecológicas distintivas entre los saurios; probablemente la más notable es la presencia de un sistema bien desarrollado para la producción e inoculación de veneno (Fry et al., 2006). Esta característica aunada a su apariencia colorida y aspecto tosco les ha otorgado reconocimiento e integración en el folclor mexicano desde periodos prehispánicos (Brown & Carmony, 1999) y más recientemente ha generado un conflicto con las personas (Brown & Carmony, 1999; Casas-Andreu, 2000), que influye negativamente en su conservación (Domínguez-Vega et al. 2014). Pero también ha motivado el interés de científicos en áreas como ecología, evolución, fisiología o medicina, donde se ha demostrado su importancia en aspectos como la conservación de ambientes amenazados (Ariano-Sánchez & Cotí, 2007), la evolución del veneno en reptiles (Fry et al., 2006), el papel de la quimiorrecepción en la identificación de los depredadores (Balderas-Valdivia, 2000) e incluso en la salud humana (Van Denburgh, 1898; Hendon & Tu, 1981; Sosa et al., 1986).

A pesar de su amplia distribución, los escorpiones se consideran especies de ocurrencia rara, lo que se ha relacionado con densidades poblacionales bajas y escasa actividad superficial (Beck & Lowe, 1991; Beck, 2002; Beck & Jennings, 2003). Como consecuencia el esfuerzo de muestreo necesario para localizar un individuo es muy elevado (Ariano-Sánchez, 2003; Beck, 2005) y los estudios sobre estos animales así como el conocimiento sobre su biología en vida libre es limitado. La ocurrencia de los escorpiones está fuertemente asociada a la selva baja caducifolia (Domínguez-Vega et al., 2012), uno de los ambientes más amenazados en México y a nivel mundial (Ceballos et al., 2010). Además, algunas de sus características intrínsecas como la tasa anual de actividad superficial, requerimientos climáticos microambientales y especialización alimentaria soportan la idea de que requiere ambientes conservados para sobrevivir (Beck & Lowe, 1991; Domínguez-Vega et al., 2012); lo que confiere a los escorpiones relevancia como especies indicadoras de la calidad de su hábitat. Sus principales amenazas son la pérdida y degradación del hábitat, el comercio ilegal y la cacería indiscriminada (Beck, 2005) y debido a la continua expansión de la frontera agrícola, ganadera y urbana en su área de distribución y a su escaza inclusión en las áreas protegidas de México (Domínguez-Vega et al., 2012) se piensa que la perturbación de su hábitat ejerce un impacto negativo directo y elevado.

Hasta el año 2013, los escorpiones se consideraban una sola especie (Reiserer et al., 2013) que en México estaba incluida para su protección en la NOM-ECOL-059-2001 bajo la categoría de amenazada (SEMARNAT, 2008). Además, a nivel internacional, se encontraba dentro de la categoría II de la CITES (CITES, 2007) y como una especie de menor importancia en la UICN (UICN, 2001). El reconocimiento de una mayor diversidad genética en los escorpiones aunado a las presiones ambientales sobre su hábitat demanda la evaluación de su estado de conservación para garantizar la persistencia de este grupo de relevancia cultural y científica.

En este estudio se presenta el panorama actual del hábitat de los escorpiones con base en sus preferencias ambientales y se genera un escenario de cambio a partir de las tendencias de uso de suelo en su área de distribución potencial. Nuestros objetivos fueron: 1) categorizar el área de distribución potencial de los escorpiones con base en la calidad del clima y la estructura y composición de la cobertura vegetal y 2) generar un escenario futuro de hábitat óptimo para los escorpiones mexicanos con base en una proyección de cambio de uso del suelo.

MÉTODO

El área de estudio se limitó con base en la distribución potencial de los escorpiones en México, reportada por Domínguez-Vega et al. (2012) y se consideró que la vegetación nativa representa su hábitat. La región está dominada por selvas bajas y zonas de transición con otros tipos de vegetación que incluyen vegetaciones de zonas áridas (matorral xerófilo), húmedas (palmares y zonas costeras) y templadas (bosques de encino y pino-encino). En México se ha presentado un largo proceso de cambio de uso de suelo que continua afectando una gran porción del país. En la selva baja caducifolia, este proceso fue particularmente marcado en la década de 1970 a 1980 (Ceballos at al 2010) y cambió drásticamente la estructura y composición de este ambiente por lo que el año de 1980 se consideró como la referencia para determinar la dinámica de cambio del hábitat de los escorpiones.

Caracterización del hábitat actual

La caracterización del hábitat se dividió en dos componentes: 1) clima y 2) cobertura vegetal, incluyendo estructura y composición con base en los reportes de Domínguez-Vega et al. (2012) y Domínguez-Vega et al. (2014) respectivamente. Para la categorización del ambiente climático se utilizaron tres variables: 1) porcentaje de precipitación en la época de sequía, 2) porcentaje de precipitación en la época de lluvia y 3) precipitación mínima en la época de lluvia. La información correspondiente a cada variable se obtuvo de capas digitales que se encuentran disponibles en internet a través de WorldClim. En cada variable se identificaron las preferencias de los escorpiones con base en Domínguez-Vega et al.(2012) y los rangos de variación en el área de estudio. Cada variable se dividió en 10 clases de igual amplitud considerando sus valores mínimos y máximos dentro del área de estudio. El valor máximo en cada clase reprenta las zonas con las características preferidas por los escorpiones y recibió el valor de 10 , el resto de las clases recibieron valores descendentes respecto a la diferencia con las preferencias de los escorpiones. Para la categorización del ambiente en relación a la cobertura vegetal se utilizaron tres variables extraidas de una capa digital de tipos de vegetación y uso del suelo (INEGI, 2005): 1) tipo de vetación, 2) grado de perturbación y 3) tamaño de parches de vegetación. Para el tipo de vegetación, se consideró un valor de preferencia sobre la selva baja, debido su fuerte asociación con la ocurrencia de los escorpiones y se le asignó un valor de 1, al resto de los tipos de vegetación se les aignó el valor de 0. Para la variable de estado de conservación se tomaron las categorias incluidas en la capa digital (vegetación primaria y secundaria) y las áreas de actividades humanas (agricultura temporal y permanente y zonas urbanas) a cada categoria se le asignó un valor descendente (5 a 1) como indicador de la calidad del hábitat. Para el tamaño de los parches se utilizó el mismo procedimeiento que para el clima. Posteriormente, se utilizó la extensión “Model Builder” del programa “ArcView”, que permite utilizar información ambiental relacionada a un área geográfica determinada y entender las relaciones entre las variables utilizadas mediante procesos de análisis espacial. En este estudio, se aplicó para generar un modelo digital de calidad de hábitat considerando las variables mencionadas y las preferencias de los escorpiones. Los procesos utilizados fueron de reclasificación de las variables en sus respectivas clases y de solapamiento de variables considerando su importancia en la distribución de los escorpiones.

Caracterización del escenario futuro del hábitat

Para la proyección del cambio en la cobertura vegetal, se utilizaron las capas digitales de tipos de vegetación y uso del suelo para México correspondientes a los años 1980 y 2005 y la extensión “Land Change Modeller” del programa IDRISI para generar una proyección de cambio para el año 2024. Para este proceso es necesario contar con una capa que represente las condiciones previas del hábitat y otra que represente las condiciones actuales: por lo que se generó un modelo de calidad de hábitat correspodiente a las condiciones ambientales de la capa de 1980 utilizando el mismo proceso que para las condiciones actuales. Posteriormente se generó el escenario de cambio para la calidad del ambiente para el año 2025y se identicaron las áreas que pueden funcionar para la protección de los escorpiones de acuerdo a su calidad y persistencia.

RESULTADOS PRELIMINARES

Las condiciones climáticas a lo largo de la distribución potencial de los escorpiones son relativamente homogeneas para las tres variables analizadas. En relación a la cobertura vegetal, se observa un ambiente heterogeneo de zonas con vegetación nativa en distinto grado de conservación mezcladas con zonas destinadas a agricultura o ganadería. Debido a que estas actividades son comunes en todo el país, se ha generado un ambiente que incluye parches de vegetación nativa que van desde algunos métros cuadrados hasta varias hectareas y esta condición se mantiene relativamente constante a lo largo de toda el área de estudio (tabla 1).

El hábitat actual de los escorpiones presenta aproximadamente la mitad de su extensión (55%) en condiciones que pueden considerarse buenas; ya que la calidad de hábitat se encontró entre los valores de 6 y 8. Sin embargo, el 45% del área de distribución potencial de estos reptiles se encuentra en condiciones que se pueden considerar inapropiadas, es decir con valores de calidad menores a 5 (Fig 1).

El área con calidad apropiada cubre una extensión aproximada de 51, 500 Km^2. Las zonas con mejor calidad de hábitat (valor de 8) se encuentran principalmente en la región norte de la distribución potencial, en los estados de Sonora y Sinaloa. Las zonas con calidad de hábitat sub-óptimo (valor de 6) se encuentran principalmente en la región centro de la distribución potencial, en la provincia de la depresión del balsas.

REFERENCIAS

Ariano-Sánchez, D. (2003). *Distribución e historia natural del escorpión, Heloderma horridum charlesbogerti Campbell y Vannini, (Sauria: Helodermatidae) en Zacapa, Guatemala y caracterización de su veneno* Universidad del valle de Guatemala.

Ariano-Sánchez, D. & Cotí, P. (2007). *Priorización de áreas de conservación en el matorral espinoso del valle Montagua, utilizando como indicadores a las especies endémicas lagarto escorpión, Heloderma horridum charlesbogerti y la iguana garroba, Ctenosaura palearis*: Zootropic / The nature conservancy.

Balderas-Valdivia, C. J. (2000). *El papel de la quimiorrecepción y la vision en el reconocimiento del alimento y de los depredadores potenciales de Heloderma horridum (Sauria: Helodermatidae).* Universidad Nacional Autónoma de México, México D. F.

Beck, D. D. (2002). *Heloderma horridum* (Weigmann 1829). Escorpión. In Historia natural de Chamela, Noguera, F. A., Vega, J. H., García, A. N. & Quesada, M. (eds). México D. F.: Instituto de biología.

Beck, D. D. (2005). *Biology of gila monsters and beaded lizards*. California: University of California press.

Beck, D. D. & Jennings, R. (2003). Habitat use by gila monsters: the importance of shelters. *Herpetological monographs, 17*, 111-129.

Beck, D. D. & Lowe, C. H. (1991). Ecology of the beaded lizard, *Heloderma horridum*, in a tropical dry forest in Jalisco, México. *Journal of herpetology, 25*, 395-406.

Brown, D. E. & Carmony, N. B. (1999). *Gila monster: Facts and folklore of america´s aztec lizard*. Salt lake city: University of Utah press.

Casas-Andreu, G. (2000). Mitos, leyendas y realidades de los reptiles en México. *Ciencia ergo sum, 7,* 286-291.

Ceballos, G., Martínez, L., García, A., Espinoza, E., Bezaury Creel, J. & Dirzo, R. (2010). *Diversidad, amenazas y áreas prioritarias para la conservación de las selvas secas del Pacífico de México*. México, D. F.: CONABIO/FCE.

CITES. (2007). *Apéndices I, II y III*: Convención sobre el comercio internacional de especies amenazadas de fauna y flora silvestres.

Domínguez-Vega, H., Monroy-Vilchis, O., Balderas-Valdivia, C. J., Gienger, C. M. & Ariano-Sánchez, D. (2012). Predicting the potential distribution of the beaded lizard and identification of priority areas for conservation. *Journal for Nature Conservation, 20,* 247-253.

Fry, B. G., Vidal, N., Norman, J. A., Vonk, F. J., Scheib, H., Ramjan, S. F. R., Kuruppu, S., Fung, K., Hedges, S. B., Richardson, M., Hodgson, W. C., Ignjatovic, V., Summerhayes, R. & Kochva, E. (2006). Early evolution of the venom system in lizards and snakes. *Nature, 439,* 584-588.

Hendon, R. A. & Tu, A. T. (1981). Biochemical characterization of the lizard toxin gilatoxin. *Biochemistry, 20,* 3517-3522.

INEGI. (2005). *Carta de uso actual del suelo y vegetación serie IV*. México D. F.: INEGI.

Reiserer, R. S., Schuett, G. W. & Beck, D. D. (2013). Taxonomic reassessment and conservation status of the beaded lizard, Heloderma horridum (Squamata: Helodermatidae). *Amphibian & Reptile Conservation, 7,* 74-96.

SEMARNAT. (2008). Norma oficial mexicana NOM-059-ECOL-2001, protección ambiental-especies nativas de México de flora y fauna silvestres- categorias de riesgo y especificaciones para su inclusión, exclusión o cambio-lista de especies. *Diario oficial*, 1-85.

Sosa, B., P., Alagón, A. C., Martin, B. M. & Possani, L. D. (1986). Biochemical characterization of the phospholipase A2 purified from the venom of the mexican beaded lizard (*Heloderma horridum horridum* Wiegmann). *Biochemistry, 25,* 2927-2933.

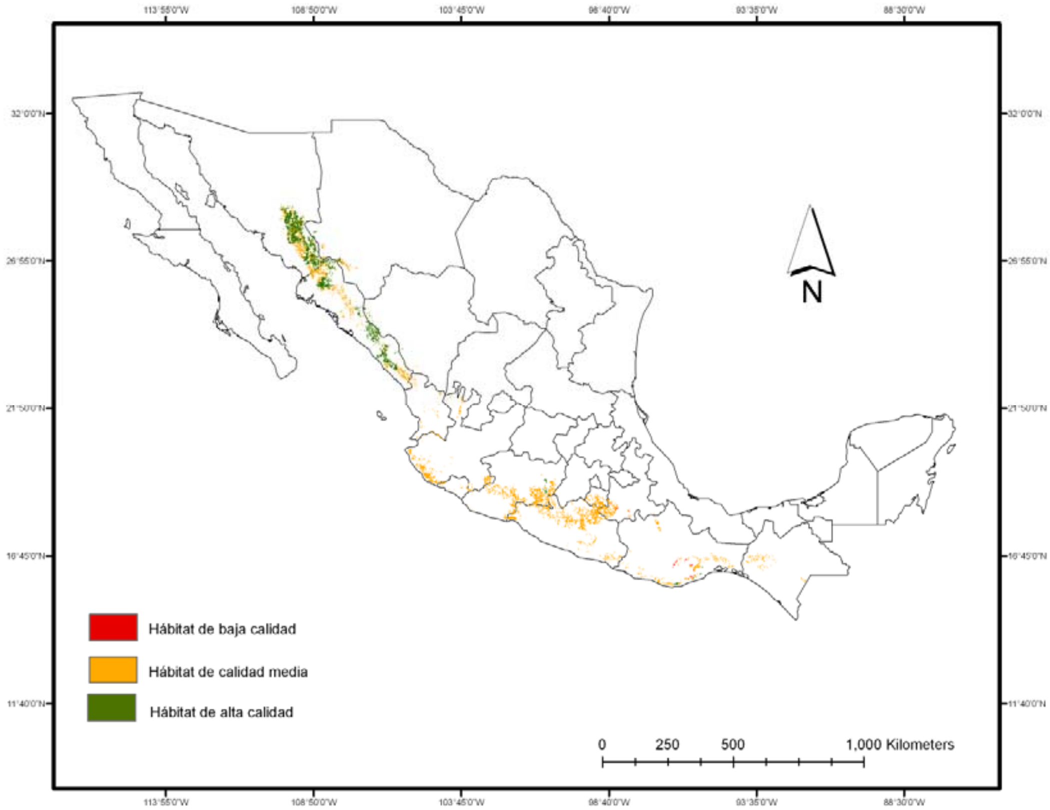
UICN. (2001). *Categorías y criterios de la lista roja de la UICN: versión 3.1*. Gland, Suiza y Cambridge, Reino Unido: Comisión de supervivencia de especies de la UICN.

Van Denburgh, J. (1898). Some experiments with the saliva of the gila monster (*Heloderma suspectum). Transactions of the american philosophical society, 19,* 199-220.

Tabla 1. Estado de la cobertura vegetal en el área de distribución potencial de los escorpiones

Variable	Clase	Extensión (km^2)
Tipo de vegetación	Selva baja	354834
	Otros tipos de vegetación	15640
Conservación de la vegetación	Vegetación primaria	93430
	Vegetación secundaria	90780
	Vegetación no nativa	170624
Tamaño de parches	1	67420
	2	30483
	3	25753
	4	18967
	5	54374
	6	36421
	7	50249
	8	45986
	9	25181

Fig 1. Modelo de calidad de hábitat actual de los escorpiones



DISCUSIÓN GENERAL

El modelo de distribución potencial demostró ser una alternativa apropiada para estimar las zonas de ocurrencia probable de los escorpiones, de manera que la propuesta realizada en este artículo refleja de manera más cercana la realidad sobre la distribución de este grupo. Sin embargo, el reconocimiento de nuevas especies en este grupo afecta de manera importante las inferencias realizadas en el primer capítulo. Por lo tanto, será necesario identificar la distribución de cada una de las especies actuales de este grupo para estimar el grado de amenaza sobre sus poblaciones.

Las principales diferencias de entre la propuesta realizada en este artículo y propuesta histórica de distribución realizada por Beck (2005), se centran en los límites de la distribución en el norte, la asociación de las áreas de distribución con la línea costera, el tamaño del área de distribución en el centro del país y la presencia de un área de distribución potencial donde los escorpiones no han sido reportados. Otra importante contribución de este trabajo es la descripción del estado de las zonas de distribución, donde se reconocen las zonas que presentan continuidad del hábitat y aquellas que están aparentemente interrumpidas por la presencia de áreas que resultan inapropiadas para la ocurrencia de los escorpiones. En este sentido, el modelo generado muestra que la continuidad del hábitat apropiado es mayor en e norte del país, también se observó que existe un área discontinua en la transición norte-centro del país, que el área de distribución potencial es mayor en el la región conocida como depresión del balsas y que la región sur presenta menos hábitat potencial del que se había pensado anteriormente.

Las barreras potenciales para la dispersión de los Helodermátidos incluyen algunas de las cordilleras más importantes de México ya que se ha demostrado que algunas características como la altitud y el tipo de vegetación afectan la ocurrencia de estos animales aun cuando han sido reportados en ambientes poco usuales (Monroy-Vilchis et al., 2005).

La protección de los escorpiones a través de las áreas naturales protegidas es muy baja, una situación que se considera relativamente común en México para la biodiversidad (Sánchez-Cordero y Figueroa, 2007; Urbina-Cardona y Flores-Villela, 2010), por lo que en este estudio se sugiere una evaluación detallada del estado de las poblaciones de los escorpiones para identificar sitios que puedan ofrecer protección a estos animales y garantizar su persistencia a largo plazo.

La distribución potencial de los escorpiones está fuertemente asociada a la selva baja, uno de los ambientes más amenazados en el mundo (Janzen, 1988; Trejo, 2005) y con mayor riqueza de vertebrados endémicos en México (Ceballos 1995). Por lo que los Helodermátidos de la selva baja pueden utilizarse como surrogados en los planes de conservación para la selva baja.

Por otra parte, las características más relevantes para determinar la probabilidad de ocurrencia de los escorpiones estás relacionadas con la estacionalidad ambiental, un hecho que parece estar asociado con los hábitos de actividad de los escorpiones y que aporta un mayor sustento a la hipótesis de que estos animales están prácticamente restringidos a este tipo de ambientes.

Derivado de la estimación de la distribución potencial de los escorpiones se realizó una evaluación de sus principales amenazas y en primer lugar se cuantificó la frecuencia de avistamientos y de caería aversiva. La frecuencia de avistamientos con 225 reportes en tres años, fue más elevada de lo esperado, si se considera que en museos y literatura científica existen aproximadamente 150 registros con descripción precisa (coordenadas) realizados entre 1990 y 2010 (Beck 2005; Domínguez-Vega et al. 2012).

Como se ha mencionado anteriormente, en México, los trabajos en campo sobre la biología de los Helodermátidos se limitan a una localidad en el estado de Jalisco (Balderas-Valdivia & Ramirez-Bautista 2005; Beck 2005; Beck & Lowe 1991; Beck & Ramirez-Bautista 1991) y a una del sur de Sonora (Gienger et al. 2005). El resto de la información de campo lo constituyen encuentros casuales, por lo que la mayor parte de la biología del grupo es aún desconocida (Domínguez-Vega et al. 2012). La notable diferencia en el número de avistamientos demuestra el escaso trabajo de campo realizado con este grupo y sugiere que los habitantes del medio rural pueden contribuir de manera importante para incrementar las colectas y en general el conocimiento de este grupo.

La frecuencia de cacería fue relativamente constante entre las localidades, lo que demuestra la aversión hacia los Helodermátidos. De acuerdo a las entrevistas, la única causa de la cacería es la creencia de que son una amenaza para los humanos, lo que está relacionado con el folklore sobre estos animales.

El 44% de los individuos observados fueron cazados. El efecto de esta actividad sobre las poblaciones es desconocido; sin embargo, debido al aparentemente bajo potencial reproductivo del grupo (Ariano-Sánchez & Salazar 2013; Golberg & Beck 2001; Gonzalez-Ruiz et al. 1996), y al efecto sinérgico de otras perturbaciones como la pérdida y fragmentación del hábitat (Robinson 1996) las consecuencias negativas sobre las poblaciones podrían ser una amenaza a su permanencia. En este estudio se evaluaron las regiones centro y sur de la distribución de los Helodermátidos; sin embargo, es sabido que se consideran peligrosos en todos los sitios donde se encuentran (Brown & Carmony 1999; Casas-Andreu 2000) por lo que se espera que el impacto por cacería sobre sus poblaciones norteñas sea similar a las analizadas aquí.

Los avistamientos se realizaron principalmente en zonas con vegetación abundante y con presencia de rocas. La relación de los Helodermátidos con la densidad de la vegetación ha sido sugerida anteriormente (Beck & Lowe 1991) y a pesar que ningún estudio ha presentado datos suficientes para demostrar estadísticamente esta relación las evidencias de diferentes estudios siguen sugiriendo la misma conducta.

Los análisis de correlación de Spearman (ver resultados) no encontraron relaciones significativas entre la frecuencia de avistamiento y cacería con las características estructurales de la vegetación lo que sugiere que ninguna de estas limita los eventos de avistamiento y cacería de manera individual. Se ha observado que la estructura del hábitat afecta diversas características biológicas que pueden estar relacionadas con aspectos como la reproducción o el tiempo de actividad (Cardozo & Chiaraviglio 2008; Trzcinski et al. 1999). Este resultado muestra la evasión de los Helodermátidos hacia los ambientes heterogéneos a través de una relación negativa entre avistamientos con el número de parches y el borde de los parches confirmando que prefieren zonas homogéneas o conservadas en cuanto a la vegetación (Domínguez-Vega et al. 2012). Otra de las variables importantes de acuerdo al análisis de correspondencia canónica fue la distancia a los cultivos, donde se observó una relación positiva con la frecuencia de avistamientos. Es probable que esta relación sea un efecto de la actividad de las personas encuestadas ya que al ser agricultores incrementan la probabilidad de encuentros con los animales en estas zonas.

Los resultados presentados muestran que el impacto por cacería hacia los Helodermátidos puede amenazar la persistencia de sus poblaciones y confirma que estos animales evaden los ambientes heterogéneos en cuanto a estructura de vegetación. Por muchos años se ha reconocido que el impacto humano sobre los bosques tropicales está dirigido por las políticas gubernamentales de desarrollo, necesidades de subsistencia de los pobladores locales y objetivos económicos de empresas, lo que ha generado paisajes fragmentados dominados por humanos (Robinson 1996). Por lo tanto, la alternativa de conservación para este grupo debe incluir un plan de educación para las personas que conviven con ellos y un plan de manejo de la cobertura vegetal que considere su estructura.

Los efectos de las modificaciones del hábitat en reptiles han sido poco estudiados, en su mayoría se encuentran restringidos a América del norte y abordan efectos sobre parámetros numéricos en los que han evidenciado resultados contradictorios para todos los grupos de vertebrados (Gardner et al 2007, Thornton et al. 2011). Sin embargo, tales inconsistencias pueden estar relacionadas con un análisis inapropiado de los efectos de la PYFH como lo señala Fahring (2003). En la evaluación realizada sobre los efectos de la pérdida y fragmentación del hábitat sobre los escorpiones se evidencia un efecto marcado de la pérdida del hábitat en la selección del hábitat al mostrar que *H. horridum* ocurre en zonas ambientalmente diferentes, probablemente para utilizar ambientes más favorables cuando su hábitat se reduce y que tales diferencias se incrementan a medida que se intensifica esta perturbación. Los resultados muestran que distintos parámetros de la calidad de la vegetación y la topografía son importantes en la ocurrencia de esta especie en los distintos estados de perturbación, lo que sugiere que la selección del hábitat puede estar determinada por distintas interacciones entre la calidad de la vegetación y la topografía. Además, probablemente igual que en *H. suspectum* la disponibilidad y calidad microambiental de los refugios pueden ser determinantes en la ocurrencia de esta especie (Beck y Jennings, 2003). Debido a que el microclima en los refugios es alterado por la pérdida de hábitat, podría esperarse observar la selección de este recurso de manera indirecta a través de la selección de las variables evaluadas. Sin embargo, la interacción entre las características de la vegetación (tipo y calidad) con la topografía puede resultar en varias combinaciones que ofrezcan las condiciones microclimáticas apropiadas para la ocurrencia de *H. horridum* y que enmascaren las características preferidas por esta especie a escala de paisaje.

CONCLUSIONES GENERALES

La distribución potencial de los Helodermátidos de la selva baja presenta un patrón similar a la distribución reportada anteriormente. Sin embargo, se observan algunas diferencias importantes que tienen implicaciones en futuros planes de conservación y estudio de este grupo. Como se había sugerido anteriormente, en este estudio se sustenta la idea de que los Helodermátidos están fuertemente asociados a la selva baja y se propone que la principal característica ambiental que restringe su ocurrencia es la estacionalidad ambiental. La distribución de los escorpiones está escasamente protegida por las áreas naturales protegidas de México y es necesario determinar un plan para la conservación de estos animales que además puede beneficiar a otras especies de la selva baja caducifolia.

La frecuencia de avistamientos en las zonas de distribución de los escorpiones es mayor a lo esperado de acuerdo al número de registros de estas especies en museos y colecciones científicas, por lo que el estudio de este grupo a través de informantes en las localidades puede beneficiar significativamente el conocimiento sobre los Helodermátidos mexicanos. La frecuencia de la cacería es elevada y puede ejercer un impacto significativo sobre las poblaciones de Helodermátidos.

La frecuencia de avistamiento y de cacería no está relacionada con las características estructurales del hábitat, parece estar relacionada con las actividades humanas y con las creencias folclóricas sobre estos animales.

La pérdida y fragmentación del hábitat modifican los patrones de selección del hábitat y amplitud de nicho de los escorpiones. A diferencia de lo observado en la mayoría de los estudios, la fragmentación del hábitat produjo cambios drásticos en los parámetros ecológicos analizados en este estudio y esta situación parece estar relacionada con las características ecológicas analizadas. Los Helodermátidos presentan una capacidad de respuesta elevada en ambientes estructuralmente perturbados de manera que realizan una selección de las características ambientalmente apropiadas, pero esta respuesta es muy baja en ambientes cuya composición ha sido modificada lo que puede comprometer la persistencia de estos animales.

REFERENCIAS BIBLIOGRÁFICAS

Alvarez-del Toro Miguel. 1982. Los reptiles de Chiapas. 3 ed. Instituto de historia natural, Tuxtla Gutierrez,Chiapas. 216 pp.

Balderas-Valdivia Carlos J. 2004. Reconocimiento diferencial de los depredadores y variación del comportamiento defensivo de *Heloderma horridum* en una población de la selva baja decidua de Jalisco, México. Tesis de doctorado. Universidad Nacional Autónoma de México. México D. F. 91pp.

Balderas-Valdivia, C. J. 2005. Respuesta congénita y variación del comportamiento aversivo en *Heloderma horridum*. Boletín de la Sociedad Herpetológica Mexicana. 13(1):1-9.

Beck Daniel D. 2002. *Heloderma horridum* (Weigman 1829). Escorpión. En: Noguera F., J. Vega, A. García y M. Quesada (eds.) Historia natural de Chamela. Instituto de biología. México D. F.

Dominguez-Vega H. 2010. Distribución potencial de *Heloderma horridum*. Tesis de Maestría. Universidad Autónoma de Baja Clifornia. Mexicali, Baja California. 81pp.