UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO
POSGRADO EN CIENCIAS BIOLÓGICAS
INSTITUTO DE ECOLOGÍA
BIOLOGÍA EVOLUTIVA Y SISTEMÁTICA

ESTUDIOS SOBRE CONSERVACIÓN DE LAS ESPECIES DEL GÉNERO *Paraphlebia* EN MÉXICO

TESIS

QUE PARA OPTAR POR EL GRADO DE:

DOCTORA EN CIENCIAS

PRESENTA:

KARINA CUEVAS YAÑEZ

TUTOR PRINCIPAL DE TESIS: DR. ALEJANDRO CÓRDOBA AGUILAR
INSITUTO DE ECOLOGÍA, UNAM
COMITÉ TUTOR: DR. MARTÍN ALEJANDRO SERRANO MENESES
CENTRO TLAXCALA DE BIOLOGÍA DE LA CONDUCTA, UATx-UNAM
DRA. ELLA GLORIA VÁZQUEZ DOMÍNGUEZ
INSTITUTO DE ECOLOGÍA, UNAM

MÉXICO, D.F. ENERO, 2016.

UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO

POSGRADO EN CIENCIAS BIOLÓGICAS

INSTITUTO DE ECOLOGÍA

BIOLOGÍA EVOLUTIVA Y SISTEMÁTICA

ESTUDIOS SOBRE CONSERVACIÓN DE LAS ESPECIES DEL GÉNERO *Paraphlebia* EN MÉXICO

TESIS

QUE PARA OPTAR POR EL GRADO DE:

DOCTORA EN CIENCIAS

PRESENTA:

KARINA CUEVAS YAÑEZ

TUTOR PRINCIPAL DE TESIS: DR. ALEJANDRO CÓRDOBA AGUILAR
INSITUTO DE ECOLOGÍA, UNAM
COMITÉ TUTOR: DR. MARTÍN ALEJANDRO SERRANO MENESES
CENTRO TLAXCALA DE BIOLOGÍA DE LA CONDUCTA, UATx-UNAM
DRA. ELLA GLORIA VÁZQUEZ DOMÍNGUEZ
INSTITUTO DE ECOLOGÍA, UNAM

MÉXICO, D.F. ENERO, 2016.

UNAM POSGRADO
Ciencias Biológicas

COORDINACIÓN

Dr. Isidro Ávila Martínez
Director General de Administración Escolar, UNAM
P r e s e n t e

Me permito informar a usted, que el Subcomité de Biología Evolutiva y Sistemática, en su sesión ordinaria del día 19 de octubre 2015, aprobó el jurado para la presentación de su examen para obtener el grado de **DOCTORA EN CIENCIAS**, del Posgrado en Ciencias Biológicas de la alumna **CUEVAS YAÑEZ KARINA** con número de cuenta **508012226** con la tesis titulada con la tesis titulada **"ESTUDIOS SOBRE CONSERVACIÓN DE LAS ESPECIES DEL GÉNERO *Paraphlebia* EN MÉXICO"**, bajo la dirección del **DR. ALEJANDRO CÓRDOBA AGUILAR:**

Presidente:	DR. ATILANO CONTRERAS RAMOS
Vocal:	DR. JULIÁN BUENO VILLEGAS
Secretario:	DR. MARTÍN ALEJANDRO SERRANO MENESES
Suplente:	DR. GERARDO SÁNCHEZ ROJAS
Suplente	DR. FEDERICO ESCOBAR SARRIA

Sin otro particular, me es grato enviarle un cordial saludo.

A T E N T A M E N T E
"POR MI RAZA HABLARA EL ESPIRITU"
Cd. Universitaria, D.F. a 03 de diciembre de 2015

M. del Coro Arizmendi

DRA. MARÍA DEL CORO ARIZMENDI ARRIAGA
COORDINADORA DEL PROGRAMA

POSGRADO EN CIENCIAS BIOLÓGICAS
COORDINACIÓN

c.c.p. Expediente del (la) interesado (a).

AGRADECIMIENTOS INSTITUCIONALES

Agradezco al Posgrado en Ciencias Biológicas de la Universidad Nacional Autónoma de México por permitirme la oportunidad de cursar el doctorado en este programa, en el Instituto de Ecología de la UNAM.

Agradezco al Consejo Nacional de Ciencia y Tecnología (CONACyT) la beca doctoral que me fue otorgada número 226198/210553.

Este trabajo se realizó con fondos de los proyectos PAPIIT IN-203115 "Biología de la conservación de las libélulas mexicanas", PAPIIT IN-222312 "Prediciendo un mundo cambiante: efectos del cambio climático en la producción de Híbridos", CONABIO JM006 "Modelación de las especies de odonatos en México", UC Mexus CONACyT (20010) "Explaining choice and maintenance of alternative reproductive tactics: field studies using the damselfly Paraphlebia zoe", CONACyT-CONICET Programa Bilateral (190554) "¿Nuevos e inesperados híbridos como resultado del cambio climático?", y al proyecto IN302115 "Biología de la conservación de las libélulas mexicanas" (UNAM-DGAPA).

Agradezco al Dr. Alejandro Córdoba Aguilar por aceptar dirigir esta tesis y por las enseñanzas aprendidas.

A la Dra. Ella Vázquez Domínguez y al Dr. Martín Serrano Meneses que formaron parte de mi comité tutoral por el apoyo y los comentarios realizados en este proceso doctoral.

AGRADECIMIENTOS PERSONALES

Agradezco al M. en C. Raúl Iván Martínez Becerril por el apoyo logístico a este proyecto.

A los miembros del jurado: Dr. Atilano Contreras Ramos, Dr. Julián Bueno Villegas, Dr. Martín Serrano Meneses, Dr. Gerardo Sánchez Rojas y al Dr. Federico Escobar Sarria, por sus observaciones que mejoraron la versión final de este escrito.

Agradezco a mi familia, que siempre han estado conmigo en todo momento, apoyando y escuchando atentamente. Gracias totales!!! Les dedico este trabajo.

A Francisco, gracias por estar conmigo apoyándome, escuchándome, dándome ánimos y por siempre creer en mí. Te dedico este trabajo.

A mis amigos, muchas gracias!!

A los compañeros de laboratorio de la conducta de artrópodos: Angelita, Miguel, Aldo, David, Alicia, y a los que ya emigraron: Adriana, Memo, Isaac, Daniel, Roberto, Maricela, Jesús. A los vecinos de cubículo Tania, Jaime y David. Gracias por su compañía y el apoyo en estos años.

A mis compañeros que me ayudaron en campo y soportaron viajes buscando libélulas: Angelita, Sonia, Rosario, Miguel, Sandra, Juan Manuel, muchas gracias!!

También agradezco a Erika que compartió sus conocimientos de genética en ese proyecto que no se dio. A Rosa Sánchez por su apoyo y a Chris Anderson. A Juan Carlos Espinosa, por su colaboración desinteresada en la generación de datos. A Edday y Cecilia por apoyar en la georreferenciación de la base de datos utilizada.

Al Dr. Jesús Muñoz y la Dra. Paty Feria por compartir parte de sus conocimientos en el modelado de distribución de especies y para Gerardo Rodríguez Tapia. A Mariana Benitez por compartir sus conocimientos en coocurrencias.

A Martha, por ese incansable apoyo moral y por andarme presumiendo con sus amistades.

A todos los que en algún momento me apoyaron y me dieron ánimos… A todos ustedes GRACIAS!

ÍNDICE

RESUMEN

En este estudio, se presentan diversos análisis para evaluar aspectos relacionados con la conservación de las especies de Odonata (libélulas y caballitos del diablo) y en particular de las especies del género *Paraphlebia* en México. Debido a la carencia de estudios en el tema, el primer capítulo se evaluó el estatus de conservación de un género de odonatos endémico de Centroamérica, *Paraphlebia* (*P. hyalina, quinta* y *zoe*), de acuerdo con el criterio B (rango geográfico) de la Lista Roja de especies de la Unión Internacional por la Conservación de la Naturaleza (UICN). Dos de las tres especies que se distribuyen en México ya habían sido evaluadas en esta lista, no obstante se observó que dos de ellas deberían situarse ahora como Vulnerable o En Peligro, producto de esta investigación. Asimismo, casi la mitad del rango de distribución estimado para las especies se encuentra en vegetación secundaria o en áreas agrícolas o urbanas. En las proyecciones a futuro se observó que el rango geográfico de una de las especies evaluadas disminuye dramáticamente (*P. zoe*), mientras que el rango potencial de distribución de otra de las especies se amplía (*P. quinta*). El segundo capítulo incluye un análisis de los registros de odonatos presentes en México. Se observó que el registro de odonatos es agregado y las ecorregiones del norte del país son las que menos cuentan con registros. En el tercer capítulo se relaciona el número de registros geográficos y de riqueza de especies con el uso de suelo y vegetación presente. Los resultados muestran que tanto los registros como las especies son más abundantes en áreas boscosas y zonas agrícolas, y menos abundantes en áreas sin vegetación y en zonas de pastizales con otro tipo de vegetación, de acuerdo con las entidades de uso de suelo. Se encontraron débiles relaciones positivas entre la riqueza de especies y la cobertura arbórea, y también débiles relaciones cuadráticas entre la riqueza de especies y el índice de huella humana. En las conclusiones generales se expresa que dado el precario conocimiento del estado de conservación de los odonatos en México, es urgente continuar con estudios tanto a nivel nacional, como particulares o regionales. Una razón es que algunos grupos tales como *Paraphlebia*, están en peligro de extinción o con algún estatus de riesgo en el futuro, y de muchos más no se tiene conocimiento sobre el estado de conservación de sus poblaciones.

ABSTRACT

In this study I evaluated several aspects related to conservation of Mexican odonate (dragonflies and damselflies) species. Given the paucity of studies in this area, in the first chapter I assessed conservation status of one endemic odonate genus of Central America, *Paraphlebia (P. hialina*, *quinta* y *zoe)*, according to the criterion B (geographical range) of the Red List of the International Union for the Conservation of Nature (IUCN). Two of the three species distributed in Mexico had been assessed already, however I found that two of them should now be placed as Endangered or Vulnerable. Also, nearly half of the estimated range for these species is located on secondary vegetation or agricultural or urban areas. Future projections predicted that the geographic range will decrease dramatically (*P. zoe*) and for the other one it will expand (*P. quinta*). The second chapter includes an analysis of odonate records found in Mexico. I found highly aggregated with fairly few records on the North. In my third chapter, I relate the number of geographical records and species richness *per area* through the land use and vegetation, tree cover and human footprint. The results showed that both records and species richness are more abundant in forest and agricultural areas, and less abundant in areas without vegetation and grassland areas with other vegetation type. I found a poor positive relationship between species richness and tree coverage, and a quadratic one between species richness and index of human footprint. I conclude that, given the precarious state of conservation of Mexican odonates, it is urgent to continue assessment studies both at a national and regional level. Some groups such as *Paraphlebia* are currently endangered or with some status risk in the near future, and we are largely unaware about the status of the majority of odonates.

INTRODUCCIÓN

La pérdida de la biodiversidad se ha incrementado en los últimos 40 años. Diversos factores han contribuido a la degradación o desaparición de los ecosistemas y de los seres vivos que viven en ellos. Por ejemplo, el aumento de la densidad poblacional humana junto con el desarrollo de sus actividades son unas de las causa principales de que miles de especies estén desapareciendo o estén en riesgo de desaparecer. Además, la pérdida de biodiversidad afecta la funcionalidad de los ecosistemas y su estabilidad (Cardinale et al. 2012) y varios indicadores muestran que la disminución de la diversidad de especies muestra una tendencia negativa (Butchart et al. 2010; Newbold et al. 2015). Con respecto a lo anterior, es transcendental generar información encaminada a la conservación de las áreas con mayor riesgo y de las especies más vulnerables, en peligro de extinción o aquellas más atractivas. Varios estudios de conservación o monitoreo se han realizado en Europa o en América del Norte (Birdlife 2004; Maes et al. 2012), principalmente con plantas o vertebrados (Doumenge et al. 1995; Hoffman et al. 2010; Croxall et al. 2012; Böhm et al. 2013; de Lange et al. 2013). Sin embargo, la información que se tiene a nivel global es heterogénea, es decir, existen muchos taxones y regiones del mundo en los que se desconoce el estado actual que guardan las poblaciones, como es el caso de varios grupos de invertebrados (Cardoso et al. 2012, Sutherland et al. 2014).

A pesar de que los insectos representan la mayor diversidad de organismos en el planeta (Cardoso et al. 2012), existen pocos estudios sobre qué variables son importantes para el mantenimiento y funcionamiento de sus poblaciones y especies. Los insectos tienen un papel relevante en el funcionamiento de los ecosistemas, además de un enorme valor utilitario y por ser parte importante en las interacciones que mantienen el buen funcionamiento de los ecosistemas (Samways 2005). Dentro de los insectos y en términos de conservación, existen grupos relativamente mejor estudiados como las mariposas o algunas especies de coleópteros, que quizás por su belleza les confiera un carácter atractivo (Lewis y Senior 2011; Thomas et al. 2011; Leschen et al. 2012). Otro grupo relativamente bien estudiado a nivel global son los odonatos (Insecta: Odonata), comúnmente llamados libélulas o caballitos del diablo. Los odonatos son organismos que en su etapa juvenil viven (generalmente) en el agua y los adultos son terrestres-aéreos (Corbet 1999). Esta ambivalencia de hábitats los han hecho idóneos para ser considerados como indicadores de calidad ambiental, sobre todo de la integridad de hábitat alrededor de los cuerpos de agua (Sato y Riddiford 2008; Simaika y Samways 2009; Silva et al. 2010; Kutcher y Bried 2014), lo que los hace excelentes candidatos para estudios de conservación (Samways 2005; Kalkman et al. 2008; Clausnitzer et al. 2009; Dolny et al. 2011).

En México, se han citado 357 especies de odonatos de las cuales 49 son endémicas (González-Soriano y Novelo-Gutiérrez 2014). Hasta el momento, ocho especies se encuentran en alguna categoría de riesgo según la Lista Roja de especies de la Unión Internacional por la Conservación de la Naturaleza (IUCN por sus siglas en inglés) Cabe señalar que dichas evaluaciones no han sido hechas por investigadores nacionales y se supone que se hicieron con escasos conocimientos del estado real de las poblaciones y especies, por lo que, en gran medida, se basan en registros anecdóticos (IUCN 2015). Por otra parte, ninguna especie de Odonata forma parte de la Norma Oficial Mexicana NOM-059-ECOL-SEMARNAT, el documento oficial mexicano que determina a las especies amenazadas o en peligro de extinción (SEMARNAT 2010). La mayoría de los estudios recientes de odonatos en el país se han enfocado a estudios taxonómicos a nivel regional (Behrstock et al. 2007; Upson et al. 2007; González-Soriano et al. 2008; Novelo-Gutiérrez y Gómez Anaya 2009; Escoto-Moreno et al. 2015). Sin embargo, es clara la escasez de información sobre los inventarios de odonatos a nivel nacional, en dónde y cómo se distribuyen las especies en el país y del estado de conservación de las mismas. Dado el deterioro ambiental en México (Landa et al. 2007), es urgente iniciar estudios encaminados a generar conocimiento que aporte información a la conservación de las especies de odonatos en México. Es por esto que en mi trabajo doctoral emprendí una línea investigación sobre biología de la conservación en este grupo.

Paraphlebia es un género endémico de Centroamérica. En México se distribuyen tres de las cinco especies que lo forman (Novelo-Gutiérrez 2008). Estas especies viven en escurrideros y en arroyos pequeños en zonas de bosque mesófilo de montaña. En varias especies los machos presentan dimorfismo (Romo-Beltrán et al. 2009), y dos especies ha sido evaluadas en la Lista Roja de Especies de la UICN. Se desconocía su distribución actual y su estado de conservación.

Mi tesis se divide en tres capítulos: En el capítulo uno analicé la distribución y la recategorización en la Lista Roja de especies dos especies de un género de odonatos endémico de Centroamérica, *Paraphlebia*, las cuales habían sido evaluadas en dicha lista.

En el capítulo dos evalué cómo se encuentra el inventario de odonatos a nivel nacional, indicando zonas con mayor esfuerzo de muestreo y aquellas donde se requieren mayores esfuerzos para conocer las especies presentes. En el capítulo tres realicé un análisis de la riqueza de odonatos con respecto al uso de suelo, cobertura arbórea y huella humana. El capítulo uno ya fue publicado en la revista *Insect Conservation and Biodiversity*. El capítulo dos se encuentra actualmente sometido a la revista *Systematics and Biodiversity*, el tercero fue sometido a *Environmental Conservation*.

OBJETIVOS

Objetivo General:

Realizar un análisis del conocimiento de riqueza de especies con un enfoque de conservación de las especies de odonatos en México y evaluar el estado de conservación de las especies del género *Paraphlebia* en México como estudio de caso.

Objetivos Particulares:

1. Estimar y generar un mapa del área de distribución del género *Paraphlebia* en México.
2. Realizar un análisis de la riqueza de especies de odonatos en México, su relación con el uso de suelo y huella humana para determinar zonas críticas de conservación de odonatos en México.
3. Proponer algunas medidas de conservación para los odonatos en México, y del género *Paraphlebia* con base en los datos obtenidos de distribución, uso de suelo y curvas de acumulación de especies.

CAPÍTULO I

Conservation status assessment of *Paraphlebia* damselflies in Mexico

Insect Conservation and Diversity

Insect Conservation and Diversity (2015) doi: 10.1111/icad.12132

Conservation status assessment of *Paraphlebia* damselflies in Mexico

KARINA CUEVAS-YÁÑEZ,[1] MIGUEL RIVAS,[1] JESÚS MUÑOZ[2] and ALEX CÓRDOBA-AGUILAR[1] [1]Departamento de Ecología Evolutiva, Instituto de Ecología, Universidad Nacional Autónoma de México, Mexico, D.F., Mexico and [2]Real Jardín Botánico (RJB-CSIC), Madrid, Spain

Abstract. 1. We assessed the conservation status of the three Mexican *Paraphlebia* damselflies based on the criterion B of the Red List of the International Union for Conservation of Nature's (IUCN): *P. hyalina*, *P. quinta*, and *P. zoe*. According to this List, *P. hyalina* has not been evaluated, *P. quinta* appears as least concern, and *P. zoe* appears as Vulnerable. Geographical records were taken from literature, enquiries to specialists and field visits. We also projected the future potential geographical range area.

2. We generated species distribution models (SDM) for *P. quinta* and *P. zoe* (as there were not enough records for *P. hyalina*) as a surrogate of the extension of occurrence (EOO) and also calculated the area of occupancy. Future distributions were projected for years 2020, 2050, and, 2080 based on predicted changes in climatic conditions.

3. Species distribution models predicted current EOO areas for *P. quinta* and *P. zoe* as 18 860 and 16 440 km^2, respectively, and around 50% of their distribution coincides with agricultural, pasture or urban sites.

4. Our SDM results indicate that IUCN-based conservation status of the three species should be changed as follows: *P. quinta* and *P. zoe* moved to endangered category, and *P. hyalina* to data-deficient category based on the reduced EOO areas and the historical loss of habitat.

5. For *P. quinta*, future climatic projections suggest an initial reduction (2020) followed by an expansion (2050 and 2080) in suitable areas, whereas for *P. zoe* there will be a decrease in predicted area for the three time periods. Preserving areas that provide shade, high humidity and perching sites seems to be a key for *Paraphlebia* species survival.

Key words. Climate change, damselfly, International Union for Conservation of Nature's, Maxent, *Paraphlebia*.

Introduction

Freshwater habitats are severely threatened by multiple factors, including resource extraction, introduction of alien species, pollution, changes in land use, anthropisation, urbanisation, and climate change (Clausnitzer *et al.*, 2009; McGeoch *et al.*, 2011; Simaika *et al.*, 2013). Consequently, researchers have increased their efforts to evaluate the conservation status of invertebrate taxa (Hawking & New, 2002), mollusks (Régnier *et al.*, 2009), and water beetles (Abellán *et al.*, 2005). Odonates (dragonflies and damselflies) are ecologically important insects in freshwater habitats. Odonates have two morphologically and ecologically different life cycle stages (aquatic or semiaquatic larvae and terrestrial adults), both of which show strong responses to habitat and climatic changes (Hassall &

Correspondence: Alex Córdoba-Aguilar, Departamento de Ecología Evolutiva, Instituto de Ecología, Universidad Nacional Autónoma de México, Apdo. Postal 70-275, Ciudad Universitaria, 04510 Mexico, D. F., Mexico. E-mail: acordoba@iecologia.unam.mx

Thompson, 2008; Clausnitzer *et al.*, 2009). Examples of such changes are deforestation and urbanisation (Lambin *et al.*, 2003; Martínez *et al.*, 2009; McGeoch *et al.*, 2011) and increases in land temperature (Hassall & Thompson, 2008).

The threat or extinction status of most invertebrate species remains unknown; consequently, exceedingly few arthropod species are included in the International Union for Conservation of Nature's (IUCN) Red List (Strayer, 2006; Cardoso *et al.*, 2011a). Related to this, approximately 0.5% from the overall number of arthropod species has been included in the International Union for Conservation of Nature's (thereafter, IUCN) Red List (Cardoso *et al.*, 2011b). One of the IUCN Red List criteria most widely employed is that of geographical range size (criterion B) (i.e. Feria *et al.*, 2009), measured as extension of occurrence (EOO, represented in B1 criterion) or the area of occupancy (AOO, represented in B2 criterion). The EOO is defined as 'the area contained within the shortest continuous imaginary boundary which can be drawn to encompass all the known, inferred or projected sites of present occurrence of a taxon, excluding cases of vagrancy' (IUCN, 2013). On the other hand, the AOO is defined as:

> the area within its 'extent of occurrence', which is occupied by a taxon, excluding cases of vagrancy. The measure reflects the fact that a taxon will not usually occur throughout the area of its extent of occurrence, which may contain unsuitable or unoccupied habitats (IUCN, 2013).

Although the IUCN suggests the minimum convex polygon or convex hull polygon to calculate EOO and AOO (IUCN, 2013), these methodologies wildly overestimate the potential distributional range by including areas inappropriate for the species' development (Simaika & Samways, 2010; Clausnitzer *et al.*, 2011). Instead, potential distribution range can be predicted using species distribution models (SDM) (Elith & Leathwick, 2009b) as surrogate measures of EOO (Feria *et al.*, 2009) and AOO (Cardoso *et al.*, 2011a). SDM overcomes the patchiness of distributional data, thus providing a more accurate representation of species distribution (Elith & Leathwick, 2009a,b; Simaika & Samways, 2009; Almeida *et al.*, 2010; Cardoso *et al.*, 2011a; Clausnitzer *et al.*, 2011).

Climate change models may provide an initial approximation to assess the future impact of environmental factors on species' range areas (Pearson & Dawson, 2003). In odonates, for example a number of studies have found profound effects of present and future climatic conditions (Hickling *et al.*, 2005; Hassall & Thompson, 2008; Sánchez-Guillén *et al.*, 2013, 2014). Nevertheless, efforts to understand the distribution of threatened odonate species using climate change scenarios are limited (but see Sánchez-Guillén *et al.*, 2014).

Within the above framework, we studied *Paraphlebia* damselflies (Insecta: Odonata: Megapodagrionidae), a Mesoamerican genus that is distributed across Mexico, Guatemala, and Honduras (Garrison *et al.*, 2010). Four species are currently recognised, of which three occur in Mexico: *P. hyalina*, *P. quinta*, and *P. zoe* (*P. zoe* is actually endemic of Mexico) (Novelo-Gutiérrez, 2008). Larvae of *Paraphlebia* can be found in humid litter, under rocks or aquatic vegetation in seepages, whereas adults live in seepages, small creeks or next to streams and/or cascades in tropical mountain forest or cloud forest (Novelo-Gutiérrez, 2008; Garrison *et al.*, 2010). According to our own observations, *Paraphlebia* species vary from uncommon to abundant in a given locality, and only in a few sites studied the abundance reaches more than 40 individuals. It is likely that the three *Paraphlebia* species that occur in Mexico may be under threat due to habitat reduction in tropical mountain forest (Williams-Linera *et al.*, 2002) which is where they live. Despite this, the IUCN Red List status categorises *P. quinta* in the least concern category (Paulson, 2009), and *P. zoe* in the Vulnerable category (Paulson and von Ellenrieder, 2006; Table 1). *Paraphlebia hyalina* has not been formally evaluated yet, but our thorough search for records suggests that it is a rare taxon, and also that the locality information in old records may be inaccurate, precluding their use in SDM generation. Under Mexican legal regulation, none of the three species appears under any risk status (NOM-059-SEMARNAT, 2010).

Therefore, we had the following aims: (i) to model the potential geographical range and extension area in Mexico with occurrence data using SDM; (ii) based on SDM

Table 1. EOO potential range estimated by SDM and AOO for the three *Paraphlebia* species.

	P. hyalina (2)	*P. quinta* (13)	*P. zoe* (48)
Current category by IUCN Red List	Not evaluated	Least concern	Vulnerable
EOO range as SDM (km^2)	Not evaluated	18 860	16 440
Proposed IUCN Red List category	Data deficient	Endangered	Endangered
AOO range (km^2)	10	48	160
No. cell/width/height (2 km)	2	12	40
Proposed IUCN Red List category	Data deficient	Endangered	Endangered

EOO, extension of occurrence; SDM, species distribution models; AOO, area of occupancy; IUCN, International Union for Conservation of Nature's.
Numbers in parentheses indicate geographical records for each species.

techniques, to revise the IUCN conservation status of these species (based on criterion B1); (iii) to determine the proportion of EOO that is under threat in Mexico by land use change and; (iv) to project tendencies in future distribution ranges for *P. quinta* and *P. zoe* based on future climatic scenarios. Our study is also framed in the need of carrying out conservation assessment exercises in Mexico as its current regulation has incorporated only a handful of insect species, none of which are odonates (NOM-059-SEMARNAT, 2010).

Materials and methods

Data collection

We only obtained two undisputable occurrences for *P. hyalina*, and so we did not perform further SDM analysis for this species. For *P. quinta* and *P. zoe*, we obtained occurrence records from museums, online databases of biodiversity (i.e. CONABIO, 2010, Mexican Government and Smithsonian Museum), scientific literature, and contacting specialists about unpublished records. The raw database was depurated to add geographical coordinates or to eliminate inconsistent records; in some cases we visited the locality to confirm doubtful records. Two records of *P. quinta* from outside its main distribution area in Los Tuxtlas region were kept after consultation with an entomologist (Rodolfo Novelo-Gutiérrez, Instituto de Ecología, A. C., Xalapa, Veracruz, México) working in the area. To increase the number of records of *P. zoe*, we carried out field trips to the Mexican states of Veracruz, Hidalgo, Puebla, San Luis Potosí and Querétaro. From July to September of 2011 and 2012, we visited seepages and small streams covered with scattered vegetation (from creeks from slight to moderate slope – Paulson, 2009) and surrounding water bodies between 11.30 and 17.00 hours, spending 2–3 h per site. We concentrated only on adults as larvae are extremely difficult to find given their colour and rocky appearance (all authors' personal observations). Sampling was conducted opportunistically, and thus occurred under a variety of weather conditions, ranging from full sun to overcast with light rain; conditions on which *Paraphlebia* species are known to be active. We re-visited localities with published records (i.e. Novelo-Gutiérrez, 2008; Escoto-Moreno & Márquez, 2011), and also sites with appropriate vegetation not previously studied. In addition, we traced a transect for approximately 1 km upstream and downstream of each site to search extensively for odonates along the seepage or streams, taking special care in the riparian vegetation, tree canopies, rocks, in or around smalls ponds, as well as on dry branches or leaves on the floor, and shrubs and tree branches in shaded places. This search took around 3 h in each place. Abundance was different across sites, ranging from 2 to 20 individuals per site. All sites were in montane cloud forest and coffee plantations, between 500 and 1500 m a.s.l. In total, we visited 45 sites, which provided 13 new records for *P. zoe*, but no new records for *P. quinta*; the final number of occurrences were 13 for *P. quinta* and 48 for *P. zoe* (Table 1). All records were georeferenced with a GPS receiver (Garmin eTrex Legend; Garmin International Inc., Olathe, KS, USA). Data locations, including historical ones, along with their georeferences are included in Table S1.

Data analysis

We generated SDM with Maxent 3.3.3k (Phillips *et al.*, 2006), a deterministic algorithm that has been shown to be among the best modelling methods (Elith *et al.*, 2006; Elith *et al.*, 2011). Models were generated setting several Maxent presets to default ('Auto features', convergence = 10^{-5}, maximum number of iterations = 500, prevalence = 0.5) and varying predictor variables and the regularisation value β (0.3, 1, and 2) to find which combination generated the best outcomes while minimising the number of model parameters, as well as producing 'closed', bell-shaped response curves guaranteeing model transferability. A regularisation multiplier higher than 1.0 allows that variables' average values in the projections spread from the empirical average of the background points (the situation if it is set to 1.0), avoid model overfitting (Warren & Seifert, 2011), and smooth the response curves. As background, we randomly selected 10,000 points from the study area. As bioclimatic predictors, we used 15 WorldClim 1.4 (www.worldclim.org) variables (Hijmans *et al.*, 2005) at 1 × 1 km pixel size, avoiding variables with patchy patterns (bio_8, bio_9, bio_18, and bio_19), which would result in unrealistic, spotty models. The extreme coordinates the analysis area was 26°N, 12°S, −86°W, −103°E. As we were interested in obtaining the best possible models and not in explaining what variables are important for each species, we did not attempt to remove correlated predictors. Maxent has the capacity of choosing the most informative variables among all predictors for modelling each species (Elith *et al.*, 2011); moreover it generates robust predictions even if there is moderate collinearity among variables (Elith *et al.*, 2011; Merow *et al.*, 2013). Performance of the models was assessed by means of the area under the curve (AUC) in a receiver operating characteristic (ROC) statistic through five-fold cross-validation, emphasising that sensitivity (true positive rate) was maximised.

Continuous Maxent models were transformed to presence/absence models using the '10 percentile training presence', as the origin of our data set caused georeferencing issues in a reduced number of presences, which would exceedingly increase the area predicted present, something undesirable in a conservation analysis. We calculated the land use change area (in km^2) of the EOO in Mexico by the model by cutting-off the original forest vegetation in Land Use and Vegetation map of INEGI (Union Layer, Series V from INEGI, 2011), to determine what percentage the estimated area is threatened by zones with land use change (crops, pasture, and urban areas).

The best models for current climatic conditions were used to generate high-resolution maps of likely range shifts due to climate change. We used the A2a scenario to produce future projections, as this scenario seems to be the more realistic at present (Nakicenovic & Sward, 2000). We generated future projections at 5 × 5 pixel size for the four global circulation models with data available for the time slices 2020, 2050, and 2080 (from Research Program on Climate Change, Agriculture and Food Security) spatially downscaled using the Delta Method (http://www.ccafs-climate.org): CCCMA-CGCM2, CSIRO-MK2.0, UKMO-HADCM3, and MIROC-NIESS99). The final presence/absence model for each species and time slice was the area where the four models predicted presence for the species considered (Fig. 1a, b). To confirm that combinations of novel climates were the most adequate in the projections, we generated the multivariate environmental similarity surfaces; this grid was reclassified and values below zero were masked to show areas of novel climate space relative to the range under which the model was fitted. Area calculations were done on rasters projected to Lambert Conformal Conic.

Results

We could calculate neither present ranges nor future distributions for *P. hyalina* as we only obtained two records. For *P. quinta* and *P. zoe*, the models combined highest performance (high AUC) and transferability (i.e. lower number of parameters and 'closed' curves. Optimal model for *P. quinta* had an AUC of 0.986 ± 0.009, and for *P. zoe* it was of 0.99 ± 0.003, meaning high predictive power in both cases. Table S2 shows a summary of the performance of the best models.

The EOO range calculated by SDM for each species is less to 20 000 km^2 (Table 1) and according to the criterion B1 of the Species Red List, both would be within the Vulnerable category (Table 1). The area predicted as suitable for *P. quinta* includes part of the Los Tuxtlas region in Veracruz, part of Oaxaca, Chiapas, and west Guatemala and south Belize (Fig. 1a). The EOO area calculated for *P. zoe* includes part of the states of Veracruz, Puebla, Hidalgo, Querétaro, San Luis Potosí, Oaxaca, and a small region of the states of Michoacán and Tamaulipas in the Sierra Madre Oriental mountains system (Fig. 1b). The estimated EOO for both species suggest that almost 50% of the distribution occurs in agricultural, pasture, or urban sites (Table 2; Fig. 2a, b). The AOO range calculated for both species is <500 km^2, meaning that they should be in the endangered category, according to the criterion B2 of the Red List (Table 1).

Future distribution projections for both *P. quinta* and *P. zoe* differ from current geographical range. Compared to present distribution ranges, *P. quinta* will contract in 2020 (41.2%; Fig. S1a), to then expand by 2050 (119.5%; Fig. S1b) and 2080 (139.5%; Fig. S1c) (Table 3). On the other hand, distribution area of *P. zoe* will be reduced for the three time periods compared to the present extension (2020: −33.9%; 2050: −29.1%; 2080: −30.2%; Fig. S2a–c, respectively, and Table 3). The CCMA-GCGM2 and NIESS99 models predicted more area in the 3 years selected (2020, 2050 and 2080) for *P. quinta*, and CGC for *P. zoe*.

Discussion

Our study is a conservation assessment of the genus *Paraphlebia*, with relevant data for conservation measures and interpretation of future distribution. Despite the fact that *P. hyalina* has a very restricted distribution (González-Soriano & Novelo-Gutiérrez, 2013) and that there was no prior evaluation by the IUCN (2013), we propose that its status should be data deficient, awaiting for more data, or endangered if we consider only its reduced AOO. Thus, we recommend continuing with field searches in places where this species has been reported. For *P. quinta*, the last categorisation was least concern (IUCN, 2013) but our results suggest that this species should be considered endangered (according to AOO). Again, further field searches will become key for future assessments. For *P. zoe*, our evaluation partly corroborates that by Paulson

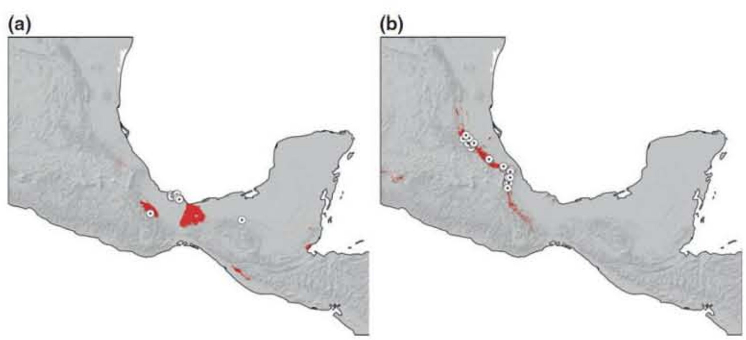


Fig. 1. Extension of occurrence calculated by species distribution models for *Paraphlebia quinta* (a) and *P. zoe* (b). Dots are actual geographical records.

Table 2. Estimated area with original vegetation and land use change for *Paraphlebia quinta* and *P. zoe* (in km^2).

	Predicted area	Estimated area with original vegetation	Estimated area with land use change
P. quinta	18 864	8500	10 363
P. zoe	16 440	8768	7672

Table 3. Consensus (average) estimated (potential) area (km^2) predicted with climatic projections for current time, and 2020, 2050, and 2080 years for *Paraphlebia quinta* and *P. zoe*.

	P. quinta	*P. zoe*
Current extension	18 814	16 440
2020	7885	5575
2050	22 495	4786
2080	26 262	4970

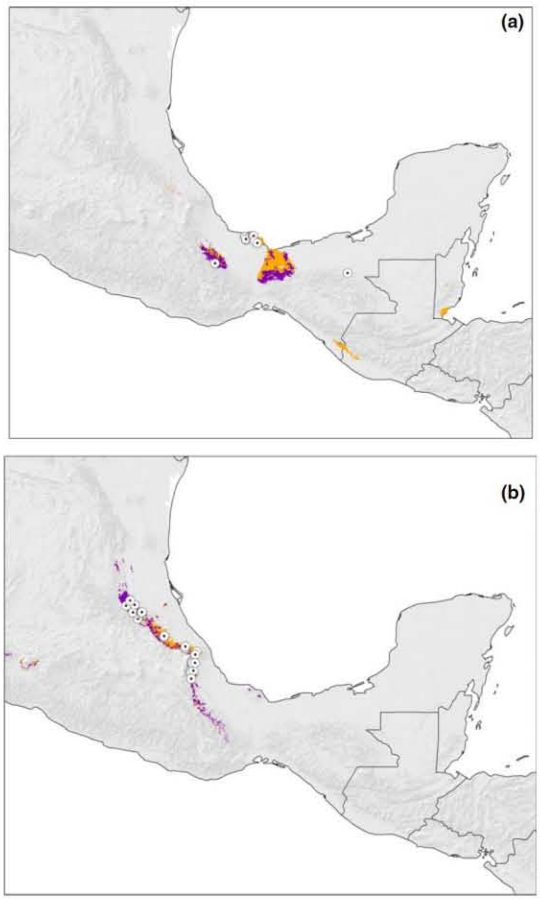


Fig. 2. Extension of occurrence estimated areas for *Paraphlebia quinta* (a) and *P. zoe* (b). Original forest vegetation appears in purple, whereas areas with current land change use (i.e. agricultural, pasture) appears in orange.

and von Ellenrieder (2006), but it may as well be considered as endangered (according to AOO). Overall, we recommend that *P. hyalina* and *P. quinta* should be looked for more intensively and, to a minor extent, *P. zoe*. This search may provide new records and also discard others. For example and related to the latter, some localities in San Luis Potosí and Hidalgo cited in Escoto-Moreno and Márquez (2011), did not correspond to the actual habitat where we found *P. zoe*, or were inconsistent with the geographical coordinates provided by these authors and other explorations we had already carried out in 2011 (e.g. Anderson *et al.*, 2012; Wong-Muñoz *et al.*, 2013).

The three *Paraphlebia* species distributed in Mexico inhabit seepages or small creeks in tropical rain forest. Our analysis shows that *P. quinta* and *P. zoe* are threatened by habitat modification via land use change. In fact, almost 50% of the area considered suitable by SDM included forest area. Our natural history observations suggest that the tropical forest provides these species with enough shadow, humidity and perching sites, which seems to be key for their development. Unfortunately, land use is under extensive change in cloud forest areas in Mexico as original vegetation is replaced by coffee plantations to a large extent (Williams-Linera *et al.*, 2002). Nevertheless, these changes still provide some shade and perching sites that are key for *P. quinta* and *P. zoe* adults as these spend most of their time resting on vegetation (e.g. González-Soriano & Córdoba-Aguilar, 2003 for *P. quinta*). Actually, adults of both sexes of *P. zoe* move relatively little when compared with other damselflies (Munguía-Steyer *et al.*, 2010). This suggests that *Paraphlebia* adults are not likely to move away and/or disperse if vegetation removal takes place. One implication for being so site faithful is that odonate species with this characteristic are less likely to survive when habitat loss takes place compared to species that are less site faithful (e.g. Lee & Rice, 2005).

Future climatic projections of the two species suggested different patterns in distribution range. *P. quinta* showed a decrease (year 2020) but then an expansion (years 2050 and 2080) in geographical range. Conversely, *P. zoe* showed a severe area reduction for the three time periods. These results somehow contradict several related studies in temperate odonates, which in general have shown a reduction in distributional range, with a poleward distribution displacement (Hickling *et al.*, 2005; Jaeschke *et al.*, 2012; Bush *et al.*, 2014). There are, however, important differences to be distinguished in this comparison. First, ours is the only study of possible future climate change effects on distribution that explicitly makes use of tropical odonate species. Thus, unlike those previous studies that used temperate odonate species, tropical odonates may show a different distribution response. In fact, Bonebrake and Deutsch (2012) have indicated that high topographical complexity (e.g. mountains) of tropical species may act as potential buffers of temperature changes, a situation that applies to all *Paraphebia* species. Second, the restricted areas that are typical of endangered species may be due to particular biological properties not necessarily shared with non-threatened species (i.e. Jones *et al.*, 2003). Properties that would make some species more susceptible to extinction are, however, unclear in odonates but still distribution range shifts may be a consequence of it. Take, for example the case of another endangered damselfly, *Ischnura gemina* whose current distribution area is very small, mainly confined to San Francisco bay (Sánchez-Guillén *et al.*, 2014). Paradoxically, SDM for 2050 and 2080 showed an increase in area for this species (Sánchez-Guillén *et al.*, 2014), which is similar to what we predicted for *P. quinta*. Of course, models of future distribution should be taken with care but, for conservation biology purposes, our intention here is to predict how such range area would take place (Akçakaya *et al.*, 2006). Trends in distribution should be assessed in the due time to see how much they correspond with what we have predicted.

In conclusion, our results provide data that help to reassess the threat status of two tropical damselflies, *P. quinta* and *P. zoe*, in the IUCN Red List, and to include them in the Mexican list of species in risk (NOM-059-SEMARNAT, 2010). Although the SDMs generated for this study are in accordance with presently known range distributions of both species, it can be argued that models generated with such a small dataset as *P. quinta*, may in fact represent overprediction areas. Nevertheless, these areas could actually be used to indicate regions where additional monitoring might reveal new occurrences. We believe our research may serve not only as a piece for conserving tropical damselfly species, but also their freshwater environments.

Acknowledgements

We thank R. Sanabria, S. Martínez, S. Rivero, J. Vanegas, and A. Nava for their assistance during field surveys. K. Cuevas-Yáñez acknowledges to a student grant and financial support provided by the Consejo Nacional de Ciencia y Tecnología (CONACyT) (226198/210553), Universidad Nacional Autónoma de México (UNAM). JM received financial support from the Ministry of Economy and Competitiveness of Spain (grant CGL2012-38624-C02-02). This study was supported by a UNAM-PAPIIT grant (IN222312) and a visiting grant by the Coordinación de Investigación Científica (UNAM) to JM. Permits for the field portion of this project were provided by the Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT) (Mexican Government) issued to AC-A. This study constitutes a partial fulfilment of the Graduate Program in Biological Sciences (Posgrado en Ciencias Biológicas) of the National Autonomous University of Mexico (UNAM) for K. Cuevas-Yáñez. Thanks to three reviewers who provided key comments to a previous version.

Supporting Information

Additional Supporting Information may be found in the online version of this article under the DOI reference: doi: 10.1111/icad.12132:

Figure S1. EOO projections for 2020 (a), 2050 (b), and 2080 (c) for *P. quinta*, indicating for each pixel the number of binary models predicting the species as present according to four General Circulation Models (CCCMA-CGCM2, CSIRO-MK2.0, UKMO-HADCM3, and MIROC-NIESS99), from green (1), yellow (2), orange (3) to red (4). Dots are actual geographical records.

Figure S2. EOO projections for 2020 (a), 2050 (b), and 2080 (c) for *P. zoe*, indicating for each pixel the number of binary models predicting the species as present according to four General Circulation Models (CCCMA-CGCM2, CSIRO-MK2.0, UKMO-HADCM3, and MIROC-NIESS99), from green (1), yellow (2), orange (3) to red (4). Dots are actual geographical records.

Table S1. Geographical records of *Paraphlebia* species.

Table S2. Summary of the variables used and the performance of the best models for each species. Models with AUC below 0.9 are not shown.

References

Abellán, P., Sánchez-Fernández, D., Velasco, J. & Millán, A. (2005) Assessing conservation priorities for insects: status of water beetles in southeast Spain. *Biological Conservation*, **121**, 79–90.

Akçakaya, H.R., Burtchart, S.H., Mace, G.M., Stuart, S.N. & Hilton-Taylor, C. (2006) Use and misuse of the IUCN Red List criteria in projecting climate change impacts on biodiversity. *Global Change Biology*, **12**, 2037–2043.

Almeida, M.C., Côrtes, L.G. & de Marco, P. (2010) New records and a niche model for the distribution of two Neotropical damselflies: *Schistolobos boliviensis* and *Tuberculobasis inversa* (Odonata: Coenagrionidae). *Insect Conservation and Diversity*, **3**, 252–256.

Anderson, C.N., Grether, G.F. & Córdoba-Aguilar, A. (2012) Characterization of 12 microsatellite loci in the waterfall damselfly (*Paraphlebia zoe*) for use in population genetic applications. *Conservation Genetic Resourses*, **4**, 175–177.

Bonebrake, T.C. & Deutsch, C.A. (2012) Climate heterogeneity modulates impact of warming on tropical insects. *Ecology*, **93**, 449–455.

Bush, A.A., Nipperess, D.A., Duursma, D.E., Theischinger, G., Turak, E. & Hughes, L. (2014) Continental-scale assessment of risk to the Australian Odonata from climate change. *PLoS ONE*, **9**, e88958.

Cardoso, P., Borges, P.A.V., Triantis, K.A., Ferrández, M.A. & Martín, J.L. (2011b) Adapting the IUCN Red List criteria for invertebrates. *Biological Conservation*, **144**, 2432–2440.

Cardoso, P., Erwin, T.L., Borges, P.A.V. & New, T.R. (2011a) The seven impediments in invertebrate conservation and how to overcome them. *Biological Conservation*, **144**, 2647–2655.

Clausnitzer, V., Kalkman, V.J., Ramc, M., Collen, B., Baillie, J.E.M., Bedjanic, M., Darwall, W.R.T., Dijkstra, K.D.B., Dowf, R., Hawking, J., Karube, H., Malikova, E., Paulson, D., Schütte, K., Suhling, F., Villanuevam, R.J., von Ellenrieder, N. & Wilson, K. (2009) Odonata enter the biodiversity crisis debate: the first global assessment of an insect group. *Biological Conservation*, **142**, 1864–1869.

Clausnitzer, V., Dijkstra, K.D.B. & Kipping, J. (2011) Globally threatened dragonflies (Odonata) in Eastern Africa and implications for conservation. *Journal of East African Natural History*, **100**, 89–111.

CONABIO (2010) *El Bosque Mesófilo de Montaña en México: Amenazas y Oportunidades para su Conservación y Manejo Sostenible*. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, México D.F., México.

Elith, J., Graham, C.H., Anderson, R.P., Dudik, M., Ferrier, S., Guisan, A., Hijmans, R.J., Huettmann, F., Leathwick, J.R., Lehmann, A., Li, J., Lohmann, L.G., Loiselle, B.A., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., Overton, J., Mc, C., Peterson, A.T., Phillips, S.J., Richardson, K.S., Scachetti-Pereira, R., Schapire, R.E., Soberón, J., Williams, S., Wisz, M.S. & Zimmermann, N.E. (2006) Novel methods improve prediction of species' distributions from occurrence data. *Ecography*, **29**, 129–151.

Elith, J. & Leathwick, J.R. (2009a) Conservation priorization using species distribution modelling. *Spatial Conservation Prioritization: Quantitative Methods and Computational Tools* (ed. by A. Moilanen, K.A. Wilson and H.P. Possingham), pp. 1–31. Oxford University Press, New York, USA.

Elith, J. & Leathwick, J.R. (2009b) Species distribution models: ecological explanation and prediction across space and time. *Annual Reviews of Ecology, Evolution and Systematics*, **40**, 677–697.

Elith, J., Phillips, S.J., Hastie, T., Dudik, M., Chee, Y.E. & Yates, C.J. (2011) A statistical explanation of MaxEnt for ecologists. *Diversity & Distributions*, **17**, 43–57.

Escoto-Moreno, E. & Márquez, J. (2011) Analysis of the geographical distribution of *Paraphlebia zoe* Selys in Hagen, 1861 (Odonata: Megapodagrionidae). *Entomological News*, **122**, 416–423.

Feria, T.P., Olson, M.E., García-Mendoza, A. & Solano, E. (2009) A GIS-based comparison of the Mexican National and IUCN methods for determining extinction risk. *Conservation Biology*, **23**, 1156–1166.

Garrison, R.W., von Ellenrieder, N. & Louton, J.A. (2010) *Damselfly Genera of the New World: An Illustrated and Annotated Key to the Zygoptera*. Johns Hopkins University Press, Baltimore, MD, USA.

González-Soriano, E. & Córdoba-Aguilar, A. (2003) Sexual behaviour in *Paraphlebia quinta* Calvert (Odonata: Megapodagrionidae): male dimorphism and a possible example of odonate female control. *Odonatologica*, **32**, 345–353.

González-Soriano, E. & Novelo-Gutiérrez, R. (2013) Biodiversidad de Odonata en México. *Revista Mexicana de Biodiversidad*, **85**, S243–S251.

Hassall, C. & Thompson, D.J. (2008) The effects of environmental warming on Odonata: a review. *International Journal of Odonatology*, **11**, 131–153.

Hawking, J.H. & New, T.R. (2002) Interpreting dragonfly diversity to aid in conservation assessment: lessons from the Odonata assemblage at middle Creek, north-eastern Victoria, Australia. *Journal of Insect Conservation*, **6**, 171–178.

Hickling, R., Roy, D.B., Hill, J.K. & Thomas, C.D. (2005) A northward shift of range margins in British Odonata. *Global Change Biology*, **11**, 502–506.

Hijmans, R.T., Cameron, S.E., Parra, J.I., Jones, P.G. & Jarvis, A. (2005) Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, **25**, 1965–1978.

INEGI (2011) Carta de uso de suelo y vegetación. <http://www.inegi.org.mx/geo/contenidos/recnat/usosuelo/> 1st July 2014.

IUCN (2013) Guidelines for using the IUCN Red List categories and criteria. Version 10. <http://jr.iucnredlist.org/documents/RedListGuidelines.pdf> 23rd January 2014.

Jaeschke, A., Bittner, T., Jentsch, A., Reineking, B., Schlumprecht, H. & Beierkuhnlein, C. (2012) Biotic interactions in the face of climate change: a comparison of three modelling approaches. *PLoS ONE*, **7**, e51472.

Jones, K.E., Purvis, A. & Gittleman, J.L. (2003) Biological correlates of extinction in bats. *The American Naturalist*, **161**, 601–614.

Lambin, E.F., Geist, H.J. & Lepers, E. (2003) Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environmental Resources*, **28**, 205–241.

Lee, A. & Rice, C. (2005) Odonates as biological indicators of grazing effects on Canadian prairie wetlands. *Ecological Entomology*, **30**, 273–283.

Martínez, M.L., Pérez-Maqueo, O., Vázquez, G., Castillo-Campos, G., García-Franco, J., Mehltreter, K., Equihua, M. & Landgrave, R. (2009) Effects of land use change on biodiversity and ecosystem services in tropical montane cloud forests of Mexico. *Forest Ecology & Management*, **258**, 1856–1863.

McGeoch, M.A., Sithole, H., Samways, M., Simaika, J.P., Pryke, J.S., Picker, M., Uys, C., Amstrong, A.J., Sippernaar-Schoeman, A.S., Engelbrech, I.A., Braschler, B. & Hamer, M. (2011) Conservation and monitoring of invertebrates in terrestrial protected areas. *Koedoe*, **53**, 1–13.

Merow, C., Smith, M.J. & Silander, J.A., Jr (2013) A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. *Ecography*, **36**, 1058–1069.

Munguía-Steyer, R., Córdoba-Aguilar, A. & Romo-Beltrán, A. (2010) Do individuals in better condition survive for longer? Field survival estimates according to male alternative reproductive tactics and sex. *Journal of Evolutionary Biology*, **23**, 175–184.

Nakicenovic, N. & Sward, R. (2000) *Emission Scenarios, Special Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK.

NOM-059-SEMARNAT (2010) Protección ambiental – Especies Nativas de México de Flora y Fauna Silvestres. Categorías de Riesgo y Especificaciones para su Inclusión, Exclusión o Cambio-Lista de Especies en Riesgo. <NOM-59-SEMARNAT.2010> 26th January 2014.

Novelo-Gutiérrez, R. (2008) Description of the larva of *Paraphlebia zoe* Selys in Hagen 1861. *Zootaxa*, **1876**, 29–34.

Paulson, D. & von Ellenrieder, N. (2006) *Paraphlebia zoe*. IUCN Red List of threatened species. Version 2012.2. <www.iucnredlist.org> 12th March 2014.

Paulson, D. (2009) *Paraphlebia quinta*. IUCN Red List of threatened species. Version 2012.2. <www.iucnredlist.org> 12th March 2014.

Pearson, R.G. & Dawson, T.P. (2003) Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? *Global Ecology and Biogeography*, **12**, 361–371.

Phillips, S.J., Anderson, R.P. & Schapire, R.E. (2006) Maximum entropy modeling of species geographic distributions. *Ecological Modelling*, **190**, 231–259.

Régnier, C., Fontaine, B. & Bouchet, P. (2009) Not knowing, not recording, not listing: numerous unnoticed mollusk extinctions. *Conservation Biology*, **23**, 1214–1221.

Sánchez-Guillén, R.A., Muñoz, J., Hafernik, J., Tierney, M., Rodriguez-Tapia, G. & Córdoba-Aguilar, A. (2014) Hybridization rate and climate change: are endangered species at risk? *Journal of Insect Conservation*, **18**, 295–305.

Sánchez-Guillén, R.A., Muñoz, J., Rodríguez-Tapia, G., Feria, T.P. & Córdoba-Aguilar, A. (2013) Climate-induced range shifts and possible hybridisation consequences in insects. *PLoS ONE*, **8**, e80531.

Simaika, J.P. & Samways, M.J. (2009) Reserve selection using Red Listed taxa in three global biodiversity hotspots: dragonflies in South Africa. *Biological Conservation*, **142**, 638–651.

Simaika, J.P. & Samways, M.J. (2010) Large-scale estimators of threatened freshwater catchment species relative to practical conservation management. *Biological Conservation*, **143**, 311–320.

Simaika, J.P., Samways, M.J., Kipping, J., Suhling, F., Dijkstra, K.D.B., Clausnitzer, V., Boudot, J.P. & Domisch, S. (2013) Continental-scale conservation prioritization of African dragonflies. *Biological Conservation*, **157**, 245–254.

Strayer, D.L. (2006) Challenges for freshwater invertebrate conservation. *Journal of the North American Benthological Society of America*, **25**, 271–278.

Warren, D.L. & Seifert, S.N. (2011) Ecological niche modeling in Maxent: the importance of model complexity and the performance of model selection criteria. *Ecological Applications*, **21**, 335–342.

Williams-Linera, G., Manson, R.H. & Isunza, E. (2002) La fragmentación del bosque mesófilo de montaña y patrones de uso del suelo en la región oeste de Xalapa, Veracruz, México. *Madera y Bosques*, **8**, 73–89.

Wong-Muñoz, J., Anderson, C.N., Munguía-Steyer, R. & Córdoba-Aguilar, A. (2013) Body size and morph as drivers of copulation duration in a male dimorphic damselfly. *Ethology*, **119**, 407–416.

Accepted 29 April 2015

Editor: Simon R. Leather
Associate editor: Steve Yanoviak

Supplementary Material.

Table 1

SPECIES	COUNTRY	STATE	LOCALITY	LONG	LAT	SOURCE
P. hyalina	Mexico	Veracruz	Sontecomapan	-95.0355	18.5132	Smithsonian Museum
P. hyalina	Guatemala	Alta Verapaz	Sepacuite	-89.7409	15.4328	Smithsonian Museum
P. quinta	Mexico	Veracruz	Tuxpan	-97.4000	20.9500	Smithsonian Museum
P. quinta	Mexico	Veracruz	Valle Nacional	-96.3029	17.7032	Smithsonian Museum
P. quinta	Mexico	Veracruz	Arroyo Frío	-95.3383	18.5667	Smithsonian Museum
P. quinta	Mexico	Veracruz	Río Tecolapan	-95.3311	18.5712	Smithsonian Museum
P. quinta	Mexico	Veracruz	Tatocapan	-95.3000	18.4614	Smithsonian Museum
P. quinta	Mexico	Veracruz	Santiago Tuxtla	-95.2996	18.4932	González & Córdoba, 2003
P. quinta	Mexico	Veracruz	Volcán San Martin	95.1500	18.5667	Smithsonian Museum
P. quinta	Mexico	Veracruz	Laguna Emilia	-95.0903	18.5936	Smithsonian Museum
P. quinta	Mexico	Veracruz	Catemaco	95.0667	18.5833	Smithsonian Museum
P. quinta	Mexico	Veracruz	Playa Escondida	-95.0500	18.6000	Smithsonian Museum
P. quinta	Mexico	Veracruz	Coyame	-95.0167	18.4333	Smithsonian Museum
P. quinta	Mexico	Veracruz	Vulcan Sta. Martha	94.9333	18.3667	Smithsonian Museum
P. quinta	Mexico	Chiapas	Misol-há	-92.0003	17.3919	Smithsonian Museum
P. zoe	Mexico	Hidalgo	Calnali Road, 2 km before to Calnali	-98.6261	20.8979	Field record
P. zoe	Mexico	Hidalgo	Cascade, 1.1 milles NE to Chapulhuacan	-98.9143	21.1684	Specialist consult
P. zoe	Mexico	Hidalgo	Calnali road, 250 to the landfill	-98.6755	20.8868	Field record
P. zoe	Mexico	Hidalgo	Tepehuacán de Guerrero, near Otongo, road some meters before a sandpit	-98.7441	20.9774	Field record
P. zoe	Mexico	Hidalgo	Tepehuacán de Guerrero road, km 8.5 to Molango-Tlanchinol road	-98.7331	20.9763	Field record
P. zoe	Mexico	Hidalgo	Ixtlahuaco	-98.7028	20.8812	Specialist consult
P. zoe	Mexico	Hidalgo	2 km to North Pemuxtitla	98.7403	20.8121	Specialist consult
P. zoe	Mexico	Hidalgo	Stram neart to Atezca Lagoon	-98.7403	20.8121	Specialist consult
P. zoe	Mexico	Hidalgo	[Otongo, Glen] Guadalupe towm	-98.7558	20.9632	Field record
P. zoe	Mexico	Hidalgo	Towards Cuazáhuatl, near to San Juan Ahuehueco	98.8882	21.0124	Field record
P. zoe	Mexico	Hidalgo	Road to Apantlazol, site 2	-98.6401	20.9848	Field record
P. zoe	Mexico	Hidalgo	Road to Apantlazol, site 3	98.6404	20.9848	Field record
P. zoe	Mexico	Hidalgo	Km 170, Tlanchinol-Huejutla highway	-98.6372	21.0229	Specialist consult
P. zoe	Mexico	Hidalgo	km 2.3 road to Apantlazol, site 1	98.6374	20.9827	Field record
P. zoe	Mexico	Hidalgo	Km. 7 carretera Tlanchinol-Huejutla	-98.6155	21.0225	Field record
P. zoe	Mexico	Hidalgo	Km. 7.5, carretera 105 Tlanchinol-Huejutla	-98.6114	21.0219	Specialist consult
P. zoe	Mexico	Puebla	Hidroeléctrica de Patla, El Pozo	-97.9034	20.2247	Cuevas, 2007
P. zoe	Mexico	Puebla	La Unión, Km 12 Dos Caminos-La Unión	-97.8966	20.2612	Specialist consult
P. zoe	Mexico	Querétaro	Km 14 carretera El Lobo-Agua Zarca, pasando el poblado de Pemoche	-99.1129	21.2294	Field record

Table 1 (continuation)

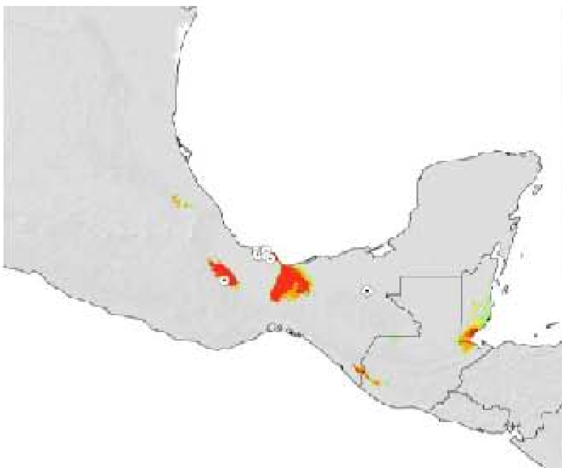
P. zoe	Mexico	San Luis Potosí	Rancho Quemado, Km. 353, carretera 85 cerca de Tamazunchale	98.8355	21.2565	Specialist consult
P. zoe	Mexico	San Luis Potosí	Las Pozas	98.9853	21.3947	CONABIO
P. zoe	Mexico	Veracruz	El Muro, Km. 16, carretera 131	-97.2205	19.8763	Specialist consult
P. zoe	Mexico	Veracruz	Ixtatahuia, carretera 131 Tlapacoyan-Altotonga	-97.2349	19.8876	Specialist consult
P. zoe	Mexico	Veracruz	Km. 18 carretera Tlapacoyan Altotonga	97.2274	19.8463	Specialist consult
P. zoe	Mexico	Veracruz	Tlapacoyan, Arroyo Colorado, Km. 14, carretera 131 Tlapacoyan Altotonga	97.2318	19.8822	Specialist consult
P. zoe	Mexico	Veracruz	Cerca de la Cascada La Tomata	-97.2179	19.9251	Specialist consult
P. zoe	Mexico	Veracruz	Calcahualco, Cuapa, Río Jamapa [Río Cuapa]	-97.0793	19.1167	Specialist consult
P. zoe	Mexico	Veracruz	Ahuacatlán, Cascada de los Tecajetes (escurridero) [Río Tecajetes]	96.9812	19.4726	Specialist consult
P. zoe	Mexico	Veracruz	Balneario Agua Alegre	96.9815	19.4488	Field record
P. zoe	Mexico	Veracruz	Camino a Cinco palos, casa de Rogelio Macías	-97.0001	19.4786	Munguía-Steyer et al., 2010
P. zoe	Mexico	Veracruz	Camino a el Tecajete (antes de la Cascada)	-96.9838	19.4729	Field record
P. zoe	Mexico	Veracruz	Cascada Bola de Oro (escurridero cercano)	96.9599	19.4729	Field record
P. zoe	Mexico	Veracruz	Cascada La Granada	-97.0093	19.4751	Field record
P. zoe	Mexico	Veracruz	Río Huehueyapan	-96.9814	19.4525	Specialist consult
P. zoe	Mexico	Veracruz	La Gloria 1	-97.0015	19.3458	Field record
P. zoe	Mexico	Veracruz	La Gloria 2	97.0043	19.3452	Field record
P. zoe	Mexico	Veracruz	La Gloria 3	-96.9957	19.3529	Field record
P. zoe	Mexico	Veracruz	4.8 millas al norte de Coscomatepec	97.0491	19.1433	Specialist consult
P. zoe	Mexico	Veracruz	Km. 30 carretera Fortín-Huatusco	-97.0225	19.0969	Specialist consult
P. zoe	Mexico	Veracruz	Puente al norte de Coscomatepec	-97.0331	19.1003	Specialist consult
P. zoe	Mexico	Veracruz	4.7 millas al norte de Huatusco Puente Ruíz Cortines	96.9647	19.1500	CONABIO
P. zoe	Mexico	Veracruz	Fortín de las Flores 1.9 mi SW & 0.5 mi N [Cerca de la población Sumidero]	-97.0261	18.8998	Specialist consult
P. zoe	Mexico	Veracruz	Cuesta de Misantla	-96.8508	19.9022	Specialist consult
P. zoe	Mexico	Veracruz	2 km al sur de Naolinco, sobre la carretera, a un costado de la Mina de arena	-96.9011	19.6689	Field record
P. zoe	Mexico	Veracruz	Cerca de Laguna Escondida (Emilia)	95.0933	18.5936	CONABIO
P. zoe	Mexico	Veracruz	Cascada Texolo Sitio 2	-96.9945	19.4004	Field record
P. zoe	Mexico	Veracruz	Puente Teocelo, 0.5 km en dirección a Teocelo, sobre la carretera Coatepec-Teocelo	-96.9825	19.4013	Field record
P. zoe	Mexico	Veracruz	Cascada Texolo Sitio 1	-96.9950	19.4018	Field record
P. zoe	Mexico	Veracruz	Puente Teocelo, sobre la carretera Coatepec-Teocelo	96.9062	19.4028	Field record

Supplementary table 2. Summary of the variables used and the performance of the best models for each species. Models with AUC below 0.9 are not shown.

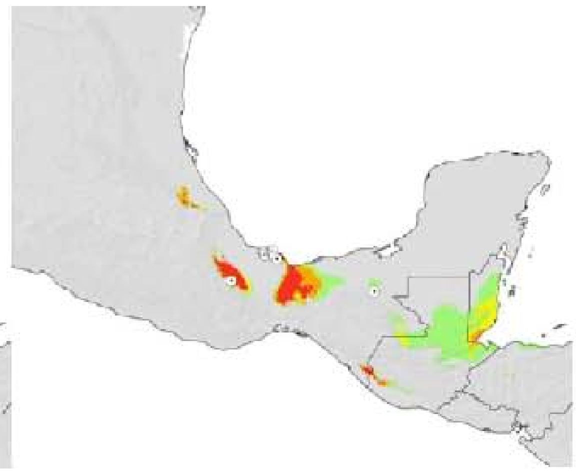
Species	variables used	betamultiplier	training AUC	n° parameters
P. quinta	all	1	0.9893	8
	* bio 3, bio 12, bio 15, bio 17	1	0.9877	5
	bio 3, bio 5, bio 6, bio 12, bio 15, bio 16, bio 17	1	0.9893	8
	bio 3, bio 12, bio 14, bio 15, bio 17	1	0.9877	5
	bio 3, bio 14, bio 15, bio 17	1	0.9856	5
	bio 3, bio 15, bio 17	1	0.9837	4
	all	0.3	0.9937	12
	bio 11 , bio 12 , bio 13 , bio 14 , bio 15 , bio 16 , bio 17	0.3	0.996	9
	bio 03 , bio 06 , bio 11 , bio 12 , bio 13 , bio 14 , bio 15 , bio 16 , bio 17	0.3	0.9937	9
P. zoe	all	1	0.997	33
	* bio 10, bio 11, bio 13	1	0.9934	8
	bio 6, bio 10, bio 11, bio 12, bio 13, bio 14, bio 15, bio 16	1	0.9946	24
	bio 6, bio 10, bio 11, bio 12, bio 13, bio 14, bio 15, bio 16	1	0.9931	14
	bio 6, bio 10, bio 11, bio 15	1	0.9789	12
	bio 6, bio 10, bio 11, bio 12, bio 16	1	0.9924	13
	bio 6, bio 10, bio 11, bio 12, bio 13, bio 14, bio 16	1	0.9933	12
	bio 5, bio 6, bio 10, bio 11, bio 12, bio 13, bio 14, bio 15, bio 16	1	0.9946	20
	bio 10, bio 11, bio 16	1	0.9883	6
	bio 10, bio 11, bio 12, bio 13, bio 14, bio 16	1	0.9932	19
	bio 10, bio 13, bio 14, bio 16	1	0.9875	21
	bio 13, bio 14, bio 16	1	0.9594	11
	bio 10, bio 13, bio 16	1	0.9338	9
	bio 10, bio 11, bio 12, bio13, bio 14	1	0.9931	15
	bio 10, bio 11, bio 14	1	0.9923	11

Supplementary material figure 1. EOO projections for years 2020 (a), 2050 (b) and 2080 (c) for *P. quinta*, indicating for each pixel the number of binary models predicting the species as present according to four General Circulation Models (CCCMA-CGCM2, CSIRO-MK2.0, UKMO-HADCM3, and MIROC-NIESS99), from green (1), yellow (2), orange (3) to red (4). Dots are actual geographical records.

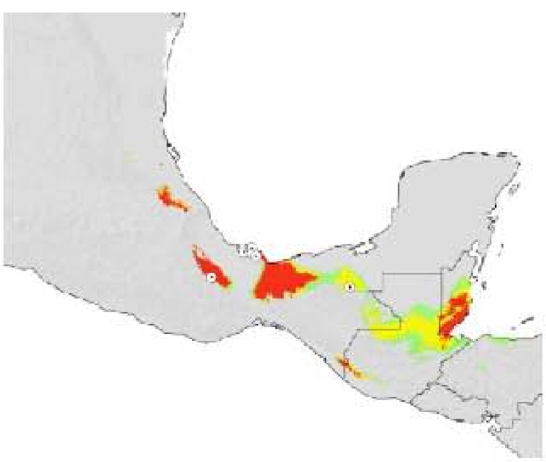
(a)



(b)

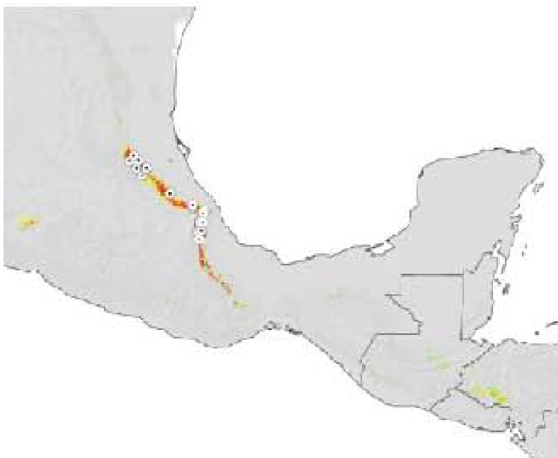


(c)



Supplementary material figure 2. EOO projections for 2020 (a), 2050 (b) and 2080 (c) for *P. zoe*, indicating for each pixel the number of binary models predicting the species as present according to four General Circulation Models (CCCMA-CGCM2, CSIRO-MK2.0, UKMO-HADCM3, and MIROC-NIESS99), from green (1), yellow (2), orange (3) to red (4). Dots are actual geographical records.

(a)



(b)

(c)

CAPÍTULO II

Are all Mexican odonate species described? An assessment of species richness and distribution of collecting sites

Are all Mexican odonate species described? An assessment of species richness and distribution of collecting sites

K. Cuevas-Yañez[1], J. C. Espinosa-Rivera[2], & A. P. Martínez-Falcón[3] A. Córdoba-Aguilar[1*]

[1]Departamento de Ecología Evolutiva, Instituto de Ecología, Universidad Nacional Autónoma de México, Apdo. Postal 70-275, Ciudad Universitaria, 04510, Mexico, D.F., Mexico

[2]Facultad de Estudios Superiores Iztacala, Av. De Los Barrios 1, Los Reyes Iztacala, Apdo. Postal 54090 Tlalnepantla, Estado de México, Mexico

[3]Instituto de Ecología A.C., Red de Interacciones Multitróficas, Carretera Antigua a Coatepec 351, El Haya, Xalapa, Veracruz 91070, Mexico

* Corresponding author: acordoba@iecologia.unam.mx

ABSTRACT

With the aim of protecting Mexican diversity, one current governmental task is to complete national biological inventories. For the case of odonate insects, several researchers have hypothesized that species richness is complete but there has not been any formal exercise to see if this is the case. Here we have investigated: a) if there is a correlation between the total of active taxonomist and species discovered in Mexico; and, b) how good distribution data are in the country. We found there is a correlation between active taxonomist and species recorded. The Mexican odonate records shown an aggregate pattern. However, species' distribution data are highly heterogeneous. We encourage researchers to continue odonate sampling at least to support three conservation actions: 1) conservation assessment of endangered species; 2) knowledge of range shifts given rising global temperatures; and 3) increase public interest and awareness in protected, touristic areas.

Key words: Odonata, Mexico, richness, rarefaction, distribution

INTRODUCTION

One current challenge embraced by the government of Mexico is to complete its national biological inventories (CONABIO, 2000; Escobar *et al.* 2009), which is key for conservation and sustainability actions within the country (Dirzo & Raven, 1994). This challenge has been somehow reached for several taxa, for example mammals (Ceballos, 2007). However, insect taxa have remained poorly known which is largely explained by the reduced number of insect specialists that work in a relatively huge area. This task makes sense if one considers that although the country concentrates between 10-15% of terrestrial species in just 1.3 % of the world's continental surface (Mittermeir & Goettsch, 1992), there are no more than 200 Mexican taxonomy specialists with possibly a dozen working with insects (Llorente-Bousquets *et al.*, 2008).

A recurrent problem in studies of biodiversity is to know whether the number of species for area is complete. In relation to the Mexican biodiversity, such uncertainty applies for a number of taxa (Escobar *et al.* 2009). For the case of odonates (damselflies and dragonflies), scientists have wondered whether the checklist of 357 species (González-Soriano & Novelo-Gutiérrez, 2014) that have been described within Mexican territory is complete and an interesting question also may be know where sites contains more species and where the investigators should lead the efforts.

Odonate collection in Mexico was slow from 1750 until 1850 and then became steadily intense from 1850 until 2000 (see González-Soriano & Novelo-Gutiérrez, 2007, 2014). Since 2000 to date, description of new species slowed down and rendered approximately 15 species, this is, one species per year (González-Soriano & Novelo-Gutiérrez, 2014). 357 species is considered a relatively high biodiversity estimate as it accounts for 5.9 % of the odonate species known worldwide (approximately 5,800 species; Kalkman *et al.*, 2008; Schorr & Paulson, 2012).

However, whether the deceleration in odonate species description implies that we are close to known all Mexican species is unclear, especially given that collecting activities have not been homogeneous for all over the country, pattern observed in other arthropods groups (Escobar *et al.* 2009). In relation to the latter, there are striking differences in the number of species occurring among the different states recognized in Mexico, and whose main explanation seems a difference in collecting effort among ecoregions rather than biotic or abiotic, state-based conditions (González-Soriano &

Novelo-Gutiérrez, 2014). Therefore, in this paper we have investigated a) if the number of taxonomists are relevant in the number of species discovered and which are the ecoregions with most Odonata records and species, b) if the distribution of geographical records presents any geographical pattern and, b) how much homogeneously the Mexican territory has been collected gathering and mapping all historical collecting points. The emphasis of they show different trends but to discuss the value of each in some conservation strategies. The results of these two aims allow us to discuss briefly their implications for Mexican conservation political strategies.

MATERIAL AND METHODS

We built a database with all odonate species described for the Mexican territory per decade from 1898 until 2014 using scientific papers, and dissertation theses. We review and depured the database, the concordance between locality and geographic coordinate was regarded, the valid name and the species as recorded in Mexico previously according to Schorr & Paulson (2015). We corroborated valid names of Odonata species and eliminated synonyms based on Garrison & von Ellendierer (2014). The database included species name, description year, locality, type locality and author. This list rendered a total of 357 species. The taxonomist work is crucial to find more species. We calculate a correlation between number of active taxonomist and species described for decade, since 1898 to 2014. Our hypothesis is the more taxonomist are active, the more species are described.

To map the distribution of odonate collected in Mexico, we gathered all collecting site data and coordinates from the main electronic databases (CONABIO, 2015; GBIF, 2015) as well as from published papers. In many cases, these data were georeferenced. All geographic records were visualized in ARC GIS v.9.3. To assess the geographical records coverage for Mexican Ecoregions, we used the Mexican Land Ecoregions layer from CONABIO (CONABIO 2007) and all records in each ecoregion were counted. After, in order to know the distributional pattern of geographical localities were distributed in a random pattern, we obtained the localities from geographical records, (1691 single localities) and calculated the average nearest neighbor for each locality. This analysis consider the neighbor ratio as the observed mean Euclidean distance between each locality and its nearest neighbor, divided by the expected mean for the localities given in a random pattern. Also, we evaluated the closeness average to each locality to the nearest highway and water body. The analysis was made in ARC GIS 9.3.

RESULTS

We obtained 8787 records from 357 species. We found a positive correlation between number of active taxonomist and species described ($n= 11$; $r=0.76$; $p<0.01$). As it is shown in the Fig. 1, there is a peak in number in species described, during 2000-2010 decade; the period of mayor taxonomist activity was in 1900-2000 decades.

We found that more than 38% of records are distributed in Tropical Humid Forest and about 28% of the records are in Tropical Dry Forest, together account more than 50% of the total records reported in Mexico. A fewer records are located in the Great Plains and Mediterranean California, both add 1% of total records (Table. 1, Fig. 2). However, the localities shown an agregated pattern, then the distribution of them was not random (Fig. 2). (Nearest neighbor ratio=0.3331; Z score=-52.58, critical value=-2.58, $p<0.01$). The average closeness to waterbodies was 16.81 km (D.E.=8.89) and to highways was 10.83 km (D.E.=8.89).

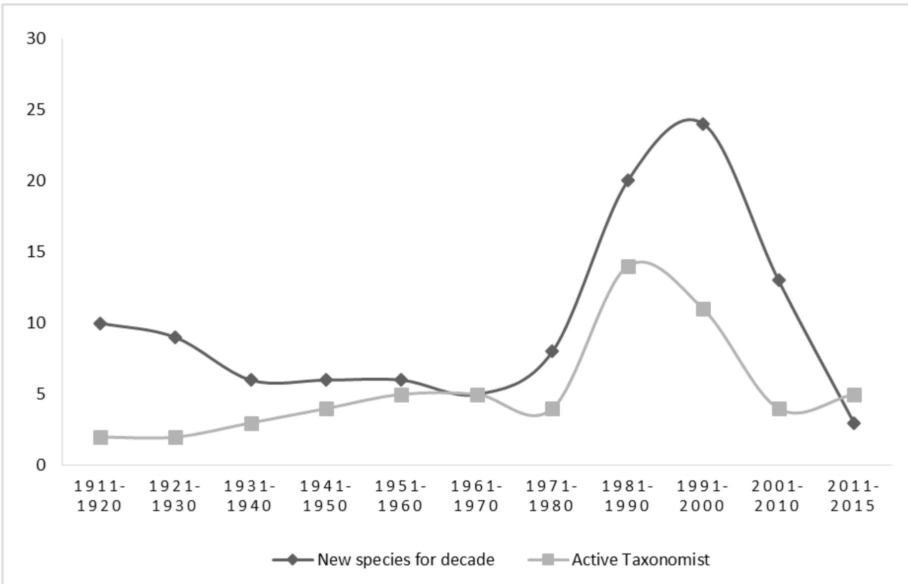


Figure 1. Graphic representation of active taxonomist and species number discovered in Mexico for decade.

Table 1. Geografical records in Ecoregions in Mexico

Ecoregion	No. geographical records
Selvas Cálido-Húmedas (Tropical Humid Forest)	3367
Selvas Cálido-Secas (Tropical Dry forest)	2458
Sierras Templadas (Mountain Range Template Forest)	1897
Elevaciones Semiáridas Meridionales (Meridional Semirarid Elevations)	598
Desiertos de América del Norte (North American Deserts)	360
California Mediterránea (Mediterranean California)	60
Grandes Planicies (Great Plains)	47

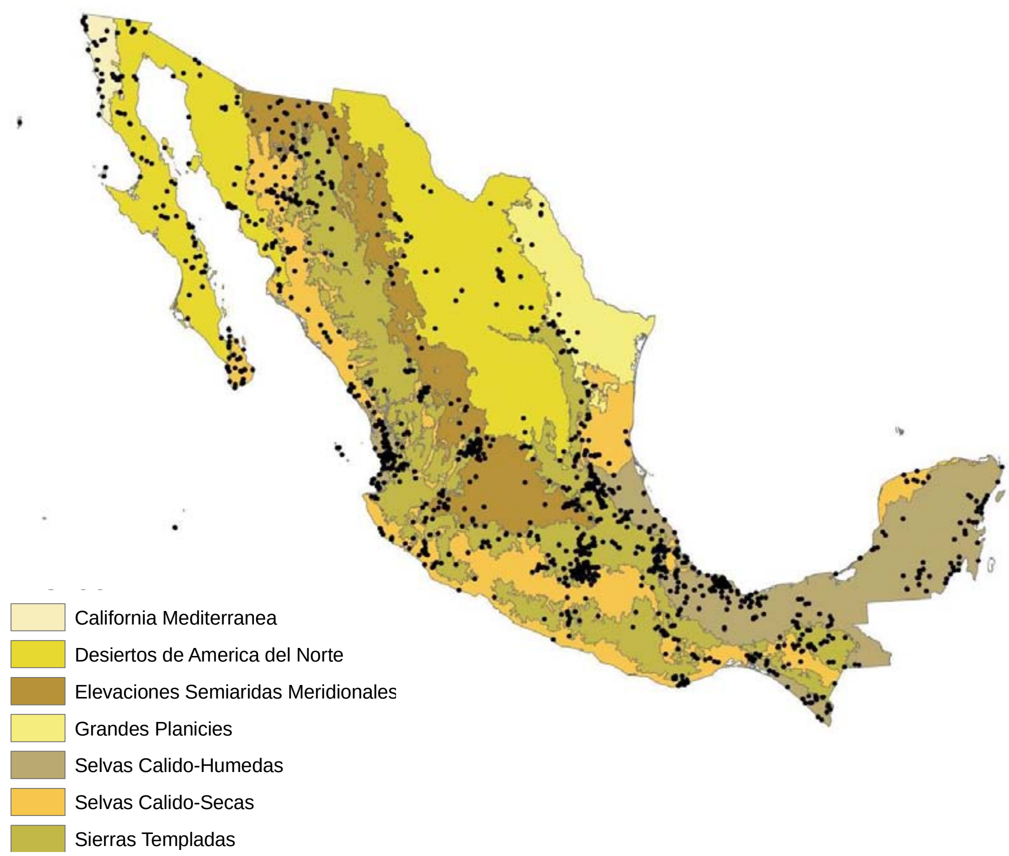


Figure 2. Collecting sites of Mexican Odonata species in the Land Ecoregions (see Table 1).

DISCUSSION

Our results indicate that exist a correlation between active taxonomist and species described. It is not surprising when more taxonomist are active, increases the taxonomic work in a country, and hence the species discovered. The importance of inventories in new areas or in areas where it is suspected there is a high species richness is crucial to improve the knowledge about national biodiversity, and the taxonomic work is an essential aspect to achieve it. However there are others aspects may affect the discovery or detection of new species or species records. The area (ecoregion) where the investigations was made (for example, if is a forest or desert) since it is more likely to find more species in a tropical forest (Clausnitzer et al. 2009). The unknown distributions of species, or if previously were found other endemic species. Of course, there is always the argument that still some species may be missing which is possibly true but such new species will be a handful at best. (CONABIO, 2000).

Our results have also shed light of a poor distribution data in different ecoregions: (1) the Great Plains, (2) Mediterranean California, and (3) North American Deserts. The most species richness in Odonata are in Tropical Forest (Clausnitzer et al. 2009), therefore, is not surprising these ecoregions exhibit most dragonflies records due to mentioned above. Also, Odonata records in the country had an aggregate pattern. This may indicate the odonates prefer sites with distinctive characteristics, for example, climate, or vegetation, or may facilitate the reproductive activities, or the dispersion ability is limited for some species (Corbet 1999) or may be necessary more sample efforts in these areas.

Notice that despite the fact that some occurrences have been described for North American Deserts and Great Plains Ecoregions (central and coast Sonora; the Mexican side of the USA-Mexican in the states of Chihuahua, Coahuila, Nuevo León and Tamaulipas); in most Tamaulipas and Campeche (Tropical Humid Forest Ecoregion), data in these ecoregions were not available and we do know if exist some studies in these areas. Such a lack of distribution data contrasts with that of other regions such as the Tropical Humid and Dry Forest where sampling has been more intense, and whose inventories have actually documented an observed relatively high odonate diversity (González-Soriano & Novelo-Gutiérrez, 2014), or possibly correspond to a particular investigators interests, or the proximity to cities or roads. Moreover, we envisage three conservation-based advantages to continue odonate sampling. One first advantage is it allows carrying out conservation assessments of species facing some degree of threat and/or that are endemic. These assessments are based on the distribution data (i.e. Feria *et al.,* 2009) which, unfortunately, are not robust for the majority of Mexican odonate species (all authors' unpub. data) and one recent example illustrates this. A conservation assessment of the three damselfly species of *Paraphlebia* that occur in Eastern Mexico indicated a huge lack of distribution records that precluded constructing species distribution models for one species (Cuevas-Yáñez *et al*., in press). This lack of distribution data also applies to other Mexican odonate species (González-Soriano & Novelo-Gutiérrez, 2014) described by the IUCN Red List as endangered: *Phyllogomphoides indicatrix*, *Progomphus amarillus*, *Heteragrion azulum*, *Lestes simplex* and *Palaemnema paulitoyaca* (IUCN, 2015). Although these species are endangered, implying that few records are available (as generally occurs for invertebrates; Cardoso *et al*., 2011), shortage of distribution data even applies to common odonate species (all authors' unpub. data). A second advantage is to predict species' range shifts given rising global temperatures. In regards to this, it is known that odonates have been shifting their distribution range polewards (e.g. Hickling *et al*., 2005). Finding or predicting such shifts again suppose having firm distribution data which is not the case for Mexico.

Finally, a third advantage of increasing collecting efforts is that, at the local scale, knowledge of odonate richness has sometimes worked to increase the value of particular sites. This is the case of botanical gardens (e.g. El Charco del Ingenio, 2015) and protected areas (e.g. Lot & Cano-Santana, 2009) that have tended to publish their odonate lists and encouraged visitors to identify odonate species by visual means. These places sometimes use the argument of having endemic species, to imply how important such areas for biodiversity. The fact that adult odonates are highly aesthetic and relatively easy to find, make them comparable to birds to some extent. On the other hand, it is known that such activities increase public interest and awareness of natural heritage (i.e. Lemelin, 2010). If these protected areas have better knowledge of their odonates, they can exploit this information, indirectly protecting their odonates.

ACKNOWLEDGEMENTS

This project was supported by a PAPIIT-UNAM grant IN-203115. K. Cuevas-Yáñez was supported by a CONACyT grant (226198/210553). This study constitutes a partial fulfillment of the Graduate Program in Biological Sciences (Posgrado en Ciencias Biológicas) of the National Autonomous University of Mexico (UNAM). Authors declare to have no conflict of interests.

REFERENCES

Cardoso, P., Erwin, T.L., Borges, P.A.V. & New, T.R. (2011) The seven impediments in invertebrate conservation and how to overcome them. *Biological Conservation*, **144**, 2647-2655.

Clausnitzer, V., Kalkman, V. J., Ram, M., Collen, B., Baillie, J. E., Bedjanič, M., ... & Karube, H. (2009). Odonata enter the biodiversity crisis debate: the first global assessment of an insect group. *Biological Conservation*, **142**(8), 1864-1869.

Ceballos, G. (2007) Conservation priorities for mammals in megadiverse Mexico: The efficiency of reserve networks. *Ecological Applications,* **17**, 569-578.

CONABIO, (2000) Estrategia Nacional sobre Biodiversidad de México. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, Mexico.

CONABIO (2007) Portal de geoinformación. Sistema Nacional de Información sobre biodiversidad. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, Mexico http://www.conabio.gob.mx/informacion/gis/ Accessed on 17 April, 2015.

El Charco del Ingenio (2015) El Charco del Ingenio, Jardín Botánico, Reserva Natural, San Miguel de Allende, Guanajuato, México. http://elcharco.org.mx/listado_libelulas.html. Accessed on 15 May, 2015.

Corbet, P. S. 1999. Dragonflies: behavior and ecology of Odonata. Comstock Pub. Ass. USA.

Cuevas-Yáñez, K., Rivas, M., Muñoz, J. & Córdoba-Aguilar, A. (In press) Conservation status assessment of *Paraphlebia* damselflies in Mexico. *Insect Conservation and Diversity.*

Dirzo, R. & Raven, P.H. (1994) Un inventario biológico para México. *Sociedad Botánica,* **55,** 29-34.

Escobar, F., Koleff, P., & Rös, M. (2009). Evaluación de capacidades para el conocimiento: El Sistema Nacional de Información sobre Biodiversidad (SNIB) como un estudio de caso. *Conabio–PNUD. México: capacidades para la conservación y el uso sustentable de la biodiversidad. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad y Programa de las Naciones Unidas para el Desarrollo, México*, 23-49.

Feria, T.P., Olson, M., García-Mendoza, A. & Solano, E. (2009) A GIS-based comparison of the Mexican National and IUCN methods for determining extinction risk. *Conservation Biology*, **23**, 1156-1166.

Garrison, R. W. & von Ellenrieder, N. (2014). A synonymic list of the New World Odonata. Available in: www.odonatacentral.org. Accessed on: 02-May-2015.

GBIF (2015) Global biodiversity information facility. http://www.gbif.org/ accessed on 12 April, 2015.

González-Soriano, E. & Novelo-Gutiérrez, R. (2007) Odonata of Mexico: revisited. *In:* Odonata: Biology of Dragonflies. B. K. Tyagi (ed.). Scientific Publishing (India), p. 105-136.

González-Soriano, E. & Novelo-Gutiérrez, R. (2014) Biodiversidad de Odonata en México. *Revista Mexicana de Biodiversidad,* **85**, 243-251.

Hickling, R., Roy, D.B., Hill, J.K. & Thomas, C.D. (2005) A northward shift of range margins in British Odonata. *Global Change Biology*, **3**, 502-506.

Lemelin, H. (2009) Goodwill hunting: dragon hunters, dragonflies and leisure. *Current Issues in Tourism*, **12**, 553-571.

Llorente-Bousquets, J.L., Michán-Aguirre, L., González-González J. & Sosa-Ortega, V. (2008) Desarrollo y situación actual del conocimiento de las especies. *In*: Capital Natural de México, vol.1: Conocimiento Actual de la Biodiversidad. CONABIO, México, pp. 193-214.

Lot, A. & Cano-Santana, Z. (2009) Biodiversidad del Ecosistema del Pedregal de San Ángel. Universidad Nacional Autónoma de México, Coordinación de la Investigación Científica, México. pp. 538.

Mittermeier, R. & Goettsch, C. (1992) La importancia de la diversidad biológica de México. *In*: Sarukhán, J. & R. Dirzo (comps.). México ante los retos de la biodiversidad. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. México (CONABIO). México.

Romo-Beltrán, A., Macías-Ordóñez, R., & Córdoba-Aguilar, A. (2009). Male dimorphism, territoriality and mating success in the tropical damselfly, Paraphlebia zoe Selys (Odonata: Megapodagrionidae). *Evolutionary ecology*, **23**(5), 699-709.

Schorr, M. & Paulson, D.M. (2015). World Odonata list. http://www.pugetsound.edu/academics/academic-resources/slater-museum/biodiversity-resources/dragonflies/world-odonata-list2/. Accessed on 15 May, 2015.

Smithsonian Museum (2015) http://www.si.edu/. Accessed on 14 April, 2015.

Sutherland, W. J., Aveling, R., Brooks, T. M., Clout, M., Dicks, L. V., Fellman, L., ... & Monk, K. A. (2014). A horizon scan of global conservation issues for 2014. *Trends in ecology & evolution*, **29**(1), 15-22.

CAPÍTULO III

Odonata species richness, land use, tree cover and human footprint in Mexico

Odonata species richness, land use, tree cover and human footprint in Mexico

Karina Cuevas-Yañez, Mariana Benítez and Alex Córdoba-Aguilar*

[1]Departamento de Ecología Evolutiva, Instituto de Ecología, Universidad Nacional Autónoma de México, Apdo. P. 70-275, Ciudad Universitaria, 04510, México D.F., México

*Corresponding author: acordoba@iecologia.unam.mx

ABSTRACT

Odonata species richness and geographic records was evaluated in 13 land uses entities in Mexico. Also, we evaluated the relationship between species richness and tree cover percentage and human footprint percentage. Our result showed both Odonata species and geographical records are more abundant in forest and agricultural areas, and decreased in areas without vegetation. There was a slight positive relationship between species richness and tree cover; and a slight quadratic relationship with human footprint was observed. Our results suggest forest is a primary source of Odonata species and agricultural areas are also an important reservoir of Odonata diversity. Odonata richness is greater in sites with more tree cover, which is related with our find that forests possess the more species richness. Odonata species richness is greater in areas with middle human footprint index, possibly by the accessibility to dragonfly habitat or sites with intermediate human perturbation are more heterogeneous and propitiate the establishment of more species.

Key words: Dragonfly, land use, human footprint, species richness, Mexico, forest.

INTRODUCTION

Biodiversity faces enormous pressures mainly by human actions including habitat degradation, land use change, pollution, habitat fragmentation, climate change or human resource exploitation (Newbold et al. 2015). Such increased pressures have been observed in the tropics, although their effects are not so well documented nor understood (Bateman et al. 2015; Specht et al. 2015). Three factors are relevant in land use areas: agricultural zones, deforestation (forest prevalence, tree cover) and human alteration (human footprint) (Meyer y Turner 1992). For example, the human footprint is heterogeneous, and has depended on geographical physiography, historic human settlements, technology use, and demographic explosion (González-Abraham et al. 2015).

Land use areas have been modified intensively c.a. 1500 years, thereby species richness has declines to a large extent (Newbold et al. 2015). For the case of Mexico, has experienced large land use changes (Mas et al. 2002; Robson and Barkes 2011; Gonzalez-Abraham et al. 2015). On top of this, forest loss due to its conversion into agricultural areas has dramatically increased in the last 20 years (Hansen et al. 2013). *Per capita* forest area has decreased by almost a third by 2000 based on the interpretation of photographs or satellite images, and changes in land use have been documented since 1980 (Mas et al. 2002; Velazquez et al. 2002).

It is known that, in general, changes in forest cover negatively affect ecosystem services (Ferraro et al. 2011; Alix-García et al. 2012), including species richness (Hansen et al. 2013). Recently some studies have shown species insects are more abundant in tropical zones as long as these zones are not disturbed (urban areas, agricultural areas and pastoral areas) (Ballesteros-Mejía et al. 2013; Becerra 2015). Furthermore, species richness in agricultural areas decreases with the prevalence of cultivated species, more intensive management and short cultivated cycles (Scalens and Mardens 2008). Both deforestation and human land use have negative effects in biodiversity in many taxa (Brown 1997; Schuzle et al. 2004; Barragán et al. 2011; Vidal et al. 2013).

Odonate (dragonflies, damselflies) species richness is greater in lotic waters on preserved tropical forest areas (Clausnitzer et al. 2009) and to a less extent in forest areas in agricultural areas (Sahlén 1999). Indeed, cultivated areas have effects on richness and species composition, and in urban or areas with some degree of human alteration. It has been seen that in places where roads are built and plant cover is removed, whereby water bodies are close to an urban area, odonate species richness decreases. For example, on the Pacific Coast of Costa Rica, Hofnansl and Schneaweihs et al (2015) found that buffer zones of forest and cultivated areas contribute similarly in species richness which is not the case for species composition. It has also been seen that habitat changes affect populations of dragonflies very quickly and dramatically (Harabis and Dolny 2011). Related to this, Junior et al. (2015) observed that urbanization causes changes in the species composition of dragonflies and richness: the suborder Anisoptera was more abundant at sites with more human disturbance than Zygoptera.

The odonate assemblages may vary, depending on habitat quality physical structure (Junior et al. 2015). However, describing the factors than contribute to the variation in a quantitative form is not an easy task. Several studies have been proposed to assess such factors, for example, channel width, quality or quantity of vegetation surrounding the water bodies, physical and chemical water components, pollution presence, or distance to cattle areas or agricultural (Findlay and Houlohan 1997; Honkanen et al. 2010; de Marco et al, 2015; Koparde et al. 2015). Nevertheless, there exists an information shortage in the influence of such factors and their interaction with land use and human influence on odonate biodiversity in Mexico.

In this study we analyzed the species and their incidence of geographical records according to land uses reported in Mexico from 2000 to 2014 years. We explored, at a broad scale, the relationship between tree cover and human footprint on dragonfly richness and the completeness of inventories, as measures of species richness.

MATERIALS AND METHODS

Odonate species and land use

We searched for dragonfly species records (adults or larvae) in Mexico, from 2000 to 2014 using CONABIO (Comisión Nacional para el uso y Conocimiento de la Biodiversidad, Mexican government) databases and literature such as published papers and unpublished data. Geographical records were depurated and georeferenced, if they lacked this reference (notice that one geographical species record consists of only one species, but one geographical coordinate may contain more than one species). We considered presence-absence species data as we did not take account the total species records abundance for each species in one geographical coordinate. Dragonfly species records were count (even if there were several for the same species) in al land use entities (see Table 1) as referred by the Mexican Land Use and Vegetation map, series V (Layer Union) (INEGI 2011). In each land use entity, we counted all species (species presence) and all geographic records (records presence).

Tree cover and human influence index

For this analysis, we made a grid of 15 x 15 km approximately for each pixel size. Each pixel with at least one species was considered. We counted all dragonfly species that fell inside each pixel. The total species number per pixel was considered as a measure of species richness (herein, SOBS). Also, we calculated the Chao2 Index (see Chao 1987 for more details. The index considerate the singletons and doubletons), as an inventory effort of species measure for each pixel (CHAO2). Both calculations (SOBS and CHAO2) were made with DIVA-GIS v.7.5 (Hijmans et al. 2002). To assess the relationship between odonate species richness with tree cover presence and the degree of human influence, we obtained the tree coverage layer according to Global Forest Change (available in: https://earthenginepartners.appspot.com/science-2013-global-forest) (Hansel et al. 2013). Trees (forest) were defined as vegetation taller than 5 meters, and we used the series 2000 percent tree cover (Hansen et al. 2013 for more metadata). Human influence (human footprint) was evaluated according to the layer of Global Human Footprint from Socioeconomic Data and Applications Center (SEDAC) which is the human influence index (HII). HII provides an updated view of anthropogenic environmental impact, considering human population density, human land and infrastructure, and human access (roads, railroads, navigable rivers or coastlines) (available in: http://sedac.ciesin.columbia.edu/data/set/wildareas-v2-human-footprint-geographic) (WCS, CIESIN 2005, see for more metadata). In each grid pixel, we calculated the average value of tree cover percentage (AVGTC) and the human influence index (AVGHII) with the ArcMap extension of the ArcGIS v.9.3 (ESRI 2008). The average values of AVGTC and

AVGHII were regressed between the SOBS and CHAO2 respectively. We run several analysis for search the best curve fit in the model regression (linear or quadratic). Analyses were made in Minitab v.17 software (Minitab Inc. 2013).

Table 1. Land use entities taken from land use and vegetation map (Series V, INEGI 2011) and number of Odonata species found between 2000 and 2014.

Land use or vegetation Entity	Description	Odonata species richness	Odonata species records
AGRICULTURAL	Rainfed and irrigation agriculture	196	1282
AGRICULTURAL-GRASSLAND	Rainfed agriculture predominance, cultivated or induced grass in less proportion	61	95
AGRICULTURAL-RAINFOREST	Rainfed agriculture, secondary vegetation of low, medium or high tropical forest	96	181
AREA WITHOUT VEGETATION	Without apparent vegetation cover	1	1
URBAN AREA	Cities, towns or urban sprawls	129	315
FOREST/RAINFOREST	Pine, oak-pine, oyamel, or cloud forest/low, medium or high tropical forest	288	1326
WATERBODY	Maritime, or internal perennial water body	31	42
SCRUB	Microphyte desert, rosetophilous, crassicaule, subtropical, thorn scrub,	93	247
OTHER VEGETATION	Mangrove, mesquite, halophytic vegetation	42	52
GRASSLAND	Cultivated or induced (or natural) grass	106	256
GRASSLAND-AGRICULTURAL	Cultivated or induced grass, rainfed agriculture	30	33
GRASSLAND-RAINFOREST	Cultivated or induced grass, secondary vegetation of low, medium or high tropical forest	25	29
RAINFOREST-AGRICULTURAL	Secondary vegetation of low, medium or high tropical forest, rainfed agriculture	56	58
RAINFOREST-GRASSLAND	Secondary vegetation of low, medium or high tropical forest, induced or cultivated grass	75	154

RESULTS

We found 4071 records from 275 odonate species. Species richness and records were mainly in forest/rainforest and agricultural areas and those species records represented more than 60 percent of the total (approximately 30 percent of the species records in forest/rainforest and the same in agricultural areas). Forest in general encompasses 23.4% of the total richness, followed by agriculture areas with 15.9% of the whole species total, and urban areas (10.5%). Our results suggest dragonflies' species and records are scarce in areas without vegetation and with grassland-rainforest land uses (Table 1, Fig 1). Dragonflies collected in urban areas represent the 7.7% of the records and 10.5% of species richness, which suggests that the urban areas occupy the third place in richness. Desert areas (scrub areas) contributed with 7.6% of the species richness (6.1% of the records). We found a significant correlation between odonate records and species richness per land use (Pearson correlation coefficient=0.987, $p<0.01$). The highest SOBS and CHAO2 values were found mostly in pixels located in Michoacán, Nayarit, San Luis Potosí and Veracruz states, while the lowest values were found in Sonora, Chihuahua, Coahuila and Zacatecas states with only one species per pixel (Fig. 3).

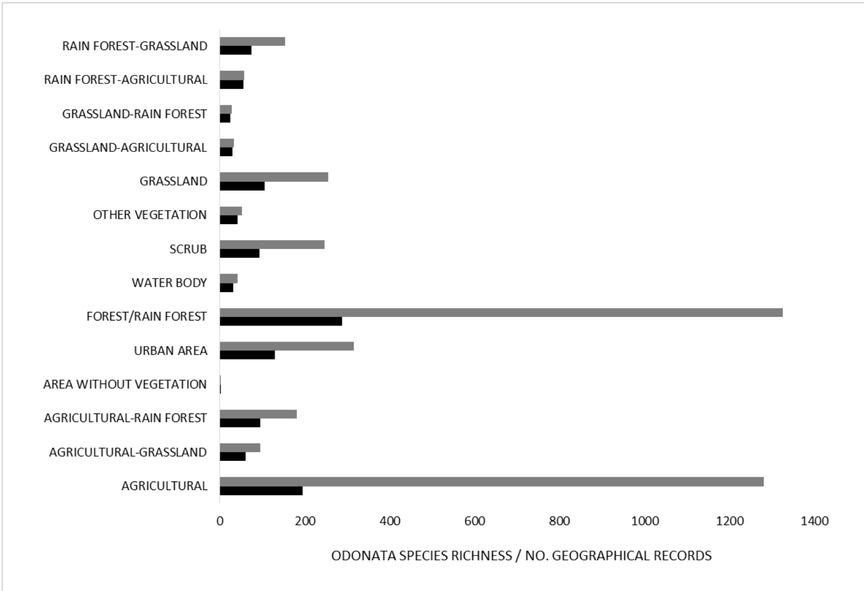


Fig. 1. Odonata species richness by land use and vegetation (black bars) and geographical records (gray bars) in the Mexican territory.

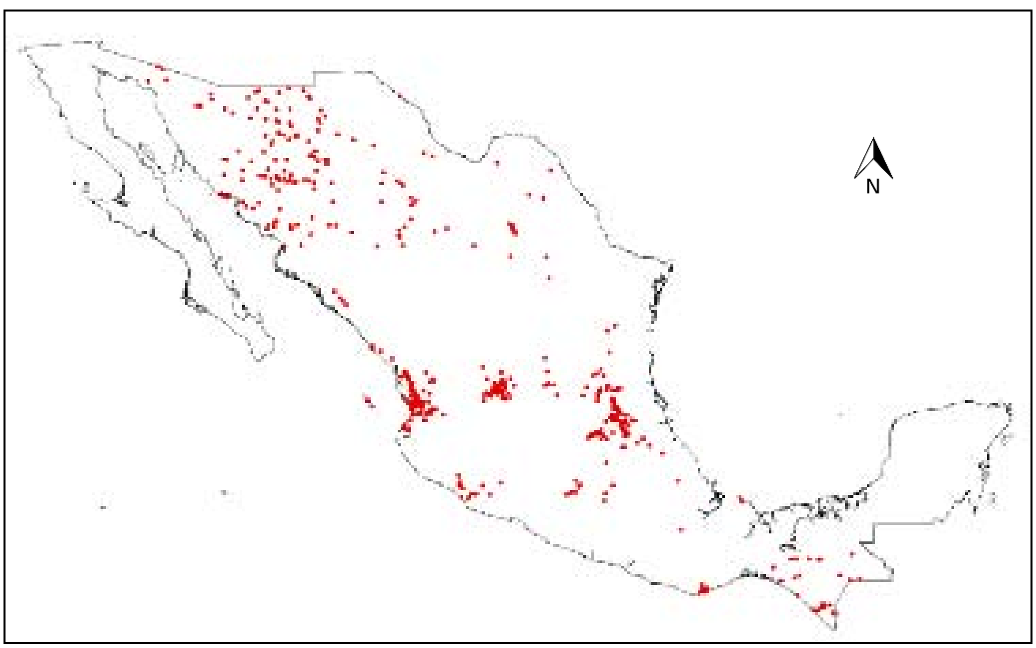


Fig. 2. Dragonfly species records for the Mexican territory. Collection range spanned from 2000 to 2014.

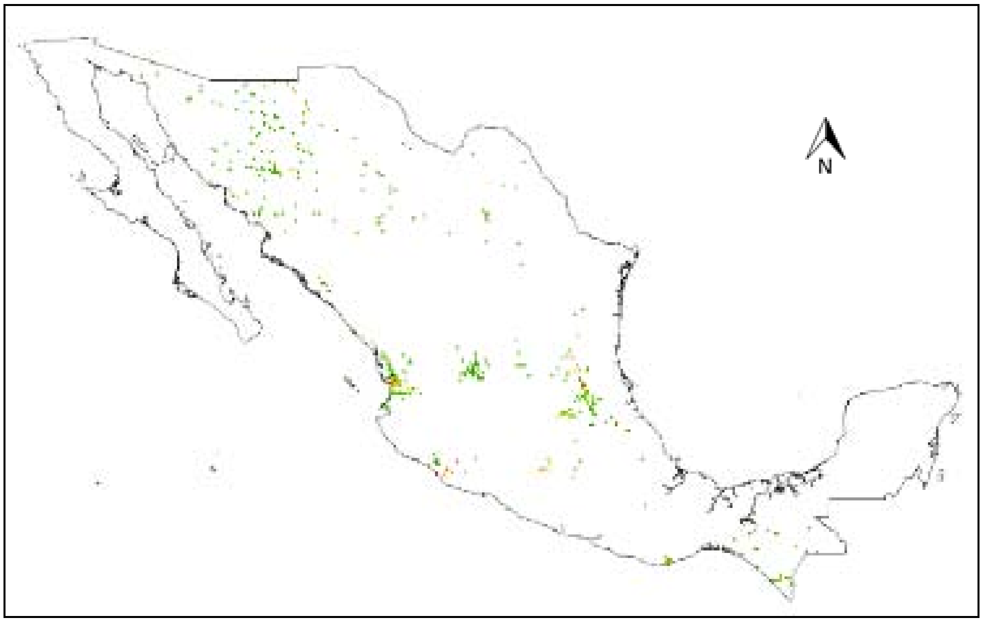


Fig. 3. Observed dragonfly species (SOBS) in a 15 x 15 km (approximately) pixel size in the Mexican territory. Green pixels indicate from 1 to 23 species, yellow pixels indicate 21-26 species, orange pixels indicate 27-40 species, and red pixels indicate 40-65 species.

We found a poor positive linear relation between SOBS and AVGTC (n=406, linear R^2=0.05, p<0.005). CHAO2 showed a similar tendency (n=406, R^2=0.0139, p=0.017). (Fig 4 a and b). The regression model with the best fit was quadratic for both SOBS and CHAO2 versus AVGHII (n=406, quadratic R^2=0.0437, p=0.001, SOBS; n=406, quadratic R^2=0.0139, p<0.05) (Fig 5 a and b).

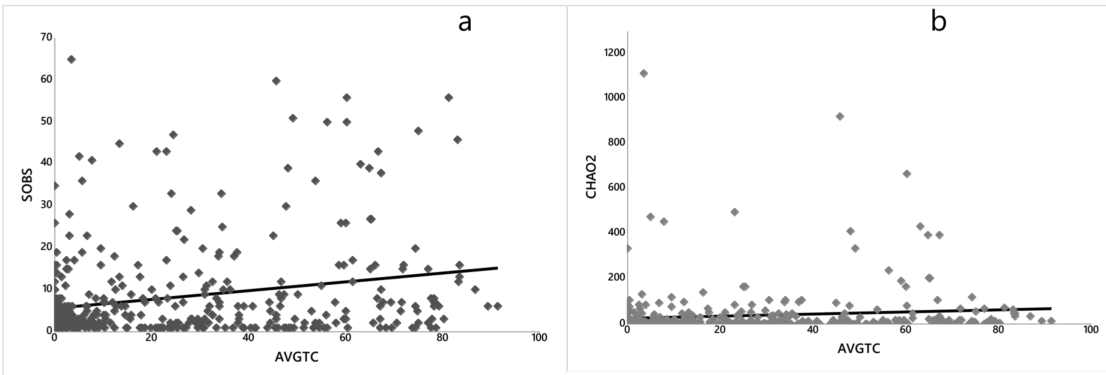


Fig. 4. Scatterplots showing the observed species (SOBS) (a), Chao 2 (CHAO2) (b) and tree cover average (AVGTC) for each pixel analyzed and their regression line.

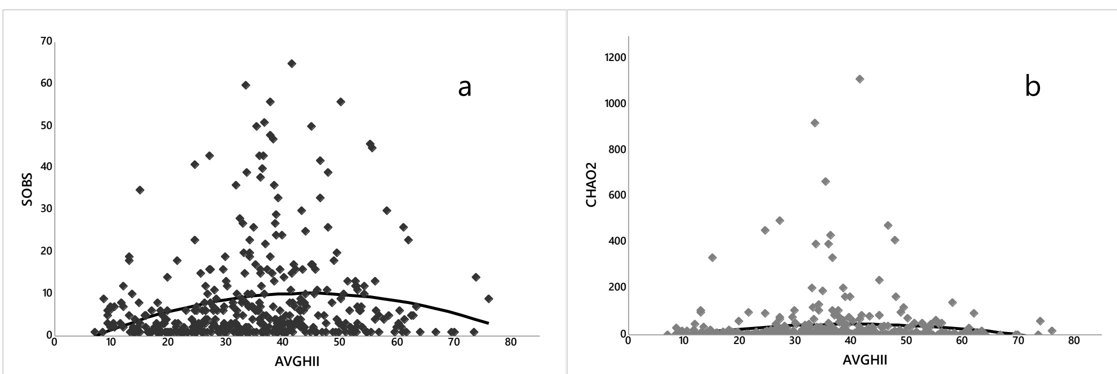


Fig. 5. Scatterplot showing the observed species (SOBS) (a), Chao 2 (CHAO2) (b) and human influence index (AVGHII) for each pixel analyzed and their regression line.

DISCUSSION

Our results suggests that odonates in Mexico can be seen in sites presumably forested or that they are more likely to occur in areas with an intermediate human footprint. Vegetation coverage, especially riparian one, is an essential landscape component for the odonate life cycle (Samways and Steytler 1996, Remsburg et al. 2009), which can be present in forest areas or agricultural water bodies. However, not completely forested areas only represents 6% of the records, likely indicating that these areas have been either less explored by researchers (see chapter one in this thesis), or that odonates do not prefer such places.

Our results also may suggest that agricultural areas are important reservoirs for Odonata species, although would be interesting to know what kind of species habit agricultural areas (endemic, restringed or wide distributed). In other countries, agricultural areas have been found to be significant for odonate abundance. For example, in low land Pacific Costa Rica, agricultural areas hold a higher species richness than forest areas albeit species' accumulation curves showed a larger species richness in forest margin habitats, and the abundance in agricultural areas was also higher (Holfhansl and Schneeweihs 2008). Despite the fact that agricultural areas have suffered anthropogenic influence, including the partial or total removal of the original vegetation coverage, these areas hold a considerably species richness. One possible hypothesis of odonate presence in cultivated areas is they may tolerate water bodies with surrounding vegetation, even when the original vegetation has been removed, or, well preserved patches are near to crops and dragonflies moves from one to another as long as riparian vegetation do not removed (Samways and Steytler 1996, Ruggiero et al. 2008). Unfortunately, our data do not allow to support totally this hypothesis. Another hypothesis is that species with a wide tolerance to disturbed environments (as some anisopterans species) can occupy cultivated places (Júnior et al. 2015). Grassland, areas (e.g. agricultural, rainforest) contained fewer records and low species richness. This is possibly due to the lack of studies in such ecosystems or that they are not as good for odonate establishment. Likewise, the faunal composition in forest and agricultural is not the same and depends on the biogeographic region, climate and disturbance conditions (Sahlen, 2006, Kalkman et al. 2008). For this reasons, odonates have been used as indicators (Kutcher et al. 2014).

Odonates in Mexico live mainly in lotic (running) freshwater bodies (Upson et al. 2007, Behrstock et al. 2007, Novelo-Gutiérrez and Gómez-Anaya 2009), (is important to mention that water bodies are presents in all land use entities, although one of them has title waterbodies) in forest areas or in agricultural areas, and their conservation status is little known (Cuevas-Yáñez et al. 2015), therefore the investigations have been conducted mainly in lotic waters. More studies are necessary to conclude the Mexican odonates species richness tendency, and the factors that act at broader scales. For example, González-Soriano and Novelo-Gutiérrez (2014) mentioned that Michoacán, Nayarit, Sonora and San Luis Potosi states recorded at least 100 odonate species, and particularly the Huasteca region in San Luis Potosi is considered a hot spot for these insects (González-Soriano et al., 2011), and in this study, our results provide partial support to this idea.

A slight positive relationship between forest cover and dragonfly species richness (SOBS) and inventory completeness (CHAO2), was observed. The results suggests there are other factors that may affect the species observed and distributions in Mexican odonates, even though we regard the variables used are also important if the odonate inventory was more complete. Climate is a main factor that affect species distributions in odonates and many organisms (Collins et al. 2015), which was not assessed in this study. In addition, little information exists about tree cover and dragonfly richness in tropical areas. Clausnitzer et al (2009) highlighted that the highest odonate richness are in running waters in tropical forests. Particularly, the neotropical forest region has highly complex habitats that result from a combination of humidity, solar radiation, vegetation composition, predator and prey presence and wind currents. Also, forest complexity provides shelter at night, or places to safely secure against adverse weather conditions (e.g. rain or strong wind) or predation for odonates. If farm sites are near forest, the latter can function as a refuge or buffer that allows establishment of odonate species (Paulson 2006). Although it is true that the tree shadows areas have negative effects on the presence of odonates (Remsburg et al. 2009), forest cover still plays an important role in almost every part of the life cycle of the average odonate.

In Japan more than the half of Odonate species depends on the forest which has a positive effect on the preservation of most species, although a broad-scale climate explains species distribution (Tsubaki and Tsuji 2006). To this extent, this study contributes to knowledge on a broad scale to where the highest species richness is present. Nevertheless, the knowledge about the conservation status of odonate populations in

Mexico is scarce, and actually there are no species conservation assessments (for an exception see Cuevas-Yañez et al. 2015) nor trustable lists of species in danger for which such assessments can be directed.

Our analysis showed a poor quadratic relationship between human influence and SOBS and CHAO2 variables. It may be interesting to explore the effects of variables separately, for example, the closeness to cities, roads, or population density to determine if these variables have a real effect in odonata richness. However, nonlinear regressions (in our case, where most observations fit a normal distribution) are less frequently observed in other taxa except dragonflies (Hernández et al. 2006). Both human activities and their influence on odonate populations have been documented in lentic (standing) waters in template zones (Findlay and Houlohan 1997; Hamasaki et al. 2009; Raebel et al 2012 a and b; Hall et al, 2015), but only a few in tropical zones and lotic systems.

Anthropogenic disturbance as, for example, road construction, may have significant effects on wetlands biodiversity (Findlay and Houlohan 1997). In this analysis, the highest richness was found in sites with an intermediate human footprint. This tendency has been also observed in odonates of the Amazon basin (Júnior et al. 2015). Stewart and Samways (1998) also noticed that high dragonfly species richness fits occurs in streams with moderate disturbance, although the species that live in such places are not endangered or threatened. This may be explained by a high metapopulation succession dynamics in sites altered by anthropogenic factors or that such high dynamics are weighted by less complex adaptations in habitat selection or may function as last refuges for species survival (Harabis and Dolni 2011). Another explanation more probable is that collections and samplings may be based by the collectors' preferences for places close to urban areas (e.g. aquatic places close to roads) to avoid the challenge implied by areas of difficult access.

We also had to consider that other factors may influence the distribution of odonate in the country. One factor crucial for odonates is the climate, as mentioned above, specially the temperature and precipitation (Collins et al., 2015). This factor, the climate, may be the first force in affect the distributions of dragonflies (Collins et al., 2015) at the scales used in this studio, and possibly, the tree cover or human footprint are not so leading the relationship with the richness; however, we observed that they have and interesting role in species richness.

It is important to consider some possible biases in this odonate assessment. First, the time span considered the investigation only encompasses records from 2000 to 2014 so that we had to exclude older records so that land use data had a better contribution to a more realistic relationship between species and land use. Therefore, there exists lacks in recent information for many areas where occurring species that are not so well known, for example Veracruz, Oaxaca or Chiapas (González-Soriano and Novelo-Gutiérrez 1996). Most of records are before 1990 (Cuevas-Yañez, personal observation). Location of odonate surveys may be restricted by a number of factors including economical, logistic or even personal biases. However these factors, we consider our results are very significant and may reflect the current tendency related of Mexican odonates.

ACKNOWLEDGEMENTS

We thank R. Behrstock, S. Upson, and D. Danforth who kindly provided part of literature used in this research. The first author acknowledges the graduate grant provided by Consejo Nacional de Ciencia y Tecnología (226198/210553) and the support by the Posgrado en Ciencias Biológias (Universidad Nacional Autónoma de Mexico, UNAM). Thanks also to J.C. Espinosa for the logistic support in the database polishing as well as to M. Rivas for GIS suggestions.

REFERENCES

Alix-Garcia, J. M., Shapiro, E. N., & Sims, K. R. (2012). Forest conservation and slippage: Evidence from Mexico's national payments for ecosystem services program. *Land Economics*, *88*(4), 613-638.

Ballesteros-Mejia, L., Kitching, I. J., Jetz, W., Nagel, P., & Beck, J. 2013. Mapping the biodiversity of tropical insects: species richness and inventory completeness of African sphingid moths. *Global Ecology and Biogeography*, *22*(5), 586-595.

Bateman, I. J., Coombes, E., Fitzherbert, E., Binner, A., Bad'ura, T., Carbone, C., ... & Watkinson, A. R. 2015. Conserving tropical biodiversity via market forces and spatial targeting. *Proceedings of the National Academy of Sciences*, *112*(24), 7408-7413.

Becerra, J. X. 2015. On the factors that promote the diversity of herbivorous insects and plants in tropical forests. *Proceedings of the National Academy of Sciences*, *112*(19), 6098-6103.

Behrstock, R. A., Danforth, D., & Upson, S. 2007. A list of the Odonata of Chihuahua state, Mexico, including new state records and the first Mexican record of *Argia alberta*, Kennedy, 1918. *Bulletin of American Odonatology*, *10*(2-3), 52-63.

Chao, A. 1987. Estimating the population size for capture-recapture data with unequal catchability. *Biometrics*, 783-791.

Clausnitzer, V., Kalkman, V. J., Ram, M., Collen, B., Baillie, J. E., Bedjanič, M., ... & Wilson, K. 2009. Odonata enter the biodiversity crisis debate: the first global assessment of an insect group. *Biological Conservation*, *142*(8), 1864-1869.

Collins, S. D., & McIntyre, N. E. (2015). Modeling the distribution of odonates: a review. *Freshwater Science*, *34*(3), 1144-1158.

Cuevas-Yáñez, K., Rivas, M., Muñoz, J., & Córdoba-Aguilar, A. 2015. Conservation status assessment of Paraphlebia damselflies in Mexico. *Insect Conservation and Diversity*. DOI: 10.1111/icad.12132.

Escobar, F., Koleff, P., & Rös, M. (2009). Evaluación de capacidades para el conocimiento: El Sistema Nacional de Información sobre Biodiversidad (SNIB) como un estudio de caso. *Conabio–PNUD. México: capacidades para la conservación y el uso sustentable de la biodiversidad. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad y Programa de las Naciones Unidas para el Desarrollo, México*, 23-49.

ESRI 2008. ArcGIS released 9.3 Software, CA. ESRI. (www.esri.com).

Ferraro, P. J., Lawlor, K., Mullan, K. L., & Pattanayak, S. K. (2011). Forest figures: ecosystem services valuation and policy evaluation in developing countries. *Review of Environmental Economics and Policy*, rer019.

Findlay, C. S., & Houlahan, J. 1997. Anthropogenic correlates of species richness in southeastern Ontario wetlands. *Conservation Biology*, 1000-1009.

González-Abraham, C., Ezcurra, E., Garcillán, P. P., Ortega-Rubio, A., Kolb, M., & Bezaury, C. J. (2015). The Human Footprint in Mexico: Physical Geography and Historical Legacies. *PloS one*, *10*(3), e0121203.

González, E., F. Noguera, & L. Oñate. 2011. A biodiversity hotspot for odonates in Mexico: The Huasteca Potosina, San Luis Potosí. *Odonatologica*, 40(3), 179–190.

González-Soriano, E., & Novelo-Gutiérrez, R. 1996. Odonata. *Biodiversidad, taxonomía y biogeografía de artrópodos de México: hacia una síntesis de su conocimiento, J. Llorente-Bousquets, AN García-Aldrete y E. González-Soriano (eds.). UNAM, México, DF*, 147-167.

González-Soriano, E., & Novelo-Gutiérrez, R. 2014. Biodiversidad de Odonata en México. *Revista Mexicana de Biodiversidad*, *85*, 243-251.

Hall, A. M., McCauley, S. J., & Fortin, M. J. 2015. Recreational boating, landscape configuration, and local habitat structure as drivers of odonate community composition in an island setting. *Insect Conservation and Diversity*, *8*(1), 31-42.

Hamasaki, K., Yamanaka, T., Tanaka, K., Nakatani, Y., Iwasaki, N., & Sprague, D. S. 2009. Relative importance of within-habitat environment, land use and spatial autocorrelations for determining odonate assemblages in rural reservoir ponds in Japan. *Ecological Research*, *24*(3), 597-605.

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., ... & Townshend, J. R. G. 2013. High-resolution global maps of 21st-century forest cover change. *Science*, *342*(6160), 850-853.

Harabis, F., & Dolny, A. 2011. The effect of ecological determinants on the dispersal abilities of central European dragonflies (Odonata). *Odonatologica*, *40*(1), 17-26.

Hernandez, K. M., Reece, B. A., & McIntyre, N. E. 2006. Effects of anthropogenic land use on Odonata in playas of the Southern High Plains. *Western North American Naturalist*, *66*(3), 273-278.

Hijmans, R. J., Guarino, L., Cruz, M., & Rojas, E. 2001. Computer tools for spatial analysis of plant genetic resources data: 1. DIVA-GIS. *Plant Genetic Resources Newsletter*, 15-19.

Hofhansl, F. P., & Schneeweihs, S. 2008. Banderillas: Effects of deforestation on dragonflies (Insecta, Odonata) in the Pacific lowland of Costa Rica. *Zugleich Kataloge der oberosterreichischen Landesmuseen Neue Serie, 80*, 237-247.

INEGI, 2011. Carta de uso de suelo y vegetación. Capa Unión Serie V.

Junior, J. M. B., Shimano, Y., Gardner, T. A., Hughes, R. M., Marco Júnior, P., & Juen, L. 2015. Neotropical dragonflies (Insecta: Odonata) as indicators of ecological condition of small streams in the eastern Amazon. *Austral Ecology*. DOI: 10.1111/aec.12242.

Kalkman, V. J., Clausnitzer, V., Dijkstra, K. D. B., Orr, A. G., Paulson, D. R., & van Tol, J. 2008. Global diversity of dragonflies (Odonata) in freshwater. *Hydrobiologia*, *595*(1), 351-363.

Kutcher, T. E., & Bried, J. T. (2014). Adult Odonata conservatism as an indicator of freshwater wetland condition. *Ecological Indicators*, *38*, 31-39.

Mas, J. F., Velázquez, A., Díaz-Gallegos, J. R., Mayorga-Saucedo, R., Alcántara, C., Bocco, G., ... & Pérez-Vega, A. 2004. Assessing land use/cover changes: a nationwide multidate spatial database for Mexico. *International Journal of Applied Earth Observation and Geoinformation*, *5*(4), 249-261.

Minitab 17. Statistical Software 2010. State College, PA.: Minitab, Inc. (www.minitab.com)

Novelo-Gutiérrez, R., & Gómez-Anaya, J. A. 2009. A comparative study of Odonata (Insecta) assemblages along an altitudinal gradient in the Sierra de Coalcomán Mountains, Michoacán, Mexico. *Biodiversity and Conservation*, *18*(3), 679-698.

Paulson, D. 2006. The importance of forests to neotropical dragonflies. *Forests and dragonflies (ed. A. Rivera)*, 79-101.

Raebel, E. M., Merckx, T., Feber, R. E., Riordan, P., Macdonald, D. W., & Thompson, D. J. 2012. Identifying high-quality pond habitats for Odonata in lowland England: implications for agri-environment schemes. *Insect Conservation and Diversity*, *5*(6), 422-432.

Raebel, E. M., Merckx, T., Feber, R. E., Riordan, P., Macdonald, D. W., & Thompson, D. J. 2012 a. Identifying high-quality pond habitats for Odonata in lowland England:

implications for agri-environment schemes. *Insect Conservation and Diversity*, *5*(6), 422-432.

Raebel, E. M., Merckx, T., Feber, R. E., Riordan, P., Thompson, D. J., & Macdonald, D. W. 2012 b. Multi-scale effects of farmland management on dragonfly and damselfly assemblages of farmland ponds. *Agriculture, ecosystems & environment*, *161*, 80-87.

Remsburg, A. J., & Turner, M. G. 2009. Aquatic and terrestrial drivers of dragonfly (Odonata) assemblages within and among north-temperate lakes. *Journal of the North American Benthological Society*, *28*(1), 44-56.

Robson, J. P., & Berkes, F. 2011. Exploring some of the myths of land use change: Can rural to urban migration drive declines in biodiversity? *Global environmental change*, *21*(3), 844-854.

Ruggiero, A., Céréghino, R., Figuerola, J., Marty, P., & Angélibert, S. 2008. Farm ponds make a contribution to the biodiversity of aquatic insects in a French agricultural landscape. *Comptes Rendus Biologies*, *331*(4), 298-308.

Sahlén, G. 2006. Specialists vs. generalists in the Odonata–the importance of forest environments in the formation of diverse species pools. *In*: Cordero A. Ed. *Forests and Dragonflies*, 153-179.

Samways, M. J., & Steytler, N. S. 1996. Dragonfly (Odonata) distribution patterns in urban and forest landscapes, and recommendations for riparian management. *Biological Conservation*, *78*(3), 279-288.

Schulze, C. H., Waltert, M., Kessler, P. J., Pitopang, R., Veddeler, D., Mühlenberg, M., ... & Tscharntke, T. 2004. Biodiversity indicator groups of tropical land-use systems: comparing plants, birds, and insects. *Ecological Applications*, *14*(5), 1321-1333.

Specht, M. J., Pinto, S. R. R., Albuqueque, U. P., Tabarelli, M., & Melo, F. P. 2015. Burning biodiversity: Fuelwood harvesting causes forest degradation in human-dominated tropical landscapes. *Global Ecology and Conservation*, *3*, 200-209.

Stewart, D. A., & Samways, M. J. 1998. Conserving dragonfly (Odonata) assemblages relative to river dynamics in an African savanna game reserve. *Conservation Biology*, *12*(3), 683-692.

Tsubaki, Y., & Tsuji, N. 2006. Dragonfly distributional predictive models in Japan: relevance of land cover and climatic variables. In: *Forests and Dragonflies: Fourth WDA International Symposium of Odonatology, Pontevedra (Spain), July 2005* (No. 61, p. 181). Pensoft Publishers.

Upson, S., Danforth, D., González-Soriano, E., Behrstock, R. A., & Bailowitz, R. 2007. A preliminary checklist of the Odonata of Sonora, Mexico. *Bulletin of American Odonatology*, *10*(2-3), 23-51.

Velázquez, A., Mas, J. F., Gallegos, J. R. D., Mayorga-Saucedo, R., Alcántara, P. C., Castro, R., ... & Palacio, J. L. 2002. Patrones y tasas de cambio de uso del suelo en México. *Gaceta Ecológica*, (62), 21-37.

Vidal, O., López-García, J., & Rendón-Salinas, E. 2014. Trends in deforestation and forest degradation after a decade of monitoring in the Monarch Butterfly Biosphere Reserve in Mexico. *Conservation Biology*, *28*(1), 177-186.

Wildlife Conservation Society - WCS, and Center for International Earth Science Information Network - CIESIN - Columbia University. 2005. Last of the Wild Project, Version 2, 2005 (LWP-2): Global Human Footprint Dataset (Geographic). Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://dx.doi.org/10.7927/H4M61H5F. Accessed 03 march 2015

DISCUSIÓN GENERAL Y CONCLUSIONES

En este estudio, los resultados mostraron datos interesantes sobre la relación entre taxónomos activos y las especies descubiertas, la riqueza de especies con el uso de suelo y la distribución geográfica del género *Paraphlebia* que está incluido en la Lista Roja de Especies de la UICN. En mi primer capítulo, muestro cómo la distribución estimada podría abarcar también áreas modificadas por acciones humanas, ya sea por transformación de la vegetación original a zonas agrícolas, de pastoreo o urbanas. Se podría sugerir para el caso de *Paraphlebia* que las zonas agrícolas cercanas a zonas forestales podrían contribuir a mantener las poblaciones, por ejemplo, aquellos cultivos que retienen parte de la vegetación original, como los cafetales de sombra, en donde efectivamente se observaron poblaciones de *Paraphlebia zoe*. Dados los resultados obtenidos, se someterá a consideración el nuevo estatus de las dos especies evaluadas (*P. zoe y P quinta*) a la Lista Roja de especies de la UICN. Además, las distribuciones proyectadas hacia el futuro muestran que *P. zoe* disminuiría considerablemente su rango de distribución, situación que podría ponerla en un riesgo mayor por lo que cambiaría su estatus en dicha lista.

En el segundo capítulo se observó que los registros de libélulas en el país muestran un patrón agregado y que el descubrimiento de nuevas especies podría estar relacionado con el número de taxónomos activos; también se detectaron diferencias en la intensidad de los registros geográficos por ecorregión. Aunque el número de especies nuevas efectivamente pudiera ser reducido, el conocimiento de especies a nivel regional podría incrementarse. Estos análisis permitieron visualizar hacia dónde deben dirigirse los esfuerzos de colecta de especies, que en este caso, se sugiere sean en zonas poco o no exploradas, para tener un panorama más completa de la fauna de odonatos de México. Esta información es de gran valor para realizar análisis biogeográficos, además, son la base para determinar patrones de distribución y permiten localizar sitios potenciales de alta riqueza para posteriormente proponerlos como áreas de conservación, considerando también las distribución de las especies endémicas (Golubou et al. 2007).

Conocer la riqueza e identidad de las especies (por ejemplo, dónde se encuentran las especies con distribución restringida o endémicas) contribuye a priorizar sitios de conservación (Fleishman et al. 2007). En este respecto, se ha mencionado que los odonatos se encuentran principalmente en cuerpos de agua lóticos en regiones boscosas tropicales

(Clausnitzer el al. 2009). Relacionado con mi tercer capítulo y como vínculo con el segundo, detecté que las áreas boscosas y agrícolas posiblemente alberguen mayor riqueza de especies y de registros geográficos de odonatos en el país. Estos sitios podrían actuar como refugios y a la vez fuente de recursos para los odonatos (Paulson 2006; Sahlén 2006); sin embargo, la alta presencia de especies en zonas agrícolas sugiere que éstos podrían ser reservorios interesantes de muchas especies de libélulas a nivel nacional, como se ha visto en otros sitios (Holfhansl and Schneeweihs 2008). Asimismo, es probable que las áreas boscosas funcionen como refugios de odonatos (Sahlén 2006).

Las actividades humanas pueden tener efectos negativos en la diversidad de especies silvestres (Newbold et al. 2015). Sin embargo, los resultados de mi trabajo muestran que existen sitios con índices de huella humana intermedia que están relacionados con mayor riqueza de odonatos (Samways y Steytler 1996; Steward y Samways 1998). Lo anterior podría deberse a que los lugares cercanos a las zonas urbanas pueden ser más accesibles a los investigadores, por lo que históricamente han sido más visitados y por ende existe mayor registro de estas especies (ver Escobar et al. 2009). Por otro lado, sitios con perturbación intermedia pueden tener una mayor diversidad de microhábitats lo que permitiría una ocupación de diferentes especies en cada uno de ellos (Stewart y Samways 1998). Si bien estas relaciones no fueron contundentes, es posible que sí tengan un efecto, aunque menor de lo esperado.

En los dos últimos capítulos se evaluaron los sitios menos colectados y cómo el uso de suelo podría impactar a los odonatos. Para el primer capítulo y con la intención de analizar algunas especies potencialmente en riesgo, hice el ejercicio de evaluar el estatus de un grupo, las del género *Paraphlebia*. Hay que subrayar que el estatus de conservación de los odonatos en México es prácticamente nulo, por lo que mi tesis en este sentido provee un primer acercamiento al tema. Ya González-Soriano y Novelo-Gutiérrez (2014) mencionaron varias especies candidatas a ser evaluadas, principalmente aquellas con distribución geográfica restringida. En el caso del género *Paraphlebia*, un grupo cuyo rango de distribución abarca la región del Golfo de México y la Sierra Madre Oriental, el área de distribución potencial que estimé mostró que dos de las tres especies que habitan en México estarían en categorías de riesgo (*P. zoe* y *P. hyalina*) y una con datos deficientes según la Lista Roja de especies de la UICN (en espera de más estudios y de búsqueda de más poblaciones). No creo que tales estatus sean excepcionales, sino más bien reflejan la situación que enfrentan muchas especies de libélulas en el país. Nuevamente se observa que las zonas boscosas son importantes sitios que albergan especies de Odonata (Clausnitzer et al. 2009)

México goza de buena reputación en términos del conocimiento taxonómico de su odonatofauna (González-Soriano y Novelo-Gutiérrez 2014). Sin embargo, es necesario incrementar los esfuerzos por conocer los odonatos de varias regiones de México. Desconocemos los patrones biogeográficos de muchos taxones de Odonata, el estado de conservación de muchas especies y de aquellas que podrían estar en riesgo de desaparecer. A este respecto, mi tesis ofrece una primera perspectiva general del estado del conocimiento nacional, y los posibles impactos de la actividad humana en la riqueza y presencia de odonatos. Ello, aunado a la evaluación del género *Paraphlebia*, muestra un panorama preocupante para los odonatos en México. Sin embargo, mis hallazgos deberán usarse como un primer esfuerzo para estudios futuros que se enfoquen en algunos de los siguientes objetivos: a) avanzar en el conocimiento regional de la riqueza y presencia de odonatos en zonas históricamente pobres en registros; b) estudios experimentales que pongan a prueba directamente cómo el cambio en el uso de suelo impactará la riqueza de odonatos; y, c) una evaluación de otras especies de odonatos para el país, sobretodo de las que se sospecha algún grado de riesgo. Estos tres objetivos no son en absoluto triviales ya que suponen un esfuerzo descomunal.

REFERENCIAS

Behrstock, R. A., Danforth, D., & Upson, S. 2007. A list of the Odonata of Chihuahua state, Mexico, including new state records and the first Mexican record of *Argia alberta*, Kennedy, 1918. *Bulletin of American Odonatology*, *10*(2-3), 52-63.

BirdLife, F. V. B. 2004. *Birds in Europe: population estimates, trends and conservation status*. Cambridge.

Böhm, M., Collen, B., Baillie, J. E., Bowles, P., Chanson, J., Cox, N., ... & Cheylan, M. 2013. The conservation status of the world's reptiles. *Biological Conservation*, *157*, 372-385.

Cardinale, B. J., Duffy, J. E., Gonzalez, A., Hooper, D. U., Perrings, C., Venail, P., ... & Naeem, S. 2012. Biodiversity loss and its impact on humanity. *Nature*, *486*(7401), 59-67.

Cardoso, P., Borges, P. A., Triantis, K. A., Ferrández, M. A., & Martín, J. L. 2012. The underrepresentation and misrepresentation of invertebrates in the IUCN Red List. *Biological Conservation*, *149*(1), 147-148.

Clausnitzer, V., Kalkman, V. J., Ram, M., Collen, B., Baillie, J. E., Bedjanič, M., ... & Wilson, K. 2009. Odonata enter the biodiversity crisis debate: the first global assessment of an insect group. *Biological Conservation*, *142*(8), 1864-1869.

Corbet, P. S. 1999. Dragonflies: behavior and ecology of Odonata. Comstock Pub. Ass. USA.

Croxall, J. P., Butchart, S. H., Lascelles, B., Stattersfield, A. J., Sullivan, B., Symes, A., & Taylor, P. H. I. L. 2012. Seabird conservation status, threats and priority actions: a global assessment. *Bird Conservation International*, *22*(01), 1-34.

de Lange, P. J., Rolfe, J. R., Champion, P. D., Courtney, S. P., Heenan, P. B., Barkla, J. W., ... & Hitchmough, R. A. 2013. Conservation status of New Zealand indigenous vascular plants, 2012. *New Zealand threat classification series*, *3*.

NOM-059-ECOL-SEMARNAT. Protección ambiental-Especies nativas de México de flora y fauna silvestres-Categorías de riesgo y especificaciones para su inclusión, exclusión o cambio-Lista de especies en riesgo.

Dolny, A., Bárta, D., Lhota, S., & Drozd, P. 2011. Dragonflies (Odonata) in the Bornean rain forest as indicators of changes in biodiversity resulting from forest modification and destruction. *Tropical Zoology*, *24*(1), 63-86.

Escobar, F., Koleff, P., & Rös, M. (2009). Evaluación de capacidades para el conocimiento: El Sistema Nacional de Información sobre Biodiversidad (SNIB) como un estudio de caso. *Conabio–PNUD. México: capacidades para la conservación y el uso* *sustentable de la biodiversidad. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad y Programa de las Naciones Unidas para el Desarrollo, México*, 23-49.

Escoto-Moreno, J. A., Novelo-Gutiérrez, R., Sigala-Rodríguez, J., Escoto-Rocha, J., Carrillo-Lara, D. E., & Reynoso-Velasco, D. 2015. First records of Odonata from Zacatecas State, Mexico. *Notulae Odonatologicae*, *8*(5), 117-155.

Fleishman, E., Noss, R. F., & Noon, B. R. 2006. Utility and limitations of species richness metrics for conservation planning. *Ecological Indicators*, *6*(3), 543-553.

Golubov, J., Mandujano, M. C., Arizaga, S., Martínez-Palacios, A., & Koleff, P. 2007. Inventarios y conservación de Agavaceae y Nolinaceae. *Colunga, P., L. Eguiartey, A. García, (eds)*, 25-52.

González-Soriano, E., & Novelo-Gutiérrez, R. 2014. Biodiversidad de Odonata en México. *Revista Mexicana de Biodiversidad*, *85*, 243-251.

González-Soriano, E., Noguera, F. A., Zaragoza-Caballero, S., Morales-Barrera, M. A., Ayala-Barajas, R., Rodríguez-Palafox, A., & Ramírez-García, E. 2008. Odonata diversity in a tropical dry forest of Mexico, 1. Sierra de Huautla, Morelos. *Odonatologica*, *37*(4), 305-315.

Hoffmann, M., Hilton-Taylor, C., Angulo, A., Böhm, M., Brooks, T. M., Butchart, S. H., ... & Collett, L. C. 2010. The impact of conservation on the status of the world's vertebrates. S*cience*, *330*(6010), 1503-1509.

Hofhansl, F. P., & Schneeweihs, S. 2008. Banderillas: Effects of deforestation on dragonflies (Insecta, Odonata) in the Pacific lowland of Costa Rica. *Zugleich Kataloge der oberosterreichischen Landesmuseen Neue Serie, 80*, 237-247.

IUCN 2015. *The IUCN Red List of Threatened Species. Version 2015.1*. <http://www.iucnredlist.org>. Downloaded on 01 August 2015.

Kalkman, V. J., Clausnitzer, V., Dijkstra, K. D. B., Orr, A. G., Paulson, D. R., & van Tol, J. 2008. Global diversity of dragonflies (Odonata) in freshwater. *Hydrobiologia*, *595*(1), 351-363.

Landa, R., Carabias, J., & Meave, J. 2014. Deterioro ambiental, una propuesta conceptual para zonas rurales de México. *Revista Economía, Sociedad y Territorio*, *1*(2).

Leschen, R. A. B., Marris, J. W. M., Emberson, R. M., Nunn, J., Hitchmough, R. A., & Stringer, I. A. N. 2012 The conservation status of New Zealand Coleoptera. *New Zealand Entomologist*, *35*(2), 91-98.

Lewis, O. T., & Senior, M. J. 2011. Assessing conservation status and trends for the world's butterflies: the Sampled Red List Index approach. *Journal of Insect Conservation*, *15*(1-2), 121-128.

Maes, J., Paracchini, M. L., Zulian, G., Dunbar, M. B., & Alkemade, R. 2012. Synergies and trade-offs between ecosystem service supply, biodiversity, and habitat conservation status in Europe. *Biological Conservation*, *155*, 1-12.

Meyer, W. B., y Turner, B. L. 1992. Human population growth and global land-use/cover change. *Annual Review of Ecology and Systematics*, 39-61.

Novelo-Gutierrez, R. (2008). Description of the larva of *Paraphlebia zoe* Selys in Hagen, 1861 (Odonata: Megapodagrionidae). *Zootaxa*, *1876*, 29-34.

Novelo-Gutiérrez, R., & Gómez-Anaya, J. A. 2009. A comparative study of Odonata (Insecta) assemblages along an altitudinal gradient in the Sierra de Coalcomán Mountains, Michoacán, Mexico. *Biodiversity and Conservation*, *18*(3), 679-698.

Paulson, D. 2006. The importance of forests to neotropical dragonflies. *Forests and dragonflies (ed. A. Rivera)*, 79-101.

Sahlén, G. 2006. Specialists vs. generalists in the Odonata, the importance of forest environments in the formation of diverse species pools. *In*: Cordero A. Ed. *Forests and Dragonflies*, 153-179.

Samways, M. J. 2005. *Insect Diversity Conservation*. Cambridge University Press.

Samways, M. J., & Steytler, N. S. 1996. Dragonfly (Odonata) distribution patterns in urban and forest landscapes, and recommendations for riparian management. *Biological Conservation*, 78(3), 279-288.

Sato, M., & Riddiford, N. 2008. A preliminary study of the Odonata of S'Albufera Natural Park, Mallorca: status, conservation priorities and bio-indicator potential. *Journal of Insect Conservation*, *12*(5), 539-548.

Stewart, D. A., & Samways, M. J. 1998. Conserving dragonfly (Odonata) assemblages relative to river dynamics in an African savanna game reserve. *Conservation Biology*, *12*(3), 683-692.

Thomas, J. A., Simcox, D. J., & Hovestadt, T. 2011. Evidence based conservation of butterflies. *Journal of Insect Conservation*, *15*(1-2), 241-258.

Upson, S., Danforth, D., González-Soriano, E., Behrstock, R. A., & Bailowitz, R. 2007. A preliminary checklist of the Odonata of Sonora, Mexico. *Bulletin of American Odonatology*, *10*(2-3), 23-51.