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Terrestrial vertebrates as surrogates for selecting conservation areas in a biodiversity hotspot in Mexico

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Systematic conservation planning (SCP) identifies priority areas for biodiversity conservation using surrogates for adequate representation of biodiversity content. The use of multiple well-known taxonomic groups rather than single ones as a surrogate set is expected to enable a better representation of most important biodiversity constituents in prioritizing conservation areas. We quantitatively analyzed if single- or multitaxa groups of terrestrial vertebrates serve best as surrogates for representing biodiversity constituents in the state of Oaxaca, a biodiversity hotspot in southern Mexico. We produced species distribution models for 1,063 terrestrial vertebrate species using a maximum entropy algorithm. To determine which fraction of each terrestrial vertebrate group best represented the remaining groups, we produced solutions requiring different proportions of species to be represented with a 10% target of the species’ potential distribution in conservation area networks. Precedence to geographical rarity, minimizing area, and enhancing compactness in shape of the selected priority areas was established using ConsNet. We further evaluated performance with surrogacy graphs for determining the representation of each group of terrestrial vertebrates treated as biodiversity constituents. Inclusion of multiple terrestrial vertebrate groups as surrogates performed best for the representation of biodiversity constituents compared to a single terrestrial vertebrate group, in all solutions with different proportions of species in these conservation areas. Terrestrial vertebrate species were poorly represented in the few protected areas (<2% of species), but representation increased significantly (99% of species) when complemented with other established conservation initiatives. SCP should include multitaxa surrogate sets and all established conservation initiatives to ensure priority areas for conservation with an adequate biodiversity representation.

KEYWORDS
biodiversity surrogates, Mesoamerica, Oaxaca, priority areas for conservation, systematic conservation planning

1 INTRODUCTION

Systematic conservation planning (SCP) aims to identify priority areas for conservation using surrogates for adequate biodiversity representation (Margules & Sarkar, 2007, 2009). These surrogates are intended to be proxies for biodiversity “constituents” (the features of biodiversity that are the ultimate goal of conservation) in conservation planning, and
need to be quantifiable to allow their estimation. Constitu-
ents of biodiversity (which used to be called “true surro-
gates” in earlier literature; Sarkar & Margules, 2002; Margules & Sarkar, 2007, 2009) are usually subsets of spe-
cies or taxa such as endangered species or endemics (Sarkar & Margules, 2002). However, available biological and distrib-
tional information for biodiversity constituents is usually lim-
ited or incomplete (Forest, 2017; Grantham, Pressey, Wells, & Beattie, 2010; Leal, Bieber, Tabarelli, & Andersen, 2010; Lentini & Wintle, 2015; Lindenmayer, Barton, & Pierson, 2015; Rodrigues & Brooks, 2007). One alternative is the inclusion of
well-known taxonomic groups as surrogates for the constitu-
ents (Lentini & Wintle, 2015; Margules & Sarkar, 2007; Sarkar et al., 2005; Wang, McShea, Li, & Wang, 2018). Several SCP
exercises have explored approaches for selecting surrogates representing biodiversity content. Sarkar et al. (2005) showed the
efficacy of environmental surrogates for a variety of biodi-
versity constituents. Tognelli (2005) used terrestrial mammals
as surrogates in South America and concluded that geographi-
crare species are effective in identifying areas for all terres-
trial mammals. Pawar et al. (2007) used amphibians and
reptiles as surrogates in the Eastern Himalayas of India. Illo-lidí-
Rangel et al. (2008) used terrestrial mammals as surrogates in
Mexico with a focus on the endangered and endemic species.
However, few studies have quantitatively analyzed if single-
or multitaxa approaches serve best as surrogates of biodiver-
sity content of a region (see Lindenmayer et al., 2015).

Recent studies have integrated the methodological
approaches of using species distribution models (SDMs) and
optimization algorithms for selecting priority areas for biodi-
versity conservation (Grantham et al., 2010; Lentini & Wint-
le, 2015; Margules & Sarkar, 2007, 2009). Briefly, SDMs use
cpyoint locality occurrences of species along with biocli-
matic and other environmental parameters to produce a spe-
cies’ potential distribution using computational algorithms
typically on a geographic information systems (GIS) plat-
form. Optimization algorithms usually involve software
designed for achieving complementarity in biodiversity rep-
resentation while selecting conservation priority areas
(Sarkar, 2012). Selection of priority areas for conservation
using complementarity typically attempt at optimization by
minimizing the area with the targeted biodiversity content
(Margules & Sarkar, 2007). SDMs and optimization algo-
rithms can be further used for exploring best surrogates in
selecting priority areas for biodiversity conservation. Priority
areas for conservation can be produced and compared using a
single- or multitaxa approach.

The state of Oaxaca is considered to be a Mesoamerican
biodiversity hotspot because of its exceptional floristic and
faunistic species richness and endemicy (García-Mendoza,
Ordoñez, & Briones-Salas, 2004; Illoldi-Rangel et al., 2008;
Koleff & Urquiza-Haas, 2011; Londoño-Murcia, Téllez-Val-
dés, & Sánchez-Cordero, 2010; Peterson, Carpenter, & Brock,
2003; Sánchez-Cordero, 2001; Sarkar, Sánchez-Cordero,
Londoño, & Fuller, 2008). Though Oaxaca contains
only 5% of Mexico’s area, it includes 35% of its amphibian
species, 26% of its reptile species, 63% of its bird species,
and 55% of its terrestrial mammal species (Briones-Salas &
Sánchez-Cordero, 2004; Flores-Villela & Geréz, 1994;
Peterson et al., 2003). Land use changes with loss and frag-
mentation of habitat and unsustainable hunting are the main
threats. As a consequence, 580 terrestrial vertebrates species
in Oaxaca are listed within a risk category in the Mexican
Red List (NOM-059-SEMARNAT-2010), the Red List of
the International Union for Conservation of Nature (IUCN),
and in the appendixes of the Convention on International
Trade in Endangered Species of Wild Fauna and Flora
(CITES) (Lavariega, Martín-Regalado, Monroy-Gamboa,
& Briones-Salas, 2017). Oaxaca contains few protected areas
which cover less than 3% of its total area which is clearly
insufficient for adequately representing its exceptional biodi-
versity (Illoidi-Rangel et al., 2008). Oaxaca also includes
several conservation initiatives and instruments proposed by
nongovernmental organizations, local communities commit-
ted to establishing protected areas while developing sustain-
able forestry programs, and international efforts to conserve
specific areas with biodiversity value. Thus, it is relevant to
determine the performance of the use of surrogates for biodi-
versity representation not only in protected areas but also
when areas are prioritized for conservation using these other
strategies (Figueroa, Sánchez-Cordero, Meave, & Trejo,
2009; García-Mendoza et al., 2004; Illoldi-Rangel et al.,
2008). Here, we quantitatively tested (a) whether using
single- or multitaxa groups as surrogates best represents bio-
diversity content in selecting priority areas for conservation
when all terrestrial vertebrate species comprise the biodiver-
sity constituents, and (b) whether protected areas com-
plemented with additional conservation initiatives improve
biodiversity representation in this Mesoamerican hotspot.

2 | METHODS

2.1 | Study area

The study area comprised the state of Oaxaca in southern
Mexico within the transition zone between the Neartic and
Neotropical biogeographic regions (18°39', 15°39'N;
93°52', 98°32'W). Oaxaca, with an area of 95,364 km², is
the fifth largest state in Mexico, has a complex topography
with several mountain ranges, holding high environmental
heterogeneity with a wide diversity of climates and vegeta-
tion. Close to 80% of the 32 main vegetation types occurring
in Mexico are represented in Oaxaca including temperate
humid montane forest, pine, pine-oak, and oak forests, tropi-
cal dry and humid forests, and xeric vegetation (García-
Mendoza et al., 2004). We declare that the data compiled
from databases, museum collections, and colleagues to con-
duct the analyses are fully acknowledge in the Supplemental
Material, Appendix S1.
2.2 Datasets

The dataset of terrestrial vertebrates for the analysis was constructed using available specimen information in national and international scientific collections, international databases such as GBIF, MaNIS (for mammals), and personal records (see Appendix S1). Terrestrial vertebrates have been extensively collected in Oaxaca; 113 species have been recorded for amphibians (Casas-Andreu, Méndez-de la Cruz, & Aguilar-Miguel, 2004), 245 species for reptiles (Casas-Andreu et al., 2004), 736 species for birds (Berlanga et al., 2017; Navarro, García-Trejo, Peterson, & Rodríguez-Contreras, 2004), and 194 species for mammals (Alfaro, García-García, & Santos-Moreno, 2007; Botello, Illoldi-Rangel, Linaje, & Sánchez-Cordero, 2007; Briones-Salas & Sánchez-Cordero, 2004; Ramírez-Pulido, González-Ruiz, Gardner, & Arroyo-Cabales, 2014). Species with less than 10 unique locality records or with incomplete georeferenced localities were excluded from the analysis following the recommendations of Phillips, Anderson, and Schapire (2006) and Phillips, Dudik, and Schapire (2006) for construction of SDMs.

2.3 Species distribution models

We produced SDMs using the software package Maxent (version 3.3.1; Phillips, Dudík, & Schapire, 2006) using the 19 environmental layers provided by WorldClim (Hijmans, Cameron, Parra, Jones, & Jarvis, 2005) and 4 topographic layers (aspect, elevation, slope, and compound topographic index) derived from the U.S. Geological Survey’s Hydro-1K layer at 1 km² resolution. SDMs were validated using the area under the receiver-operating characteristics curve (AUC). SDMs with AUC >0.75 were considered statistically significant (Morueta-Holme, Flojgaard, & Svenning, 2010; Pawar et al., 2007). Maxent also performs basic statistical analyses, which can be used to identify a threshold for binary predictions. These are only presence records, so to avoid over-prediction of the SDMs some authors have used a 10% threshold for training points and the remaining to test the training points (i.e. the 10th percentile training presence threshold) (Margules & Sarkar, 2007; Morueta-Holme et al., 2010). To capture only areas with relatively high species presence, we used an arbitrary threshold of 0.7; this value is higher than any previously suggested threshold and is, therefore, much more conservative. We further refined the potential distributions predicted by the SDMs into predicted extant species distributions by including only remnant natural habitat using the land use and vegetation map of the National Institute of Geography and Informatics (INEGI) for the year 2007 (Botello, Sarkar, & Sánchez-Cordero, 2015; Sánchez-Cordero, Cirelli, Munguía, & Sarkar, 2005; Sánchez-Cordero, Figueroa, Illoldi-Rangel, & Linaje, 2009).

2.4 Biodiversity representation in protected areas

We included federal, state, and municipal protected areas in Oaxaca (Monroy, Sánchez-Cordero, Briones-Salas, Lira-Saade, & Maass, 2015), as well as other established conservation initiatives, such as voluntarily established conservation areas protected by local communities, areas established by the National Commission of Forestry (CONAFOR), areas of payment for environmental services divided in biodiversity services and hydrological services, for our analyses (Table 1; Figure 1). We used a 10% target for the extant species distributions for the representation of all vertebrate species (biodiversity constituents) in the decreed conservation areas in Oaxaca (Illoldi-Rangel et al., 2008; Pawar et al., 2007), using a 0.01 cell grid, equivalent to approximately 1 km² in a GIS model representation. The result was a grid of 470 by 302, which resulted in 141,940 cells for Oaxaca. We then overlayed extant SDMs of terrestrial vertebrates with protected areas and conservation initiatives to determine their representation of each terrestrial vertebrate group (Table 1).

We used the ConsNet decision support tool (Ciarleglio, 2008; Ciarleglio, Barnes, & Sarkar, 2009) and, within it, optional heuristic algorithms designed to select additional conservation priority areas primarily based on complementarity. This complementary parameter is an asymmetric measure quantifying the contribution of additional selected cells to the formerly selected areas with respect to the representation of biodiversity surrogates that have not already achieved their intended target (Sarkar, 2012). However, as complementarity

| Table 1 Terrestrial vertebrate species (1,063) representation using a 10% target of species distribution models in decreed protected areas and in other proposed conservation initiatives in Oaxaca, Mexico |
|---------------------------------|----------------|----------------|----------------|----------------|----------------|
| Decreed protected areas         | Area (km²)    | Amphibians (%) | Reptiles (%)   | Birds (%)       | Mammals (%)    | Terrestrial vertebrates (%) |
| Voluntarily conservation areas  | 3927.8         | 1.18           | 3.36           | 0.33           | 1.11           | 1.76                  |
| CONAFORb                        | 2004.9         | 0.07           | 0.21           | 0              | 0              | 0.08                  |
| Biodiversityc                   | 6456.34        | 4.25           | 12.22          | 12.04          | 22.77          | 15.13                 |
| Hydrologicd                     | 20828.20       | 21.82          | 62.83          | 92.04          | 93.88          | 90.26                 |
| All conservation initiatives    | 56672.6        | 25.71          | 74.00          | 99.66          | 98.88          | 99.82                 |

a Conservation areas proposed voluntarily by local communities.
b Reforestation areas proposed from 2003 to 2007 by the Mexican National Commission of Forestry (CONAFOR).
c Specific areas of payment for conserving environmental services.
d Specific areas of payment for conserving hydrologic services.
does not explicitly differentiate geographically rare and common species, the set of algorithms implemented in ConsNet includes one that incorporates a rarity-complementarity approach (ConsNet-RF4; adjacency) for area prioritization to give preferential treatment to rare species (Sarkar, Aggarwal, Garson, Margules, & Zeidler, 2002). ConsNet was used to search for optimal solutions of maximal biodiversity representation in a minimal area (Pawar et al., 2007).

We produced solutions with different targets for the representation of surrogate species (25, 50, 75, and 100%) for each taxonomic group. This allowed a determination of which fraction of each terrestrial vertebrate group best represented the remaining groups, that is the constituents with their 10% representation target (Margules & Sarkar, 2007). We ran 400,000 iterations to minimize area and shape of the selected priority areas (ConsNet-min cells and shape ITS).
Performance of the surrogates was evaluated using surrogacy graphs, which are an extension of species accumulation graphs (Garson, Aggarwal, & Sarkar, 2002; Sarkar et al., 2005; Sarkar, Parker, Garson, Aggarwal, & Haskell, 2000). We determined the adequacy of each taxonomic group as a surrogate (Sarkar et al., 2005).

3 | RESULTS

A total of 1,308 species of terrestrial vertebrates have been reported for Oaxaca, of which 1,063 species (81%, see Appendix S1, b) had sufficient data for producing robust SDMs and these species were considered as the total set of biodiversity constituents for Oaxaca. Single-taxon representation in protected areas ranged from less than 0.5% (birds) to approximately 4% (reptiles). Protected areas also

![Surrogacy graphs of 1,063 terrestrial vertebrates in Oaxaca considering different proportion of species for each group. (a) Surrogacy graph of amphibians as surrogates and the remaining terrestrial vertebrates as constituents of biodiversity. (b) Surrogacy graph of reptiles and the remaining terrestrial vertebrates as constituents of biodiversity. (c) Surrogacy graph of birds as surrogates and the remaining terrestrial vertebrates as constituents of biodiversity. (d) Surrogacy graph of mammals as surrogates and the remaining terrestrial vertebrates as constituents of biodiversity.](image-url)
performed poorly at representing all terrestrial vertebrates, with less than 2% of species (Table 1, Figure 1). Conservation areas proposed by local communities performed worst, representing less than 1% of species; birds and mammals were not represented at all. Conservation areas established by governmental agencies as CONAFOR, increased representation of single and all terrestrial vertebrates, ranging from 12% (reptiles and birds) to 23% (mammals); all terrestrial vertebrates were represented at only 15%. Conservation areas established by governmental and international agencies for providing biodiversity and hydrological services, respectively, represented adequately single-taxa and all terrestrial vertebrates, ranging from 23% (amphibians) to 99.6% (birds); terrestrial vertebrates were represented by 90 and 99% in areas for conserving biodiversity services, and hydrological services, respectively (Table 1). When areas of all conservation initiatives were overlapped, single-taxa and all terrestrial vertebrates reached close to or full representation (Table 1; Figure 1).

Multitaxa surrogates performed best at the prioritization of conservation areas compared to single-taxon surrogates, when representing 25, 50, 75, and 100% species of all terrestrial vertebrates. Birds ranked at the top as single-taxon estimator surrogates, followed by reptiles and mammals; amphibians ranked worst (Figure 2). Interestingly, when 25% (266 species) of terrestrial vertebrates were included as surrogates, they represented 90% (904 species) of all terrestrial vertebrates, similarly when 50, 75, and 100% of the terrestrial vertebrates were included as surrogates. A similar trend was observed in birds: when 25% (147 species) of birds were included as surrogates, they represented close to 80% of all terrestrial vertebrates, similarly when 50, 75, or 100% species of birds were included as surrogates. Reptiles and mammals performed less well as surrogates when 25% (56 and 43 species, respectively) was included, representing close to 50% (476 and 545 species, respectively) of all terrestrial vertebrates. A significant increase representing all terrestrial vertebrates was observed when 50, 75, and 100% species of reptiles and mammals were included as surrogates. Amphibians performed worst as surrogates for representing terrestrial vertebrates; a slight increase in representation was observed only when 75% (128 species) and 100% species of amphibians were included as surrogates for all terrestrial vertebrates (Figure 2).

Amphibians performed best with 25 and 50%, but at 75 and 100% were the same as all the terrestrial vertebrates (Figure 3a). Reptiles performed a slightly better to birds as surrogates for all terrestrial vertebrates at all percentages, ranging from 90 to 100% species, except when 25% of the species were used, reaching approximately 80% of terrestrial vertebrates. Reptiles represented birds moderately, ranging from 70 to 85%, but represented mammals poorly, reaching only 60% of species (Figure 3b). Birds performed best as surrogates for all terrestrial vertebrates, ranging from 90 to 100%; even when 25% species of birds were included, they represented 90% species of all terrestrial vertebrates. Birds represented amphibians, reptiles, and mammals poorly when 25% species of birds were included; an increase to 80% of representation of reptiles was observed, when 50% species or more birds were included. Birds represented amphibians worst; even when all bird species were included, they only presented 20% species of amphibians (Figure 3c).

Mammals performed similarly as birds as surrogates for all terrestrial vertebrates, ranging from 90 to 100%, even when 25% species of mammals were included. Mammals represented birds moderately, ranging from 80 to 85% species of birds. A poor representation of only 15% species of amphibians and 20% of reptiles was observed when 25% species of mammals were included; an increase in representation of 20% of species of amphibians and 60% of reptiles, respectively, was observed when all mammals were included as surrogates (Figure 3d). Terrestrial vertebrates almost reached 100% of the surrogates at 25, 50, and 75% of representation of biodiversity constituents including their own group as rue surrogates (Figure 3a–d).

4 | DISCUSSION

Several studies have recommended a minimum of 10 to 15% area of a region or country for conserving biodiversity (see Sarkar et al., 2006 for a review). Mexico includes a national system of protected areas distributed nationwide that includes approximately 12% of its territory but it still lacks an adequate representation of biodiversity content (Sarukhán et al., 2009). For example, several regions identified as biodiversity hotspots are highly underrepresented and they are not included in protected areas. An important number of protected areas in Mexico appear to have been decreed ad hoc as indicated by their poor representation of the country’s biodiversity (Brandon, Goenflo, Rodrigues, & Waller, 2005; Cantú, Wright, Scott, & Strand, 2004; Sarukhán et al., 2009).

Protected areas in Oaxaca contain less than 3% of its territory with less than 2% of all terrestrial vertebrates represented in them. This clearly is insufficient for conserving the state’s exceptional biodiversity (Illoldi-Rangel et al., 2008; Table 1). Thus, it is necessary to incorporate additional areas into Oaxaca’s current conservation area network using alternative strategies and programs for increasing biodiversity representation in conservation areas. Additional proposed conservation areas in Oaxaca must consider biodiversity content rather than simply reflect governmental or political criteria, which would result only in more ad hoc protected areas (Margules & Sarkar, 2009). Only a few quantitative studies exist exploring how established conservation programs or instruments contribute to increase biodiversity representation regionally or nationally (see Sarukhán et al., 2009). The situation requires the use of SCP to ameliorate the representation shortcomings. An SCP approach is
particularlly relevant in biodiversity hotspots where biodiversity underrepresentation in protected areas is extreme, as in the case of Oaxaca (Margules & Sarkar, 2007; Illoldi-Rangel et al., 2008; Table 1).

There are a number of conservation initiatives in Oaxaca involving governmental agencies, non governmental organizations, and local communities that have established conservation areas for specific objectives related to biodiversity conservation (Table 1). For example, there are 126 conservation areas voluntarily proposed by local communities such as the “Unión de Comunidades Zapotecas-Chinantecas” located north of Oaxaca, and the “Sistema Comunitario para la Biodiversidad” in the coast that have established very successful conservation programs recognized internationally for their formulation, organization, and performance in ecosystems management. The former conservation initiative protects important habitats including a montane cloud forest with high floral and faunal endemism (Bray et al., 2003; Martin et al., 2011; Monroy et al., 2015; Ortega del Valle et al., 2010; Robson, 2007, 2009). The National Commission of Forestry (CONAFOR) established reforestation areas in Oaxaca from 2003 to 2007 that protect wide areas of vegetation cover of native trees and shrubs with its Pro-Árbol program (CONAFOR, 2010). There are also programs of payment for conserving areas for their importance to biodiversity and provision of environmental services (Bray et al., 2003; Martin et al., 2011; Robson, 2007). Lastly, hydrologic areas are inland water systems of high importance and their protection is financed via payments for conserving these hydrologic services (CONAFOR, 2010).

These conservation initiatives provide incentives to overcome the deficiency of protected areas to conserve Oaxaca’s biodiversity. As our study shows, all conservation initiatives in Oaxaca appear to overcome such deficiency when viewed as an integrated conservation strategy. However, these conservation initiatives need to be better integrated, working in close collaboration with each other. Several conservation initiatives overlap in some regions, which potentially allows a more efficient coordination to optimize conservation programs. Conversely, there are priority regions that are poorly represented within any of the conservation initiatives (Bray et al., 2003; Martin et al., 2011; Robson, 2007) (Figure 1). Our study provides a framework for identifying priority areas for conservation in Oaxaca and proposes the need to define a regional policy coordinating all conservation initiatives to ensure a better representation of biodiversity for long-term conservation programs (Table 1; Figure 1).

In our study, single-taxon surrogates showed high discrepancies in representing terrestrial vertebrates in conservation areas in Oaxaca. Single-taxon surrogates with a higher number of species such as birds performed better, increasing the representation of other terrestrial vertebrate taxonomic groups. Single-taxon surrogates with a low number of species performed worst, for instance, amphibians. Single-taxon surrogates such as mammals and reptiles with an intermediate number of species performed better than amphibians, but worse than birds. Our study clearly showed that multitaxa surrogates are best in representing terrestrial vertebrates in conservation areas (Figures 2 and 3) in agreement with other studies (Forest, 2017; Grantham et al., 2010; Leal et al., 2010; Lentini & Wintle, 2015; Lindenmayer et al., 2015; Wang et al., 2018). It is likely that when more taxa are included as surrogates, a higher diversity of habitat types is included resulting in a better representation of all biodiversity features in conservation areas (Grantham et al., 2010; Leal et al., 2010; Wang et al., 2018). This idea is supported by the fact that birds performing best as single-taxon surrogates cover a wider range of habitat types compared to other vertebrates (García-Mendoza et al., 2004), but this hypothesis needs to be tested more rigorously (Margules & Sarkar, 2007).

The interesting result was that some terrestrial vertebrate groups performed much better as surrogates in representing terrestrial vertebrate species in conservation areas compared to others (Forest, 2017; Grantham et al., 2010; Leal et al., 2010). As mentioned, bird species performed best of all terrestrial vertebrates, and amphibians performed worst. Both faunistic groups are typically included in representing biodiversity in surrogacy studies worldwide and regionally (Lindenmayer et al., 2015; Margules & Sarkar, 2007, 2009). Our results open the possibility of restricting biodiversity surrogates to selected taxa (e.g. birds) that performed well in Oaxaca for identifying conservation priority areas in other regions in Mexico. Whether birds will perform best and amphibians worst as biodiversity surrogates in other region in Mexico still needs to be tested. More studies including multitaxa surrogate performance are needed before establishing fixed protocols using single-taxon surrogates for prioritizing conservation areas elsewhere. Further, our study used a fixed 10% of target for the species included for the selection of conservation priority areas that were the constituents of biodiversity in our analysis, viz., all terrestrial vertebrate species. This conservation prioritization exercise can be further refined by varying the targets based on species’ conservation status. For example, differences in targets could vary from 100% for endemic species or those at high risk of extinction to 10% for species of least concern (Botello et al., 2015; Illoldi-Rangel et al., 2008). There is also a need to explore the relative importance of different taxonomic groups as biodiversity surrogates linked to the species’ conservation status at different spatial scales. This is particularly important in biodiversity hotspots where many species are identified in national and international Red Lists.
Botello, F., Sarkar, S., & Sánchez-Cordero, V. (2015). Impact of habitat loss on... 
Bray, D. B., Merino-Pérez, L., Negreiros-Castillo, P., Segura-Warnholtz, G., Torres-Rojo, J. M., & Vester, H. F. M. (2003). Mexico’s community-managed forests as a global model for sustainable landscapes. Conservation Biology, 17, 672–677.

Our results showed that a careful consideration of selecting specific faunistic or floristic groups as surrogates for representing biodiversity in a specific region should be conducted prior to their use for area prioritization, particularly when analyzing regions considered to be biodiversity hotspots and, therefore, meritting most attention in conservation planning (Illoidi-Rangel et al., 2008; Margules & Sarkar, 2007). In conclusion, our study showed that SCP exercises in biodiversity hotspots should include multitaxa surrogates, as well as all established conservation initiatives to identify new priority areas for conservation for adequate biodiversity representation.

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CONFLICTS OF INTEREST
The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS
All authors contributed equally to data compilation, analyses of data, and writing the paper.

REFERENCES
Alfaro, A. M., García-García, J. L., & Santos-Moreno, A. (2007). The false vampire bat Vampyrum spectrum in Oaxaca, Mexico. Bat Research News, 46, 145–146.
Berlanga, H., Gómez de Silva, H., Vargas-Canales, V. M., Rodríguez-Conteras, V., Sánchez-González, L. A., Ortega-Alvarez, R., & Calderón-Parra, R. (2017). Aves de México: Lista actualizada de especies y nombres comunes. México: CONABIO.
Botello, F., Illoidi-Rangel, P., Linaje, M., & Sánchez-Cordero, V. (2007). New record of the squirrel retriever (Spermophilus variegatus) in the state of Oaxaca, Mexico. The Southwestern Naturalist, 52, 326–328.
Botello, F., Sarkar, S., & Sánchez-Cordero, V. (2015). Impact of habitat loss on distributions of terrestrial vertebrates in a high-biodiversity region in Mexico. Biological Conservation, 184, 59–65.
Brandon, K., Goenflo, L., Rodríguez, A., & Waller, R. (2005). Reconciling conservation, people, protected areas, and agricultural suitability in México. World Development, 33, 1403–1418.
Bray, D. B., Merino-Pérez, L., Negreiros-Castillo, P., Segura-Warnholtz, G., Torres-Rojo, J. M., & Vester, H. F. M. (2003). Mexico’s community-managed forests as a global model for sustainable landscapes. Conservation Biology, 17, 672–677.
Briones-Salas, M. A., & Sánchez-Cordero, V. (2004). Mamíferos. In A. J. García-Mendoza, M. J. Ordoñez, & M. Briones-Salas (Eds.), Biodiversidad de Oaxaca (pp. 423–447). México: Instituto de Biología, Universidad Nacional Autónoma de México-Fondo Oaxaqueño para la Conservación de la Naturaleza-World Wildlife Fund.
Canseco-Márquez, L., Ramírez-González, C. G., & González-Bernal, E. (2017). Discovery of another new species of Charadrahyla (Anura, Hylidae) from the cloud forest of northern Oaxaca, México. Zootaxa, 4329(1), 64–072.
Cantú, C., Wright, R. G., Scott, J. M., & Strand, E. (2004). Assessment of current and proposed nature reserves of México based on their capacity to project geophysical features and biodiversity. Biological Conservation, 115, 411–417.
Casas-Andreu, G., Méndez-de la Cruz, F. R., & Aguilar-Miguel, X. (2004). Anfibios y reptiles. In A. J. García-Mendoza, M. J. Ordoñez, & M. Briones-Salas (Eds.), Biodiversidad de Oaxaca (pp. 375–390). México: Instituto de Biología, Universidad Nacional Autónoma de México-Fondo Oaxaqueño para la Conservación de la Naturaleza-World Wildlife Fund.
Ciarellegio, M. 2008. Modular abstract self-learning Tabu search (MASTs): Metaheuristic search theory and practice. (dissertation). University of Texas at Austin.
Ciarellegio, M., Barnes, J. W., & Sarkar, S. (2009). ConsNet: New software for the selection of conservation area networks with spatial and multi-criteria analyses. Ecography, 32, 205–209.
CONAFOR Comisión Nacional Forestal. (2010). Servicios ambientales y cambio climático. Zapopan, Jalisco, México: Coordinación General de Producción y Productividad. Comisión Nacional Forestal.
Figueroa, F., Sánchez-Cordero, V., Meave, J. A., & Trejo, I. (2009). Socioeconomic context of land use and land cover change in Mexican biosphere reserves. Environmental Conservation, 36, 180–191.
Flores-Villela, O., & Geréz, P. (1994). Biodiversidad y conservación en México: vertebrados, vegetación y uso del suelo (2nd ed.). Distrito Federal, México: Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, Universidad Nacional Autónoma de México.
Forest, F. (2017). Quest of adequate biodiversity surrogates in a time of urgency. PNAS, 28(114), 12638–12640.
García-Mendoza, A. J., Ordoñez, M. J., & Briones-Salas, M. (Eds.). (2004). Biodiversidad de Oaxaca. México: Instituto de Biología, Universidad Nacional Autónoma de México-Fondo Oaxaqueño para la Conservación de la Naturaleza-World Wildlife Fund.
Garson, J., Aggarwal, A., & Sarkar, S. (2002). Birds as surrogates of biodiversity: An analysis of a data set from southern Québec. Journal of Biosciences, 27, 347–360.
Grantham, H. S., Pressey, R. L., Wells, J. A., & Beattie, A. J. (2010). Effectiveness of biodiversity surrogates for conservation planning: Different measures of effectiveness generate a kaleidoscope of variation. PLoS One, 5(7), e11430. https://doi.org/10.1371/journal.pone.0011430
Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., & Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology, 25, 1965–1978.
Illoidi-Rangel, P., Fuller, T., Linaje, M., Pappas, C., Sánchez-Cordero, V., & Sarkar, S. (2008). Solving the maximum representation problem to prioritize areas for the conservation of terrestrial mammals at risk in Oaxaca. Diversity and Distributions, 14, 493–508.
Koleff, P., & Urozqui-Haas, T., coordinators. (2011). Planeación para la conservación de la biodiversidad terrestre en México: retos en un país megadiverso. Distrito Federal, México: Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, Comisión Nacional de Áreas Naturales Protegidas.
Lavariaga, M. C., Martín-Ragelado, N., Monroy-Gamboa, A. G., & Briones-Salas, M. (2017). Estado de conservación de los vertebrados terrestres de Oaxaca, México. Ecosistemas y recursos Agropecuarios, 4(10), 135–146.
Leal, I. R., Biber, A. G. D., Tabarelli, M., & Andersen, A. N. (2010). Biodiversidad surrogacy: Indicador taxa as predictors of total species richness in Brazilian Atlantic forest and Caatinga. Biodiversity and Conservation, 19(12), 3347–3360.
