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Niche breadth and the implications of climate change in the conservation of the genus *Astrophytum* (Cactaceae)

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The niche breadth of a species reflects its ability to inhabit different conditions, and to use different resources, hence, species with wider niche are expected to be more resilient to anthropogenic derived climate change. We estimated the niche breadth of all species of the genus *Astrophytum* from macro-environmental variables and measures of local habitat uses, in order to evaluate whether species having wider niche breadths are less prone to experience unsuitable conditions projected by the A1B and A2 scenarios of the IPCC for 2020 and 2050, and analyzed the implications of projections for the conservation of the genus *Astrophytum*. Our analysis suggests that most of populations of the four species will experience increasingly unsuitable conditions due to the increase of temperature and reduction in precipitation. The species less affected were those with wider niche breadth and situated in the middle of the latitudinal range and in the middle or lower extreme of the precipitation range for the genus (*A. capricorne* and *A. myriostigma*). Although the main threats for *Astrophytum* species come from the destruction of their habitats and activities as illegal extraction, climate change may reduce the chances for the regeneration of populations and the success of reintroduction programs.

1. Introduction

Niche breadth comprises the set of environmental conditions in which a species can exist, or the set of resources used by the species (Gaston et al., 1997), and it is primarily determined by its physiological tolerances to abiotic conditions (Baltzer et al., 2007). Species with broad climatic tolerances may be less affected by the local variation in the availability of resources and the environmental conditions, because they can persist in several types of habitats and in a wide geographical distribution (Brown, 1984; Baltzer et al., 2007). Consequently, species with broader niches might be less vulnerable to the abrupt environmental variation under anthropogenic climate change, while at the opposite end, endemic species with narrow niches and with restricted distribution ranges would be particularly threatened by climate alterations (Brown, 1984; Johnson, 1998).

Species with large distribution ranges may be more resilient to the negative effects of climate change because they are able to recolonize areas in which were extinct (Williams et al., 2006). At the same time, chances for recolonization depend on the genetic flow between populations under different selective regimes, which may counteract local adaptation (Kickpatrick & Barton, 1997), and on the presence of unspecialized biological traits in the species (e. g., seeds with high dispersal capacity, wide range of germination temperature, wide temporal range of germination, high diversity of habitats exploited, etc.) that allow them to be dispersed over long distances (Thompson et al., 1999; Lester et al., 2007), as well as safe sites to the establishment and colonization provided by facilitator plants (Bruno et al., 2003). Additionally, plants inhabiting unpredictable environments like arid and semiarid regions have

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strategies to deal with changing environmental conditions (Gutterman, 1994).

The hypothesis that species with narrow niches are more susceptible to climate change, has received support from studies modeling the distribution under different climate change scenarios, but there is not a unique tendency in the fate of these species. For example, projections of atmospheric CO_2 increase and, consequently, in temperature for 2050 in Europe, suggest that some of the species more affected will be those inhabiting in colder northern regions, small densities, and marginal species with less tolerance to the aridity, while several southern species may extend their potential range of distribution or experience small changes in the size of their ranges (Huntley et al., 1995; Thuiller et al., 2005). As another example, projections of changes in the distribution used to estimate extinction percentages for several endemic species (mammals, birds, amphibians, reptiles, invertebrates and plants), predicted that species with limited dispersal and/or with fragmented distribution are more prone to the extinction (Thomas et al., 2004; Malcolm et al., 2006). However, it has been pointed out that the ability to dispersal is of little significance in the prediction of the size distribution range of several species (Lester et al., 2007).

Under climate change, alteration of the precipitation, and principally of temperature regimes, affect the life cycle of species by modifying aspects as flowering time in plants, migration and timing of reproduction in animals, biotic interactions, and a mismatching between trophic levels (Parmesan and Yohe, 2003; Rosenzweig et al., 2008). For example, as a consequence of climate change, the abundance peak in the main food supply (a caterpillar) to the pied flycatcher (*Fycedula hipoleuca*) during its reproductive period occurs earlier, which has caused a decrease of their populations between 10 and 90% in less than twenty years (Both et al., 2006). In other examples, records of over 150 years of the flowering in forty-three plant species in North America, indicate a relationship between the increase in temperature and a progressively early flowering time (Miller-Rushing and Primack, 2008). Similar observations were also reported in a study that included data from over twenty years for plants from the Mediterranean region (Peñuelas et al., 2002). Additionally, in this last study a relationship between the increase in the annual mean temperature and the elongation of leaf persistence, the advancement of fruiting period, and delay in the date arrival of several migratory bird species were reported.

Species of the Cactaceae family are among the most threatened species by habitat alterations and illegal extraction (Anderson et al., 1994; Arias et al., 2005). Cactaceae are confined to the American continent, mostly to the arid and semiarid regions, with some species showing restricted distribution and frequently representing endemisms (Hernández and Bárcenas, 1995). Thus, anthropogenic threats and the ecological characteristics of cacti species altogether, make this group of plants particularly vulnerable, such that all members of the family are included in the Appendix II of the Convention of International Trade in Endangered Species (CITES), several in the Appendix I of CITES, and many others in the Mexican endangered species list (Norma Oficial Mexicana NOM-059-Semarnat-2010) and the Red List of the International Union for Conservation of Nature (Arias et al., 2005). In addition, climate change associated with the increase in the atmospheric CO_2 by anthropogenic activities may accelerate the loss of many cacti species by modifying the conditions suitable for their populations, and by reducing the probabilities of recruitment (Téllez-Valdés and Dávila-Aranda, 2003; Zepeda-Martínez et al., 2013).

Besides natural factors, such as the predation by insects and mammals, populations of *Astrophytum* species (Cactaceae) are highly threatened by illegal extraction and the destruction of their habitats (Hernández and Bárcenas, 1995; Martínez-Ávalos et al., 2004, 2007; Ferguson et al., 2013), and potential effects of climate change remain unknown. We estimated the niche breadth of *Astrophytum* species using the macro-environmental characteristics in the set of populations, and using measures of the use of local habitat in the area occupied by two relatively conserved populations of each species, in order to analyze whether species with widest niche breadths are less prone to experience unsuitable conditions under climate change, and to examine implications of climate change in the conservation of *Astrophytum*.

2. Material and methods

2.1. *Astrophytum* species

Astrophytum (Cactaceae) is a genus distributed primarily in the Chihuahuan desert in México, with exception of *A. asterias* whose distribution is extended to southern Texas in the United States (Bravo-Hollis and Sánchez-Mejorada, 1991; Hernández and Gómez-Hinostrosa, 2011). In this study, we included the four species of *Astrophytum* recognized in the catalog of the Mexican taxonomic authorities on cacti (Fig. 1): *A. asterias, A. capricorne, A. myriostigma* and *A. ornatum* (Guzmán et al., 2007). A fifth species named *A. caput-medusae* was not included in the study because it has only been registered in a single locality (Hernández and Gómez-Hinostrosa, 2011), and *A. coahuilense*, recognized as species by some authors (e. g., Bernhard, 1987; Montanucci, 2008) and as a variety or synonym of *A. myriostigma* by others (e. g., Bravo-Hollis and Sánchez-Mejorada, 1991; Guzmán et al., 2007; Hernández and Gómez-Hinostrosa, 2011), in our data set was included in *A. myriostigma*.

2.2. Obtaining geographic coordinates of *Astrophytum* populations from presence records

We obtained the geographic coordinates of species from the records of the National Herbarium (MEXU, Universidad Nacional Autónoma de México), the data bases of the World Biodiversity Information Network (REMIB) and the Global Biodiversity Information Facility (GBIF). Additionally, we used the records of studied

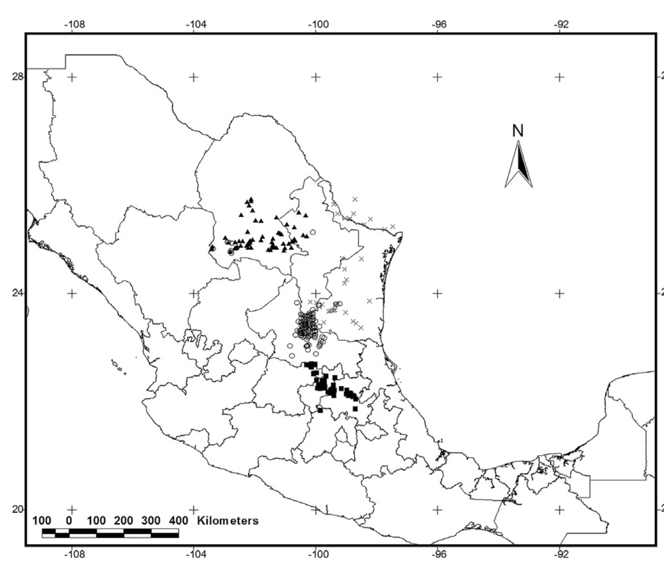

Fig. 1. Geographic distribution of *Astrophytum* species (Cactaceae). The four species included in the study are indicated with different symbols: *A. asterias* (crosses), *A. capricorne* (triangles), *A. myriostigma* (circles) and *A. ornatum* (squares).