Spring 2016

Long Live the King? A GIS Analysis of Climate Change's Impact on the Future Wintering Range and Economy of the Monarch Butterfly (Danaus plexippus) in Mexico

Megan E. Zagorski
Gettysburg College

Long Live the King? A GIS Analysis of Climate Change's Impact on the Future Wintering Range and Economy of the Monarch Butterfly (Danaus plexippus) in Mexico

Abstract

The annual migration of the monarch butterfly (Danaus plexippus) is a natural phenomenon widely integrated into the popular and social imagination of North America. However, this migratory population has recently declined. I investigated the threat of climate change on the future distribution of suitable monarch habitat, using ArcGIS to create a model of current and future monarch habitat. I also analyzed municipal data for 5 communities in Mexico State in an examination of the social aspects of the Monarch Butterfly Biosphere Reserve [MBBR]. According to my model, an estimated 38.6% to 69.8% of current monarch habitat may be lost within the MBBR by 2050, potentially affecting 14 of the 19 current colonies, while throughout the Trans-Mexican Volcanic Belt, 52% to 76% of suitable habitat could disappear. Most members of these 5 communities work in the agriculture and service sectors, and all but one reported a tourist infrastructure. The potentially large losses in suitable habitat question the effectiveness of protected areas in the face of climate change, and suggest the need to develop a more resilient strategy to protect both natural and social aspects of the monarch migration.

Keywords

Monarch butterfly, Danaus plexippus, climate change, Monarch Butterfly Biosphere Reserve

Disciplines

Animal Studies | Environmental Studies | Latin American Languages and Societies | Latin American Studies

Comments

Latin American, Caribbean and Latino Studies Senior Thesis

Long live the king? A GIS analysis of climate change's impact on the future wintering range and economy of the monarch butterfly (*Danaus plexippus*) in Mexico

Megan Zagorski

April 2016

Spanish-Latin American, Caribbean, and Latino Studies Capstone

GETTYSBURG COLLEGE

Gettysburg, PA

Advisor: Alvaro Kaempfer

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

ABSTRACT

The annual migration of the monarch butterfly (*Danaus plexippus*) is a natural phenomenon widely integrated into the popular and social imagination of North America. However, this migratory population has recently declined. I investigated the threat of climate change on the future distribution of suitable monarch habitat, using ArcGIS to create a model of current and future monarch habitat. I also analyzed municipal data for 5 communities in Mexico State in an examination of the social aspects of the Monarch Butterfly Biosphere Reserve [MBBR]. According to my model, an estimated 38.6% to 69.8% of current monarch habitat may be lost within the MBBR by 2050, potentially affecting 14 of the 19 current colonies, while throughout the Trans-Mexican Volcanic Belt, 52% to 76% of suitable habitat could disappear. Most members of these 5 communities work in the agriculture and service sectors, and all but one reported a tourist infrastructure. The potentially large losses in suitable habitat question the effectiveness of protected areas in the face of climate change, and suggest the need to develop a more resilient strategy to protect both natural and social aspects of the monarch migration.

INTRODUCTION

Monarch Biology

No insect has quite captured the popular imagination like the monarch butterfly (*Danaus plexippus*). Although conservation efforts, especially those with a broad citizen base, primarily focus on large charismatic megafauna, certain microfauna like the monarch elicit similar responses (Landis 2014). Boldly colored and embarking on an impressive annual migration, monarchs are the state insect for seven states and the focus of various citizen science projects (Diffendorfer et al. 2014; Ries and Oberhauser 2015). Unlike larger organisms, monarchs are easily raised in classrooms or homes, providing intimate contact to a wide range of individuals. The effects of this unique connection can be seen in the proliferation of concern over their decline. In the U.S., more than 30 state and federal agencies, academics, and NGOs have organized Monarch Joint Venture to improve habitat throughout the U.S. (Monarch Joint Venture [MJV] 2015). The U.S. Fish and Wildlife Service [USFWS] have also allocated an additional 2 million dollars for projects throughout the Midwest to create school gardens and enhance habitat (USFWS 2015). Internationally, Canada, the United States, and Mexico coordinate efforts through the North American Monarch Conservation Plan (Commission for Environmental Cooperation [CEC] 2008). This level of effort is rarely achieved even for vertebrates, demonstrating the monarch’s special social role.

A large part of the monarch’s allure comes from their famous annual migration to Mexico. Leaving Mexico in March, the population east of the Rocky Mountains moves north to exploit the emerging milkweed, successively extending their range into the United States and Canada over four generations (Oberhauser 2004). However, as a tropical butterfly, monarchs cannot survive the harsh temperate winters and must therefore return south as temperatures drop, prompting their magnificent southern migration (Anderson and Brower 1993; Batalden et al.

2007). What makes their migration south truly amazing is that the returning butterflies are four generations removed from the last winter migrants. While the precise methods are still unknown, some hypothesize that they navigate using magnetic fields or the sun (Perez and Taylor 2004; Solensky 2004). Traveling for 4000 km, the summer's fourth and final generation postpones reproduction to perform the second longest migration in the insect world (Alonso-Mejía et al. 2007; Solensky 2004; Vidal and Rendón-Salinas 2014). Every November, these butterflies return to the same isolated forests in the Trans-Mexican Volcanic Belt (Calvert and Brower 1986; Brower et al. 2009). For the next 5 months, the monarchs cluster on oyamel fir (*Abies religiosa)* and to a lesser extent pine trees, primarily *Pinus pseudostrobus*, to shelter throughout the winter (Brower et al. 2009; Vidal and Rendón-Salinas 2014). These cool temperatures allow them to survive until spring by slowing their metabolism and maintaining their lipid stores (Alonso-Mejía et al. 2007; Brower et al. 2009; Calvert and Brower 1986; Masters 1993; Vidal and Rendón-Salinas 2014). Although mixed pine forests are found in mountain ranges throughout Mexico, the preferred oyamel forests are locally distributed remnant populations from the last glacial ice age (Rzedowski 1978; Oberhauser and Peterson 2003). Although restricted in range, they appear to be the preferred host for the wintering monarch butterflies. However, it is still unclear whether the monarchs need the oyamels to survive the winter or the two species share a common environmental niche (Saenz-Romero et al. 2012).

Monarch winter survival is not only linked to the oyamels. During their stay in Mexico, monarchs are subject to a variety of other environmental factors. Predated by mice (*Peromyscus maniculatus*, *P. spicilegus*, *Microtus mexicanus*) (Brower et al. 1985), black-backed orioles (*Icterus abeillei*) and black-headed grosbeaks (*Pheucticus melanocephalus*), the size of the colony enhances survival, essentially creating a refuge in numbers (Arellano G. et al. 1993). In larger colonies, avian-related mortality is relatively low, but in smaller colonies it can reach 44% (Arellano G. et al. 1993). Survival is also influenced by the presence of accumulated fat reserves, with greater survivorship among individuals with larger lipid supplies (Alonso-Mejía et al. 2007; Calvert and Brower 1986; Masters 1993). Moreover, climate and weather also play an important but unpredictable role in winter survival. Monarchs need cool weather to slow their metabolisms and extend their reserves, but temperatures cannot fall too far. Partial (half) mortality for dry monarchs occurs by -8 ^{o}C and full mortality occurs by -15^{o}C (Anderson and Brower 1993; Anderson and Brower 1996). However, storms greatly decrease monarch survival by wetting the butterflies and increasing the risk of freezing. Half of wet butterflies die by -4.4^{o}C and all succumb at temperatures of -7.8^{o}C (Brower et al. 2004). Therefore, forest quality is vital to monarchs, as fragmentation decreases the forest's ability to create a suitable microclimate.

Monarch Butterfly Biosphere Reserve

In recognition of this migratory phenomenon, the Mexican government created the *Reserva Biósfera Mariposa Monarca* (Monarch Butterfly Biosphere Reserve, or MBBR) (Fig. 1) with a national decree in 1986 (Alonso-Mejía et al. 2007; Tucker 2004; Vidal et al. 2014). Initially covering 16,110 ha, of which 28% fell within 5 restricted-access core areas, the reserve was designed to protect the colonies (Missrie 2004; Snook 1993; Tucker 2004). However, the creation of the reserve did not immediately improve the monarch's plight. The core areas only protected 5 of the 20 colonies and did not account for their downslope movement as the season progresses (Missrie 2004; Tucker 2004). Additionally, the implementation of the MBBR suddenly restricted community members' access to resources since it was formed primarily from communal lands belonging to ejidos and indigenous communities (Snook 1993; Tucker 2004).

As of 2001, 55 ejidos and 13 indigenous communities owned 82% of the land in the MBBR which they were unable to utilize (Tucker 2004). Before its creation, community members harvested medicinal plants and firewood and sold lumber to supplement their income, leading to high rates of illegal logging once their activities were restricted (Honey-Rosés 2009; Rodríguez and Vizcarra 2015; Snook 1993; Tucker 2004). Afraid their already tenuous economic situation would worsen with the creation of a protected area, individuals tried to maximize the economic value of their land. The uncertainty and various changes in the management of the park served to heighten these fears, especially since there were no other economic alternatives offered to offset their loss (Honey-Rosés 2009). Not only did the logging reduce the number of trees available for monarchs, it also reduced the thermal protection provided by the canopy, increasing mortality. Therefore, the relationship between the communities, forest, and butterflies is vital to the long-term viability of the reserve.

In 2000, the MBBR was redrawn, extending protection over 56,259 ha and combining and extending the five core areas into two covering 13,551 ha (Missrie 2004; Tucker 2004; Vidal et al. 2014). Although still not perfect, the new boundaries are better aligned with the colonies and habitat. Stricter rules limit all activity within the core areas to scientific, preservation, and environmental education, while controlled logging and other activities are allowed to continue in the buffer zone (Missrie 2004, Rodríguez and Vizcarra 2015). In recent years, more inclusionary policies have led to a decline in deforestation, but have not succeeded in its complete elimination (Honey-Rosés 2013, Monterrubio et al. 2013, Vidal et al. 2014). However, in 2008 the MBBR was declared a UNESCO World Heritage site, garnering additional protection (Vidal and Rendón-Salinas 2014).

Tourism

Complementing the efforts to restrict usage, the federal government has increasingly supported the creation of “alternative tourism” centered on protected areas (Rodríguez and Vizcarra 2015). Within this category, nature-based tourism is the dominant form of tourism. Near the MBBR, tourism is focused on the communities closest to the colonies, where ecotourism has been used to replace the income they have lost from extractive activities (Rodríguez and Vizcarra 2015; Tucker 2004). However, tourism here is highly seasonal, centered on the opening of the MBBR from November to March (Brenner and Job 2006). Even still, benefits are divided within these communities. In the ejidos, benefits are only distributed to the ejidatarios (Rodríguez and Vizcarra 2015, Tucker 2004). Nevertheless, not all community members are ejidatarios, and among ejidatarios, decisions are only made by men, limiting the benefits of tourist operations for the whole community (Rodríguez and Vizcarra 2015). Only the wives of ejidatarios are allowed to sell food and art at the best locations near the reserve, and their sons rent horses, excluding the other community members (Tucker 2004).

Nevertheless, tourist initiatives have improved seasonal income, community organization, and environmental protection (Monterrubio et al. 2013). But while it has led to an increased appreciation for the ecological value of the reserve, tourism is also a threat. According to Rodríguez and Vizcarra’s (2015) estimate, over 100,000 tourists visit annually. With this many individuals visiting in 5 months, their effect is concentrated. Erosion of trails as well as damaged undergrowth are clear results of tourism (Landis 2014; Tucker 2004). Increased levels of trash left by tourists and vendors are also an issue, as is disturbance of the butterflies (Tucker 2004; Vidal and Rendón-Salinas 2014). Disturbing the butterflies causes them to take flight, using precious energy stores (Vidal and Rendón-Salinas 2014). Consequently, tourism can be a double-edged sword, both helping and hurting wintering monarchs.

Threats

Despite recent efforts, the eastern population has declined dramatically in the last several decades, endangering the migratory phenomenon. In addition to illegal deforestation and tourism, monarchs face additional problems in their breeding grounds and in Mexico. The availability of milkweed in the U.S. and Canada has dropped sharply with the introduction of genetically modified crops and industrial agriculture (Vidal and Rendón-Salinas 2014; Brower et al. 2012). These developments allow widespread application of herbicides that kill native plants traditionally found alongside crops, including milkweed (Brower et al. 2012; Vidal et al. 2014). Unlike generalist species that have a wide array of host plants, monarch caterpillars are milkweed obligates, so without milkweed, fewer survive to continue the journey north (Landis 2014). Corresponding to areas of agricultural intensification, the Midwest, particularly the Corn Belt, has been the hardest hit and is consequently the target of the USFWS's monarch initiatives Monarch Joint Venture Initiative (MJV 2015; USFWS 2015).

Other threats are less easily reversed. At times, severe winter storms can result in massive monarch mortality. Intermittent and unpredictable, those storms that bring precipitation inhibit the monarchs' internal anti-freeze capabilities, raising the lethal temperature limit while also lowering the ambient temperature (Alonso-Mejía et al. 2007; Barve et al. 2012; Calvert et al. 1983). Although infrequent, severe winter storms have been linked to episodes of high mortality in 1981 (53% mortality), 1992 (80% mortality), 2002 (75% mortality) and 2009-10 (50% mortality) (Brower et al. 2004; Brower et al. 2012; Calvert et al. 1983). Global climatic shifts in temperature and oceanic and atmospheric currents are projected to increase the intensity and frequency of these winter storms (Barve et al. 2012; Landis 2014).

In addition to altered weather patterns, the climate also impacts biotic variables important to monarch survival. According to the Intergovernmental Panel on Climate Change [IPCC] (2001), climate change will have multiple effects, one of the most important of which is a rise in temperatures. However, future changes are relatively unknown and are highly dependent on current actions to reduce greenhouse gases. Therefore, the IPCC created multiple scenarios to predict change in greenhouse gas emissions based on a variety of factors. There are four primary situations, each with a different storyline concerning economic growth, technological advancements, population growth and levels of regional and global unity. Of these four, for most cases the two extremes are generally represented by situations A2 and B1. For most greenhouse gas emissions, Series A2 tends to be near the top and focuses on regional disunity with different regions continuing to produce at varying levels, while situation B1 emphasizes low population growth, adding clean technology and a change toward a service-based economy instead of one focused on manufacturing (IPCC 2000).

Predictions of greenhouse gas levels are a proxy for temperature, assuming that an increase in greenhouse gases would also lead to a rise in temperatures. This would ultimately lead to the gradual replacement of montane ecosystems with lower elevation species as their niches shrink and expand respectively (IPCC 2001). Higher metabolisms caused by increased temperatures will cause the monarchs to utilize their stored lipid reserves more quickly, forcing them to find nectar sooner than normal (Brower et al. 2009). Additionally, altered temperatures may impact their reproductive cycle. Either exiting reproductive diapause too early or increasing the temperatures in their breeding grounds could have important consequences, as could changes in the emergence of milkweed (Batalden et al. 2007; Zipkin et al. 2012). In California, Forister and Shapiro (2003) documented the first flight dates of butterflies, which became gradually earlier over the past 40 years. Milkweed would also likely be affected, which in an extreme case could lead to a potential mismatch between available habitat and monarch arrival dates (Batalden et al. 2007).

Finally, the range of the oyamel and pine trees upon which the monarchs depend will also likely be altered. Since they are a glacial species, their ideal habitat will move farther up the slopes. However, plants, particularly trees, require decades or centuries to move ranges depending on their dispersal and growth rates (Crozier and Dwyer 2006, Saenz-Romero et al. 2012). Although it is still unclear whether monarchs need the oyamels during the winter or if they merely share a mutual niche, in either case their suitable habitat will likely shrink (Saenz-Romero et al. 2012). Therefore, given these threats and opportunities, I investigated the presence of suitable habitat for the monarch butterfly in 2050, asking two questions:

1. How much area will exist in 2050 as potential winter habitat for the monarch butterfly within the MBBR and throughout Mexico?

2. What are the economic and cultural implications of this change for local communities?

METHODS

Estimating Monarch Responses to Climate Change

Data sources

Although colonies move throughout the season and may not reform every year, my analysis was based on the primary, or "permanent" monarch colonies listed in Vidal and Rendón-Salinas (2014), from which I obtained coordinates. Shapefiles of North American geopolitical borders, terrestrial protected areas, and an elevation raster were obtained from the North American Atlas, run by the Commission for Environmental Cooperation [CEC], a joint effort by Natural Resources Canada, Instituto Nacional de Estadística y Geografía [INEGI], and the National Atlas of the United States. The land cover for 1998 came from the Comisión Nacional para el Conocimiento y uso de la Biodiversidad [CONABIO], and the Mexican states shapefile came from INEGI. Current climate data (30 seconds resolution) and altitude rasters were obtained from CliMond (Hijmans et al. 2005). Data for 2050 was in 2.5 seconds resolution and came from the Consultative Group on International Agricultural Research's program on Climate Change, Agriculture, and Food Security. From the available models, I chose the following three for the IPCC's B1 and A2 situations: Canadian Centre for Climate Modeling and Analysis (CCCma) Coupled Global Climate Model with t47 atmospheric resolution, the Goddard Institute for Space (GISS) Model E-R, and the Hadley Centre for Climate Prediction and Research (HadCM3). These scenarios were chosen because they depict two disparate situations and therefore provide a range of possibilities.

Creating a model of monarch preferences

After selecting for Mexico from the CEC data, I selected the Monarch Butterfly Biosphere Reserve [MBBR] out of the terrestrial protected areas. Because the monarchs only overwinter from November through March (Brower et al. 2009), I calculated the average minimum temperature and then extracted the new raster using Mexico as a mask to obtain the average winter temperature in Mexico.

To build the model, I imported the locations of the permanent colonies within and outside of the MBBR listed in Vidal and Rendón-Salinas (2014) into ArcGIS 10.3.1 (ESRI 2015) and buffered them by 0.5 km, the maximum distance colonies migrate (Calvert and Brower 1986). However, since each colony was observed for at least 2 years the yearly locations of each colony overlapped were buffered. Therefore, to avoid pseudo-replication, I averaged the coordinates and surface areas for each colony, using these values in my model. To produce pseudo-absences, I created a fishnet based on the coordinates of the overwintering area listed in Brower et al. (2009). After importing to Google Earth, I found the coordinates at each intersection, eliminating any points close to the established colony locations, for a total of 112 pseudo-absences. Although a 1:1 ratio is preferred, this would reduce the sample size too far, potentially limiting the model's reliability (Franklin 2009). For import into ArcGIS, all coordinates were converted from degrees-minutes-seconds to decimal degrees through the Montana State University (www.rcn.montana.edu/resources/converter.aspx).

I selected 8 covariates based on a literature review of monarch overwintering biology, including oyamel, pine, 4 temperature categories, within 1 km of water, and aspect. First, I created two shapefiles from the landcover (CONABIO 1998) dataset: oyamel, the best habitat, and pine forests, a subprime habitat (Brower et al. 2009; Calvert and Brower 1986; Vidal and Rendón-Salinas 2014). Because Calvert and Brower (1986) found that all colonies were within 1 km of a water source, I buffered all bodies of water and dissolved the shapefile. Additionally, I found the aspect of the entire country, selecting for the south and southwest-facing slopes favored by the colonies (Calvert and Brower 1986; Missrie 2004). After extracting the Mexican aspects, I reclassified the raster into two categories: south and southwest, and all other directions, then converted the raster to a polygon. Additionally, temperature plays an important role in determining monarch overwintering survival. Using the classifications in Masters (1993), I divided the average minimum temperature raster into 4 categories in ^{o}C (<-4, -4 to 4, 4 to 6, >6), converted it to a polygon, and created a shapefile for each category.

To obtain inputs, I buffered each of the pseudo-absences and averaged colony locations by 0.5 km, the maximum distance colonies migrate during the winter season (Calvert and Brower 1986). I then intersected these buffers with the shapefile for each covariate to obtain the area of each near the monarch colonies. To find the area, I added a field and calculated the area (ha) for each shapefile, importing these values to Excel. This table was then imported to SPSS Version 22 (IBM 2013), where I ran a binary logistic regression using colony locations as the dependent variable and each of the 8 classifications as the covariates. Covariates from the final, most parsimonious output were used to produce a map of future monarch suitability.

Applying the model

Using the three covariates identified as important (oyamel, pine, temperature -4 to 4) to determining the location of monarch colonies, I projected the future fundamental niche of overwintering monarch butterflies in 2050. However, because a literature search did not provide enough information to also model a shift in pine and oyamel, I used their current distributions. I extracted Mexico from the HadCM3, GISS, and CCCma rasters for both and followed the protocol listed above to obtain a shapefile of temperature between -4 and 4 ^{o}C. After dissolving each shapefile, I intersected all three to find the regions where they all agreed, following Saenz-Romero et al. (2012). However, I kept situations A2 and B1 separate in order to investigate the range of potential outcomes for 2050. To obtain locations that matched my model's important covariates, I merged the pine and oyamel shapefiles and intersected it with the temperature predictions to find the predicted fundamental niche based on current temperatures for 2050 situations A2 and B1, adding a field and calculating the area in hectares. While there were suitable regions in the western Sierra Occidental range, I ultimately limited the scope of the model to the Trans-Mexican Volcanic Belt since there is little evidence for colonies outside of this geographic area, particularly beyond the mountains on the Pacific coast (De la Maza and Calvert 1993).

Communities

To understand the current status of the communities, I obtained demographic data (2013) for 5 communities in Mexico state from the *Instituto de Información e Investigación Geográfica, Estadística y Catastral del Estado de México* [IGECEM]. Four of the communities, San José del Rincón, Temascalcingo, Donato Guerra, and Villa de Allende, are close to the reserve in Mexico state (López-García and Alcántara-Ayala 2012). Toluca, the fifth location, is the capital of Mexico state and was therefore used as a benchmark to compare the other communities. It was assumed that Toluca, the state capital, would have the highest levels of economic development and infrastructure. Only data for Mexico state were available over the Internet. However, given the relatively close proximity of these communities to their counterparts in Michoacán, they can act as suitable proxies.

To assess development, two variables were used: literacy rates among those 15 and older and percent of households with a car or truck. Although there are critiques of “development” indices such as the United Nations Development Programme’s Human Development Index, literacy rates are often one indicator of development (Kelley 1991; Noorbakhsh 1998). Additionally, according to Rodríguez and Vizcarra (2015), jobs in El Rosario were divided according to literacy. Ownership of motor vehicles was chosen because not only are vehicles an expensive initial investment, but they also require investments over time in the form of money for gas, tires, and repairs. Moreover, in Michoacán, for many, access to the reserve is limited by vehicle availability (Tucker 2004).

The employment industries of each community were also compared to gain an understanding of the economic focus of each community. Additionally, the availability and rating of hotels and hostels as well as other existing tourist infrastructure were compared across the 5 communities.

RESULTS

Future Climate

Three of the 8 covariates, oyamel, pine, and temperature (-4 to 4 ^{o}C) were used in the final model, which correctly predicted 95.4% of the overall presence and absence of monarch colonies (Table 1, Table 2). Of these 3 covariates, only oyamel ($p < 0.000$) and pine ($p < 0.001$) were significant (Table 1). Despite this, the inclusion of temperature (-4 to 4 ^{o}C) was significantly important to the model (Table 3).

Of the 19 permanent colonies listed in Vidal and Rendón-Salinas (2014), 5 fall outside of the reserve (Fig. 2). The average permanent colony size ranges from 0.05 ha to 2.34 ha, with El Rosario as the largest (Fig. 2). Mean colony size is 0.37 ha (Fig. 2).

Currently, within the MBBR, the monarch fundamental niche is an estimated 51,016 ha (Table 4). By 2050, this zone will shrink to an area that is 61.4% (B1) to 30.2% (A2) of the current range (Table 4, Fig. 3). Accordingly, of the current colony locations, 14 will still fall within the fundamental niche in situation B1 and 7 in situation A2 (Fig. 3). Throughout the Trans-Mexican Volcanic Belt, there is currently an estimated 914214.9 ha of fundamental niche habitat for overwintering monarchs (Table 4). However, by 2050 situation B1, only 48% of this area will be favorable, which is reduced to 34% under situation A2 (Table 4, Fig. 4).

Communities

In all 5 communities, literacy rates for individuals 15 years and older were above 80%, ranging from 80% to 95.5% in San José del Rincón and Toluca respectively (Fig. 5). Illiteracy rates ranged from a low of 4% in Toluca to a high of 19.6% in San José del Rincón (Fig 5).

Only in Toluca did more than half of households (50.47 %) own a car (Fig. 6). For the other four communities, over 65% of households did not own a car, with the highest percentage in Donato Guerra at 82.6% (Fig 6). Outside of Toluca, Temascalcingo had the highest percentage of households with a car, at 33.2% (Fig. 6).

Employment was more varied among the 5 communities. In Temascalcingo and Toluca, the service sector employed the highest percentage of individuals, while agriculture and livestock employed the least (Fig. 7). This difference was clearest in Toluca, where nearly 80% are employed in the service sector and only 1.2% in agriculture as opposed to the much smaller difference between these two sectors in San Felipe del Progreso (Fig. 7). While not identifying tourism specifically, it is likely that many of those employed in the service sector would also provide services to tourists. In San José del Rincón, Donato Guerra, and Villa de Allende, agriculture and livestock employed the highest percentage of individuals, at 43.7%, 46% and 41.7% respectively (Fig. 7). For every community except Donato Guerra, the industrial sector employed the second highest percentage (Fig. 7).

Toluca clearly had the largest tourist infrastructure, ranking first in number of establishments (Table 5). San José del Rincón was the only community to not report a tourist infrastructure (Table 5, Table 6). While the other communities had at least one establishment, Temascalcingo had the most with 4 hotels, including one 3-star accommodation (Table 5). Apart from San José del Rincón, each town had 1 Tourist Information Office (Table 5). However, only Temascalcingo and Toluca had restaurants and travel agents (Table 5).

DISCUSSION

Analysis of the Model

Overall, the model's ability to predict the presence or absence of monarch colonies was extremely good (Table 2). The presence of oyamel as a significant variable in predicting the presence of monarch colonies was not unexpected given the high number of colonies found in oyamel forests (Anderson and Brower 1993; Brower et al. 2009; Calvert and Brower 1986; Vidal and Rendón-Salinas 2014). Although it is still unclear whether the oyamels are necessary for monarch survival, the high correlation between the two species indicates a link, either a direct dependence or an indirect abiotic factor (Saenz-Romero et al. 2012). While the focus of most studies has been on oyamels, pine trees were also an important predictor for the presence of monarch colonies (Table 1). This, in addition to the use of Monterey pines (*Pinus radiata*) in southern California by the western population indicates the need for more studies determining the biotic needs of wintering monarchs (Vane-Wright 1993). Given the uncertainty regarding their necessity for the monarchs, the inclusion of two biotic variables as the most significant and therefore most important variables in the equation may instead point to their ability to create microclimates.

Therefore, abiotic factors, particularly microclimates, may prove to be more important for the colonies' winter survival. Mature, undisturbed forests not only provide a closed canopy but also larger individual trees. A closed canopy reduces the daily temperature variation and although it may limit sunlight during the day making the monarchs slower to warm up and fly, the canopy also retains heat at night, providing protection from the dangerous cold (Alonso-Mejía et al. 2007; Anderson and Brower 1993; Honey-Rosés 2008). Additionally, larger trees moderate the surrounding temperature by limiting fluctuation so that monarchs on the trunks of large trees are less likely to perish than those on thinner branches or smaller trees (Brower et al. 2009).

The role of temperature in determining monarch survival beyond the microclimate is also important, as indicated to a lesser degree in Tables 1 and 3. Although not making a significant difference to the prediction of the presence or absence of monarchs, the temperature between -4 and 4 ^{o}C was nonetheless an important category to include in the model (Table 1, Table 3). At the lower end of this range, at least half of wet monarchs die. Consequently, this temperature range was likely identified as more important than the others because it represents the beginning of temperature-dependent mortality, with some dying by -1.5^{o}C, and over half of wet monarchs dying by -4 ^{o}C (Anderson and Brower 1996; Masters 1993). Locations with an average temperature below -4 ^{o}C would never host a colony due to the high mortality, and the other two temperature categories fall above the threshold needed for movement, so they have a lesser impact on monarch survival. Although these temperature categories covered the average winter temperatures that overwintering monarchs are most likely to encounter on a regular basis, the possibility for large-scale mortality is still present. Extreme weather events will continue to occur, hitting monarch colonies in suitable habitat (Brower et al. 2012; Calvert et al. 1983). However, it is tremendously difficult if not impossible to predict the future presence of these deadly storms or the locations they are most likely to strike. The one factor that does appear to be more or less certain is their increasing frequency and unpredictability (Landis 2014). How this will affect the colonies has yet to be seen.

However, the model was not perfect. The Contepec colony did not fall within a predicted habitat for the current or future regions, despite falling within the northern portion of the reserve (Fig. 3). This failure to predict its presence is likely caused by the lack of oyamel or pine within this part of the reserve, which could in turn be caused by small changes in the original data. Since the landcover data was on a national scale, it may have excluded small patches of forest (Fig. 2). As the two most important variables for this model, the lack of oyamel or pine hindered the prediction of the Contepec colony's location. To create a more accurate model, ground truthing could refine the initial input data. Nevertheless, the model did correctly predict the presence of the other 18 colonies.

Other variables not included in the model were the presence of water and aspect. Calvert and Brower (1986) found that monarch colonies were within 1 km of water sources, while Missrie (2004) found that many were within 400 m. Nevertheless, distance to water sources was not important in my model. This exclusion of water may have been affected by the differing scales. Calvert and Brower (1986) were able to directly observe monarch behavior in relation to physical characteristics. However, the data for my model came from a national dataset for Mexico. Therefore, if the water sources were seasonal or small unnamed creeks, they may not have been included in the national dataset. Additionally, aspect was also not considered to be an important variable in my model. Although Anderson and Brower (1993), Calvert and Brower (1986), and Missrie (2004) found that colonies preferred south and southwest-facing slopes for the thermal advantages they provide, colonies change their position throughout the winter. Therefore, the different times of data collection may have influenced the model. Additionally, aspect was not as clearly defined as other variables, with several colonies also located on western and south southeast slopes, which may have limited the usefulness of using aspect to predict colony locations (Calvert and Brower 1986).

Implications for Monarchs

Despite several shortcomings, this model has predicted an alarming loss of suitable habitat that could have enormous consequences for future management. Even in the best-case scenario, an estimated 38.6% of suitable habitat within the MBBR and 52% throughout the Trans-Mexican Volcanic Belt will be lost (Fig. 3, 4). However, this also assumes that the oyamel and pine forests remain in their current locations. Nevertheless, as living organisms, they too will likely respond to changing conditions. Although species will likely disperse, Thomas et al. (2004) still estimate a minimum extinction of 9% species, potentially reaching 20%. However, trees hold little control over their own distribution, instead relying on animals and the wind to disperse their seeds to favorable locations (Crozier and Dwyer 2006; Saenz-Romero et al. 2012). Given these restrictions, their ability to match their range in accordance with newly altered conditions will be limited, further decreasing the available habitat. Other species of conifers, including ponderosa pine (*Pinus ponderosa*) and Douglas firs (*Pseudotsuga mensiesii*) will be similarly affected by climate change, particularly by drought and upslope movement (Marinelli 2015). In their study of suitable habitat for the oyamel fir, Saenz-Romero et al. (2012) estimated that this area would decline by 69.2% in 2030 and 96.5% by 2090. Additionally, areas that become climatically suitable for these trees may not have adequate soils to support large plants, particularly if these locations are upslope areas subject to high erosion (Marinelli 2015; Saenz-Romero et al. 2012). Nevertheless, the effect may not be immediate. Existing trees are well established and will likely persist for years if not decades given the right conditions. However, the stress of an altered climate will make them more susceptible to disease, hastening their decline. In Mexico, oyamels are already beginning to suffer in a hotter, drier environment (Marinelli 2015; Saenz-Romero et al. 2012). As trees die, forest canopies will lose their protective abilities until new trees replace them, impacting monarch survival.

In California, the western monarch population primarily uses Monterey pines (*Pinus radiata*) as roosting sites (Vane-Wright 1993). Therefore, monarchs may be flexible and able to adapt to altered conditions. Additionally, an “assisted migration” program could rapidly extend the ranges of species to match predicted suitable habitats (Zimmer 2009). However, this approach is highly controversial. Ecological systems are extremely complex, and relationships between species and abiotic factors are still being explored. Opponents view assisted migration as an example of scientists meddling with the natural order and deciding which species to prioritize (Zimmer 2009). However, modeling technology is constantly improving and intervention is one method of preventing extinctions caused by anthropogenic actions. Regardless of this debate, in 2014 several hundred oyamel seedlings were planted upslope in an area that is predicted to be ideal habitat by 2030. However, this is an expensive endeavor. At these elevations, soil must be added and the seedlings protected from frost (Marinelli 2015). Additionally, populations vary genetically based on elevation and must be matched accordingly to ensure the greatest possibility of survival (Saenz-Romero et al. 2012). Consequently, it may not be viable on a large scale, but anticipating how the butterflies themselves will react is also unpredictable. Although assisted migration is a drastic measure, it may be inevitable.

Implications for Protected Areas

Assisted migration and changing distributions also raises the question of the efficacy and future of protected areas in the face of climate change, particularly those created to preserve specific natural phenomena. Climate change is predicted to have a large impact on tourism and protected areas. By changing local weather patterns, climate change can impact when tourists visit parks, often extending the season (Fisichelli et al. 2015). However, in a park with highly seasonal natural phenomena like the MBBR, tourism is highly dependent on timing and presence of the object of interest, and so is less flexible. Additionally, altered weather patterns may impact accessibility and transportation, particularly under increased levels of precipitation (De Urioste-Stone et al. 2016). This could be an issue for attracting and maintaining tourist access to the MBBR. In 2010, high amounts of precipitation, when combined with changes in landcover, caused a landslide near Angangueo killing 16 people and damaging monarch habitat and roads (López-García and Alcántara-Ayala 2012).

Perhaps the most relevant issue facing the MBBR is the alteration of plant and animal distributions. In parks created to protect specific natural phenomena or animals, the possibility of their disappearance from park borders questions the purpose of maintaining these areas. This is not an issue only confined to Mexico. In the U.S., wildlife distributions have begun to change in Denali National Park, pine trees have become more susceptible to insects and drought, and alpine species like the pika (*Ochotona princeps*) have moved upslope (Dorminey 2013; Knapp et al. 2014; Zimmer 2009). Additionally, climate change threatens the future of two iconic species bearing the names of their respective parks: giant sequoias (*Sequoiadendron giganteum*) and Joshua trees (*Yucca brevifolia*), creating a major philosophical issue about the relevance of protected areas (Dorminey 2013; Solomon 2014). As odd as some may seem, proposals for management of these species have run the gamut of passive management, allowing change to occur naturally, to active intervention in the form of watering giant sequoias to combat drought (Dorminey 2013). These more extreme measures would likely be unfeasible in an area like the MBBR, and yet given predictions, between 7 and 14 of the current colony locations could be situated in poor or unsuitable habitat by 2050 (Fig. 3). Additionally, due to its effects on species physiology and habitat, climate change will likely induce range shifts, also affecting the colonies (Kappelle et al. 1999). Therefore, the future role of parks, particularly those with a narrow focus, is uncertain.

Implications for Communities

Given the precarious situation of protected areas, tourism as an economic alternative for communities is also subject to scrutiny. Encouraged by the government and organizations, successful tourist enterprises require investments in personnel and infrastructure. Currently, all of the communities in Mexico state have at least one hotel or inn, however, these are insufficient to host the estimated 100,000 annual visitors (Rodríguez and Vizcarra 2015). To ameliorate this issue, in 2013 the state government and federal Tourism Secretary invested 8 million Mexican pesos (slightly over 45,000 U.S. dollars) to improve access to the reserve as well as the overall experience, providing bathrooms and signage (EdoMéx 2013; EdoMéx 2014). Aimed at attracting tourists, these investments will allow the communities to expand their programs and economic independence.

As the economy expands, so too will environmental protection. Before the establishment of economic alternatives, illegal logging was prevalent in the reserve because the local communities had no replacement for the income they lost (Honey-Rosés 2009). However, with the increase in income from tourist-related activities, the value of the forest itself has begun to change. In fact, as tourist-related income increases, interest in forest protection also increases (Tucker 2004). Therefore, investment in tourism and related activities is an important component of protecting the future of the monarch butterflies. However, if expansion is successful, communities must still guard against overexploitation of the reserve because tourism also threatens the long-term health of the monarch population (Snook 1993).

Consequently, total dependence upon tourism should be avoided. The most important factor for monarch survival is the presence of the forests because they create suitable microclimates. However, competition between communities to bring tourists as close as possible to the butterflies often leads to poor habitat management. Existing trails have already eroded because of the high volume of visitors that also destroy the undergrowth (Landis 2014). Noise pollution and trash from visitors also disturb the monarchs and forest (Tucker 2004; Vidal and Rendón-Salinas 2014). Without careful management and repair, current levels of tourism may become unsustainable let alone increasing the number.

However, tourism alone will not support the whole economy. Many visitors currently arrive through pre-arranged package tours, limiting the benefits to the host communities (Brenner and Job 2006). In order to maximize the economic value, the host communities must work to attract visitors directly instead of hosting tour companies. Other factors also limit the economic potential of tourism. Colony formation and size are highly variable. Some colonies are larger and reliably appear year after year, providing a greater tourist draw than the smaller colonies that may not form every year. Although a variable phenomenon, many tourists expect a reliable experience. Unpredictability may ultimately impact the total number of tourists that come. In addition, some towns can take advantage of their geography more readily than others, especially depending on the infrastructure development. Angangueo, Michoacán, is one of the best candidates for further tourism development. Located near the El Rosario colony, one of the largest and most reliable colonies, the town has already developed a tourist infrastructure around the reserve, as has Cerro Prieto, Michoacán, around another large colony (Brenner and Job 2006). Tourism is therefore a viable possibility for some communities. However, to maximize the economic impact of tourism, the number of communities involved should be restricted. While 100,000 visitors is a large number, when divided amongst the communities as well as outside tours, some smaller communities may not recover their investment, which could lead to resentment and further habitat degradation.

However, if different communities pursue multiple projects, direct competition could be alleviated, improving the ecological and economic situations of all of the communities. In order to administer sustainable extraction of forest resources, the Payment for Environmental Services [PES] program protects ecosystem integrity while supporting local communities. This program emphasizes the services provided by fully functioning ecosystems, particularly their role in filtering air and water for human consumption. As part of the program, landowners are paid in exchange for ending logging on their lands, a promise supported by satellite imagery. This program helps maintain forest health and biodiversity while also ensuring the security of the landowner and communities that rely on the water. Communities receive increased benefits, including long-term use and improved ecosystem services such as water filtration and carbon sequestration while maintaining healthy forests (Manzo-Delgado et al. 2014; Rodríguez R. and Ávila Foucault 2013). This program could also help avoid over-protection of the reserve. The strict regulations within the core area of the MBBR have led to an accumulation of brush (Tucker 2004). While the integrity of the forest should be protected, accumulation of undergrowth also increases the risk of large-scale forest fires, which would have catastrophic consequences, potentially reducing the area and quality of overwintering forest for the monarchs as well as the local communities.

Additionally, there are current efforts to engage communities in ecological restoration. The La Cruz Habitat Protection Project works with volunteer farmers to raise saplings while nurseries in San Pablo Malacatepec, raise trees for reforestation activities (EdoMéx 2015; Sill 2009). Both of these projects have reforested degraded areas, improving water quality and decreasing susceptibility to erosion and landslides. Their current reforestation efforts may also expand the current suitable areas. At the extinct El Cedral colony, saplings have begun to attract butterflies again (Sill 2009). In raising saplings for transplantation, these projects could also supply trees to assisted migration efforts if they are eventually pursued. Monarchs are resilient, and the direct involvement of community members forges links that are stronger than a simple economic relationship. Even if the monarchs ultimately leave this region, a sense of stewardship will help communities combat the effects of climate change by maintaining their forests.

Although centered on the monarch butterfly and the reserve, the creation of a diverse economy will ultimately be more resilient than one focused solely on tourism. Moreover, the current efforts reflect a change toward a more inclusive management focus for the park, steps that will ultimately determine its success or failure. Community use is also common in National Forests in the U.S., where a stakeholder approach has been utilized to reduce conflict (Wilson 2003). Despite the tensions inherent in this system, the creation of management plans balancing ecological, social, and economic issues of the immediate communities creates improved community cooperation, and could be applied in Mexico (Wilson 2003). Tucker (2004) found that although the situation was improving, government officials and their decisions were often viewed as aloof and ignoring community concerns, leading to rebellion and degradation, primarily through illegal logging. However, by including representatives from each community as well as the various levels of government and international NGOs involved with the MBBR, a sound compromise could be reached. This is not to say that this option is easy. Instead, it requires extensive communication between all stakeholders. Improved communication between governments and the communities may be starting, as new government officials begin to increase accessibility and communication with community members (Tucker 2004).

Future Studies

Future studies should focus on opinions held by community members in Mexico. It would be particularly interesting to gauge the degree to which various groups are willing to create and implement a sustainable management plan. As part of this investigation, attitudes toward international conservation organizations as well as government programs should be measured to determine if recent programs have been successful in improving relations with communities and in reducing illegal logging. Additionally, a more complete analysis of economic data from all of the communities would provide a more accurate understanding of the current situation. An interesting corollary would be the analysis of past economic data to determine the economic impact of the reserve on individuals as well as measure the success of tourism and other state-sponsored activities in replacing logging as a viable economic alternative.

Additionally, the model itself could be refined. Although I used the smallest rasters freely available, the raster for future climate had a larger grid size than the current climate raster. Therefore, I lost some accuracy in the future projections. In comparison to other areas, the study area is quite small and the projections would greatly benefit from a higher level of detail. Moreover, the extent of the oyamel and pine forests should be ground-truthed in Mexico. Since the landcover data is from 1998, it has likely changed with differential logging pressures and agriculture. This, in addition to research into the requirements of both types of forests would allow for a more accurate model and would also allow for the extrapolation of forest extent under a changed climate.

CONCLUSION

The protection of the monarch migration is fundamental to regional identity. Returning every year around the first week of November, the butterflies have come to symbolize the return of loved ones for Día de los Muertos (Piña Garduño 2015; Sill 2009). This spiritual component, when combined with regional pride, could be an important factor in protecting the overwintering sites of the monarch butterfly. However, only through cooperation can the situation be improved. The estimates of the 2015-16 wintering population show that numbers have increased, but are still well below recorded highs 20 years ago (Burnett 2016). While it will be several years before we know if this upward trend will continue, tri-national efforts to coordinate programs and invest money may be one of the most important tools in reversing the decline.

While the long-term status of the monarch colonies and MBBR are uncertain, even if they leave this area, they could aggregate elsewhere in Mexico. There are multiple reports of short-term monarch colonies throughout the Trans-Mexican Volcanic Belt in the states of Jalisco, Oaxaca, Puebla, and Morelos (De la Maza and Calvert 1993). Although De la Maza and Calvert (1993) did not find any of these reported colonies, Brower (1986) reported that they are usually small and unreliable. However, if conditions change to become more suitable, these colonies could grow. If they follow the oyamel, by 2090 they will likely be found on higher slopes outside of the MBBR (Saenz-Romero et al. 2012). Either way, forest quality must be maintained, if not improved. Even if they choose to colonize other areas, healthy forests are vital to human and ecosystem health and will only become more important.

International cooperation will also be necessary to reduce the effects of climate change. Although the monarch will likely lose some habitat to an altered future climate, the degree of change is still undecided. Although the climate will continue to change over the next 50 -150 years, action now could reduce the negative effects and severity of the change, thus improving the outlook for wintering habitat and a continued monarch migration as well as the continuation of many other biotic phenomena (Conroy et al. 2011). While it may seem difficult, immediate action will ultimately reduce costs over the long-term in human, environmental, and economic terms.

LITERATURE CITED

Alonso-Mejía, A., E. Rendón-Salinas, E. Montesinos-Patiño, and L.P. Brower. 2007. Use of lipid reserves by monarch butterflies overwintering in Mexico: implications for conservation. Ecological Applications, 7 (2007), pp. 934–947.

Anderson, J.B., and L.P. Brower. 1993. Cold-hardiness in the annual cycle of the monarch butterfly. In S.B. Malcolm, M.P. Zalucki (Eds.), Biology and Conservation of the Monarch Butterfly. Science Series 38, Natural History Museum of Los Angeles County, Los Angeles, USA, 156-164.

Anderson, J. B. and L. P. Brower. 1996. Freeze-protection of overwintering monarch butterflies in Mexico: critical role of the forest as a blanket and an umbrella. Environmental Entomology 21:107-116.

Arellano G., A., J.I. Glendinning, J.B. Anderson, and L.P. Brower. 1993. Interspecific comparisons of the foraging dynamics of black-blacked orioles and black-headed grosbeaks on overwintering monarch butterflies in Mexico. In S.B. Malcolm, M.P. Zalucki (Eds.), Biology and Conservation of the Monarch Butterfly. Science Series 38, Natural History Museum of Los Angeles County, Los Angeles, USA, 315-322.

Barve, N., A.J. Bonilla, J. Brandes, J.C. Brown, N. Brunsell, F. V. Cochran, R.J. Crosthwait, J. Gentry, L.M. Gerhart, T. Jackson, A.J. Kern, K.S. Oberhauser, H.L. Owens, A.Townsend Peterson, A.S. Reed, J. Soberón, A.D. Sundberg, and L.M. Williams. 2012. Climate-change and mass mortality events in overwintering monarch butterflies. Revista Mexicana de Biodiversidad 83, 817-824.

Batalden, R.V., K. Oberhauser, and A. Townsen. 2007. Ecological niches in sequential generations of eastern North American monarch butterflies (Lepidoptera: Danaidae): the ecology of migration and likely climate change implications. Environmental Entomology, 36, 1365–1373.

Brenner, L., and H. Job. 2006. Actor-oriented management of protected areas and ecotourism in Mexico. Journal of Latin American Geography 5(2):7-27.

Brower, L.P. 1986. New perspectives on the migration biology of the monarch butterfly, Danaus plexippus L. Migration: mechanisms and adaptive significance. In: Migration: mechanisms and adaptive significance (ed. Rankin MA), 748-785. Marine Science Institute, the University of Texas at Austin, Port Aransas, TX.

Brower, L.P., B. Elizabeth Horner, Melanie A. Marty, Christine M. Moffitt and Bernardo Villa-R. 1985. Mice (*Peromyscus maniculatus, P. spicilegus, and Microtus mexicanus*) as Predators of Overwintering Monarch Butterflies (*Danaus plexippus*) in Mexico. Biotropica 17(2): 89-99

Brower, L.P., D.R. Kust, E. Rendón-Salinas, E. García-Serrano, K.R. Kust, J. Miller, C. Fernández del Rey, and K. Pape. 2004. Catastrophic winter storm mortality of monarch butterflies in Mexico during January 2002. In K.S. Oberhauser and M.J. Solensky (Eds.), The Monarch Butterfly: Biology and Conservation. Cornell University Press, Ithaca, 151-168.

Brower, L.P., E.H. Williams, D.A. Slayback, L.S. Fink, M.I. Ramirez, R.R. Zubieta, M. Ivan Limon Garcia, P. Gier, J.A. Lear, and T.Van Hook. 2009. Oyamel fir forest trunks provide thermal advantages for overwintering monarch butterflies in Mexico. Insect Conservation and Diversity 2:163-175.

Brower, L.P., O.R. Taylor, E.H. Williams, D.A. Slayback, R.R. Zubieta, M.I. Ramirez. 2012. Decline of monarch butterflies overwintering in Mexico: is the migratory phenomenon at risk? Insect Conservation and Diversity 5:95-100.

Burnett, V. 2016. Monarch butterfly migration rebounds, easing some fears. The New York Times. Accessed 28 Feb. 2016 from http://www.nytimes.com/2016/02/28/world/americas/monarch-butterfly-migration-rebounds-easing-some-fears.html?smid=fb-nytimes&smtyp=cur&_r=0

Calvert, W.H., and L.P. Brower. 1986. The location of monarch butterfly (*Danaus plexippus* L.) overwintering colonies in México in relation to topography and climate. Journal of the Lepidopterists' Society, 40, 164–187.

Calvert, W.H., W. Zuchowski, and L.P. Brower. 1983. The effect of rain, snow and freezing temperatures on overwintering monarch butterflies in Mexico. Biotropica, 15, 42–47.

Commission for Environmental Cooperation [CEC]. 2008. North American Monarch Conservation Plan. Montreal, Canada.

Conroy, M.J., M.C. Runge, J.D. Nichol, K.W. Stodola, and R.J. Cooper. 2011. Conservation in the face of climate change: the roles of alternative models, monitoring, and adaptation in confronting and reducing uncertainty. Biological Conservation 144:1204-1213.

Crozier, L., and G. Dwyer. 2006. Combining population-dynamic and ecophysiological models to predict climate-induced insect range shifts. American Naturalist 167: 853-866.

De la Maza E., J., and W.H. Calvert. 1993. Investigations of possible monarch butterfly overwintering areas in Central and Southeastern Mexico. In S.B. Malcolm, M.P. Zalucki (Eds.), Biology and Conservation of the Monarch Butterfly. Science Series 38, Natural History Museum of Los Angeles County, Los Angeles, USA, 295-297.

De Urioste-Stone, S.M., L. Le, M.D. Scaccia, and E. Wilkins. 2016. Nature-based tourism and climate change risk: Visitors' perceptions in Mount Desert Island, Maine. Journal of Outdoor Recreation and Tourism: In press.

Diffendorfer, J.E., J.B. Loomis, L. Ries, K. Oberhauser, L. Lopez-Hoffman, D. Semmens, B. Semmens, B. Butterfield, K. Bagstad, J. Goldstein, R. Wiederholt, B. Mattson, and W.E. Thogmartin. 2014. National Valuation of Monarch Butterflies Indicates an Untapped Potential for Incentive-Based Conservation. Conservation Letters 7(3): 253-262.

Dorminey, B. 2013, 21 March. Giant Sequoias face looming threat from shifting climate. Yale Environment 360. http://e360.yale.edu/feature/giant_sequoias_face_looming_threat_from_shifting_climate/2631/

EdoMéx. 2013. Invertirán GEM y Sectur 8 MDP en infraestructura turística de los santuarios de la mariposa monarca. Accessed --- from http://edomexinforma.com/2013/08/sectur-8-mdp-mariposa-monarca/

EdoMéx. 2014. Supervisa GEM trabajos en santuarios de la mariposa monarca. Accessed 19 Feb., 2016 from http://edomexinforma.com/2014/01/supervisionsantuarios/

EdoMéx. 2015. Proyectos productivos evitan tala clandestine en la Reserva Biósfera de la Mariposa Monarca. Accessed 19 Feb., 2016 from http://edomexinforma.com/2015/11/proyectosevitantalaclandestina/

Fisichelli, N.A., G.W. Schuurman, W.B. Monahan, and P.S. Ziesler. 2015. Protected area tourism in a changing climate: will visitation at US National Parks warm up or overheat?. PLoS ONE 10(6).

Forister ML, Shapiro AM (2003) Climatic trends and advancing spring flight of butterflies in lowland California.Global Change Biology, 9, 1130–1135.

Franklin, J. 2009. Mapping species distributions: spatial inference and prediction. Cambridge University Press, Cambridge, UK.

Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25:1965-1978.

Honey-Rosés, J. 2008. Disentangling the proximate factors of deforestation: The case of the Monarch Butterfly Biosphere Reserve in Mexico. Land Degradation and Development. 20:22-32.

Intergovernmental Panel on Climate Change [IPCC]. 2000. Emissions scenarios: summary for policymakers. Accessed from http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf

Intergovernmental Panel on Climate Change [IPCC]. 2001. Latin America. In Climate change Intergovernmental Panel on Climate Change [IPCC]. 2001. Latin America. In Climate change 2001: impacts, adaptation, and vulnerability. Ed. J.J. McCarthy, O.F. Canziani, N.A. Leary, D.D. Dokken, and K.S. White. Cambridge University Press, Cambridge, UK:693-734.

Kappelle M, Van Vuuren MMI, Baas P (1999) Effects of climate change on biodiversity: a review and identification of key research issues. Biodiversity Conservation 8:1383–1397

Kelley, A.C. 1991. The Human Development Index: “handle with care.” Population and Development Review 17(2): 315-324.

Knapp, C.N., F.S. Chapin III, G.P. Kofinas, N. Fresco, C. Carothers, and A. Craver. 2014. Parks, people, and change: the importance of multistakeholder engagement in adapation planning for conserved areas. Ecology and Society 19(4): 16.

Landis, T.D. 2014. Monarch waystations: Propagating native plants to create travel corridors for migrating monarch butterflies. Native Plants 15(1):5-16.

López-García, J., and I. Alcántara-Ayala. 2012. Land-Use Change and Hillslope Instability in the Monarch Butterfly Biosphere Reserve, Central Mexico. Land Degradation and Development 23:384-397.

Manzo-Delgado, L., J. López-García, and I. Alcántara-Ayala. 2014. Role of forest conservation in lessening land degradation in a temperate region: the Monarch Butterfly Biosphere Reserve, Mexico. Journal of Environmental Management 138:55-66.

Marinelli, J. 2015, 21 Dec. To protect monarch butterfly, a plan to save the sacred firs. Yale Environment 360. http://e360.yale.edu/feature/to_protect_monarch_butterfly_a_plan_to_save_the_sacred_firs/2942/

Masters, A.R. 1993. Temperature and thermoregulation in the monarch butterfly. In S.B. Malcolm, M.P. Zalucki (Eds.), Biology and Conservation of the Monarch Butterfly. Science Series 38, Natural History Museum of Los Angeles County, Los Angeles, USA, 147-156.

Missrie, M. 2004. Design and implementation of a new protected area for overwintering monarch butterflies in Mexico. In K.S. Oberhauser and M.J. Solensky (Eds.), The Monarch Butterfly: Biology and Conservation. Cornell University Press, Ithaca, 141-150.

Monarch Joint Venture [MJV]. 2015. Accessed 21 Feb., 2016 from http://www.monarchjointventure.org/

Monterrubio, J.C., G. Rodríguez-Muñoz, and M.M. Mendoza-Ontiveros. 2013. Social benefits of ecotourism: the Monarch Butterfly Reserve in Mexico. Enlightening Tourism: A Pathmaking Jounal 3(2): 105-124.

Noorbakhsh, F. 1998. The Human Development Index: some technical issues and alternative indices. Journal of International Development 10:589-605.

Oberhauser, K. 2004. Overview of monarch breeding biology. In K.S. Oberhauser and M.J. Solensky (Eds.), The Monarch Butterfly: Biology and Conservation. Cornell University Press, Ithaca, 3-7.

Oberhauser, K., and A.T. Peterson. 2003. Modeling current and future potential wintering distributions of eastern North American monarch butterflies. Proceedings of the National Academy of Science USA, 100, 14063–14068.

Perez, S.M. and O.R. Taylor. 1993. Monarch butterflies migratory behavior persists despite changes in environmental conditions. The Monarch Butterfly: Biology and Conservation. Cornell University Press, Ithaca, 85-88.

Piña Garduño, E.R. 2015. Día de Muertos. Temascalcingo de José María Velasco. Accessed 3 March 2016 from http://vivetemascalcingo.blogspot.com/2015/10/dia-de-muertos.html

Ries, L, and K. Oberhauser. 2015. A Citizen Army for Science: Quantifying the Contributions of Citizen Scientists to our Understanding of Monarch Butterfly Biology. BioScience 65(4):419-430.

Rodriguez, G., and I. Vizcarra. 2015. Turismo comunitario y genero: la incorporacion de las mujeres al proyecto turistico del Ejido El Rosario, Ocampo, Mexico. Spanish Journal of Rural Development 6(1):55-70.

Rodríguez R., K.J., and S. Ávila Foucault. 2013. Instrumentos económicos voluntaries para la conservación: una Mirada a su surgimiento y evolución en México. Sociedad y Economía 25:75-106.

Rzedowski, J. 1978. Bosque de coníferas. In J. Rzedowski, Vegetación de México. México, D.F.: Editorial Limusa, 283-314.

Saenz-Romero, C., Rehfeldt, G.E., Duval, P., and Lindig-Cisneros, R.A. 2012. Abies religiosa habitat prediction in climatic change scenarios and implications for monarch butterfly conservation in Mexico. Forest Ecology and Management.

Sill, S. 2009. Reforesting Michoacán. American Forests. 114(4): 9-12.

Snook, L.C. 1993. Conservation of the monarch butterfly reserves in Mexico: Focus on the forest. In S.B. Malcolm, M.P. Zalucki (Eds.), Biology and Conservation of the Monarch Butterfly. Science Series 38, Natural History Museum of Los Angeles County, Los Angeles, USA, 363-375.

Solensky, M.J. 2004. Overview of monarch migration. In K.S. Oberhauser and M.J. Solensky (Eds.), The Monarch Butterfly: Biology and Conservation. Cornell University Press, Ithaca, 79-83.

Solomon, C. 2014. The Wilderness Act is facing a midlife crisis. The New York Times. Accessed from http://www.nytimes.com/2014/07/06/opinion/sunday/the-wilderness-act-is-facing-a-midlife-crisis.html?_r=0

Thomas, C.D., A. Cameron, R.E. Green, M. Bakkenes, L.J. Beaumont, Y.C. Collingham, B.F.N. Erasmus, M. Ferreira de Siquiera, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A.S. van Jaarsveld, G.F. Midgley, L. Miles, M. A. Ortega-Huerta, A.T. Peterson, O.L. Phillips, and S.E. Williams. 2004. Extinction risk from climate change. Nature 427:145-148.

Tucker, C.M. 2004. Community institutions and forest management in Mexio's Monarch Butterfly Reserve. Society and Natural Resources 17:569-587.

U.S. Fish and Wildlife Service [USFWS]. 2015. Monarch projects. Accessed 20 Feb. 2016 from http://www.fws.gov/savethemonarch/projects.html

Vane-Wright, R.I. 1993. The Columbus Hypothesis: an explanation for the dramatic 19th century range expansion of the monarch butterfly. In S.B. Malcolm, M.P. Zalucki (Eds.), Biology and Conservation of the Monarch Butterfly. Science Series 38, Natural History Museum of Los Angeles County, Los Angeles, USA, 179-187.

Vidal, O., and E. Rendón-Salinas. 2014. Dynamics and trends of overwintering colonies of the monarch butterfly in Mexico. Biological Conservation. 180:165-175.

Vidal, O., J. López-García, and E. Rendón-Salinas. 2014. Trends in deforestation and forest degradation after a decade of monitoring in the monarch butterfly biosphere reserve in Mexico. Conservation Biology, 28:177–186.

Wilson, R.K. 2003. Communit-based management and National Forests in the western United States – five challenges. Policy Matters 12:216-224.

Zimmer, C. 2009, 20 April. As climate warms, species may need to migrate or perish. Yale Environment 360.

http://e360.yale.edu/feature/as_climate_warms_species_may_need_to_migrate_or_perish/2142/

Zipkin, E.F., L. Ries, R. Reeves, J. Regetz, and K.S. Oberhauser. 2012. Tracking climate impacts on the migratory monarch butterfly. Global Change Biology 18:3039-3049.

APPENDIX

Table 1: Covariates used to predict the final model (df=1).

Covariate	**Beta value**	**Standard error**	**Wald**	**p-value**
Oyamel	.077	.019	15.916	.000
Pine	.058	.018	10.367	.001
Temperature (-4 to 4 ^{o}C)	2.212	16.233	.019	.892

Table 2: Overall percentage correct for the third and final step of the binary logistic model.

Colony Presence/Absence	Correct Predicted Percentage
Not present	96.4
Present	89.5
Overall	95.4

Table 3: Importance of each of the selected covariates to the model.

Covariate	**Model Log Likelihood**	**p-value**
Oyamel	-54.235	.000
Pine	-31.882	.001
Temperature (-4 to 4 ^{o}C)	-25.879	.000

Table 4: Summary of the change in area (ha) of suitable monarch habitat, given that oyamel and pine forests do not change their range.

	Area (ha)		
	Current	**B1 2050**	**A2 2050**
MBBR	51016	31301.9	15382.1
Mexico	914214.9	442404.3	312795.2

Table 5: Hotels and inns in 5 communities in Mexico state as of 2012. Data were obtained from IGECEM*.

	Temascalcingo	**Donato Guerra**	**Villa de Allende**	**Toluca**
Total Number	4	1	2	55
5 Stars				2
4 Stars				13
3 Stars	1			3
1 Star	2			5
Family-run Inns	1			2

*The data for San José del Rincón did not include a section on lodging.

Table 6: Tourist infrastructure in 5 communities in Mexico state as of 2012. Data were obtained from IGECEM*.

	Temascalcingo	**Donato Guerra**	**Villa de Allende**	**Toluca**
Tourist Information Office	1	1	1	1
Food and Drink Establishments	5			152
Travel Agents	1			73

*The data for San José del Rincón did not include a tourism section.

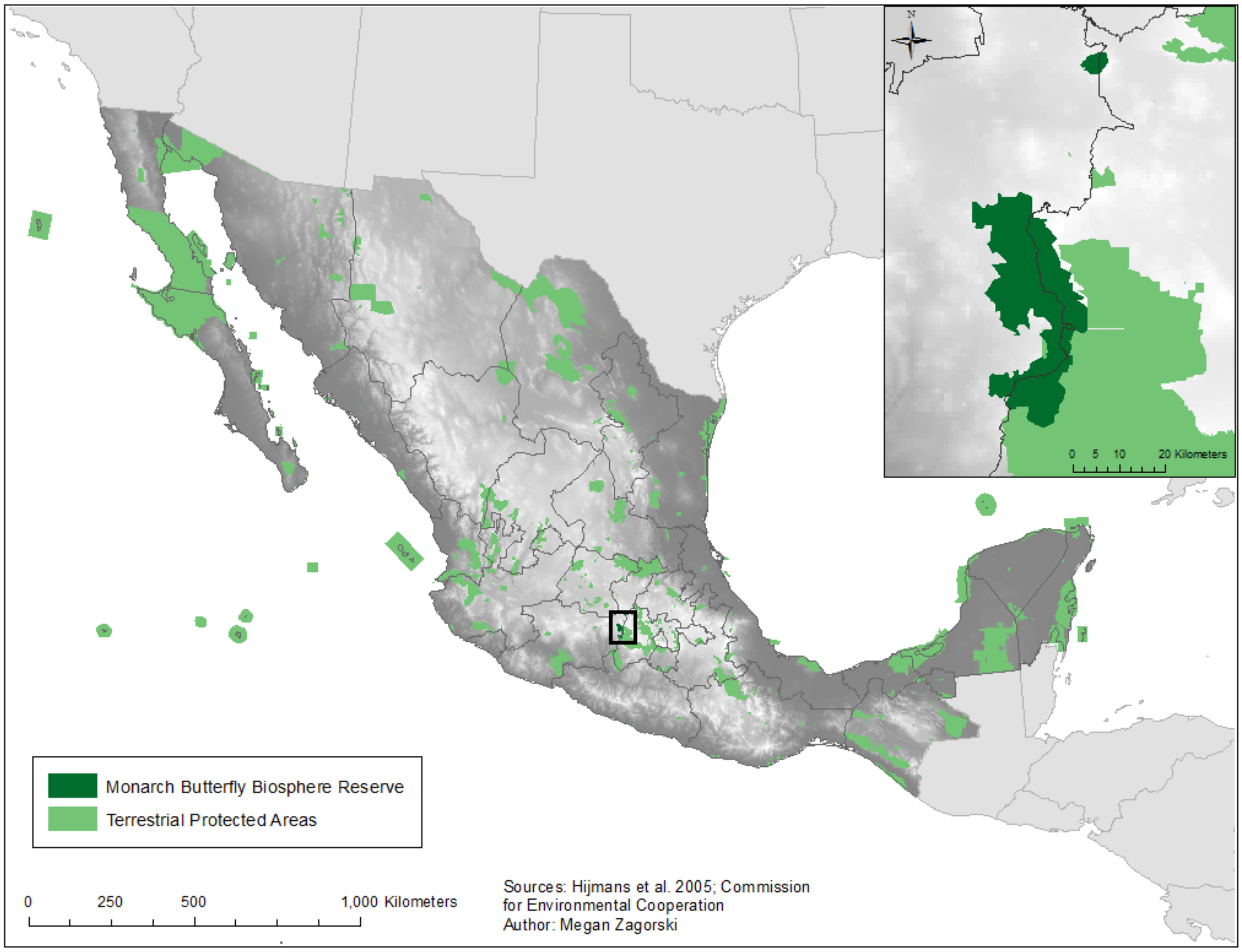

Figure 1: Location of the Monarch Butterfly Biosphere Reserve in relation to other protected areas in Mexico.

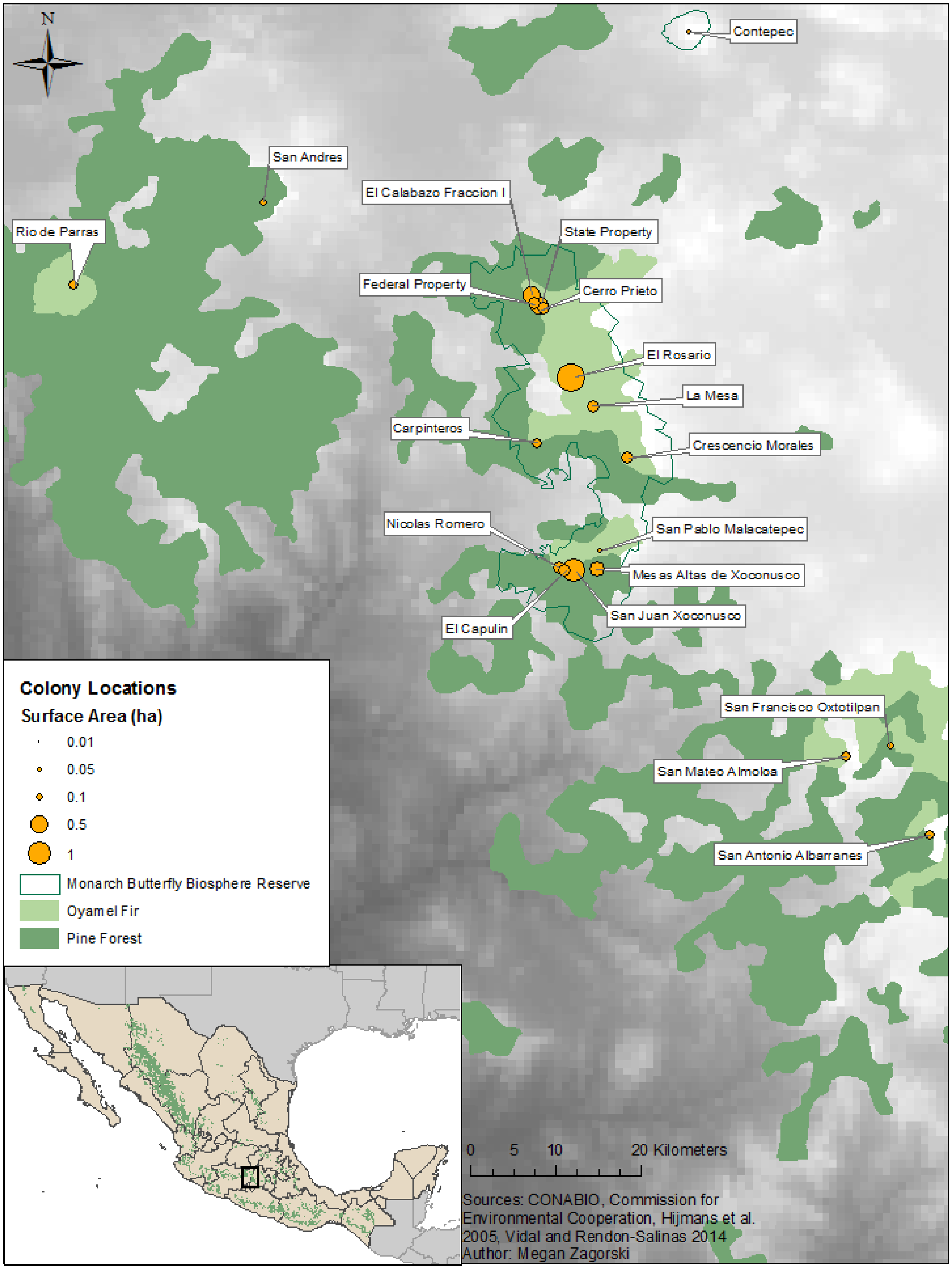

Figure 2: Average location and surface area (ha) of the 19 primary monarch overwintering colonies. Location and surface area were obtained from Vidal and Rendón-Salinas (2014).

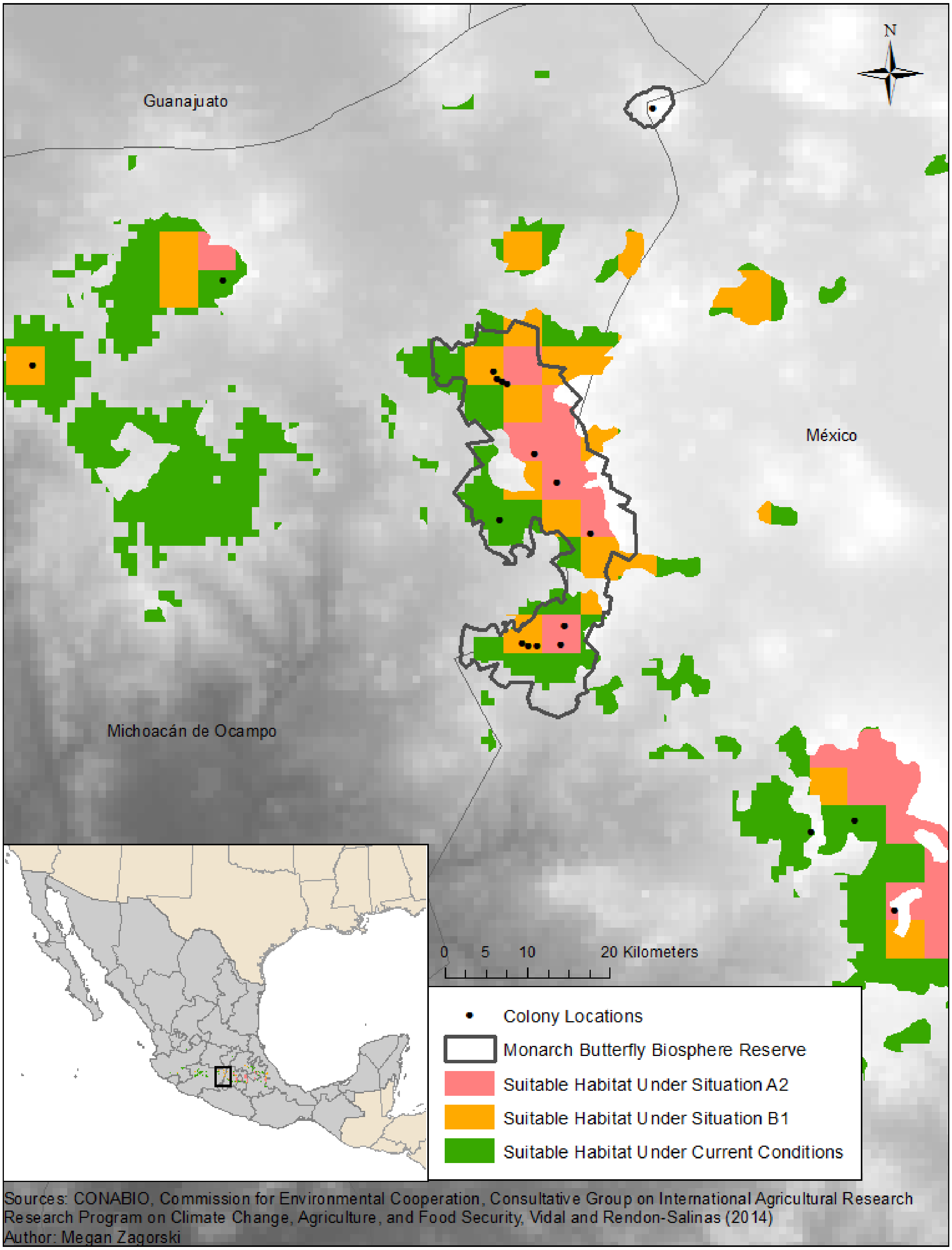

Figure 3: Change in suitable monarch habitat from current conditions to 2050 (IPCC scenarios A2 and B1) in the Monarch Butterfly Biosphere Reserve.

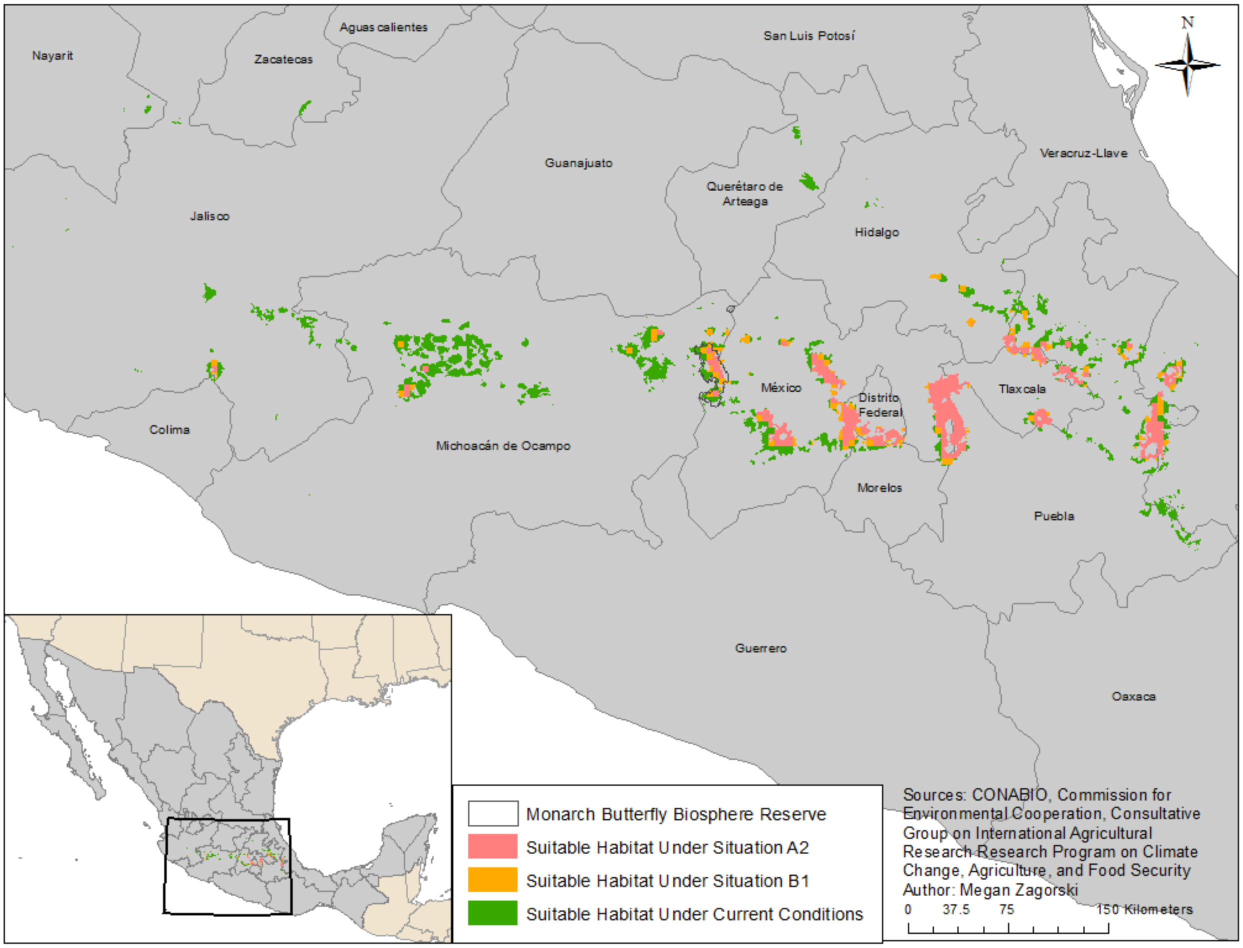

Figure 4: Change in suitable monarch habitat from current conditions to 2050 (Situations A2 and B1) in the Trans-Mexican Volcanic Belt.

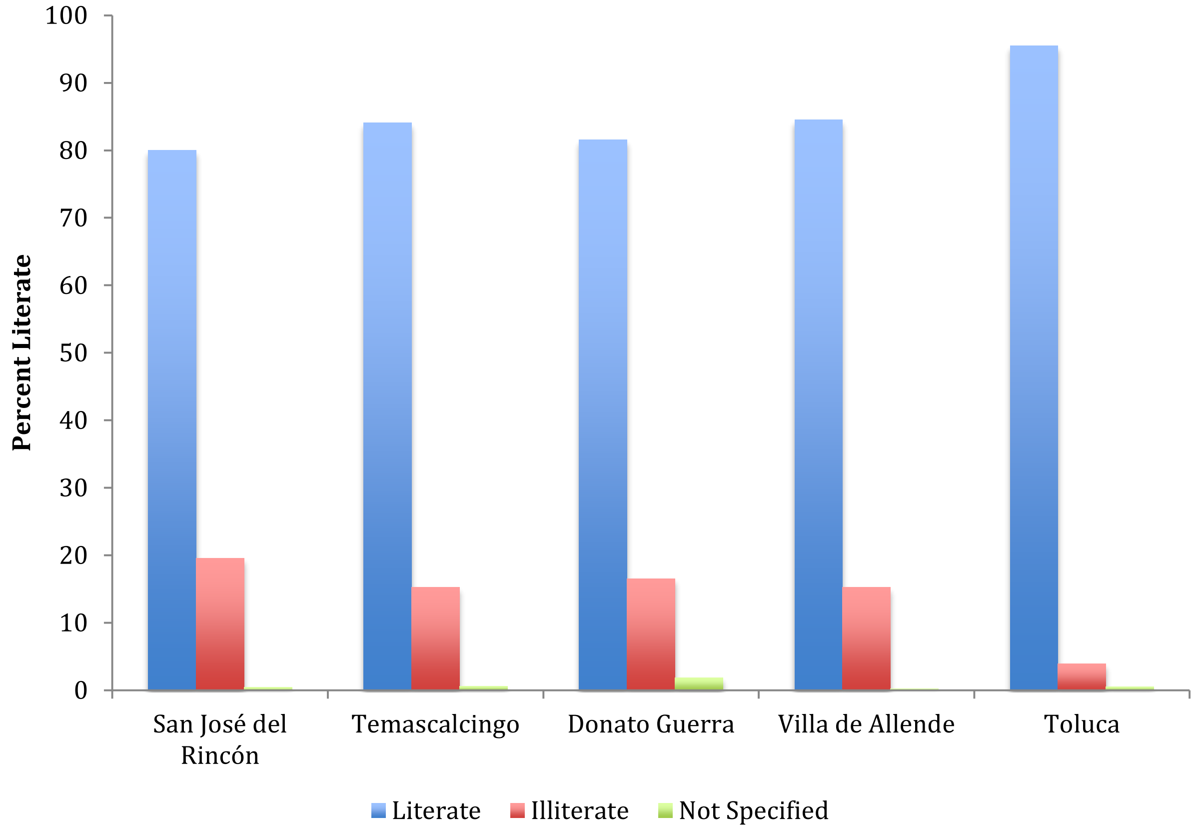

Figure 5: Literacy rates for individuals 15 years and older in 5 communities in Mexico state. Data is from 2010 and was obtained from IGECEM.

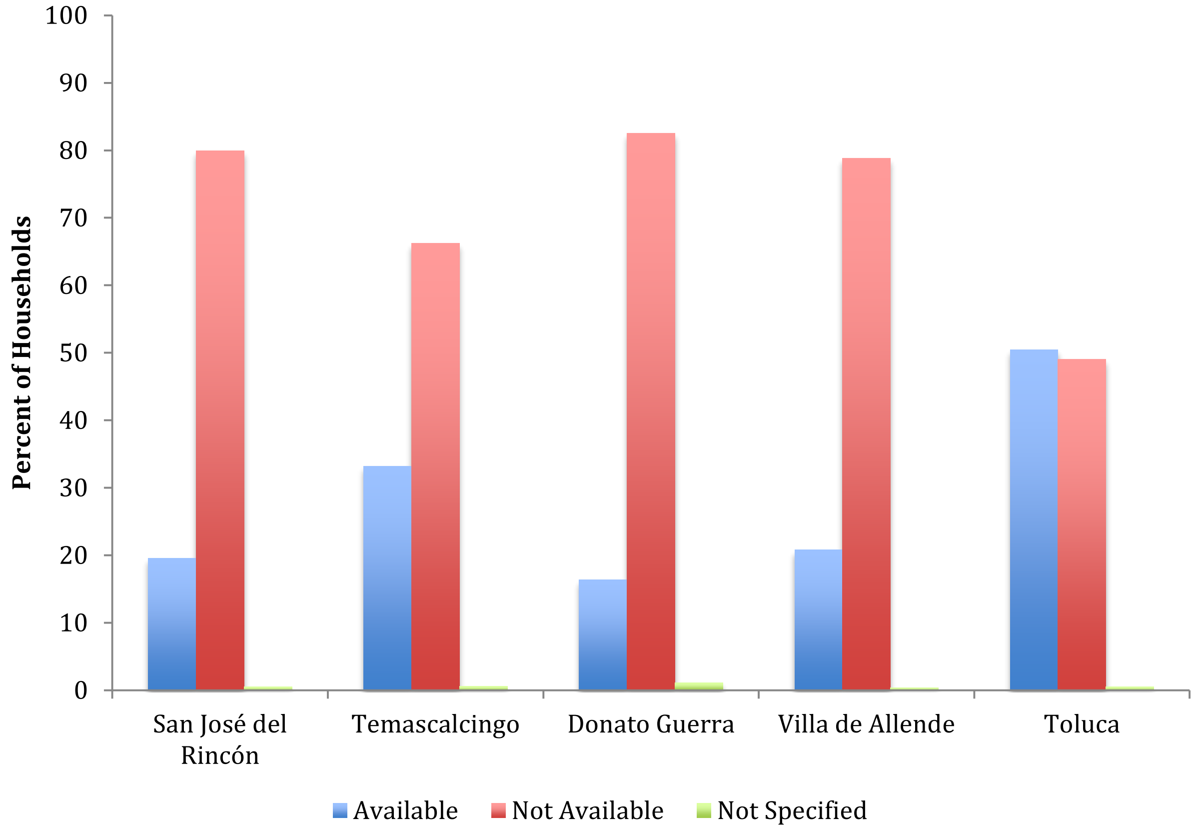

Figure 6: Car ownership in 5 communities in Mexico state. Data is from 2010 and was obtained from IGECEM.

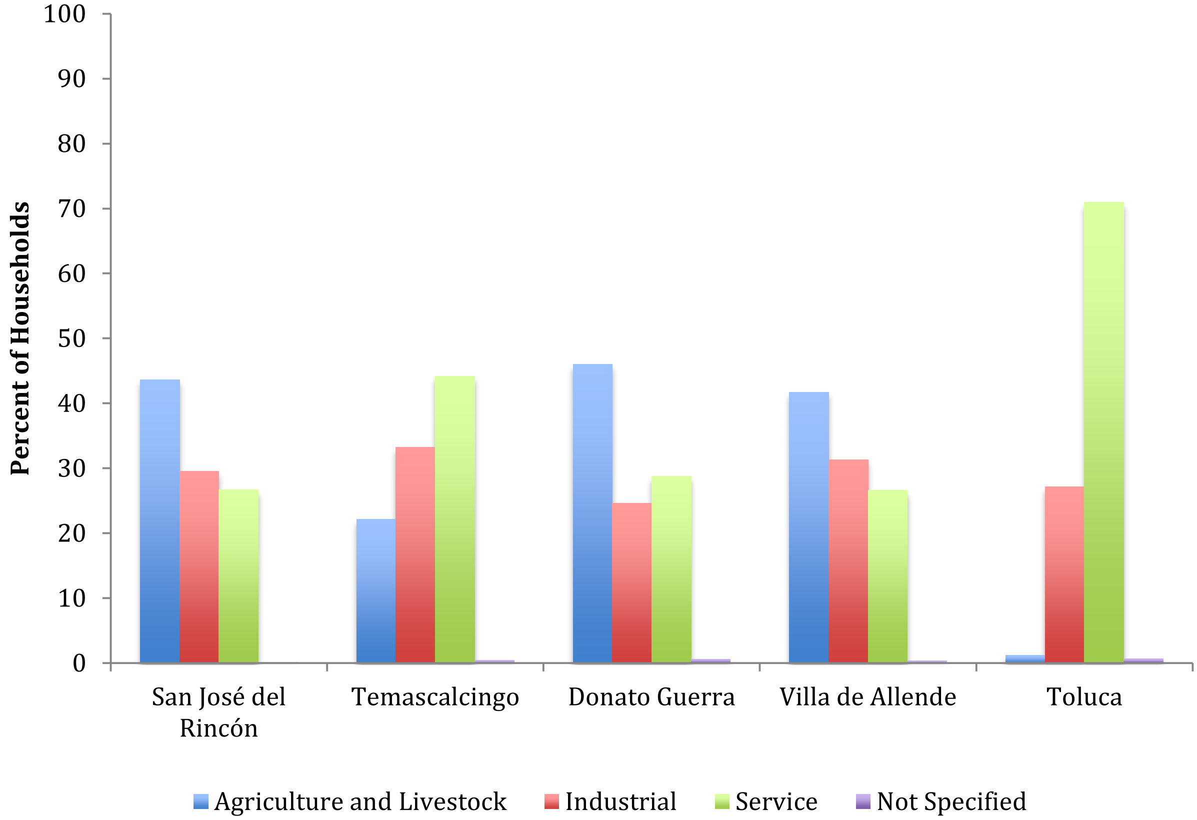

Figure 7: Employment by industry for 5 communities in Mexico state. Data is from 2010 and was obtained from IGECEM.