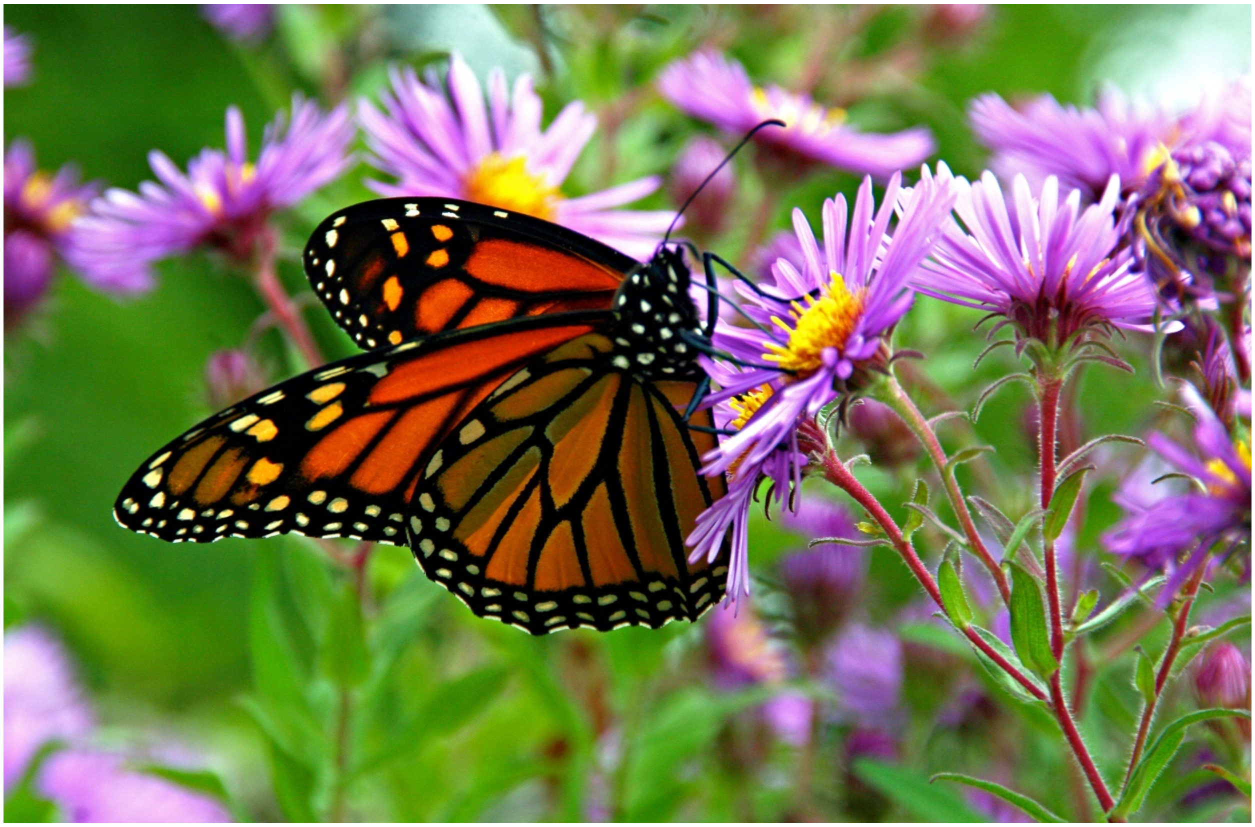

Research Proposal

Can loss of monarch migration habitat across Mexico be attributed to anthropogenic pressures?

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COLLEGE OF LIBERAL ARTS AND SCIENCES
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Abstract

This research quantifies the change in monarch butterfly (*Danaus plexippus)* Fall migration habitat in Mexico and determines where anthropogenic built environment have altered this habitat. Quantifying this change fills a gap in the literature so comparisons can be made across nesting, migration, and overwintering habitat change in relation to declines in the monarch butterfly population. The study area is defined through GBIF occurrence data. Monarch habitat is modeled for 2005 and 2010 with MaxEnt using landcover from the CEC, rivers and streams from the USGS, a DEM from the INEGI. Anthropogenic pressures are modeled for corresponding years using population centers from INGEI, and roads from IMT. A transition matrix is created in QGIS to quantify total monarch habitat change as well as anthropogenic built environment induced habitat change. This research found monarch habitat decreases in mixed forest (14%), shrubland (9%), and wetlands (6%). As well as increases in cropland (6%) and grassland (5%). Anthropogenic built environment contributed to 11% loss in mixed forest, 4% loss in shrubland, 2% loss in wetland, and an increase in 6% cropland, and 4% grassland. Monarch migration habitat is decreasing and largely modified through anthropogenic built environment. This is believed to be caused by the large economic dependence on agriculture in migration habitat. Loss of migration habitat is parallel with the declining monarch population. Further, the author suggests a correlation analysis between the decline of each habitat, nesting, migration, and overwintering, relative to the decline in monarch populations to determine the primary driver.

Introduction

The North American monarch butterfly (*Danaus plexippus)* is notably recognized for the cultural ecosystem services it provides, but in 2015, the United States White House placed it second to honey bees for insect pollinator conservation priority. Throughout the monarch's immense 4,000 km extent of habitat, nesting, migratory, and overwintering habitats have undergone loss resulting in a precipitous decline of the species. The relative impact of each type of habitat loss has been theorized, but without a complete picture, there is no consensus. Nesting habitat has been studied in relation to the milkweed (*Asclepias*) and changes in overwintering habitat is well documented, with analyses from 1971, and models projecting late into the 21st

century. This research analyzes the change in monarch migration habitat in Mexico to address the gap in the literature.

In the Midwest, where nearly half of the monarch's breeding grounds are represented, monarch production has experienced an 81% decline from 1999 to 2010 (Pleasants & Oberhauser, 2013). Agricultural intensification, the introduction of genetically modified (GM) crops, and consequent pesticide and herbicide applications have been shown to decrease the milkweed, the monarchs sole nesting plant (Pleasants & Oberhauser, 2013; Schütte et al., 2017; Stenoien et al., 2016). Pleasants and Oberhauser (2013) suggests a strong correlation in the monarchs decline with the loss of milkweed.

Decline of overwintering habitat has been attributed to illegal logging, agricultural expansion, and extreme weather events (Honey-Rosés, 2008; Vidal & Rendón-Salinas, 2014). Historical accounts of deforestation and disturbance have been analyzed from 1971 to 1999 (Brower et al., 2002). Further literature, exploring illegal logging, timber harvesting, natural disasters, agricultural expansion, and natural forest loss, was consolidated in Honey-Rosés (2008) deeming illegal logging as the primary driver. In 2013, overwintering monarchs occupied only 0.67 ha, compared to the preceding 19-year average of 6.3 ha (Vidal & Rendón-Salinas, 2014). Studies have continue to explore these factors and make projections with climate models for the future, which anticipate further habitat decline (Sáenz-Romero et al., 2012; Zagorski, 2016).

Migration habitat, and its significance to the decline of the monarch population, remains a gap in the literature. It has been suggested that feeding during southern migration, particularly in Texas and Mexico, is essential to overwintering survival (Brower, Fink, & Walford, 2006; Buckley & Nabhan, 2016; López-Hoffman et al., 2010). Land management and disturbed areas are documented as important for increasing the supply of nectar producing flora (Rudolph et al., 2006). Additionally, the importance of forest, cropland , and grassland for roosting (Davis, Nibbelink, & Howard, 2012). However, land use/cover change in these areas has not been quantified and the correlation with monarch decline has not been documented. This lack of knowledge has made it difficult to determine the significance of migration habitat relative to nesting or overwintering habitat for the survival of the monarch butterfly.

Current migration research implies, the success of surviving overwintering and returning north to breed, is dependent on successful migration. This includes adequate nectar producing flora and adequate roosting habitat along migration corridors. This research is the first to quantify how this habitat has been changing in Mexico. It addresses the gap in the literature of monarch migration habitat change. Additionally, it provides the foundation for many important questions to be answered. This knowledge allows a comparison across nesting, migration, and overwintering habitats to draw a more definitive conclusion on the primary driver of monarch butterfly population decline. It allows questions, such as the significance of nectar producing flora and roosting habitat, to be addressed. Additionally, how change in migration habitat is correlated with the decline of the monarch butterfly. This research allows future study to obtain a complete understanding of the how each monarch butterfly habitat impacts the success of the species.

Literature Review

This study measures the area of monarch migration habitat in the Texas/Mexico flyway, or corridor, that is converted to population centers, roads, and deforested from 2005 to 2010. This research is important, because the lipids monarchs receive during this stretch of their migration are crucial for surviving overwintering and there is currently lack literature available on this topic.

The Importance of Monarchs

Monarch butterflies (*Danaus plexippus*) are a unique migratory species that serve as a tri-national transboundary pollinator with eastern populations traveling over 4000 km from the Great Lakes in southern Canada to overwintering sites in the *Abies religiosa* (Oyamel or sacred fir) forests of central Mexico (Brower, Fink, & Walford, 2006; Vidal & Rendón-Salinas, 2014a). This habitual migration spans farther than any other insect, excluding the dragonfly (*P. flavenscens)*, and can take four generations to complete (Anderson, 2009). During the monarch's migration, they provide regulatory ecosystem services through the propagation of nectar corridors, which symbiotically provide sustenance for a variety of pollinators (Buckley & Nabhan, 2016). Stressing their importance, the White House places monarch butterflies as their top pollinator conservation priority behind the honey bee (WH, 2016). Renowned as a cultural ecosystem service, the monarch has become the state insect of seven U.S. states, the official insect of Quebec, and the Monarch Butterfly Biosphere Reserve (MBBR) in Michoacán, Mexico was declared a UNESCO world heritage site in 2008.

Pollinators provide crucial ecosystem services that aid in at least 75% of agriculture production, facilitate the propagation of flora, maintain healthy habitats for many species, offer cherished cultural amenities, and add billions of dollars to the US economy alone (Marks, 2005). In efforts to quantify the value of the monarch butterfly to US citizens Diffendorfer et al. (2014) consolidated valuation surveys conducted by the National Gardening Association (NGA). The goal of this was to determine how much market based approaches could be used in conservation efforts. Individuals, stratified by demographics and earnings, demonstrated willingness for a one-time payment between $4.78 and $6.64 billion dollars to support monarchs. This was calculated as an aggregate of plant spending on nectar and nesting plants, as well as providing donations. The authors also found that 55% of Americans were not even aware that monarch populations are in decline. It should be noted that out of the 2,290 respondents, 2,132 lived in monarch prevalent areas (Diffendorfer et al., 2014).

Monarch Habitat

Migrating pollinators, such as the monarch butterfly, require three types of habitat to survive: a) Nesting, host plants for safe reproduction; b) migration, nectar corridors that provide fuel, shelter, and water; and c) overwintering sites, consistent suitable climate and sustainable accommodations. Nesting habitats have been generally characterized by the presence of milkweed, the sole host plant for monarch larvae (Flockhart et al., 2015). The extent can range from the southern United States to Canada bordering on the Great Lakes. The exist in East and West distributions seperated by the Rocky Mountains. Western populations generally reside in California through out the entire year (Brower et al., 2006).

Nectar for migratory habitats is abundant in areas conducive to flowering flora. This includes grasslands and fields, as well as forests with prescribed burns and roadsides without herbicide application (Rudolph et al., 2006). Monarchs also require bodies of water for hydration and forest for roosting (Davis et al., 2012). The extent of migratory habitat can range from Canada to overwintering sites in Michoacán, Mexico and Mexico State (Brower et al., 2006; Vidal & Rendón-Salinas, 2014a).

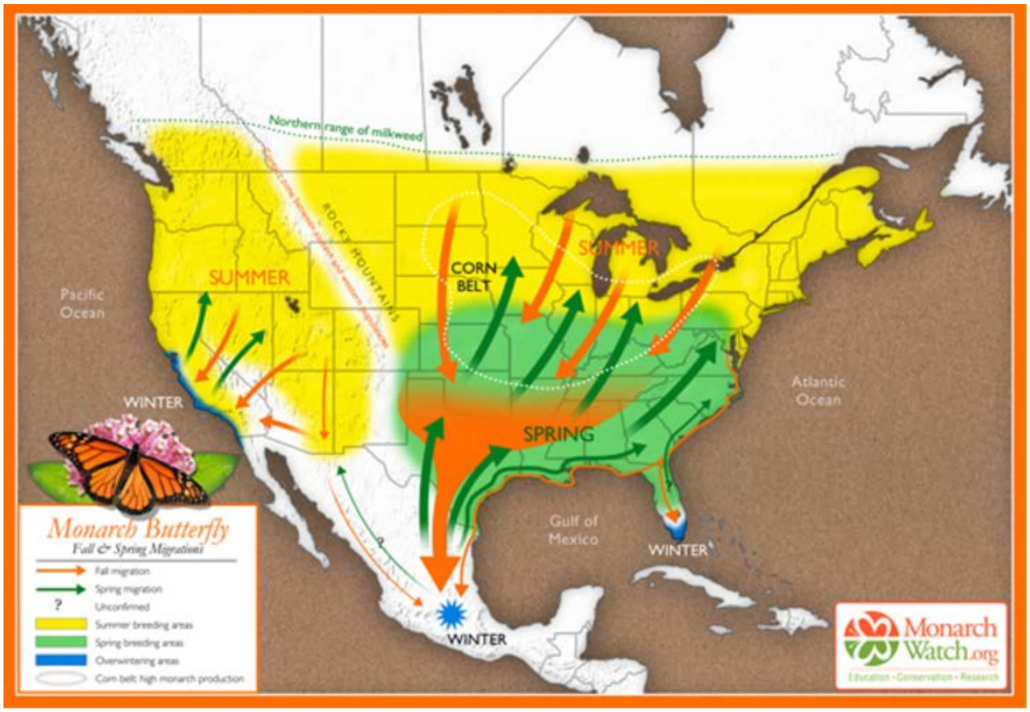

Figure 1. Monarch butterfly migration corridors cartographic illutration

Overwintering monarchs have been found in 19 colonies on the top of mountain massifs in the Trans-Mexican Volcanic Belt of Michoacán and Mexico State, between latitudes 19° and 20° North (Vidal & Rendón-Salinas, 2014a). 14 of these colonies can be found with the MBBR. Here, they exist in microclimates within *Abies religiosa* dominate forest, starting at high elevations, in primarily forest core, and working their way downhill towards the end of winter (Brower et al., 2016; Lemoine, 2015). Decline of these habitats has been facilitated largely by illegal logging (Honey-Rosés, 2008).

Threats to the Monarch in the United States

A variety of threats face the monarch and have been recognized as contributors to its precipitous decline. Its large distribution range and migratory routes have been changed by anthropogenic activity directly and indirectly. The largest impact on nesting and breeding habitat has consistently been referred to as agricultural intensification, the of the use of GM crops, and the consequent application of herbicides (Pleasants & Oberhauser, 2013; Schütte et al., 2017;

Stenoien et al., 2016). These uses are especially harmful to pollinator breeding habitat. Schütte et al. (2017) has indicated that the considerable decline of milkweed, the monarch's exclusive larvae host plant, has resulted indirectly from the adoption of herbicide resistant (HR) crop strains. The main argument in the study is that, HR crops are used to decrease biodiversity, and intern, have damaged species richness even beyond farmland (Schütte et al., 2017).

Table 1. Total milkweed and monarch egg production in agricultural and non-agricultural fields from 1999 to 2010

Year	Total non-ag milkweeds*	Total ag milkweeds*	Eggs/ plant-non-ag†	Eggs/ plant-ag‡	Production non-ag§	Production ag¶	Total production**
1999	185.4	213.2	0.243	0.945	45.0	201.4	246.5
2000	187.1	183.8	0.144	0.796	26.9	146.3	173.2
2001	195.0	155.4	0.299	1.661	58.3	258.2	316.5
2002	191.5	133.4	0.197	0.659	37.6	87.9	125.5
2003	184.7	115.8	0.173	1.125	31.9	130.2	162.1
2004	177.9	99.4	0.102	0.395	18.1	39.3	57.4
2005	172.0	85.2	0.205	0.796	35.2	67.8	103.0
2006	167.5	72.8	0.277	1.077	46.4	78.5	124.9
2007	161.4	62.8	0.274	1.066	44.2	66.9	111.1
2008	146.6	54.4	0.154	0.599	22.6	32.6	55.2
2009	135.7	46.9	0.120	0.465	16.2	21.8	38.0
2010	127.4	40.3	0.311	1.210	39.6	48.7	88.4

*$m^2 \times 1000$; from Table 1.
†from MLMP.
‡Non-ag eggs/plant × 3.89 (ratio of ag to non-ag, see Table 2), except for 2000–2003 from Table 2.
§Total non-ag milkweeds × Eggs/plant non-ag.
¶Total ag milkweeds × Eggs/plant ag.
**Production non-ag. + Production ag.

Nearly half of the North American monarchs that overwinter in Mexico, migrate from the Midwest, where milkweed has been largely destroyed by agriculture. To understand the implications of this loss of nesting habitat, Pleasants & Oberhauser (2013) observed the change in milkweed populations and compared them to overwintering populations of monarch for the same time period. Milkweed densities were calculated through the Iowa census, 1999 and 2009, and validated by the MLMP (Monarch Larva Monitoring Project), a citizen science initiative to monitor monarch larva production in Canada and the United States. An extrapolation was made to determine monarch production from MLMP data suggesting an average number of eggs per milkweed stem. This study covered agricultural and non-agricultural areas. Pleasants and Oberhauser (2013) found a 31% decline for milkweed in non-agricultural areas and an 81% in agricultural areas, with an aggregate 58% decline. The monarch butterfly production decline was estimated to be 82%. Milkweed in agricultural areas is significant because the number of eggs per stem is 3.89 time higher (Pleasants & Oberhauser, 2013).

Efforts have been made to assess whether a correlation exists between the decline in milkweed and decline of the monarch butterfly in overwintering sites. Inamine et al. (2016) used 22 years of citizen science records over successive migratory regions from the US Northeast, the Midwest, and Texas, acquired through the North American Butterfly Association (NABA, 2016). Overwintering counts, used to determine geographic correlation of decline, were acquired through the World Wildlife Fund (WWF, 2016). The analysis of these counts showed monarch populations have experienced little decline in the US and conversely, the most decline in Mexico

(Inamine et al., 2016). The study concluded showing increased fragmentation in migratory habitat as the primary factor of monarch decline. While the findings in Inamine et al. (2016) corroborate earlier work, such as Davis and Dyer (2015), subsequent studies have pointed to flaws in the data.

Stenoien et al. (2016) has refuted the claims from Inamine et al. (2016), suggesting instead, that loss of nesting habitat has accelerated the monarch's population decline. The research of Stenoien et al. (2016) focuses on the loss of milkweed in the Midwest due to the spread of GM crops, the application of glyphosate, and the densities of monarch egg counts on milkweed. In examination of NABA data, Stenoien et al. (2016) noted that counts are conducted by volunteers whose attendance is variable by year and location. Even counts at similar locations can yield different results. Volunteers are oriented at sampling locations by personal preference and general exclude urban environments and agricultural fields. Since monarch nesting habitat has been converted into GM agricultural areas, logic should follow that if monarch populations remain consistent, a higher density of monarchs should be counted per nesting area, thus the conclusion of Inamine et al. (2016) was formed from a spatial bias (Stenoien et al., 2016).

The Role of Lipids

Due to the immense distance and complete reliance on nectar for sustenance, migratory habitats are exceptionally important for the monarch. When monarchs feed on nectar from forbs, they accumulate lipids, which serve as their energy stocks. These are not only necessary for completing the migration, but are even more vital in surviving overwintering (Brower et al., 2006). Brower et al. (2006) conducted surveys for 4 years in Virginia from 1998 to 2001 extracting lipids from routine monarch samples. This was compared to monarch lipid level of overwintering colonies in Mexico. Because lipid levels in Virginia were 4% of what they found in Mexican butterflies, it was concluded that little lipid gathering occurred before Texas. Further, has been suggested that lipid collection is most important between Texas and overwintering sites in Mexico, particularly in areas where butterflies can roost (Brower et al., 2006).

Land management can facilitate the success or decline of herbaceous flowering plants that support migratory habitat. Rudolph et al. (2006) examined the recent historical practice of fire suppression on natural lands as it relates to the abundance of nectar producing flora. The research took place in the Ouachita Mountains of west-central Arkansas from 1999 to 2004, where herbaceous flowering plants where counted by season in fire suppressed areas and areas that had conducted prescribed burns. In general, areas with an absence of prescribed burns had sparse amounts of nectar producing flora, whereas in disturbed areas, nectar resources were abundant. Disturbed areas included, "road verges, utility rights-of-way, fence rows, and areas of recent timber harvest" (Rudolph et al., 2006). However, total nectar concentrations in disturbed areas were unable to be calculated due to their patchy fragmented distribution.

Due to increasing average temperatures, wildflower peak flowering times are occurring 3 to 5 weeks earlier, while monarch butterfly migration patterns remain the same (Buckley & Nabhan, 2016). This phenomenon was referred to by Buckley and Nabhan (2016) as a phenological gap. Implications for monarchs to miss prime opportunity in their migration to accumulate lipids has raised concern. The authors provided a meta-analysis focusing on the nectar corridor between Texas and overwintering sites in Mexico and advocate transnational coordination to bolster food chains, such as species of *Asteraceae*, and watercourses on both sides of the border (Buckley & Nabhan, 2016; López-Hoffman et al., 2010)

Nectar Corridors, a Gap in the Literature

Nectar corridors into and through Mexico are some of the most crucial to the survival of overwintering monarch colonies (Brower et al., 2006; Buckley & Nabhan, 2016; López-Hoffman et al., 2010). While widely distributed roosts have been identified across the US, indicative of several major flyways, or migration corridors, we are led to believe there is only one major flyway through Mexico to overwintering sites (Howard & Davis, 2009). This is assumed to begin at the confluence of the two Texas flyways. The Central Texas flyway, the primary corridor through the center of the state, and Coastal Texas flyway, which follows the Gulf coast (Calvert & Wagner, 1997; Howard & Davis, 2009) Outside of this, there is very little written about the migratory corridor(s) through Mexico, to and from overwintering sites. This is certainly a gap in the literature and an important one for monarch conservation.

Illegal Logging in Overwintering Sites

Forest conservation of the *Abies religiosa* forests of central Mexico has been at the forefront of protecting monarch overwintering habitat. Illegal logging has historically been the primary driver of deforestation, with contemporary enforcement and management efforts attempting to curb this phenomenon (Honey-Rosés, 2008; Vidal & Rendón-Salinas, 2014a). Some of the first quantitative data analyzing the *Abies religiosa* forests was published by Brower et al. (2002) and uses photogrammetry to cover years 1971 to 1999. This was inclusive of the 12 mountain massifs in the Trans-Mexican Volcanic Belt, between latitudes 19° and 20° North, known to house overwintering colonies of the monarch. Using GRASS GIS, the authors analyzed a total of approximately 11,700 km^2 *Abies religiosa* dominate, mixed forest. While definitions of disturbed and degraded, or altered and semi-altered, forest vary throughout the literature, the trend of human influence changing monarch butterfly overwintering habitat remains consistent. The authors found 44% of the forest in the study area was either disturbed (falling to 30% to 80% forest coverage) or degraded (falling below 30% forest coverage), between 1971 and 1984, and 38% between 1984 and 1999.

Navarrete et al. (2011) defined disturbance as forest cover falling to between 40% and 70% and degradation falling below 40%. From 1993 to 2006, the disturbed area 5,239 ha were estimated to be disturbed. While 6% of this was authorized timber extraction, 61% was illegal logging (Navarrete et al., 2011). Vidal et al. (2014b) defined degradation as the forest cover total percentage falling into a lesser quantile post change and deforestation as forest cover lessening to below 10%. From 2001 to 2012, 1,254 ha of forest in core zones were deforested and 925 degraded, 2,057 ha of the total disturbed area was a product of illegal logging (Vidal, López-García, & Rendón-Salinas, 2014b).

To this date, illegal logging is still the primary threat to overwintering sites. Between 2013 and 2015, 10 hectares of forest were cleared due to illegal logging in the Sierra Chincua of the MBBR (Brower et al., 2016). This section of forest is vital, as it makes up a core area where overwintering populations have been located. From the monarchs November arrival in the MBBR, gatherings form at the headwaters of the Sierra Chincua arroyos and through the season, migrate downslope to these areas that have been logged . Brower et al. (2016) express concern that logging in this area could lead to premature return migration to the United States.

Honey-Rosés (2008) conducted a meta-analysis of threats to overwintering sites to better provide a consensus of the literature. This study reviewed publications concerned with natural forest loss (from disease, old age, or strong winds), agricultural clearing, domestic timber extraction, forest fires, authorized timber harvesting, and illegal logging. While agricultural clearing has been a popular conclusion as the primary factor, identification of each factors relative impact demonstrated that illegal logging was the greatest contributor to deforestation (Honey-Rosés, 2008).

Navarrete et al. (2011) provided an analysis to determine the significance of FMP (Forest Management Programs) on LTU (land tenure units), in regards to deforestation. 26 LTU with FMP were included in the study, with 13 inside the buffer zone of the MBBR and 13 in the core zone. The presence of FMP did not yield homogeneous results in either zone. However, LTU that experienced land use change, showed a higher probability for illegal logging (Navarrete et al., 2011).

Illegal logging has been explored as a product of unfavorable socio-economic conditions in Michoacán. Over 1 million people neighboring the reserve live in poverty. Low wages, large agrarian communities, seasonal migratory occupations, and reliance on wood for fuel are believed to incentivize illegal logging as a quick and lucrative means of income (Vidal et al., 2014b). From 2005 to 2007, areas of the reserve inhabited by indigenous groups experienced 731 ha of illegal logging (Vidal & Rendón-Salinas, 2014a). From 2007 to 2014, increased law enforcement presence, philanthropic economic stimulus, and payment for ecosystem services programs, have been credited to be large deterrents of illegal logging (Vidal & Rendón-Salinas, 2014a)

Monarch overwintering populations have been typically measured through the total area they occupy (Inamine et al., 2016; Pleasants & Oberhauser, 2013; Vidal & Rendón-Salinas, 2014a). Calculating a 19-year average from 1993 to 2013, the total overwintering area mean per year has been 6.3 ha. The data presented by Vidal & Rendón-Salinas (2014a) shows a strong decline in overwintering colonized area, with only 0.67 ha occupied by monarchs in 2013.

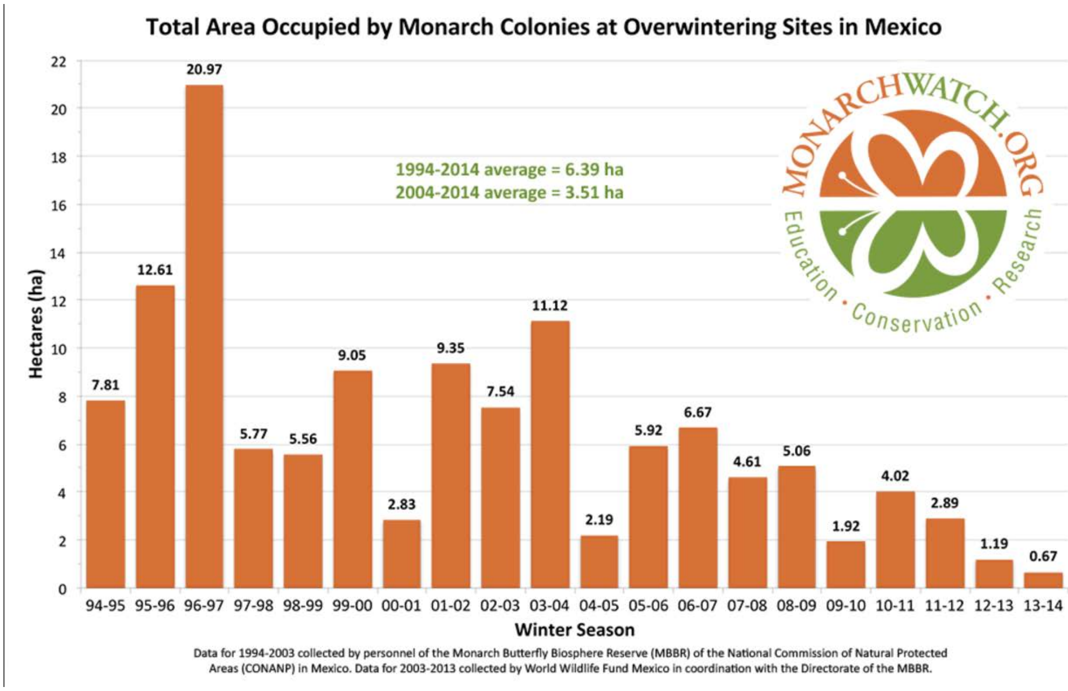

Figure 2. Total area occupied by overwintering monarch colonies in the Monarch Butterfly Biosphere Reserve

Modeling Habitat

Habitat quality, fragmentation, connectiveity, and disturbance have been key issues for indivudal species and biodiversity (Hanski, 2011; Prugh et al., 2008). To better understand the changing extent of a species habitat, Ecological Niche Modeling (ENM), otherwise known as Species Distribution Modeling (SDM), has become an imporant tool. In the study of monarch butterflies, a particular ENM, GARP (genetic algorithm for rule-set prediction), has been popular at modeling the monarchs habitat (Batalden et al., 2007; Oberhauser & Peterson, 2003). These studies use species occurance data overlayed with environmental variables and algorithms, such as GARP, extrapolate these occurances to model the extent of the species habitat. ENM is even used to model species richness for *Nymphalidae* (White & Kerr, 2006). The process of creating an ENM or SDM, is explored comprehesively in the seminal article, Guisan and Zimmermann (2000). Environmental data sources, varying algorthisms, and citations of their usage, can be found in Miller (2010).

The occurance data for SDM can be extracted from databases and modeled using statistical programming lanuages such as R (Hijmans & Elith, 2017). For data collection and extraction, R can interface with occurance data catalogs through programming libraries such as dismo and rgbif. Global Biodiversity Information Faciltiy (GBIF) is now a widely used database for species occurance data, and the largest, most comprehensive of its kind (Beck et al., 2014; Fei & Yu, 2016; Töpel et al., 2016). However, this is met with speculation. The quality of the data has been questioned, because of uneven temporal and spatial clustering of data collection, spatial bias has been suggested (Beck et al., 2014). Although there is no consensus on accounting for and correcting spatial bias, various methods have been tested. Sytemic Sampling, in which neighboring and redundant samples are removed by defining a minimum gridcell, where only one sample can exist at a time, has been shown to be effective in correcting spatial bias (Fourcade et al., 2014). This can lead to an underrepresentation of habitat.

Recently, MaxEnt has become the most popular SDM software, typically outperforming others due to its highly accurate predictive algorithms and ease of use (Merow, Smith, & Silander, 2013). MaxEnt has been found particular better than more traditional algorithms, such as GARP, for modeling the habitat of *Danaus plexxipus* (Hernández et al., 2006). The accuracy is highly variable upon the quality of occurance data and the significance of environmental variables chosen (Syfert, Smith, & Coomes, 2013). Syfert (2013) found error rates, including false presence and absence, upto 20% after correcting for bias. Solutions for correcting spatial bais can include spatial filtering the sample population to avoid overfitting (Boria et al., 2014). Fourcade et al. (2014) evaluates 5 methods for reducing spatial bias within MaxEnt finding Systemic Sampling (described above) to be the most effective.

For the monarch specifically, various environmental variables have been used to explain their habitat. The ecological niche for monarchs in nesting areas has been found to be prevasive, but consitent using environmental variables such as temperature (minimum, maximum, and mean), solar radiation, precipitation, elevation, slope, aspect, and water accumulation (Batalden et al., 2007). Addtionally, the presence of the milkweed is conceivably a very strong indicator of nesting habitat (Flockhart et al., 2015; Pleasants & Oberhauser, 2013).

Migration habitat has not been studied in great detail, despite the imparative of lipid accumulation to survive overwintering. Efforts to explore migration habitat include a four year census and lipid measurements during fall migration. Results demonstrated a higher density of monarchs near fields containing goldenrod, aster, clover, alfalfa, as well as along streams and roadways where herbicides were not applied (Brower et al., 2006). Monarchs also have fairly predictiable roosting locations. 97% are found within a 10km radius of pine, conifer, willow, pecan, oak, and/or maple trees, with the majority of roosts being near a water sources (Davis et al., 2012). Roosts appear more frequently in croplands and grasslands as the migration heads south. In central Texas, 67% were found near cropland and in southern Texas, 61% were found in grassland (Davis et al., 2012).

Within the 19 overwintering colonies that monarchs are found, they require very particular microclimatic conditions to survive (Vidal & Rendón-Salinas, 2014a). They have been found at altitudes from 2200 to 3600 meters in primarily late succession vegetation, specifically *Abies religiosa*, *Pinus-Quercus*, and *Cupressus* (Ramírez, Azcárate, & Luna, 2003). Grasslands and shrubs have also been included in identifying their habitat. Bojórquez-Tapia et al. (2003) evaluates overwintering environmental conditions with GIS, finding an increase in monarch presence above 2890 meters, on moderately steep slopes, in non-deforested pine-oak and fir forest, south-southwest aspect, and within 400 meters from streams. Further evaluated factors include precipitation, potential irradition, proximity to human settlements and roads, but no exact significance was provided. After overwintering habitat was modeled, 56% of monarchs were found in core areas and 25% in buffer areas of the MBBR(Bojórquez-Tapia et al., 2003).

Since *Abies religiosa* forest is strongly associated with the microclimates monarchs need to survive overwintering, declines in the total *Abies religiosa* canopy cover may reduce overwintering habitat in the MBBR (Sáenz-Romero et al., 2012). Several models have been used to emulate future climatic conditions, *Abies religiosa* habitat, and estimate the effect on overwintering monarch populations. Sáenz-Romero et al. (2012), following Iverson and Prasad's (1998) bioclimate model, uses the randomForest package in R, and climate grids (available from: http://forest.moscowfsl.wsu.edu/cli- mate/). The study finds a decline in total canopy cover of *Abies religiosa* of 69.2% by 2030, 87.6% by 2060, and 96.5% by 2090. The authors conclude by saying future overwintering habitats may not occur in the MBBR nearing 2100.

Other climate models have used GIS to quantify the loss of suitable habitat for the monarch. Zagoriski (2016) used 8 environmental variables, including temperature, water bodies, aspect, and vegetative cover to create depictions of conceivable overwintering area. The author estimates a loss of 38.6% to 69.8% of habitat within the MBBR by 2050 and 52% to 76% for the entire Trans-Mexicn Volcanic Belt (Zagorski, 2016).

Modeling Anthropogenic Impact

There is no consensus on how to model anthropogenic impact. Even when considering similar species, it can be modeled and assessed a variety of ways. Anthropogenic indicators of disturbance or degredation have been listed as agriculture, populated areas, roads and highways, powerlines, irrigation canals, railroads, campgrounds, oil and gas wells, landfills, and rest stops (Leu, Hanser, & Knick, 2008). Some researchers differentiate between human areas, and semi-natural areas identified as privately own woodlands and rangelands (Ellis et al., 2010). Others have modeled human behavior in relation to anthropogenic features, such as including walking distance from roads and urban centers, simulated with cost distance matrices using slope as a friction raster (Moreno-Sanchez, Moreno-Sanchez, & Torres-Rojo, 2011). Different activities that result in deforestation (e.g., illegal logging, timber harvesting) are also reviewed as varying levels of anthropogenic impact (Vidal et al., 2014b). Mckinney (2009) seperates anthropogenic disturbance into physical gradients and habitat-loss gradients. Phyiscal gradients are the direct impacts, population centers, built-up areas, and roads, whereas habitat-loss gradients are the natural losses, or indirect impacts, stemming from the physical gradients. This research looks specificly at physical gradients.

Methods

This study examines anthropgenic disturbance in monarch migration habitat of the Texas/Mexico flyway. Monarch habitat is generated through species distribution modeling based off of GBIF occurance data and select environmental variables, then disturbance is classified as the percentage in land cover change from monarch habitat to anthropogenic environmental variables.

Study Area

The study area includes the migratory flyway between the border of Texas and overwintering sites in central Mexico. QGIS 2.18.3 is used to create a bounding box around the 4,024 *Danaus plexippus* occurance locations in Mexico between 2005 and 2010 from the GBIF database. Occurance data not part of the Texas/Mexico flyway, on the border of Arizona, is exluded from the study.

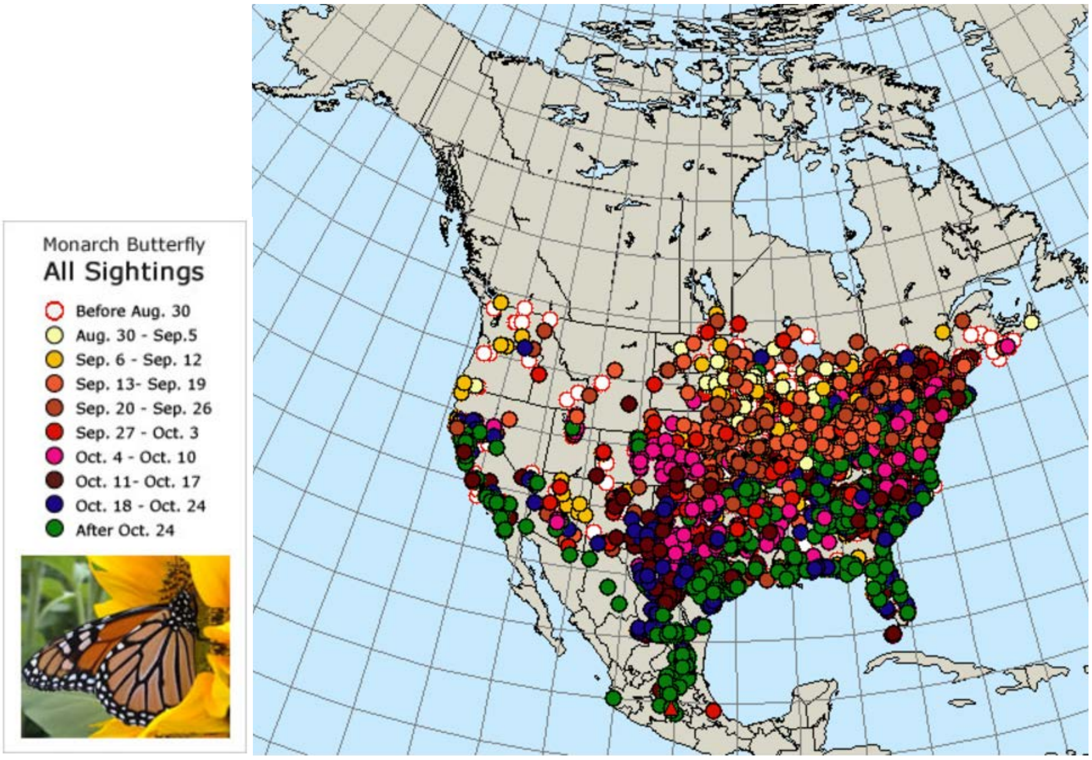

Figure 3. Journey North (primary GBIF contributor) Fall migration occurance data map

Data

1. Occurance data: 4,024 *Danaus plexippus* occurance locations are obtained from the GBIF database representing all reported occurances of the species between 2005 and 2010 (GBIF, 2017).
2. Environmental variables: Landcover is obtained from the Commission for Environmental Cooperation (CEC). They host data produced through an international collaboration between the governments of Canada, Mexico, and the United States. Landcover is obtained for 2005 and 2010 and its produced from MODIS satellite imagery at 250 meter resolution. The following subclasses are included: mixed forest, tropical or sub-tropical shrubland, temperate or sub-polar shrubland, tropical or sub-tropical grassland, temperate or sub-polar grassland, sub-polar or polar shrubland-lichen-moss, sub-polar or polar grassland-lichen-moss, wetland, and cropland. Grasslands and Wetlands are also obtained from the CEC generated from MODIS satellite imagery at 250 meter resolution. Rivers and streams are obtained from the North American Atlas of 10 meter Hydrography (USGS, 2017). A digital elevation model (DEM) is obtained from The National Institute of Statistics, Geography, and Informatics, the equivalent to the USGS for Mexico (INEGI, 2017).
3. Anthropogenic variables: Population Centers locations are obtained from INEGI for the 2005 and 2010 census (INEGI, 2017). Roads are obtained from Mexican Institude of Transportation (IMT) for years 2005 and 2010 and do not include unpaved roads. These

two anthropogenic variables have been suffcient in previously assessing anthropogenic pressures (Moreno-Sanchez et al., 2011).

Analysis

1. Using RStudio 3.3 and the library dismo, all occurance data for Mexico is extracted, downloaded, and consolidated from GBIF into a single georeferenced .CSV (Hijmans & Elith, 2017).
2. QGIS is used to convert the .CSV into a Shapefile and construct and a bounding box around all occurances representing the Texas/Mexico flyway, between the border of Texas and overwintering sites in Mexico, thus defining the extent of the study area.
3. Environmental variable data and anthropogenic varaible data are downloaded as GeoTIFFs and Shapefiles from respective sources.
4. Two-thirds of occurance data and environmental variable data are used to generate a species distribution GeoTIFF with MaxEnt 3.3 for 2005 and 2010 with respective years data sources.
5. One-third of occurance data are used for testing and reporting the reliability of the SDM (White & Kerr, 2006).
6. Anthropogenic variable data are combined into one feature layer in QGIS for years 2005 and 2010. These are overlayed with the respective years SDM.
7. A transition matrix is created in QGIS, identifying monarch habitat that has been converted into population centers, roads, and forest that has been converted to grassland (Li et al., 2009; Vega et al., 2009).

Expected Results

The results of this study will quantify the anthropogenic pressures on monarch migration habitat. This will be broken down by the particular land cover types in migration habitat illustrating the most susceptible land cover types to anthropogenic pressure as well as describing the geographic region in which this has occurred most and least prominently. Results will also include the transition matrices from 2005 to 2010 for both the monarch migration habitat and anthropogenic pressures to additionally quantify the change in each outside of their relational context. Significant outputs from the species distribution model will be included indicating the relative significance of each environmental variable in the species distribution model.

Discussion

The literature on monarch habitat indicates anthropogenic pressures as the primary driver of nesting and overwintering habitat loss. Monarch habitat has been replaced by agricultural expansion and degraded through illegal logging. Migration habitat, chiefly forest edge and grassland, is susceptible to these types of changes. From this we can assume that anthropogenic pressures have influenced the change in monarch migration habitat. From the measure of landcover change in nesting and overwintering habitat, it can also be hypothesized that humans are the main drivers of habitat loss in migratory corridors.

What is not known at this point, is how much anthropogenic habitat generation is occurring. Disturbed areas have been shown in the literature to be conducive to nectar producing flora, and therefore, some level of anthropogenic disturbance may be creating new areas for monarchs to collect lipids. While this research looks at the quantification of anthropogenic pressures on migration habitat, the net impact of humans, whether positive or negative, is undetermined.

The findings of this research allow investigation into particular practices and their impact on monarch migration habitat. It presents room for finer scale inquiry to the urban wildlife interface and how various types of disturbance can facilitate habitat change. Additionally, this research allows future comparison between nesting, migratory, and overwintering habitats in determining their relative significance to the success and decline of the monarch butterfly.

Conclusion

This research will either reject or be unable to reject the hypothesis that loss of monarch migration habitat can be primarily attributed to anthropogenic pressures. This will be based on the relative percentage of monarch migration habitat loss from anthropogenic pressures and the percent loss that is unexplained by the study. This study will conclude talking about the proportional habitat loss and how that fits into the scholarship. Dependent on the conclusion, future research will be recommended to gain deeper insights into the changes of monarch migration habitat in Mexico, as well as smaller scale research comparing the changes between nest, migratory, and overwintering habitats.

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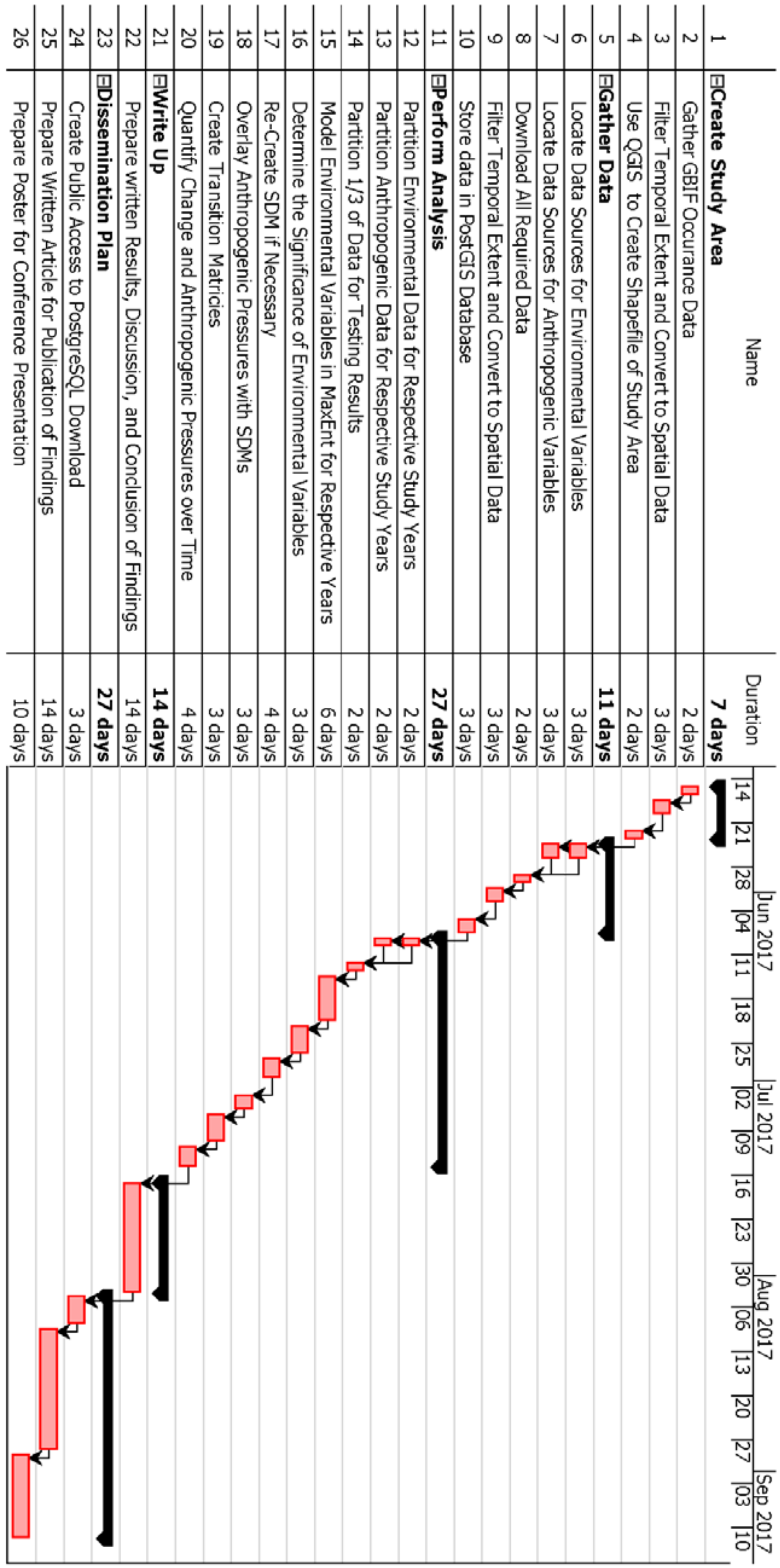
Budget

Item	**Justification**	**Sub-total**	**Total**
Salaries and wages			
Principal Investigator: James Raines	@$30/hr x 20 hrs/week x 30 weeks (15 weeks/academic semester x 2 academic semesters) □ Oversee and coordinate project. □ Quality control. □ Write reports, articles for scientific journals, prepare submissions to conferences. □ Coordinate with external researchers including site visits.	$18,000	
Principal Investigator Summer	@$30/hr x 40 hrs/week x 8 weeks	$9,600	$27,600
Co-Principal Investigator:	@$25/hr x 20 hrs/week x 30 weeks (15 weeks/academic semester x 2 academic semesters) □ Perform data collection as describe in methodology. □ Perform data processing as described in methodology. □ Assist in report and articles writing. □ Assist in conference preparation and presentations.	$15,000	
Co-Principal Investigator Summer	@$25/hr x 20 hrs/week x 8 weeks	$4,000	$19,000
		Total	$46,600
Fringes and labor overhead			
Principal investigator	27% PI James Raines		$1,662
Co-Principal Investigator	3% Co-PI		$198
		Total	$1,860

	Total Salary and Fringes		**$48,460**
Use of GIS lab equipment and resources			
Use of Dept. of Geography research lab equipment and resources	$500		$500
Publication costs			
Journal publication costs	$600 Scientific journal publication cost		$600
Printing costs			
Letter/Legal size printed maps. Poster size maps and informational posters.	$200		$200
Conferences registration			
Conference registration costs	$1200 Conference registration cost for 2 presenters @$600 each.		$1,200
	Total Direct Costs		**$50,960**
	Indirect Costs University Rate 56%		$28,538
Grand Total			**$79,498**

Project Time Management



Data Management Plan

Types of Data

1. Raw Data: These data include the monarch occurrence data acquired through GBIF, all environmental variables and anthropogenic variables to be used in species distribution modeling.
2. Refined Data: These data include the shapefile of the extent of the study area, monarch occurrence data, environmental variables, and anthropogenic variables all within the bounds of the study area. These data are partitioned into respective study years, 2005 and 2010, and 1/3 partitioned for testing the results.
3. Analyzed Data: These data include the species distribution models and anthropogenic pressure maps for study years, 2005 and 2010, as well as the transition matrices of the distribution models and anthropogenic pressures.

Data and Metadata Standards

All data will be kept and analyzed in data standards that comply with the Open Geospatial Consortium (OGC) Abstract Specifications. Vector data will be stored in Shapefiles and raster data will be stored in GeoTIFFs. The purpose is to provide data formats that specifically address interoperability challenges and allow cross-platform accessibility open-source, free, and at no charge.

Policies for Access and Sharing

All data, metadata, and analyses collected and produced under the proposed research will be made publicly accessible for viewing and distribution at no charge. Since all data will be kept in OGC standards, these data will be equally accessible regardless of operating system, platform, or software. Any published manuscripts will be provided to the public as open-access as distributed through the journal of publication.

Data Archiving

All data, as described in Types of Data, will be archived in two fashions. 1) For public distribution, a PostgreSQL instance with PostGIS extension will be hosted on an Amazon Web Service Relational Database System. A public user will be added as named, "public", with no password and will provide permissions for download, but not editing. Accessibility will be indiscriminate and available to anyone with computer and internet access. 2) For backup, all data will be stored in an external hard drive in the possession of the authors.

Dissemination Plan

In part, this research will serve to create base layers for monarch habitat in Mexico, which has not been previously performed. To adequately disseminate this knowledge, the author will submit a written article for publication to engage academics and enrich the scholarship around this subject. Verbal and poster presentations will be designed for dissemination at minimum one conference. Additionally, all data and publications will be open-access online and available for the public.

Appendix

Research Instruments

For the purposes of data collection and analysis several pieces of software were used:

Data collection: R Studio version 3.3.2 (2006-10-31) was used to aggregate all GBIF monarch occurrence data across sources and limit it to the study area. R packages used in this process include dismo, GISTools, rgbif, and rgdal. R is free and open source software.

Data Analysis: Species distribution models were created using a machine learning algorithm called Maximum Entropy Modeling through a graphical user interface, MaxEnt version 3.4.0. MaxEnt is available free and open source under a MIT license.

Transition matrices were calculated using Quantum GIS (QGIS) version 2.18.7 Las Palmas. QGIS is open source, interoperable, and licensed under the GNU General Public License.

Data Storage and Archive: Data is stored and available through a PostgreSQL data with PostGIS spatial extension. PostgreSQL is open source and interoperable object-relational database management system.

Supplemental Figures

Outputs from each research stage will be included here for the purposes of validation and replication.