NORTH DAKOTA GAME AND FISH DEPARTMENT

Final Report

Species distribution modeling of rare insect species in North Dakota.

Project T-47-R-1

April 1, 2015 – December 31, 2016

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Submitted by Greg Link

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Bismarck, ND

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Distribution of insects in North Dakota

Final Report

On the State Wildlife Grant:

"Species distribution modelling of rare insect species in North Dakota"

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Table of Contents

Introduction

Species of Conservation Priority: Terrestrial insects. While there are currently no insect species on the species of conservation priority lists, there are a number of insect species that might reasonably be added to that list. These species would include: Dakota stonefly (*Perlesta dakota*), American burying beetle (*Nicrophorus americanus*), Belfragii's chlorochroan bug (*Chlorochroa belfragii*), Poweshiek skipperling (*Oarisma poweshiek*), Dakota skipper (*Hesperia dacotae*), Tawny crescent (*Phyciodes batesii*), Monarch (*Danaus plexippus*), and Regal fritillary (*Speyeria idalia*).

The current State Wildlife Action Plan for North Dakota does not include any insects on the Species of Conservation Priority lists, primarily due to a lack of information. The State Wildlife Action Plan does call for on-going consideration of adding invertebrates, including insects, to the Species of Conservation Priority lists if data become available suggesting they should be added. There are a number of insect species (listed above) that might be of conservation concern given apparent rarity, declining population sizes, or habitat loss and fragmentation. In general, insect species are understudied in North Dakota and many of the species that might be added to the Species of Conservation Priority lists are often hard to study in the field due to limited times when they are active as adults, cryptic coloring and/or habits, and difficulties in capturing specimens for study. Given these challenges, it is vital that we have some idea where these species might occur in the state of North Dakota in order to focus the intensive sampling necessary to get good data to determine if species are sufficiently at risk to warrant adding to the Species of Conservation Priority list.

Museum collections represent a relatively untapped source of information on species distributions (Ponder et al., 2001). Museum collections can provide locality or presence-only data. Additionally, for species that have been studied, published reports can provide locality data as well. Locality data can be interpreted via species distribution models. Traditionally, species distribution modeling for insects has focused on various measures of temperature (i.e., maximum and minimum temperatures, time of first frost, degree days) and precipitation to determine where species might be expected to be found (Sobek-Swant et al., 2012). However, further details of the environment that might matter for insect species can be captured via soils which either directly influence species or indirectly via vegetation (Crawford and Hoagland, 2010) or land cover (Wilson et al., 2013). Museum specimens are considered presence only data which need to be interpreted in the correct statistical manner (Newbold, 2014; Wilson *et al.*, 2013). MaxEnt is a statistical package that uses entropy rules to correctly relate presence data to environmental variables (Elith *et al.*, 2011). Output from such models allow one to create maps with probabilities of species occurrence. These maps can then be used to guide fieldwork to further study these species to determine if they need to be added to the Species of Conservation Priority Lists.

Methods

Insect Locality Data

I compiled locality data for seven insect species - Dakota Stonefly (*Perlesta dakota*), American Burying beetle (*Nicrophorus americanus*), Belfragii's Chlorochroan Bug (*Chlorochroa belfragii*), Poweshiek Skipperling (*Oarisma poweshiek*), Dakota Skipper (*Hesperia dacotae*), Tawny Crescent (*Phyciodes batesii*), Monarch Butterfly (*Danaus plexippus*), and Regal Fritillary (*Speyeria idalia*) – by searching through insect collections at three museums in North Dakota (Cyril Moore Science Center Museum Insect Collection at Minot State University, North Dakota State Insect Reference Collection at North Dakota State University, and University of North Dakota Invertebrate Museum Insect Collection). Insect collections were searched for identified specimens from any of the seven focal species. For each specimen found, I recorded date and location of capture.

For each species, I searched electronic museum records from other collections, but did not find any records of individuals captured in North Dakota. I also searched for literature records that might have locality data for the seven species of interest (sources used are reported in each species section in the results). Finally, I compiled a number of reports to various government agencies which reported locality data for butterflies in the list of species (Orwig, 1997; Royer, 1995a; Royer, 1995b; Royer, 1995c; Royer, 1995d; Royer, 1996; Royer, 1997; Royer, 2002; Royer and Marrone, 1992a; Royer and Marrone, 1992b; Royer and Marrone, 1992c; Royer and Marrone, 1992d; Royer and Royer, 1998).

Location data was converted to lat/long coordinates in decimal degrees. UTM or degree minute second lat/long coordinates were converted to decimal degrees. For locations recorded as political entities (counties, townships, etc.) the lat/long coordinate for the center of the political entity was used. Locations recorded using the public land survey system (township/range) were placed at the center of the smallest unit recorded (e.g., section or quarter section). I distinguished between locality records that were reported at the county level (only county information available) versus those with a more specific location (either a well-defined place such as a town or campground, a section in the public land survey system, or exact co-ordinates).

Predictor Variables

To try to explain, and eventually predict, species distributions across North Dakota I gathered climate, land use/land cover and soils distribution data.

Climate data

Climate data were taken from the PRISM climate group website (http://www.prism.oregonstate.edu/). This group collates climate datasets from a broad collection of monitoring networks and applies spatially-explicit statistical methods to model the spatial distribution of the various climate variables (see Daly et al., 2008 for details). One of the datasets created by the PRISM group is the 30-year normal set. This dataset describes annual average values of the climate variables over the most recent three full decades (currently 1981-2010). I chose to use this dataset as the time period of the dataset coincided with the dates of the vast majority of the locality data. Also, the use of the averaged values gives an idea of the normal climate an area experiences and is not driven by unique weather events, making the average values better for predicting species localities. The dataset used had a spatial resolution of 800 m and covered the entire state of North Dakota. Variables were: total annual precipitation, mean annual temperature, minimum annual temperature, maximum annual temperature, mean dewpoint temperature, minimum vapor pressure deficit, and maximum vapor pressure deficit.

Land use/Land cover

Land use/land cover data were derived from the US Geological Survey National Gap Analysis Program (GAP) National Land Cover Data Set, Version 2 (https://gapanalysis.usgs.gov/) as this is a land cover/land use data set focused on habitat identification, which suits our needs well. The national data set is derived from Landsat TM satellite imagery taken from 1999-2001, which corresponds well with the bulk of the insect locality data. The imagery is measured on a 30 m resolution. The Landsat TM imagery is classified into land cover types using statistical processing of the image. The classified image has a very fine gradation of land cover categories. I downloaded the classified image for North Dakota.

I reclassified the North Dakota GAP data into eight broader categories to capture major changes in land cover/land use that were likely to influence insect species distributions (Table 1). After reclassifying the image, I calculated the proportion of coverage using a 750 m by 750 m sliding window. For each pixel in the original image, I calculated the proportion of the pixels in the window (centered on the target pixel) for a particular land cover type. This process created a new image that showed the amount of each land cover type in the surrounding landscape. I performed this process for wooded cover, grass cover, wetland cover, agriculture cover, and developed cover. I presumed that more natural cover types (wooded, grass, and wetlands) might be more likely to support the insects of study, while more anthropogenic cover types (agriculture, developed) might be less likely to support the insects of study.

Table 1: Categories used in reclassifying the GAP data. Categories used in the analysis are indicated by an *.

Category	Description	Level 3 Categories
Wooded*	Tree cover	0-288
Grass*	Natural grass cover	300-400
Wetland*	Water with vegetation	401-457
Shrub	Shrub cover	483-491
Badlands	Badland and cliff cover	535-537
Agriculture*	Agricultural land use including row crops, hay and pasture	555-572
Open Water	Open water without vegetation	578-579
Developed*	Low to high density developed	580-584

Soil distribution data

I downloaded the US Department of Agriculture, Natural Resources Conservation Service, National Cooperative Soil Survey maps for 2016 (https://websoilsurvey-dev.dev.sc.egov.usda.gov). This map provides quite detailed delineation of soil types, to the extent that the number of soil categories were difficult to analyze. The intent of adding soil type to the analysis was to capture potential vegetation changes that might influence the insect distributions.

To capture broader soil and/or vegetation types, I decided to use level IV Omernik ecoregions (Omernik, 1987; Omernik and Gallant, 1988). These ecoregions use a combination of ecological factors, such as geology, landform, soils, and vegetation, to map areas that are ecologically similar. The map of ecoregions for North Dakota was downloaded from the North Dakota GIS Data Hub (https://www.nd.gov/itd/statewide-alliances/gis). The downloaded map was a shape file which I rasterized to be compatible with the other environmental predictor data sets.

All image processing and raster manipulation was performed in the statistical package, R (R Development Core Team, 2016).

Species Distribution Modeling

Species distribution modeling uses environmental variables (like climate and landcover) to predict the geographic distribution of a species. Many approaches require both presence and absence data (Elith and Leathwick, 2009) but absence data can be difficult to obtain and is not available when working with museum collections, as we do not have the history of where entomologists have searched for insect species in the past. Maximum entropy modeling of species distributions can be conducted on presence-only datasets (Elith et al., 2006) and has been found to be comparable to other methods and able to run with less data (Phillips et al., 2006). Maximum entropy modeling can be achieved using a software package, Maxent (Phillips et al., 2004) which applies a machine learning algorithm to relate species presence data to potential predictor variables, including climate, land cover, terrain, and vegetation structure (Elith et al., 2011; Wilson et al., 2013). This approach has been successfully used to investigate invertebrate distributions (Crawford and Hoagland, 2010; Johnson et al., 2016; Sobek-Swant et al., 2012)

I conducted distribution modeling using Maxent (Phillips et al., 2017) via the "dismo" package (Hijmans et al., 2017) in Program R (R Development Core Team, 2016). Due to the relatively small number of observations I used all of the presence data to fit the Maxent models, as opposed to holding aside a test dataset (Merow et al., 2013). I used area under curve (AUC) of the receiver operator curve to assess the goodness-of-fit of the derived models (Merow et al., 2013). The relative importance of the various predictor variables in the maxent models was evaluated by looking at the percent contribution (related to the path used to obtain the model) and permutation importance values (derived from the final model via changing the values of that particular value at random and assessing the impact on the model) (Phillips, 2017). The fitted Maxent models were used to create maps of the predicted probability of the species occurring across North Dakota.

Results

Species Locality Data

*Dakota stonefly (*Perlesta dakota*)*

The Dakota stonefly, *Perlesta Dakota,* was discovered in North Dakota relatively recently (Kondratieff and Baumann, 1999). I did not find any specimens in any of the collections searched and all three localities are due to Kondratieff & Baumann (1999) and are shown in Figure 1. Like many insect species in North Dakota, very little sampling has been done to determine where these stoneflies might occur across North Dakota.

Given the small number of localities recorded for the Dakota stonefly no further analysis was conducted on their distribution.

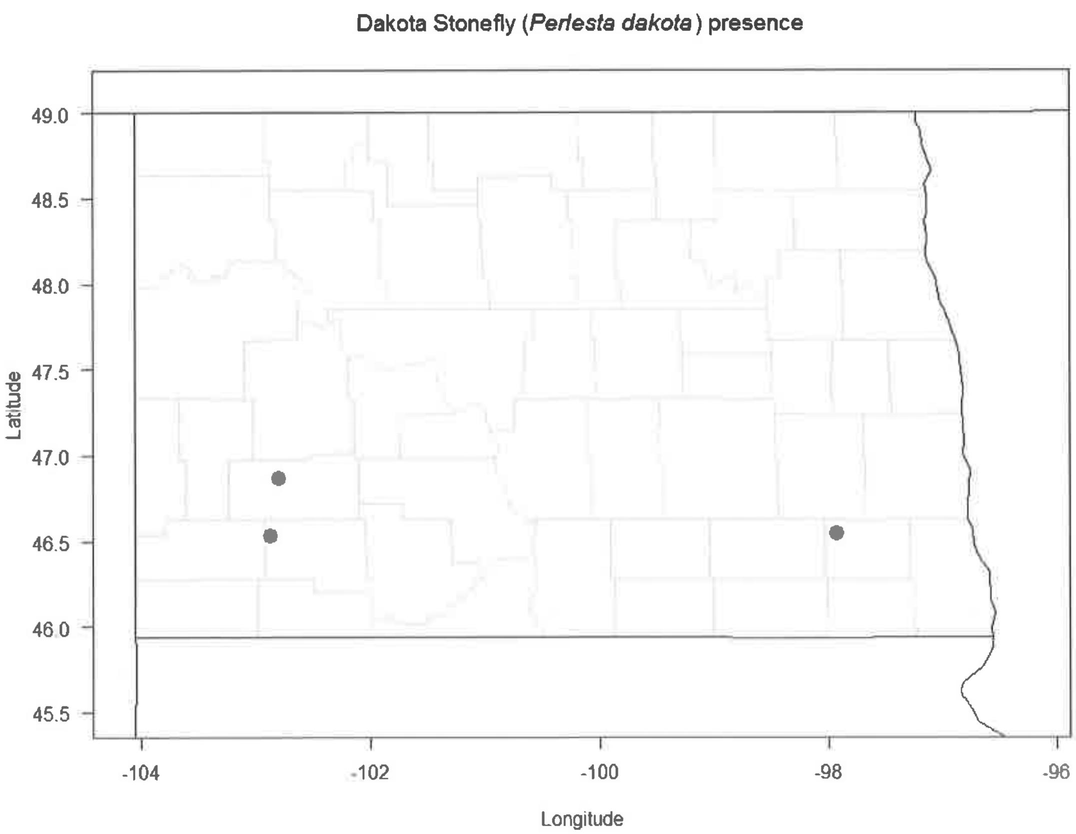

Figure 1: Locations where Dakota stoneflies were found. Grey lines outline the counties of North Dakota.

*American burying beetle (*Nicrophorus americanus*)*

The American burying beetle (*Nicrophorus americanus*) has been listed as a federally endangered species since 1989 (Federal Register 54:29652-29655). The species is currently known to occur in Arkansas, Kansas, Massachusetts, Neraska, Ohio, Oklahoma, Rhode Island, South Dakota, and Texas (https://ecos.fws.gov/ecp0/profile/speciesProfile?spcode=I028), however the historic range is thought to have potentially included the southeast corner of North Dakota (Raithel, 1991). The species is also easily misidentified with a much more common species of burying beetle, *Nicrophorus marginatus*, a wide-spread burying beetle. Given the potential for the American burying beetle to have occurred in North Dakota and the report of beetles that looked like an American burying beetle, this species was consider as a possible North Dakota resident. However, I did not find any specimens from North Dakota in any insect collections. North Dakota State University does have a single specimen but it is from Iowa.

Given the lack of any evidence of the American burying beetle in North Dakota, no further analysis was conducted on their distribution.

*Belfragii's chlorochroan bug (*Chlorochroa belfragii*)*

Chlorochroa belfragii was once a candidate species for federal listing but it is no longer listed, though still a species of management concern. The apparent rareness of the species is most likely due to difficulties in collecting. Location data were taken from Wheeler (2015) and Rider (2012) and collections at NDSU and UND (most of which were reported in the two publications).

C. belfragii has been reported from Iowa, Minnesota, Nebraska, North Dakota, South Dakota, and Manitoba, though in relatively low numbers in all states or provinces (Wheeler, 2015). Based on direct observation and co-occurrence of herbarium specimens and insect specimens, it is thought that the bug is specialized on prairie cordgrass (*Spartina pectinata*) which tends to occur in saline soils ((Wheeler, 2015). While the number of current locations in North Dakota did not permit habitat suitability modeling, future surveys for *C. belfragii* should focus on areas with prairie cordgrass and saline soils.

Belfragii's Chlorochroan Bug (*Chlorochroa belfragii*) presence

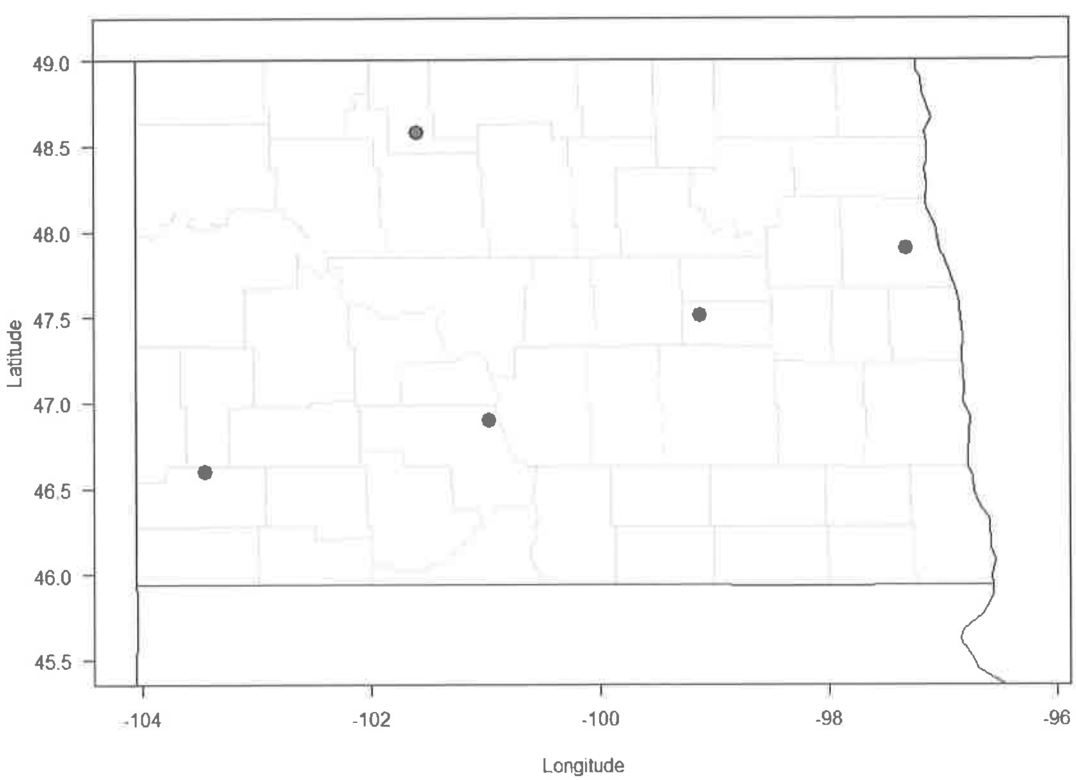

Figure 2: Locations where Belfragii's chlorochroan bugs were found. Grey lines outline the counties of North Dakota.

*Poweshiek skipperling (*Oarisma poweshiek*)*

Poweshiek skipperling (*Oarisma poweshiek*) has been a federally listed endangered species since 2013 (Federal Register 78: 63573-63625). This species has traditionally been thought to be restricted to the southeast corner of the state (Royer, 2003). The Grand Forks county record from the UND museum collection represents a new county record but the record is from the 1960s. Records came from the collections of at NDSU, MSU, and UND and a number of reports focused on Poweshiek distribution and abundance in North Dakota (Orwig, 1997; Royer and Marrone, 1992b). Overall, I found 61 records of Poweshiek skipperling presence, though a fair number of those where from the same location (Figure 3).

Habitat suitability modeling was conducted for this species.

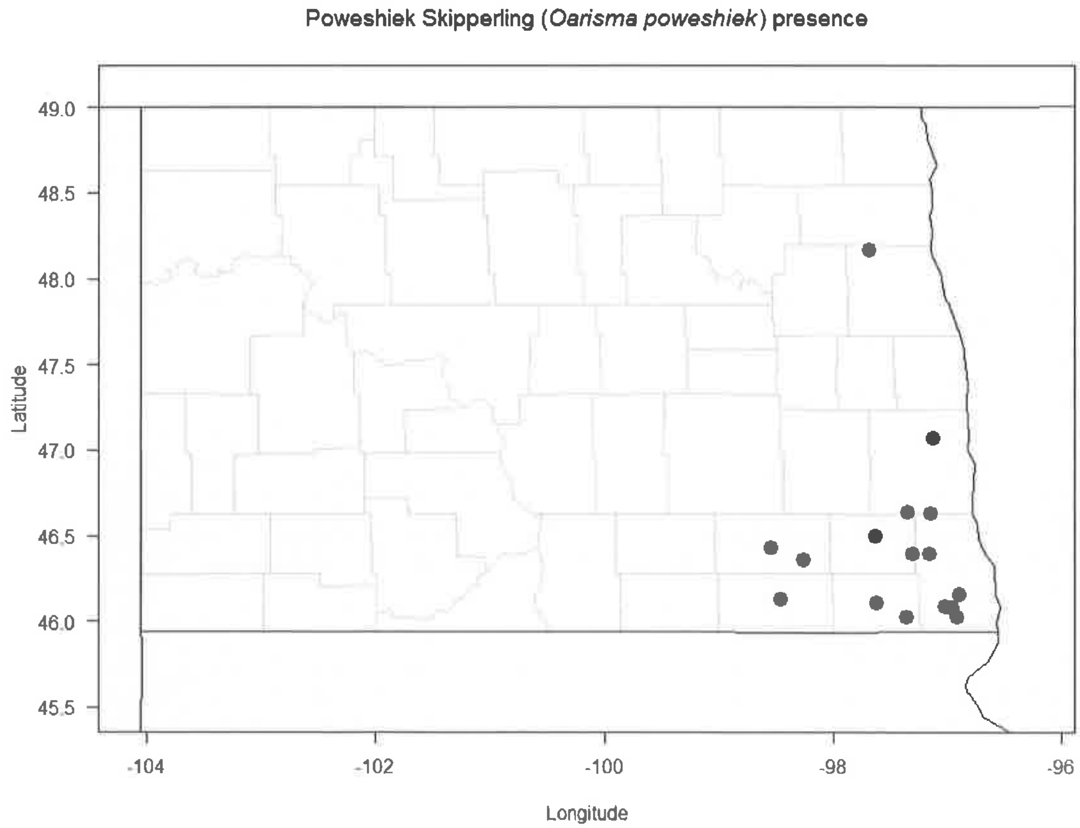

Figure 3: Locations where Poweshiek skipperlings were found. Green dots indicate locations that were tied to a specific place while red dots indicate locations that were only resolved at the county level. Grey lines outline the counties of North Dakota.

*Dakota skipper (*Hesperia dacotae*)*

Dakota skipper (*Hesperia dacotae*) has been a federally listed threatened species since 2013 (Federal Register 78: 63573-63625). The Dakota skipper is found in North Dakota, South Dakota, Minnesota, Manitoba, and Saskatchewan Species at Risk Act Recovery Strategy Series Species at Risk Act Recovery Strategy Series(Environment Canada, 2007; Royer and Marrone, 1992a). The species requires mesic tall-grass to dry mesic mid-grass prairie with a variety of composites for nectar sources, ideally with the grass and nectar plants interdigitated (McCabe, 1981; Royer and Marrone, 1992a). The flight season is short – about 3 weeks beginning in late June (McCabe, 1981; Royer and Marrone, 1992a) – which can make field surveys difficult. Records came from the MSU and NDSU collections, a number of reports (Orwig, 1997; Royer, 1995c; Royer, 2002; Royer and Marrone, 1992a; Royer and Royer, 1998). Overall, I found 121 records of Dakota skipper presence, with some of those from the same location (Figure 4)/

Habitat suitability modeling was conducted for this species.

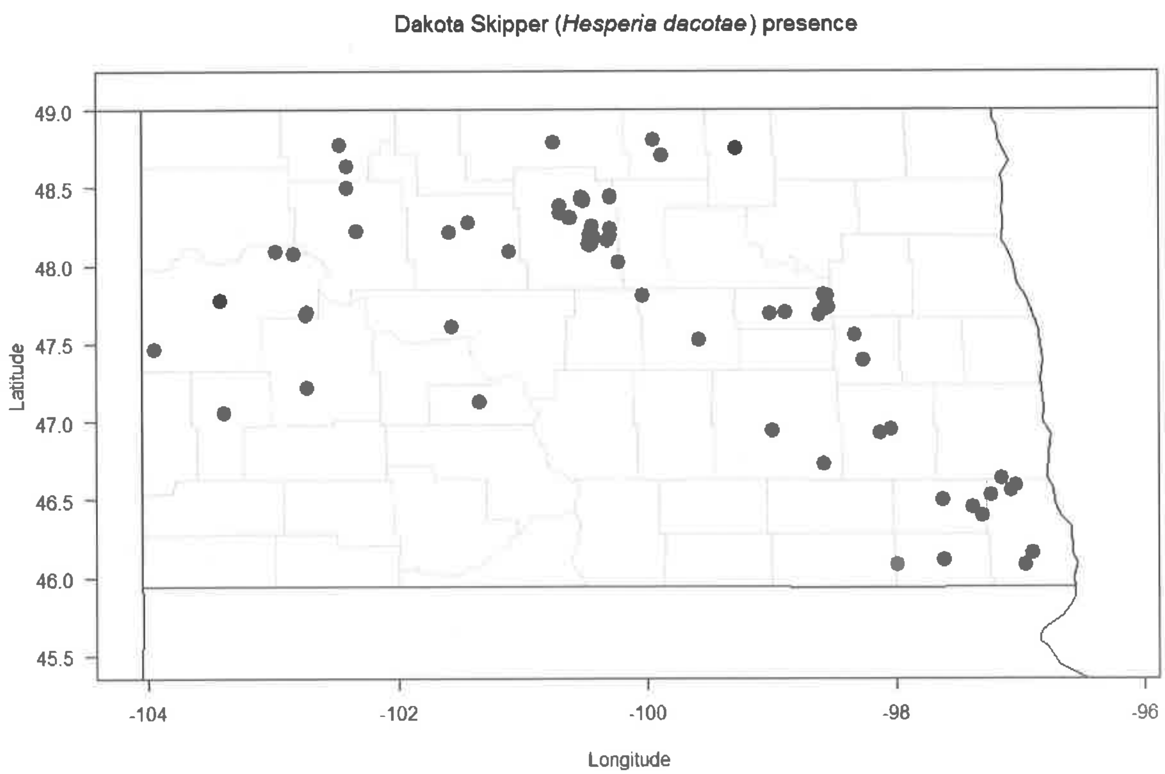

Figure 4: Locations where Dakota skippers were found. Green dots indicate locations that were tied to a specific place while red dots indicate locations that were only resolved at the county level. Grey lines outline the counties of North Dakota.

*Tawny crescent (*Phyciodes batesii*)*

The Tawny crescent was a candidate for federal listing as recently as 1994 (Federal Register 59: 58982-59028). The US range of the species stretches from New England west to North Dakota (Royer and Marrone, 1992d). The Tawny crescent tends to be found in forest to grassland transitions, such as moist clearings in aspen or green ash woodland margins in North Dakota, with populations tending to stretch along riparian zones (Royer and Marrone, 1992d). Records came from the MSU, NDSU, and UND collections along with published reports (Royer, 2002; Royer and Marrone, 1992d). I found 60 records of Tawny crescent presences, with some of those from the same locations (Figure 5).

Habitat suitability modeling was conducted for this species.

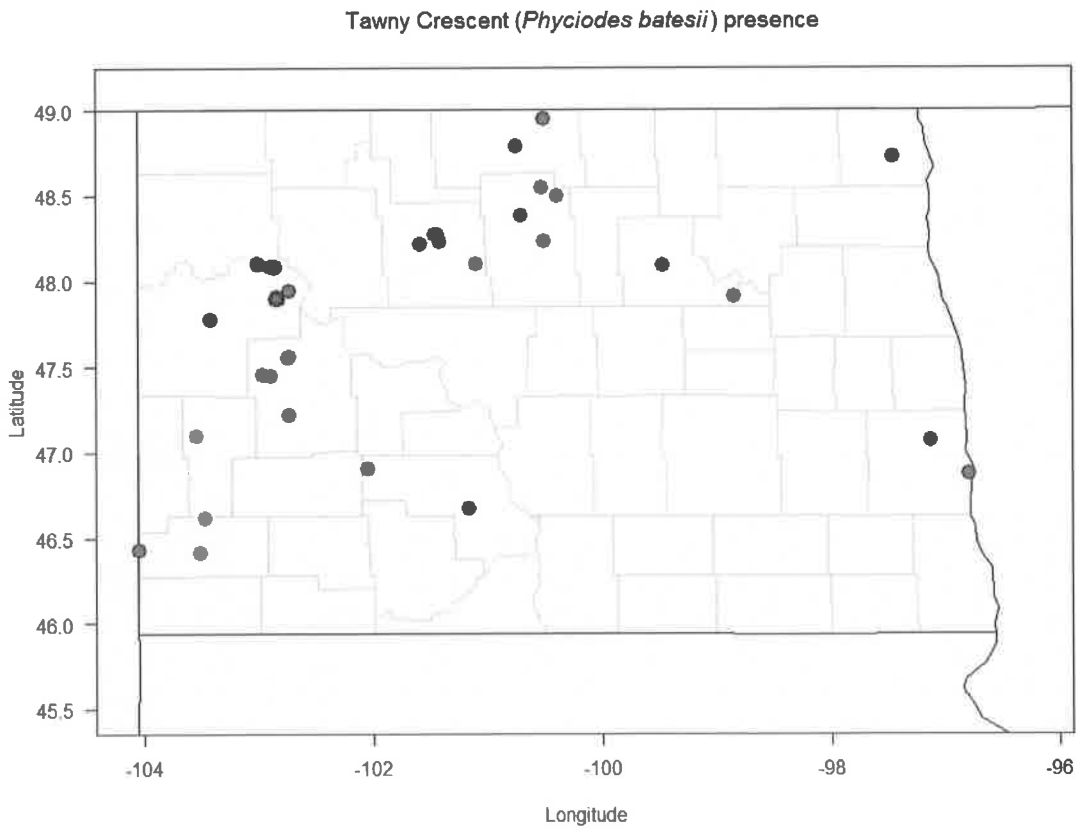

Figure 5: Locations where Tawny crescents were found. Green dots indicate locations that were tied to a specific place while red dots indicate locations that were only resolved at the county level. Grey lines outline the counties of North Dakota.

*Monarch (*Danaus plexippus*)*

The Monarch is currently under review for federal listing (Federal Register 79: 78775-78778) due to declining population numbers. The US range of the species is extensive (http://www.butterfliesandmoths.org/species/Danaus-plexippus) and it has been reported from most North Dakota counties (Royer, 2014). Until recently, the Monarch was considered a common butterfly and, as such, was not collected much, nor have there been any studies conducted on the species in North Dakota that I am aware of. Subsequently, the locality records for Monarchs are likely less complete than those for other North Dakota species. Many museum specimens were caught close to the hosting collection. Records came from the MSU, NDSU, and UND collections along with published reports (Orwig, 1997; Royer, 1995a; Royer, 1995b; Royer, 1995c; Royer, 1995d). I found 168 records of Monarch presences, with many of those from the same locations (Figure 6).

Habitat suitability modeling was conducted for this species.

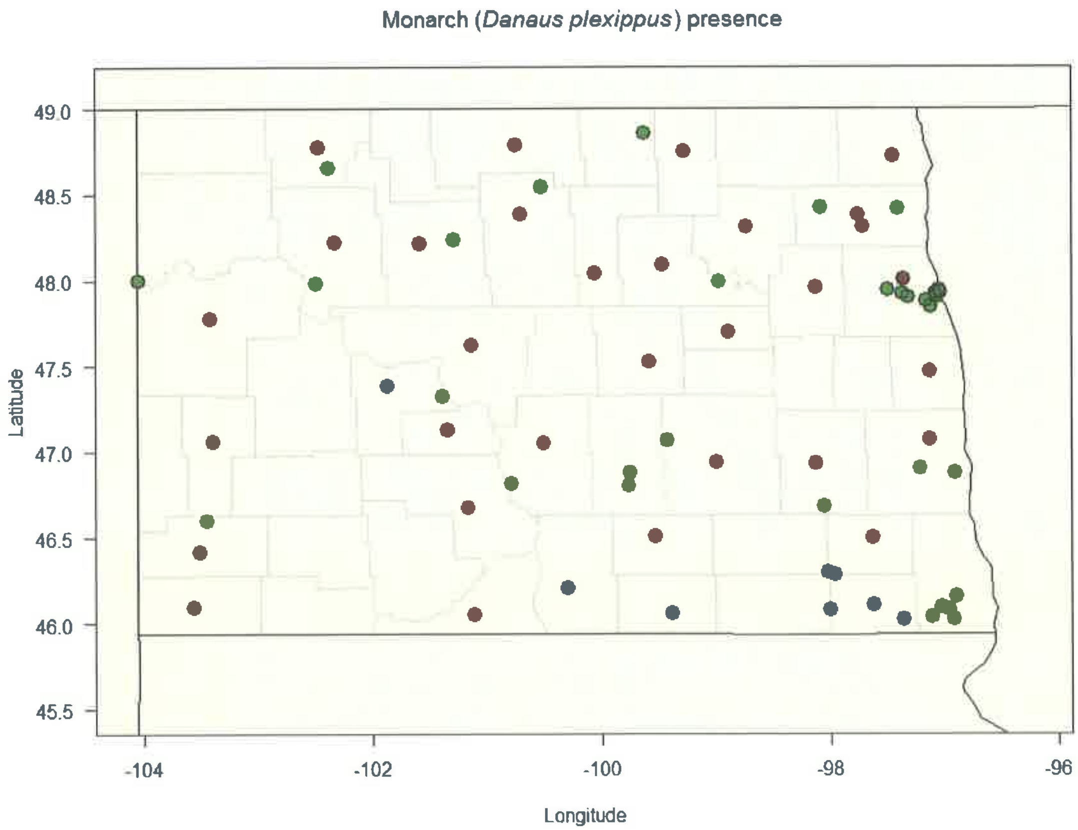

Figure 6: Locations where monarch butterflies were found. Green dots indicate locations that were tied to a specific place while red dots indicate locations that were only resolved at the county level. Grey lines outline the counties of North Dakota.

*Regal fritillary (*Speyeria idalia*)*

The Regal fritillary is currently under review for federal listing (Federal Register 80: 56423-56432). The US range of the species stretches from New England to Montana (http://www.butterfliesandmoths.org/species/Speyeria-idalia). The Regal fritillary is found in undisturbed prairie with sufficient nectaring plants and the presence of the larval food plant (*Viola* spp.) (Royer and Marrone, 1992c). Records came from the MSU, NDSU, and UND collections along with published reports (Orwig, 1997; Royer, 1995a; Royer, 2002; Royer and Marrone, 1992c). I found 67 records of Regal fritillary presences, with some of those from the same locations (Figure 7).

Habitat suitability modeling was conducted for this species.

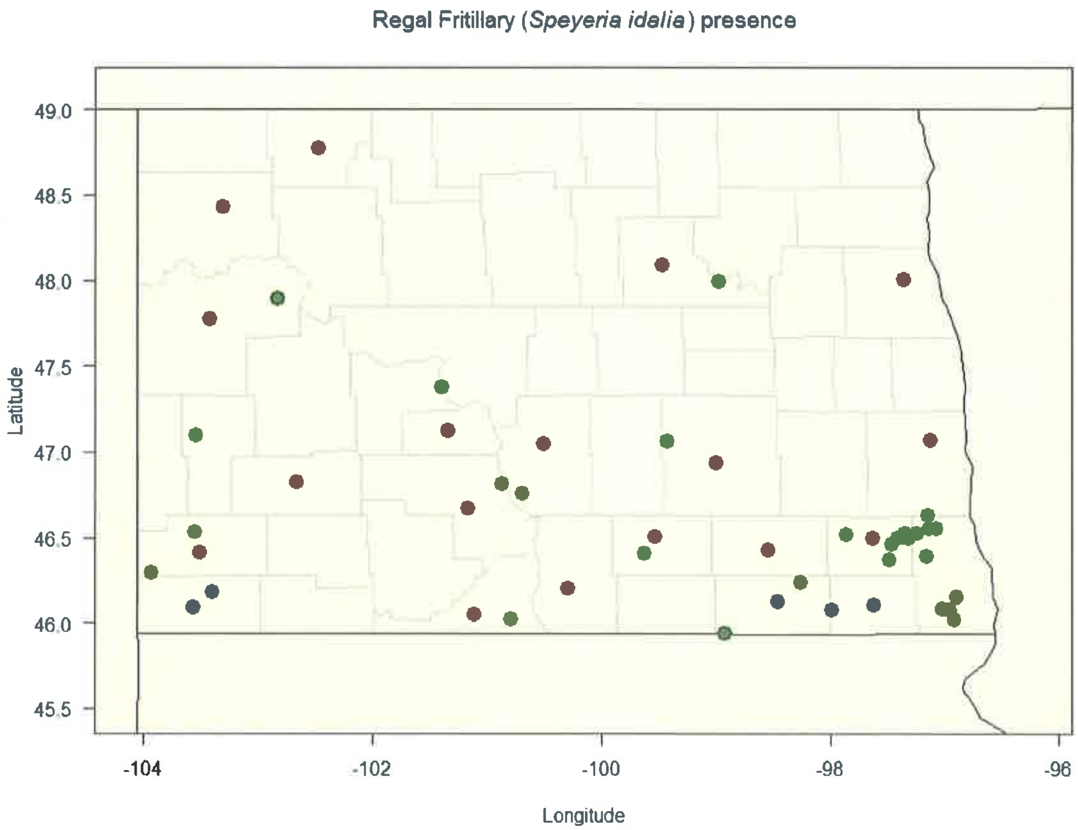

Figure 7: Locations where monarch butterflies were found. Green dots indicate locations that were tied to a specific place while red dots indicate locations that were only resolved at the county level. Grey lines outline the counties of North Dakota.

Predictor Variables

Climate data

The climate data were extracted from the PRISM national normal (30-year 1981-2010 averaged) dataset recorded with an approximately 800 m by 800 m pixel size. The data are derived from multiple ground-based weather stations and then interpolated using a spatially-explicit statistical method (see Daly et al., 2008 for details). I re-projected the rasters from PRISM in R to put them on the same projection as the other predictor variables.

From the PRISM dataset, I pulled normal total annual precipitation (Figure 8), normal mean annual temperature (Figure 9), normal minimum annual temperature (Figure 10), normal maximum annual temperature (Figure 11), normal mean dew temperature (Figure 12), normal minimum vapor pressure deficit (Figure 13), and normal maximum vapor pressure deficit (Figure 14).

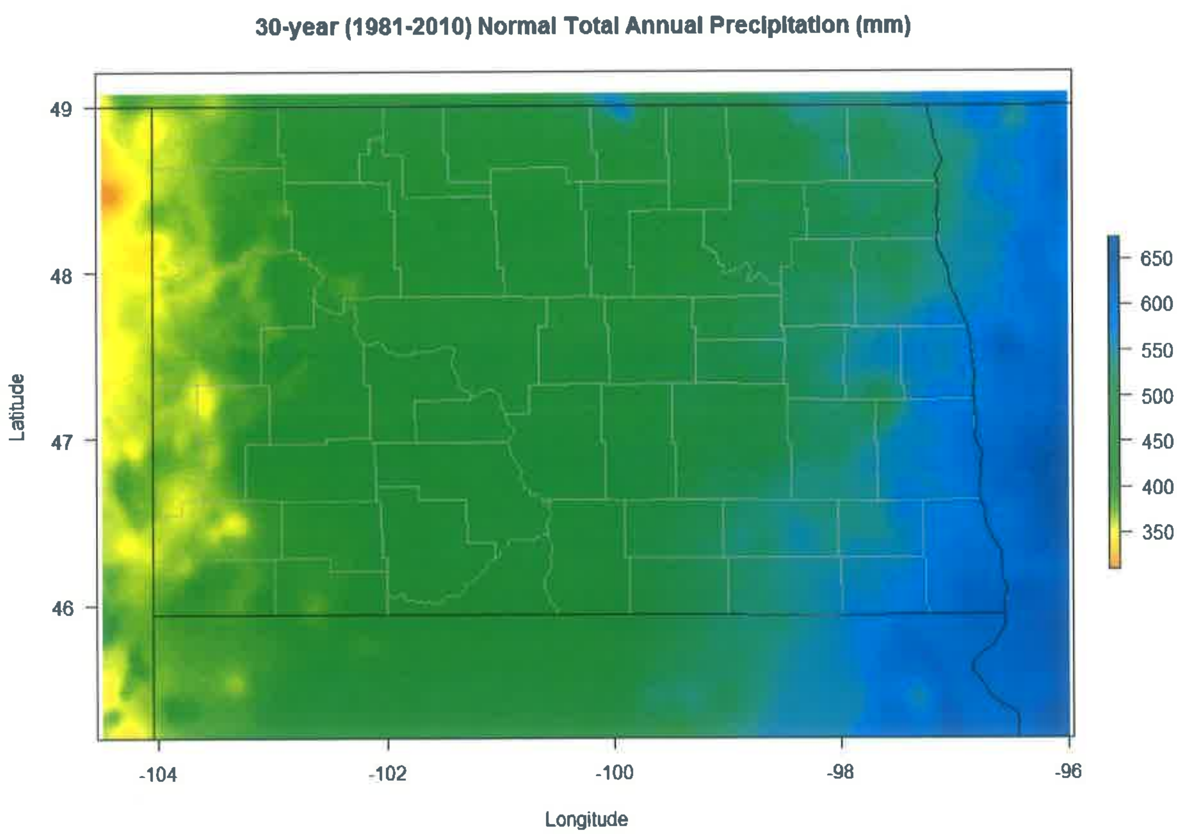

Figure 8: Distribution of 30-year normal total annual precipitation across North Dakota. Pixel size is 800 by 800 m.

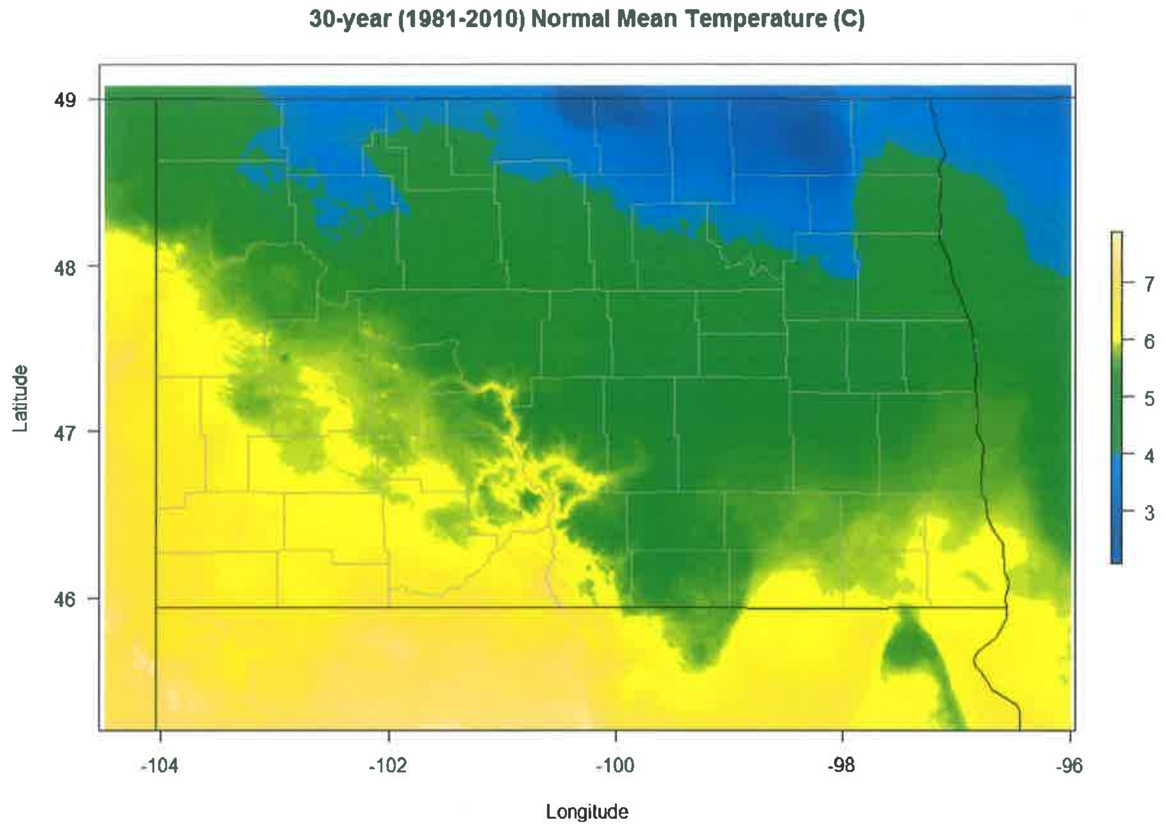

Figure 9: Distribution of 30-year normal mean annual temperature across North Dakota. Pixel size is 800 by 800 m.

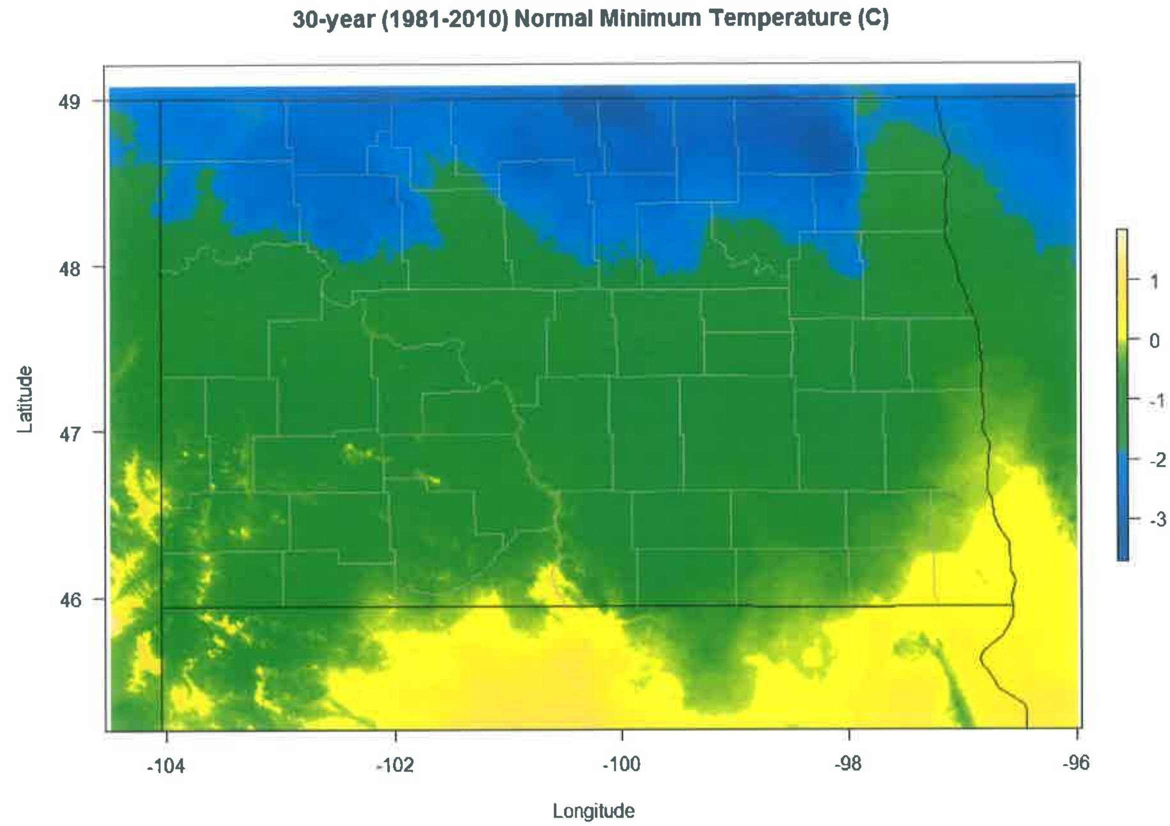

Figure 10: Distribution of 30-year normal minimum annual temperature across North Dakota. Pixel size is 800 by 800 m.

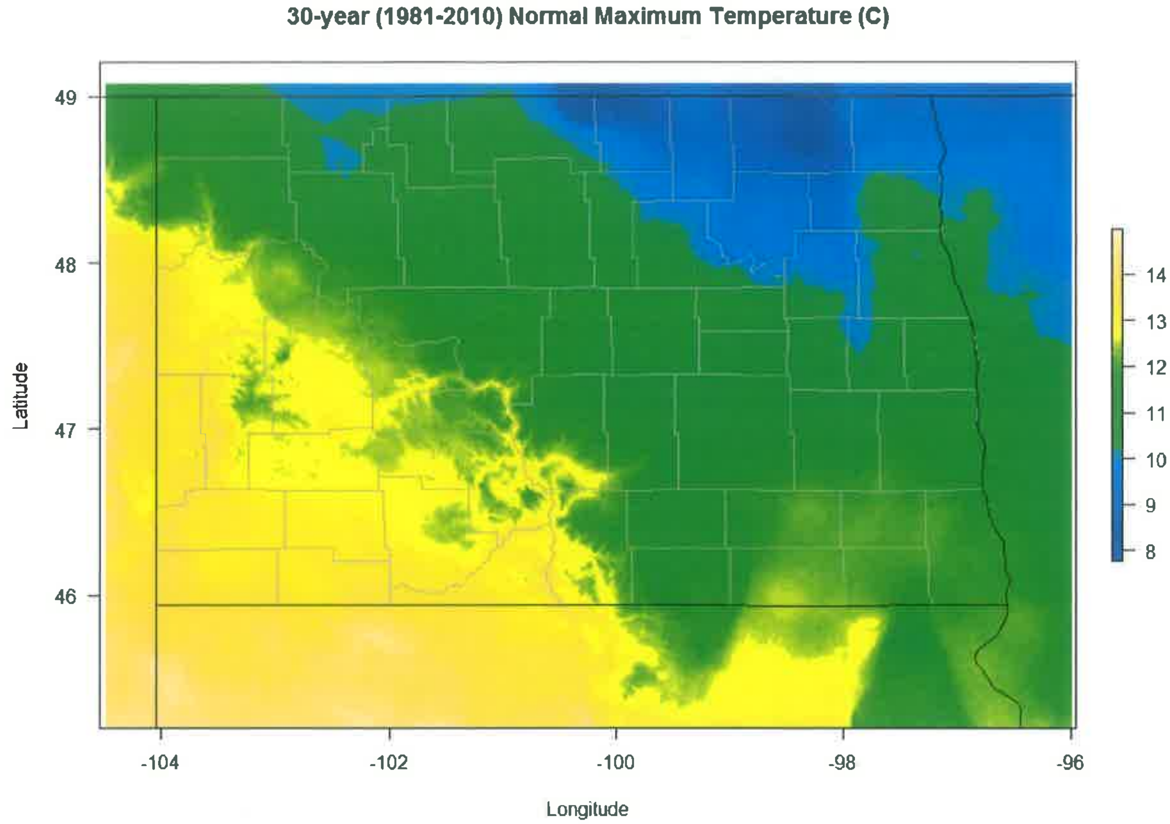

Figure 11: Distribution of 30-year normal maximum annual temperature across North Dakota. Pixel size is 800 by 800 m.

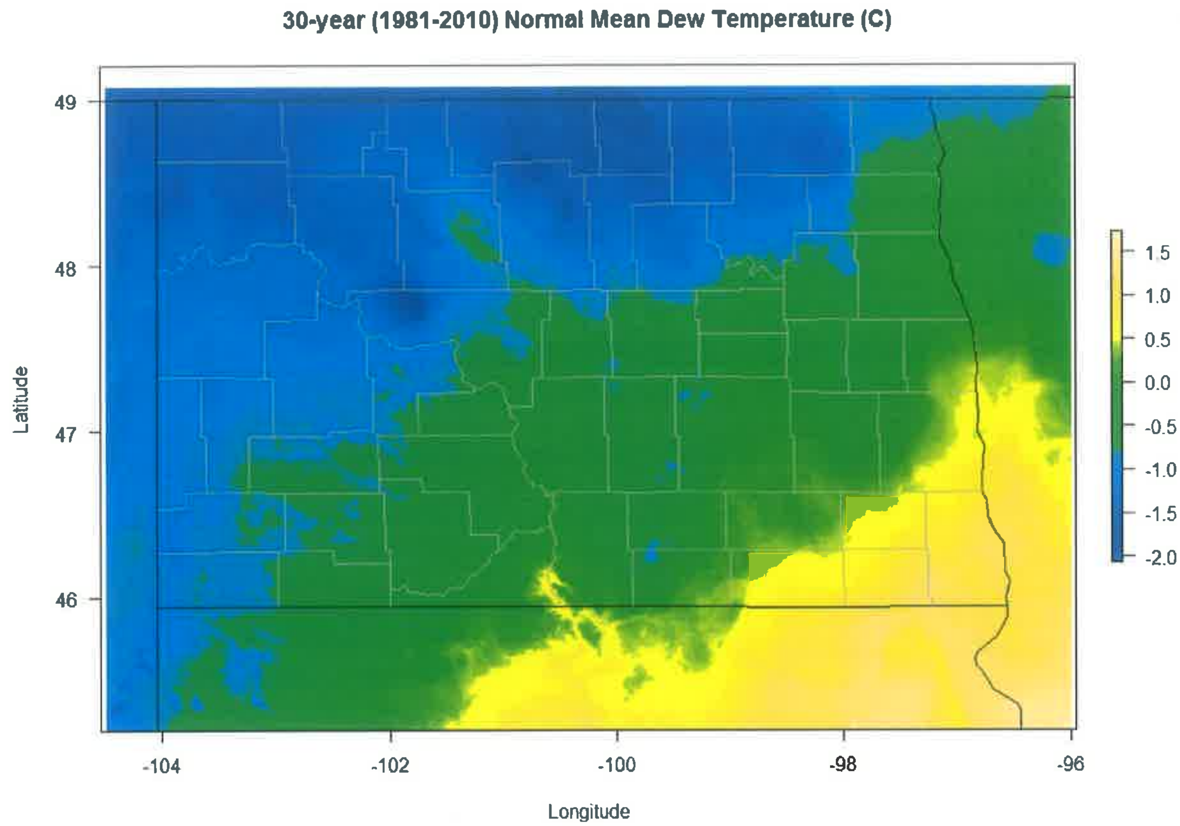

Figure 12: Distribution of 30-year normal mean annual dew temperature across North Dakota. Pixel size is 800 by 800 m.

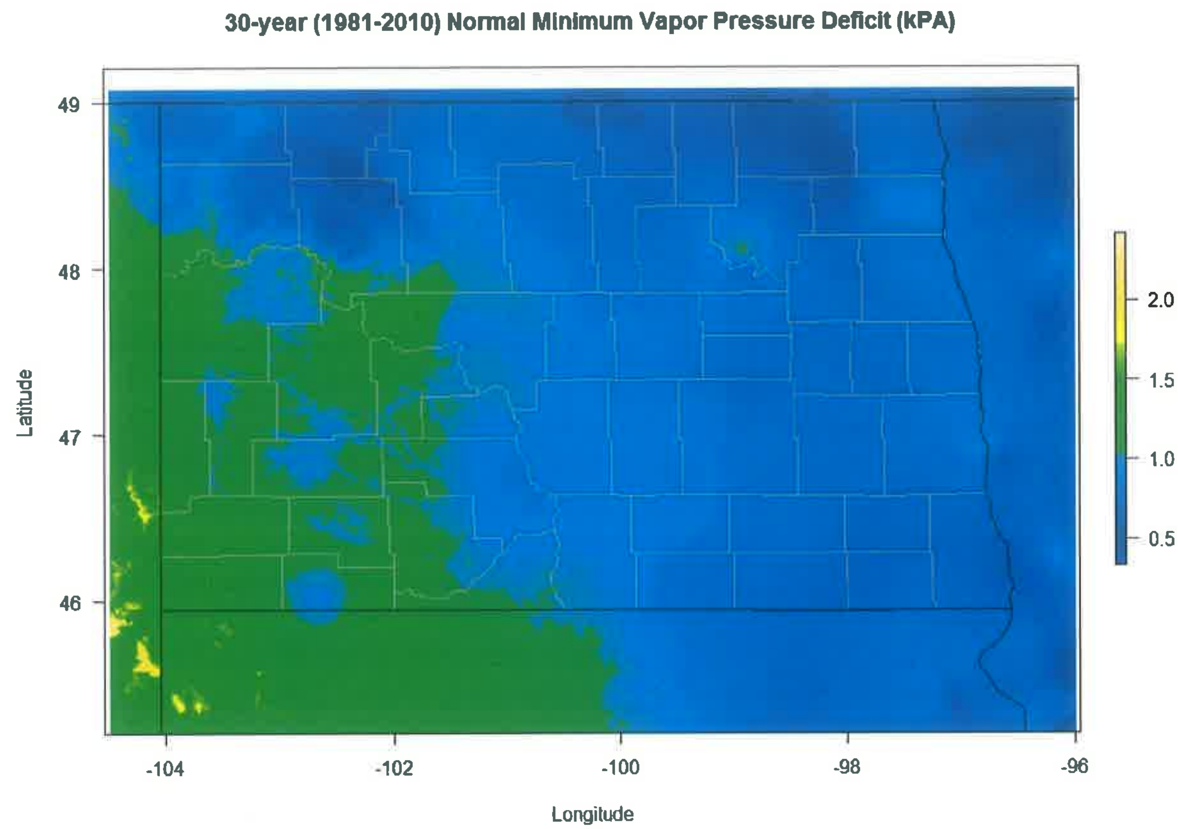

Figure 13: Distribution of 30-year normal minimum annual vapor pressure deficit across North Dakota. Higher values indicate a drier environment. Pixel size is 800 by 800 m.

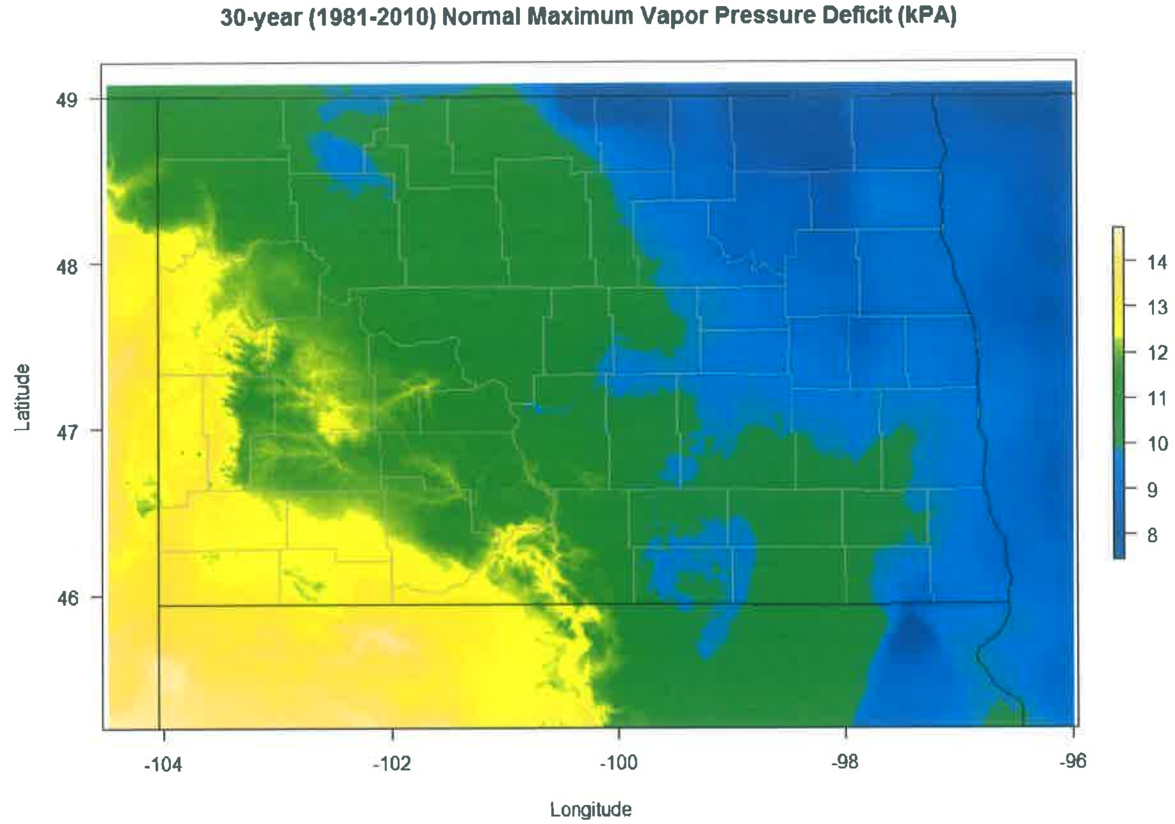

Figure 14: Distribution of 30-year normal maximum annual vapor pressure deficit across North Dakota. Higher values indicate a drier environment. Pixel size is 800 by 800 m.

Land cover/Land use data

Land use/land cover data were derived from the US Geological Survey National Gap Analysis Program (GAP) National Land Cover Data Set, Version 2 (https://gapanalysis.usgs.gov/). The national data set is derived from Landsat TM satellite imagery taken from 1999-2001, which corresponds well with the bulk of the insect locality data. The imagery is measured on a 30 m by 30 m pixel resolution. I downloaded the classified image for North Dakota and reclassified the data into eight broad categories (Figure 15).

After reclassifying the image, I calculated the proportion of coverage using a 750 m by 750 m sliding window. For each pixel in the original image, I calculated the proportion of the pixels in the window (centered on the target pixel) for wooded cover (Figure 16), grassland cover (Figure 17), wetland cover (Figure 18), agriculture cover (Figure 19), and developed cover (Figure 20).

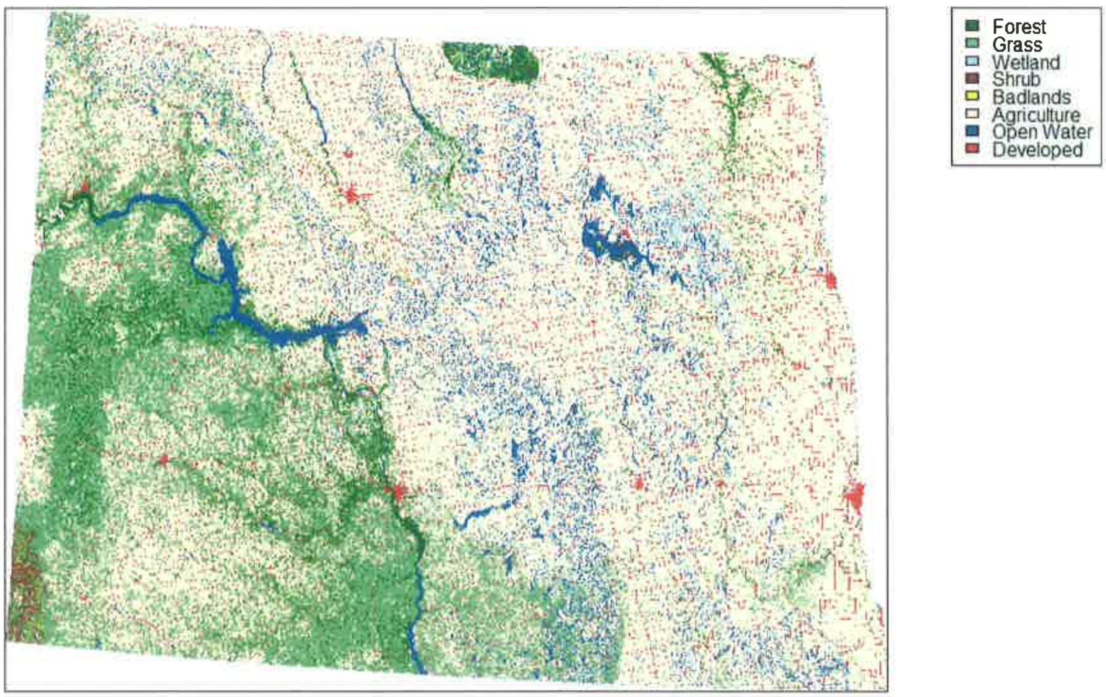

Figure 15: Map of re-classified land use/land cover data for North Dakota. Original data were GAP data derived from 1999-2001 satellite imagery. Land cover from designation from the GAP data were grouped into 8 broad categories. Pixel size is 30 by 30 m.

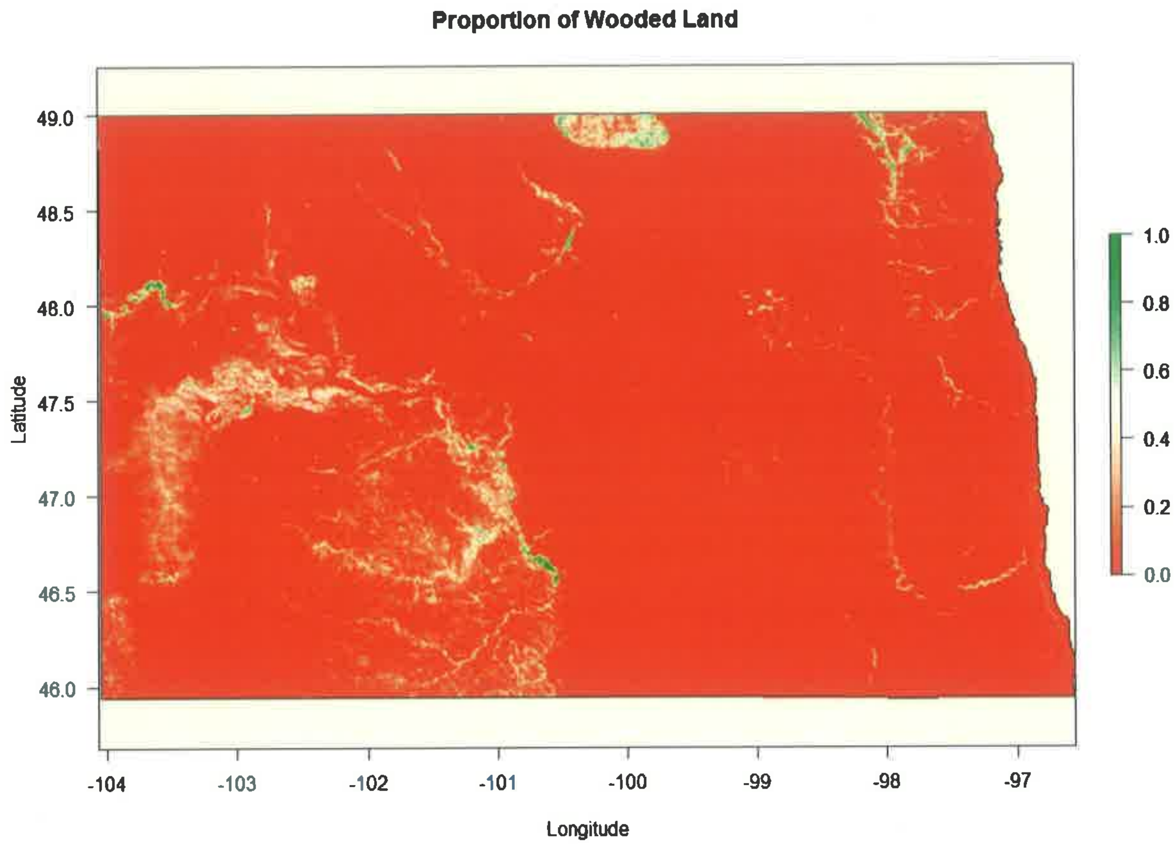

Figure 16: Proportion of the surrounding landscape (based on a 750 m by 750 m sliding window) consisting of wooded pixels.

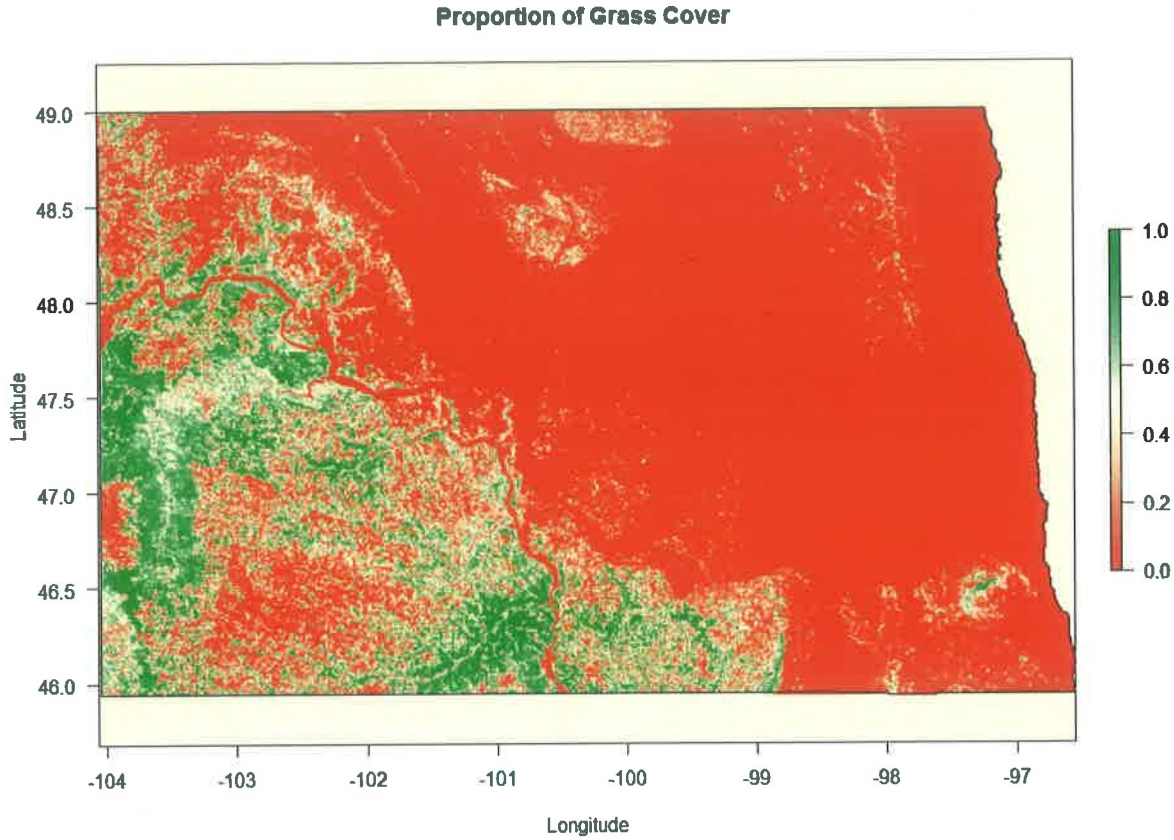

Figure 17: Proportion of the surrounding landscape (based on a 750 m by 750 m sliding window) consisting of grassland pixels.

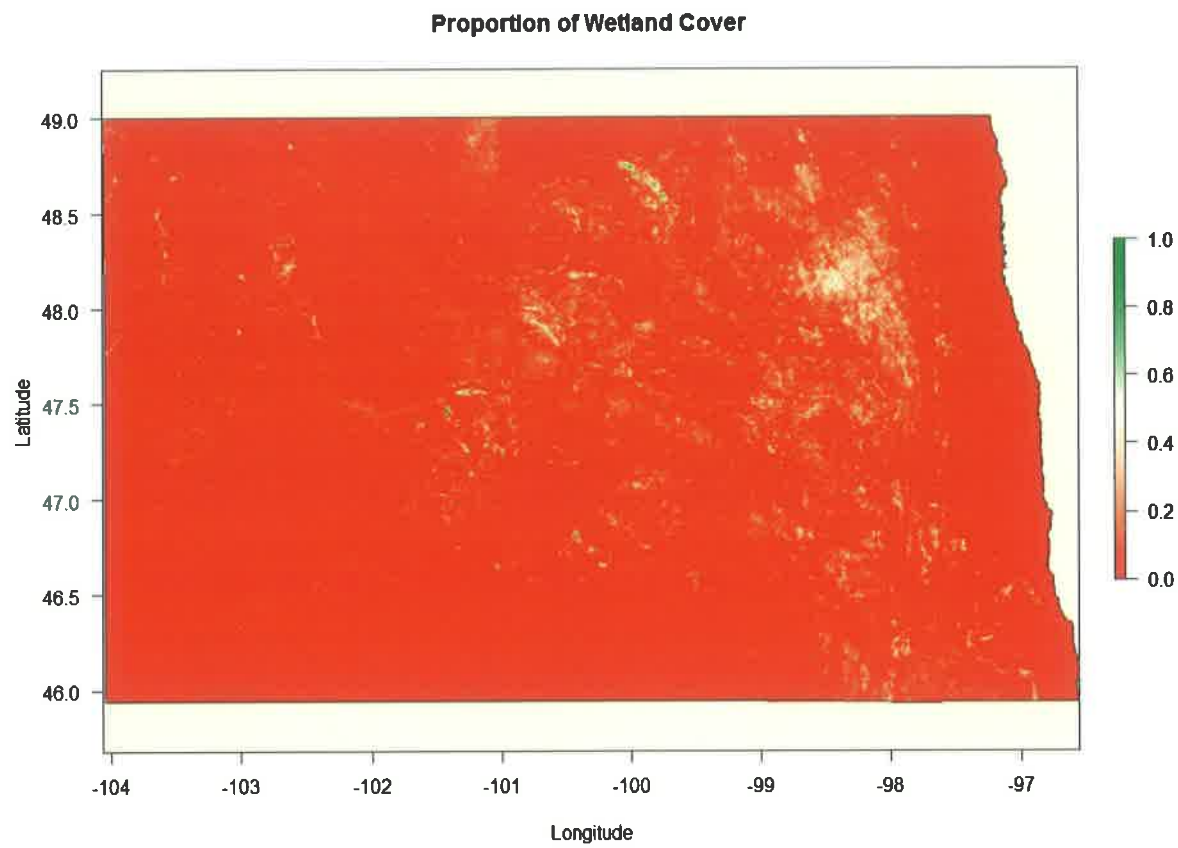

Figure 18: Proportion of the surrounding landscape (based on a 750 m by 750 m sliding window) consisting of wetland pixels.

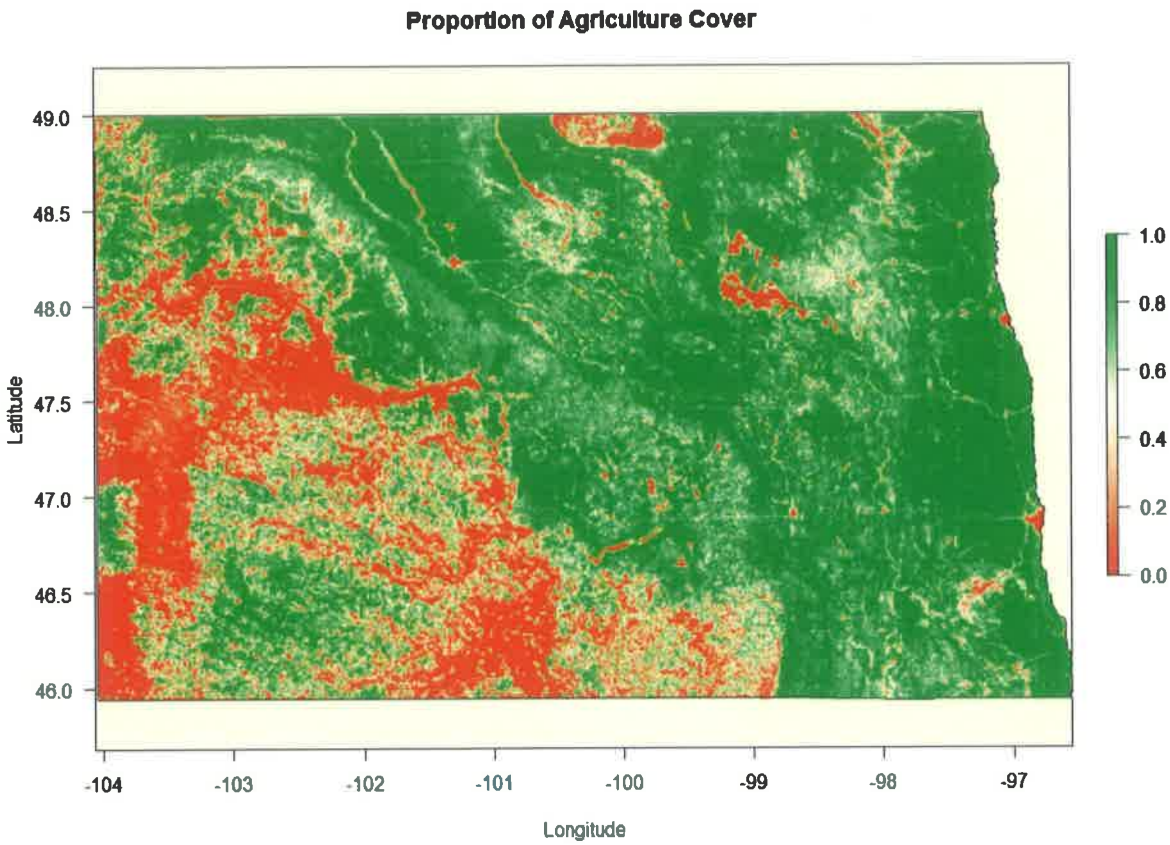

Figure 19: Proportion of the surrounding landscape (based on a 750 m by 750 m sliding window) consisting of agriculture pixels.

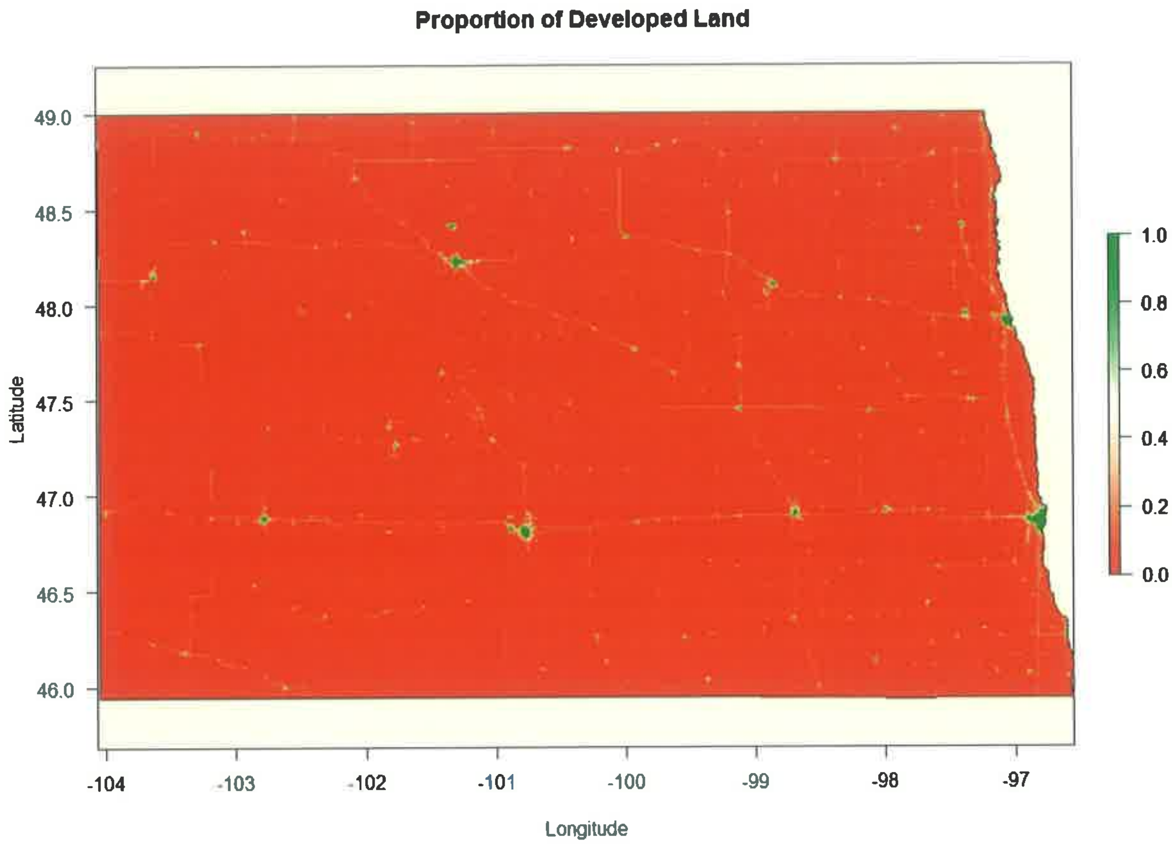

Figure 20: Proportion of the surrounding landscape (based on a 750 m by 750 m sliding window) consisting of developed pixels.

Ecoregion data

A map of ecoregions for North Dakota was downloaded from the North Dakota GIS Data Hub (https://www.nd.gov/itd/statewide-alliances/gis; Figure 21). The downloaded map was a shape file which I rasterized and re-projected to be compatible with the other environmental predictor data sets.

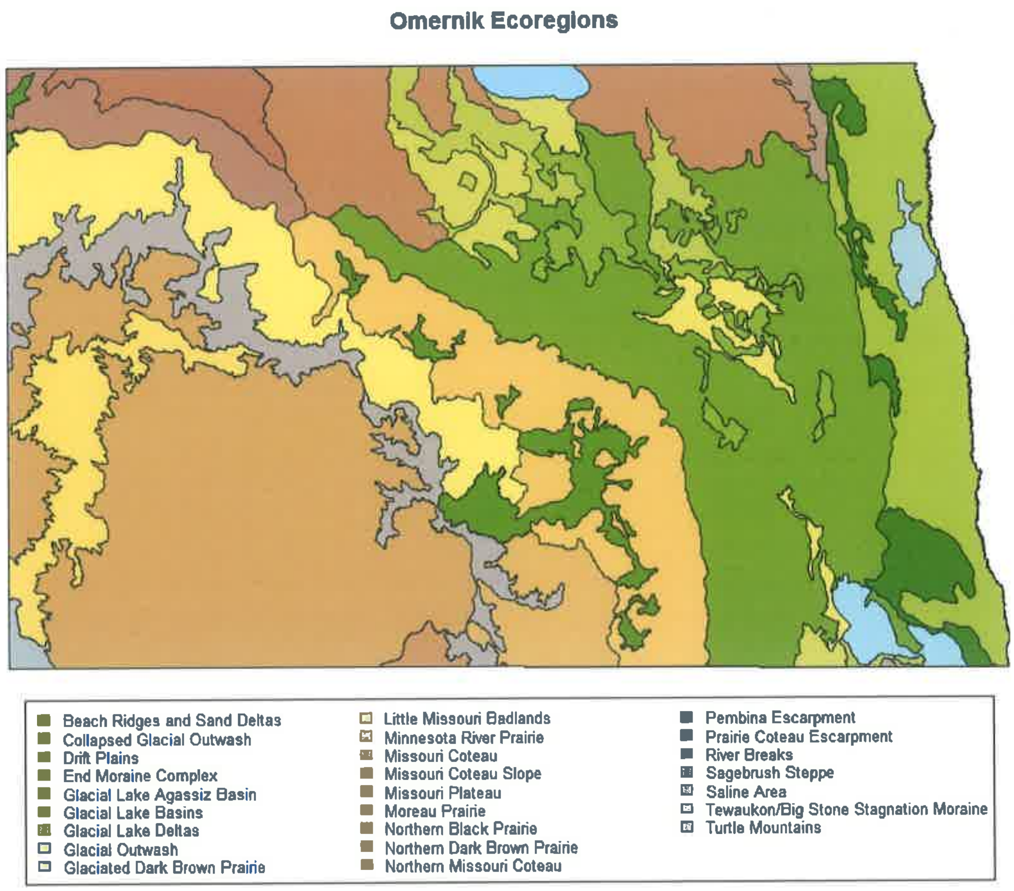

Figure 21: Map of Omernick ecoregions for North Dakota.

Species Distribution Modeling

*Poweshiek skipperling (*Oarisma poweshiek*)*

The Maxent habitat suitability model fit the Poweshiek skipperling data quite well with a receiver operating characteristic area under the curve value of 0.979. Dew point temperature, total annual precipitation, and ecoregions played the largest role during the formation of the final Maxent model (Table 2). The final model predicted Poweshiek skipperling presence primarily from total annual precipitation and minimum annual temperature, with secondary influences of ecoregion and proportion of grassland cover (Table 2).

The predicted distribution of the Poweshiek skipperling is confined to the southeast corner of the state (blue areas in Figure 22), apparently limited by temperature and precipitation needs. There is some indication in the model of the potential for the skipperlings to be found further west and north along the Red River valley (white areas in Figure 22), though with much lower probability than the blue areas in the map. The rest of the map indicates low probabilities of finding the skipperling (red areas in Figure 22). While this model predicts the broad area in which one might find the Poweshiek skipperling, it is important to note that the model is not assessing fine habitat details such as presence of suitable plant hosts, so there is no guarantee that the skipperling will be found in the areas identified as suitable by the model. On the other hand, the skipperling is much more likely to be found in those areas *if local conditions are sufficient* than in other areas of North Dakota deemed unsuitable by the model.

Table 2: Contributions of the predictor variables to the MaxEnt model of Poweshiek skipperling presence.

Variable	Percent contribution	Permutation importance
Mean annual dew point temperature	48.0	0
Total annual precipitation	19.2	78.0
Ecoregions	18.8	2.9
Proportion grassland cover	5.2	3.9
Proportion wetland cover	5.1	1.3
Minimum annual temperature	1.9	10.8
Proportion agriculture cover	0.8	1.4
Proportion wooded cover	0.6	1.4
Proportion developed cover	0.3	0.3
Minimum annual vapor pressure deficit	0	0
Mean annual temperature	0	0
Maximum annual temperature	0	0
Maximum annual vapor pressure deficit	0	0

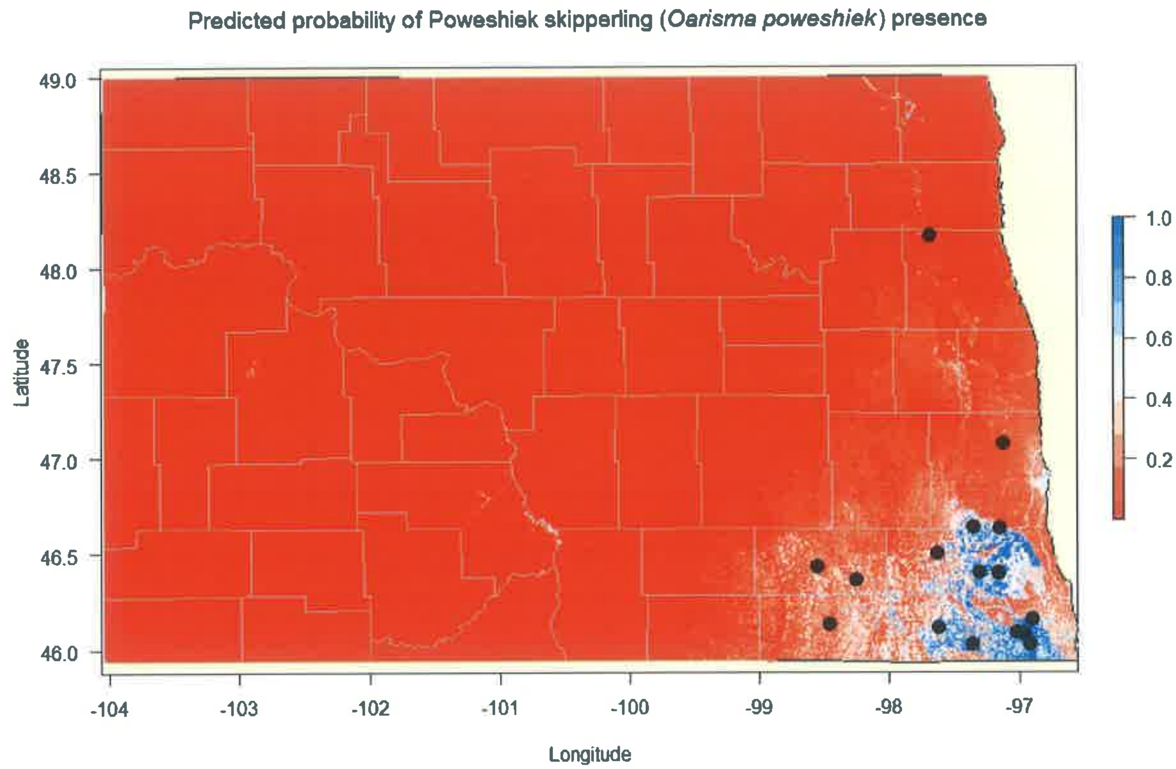

Figure 22: Map of the probability of finding Poweshiek skipperling in North Dakota as predicted by the MaxEnt model ran (see Table 2 for model details). Dots indicate the locations of the locality data that were used to construct the model. Grey lines indicate county boundaries.

*Dakota skipper (*Hesperia dacotae*)*

The Maxent habitat suitability model fit the Dakota skipper data quite well with a receiver operating characteristic area under the curve value of 0.882. Ecoregions played the largest role in the formation of the model, with much smaller contributions from maximum temperature, dew point temperature, and a number of land cover variables (Table 3). The final model predicted Dakota skipper presence primarily from ecoregion, and secondarily minimum vapor pressure deficit, with much smaller contributions from dew point temperature and grassland cover (Table 3).

The Dakota skipper seems more likely to occur on glacial deltas, glacial outwash, and beach ridges and sand deltas (blue areas in Figure 23). The map of the predictions of the model suggest that there is a potential to find more populations of Dakota skipper along the beach ridges stretching north from Traill and Steele counties through Grand Forks, Walsh, and Pembina Counties (white areas in Figure 23). Again, the caveat applies that the model just identifies potential suitable areas based on broader measures of suitability, it is still possible that there may not be appropriate habitat in terms of plant communities.

Table 3: Contributions of the predictor variables to the MaxEnt model of Dakota skipper presence.

Variable	Percent contribution	Permutation importance
Ecoregions	79.3	68.0
Maximum annual temperature	4.2	2.2
Proportion wetland cover	3.5	2.8
Proportion developed cover	3.0	1.5
Proportion grassland cover	2.7	4.3
Mean annual dew point temperature	2.3	5.6
Proportion agriculture cover	1.6	1.6
Maximum annual vapor pressure deficit	1.1	0.9
Minimum annual vapor pressure deficit	0.8	9.5
Proportion wooded cover	0.6	0.8
Total annual precipitation	0.4	1.9
Mean annual temperature	0.4	1.0
Minimum annual temperature	0.1	0

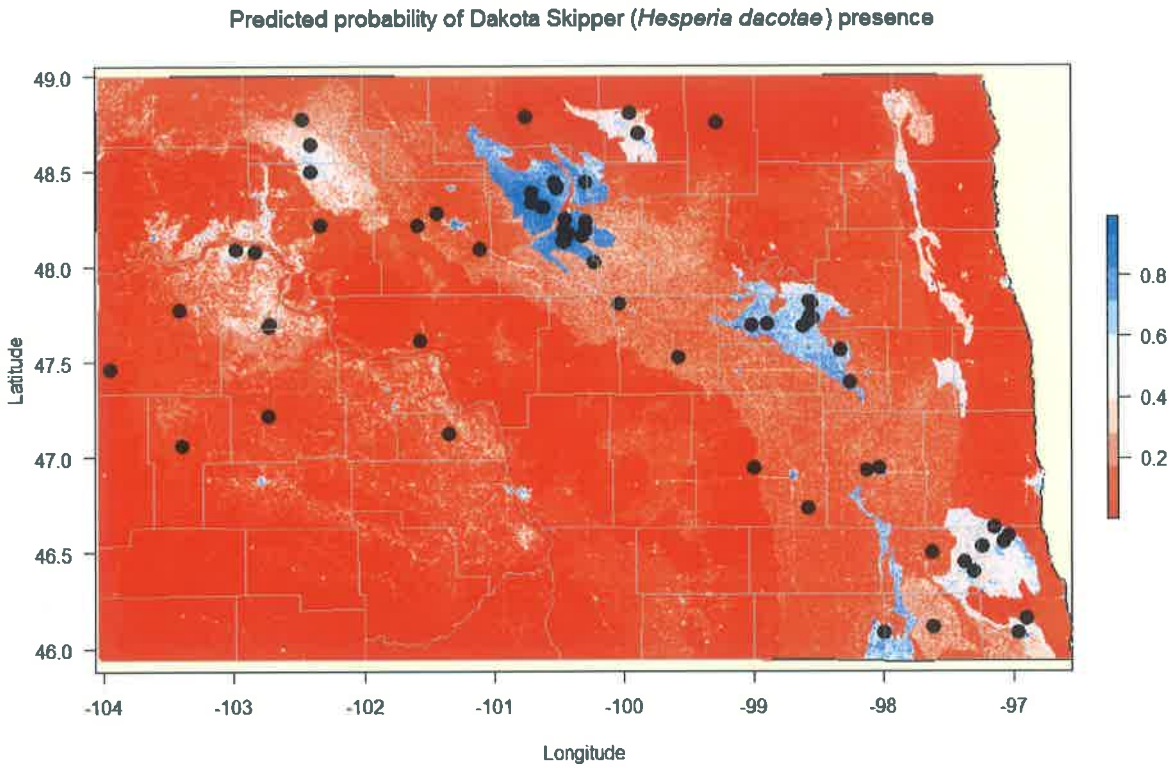

Figure 23: Map of the probability of finding Dakota skipper in North Dakota as predicted by the MaxEnt model ran (see Table 3 for model details). Dots indicate the locations of the locality data that were used to construct the model. Grey lines indicate county boundaries..

*Tawny crescent (*Phyciodes batesii*)*

The Maxent habitat suitability model fit the Tawny crescent data very well with a receiver operating characteristic area under the curve value of 0.927. Wooded cover and, secondarily, ecoregions and agricultural cover played the biggest roles in model formation (Table 4). The final model predictions of Tawny crescent presence were driven by ecoregion, dew point temperature, minimum vapor pressure deficit, and wooded cover (Table 4).

The Tawn crescent was most likely to be found in badlands and river breaks in the west (blue areas in Figure 24) with some populations likely to be found in the north central glacial lake deltas and end moraine complexes (white areas in Figure 24).

Table 4: Contributions of the predictor variables to the MaxEnt model of Tawny crescent presence.

Variable	Percent contribution	Permutation importance
Proportion wooded cover	51.1	16.0
Ecoregions	15.9	26.6
Proportion agriculture cover	11.7	2.7
Mean annual dew point temperature	6.7	19.4
Minimum annual vapor pressure deficit	5.4	18.0
Proportion developed cover	3.8	5.3
Mean annual temperature	3.7	2.3
Proportion grassland cover	0.9	6.5
Proportion wetland cover	0.5	1.0
Maximum annual vapor pressure deficit	0.2	2.5
Total annual precipitation	0.1	0
Minimum annual temperature	0	0
Maximum annual temperature	0	0

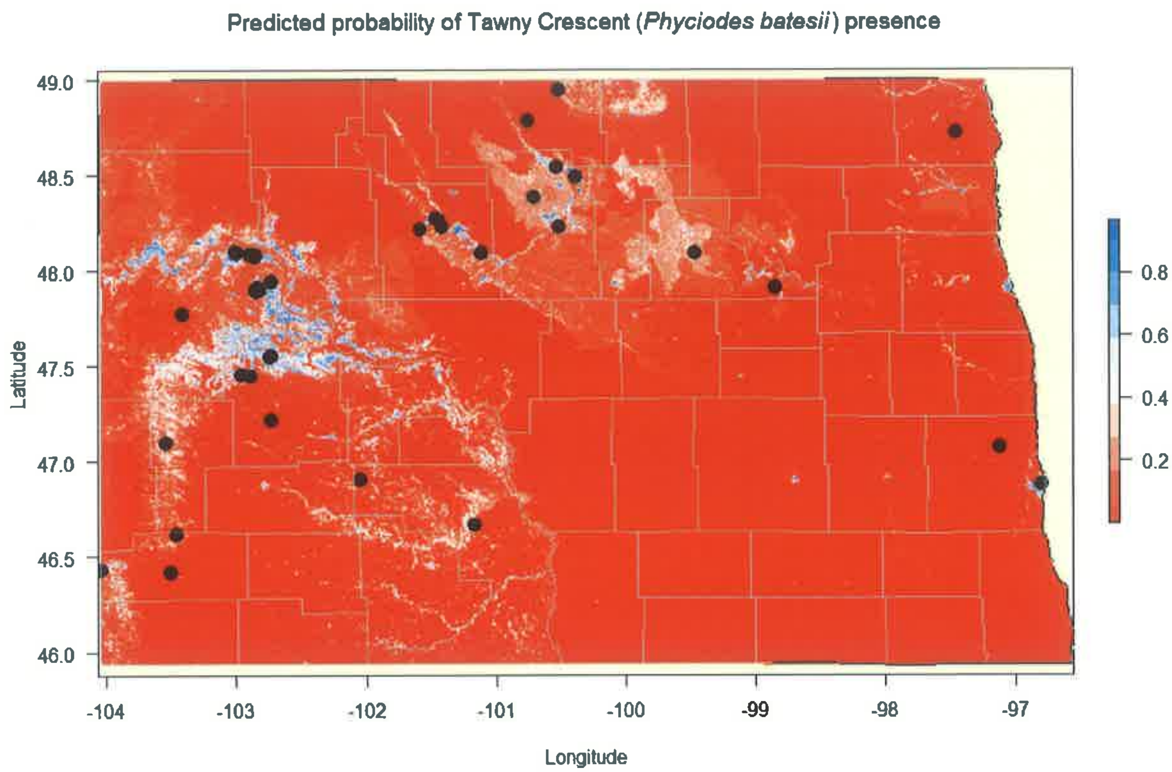

Figure 24: Map of the probability of finding Tawny crescent in North Dakota as predicted by the Maxent model ran (see Table 4 for model details). Dots indicate the locations of the locality data that were used to construct the model. Grey lines indicate county boundaries.

*Monarch (*Danaus plexippus*)*

The Maxent habitat suitability model fit the Monarch data reasonably with a receiver operating characteristic area under the curve value of 0.786. This species was the one most poorly described by a Maxent model. The model formation was primarily driven by developed cover and ecoregions (Table 5). Predictions of Monarch presence by the model were primarily due to ecoregion, and secondarily due to agricultural cover and grassland cover (Table 5).

The model has some areas of higher likelihood of finding a Monarch spread across the central and eastern regions of North Dakota (blue areas in Figure 25). Some of those are likely driven by sampling bias since students collecting for entomology classes around Grand Forks and Fargo might inflate the occurrence data, particularly since there weren't any focused studies on Monarchs to provide data more distributed across the state (as opposed to the other butterfly species modeled). Partly, the pattern in the predicted map is due to the nature of the Monarch distribution, in that it tends to be found widely across the state and the species is quite a habitat generalist as long as it can find its larval host plant (milkweeds) which tend to be widely distributed.

Table 5: Contributions of the predictor variables to the Maxent model of Monarch presence.

Variable	Percent contribution	Permutation importance
Proportion developed cover	59.1	5.9
Ecoregions	24.3	42.8
Total annual precipitation	6.9	9.3
Proportion agriculture cover	5.4	21.8
Proportion wetland cover	2.1	0.4
Proportion grassland cover	1.6	12.8
Proportion wooded cover	0.3	0
Mean annual dew point temperature	0.3	6.3
Minimum annual vapor pressure deficit	0	0
Maximum annual vapor pressure deficit	0	0
Minimum annual temperature	0	0.7
Mean annual temperature	0	2.3
Maximum annual temperature	0	0

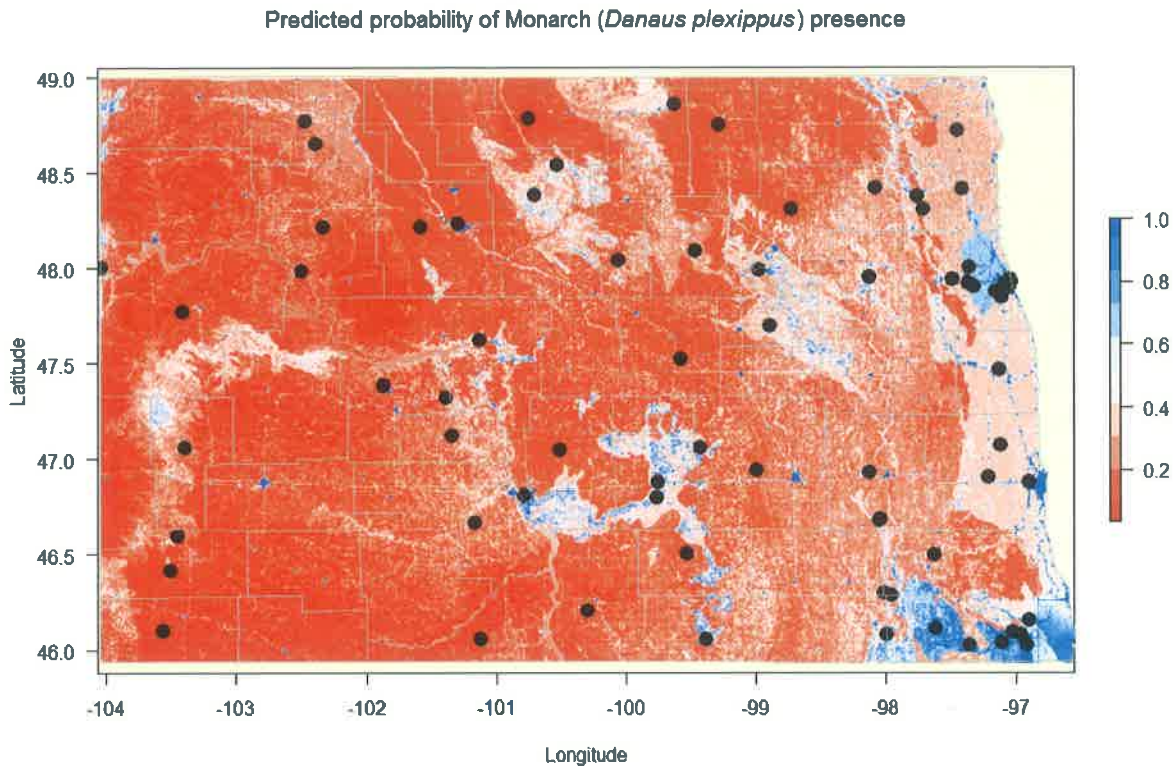

Figure 25: Map of the probability of finding Monarchs in North Dakota as predicted by the MaxEnt model ran (see Table 5 for model details). Dots indicate the locations of the locality data that were used to construct the model. Grey lines indicate county boundaries.

*Regal fritillary (*Speyeria idalia*)*

The Maxent habitat suitability model fit the Regal fritillary data quite well with a receiver operating characteristic area under the curve value of 0.806. Model creation was driven primarily by dew point temperature and ecoregion and secondarily by grassland cover (Table 6). Predictions from the final model were driven primarily by dew point temperature and secondarily by ecoregion and grass cover, with some contribution by vapor pressure deficit (Table 6).

The Maxent model predicts Regal fritillary presence primarily in the south and east of North Dakota where the dew point temperature is higher (blue areas in Figure 26) though there are some other potential areas in the northern areas of North Dakota which seem linked to particular ecoregions (white areas in Figure 26).

Table 6: Contributions of the predictor variables to the Maxent model of Regal fritillary presence.

Variable	Percent contribution	Permutation importance
Mean annual dew point temperature	31.8	44.5
Ecoregions	30.4	18.8
Proportion grassland cover	15.1	10.6
Proportion developed cover	8.3	4.3
Proportion agriculture cover	7.7	3.9
Proportion wetland cover	1.8	1.5
Maximum annual vapor pressure deficit	1.5	7.9
Mean annual temperature	1.4	0.5
Total annual precipitation	0.9	0.9
Proportion wooded cover	0.6	0.1
Maximum annual temperature	0.2	0
Minimum annual vapor pressure deficit	0.2	7.0
Minimum annual temperature	0	0

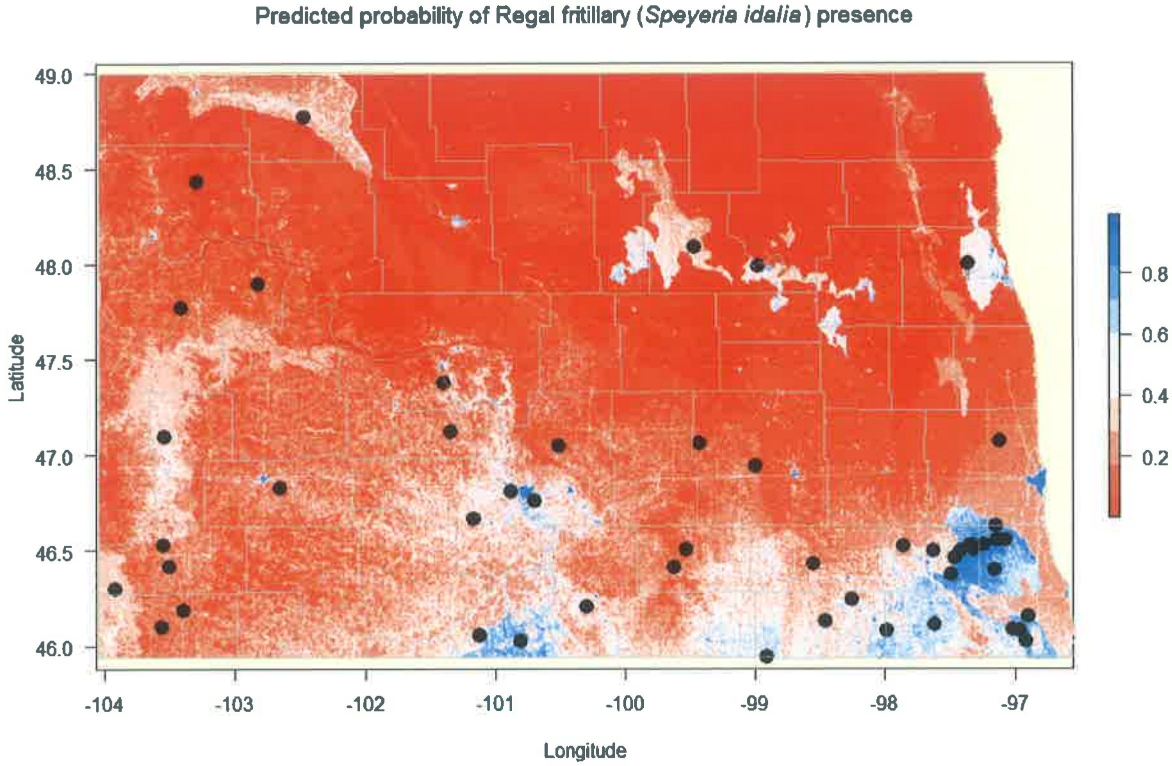

Figure 26: Map of the probability of finding Regal fritillary in North Dakota as predicted by the MaxEnt model ran (see Table 6 for model details). Dots indicate the locations of the locality data that were used to construct the model. Grey lines indicate county boundaries.

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