2023 TECHNICAL REPORT

Monarch Habitat Modeling

Landscape-Scale Approach to Identifying Monarch Habitat in the United States

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Final Report, April 2023

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- Dr. Jay Diffendorfer, Research Ecologist, Geosciences and Environmental Change Science Center, USGS
- Laura Lukens, National Monitoring Coordinator, Monarch Joint Venture

The following staff from the U.S. Fish & Wildlife Service reviewed the report and provided input:

- Dr. Kelly Nail
- Phil Delphey
- Ryan Drum
- Sean Sweeney

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- Dr. Eric Lonsdorf, Emory College
- Stephanie McKnight, Xerces Society
- Stephanie Frische, Botanist, Xerces Society
- Dr. David Zaya, Plant Ecologist, University of Illinois
- Dr. Ray Moranz, Grazing Lands Ecologist, Xerces Society
- Dr. Tyler Flockhart, Flockhart Consulting
- Dr. Chip Taylor, University of Kansas and *Monarch Watch*

ABSTRACT

In the United States, the potential listing of the monarch butterfly under the Endangered Species Act has compelled companies to understand their land's relationship to monarchs, both to guide meaningful conservation actions and to better understand legal liability. The historic establishment of a Candidate Conservation Agreement with Assurance for Energy and Transportation Land provides electric power companies with the opportunity to avoid legal liabilities if the monarch is listed.[1] However, developing a clear understanding of a company's relationship to monarchs is confounded by the scale and distribution of land assets of individual power companies (25,000–500,000 acres [10,117–202,343 hectares]); the complexity of monarch science; unanswered basic questions, including the definition of *monarch habitat*; and the lack of a science-based approach for evaluating large land assets for monarch habitat.

The objective of the project that is the subject of this report was to develop an approach based on a geographic information system (GIS) to help electric power companies better understand the location and extent of monarch habitat within their landholdings. Over two years, we convened a scientific advisory committee, consulted with topical experts, reviewed progress collaboratively with the U.S. Fish & Wildlife Service, and adjusted our methods based on real-time validation of modeling results by power company land managers.

This report summarizes the process and final methods for a landscape-scale, GIS-based approach to identifying monarch habitat in the United States. This is a vegetation-driven model, as follows: *milkweed suitability + floral resource suitability = monarch habitat suitability.* Ultimately, we developed three method variations (Western, Great Plains, and Eastern), each of which is sensitive to regional differences in monarch-related vegetation across the contiguous United States. All model results require field verification.

Keywords

Floral
Habitat
Landholdings
Milkweed
Monarch

[1] U.S. Fish & Wildlife Service, 2020.

EXECUTIVE SUMMARY

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Product Type: Technical Report

Product Title: Monarch Habitat Modeling: Landscape-Scale Approach to Identifying Monarch Habitat in the United States

Primary Audience: Companies seeking to assess their monarch-related landholdings

Secondary Audience: Land managers, monarch scientists, and habitat modelers

KEY RESEARCH QUESTION

Many electric power companies are responsible for large amounts of land and associated natural resources as part of their operations. However, companies have few tools for assessing monarch habitat across diverse and extensive landholdings, or for developing a strategy for managing monarch habitat. The objective of our project was to develop an approach based on a geographic information system (GIS) to help electric power companies better understand the location and extent of monarch habitat within their landholdings to inform an overall monarch management strategy.

RESEARCH OVERVIEW

This report summarizes the process and final methodology for a United States–based monarch habitat model that can be used by electric power companies to identify potential monarch habitat within their landholdings.

KEY FINDINGS

- This project faced several challenges—the lack of a definition of *monarch habitat*, scientific barriers to applying existing methods, and sparse reliable field data for milkweed and nectar resources.
- We convened a scientific advisory committee, consulted with topical experts, reviewed insights collaboratively with the U.S. Fish & Wildlife Service, and adjusted our methods based on real-time validation of modeling results by power company land managers.
- Ultimately, we developed three method variations (Western, Great Plains, and Eastern), each of which is sensitive to regional differences in monarch-related vegetation across the contiguous United States.
- This is a vegetation-driven model, as follows: milkweed suitability + floral resource suitability = monarch habitat suitability.
- All model results require field verification.

WHY THIS MATTERS

How organizations manage monarchs and related regulatory risk will be influenced by individual land management practices, presence of relevant habitat, projections of future conservation/impacts, and broader organizational considerations. A first step in developing a monarch management plan is simply to understand how an organization's total land assets overlap with monarch habitat. This methodology uses best available science to efficiently evaluate large amounts of land against monarch habitat characteristics.

HOW TO APPLY RESULTS

Organizations skilled in GIS analysis can apply the methods described in this report to their lands, or work with EPRI to complete the analysis.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- Monarch Management Logic Structure (epri.com)
- Evaluating Landholdings for Monarch Habitat (epri.com)
- Conservation Actions for Electric Power Companies to Support Monarch Butterflies (epri.com)
- Program on Technology Innovation: New Frontiers in Milkweed Detection—Evaluating the Potential of Satellite Data and Machine Learning (epri.com)

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1 INTRODUCTION AND PURPOSE

The U.S. Fish & Wildlife Service (USFWS) announced in December 2020 that the monarch butterfly (*Danaus plexippus*) was a candidate for listing under the Endangered Species Act (ESA; USFWS 2020). Because USFWS is focused on other, higher-priority listing actions, the monarch butterfly will remain a candidate for listing, with USFWS reviewing its status each year. The next listing consideration is anticipated in 2023 and no later than 2024. Given the monarch butterfly's geographic range and cultural importance, its legal protection status receives broad public attention, and a listing under the ESA could have implications for land management throughout the United States.

Many electric power companies are responsible for managing land—including habitat—as part of their operations. However, companies have few tools for assessing monarch habitat or developing a strategy for managing such habitat in their landholdings. The potential listing of monarch under the ESA has compelled companies to understand their land's relationship to monarchs, both to guide meaningful conservation actions and to better understand legal liability. The historic establishment of a Candidate Conservation Agreement with Assurance (CCAA) for Energy and Transportation Land provides electric power companies with the opportunity to avoid liabilities if the monarch is listed (USFWS 2020). However, developing a clear understanding of a company's relationship to monarchs is confounded by the complexity of monarch science; unanswered basic questions, including the definition of *monarch habitat*; and the lack of a science-based approach for evaluating landholdings for habitat at a landscape scale.

The objective of our project was to develop an approach based on a geographic information system (GIS) to help electric power companies better understand the location and extent of monarch habitat within their landholdings. This project faced several challenges—the lack of a definition of *monarch habitat*, scientific barriers to applying existing methods to this effort, and sparse reliable field data for milkweed and nectar resources.

Over two years beginning in March 2021, we worked with a core team of experts, consulted with topical experts, collaborated with USFWS, and adjusted methods based on real-time validation of modeling results by power company land managers. Ultimately, we developed three method variations (Western, Great Plains, and Eastern), each of which is sensitive to regional ecological differences in monarch-related vegetation across the contiguous United States.

This report summarizes the process and final methodology that can be used by electric power companies in the United States to identify potential monarch habitat within their landholdings. The Electric Power Research Institute (EPRI) is applying modeling results, along with additional considerations, to assist companies in developing monarch management strategies.

Acronyms and Abbreviations

CCAA	Candidate Conservation Agreement with Assurance
CDL	Cropland Data Layer
EPRI	Electric Power Research Institute
ESA	Endangered Species Act
ft	foot, feet
GIS	geographic information system
km	kilometer(s)
m	meter(s)
NAIP	National Agriculture Imagery Program
NDVI	normalized difference vegetation index
NLCD	National Land Cover Database
ROW	right-of-way
SAC	scientific advisory committee
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish & Wildlife Service
USGS	U.S. Geological Survey

2 METHODS

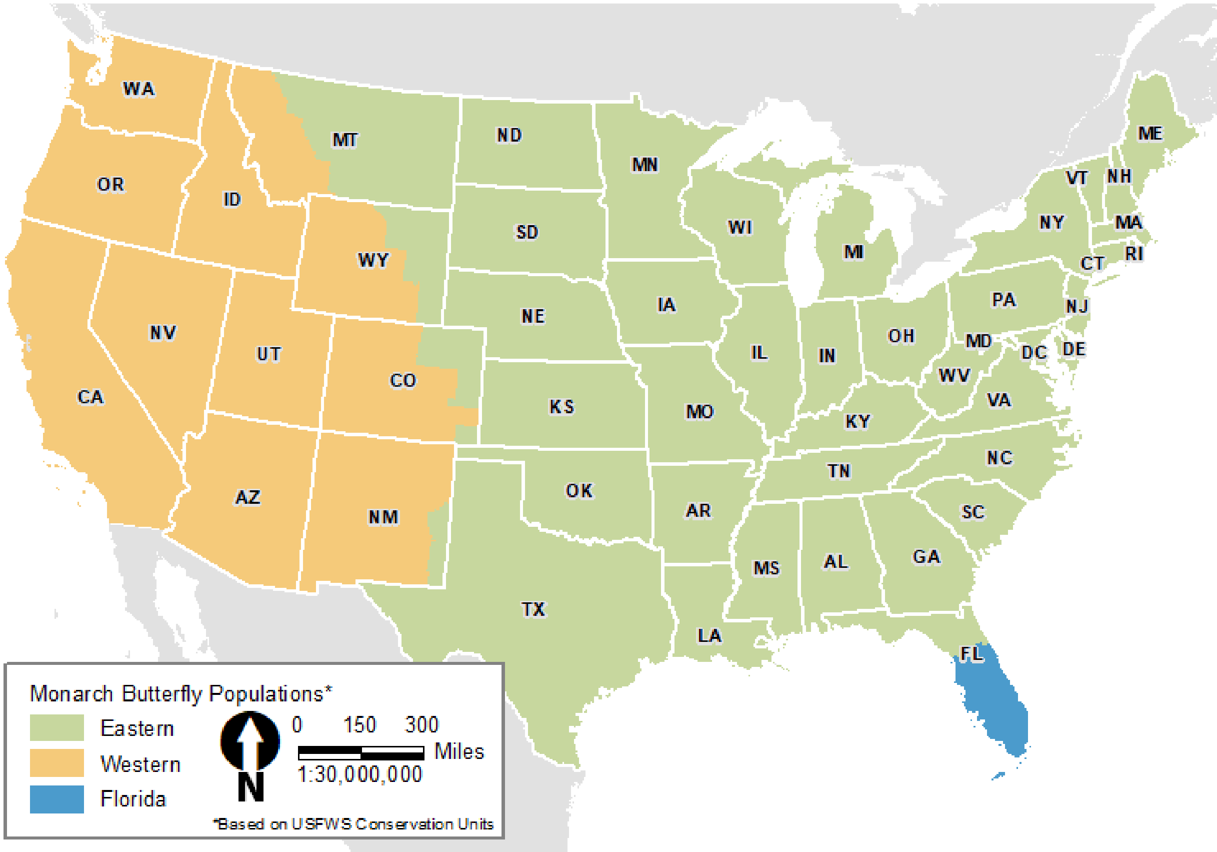
Landscape-Scale Methods

Many power companies manage large amounts of diverse landholdings. Cumulative landholdings commonly range from 20,000 acres to 500,000 acres (8094–202,343 hectares) across various asset types, including transmission and distribution lines, substations, power plant sites, offices and facilities, ground-mounted solar arrays, and wind power. Additionally, many companies manage “surplus property,” which is owned and/or managed by the company but not used for electric power infrastructure. Property management and ownership vary depending on the property type and include easement, lease, and owned. Further, the land assets themselves can be enormously diverse even within one company, spreading across ecoregions, watersheds, and state lines. With these complexities in ecology, ownership, and scale, it can be challenging for companies to catalog their land assets and analyze them against specific species’ needs or “biodiversity” as a whole.

Due to the scale of power company lands, it is useful to have a landscape scale approach to identify, at a high level, company lands most likely to support monarch habitat. **All model results need field verification to confirm the presence or absence of the anticipated habitat at specific sites.**

Study Area

The study area was the eastern and western monarch populations in the United States (see Figure 1). We did not attempt to develop a regional variation for Florida, which has unique (that is, year-round) resident population considerations.



1 mile = 1.609 km

Figure 1. Monarch butterfly populations in the study area

Experts and Advisors

Numerous experts participated in this effort, as noted in the following.

Scientific Advisory Committee

A core scientific advisory committee (SAC) was formed in January 2021 to develop the methods. The SAC consisted of the following individuals (see Appendix C for detailed biographies):

- Dr. Wayne Thogmartin, Research Ecologist, Upper Midwest Environmental Sciences Center, U.S. Geological Survey (USGS)
- Dr. Jay Diffendorfer, Research Ecologist, Geosciences and Environmental Change Science Center, USGS
- Laura Lukens, National Monitoring Coordinator, Monarch Joint Venture

Land Managers

Land managers at eight electric power companies across the United States reviewed various iterations of the modeling results against their landholdings. Results were reviewed with company land managers as initial validation for the methods. Several companies conducted site-based verification of the modeling results and reported good consistency. In several cases, the validation step resulted in revisiting modeling assumptions, updating the methods, and revalidating with land managers.

Monarch Experts

Additional experts provided input during the project, specifically to inform assumptions regarding relative milkweed abundance and quality classifications in the Midwest and Eastern monarch ranges. The following responded to our team's queries and were willing to be acknowledged in this study, although inclusion of their names does not suggest endorsement of the study results:

- Stephanie Frische, Botanist, Xerces Society
- Dr. David Zaya, Plant Ecologist, University of Illinois
- Dr. Ray Moranz, Grazing Lands Ecologist, Xerces Society
- Dr. Tyler Flockhart, Flockhart Consulting

U.S. Fish & Wildlife Service

Experts with USFWS reviewed the methods and provided input at various stages of this project:

- Dr. Kelly Nail, USFWS
- Phil Delphey, USFWS
- Ryan Drum, USFWS
- Sean Sweeney, USFWS

General Assumptions and Decisions

During the early stages of work, several science-supported decisions were made regarding the modeling approach. Decisions were made with consideration of the purpose of this modeling—to assist companies in understanding their likely association with current monarch habitat. The following was decided:

- National-scale and publicly sourced geospatial data would be used, when possible, to map monarch habitat throughout the contiguous United States. We originally intended to rely on the best available existing methods, which we anticipated would be summarized in Thogmartin et al.'s paper "Restoring Monarch Butterfly Habitat in the Midwestern US: 'All

Hands on Deck'" (Thogmartin et al. 2017) because this was a key source of USFWS's approach to identifying monarch habitat during the 2020 species status assessment as part of the listing evaluation (USFWS 2020). This method evaluated five land cover sectors in midwestern states in terms of their current and potential ability to support milkweed (a requirement for monarch breeding), evaluated the potential for milkweed restoration in those five sectors, and developed scenarios to support USFWS's monarch population restoration goals. Unfortunately, we could not apply this prior work to our study area because it focused on midwestern land cover and should not be assumed to apply to areas outside the Midwest.

- We anticipated following the USFWS definition of *monarch habitat* to guide our methods. USFWS did not provide a clear definition during the time of this study (stems of milkweed, combination of milkweed and nectar, presence of butterflies themselves, and so on). In the absence of a specific definition of *monarch habitat* from USFWS, we would not only focus on milkweed (which is critical for breeding habitat and the larval stage), but also consider the suitability of floral resources (which is critical for migratory habitat and the adult stage). Due to regional differences in milkweed and floral resources as well as regional climatic, soil, and ecological variability, we would attempt to identify the best available existing milkweed and floral data by region.
- Although monarch behavior (such as fly distance, foraging behavior, mating patterns, or habitat connectivity) is a valuable consideration, we would not include it. Additionally, we did not consider factors outside the direct authority and control of the land manager, including pesticide drift, adjacent property conditions, and climate change influences.
- We would focus on the **current** habitat suitability (the capacity of the current habitat to support the species) rather than future habitat potential. Although results can reveal potential restoration areas, the model did not attempt to predict or prioritize where restoration efforts should take place, which would have required careful consideration of habitat connectivity, pesticide drift, climate change, monarch behavior, legal requirements and limitations of the power company, and additional dynamic factors.
- Because the purpose of the model is to inform company actions within company landholdings, we would work to use the highest-resolution data available, ideally with a resolution suitable for informing parcel-level analysis. Some studies and data sources were simply too coarse for representing monarch habitat at a parcel level. For example, several species of milkweed suitability were modeled at a latitude of 40° with a 10 arc-minute, which equates to cell sizes larger than 14 km. We deemed this resolution far too coarse to reasonably represent monarch habitat at the parcel level, and it was not applied.
- We did not use the Landscape Prioritization Model, developed by a team of researchers and the Monarch Joint Venture (Cariveau et al. 2020) to help roadside right-of-way (ROW) managers assess how roads in their state relate to landscape-scale factors affecting monarch habitat quality. The model is similar to the model we ultimately developed in that it uses the U.S. Department of Agriculture's (USDA's) Cropland Data Layer (CDL), but it also incorporates other data (for example, potential pesticide sources) and generates more outputs (such as high-quality monarch habitat patches). The SAC discussed the input data

used as well as the additional outputs generated, and there was low certainty as to whether these additions should be included in our methodology. For example, the data on pesticide application are limited, and the application in fields can vary considerably from year to year. Additionally, there is uncertainty regarding the impact that pesticides have on habitat adjacent to areas where pesticides have been applied. To be clear, the authors and SAC did not necessarily disagree with the methods in the Landscape Prioritization Model, but they determined that the level of uncertainty in applying some of the data across our study area was too high.

- Site-based verification would be required to confirm habitat. The monarch habitat map would help identify areas **most likely** to support monarch habitat, but site-based verification would be required for confirming the presence and quality of suitable habitat.

Modeling Approach

We identified two main variables to consider at a landscape scale—milkweed suitability and floral resource suitability. We combined these two variables, with equal weight, to represent monarch habitat suitability:

milkweed suitability + floral resource suitability = monarch habitat suitability

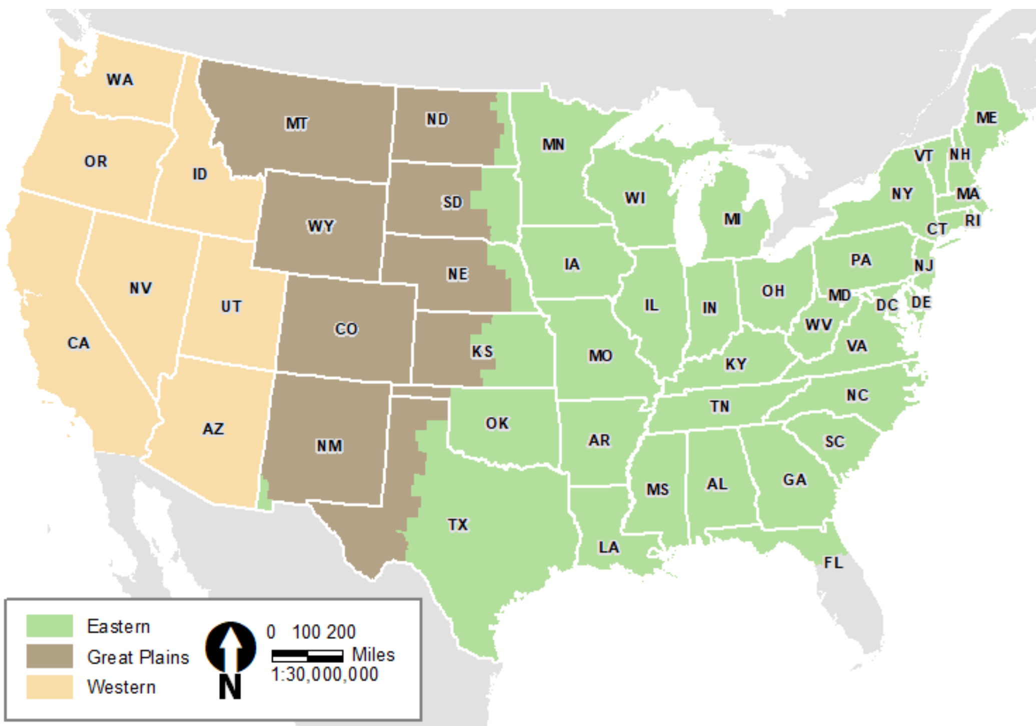
These two variables were associated with national land cover classifications to generate an overall estimate of habitat suitability. Pilot runs of the methods were shared with electric power company land managers, who considered the accuracy of the model outputs based on what they observed in the field. Several validation cycles were completed—that is, we shared model results with land managers, who in turn identified inconsistencies between model results and their observations. Then, we modified the model and once again shared the updated model results with land managers. Two companies conducted a small set of site visits to validate the model outputs within their landholdings and reported consistency with the model results.

A lack of reliable field data for Eastern milkweed resources was a major limitation. Because of the differences in how milkweed and soil characteristics are distributed in different parts of the monarch population, using consistent proxies between milkweed abundance and land cover type across the United States resulted in inaccuracies compared to actual field conditions. This was independently confirmed during validation of model results with the land managers in the Great Plains. Therefore, we determined that habitat modeling—and specifically the milkweed suitability estimates by land cover type—needed to be region-specific.

Note three important assumptions regarding milkweed:

- An estimate for milkweed quality was not done, only abundance. We used the abundance estimates as a proxy for overall milkweed suitability.
- We did not include tropical milkweed (*Asclepias curassavica*) in the abundance estimates because there is considerable ongoing scientific debate about the value of tropical milkweed to monarchs.
- Aside from the exclusion of *A. curassavica*, we did not consider the importance of various milkweed species to monarchs. We assumed that all "milkweeds" are equally important to monarchs across all regions.

Three regional methods were developed—Eastern, Western, and Great Plains (see Figure 2). Florida was not part of the study area, and we did not attempt to develop a regional variation for Florida, whose unique monarch conditions include a resident population that persists year-round. Each method used best available data and combined milkweed suitability and floral resource suitability, equally weighted, to represent overall monarch habitat suitability.



1 mile = 1.609 km

Figure 2. Boundaries of regional methods

The floral resource methods were applied across all regions. Only the milkweed methods varied by region.

Floral Resources—All Regions

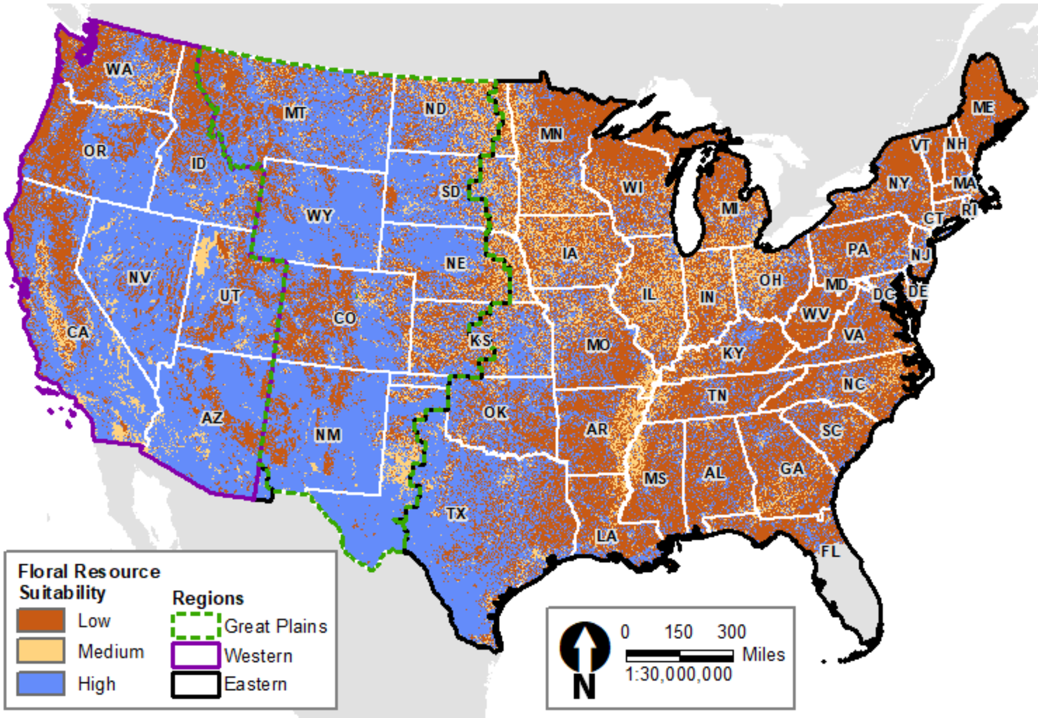
For floral resource data, we leveraged EPRI's Wild Bee Habitat Model methodology (in development), which employs a table representing the relative abundance of floral resources by land cover type using the USDA's CDL. This floral resource table was provided by Dr. Eric Lonsdorf (2020) and is informed by his work developing the InVEST pollinator abundance model (The Natural Capital Project 2019), as outlined in the text box, and co-authoring *Modeling the Status, Trends, and Impacts of Wild Bee Abundance in the United States* (Koh et al. 2016). A floral resource index for land cover types was created (Koh et al. 2016) by surveying a panel of 14 experts. The table represents relative abundance as an index (0–1) of floral resources for each land cover type in the CDL. Our SAC deemed this table to be appropriate data to represent floral resources across the contiguous United States, and we used the floral resources abundance portion of the index, with modifications (see Appendix B).

This land cover–based suitability table (see Table 16) was joined with the 2021 CDL (30-m) (U.S. Department of Agriculture 2021) to generate a raster layer representing floral resource suitability. Floral resource suitability was represented as an index (0–1), with 0 representing no relative floral abundance and 1 representing maximum relative floral abundance. To simplify this information, the index (0–1) was converted to Low, Medium, or High floral resource suitability (see Table 1). The results are shown in Figure 3.

The InVEST pollinator model focuses on wild bees as a main pollinator for crops. Two of the most important resources that support bee persistence on the landscape are suitable nesting sites and ample food supply. When these resources are present, bees can then fly to nearby crops and provide pollination services. Accordingly, the model incorporates a user's estimate of availability of bee nest sites, floral resources on the landscape, and bee flight range information to develop an index of bee abundance on each raster cell across the landscape. This index is called the Pollinator Supply. *The model then uses the bee flight range information to develop an index of bee abundance visiting each raster cell with crops. An optional last step is to calculate an index of the value of bees to crop production for each raster cell across the landscape. Some of the model's limitations are the exclusion of non-farm habitats that contribute to pollinator abundance and the importance of land parcel size.*

Table 1. Floral resource suitability simplification

Index Value	Simplified Suitability
<0.25	Low
0.25–0.45	Medium
>0.45	High



1 mile = 1.609 km

Figure 3. Floral resource suitability in each region

Modifications were made to the floral resource table, which was developed for bees, to be applicable to monarchs (see Table 2). These modifications were made to four specific land cover types that have lower suitability values for monarchs compared to bees in general.

Table 2. Floral resource suitability simplification, modified for monarchs (Provided by Eric Lonsdorf.)

Cropland Data Layer Class	Bee Suitability	Monarch Suitability
Deciduous Forest	High	Low
Evergreen Forest	Medium	Low
Mixed Forest	Medium	Low
Woody Wetlands	High	Low

Milkweed Resources—Western Region

Several high-quality scientific resources existed for estimating milkweed data in the Western region, namely, "Host Plants and Climate Structure Habitat Associations of the Western Monarch Butterfly" (Dilts et al. 2019). With this study, it was possible to use milkweed occurrence information in the Western region rather than associating land classes to milkweed abundance.

Dilts et al. (2019) represents an effort to map breeding and migratory habitat for the Western monarch butterfly. More than 8000 observations of adult and juvenile monarchs and more than 20,000 records from 13 milkweed host plant species were used. The research developed 17 milkweed suitability models covering seven Western states (Arizona, California, Idaho, Nevada, Oregon, Washington, and Utah). We elected to use the suitability model that represented nontropical breeding, shown in Figure 4. We selected this model because it used records of occurrence only in areas >3.6 km away from known occurrences of tropical milkweed. Tropical milkweed occurrences were excluded from this model because they are nonnative and might bias modeling of native occurrences. Milkweed suitability values were represented as an index from 0 to 100, as represented by Dilts et al. (2019).

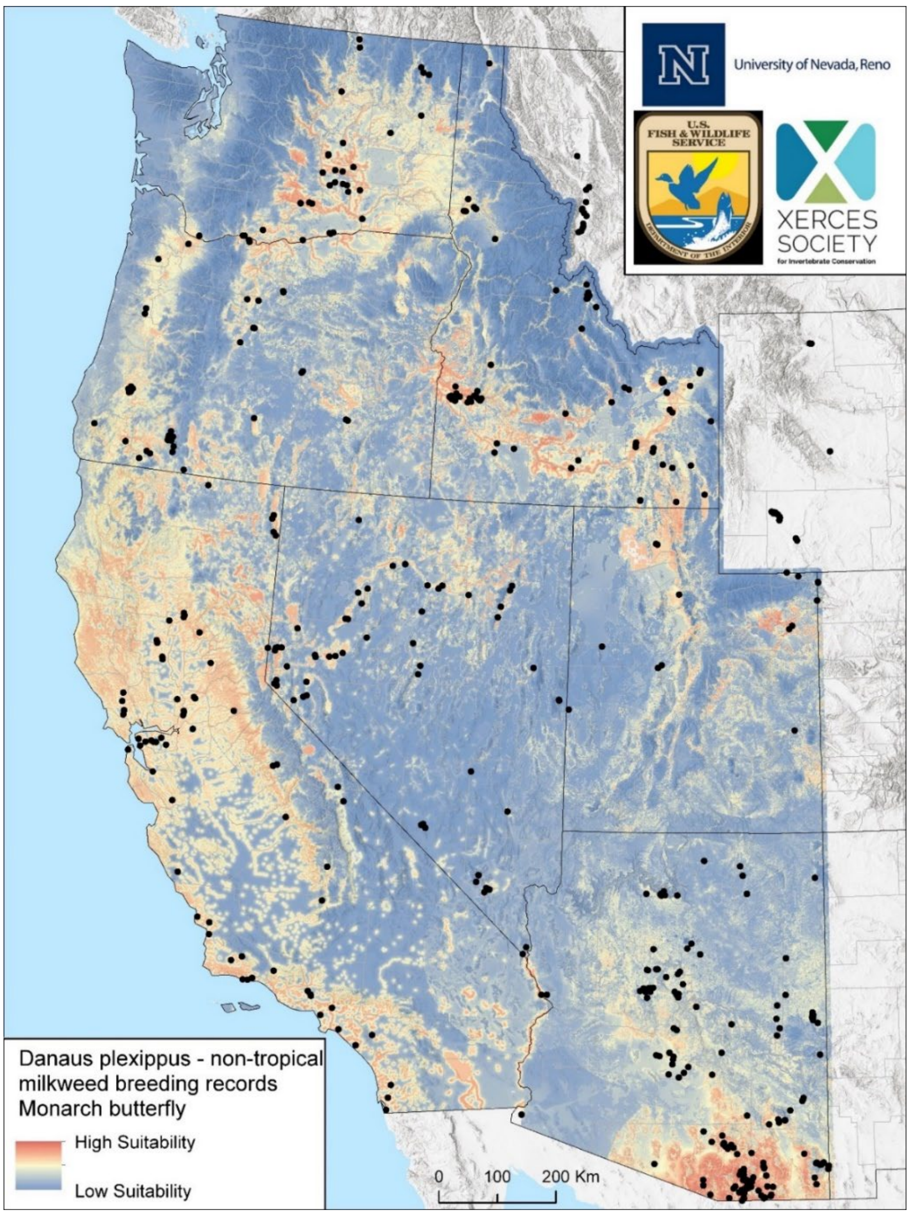
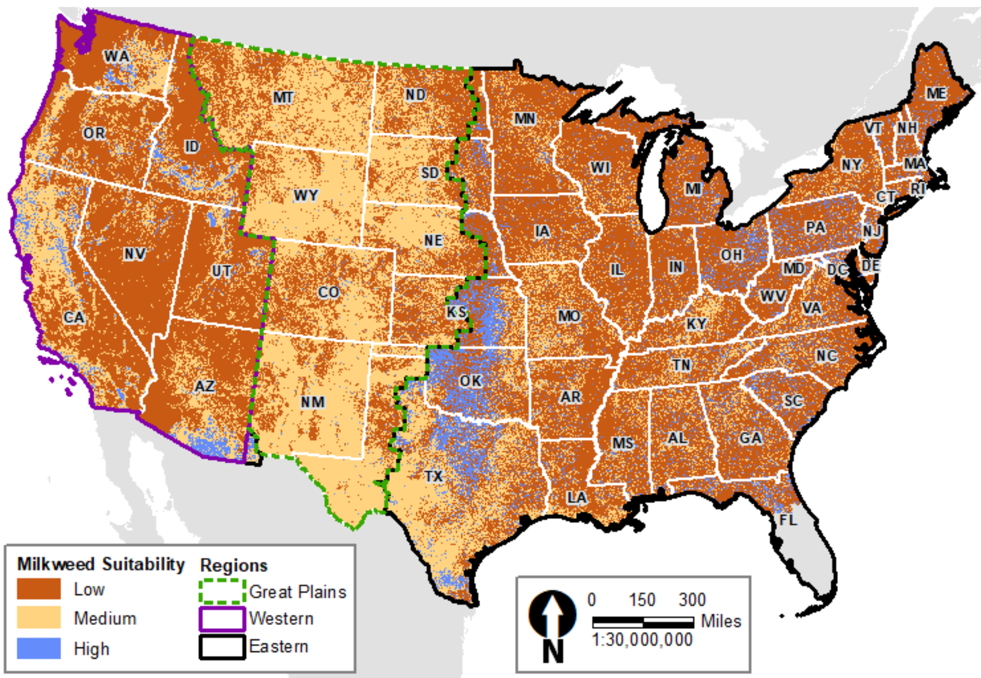


Figure 4. *Danaus plexippus*: breeding records excluding tropical milkweed (Dilts et al. 2019)

To simplify, we converted the index to Low, Medium, or High milkweed suitability values. The values in the index ranged from 0 to 95. We converted the Dilts et al. (2019) index to Low, Medium, or High using an equal interval method (equal thirds) (see Table 3). Results are shown in Figure 5.

Table 3. Milkweed suitability simplification

Index Value	Simplified Milkweed Suitability
0–31	Low
32–63	Medium
64–95	High



1 mile = 1.609 km

Figure 5. Milkweed resource suitability by region

Although Dilts et al. (2019) is the best available information across Western states, it does come with a considerable drawback—the resolution is 270 m. Efforts are underway to improve on these models in the Western population (Arizona, specifically) to improve the resolution to 90 m (Gade and Nelson 2021).

Milkweed Resources—Eastern Region

Lack of available data and scientific publications made estimating milkweed abundance in the Eastern range challenging. In contrast to the Western region, where there was a unique dataset of milkweed occurrences, it was necessary to estimate milkweed by land class for the Eastern region. The following made this particularly challenging:

- There is little completed research of land cover–specific milkweed density outside the upper Midwest.
- Although milkweed occurrence information is limited, experts agreed that associating a specific land cover class to a consistent milkweed abundance assumption east of the Rocky Mountains in the United States would be inaccurate.
- The relationship between land cover classification and milkweed could be an issue more accurately characterized by vegetation managers and botanists than monarch scientists.
- The southeastern states are particularly bereft of research on milkweed occurrence and density; this area is at the edge of the range for some milkweed species common to midwestern and northeastern states while solidly inside the range of other milkweed species most commonly found in southern states. The relative differences in milkweed density between the northern and southern breeding regions are not well understood based on scientific datasets.

Given the lack of field data and published resources to estimate milkweed weed abundance and quality in the Eastern monarch range, we used expert opinion, an approach appropriate in data-limited situations.

Milkweed Abundance Expert Opinion

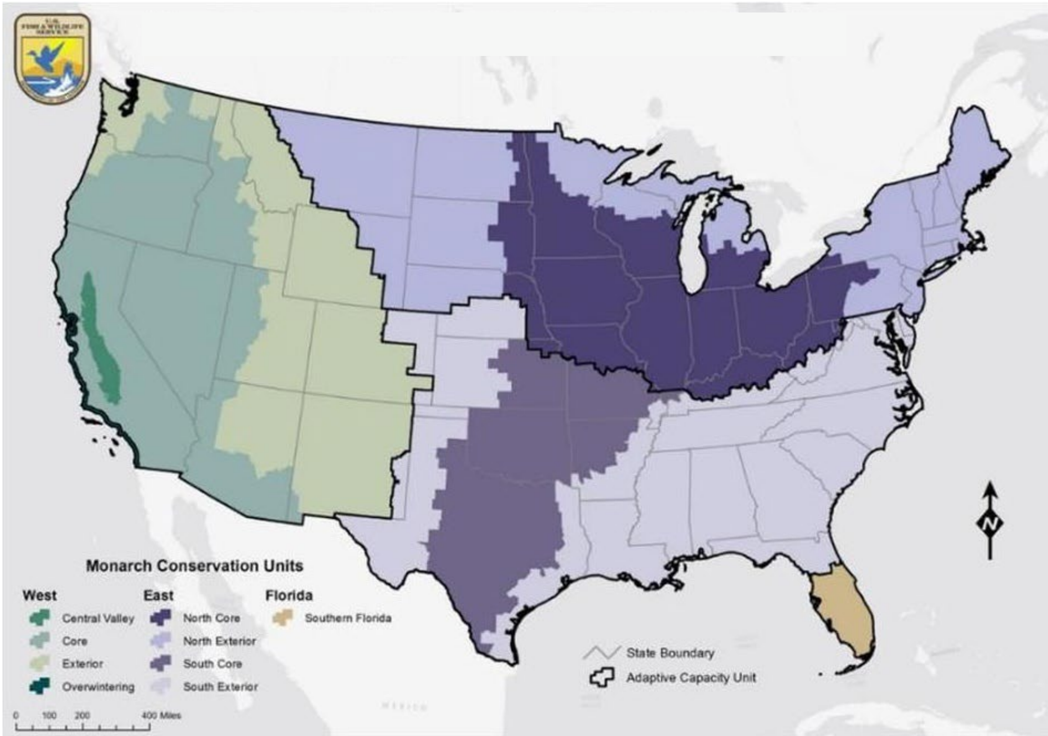
First, the SAC independently estimated (without knowledge of one another's estimates) the milkweed abundance for each of the 16 land cover types from the National Land Cover Data (USGS 2019) in the Eastern region (see Table 4). The SAC's opinion was informed by a large set of scientific literature, including the publications listed in Attachment 1. Current milkweed abundance is defined as:

- High = >10 stems/acre (>10 stems/0.4 hectare)
- Medium = 1–10 stems/acre (1–10 stems/0.4 hectare)
- Low = <1 stem/acre (<1 stem/0.4 hectare)

Table 4. SAC estimates of Eastern milkweed suitability

Land Cover Class	SAC Expert 1	SAC Expert 2	SAC Expert 3	Consensus
Barren Land	Low	Low	Low	Low
Cultivated Crops	Low	Low	Low	Low
Deciduous Forest	Low	Low	Low	Low
Developed, High Intensity	Low	Low	Low	Low
Developed, Low Intensity	Medium	Medium	Medium	Medium
Developed, Medium Intensity	Low	Low	Low	Low
Developed, Open Space	High	Medium	Medium	High
Emergent Herbaceous Wetlands	Low	High	Medium	Medium
Evergreen Forest	Low	Low	Low	Low
Hay/Pasture	Medium	Medium	Medium	Medium
Herbaceous	High	Medium	High	High
Mixed Forest	Low	Low	Medium	Low
Open Water	Low	Low	Low	Low
Shrub/Scrub	High	Medium	Medium	Medium
Unclassified	Low	Low	Low	Low
Woody Wetlands	High	Low	Low	Low

Given the importance of milkweed abundance in the model, we opted to validate the SAC's estimates by consulting outside experts. In October 2021, a survey was designed (see Appendix A) and sent to eight experts, four of whom responded (an agronomist, plant ecologist, biologist, and pollinator ecologist). Fifteen land cover types were included, as defined by the National Land Cover Database (NLCD), as well as five regions, as defined by USFWS monarch conservation units (see Figure 6).



1 mile = 1.609 km

Figure 6. Monarch Butterfly Conservation Units in the contiguous United States

We provided the following instructions and definitions:

INSTRUCTIONS: Please select your estimate of High, Medium, or Low associated with the quantity of current (not potential) milkweed occurrence associated with each National Land Cover Database (NLCD) category and region. Only complete the regions applicable to your expertise, but please enter estimates for all NLCD types in the region you are completing.

Abundance is the average over the region, not abundance at specific sites.

This survey is related to CURRENT milkweed abundance (not potential for restoration).

Current milkweed abundance is defined as:

- High = >10 stems/acre
- Medium = 1–10 stems/acre
- Low = <1 stem/acre

Confidence level is your qualitative assessment based on current state of knowledge and observation.

- High = Extremely Confident
- Medium = Mostly Confident
- Low = Somewhat Confident

With both the expert opinion survey and the input of the SAC, we created a single overall estimate of milkweed abundance for the Eastern region (see Table 4). The survey expert estimates were in general agreement with the SAC's estimates (see Table 5). However, the estimates for one land cover type—Developed, Open Space—were notably different. The SAC estimated this land cover type to possess high abundance, whereas the other experts estimated Medium (two experts) or Low (one expert). After discussion and review of published literature, including Johnston et al. 2019, the original SAC consensus estimates were used to represent milkweed abundance for Developed, Open Space, although uncertainty is noted.

Table 5. Expert milkweed suitability estimates and corresponding confidence level

Land Cover Types	SAC Consensus	Expert 1	Expert 2	Expert 3	Expert 4	
		North Core	North Core	North Exterior	South Core	South Exterior
		Current Milkweed Abundance	Current Milkweed Abundance	Current Milkweed Abundance	Current Milkweed Abundance	Current Milkweed Abundance
Barren Land	Low	Low	Low	Low	Low	Medium
Cultivated Crops	Low	Low	Medium	Low	Low	Low
Deciduous Forest	Low	Low	Medium	Low	Low	Medium
Developed, High Intensity	Low	Medium	Low	Low	Low	Low
Developed, Low Intensity	Medium	Low	Medium	Low	Medium	Medium
Developed, Medium Intensity	Low	Medium	Medium	Low	Low	Medium
Developed, Open Space	High[2]	Medium	Medium	Low	Low	Medium
Emergent Herbaceous Wetlands	Medium	Medium	High	Low	Low	Medium
Evergreen Forest	Low	Low	Low	Low	Medium	Medium
Hay/Pasture	Medium	Medium	High	Medium	Medium	Low
Herbaceous	High	High	High	High	High	High
Mixed Forest	Low	Low	Low	Low	Medium	Medium
Open Water	Low	Low	Low	Low	Low	Low
Shrub/Scrub	Medium	Medium	Medium	Medium	Medium	Medium
Woody Wetlands	Low	Low	Medium	Low	Low	Medium

[2] SAC consensus informed by published research, including https://www.frontiersin.org/articles/10.3389/fevo.2019.00210/full.

Milkweed Resources—Great Plains Region

On validation of draft milkweed suitability modeling results using the Eastern region methodology, land managers from electric power companies in the Great Plains noted the high estimates of milkweed to be inconsistent with their observations in their ranch-dominated region. Similarly, the SAC independently observed possible over-attribution of milkweed abundance in the same region, which is further noted in published literature, including Spaeth Jr. et al. 2022. If the model considers soil characteristics, lower soil productivity (see Figure 7), climate, and the USFWS Monarch Butterfly Conservation Units (see Figure 6), the SAC concluded that it is reasonable to downgrade the milkweed suitability of two specific land cover types in the Great Plains—herbaceous and hay/pasture. Specifically, we downgraded milkweed abundance by one level from what was applied in the Eastern region (such as from High to Medium) (see Table 6) in the Great Plains that is outside the core Monarch Butterfly Conservation Units and outside the West, where we applied Dilts et al. (2019).

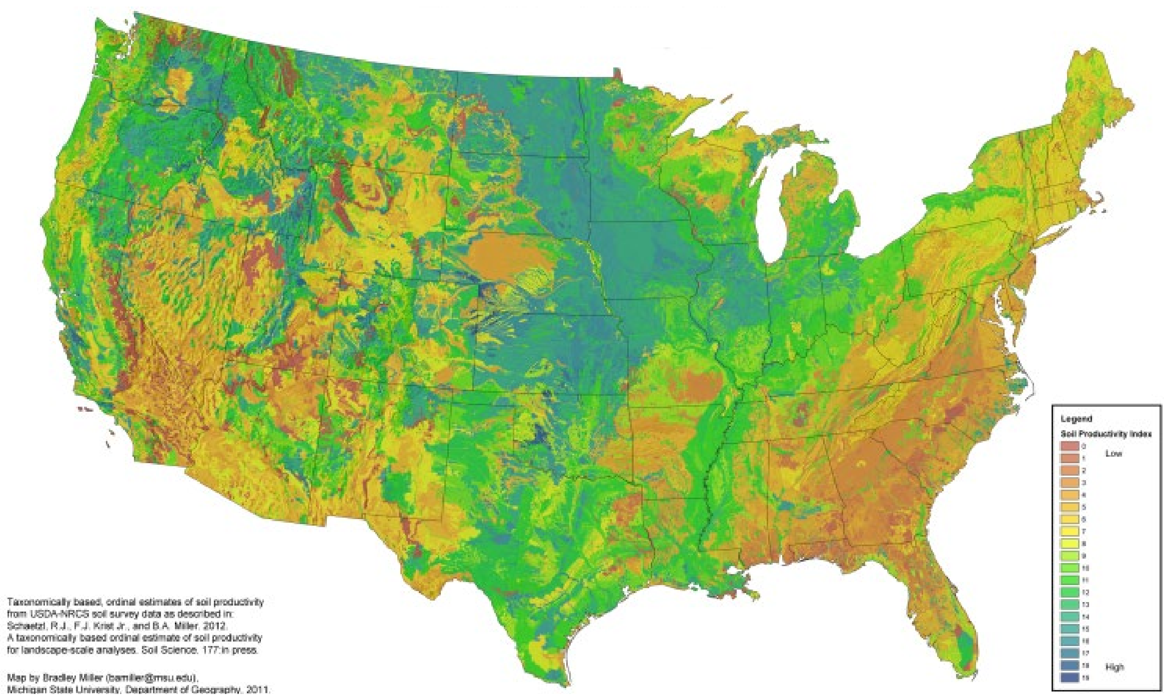


Figure 7. Soil productivity index

Table 6. Great Plains milkweed suitability

Land Cover Class	Milkweed Suitability
Barren Land	Low
Cultivated Crops	Low
Deciduous Forest	Low
Developed, High Intensity	Low
Developed, Low Intensity	Medium
Developed, Medium Intensity	Low
Developed, Open Space	High
Emergent Herbaceous Wetlands	Medium
Evergreen Forest	Low
Hay/Pasture	Low
Herbaceous	Medium
Mixed Forest	Low
Open Water	Low
Shrub/Scrub	Medium
Unclassified	Low
Woody Wetlands	Low

Final Methodology and Model Results

Table 7 presents the data used in the two-variable approach for each of the three regions.

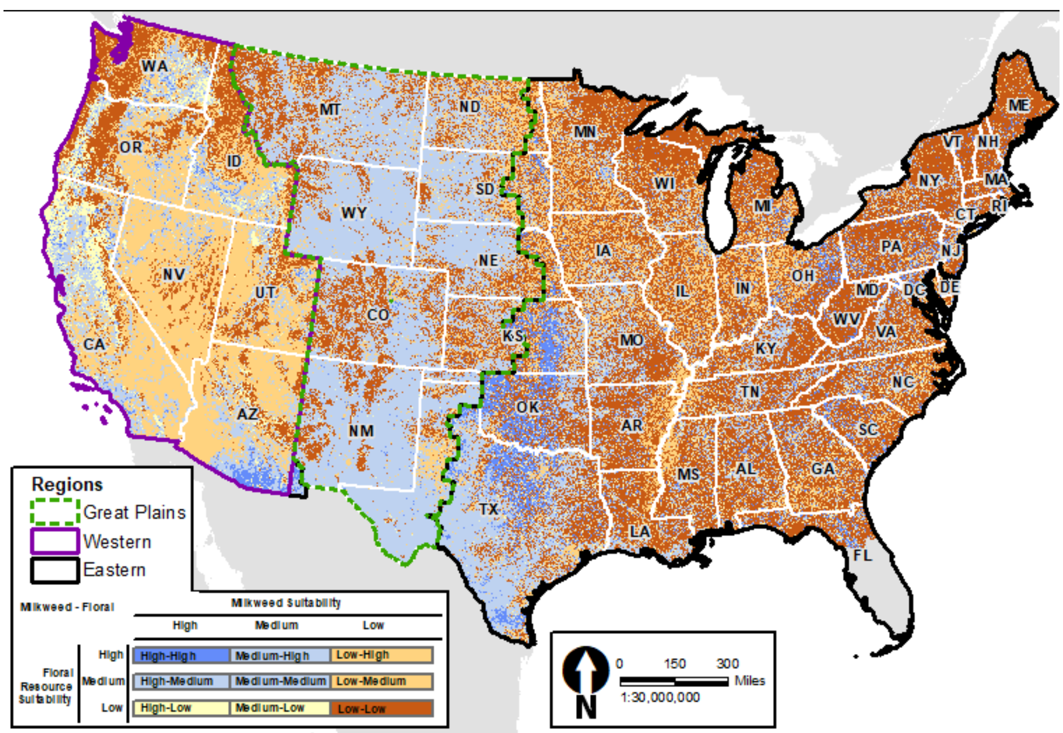
Table 7. Final monarch butterfly habitat model methodology by region

Region	Milkweed Suitability	Floral Resource Suitability
Eastern	Species expert opinion and 2019 NLCD	InVEST Relative Abundance of Floral Resources, with modifications, and 2020 Cropland Data Layer
Western	*Danaus plexippus*—breeding records, water, climate variables, excluding tropical milkweed (Dilts et al. 2019)	InVEST Relative Abundance of Floral Resources, with modifications, and 2020 CDL
Great Plains	Species expert opinion and 2019 NLCD, with modifications	InVEST Relative Abundance of Floral Resources, with modifications, and 2020 CDL

The two raster datasets in each region (Figures 3 and 5) were combined using the ArcGIS Combine tool so that a unique value for each raster cell is assigned to each unique combination of input values (see Table 8). The result is a 30-m raster layer representing nine milkweed-floral values (see Figure 8).

Table 8. Percentage of monarch butterfly habitat suitability values by region

Milkweed-Floral Values	Percentage of Eastern Region	Percentage of Western Region	Percentage of Great Plains Region
Low-Low	48%	19%	23%
Low-Medium	11%	4%	8%
Low-High	3%	45%	4%
Medium-Low	3%	7%	2%
Medium-Medium	1%	16%	1%
Medium-High	16%	16%	62%
High-Low	8%	1%	<1%
High-Medium	<1%	1%	<1%
High-High	9%	3%	<1%



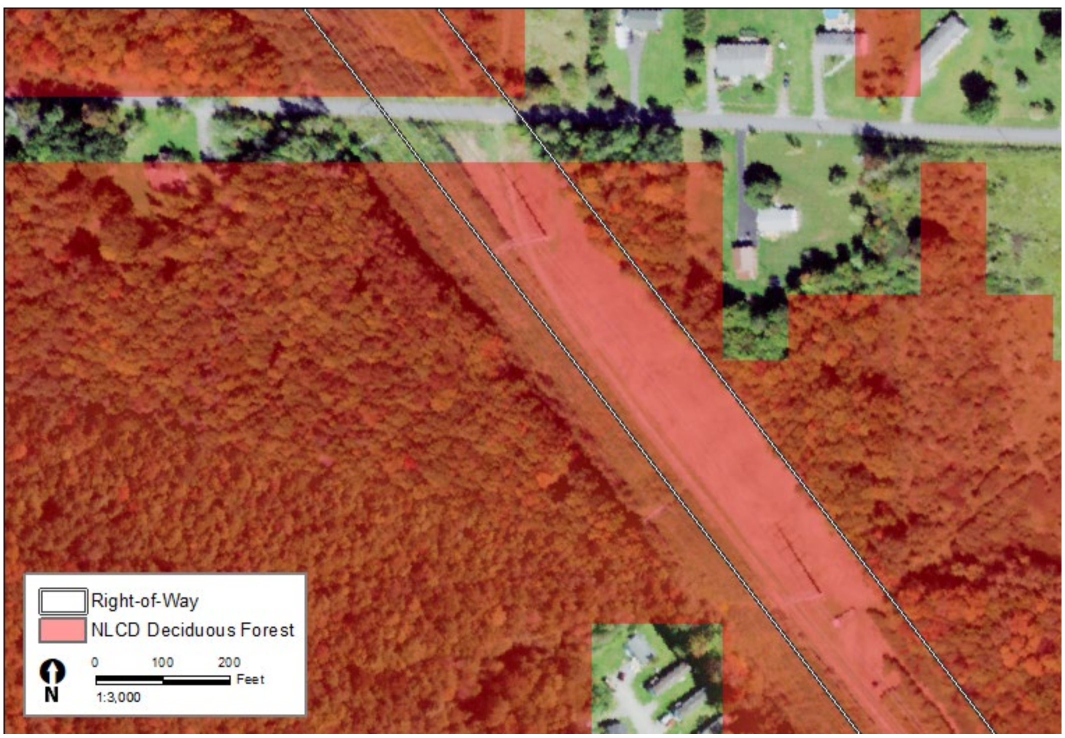
1 mile = 1.609 km

Figure 8. Monarch butterfly habitat suitability in each region

Issues with Land Cover in ROWs

During model validation with company land managers, an issue specific to ROWs in the Northeast was discovered. While reviewing the acres of monarch habitat suitability by landholding type with a company in the Northeast (Company A), a significant error was identified in the amount of a specific land cover type within the company's ROW. The company's manager noted that the estimate of more than 20% ROWs being classified as *deciduous forest* land cover was incorrect and should be much lower. The company works to ensure that vegetation that could impact the transmission lines, including deciduous forest, is removed from ROWs wherever possible.

When visually reviewing the areas classified as deciduous forest land cover from the NLCD, it became clear that the approximately 200-ft-wide (61-m-wide) ROW is too narrow to accurately classify land cover types with the 30-m cell size of the NLCD (see Figure 9). When the ROW is surrounded by forest, surrounding forest patches influence the NLCD's classification of the 30-m cells within the ROW.



1 ft = 0.305 m

Figure 9. Example of incorrect classification of deciduous forest land cover type

The relatively coarse resolution of the NLCD is a primary reason for the overestimate of deciduous forest within the ROW. To address this, a search for alternative sources of land cover data in the region was made by reviewing state and national GIS data repositories. No data that offered better than 30-m cell size were found. No alternative land cover datasets were identified, so the discussion turned to methods of developing one. Therefore, we pursued an approach that would involve classifying four-band National Agriculture Imagery Program (NAIP) photographs. The most recent photographs captured by NAIP for the region are from 2019 and are much higher in resolution (0.6-m cell size). Additionally, we classified the photographs into a few land cover types by applying a normalized difference vegetation index (NDVI).

Five land cover types were identified for evaluation and calibration using NDVI. The number of land cover types needed to be small because NDVI is not intended to be used to classify land cover; it is intended to be used to describe the greenness—the relative density and health of vegetation, with an index of -1 to 1—of each cell in a photograph. Because of this, NDVI cannot differentiate between types of vegetated areas well; it is intended to determine how green they appear. Land cover types we aimed to classify are shown in Table 9.

Table 9. Proposed land cover types in NLCD deciduous forest areas

Land Cover Type
Woody Wetlands
Barren
Herbaceous
Shrub/Scrub
Forest

Ten points were randomly selected within Company A’s ROW for calibrating and evaluating a method of classifying five land cover types by applying NDVI to NAIP photographs. Through an iterative process of applying different breaks in the NDVI and reviewing the results across the 10 randomly selected points, we developed the NDVI values shown in Table 10 and Figure 10. A high-level evaluation of the classification of the NAIP photographs, using the breaks shown in Table 10, was performed.

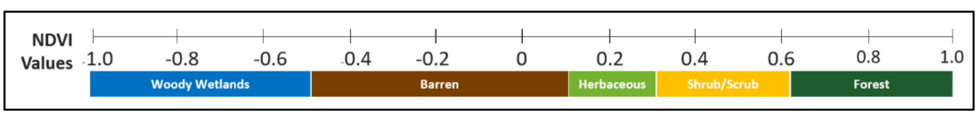


Figure 10. Proposed NDVI values in NLCD deciduous forest areas

Table 10. Proposed NDVI values in NLCD deciduous forest areas

Land Cover Type	NDVI Values (-1.0 to 1.0)
Woody Wetlands	-1.0 to -0.5
Barren	-0.5 to 0.03
Herbaceous	0.03 to 0.3
Shrub/Scrub	0.3 to 0.61
Forest	0.61 to 1

The land manager confirmed that the updated land cover analysis appeared generally accurate. Inaccuracies seemed to be most common at the lower end of the NDVI. Two issues of note were discussed.

First, the NDVI-derived land cover types *woody wetlands* and *barren* likely include several other land cover types with no live green vegetation (for example, *open water* or *developed*). These inaccuracies were considered acceptable because areas of low greenness will be considered low suitability for milkweed. The primary use of the land cover data is to serve as a proxy for milkweed suitability, so it is not necessary to differentiate the types of land cover in these areas with little to no live green vegetation.

The second issue discussed was that training samples could more accurately inform where the various breaks in the NDVI should be placed. Because this effort to model suitable monarch butterfly habitat does not entail fieldwork and strives to use existing data as much as possible, collecting training samples was not pursued.

We also evaluated how the results compared to NLCD land cover types other than d*eciduous forest*. This was done within the extent of the USGS 7.5 Minute Quadrangle Quarter Quad Map Index containing each of the 10 randomly selected points. It became clear that the NDVI-derived approach to land cover was useful in improving classification of land cover types other than *deciduous forest*. Based on these observations, we decided to drop most NLCD land cover types, except *cultivated crops* and *hay/pasture*, in favor of the NDVI-derived land cover types. Table 11 summarizes the sources and rationale for each land cover type and lists the land cover classes (and sources used) to represent land cover classes.

Table 11. Land cover types within Company A's right-of-way and assigned milkweed suitability

Land Cover Type	Milkweed Suitability	Data Source	Rationale
Barren Land	Low	NDVI	NDVI captures a lot of the disturbed areas
Cultivated Crops	Low	NLCD	NLCD often correctly classifies crops
Deciduous Forest	Low	NDVI	NLCD overstates, however NDVI incorrectly captures canopy shadow. Replace with new class of Forest.
Hay/Pasture	Medium	NLCD	NLCD often correctly classifies hay/pasture
Herbaceous	High	NDVI	Not well classified in NLCD
Shrub/Scrub	Medium	NDVI	Unable to reproduce in NDVI
Woody Wetlands	Low	NDVI	—

Using the updated land cover within Company A's ROW resulted in a large decrease in *forest* and a large increase in *herbaceous* and *shrub/scrub*, which overall increased the amount of likely monarch habitat in the ROW.

When ROWs Need Modified Methods

The issue with the habitat model being inconsistent with land manager validation and actual field conditions can be expected when the surrounding land cover type is significantly different from the land managed under the transmission lines. In the Northeast, which is heavily forested, there is a very different vegetation type under the managed transmission lines than is reflected in the NLCD information.

3 METHOD LIMITATIONS

The monarch habitat suitability map was created using the best available data to consider monarch habitat suitability at a landscape scale across the United States. There are limitations that should be addressed in the future with more time, funding, and data, such as the following:

- This is a vegetation-driven model. It does not consider complex monarch biology, including where butterflies are across space and time, the comparative importance of monarch habitat across regions/states, reproductive and behavior habits, or population dynamics (including the role of the Mexico overwinter sites).
- There are regional differences in how monarchs use milkweed and nectar resources. Our model equally weights nectar and milkweed and does not account for different species of milkweed nor regional differences in how monarchs depend on these resources from north to south or east to west.
- There are embedded scientific limits to interpreting the national maps from the model; monarchs depend on these resources at varying degrees and at different times of year throughout the country. Guiding national monarch conservation priorities by applying the modeling results at a national scale would be inappropriate.
- Model results and the habitat suitability map do not replace the need for field surveys to accurately determine the location of suitable habitat.
- As companies develop a monarch management plan, GIS data cannot be used alone. Other factors, including local monarch expert opinion, interpretation of the GIS modeling outputs, and broader company goals and responsibilities, must be considered.
- An estimate for milkweed quality was not done, only abundance. We used the abundance estimates as a proxy for overall milkweed suitability.
- Floral and milkweed resource maps are 30-m and 270-m resolution, respectively. Using these resolution data was necessary to develop a method that could be applied to many regions throughout the United States. In the future, state or local land cover data could be used to create higher-resolution maps.
- The CDL and NLCD are imperfect, each having various misclassification rates for land cover. Such misclassification can lead to incorrect habitat suitability classifications.
- There are varying levels of certainty regarding the milkweed estimates in the range of the Eastern monarch population. Methods could be updated as more data on milkweed occurrence and density become available (for example, the Integrated Monarch Monitoring Program).

4 APPLYING THE MODEL

Electric power companies are interested in understanding the spatial distribution of monarch habitat suitability within their landholdings. At present, companies lack this information, preventing them from making informed decisions about where to consider monarch butterfly needs. As described in EPRI's Monarch Management Logic Structure, the first step in developing a monarch management strategy is to understand the lands that overlap with habitat (see Figure 11), followed by detailed analysis of current land management activities and avoidance and minimization measures for habitat impacts. Finally, the company's overall risk tolerance versus liability needs to be evaluated (see Figure 12). Therefore, the Monarch Habitat Model described in this report is only one input needed in analysis to inform company monarch management decisions, including participation in the Monarch CCAA for Energy and Transportation Lands.

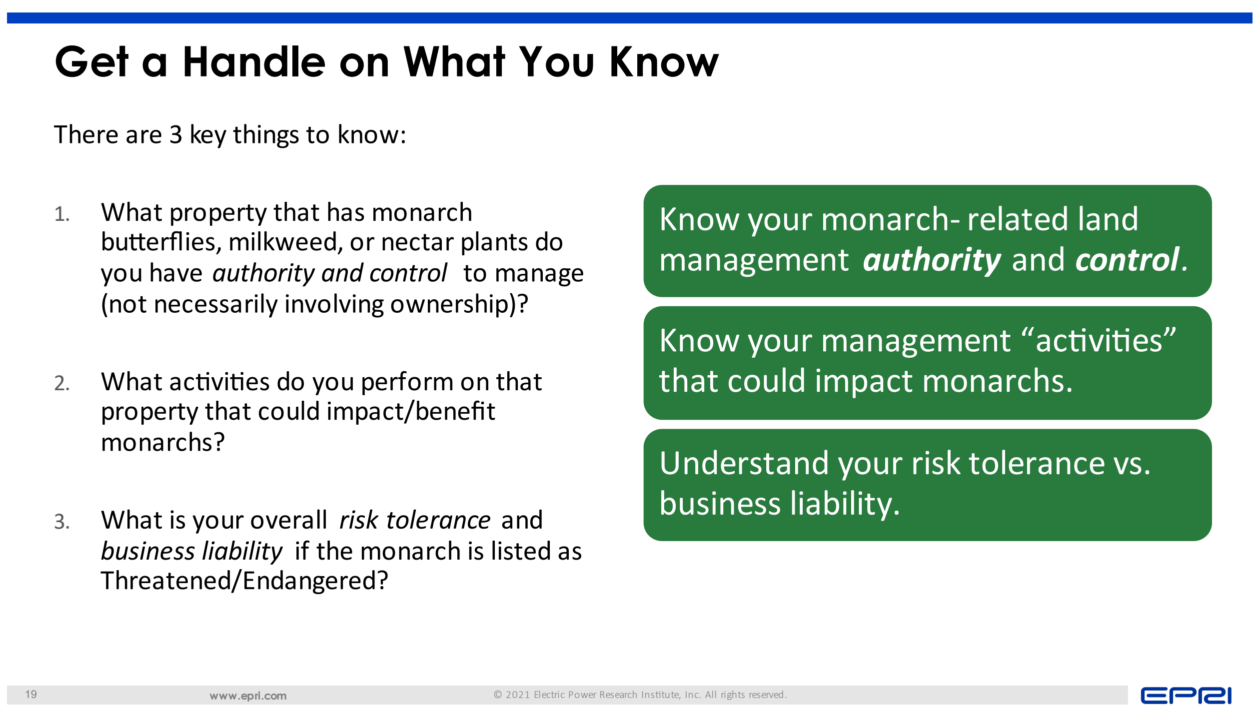


Figure 11. "Get a Handle on What You Know" (Excerpt from Monarch Management Logic Structure.)

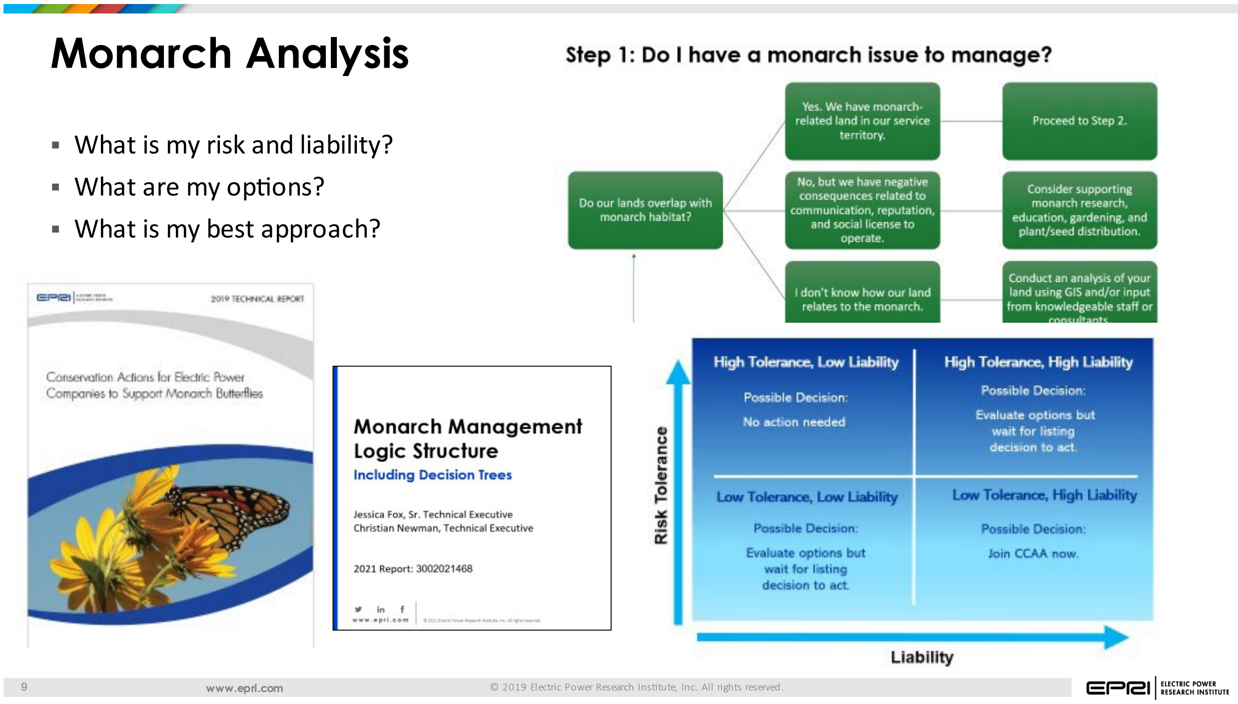


Figure 12. Overview of monarch management considerations

The "highly suitable" monarch habitat was determined by SAC to include medium or high milkweed and high floral, across all regions of the United States (see Table 12). Regional variations in dependence of monarchs' relative proportion of milkweed to floral resources were not incorporated into the national model, nor were regional-specific milkweed species dependencies.

Table 12. Definition of *highly suitable monarch habitat*

Monarch Habitat Suitability (Milkweed-Floral)	Breeding (Milkweed)	Migratory (Floral)	Highly Suitable
Low-Low			
Low-Medium			
Low-High		X	
Medium-Low	X		
Medium-Medium	X		
Medium-High	X	X	X
High-Low	X		
High-Medium	X		
High-High	X	X	X

Using the Monarch Habitat Model, we developed summary tables and maps showing the amount and location of monarch habitat and delivered them to companies (see Tables 12–14). Part of this analysis included reviewing regional, subregional, and parcel data to fully understand opportunities and approaches for managing monarchs. Specifically, the goal of the analysis was to identify suitable monarch habitat, not necessarily to identify opportunities for restoration. However, some of the "low" areas could be good candidates to consider for restoration, depending on underlying land cover, soils, and vegetation management options (for example, Developed, High Intensity might not be suitable for monarch restoration).

Table 13. Example of acres of highly suitable monarch habitat by facility (acres)

Type	High-High (ac.)	Medium-High (ac.)	Total Highly Suitable Monarch Habitat (ac.)	Percent Of Total Landholding
Transmission	4,000	101,000	105,000	40%
Facilities	8,500	10,000	18,500	30%
Substations	2,000	3,000	5,000	22%
Generation	5,000	60,000	65,000	45%
Total	19,500	174,000	193,500	30%

1 acre = 0.4 hectare

Table 14. Example land cover within landholdings by facility type (acres)

Land Cover Type	Generation	Facilities	Substations	Transmission	Total
Barren Land					900
Cultivated Crops					2,000
Deciduous Forest					650
Developed, High Intensity					3,120
Developed, Low Intensity					10,000
Developed, Medium Intensity					12,000
Developed, Open Space					13,000
Emergent Herbaceous Wetlands					500
Evergreen Forest					6,000
Hay/Pasture					3,700
Herbaceous					80,000
Mixed Forest					15,330
Open Water					2,500
Shrub/Scrub					90,000
Woody Wetlands					800
Total	100,500	30,000	10,000	100,000	240,500

Acres by land cover and facility type

1 acre = 0.4 hectare

5 SUMMARY

The objective of our project was to develop a GIS-based approach to help electric power companies better understand the location and extent of monarch habitat within their landholdings in the contiguous United States. The challenges we faced included the lack of a definition of *monarch habitat*, scientific barriers to applying existing methods to this effort, and sparse reliable field data for milkweed and nectar resources. Still, we developed methodology applicable to the United States for initial understanding of monarch habitat suitability that can be used by electric power companies to assess current monarch habitat within their landholdings. The overall methods were driven by association between national land cover classifications to the suitability of milkweed and nectar resources important to monarchs:

milkweed suitability + floral resource suitability = monarch habitat suitability

With several important limitations noted, region-specific modeling methods are being successfully applied to power company landholdings throughout the United States. The model can be improved with better field data for milkweed and nectar resources as well as more sophistication in considering the regional variations in monarch reliance on those resources. Guiding national monarch conservation priorities by applying the modeling results at a national scale would be inappropriate; the purpose of this effort was to develop outputs to guide company decisions, which involved using the model at subregional scales.

It is important to recall that USFWS is continuing to determine the most appropriate approach for defining habitat, and the legal definition of *monarch habitat* might ultimately be different from the methods applied in our model. Companies will want to be thoughtful about their legal liability and risk once USFWS finalizes the listing decision under the ESA. Further, consultation with local monarch and botanical experts will be important for making informed decisions about how to manage specific land assets.

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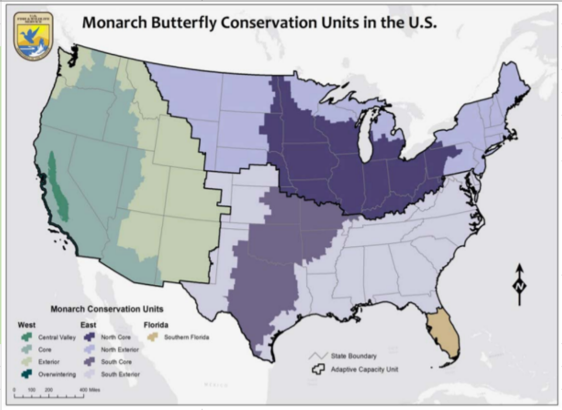
A EXPERT MILKWEED SURVEY

The survey in Figure 13 was sent to eight experts. The input provided by the four responding experts informed the project's assumptions about milkweed abundance and quality classifications in the Midwest and Eastern monarch ranges. Table 15 describes the land classifications used in the survey.

	A	B	C	D
1	PLEASE COMPLETE ALL GREEN SECTIONS			
2				
3	**First Name**			
4	**Last Name**			
5	**Organization**			
6	**Email**			
7	**Phone**			
8	**Region where your expertise applies related to monarch-supporting milkweed (i.e. Midwest, Northeast, Southeast).**			
9	**Are you willing to be acknowledged as providing an opinion for this aspect of the protocol development?**	Make Selection		



14 **INSTRUCTIONS**: Please select your estimate of High, Medium, or Low associated with the quantity of current (not potential) milkweed occurrence associated with each National Land Cover Dataset (NLCD) category and region. Only complete the regions applicable to your expertise, but please enter estimates for all NLCD types in the region you are completing.

Clarifications:

Abundance is the average over the region, not abundance at specific sites.

This survey is related to CURRENT milkweed abundance (not potential for restoration).

Current Milkweed Abundance are defined as:

- High = >10 stems/acre
- Medium = 1-10 stems/acre
- Low = <1 stem/acre

Confidence Level is your qualitative assessment based on current state of knowledge and observation.

- High = Extremely Confident
- Medium = Mostly Confident
- Low = Somewhat Confident

15 **Optional**: Enter more specific stems/acre abundance estimates, as averaged over the region.

	A	B	C	D
16				
17	**REGION: North Core**			
18	**NLCD_2016**	**Current Milkweed Abundance**	**Confidence Level**	**Optional: Type Specific Estimate (Stems/acre)**
19	Barren Land			
20	Cultivated Crops			
21	Deciduous Forest			
22	Developed, High Intensity			
23	Developed, Low Intensity			
24	Developed, Medium Intensity			
25	Developed, Open Space			
26	Emergent Herbaceuous Wetlands			
27	Evergreen Forest			
28	Hay/Pasture			
29	Herbaceuous			
30	Mixed Forest			
31	Open Water			
32	Shrub/Scrub			
33	Woody Wetlands			
34				
35				
36	**REGION: North Exterior**			
37	**NLCD_2016**	**Current Milkweed Abundance**	**Confidence Level**	**Optional: Type Specific Estimate (Stems/acre)**
38	Barren Land			

Survey - Complete Me! | Project Summary | Large Map Image | **NLCD Land Classifications**

Figure 13. Expert survey

Table 15. NLCD land classification descriptions included in the expert survey

Class/Value	Classification Description
Water	**Open Water** — Areas of open water, generally with less than 25% cover of vegetation or soil.
	Perennial Ice/Snow — Areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.
Developed	**Developed, Open Space** — Areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
	Developed, Low Intensity — Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20–49% of total cover. These areas most commonly include single-family housing units.
	Developed, Medium Intensity — Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50–79% of the total cover. These areas most commonly include single-family housing units.
	Developed High Intensity — Highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses, and commercial/industrial. Impervious surfaces account for 80–100% of the total cover.
Barren	**Barren Land (Rock/Sand/Clay)** — Areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
Forest	**Deciduous Forest** — Areas dominated by trees generally taller than 5 m and with greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
	Evergreen Forest — Areas dominated by trees generally taller than 5 m and with greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
	Mixed Forest — Areas dominated by trees generally taller than 5 m and with greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
Shrubland	**Dwarf Scrub** — Alaska only areas dominated by shrubs shorter than 20 cm and with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.
	Shrub/Scrub — Areas dominated by shrubs shorter than 5 m and with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage, or trees stunted from environmental conditions.

Table 15 (continued). NLCD land classification descriptions included in the expert survey

Class/Value	Classification Description
Herbaceous	**Grassland/Herbaceous** — Areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management, such as tilling, but they can be used for grazing.
	Sedge/Herbaceous — Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grasslike plants and includes sedge tundra and sedge tussock tundra.
	Lichens — Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.
	Moss — Alaska only areas dominated by mosses, generally greater than 80% of total vegetation.
Planted/Cultivated	**Pasture/Hay** — Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
	Cultivated Crops — Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton as well as perennial woody crops, such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
Wetlands	**Woody Wetlands** — Areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
	Emergent Herbaceous Wetlands — Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

B FLORAL RESOURCE SUITABILITY

Table 16 is based on the work of Dr. Eric Lonsdorf (2020) and the floral resource index in *Modeling the Status, Trends, and Impacts of Wild Bee Abundance in the United States* (Koh et al. 2016). Our SAC used the floral resources abundance portion of the index, with modifications.

Table 16. Relative abundance of floral resources and assigned suitability

Code	Land Cover	InVEST Relative Abundance of Floral Resources	Floral Resource Suitability
1	Corn	0.157236422	Low
2	Cotton	0.259618459	Medium
3	Rice	0.168805836	Low
4	Sorghum	0.157236422	Low
5	Soybeans	0.268583785	Medium
6	Sunflower	0.49545325	High
10	Peanuts	0.268583785	Medium
11	Tobacco	0.268399373	Medium
12	Sweet Corn	0.157236422	Low
13	Pop or Orn Corn	0.157236422	Low
14	Mint	0.37714837	Medium
21	Barley	0.168805836	Low
22	Durum Wheat	0.168805836	Low
23	Spring Wheat	0.168805836	Low
24	Winter Wheat	0.168805836	Low
25	Other Small Grains	0.168805836	Low
26	Dbl Crop WinWht/Soybeans	0.267295416	Medium
27	Rye	0.168805836	Low
28	Oats	0.168805836	Low
29	Millet	0.168805836	Low
30	Speltz	0.168805836	Low
31	Canola	0.434199645	Medium
32	Flaxseed	0.434199645	Medium
33	Safflower	0.434199645	Medium
34	Rape Seed	0.434199645	Medium
35	Mustard	0.434199645	Medium
36	Alfalfa	0.313291555	Medium

Table 16 (continued). Relative abundance of floral resources and assigned suitability

Code	Land Cover	InVEST Relative Abundance of Floral Resources	Floral Resource Suitability
37	Other Hay/Non Alfalfa	0.450428722	HIgh
38	Camelina	0.434199645	Medium
39	Buckwheat	0.371268293	Medium
41	Sugarbeets	0.21390243	Low
42	Dry Beans	0.268583785	Medium
43	Potatoes	0.322284457	Medium
44	Other Crops	0.312087549	Medium
45	Sugarcane	0.168805836	Low
46	Sweet Potatoes	0.322284457	Medium
47	Misc Vegs and Fruits	0.278332583	Medium
48	Watermelons	0.320754546	Medium
49	Onions	0.21390243	Low
50	Cucumbers	0.322335022	Medium
51	Chick Peas	0.254939371	Medium
52	Lentils	0.168805836	Low
53	Peas	0.254939371	Medium
54	Tomatoes	0.322284457	Medium
55	Caneberries	0.441217947	Medium
56	Hops	0.168805836	Low
57	Herbs	0.37714837	Medium
58	Clover/Wildflowers	0.752105893	High
59	Sod/Grass Seed	0.24549423	Low
60	Switchgrass	0.24549423	Low
61	Fallow/Idle Cropland	0.317106193	Medium
63	Forest	0.482223419	Low
64	Shrubland	0.560492743	High
65	Barren	0.253280228	Medium
66	Cherries	0.344578281	Medium
67	Peaches	0.344578281	Medium
68	Apples	0.344578281	Medium
69	Grapes	0.224126373	Low

Table 16 (continued). Relative abundance of floral resources and assigned suitability

Code	Land Cover	InVEST Relative Abundance of Floral Resources	Floral Resource Suitability
70	Christmas Trees	0.316633697	Medium
71	Other Tree Crops	0.367659457	Medium
72	Citrus	0.358212334	Medium
74	Pecans	0.227475043	Low
75	Almonds	0.344578281	Medium
76	Walnuts	0.227475043	Low
77	Pears	0.344578281	Medium
81	Clouds/No Data	N/A	Low
82	Developed	N/A	Medium
83	Water	0	Low
87	Wetlands	0.483599156	HIgh
88	Nonag/Undefined	N/A	Low
92	Aquaculture	0	Low
111	Open Water	0	Low
112	Perennial Ice/Snow	0	Low
121	Developed/Open Space	0.488612477	High
122	Developed/Low Intensity	0.536726367	High
123	Developed/Med Intensity	0.439643198	Medium
124	Developed/High Intensity	0.342894466	Medium
131	Barren	0.253280228	Medium
141	Deciduous Forest	0.530005956	Low
142	Evergreen Forest	0.415253678	Low
143	Mixed Forest	0.482223419	Low
152	Shrubland	0.560492743	High
176	Grassland/Pasture	0.450428722	High
190	Woody Wetlands	0.513648933	Low
195	Herbaceous Wetlands	0.47352604	High
204	Pistachios	0.227475043	Low
205	Triticale	0.168805836	Low
206	Carrots	0.21390243	Low
207	Asparagus	0.181167024	Low

Table 16 (continued). Relative abundance of floral resources and assigned suitability

Code	Land Cover	InVEST Relative Abundance of Floral Resources	Floral Resource Suitability
208	Garlic	0.21390243	Low
209	Cantaloupes	0.322335022	Medium
210	Prunes	0.344578281	Medium
211	Olives	0.223464364	Low
212	Oranges	0.358212334	Medium
213	Honeydew Melons	0.322335022	Medium
214	Broccoli	0.254939371	Medium
215	Avocados	N/A	Low
216	Peppers	0.322284457	Medium
217	Pomegranates	0.344578281	Medium
218	Nectarines	0.344578281	Medium
219	Greens	0.254939371	Medium
220	Plums	0.344578281	Medium
221	Strawberries	0.297459371	Medium
222	Squash	0.360610595	Medium
223	Apricots	0.344578281	Medium
224	Vetch	0.268583785	Medium
225	Dbl Crop WinWht/Corn	0.267295416	Medium
226	Dbl Crop Oats/Corn	0.267295416	Medium
227	Lettuce	0.254939371	Medium
228	Dbl Crop Triticale/Corn	N/A	Low
229	Pumpkins	0.360610595	Medium
230	Dbl Crop Lettuce/Durum Wht	0.267295416	Medium
231	Dbl Crop Lettuce/Cantaloupe	0.322335022	Medium
232	Dbl Crop Lettuce/Cotton	0.267295416	Medium
233	Dbl Crop Lettuce/Barley	0.267295416	Medium
234	Dbl Crop Durum Wht/Sorghum	0.267295416	Medium
235	Dbl Crop Barley/Sorghum	0.267295416	Medium
236	Dbl Crop WinWht/Sorghum	0.267295416	Medium
237	Dbl Crop Barley/Corn	0.267295416	Medium
238	Dbl Crop WinWht/Cotton	0.267295416	Medium

Table 16 (continued). Relative abundance of floral resources and assigned suitability

Code	Land Cover	InVEST Relative Abundance of Floral Resources	Floral Resource Suitability
239	Dbl Crop Soybeans/Cotton	0.267295416	Medium
240	Dbl Crop Soybeans/Oats	0.267295416	Medium
241	Dbl Crop Corn/Soybeans	0.267295416	Medium
242	Blueberries	0.441217947	Medium
243	Cabbage	0.254939371	Medium
244	Cauliflower	0.254939371	Medium
245	Celery	0.254939371	Medium
246	Radishes	0.21390243	Low
247	Turnips	0.21390243	Low
248	Eggplants	0.322284457	Medium
249	Gourds	0.360610595	Medium
250	Cranberries	0.441217947	Medium
254	Dbl Crop Barley/Soybeans	0.267295416	Medium

C SCIENTIFIC ADVISORY COMMITTEE (SAC)

Dr. Wayne Thogmartin—*Research Ecologist, Upper Midwest Environmental Sciences Center, USGS*

Wayne is a quantitative ecologist whose current work involves various spatio-temporal analyses of bat, bird, and monarch butterfly abundance, with primary interest in determining risk of extinction, migratory connectivity, and consequences of stressors on population dynamics.

Dr. Jay Diffendorfer—*Research Ecologist, Geosciences and Environmental Change Science Center, USGS*

Jay, an ecologist, has conducted spatial ecology and conservation biology research, including a USGS-funded postdoctoral position at the University of Miami. He then worked as a professor at San Diego State University, studying relationships between urbanization, fire, and invasive species on native flora and fauna in southern California. His field research involved radiotelemetry, capture-recapture, and vegetation studies. He continues to expand his research focus and currently works on science related to the energy-environment nexus, ecosystem services, and applied ecology.

Laura Lukens—*National Monitoring Coordinator, Monarch Joint Venture*

Laura has been studying monarchs since 2014 and currently works as the National Monitoring Coordinator for the Monarch Joint Venture. She coordinates data collection projects throughout the United States and cultivates a network of researchers and science initiatives to advance monarch research and conservation priorities.

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