IDAHO DEPARTMENT OF FISH AND GAME

Virgil Moore, Director

Project F16AF01105, Amendment #1

Milkweed and Monarch Modeling

Final Performance Report

Performance Period
1 August, 2016 to 30 June, 2018

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FEDERAL AID IN WILDLIFE RESTORATION
FINAL PERFORMANCE REPORT

1. **State:** Idaho

   Grant number: F16AF01105, Amendment #1

   Grant name: Milkweed and Monarch Modeling

2. **Report Period:** 1 August, 2016 – 30 June, 2018

   Report due date: 28 September 2018

3. **Location of work:** Idaho

4. **Objectives**

Our overall objectives were to 1) use recent field data to refine the known distribution of milkweed and monarchs in Idaho and 2) assess potential changes in milkweed and monarch distributions in the state using the most scale-relevant data available under moderate and severe climate change scenarios. To achieve these objectives we compiled existing and recently collected observation data and evaluated its quality for use in models, compiled and/or developed scale-relevant spatial data necessary for use as covariates in models, assessed model parameters and developed current distribution models. We then developed scale-relevant future projections of key variables and assessed potential changes in species distributions based on modeled projections.

5. **If the work in this grant was part of a larger undertaking with other components and funding, present a brief overview of the larger activity and the role of this project.**

Previous mapping of western milkweed and monarch observations and modeling of potential distributions across the western states by USFWS, Xerces Society, and others has suggested that monarchs may be constrained by low milkweed species diversity, semi-arid climates, and unsuitable temperature regimes associated with elevation or latitude. However, surveys in Idaho suggest that areas previously deemed thermally unsuitable for monarch reproduction may support suitable natal habitat. Beginning in 2015, IDFG engaged in several efforts aimed at improving our knowledge base for these species including working with the Monarch Joint Venture to develop a western monarch monitoring framework and collaborating with Washington on a Monarch C-SWG project (Waterbury and Potter 2018). This latter project provided the primary mechanism for data collection necessary to fulfill our model refinements, including assistance with compiling existing monarch and milkweed records, implementing coordinated statewide surveys, and training Idaho Master Naturalists and other citizen scientists to ensure data consistency and accuracy.

6. Describe how the objectives were met.

Milkweed and Monarch Observations

All known observations of monarch and milkweed in Idaho as of April 26, 2018, were compiled for this modeling effort. This included data from the Western Monarch and Milkweed Occurrence Database (museum specimens, older survey efforts, and incidental observations), recently collected IDFG and College of Idaho survey data (summers 2016, 2017), and incidental observations recorded in iNaturalist and in the Idaho Fish and Wildlife Information System (IFWIS) Species Diversity Database. We carefully evaluated all data for use in the distribution models to ensure spatial and temporal accuracy. As part of this evaluation, we determined sufficient data exists to model monarch breeding habitat in Idaho (n=1603 monarch records) and 2 of the milkweed species, the most common Showy milkweed (*Asclepias speciosa*) (n=5258) and the lesser common Swamp milkweed (*Asclepias incarnata*) (n=313). Other milkweed species documented but not modeled included Narrow-leaf Milkweed (*Asclepias fascicularis*) (n=94), Pallid Milkweed (*Asclepias cryptoceras*) (n=84), and Spider Milkweed (*Asclepias asperula*) (n=7). All of these compiled data were provided to Idaho Department of Fish and Game (2018) and to Western Monarch and Milkweed Occurrence Database (2018) for long-term data storage and accessibility.

Compiled observation data, such as these, are prone to errors of observational certainty, spatial accuracy, and sampling bias both geographically (e.g., more samples in easily accessible areas) and environmentally (e.g., more samples at lower elevations). To maximize observational certainty, we used only observations classified as verified (e.g., specimen, DNA, or photograph) or trusted (e.g., documented by a biologist, researcher, or taxonomic expert). To maximize spatial accuracy, we limited our data set to those locations with ≤100m accuracy. Even though the vast majority of our observations resulted from targeted inventory or survey efforts (93% of showy milkweed, 91% of swamp milkweed, and 88% of monarch observations), sampling bias was still an issue as the data were highly clustered at fine scales in portions of the state. Species distribution models can be sensitive to such bias and several authors have suggested spatial filtering of the presence data to account for it (Phillips et al. 2009, Veloz 2009, Anderson and Raza 2010, Kramer-Schadt et al. 2013, Radosavljevic and Anderson 2013). The key to spatial filtering is to randomly subsample presence data with a minimum distance separating the sample points, thereby limiting spatial autocorrelation and reducing the environmental bias caused by uneven sampling. That minimum distance is somewhat arbitrary, however, and depends on the environmental conditions of the study area as well as the resolution of the data used for modeling. We reduced the locally dense sampling of monarch and milkweed by randomly subsampling the observations with a minimum distance of 270m. These filtering procedures (trusted or verified, ≤100m accuracy, and >270m separation) resulted in a total of 1079 showy milkweed observations, 100 swamp milkweed observations, and 344 monarch observations available for use in our modeling efforts.

Environmental Variables

Previous modeling efforts at regional scales have focused on a number of climatic, topographic, and edaphic environmental covariates at broader spatial resolutions (90-900m cell sizes) (Lemoine 2015, Dilts et al. 2018). Learning from and building on these efforts, we compiled and/or developed finer-scale versions of these covariates (Table 1), striving to use environmental data at scales most applicable to monarch and milkweed. We ensured all spatial data was in a common geographic coordinate system, spatial resolution (30mX30m) and extent, and exported as ASCII files for input into Maxent. All spatial analyses were conducted in ArcGIS 10.5.1 (ESRI 2017).

Topographic variables developed from the National Elevation Data (NED) (30m) (USGS 2016) included elevation, slope, aspect, compound topographic index (CTI), roughness, and vector ruggedness measure (VRM). Both CTI and roughness were calculated using Evans et al. (2014) while VRM was based on Sappington et al. (2007).

Edaphic measures developed were characteristics known to either affect the availability of nutrients or exert direct physiological limitations, or both, on plants and included percent sand, percent silt, percent clay, pH, available water supply, calcium carbonate, cation-exchange capacity, organic matter, and depth to a restrictive layer. To focus on the most critical soil for plant establishment, we used a weighted average of all soil mapunits in the top 0-25cm. These data were developed at 10m resolution following the national standard methodology used by Natural Resource Conservation Service (NRCS) in development of similar products with Soil Survey Geographic (SSURGO) data (USDA NRCS 2012).

Climatic variables used in previous efforts relied on PRISM temperature and precipitation at moderate resolution (900m). We used a more recent temperature data developed at finer spatial resolution (250m) for the Northern Rockies (Holden et al. 2015) in combination with the precipitation data from PRISM (800m) (PRISM Climate Group 2012). The original PRISM precipitation data at 800m resolution were resampled to 250m to match the temperature data. Using monthly 30-year normals (1981-2010) from both temperature and precipitation datasets, we calculated 19 bioclimatic variables patterned after Hijmans et al. (2005) which have been used extensively in wildlife habitat modeling (e.g., Elith et al. 2006, Anderson and Gonzalez 2011, Stanton et al. 2011) and in previous monarch and milkweed modeling studies (e.g., Lemoine 2015, Dilts et al. 2018).

To portray mid-century climate conditions we used projections from 20 climate models participating in the Fifth Coupled Model Intercomparison Project (CMIP5) that were statistically downscaled using the Multivariate Adaptive Constructed Analogs (MACA, Abatzoglou and Brown, 2012). Data were downscaled using the historical training dataset of Abatzoglou (2013) at a 4-km spatial resolution. We calculated differences in monthly climate averages of minimum temperature (tmin), maximum temperature (tmax), and precipitation (ppt) between 1981-2010 and 2040-2065 for each of the 20 models given two emission scenarios. These 2 scenarios represent a moderate storyline with stabilization (Representative Concentration Pathway [RCP] 4.5) and a more severe storyline with continuous greenhouse gas emissions (RCP 8.5). Differences between future and baseline monthly climate data were superposed to the higher spatial resolution gridded dataset to provide an estimate of the projected climate fields. We then recalculated the 19 bioclimatic variables using these projected values.

Other potentially informative landscape-related variables developed included distance to intermittent streams and distance to perennial streams and waterbodies based on the National Hydrography Data (2012) (FCodes 46006 and 46003, respectively). We considered including land cover and percent natural following Dilts et al (2018), however, we opted to exclude these variables as future projections under climate change do not yet exist and could not be included in a model if they were important. Also the spatial and thematic scale of the available land cover data (USGS GAP 2016) did not accurately reflect milkweed occurrences (e.g., >50% of both showy and swamp milkweed locations were mapped as developed, cultivated cropland, or open water).

Finally, monarch habitat is generally assumed to be constrained by the occurrence of milkweed. Thus, the outputs from the showy and swamp milkweed models were included with the previous covariates when modeling monarchs.

Current/Future Habitat Suitability

We used maximum entropy methods (MaxEnt 3.4.1; Phillips et al. 2006, Phillips and Dudík 2008) to model current species distributions for monarch, showy milkweed, and swamp milkweed, as well as the suitability of future climate for each species. Given a set of environmental variables and species presence locations, MaxEnt identifies the correlations between each variable and the presence data, compares that with the range of environmental conditions available in the modeled region, and develops a continuous model of the relative likelihood, or probability, of suitable habitat across the study area based on environmental similarity to known occupied sites. We supplied MaxEnt with the occurrence data as described above, as well as background points consisting of 10,000 randomly generated pseudoabsences across Idaho that were >270m apart, >270m from presence locations, and outside of waterbodies.

Given the great flexibility and 'art' in developing species distribution models, several model parameters need to be carefully assessed. Following recommended approaches, we developed current distribution models for these 3 species using species-specific model parameters, particularly with regard to collinearity, regularization multiplier and feature types. In an iterative approach, we optimized each model for regularization multiplier and feature types using the *enmSdm* package (Smith 2017) in R 3.5.0 (R Core Team 2018) and selected the best performing combination based on AICc (Warren and Seifert 2011, Wright et al. 2015). Beginning with a full model inclusive of all covariates (n=37), we implemented 10-fold cross-validation and jackknifing to measure importance of each variable to the resulting model. Variables were then ranked based on their permutation importance and removed if less than 1% contribution. Correlated variables with P>0.75 were also removed keeping the variable with the higher permutation importance. This process of model optimization, development, and variable ranking and removal was repeated until all variables had a minimum contribution of 2% or greater. The final model for each species represented the average of 10 cross-validation replicates using the optimized parameters and most important variables. We then projected the final models for each species onto spatial data projected for the two climate mid-century scenarios.

We imported all mean model outputs into ArcGIS 10.5.1 (ESRI 2017) and identified areas of suitable and unsuitable habitat based on the 'balance training omission, predicted area and threshold value' threshold calculated by MaxEnt. This threshold uses weighting constants to provide a balance between over-fitting and over-estimating. The current and two future models for each species were then overlaid to calculate the overall projected range change, the proportion of current suitable habitat projected to become unsuitable ("loss") and the proportion of future habitat projected in currently unsuitable areas ("gain"). Lastly, we tabulated the areas of gain and loss for IDFG Wildlife Management Areas (WMAs) to identify potential areas of concern.

MaxEnt accurately predicted distributions for showy milkweed, swamp milkweed, and monarch with AUC = 0.899, 0.981, and 0.929, respectively. The best fit models based on AICc for all three species employed linear, quadratic, and product features, with a regularization multiplier of 0.5 for showy milkweed and monarch and a regularization multiplier of 2.0 for swamp milkweed. For showy milkweed, the final predicted distribution was best explained by elevation, precipitation during the wettest month, mean diurnal temperature range, distance to perennial water, and soil depth (in ranked order according to permutation importance). Similarly, the most important variables contributing to swamp milkweed distribution were elevation, distance to perennial water, and several climate variables including isothermality, temperature seasonality, minimum temperature of the coldest month, precipitation seasonality, and precipitation of the coldest quarter (in ranked order). Monarch distribution relied heavily on the modeled prediction of showy milkweed as well as elevation, distance to perennial water, and mean temperature of the wettest quarter (in ranked order). Nearly all predicted suitable habitat for swamp milkweed (1.6% of Idaho) is encompassed by that predicted as suitable habitat for showy milkweed (7.7% of Idaho). Similarly, nearly all predicted suitable habitat for monarch (5.7% of Idaho) is within showy milkweed habitat.

Projecting distributions of all three species to mid-century suggests only minor changes are in store statewide under either the moderate (RCP4.5) or more severe (RCP8.5) emission scenario. For showy milkweed, the proportion of currently suitable habitat across the state is projected to decrease slightly (0.71%, 420 acres) while just 0.01% (9 acres) that is unsuitable now may become suitable. Similarly, the proportion of currently suitable habitat for monarch is projected to decrease slightly (0.34%, 200 acres) while only 0.40% (240 acres) that is unsuitable now may become suitable. Only swamp milkweed is projected to not lose any suitability and instead, projections indicate 2.76% (1639 acres) of unsuitable habitat may become suitable by mid-century.

Although overall statewide changes are minimal, local changes in particular WMAs may be more substantial. For example, 13 WMAs are projected to gain suitable habitat for swamp milkweed (including >1500 acre gains in Mud Lake, Sterling, Market Lake) and 1 (Craig Mountain WMA) is projected to both gain and lose habitat. Conversely, gains for showy milkweed are minor in extent and limited to only 2 WMAs (CJ Strike and Craig Mountain) which are projected to both gain and lose habitat, while 15 WMAs are projected to lose suitable habitat although all projected losses are <1100 acres. Monarch projections are more variable with 3 WMAs projected to experience gains only, 6 to experience losses only, and 8 to experience both gains and losses (all <365 acres).

7. **Discuss differences between work anticipated in grant proposal and grant agreement, and that actually carried out with Federal Aid grant funds.**
   There were no differences between work in the project proposal and work actually performed.

8. List any publications or in-house reports resulting from this work.
A manuscript is currently in preparation. We will share a copy of this document with USFWS when it is published.

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