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A SIMPLE GIS APPROACH TO PREDICTING RARE PLANT HABITAT: NORTH CENTRAL ROCKY MOUNTAINS, UNITED STATES FOREST SERVICE, REGION ONE

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A SIMPLE GIS APPROACH TO PREDICTING RARE PLANT HABITAT: NORTH CENTRAL ROCKY MOUNTAINS, UNITED STATES FOREST SERVICE, REGION ONE

By

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A Simple GIS Approach to Predicting Rare Plant Habitat: North Central Rocky Mountains, United States Forest Service, Region One

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Understanding the potential distribution of rare species is a key component in managing and regulating land-use activities. Predictive modeling of plant distributions rests on the assumption that correlations exist between the presence or absence of a species and selected climate, topographic, substrate, and land-cover variables.

Using the DOMAIN algorithm along with Geographic Information Systems (GIS) techniques, a biophysical envelope model was applied to 21 rare plant species listed on the Region One Regional Forester's Sensitive Species List. Environmental variables, including annual precipitation, mean May temperature, slope, aspect, elevation, geologic material and dominant vegetation type, were used as predictors. Model output was field-verified by expert botanists who used their knowledge to assess areas predicted as potential habitat. A total of 44 new rare plant species element occurrences were located, including two new state occurrence records for Idaho. Model evaluation used a multi-layered approach: (1) the percentage of known occurrences within areas of predicted potential habitat (2) whether botanists found potential habitat within predicted areas; and (3) whether new occurrences were found within predicted areas. Model success for each species was evaluated using error matrices populated with the number of pixels correctly or incorrectly classified as habitat.

Misclassification of suitable and unsuitable habitat is inevitable in any habitat modeling procedure, and sources of error may be caused by inherent problems in the modeling process or complications arising from an organism's ecology. Plant species for which habitat was not successfully modeled were often associated with microhabitats, had inappropriate environmental parameters used as input, or had unusual distribution patterns.

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TABLE OF CONTENTS

1. INTRODUCTION ... 1
2. BACKGROUND ... 4
   2.1. Rare Plant Species ... 4
   2.2. Predictive Habitat Models ... 6
   2.3. Study Area Description ... 10
3. METHODS ... 12
   3.1. Data Acquisition ... 12
      3.1.1. Element Occurrences ... 12
      3.1.2. Environmental Variables ... 13
   3.2. DOMAIN Model ... 15
   3.3. Field Evaluation ... 17
   3.4. Prediction Assessment ... 19
4. RESULTS ... 21
   4.1. Broad-fruit Mariposa ... 22
   4.2. Clustered Lady's Slipper ... 23
   4.3. Constance's Bittercress ... 23
   4.4. Coville Indian Paintbrush ... 24
   4.5. Evergreen Kittentail ... 26
   4.6. Hall's Rush ... 26
   4.7. Hollyleaf Clover ... 27
   4.8. Howell's Gumweed ... 28
   4.9. Idaho Douglasia ... 29
   4.10. Idaho Strawberry ... 30
   4.11. Lemhi Beardtongue ... 31
   4.12. Pacific Dogwood ... 32
   4.13. Payson's Milkvetch ... 33
   4.14. Puzzling Halimolobos ... 34
   4.15. Small Onion ... 34
   4.16. Tapered-root Orogenia ... 35
5. DISCUSSION AND FUTURE RESEARCH ... 38
6. CONCLUSION ... 44

LIST OF TABLES

Table 1. Description of physiographic, vegetative, and climatic characteristics for each forest located within the study area.. 52
Table 2. Species used for habitat prediction. 53
Table 3. List of the major geologic parent materials in the study area. 54
Table 4. Reclassification table for VMAP and SILC3 vegetation cover grids. 55
Table 5. Species surveyed within each National Forest. 56
Table 6. Macrohabitat types of Region One. 56
Table 7. The number of new element occurrences located through field surveys, known occurrence accuracy, and amount of predicted habitat in both 'likely' and 'most likely' thresholds by Forest. 57
Table 8. Results from field verification broad-fruit mariposa. 58
Table 9. Predicted occurrence vs. found occurrence for broad-fruit mariposa. 58
Table 10. Results from field verification for clustered lady's slipper. 58
Table 11. Predicted occurrence vs. found occurrence for clustered lady's slipper. 59
Table 12. Results from field verification Constance's bittercress. 59
Table 13. Results from field for Coville Indian paintbrush 59
Table 14. Predicted occurrence vs. found occurrence for Coville Indian paintbrush. 60
Table 15. Results from field verification for evergreen kittentail 60
Table 16. Predicted occurrence vs. found occurrence for evergreen kittentail. 60
Table 17. Results from field verification for Hall's rush 61
Table 18. Results from field verifiction for hollyleaf clover 61
Table 19. Results from field verification for Howell's gumweed 61
Table 20. Results from field verification for Idaho Douglasia 62
Table 21. Predicted occurrence vs. found occurrence for Idaho Douglasia. 62
Table 22. Results from field verification for Idaho strawberry 62
Table 23. Predicted occurrence vs. found occurrence for Idaho strawberry. 63
Table 24. Results from field verification for Lemhi beardtongue 63
Table 25. Predicted occurrence vs. found occurrence for Lemhi beardtongue. 63
Table 26. Results from field verification for Pacific dogwood 64
Table 27. Predicted occurrence vs. found occurrence for Pacific dogwood. 64
Table 28. Results from field verification for Payson's milkvetch 64
Table 29. Results from field verification for puzzling halimolobos. 65
Table 30. Results from field verification for small onion 65
Table 31. Predicted occurrence vs. found occurrence for small onion. 65
Table 32. Results from field verification for tapered-root orogenia 66
Table 33. Predicted occurrence vs. found occurrence for tapered-root orogenia. 66

LIST OF FIGURES

Figure 1. Study area……………………………………………………………….67
Figure 2. Original header of DOMAIN grid file before flag variable it set using Hex Editor…………………………………………..…………………………………..68
Figure 3. Example continues and categorical flag variables set within Hex Editor…… 68
Figure 4. Gower similarity grid for Coville Indian paintbrush…………………………69
Figure 5. Predicted habitat overview map for Coville Indian paintbrush………………70
Figure 6. Travel route predicted habitat map for Coville Indian paintbrush…………....71
Figure 7. Predicted species habitat density map for Nez Perce National Forest………..72
Figure 8. Field site validation form……..………………………………………………73
Figure 9. Number of new element occurrence vs. the number of element occurrences used as input into the model…………………………………………………………...74

1. INTRODUCTION

Nearly 25% of the estimated 250,000 species of vascular plants in the world may become extinct within the next fifty years, and 22% of vascular plant species in the United States are currently of conservation concern (Schemske et al., 1994). Many species have already been reduced to one or two populations with few individuals, causing plant conservation to become of vital importance in forest management and planning. The United States Forest Service manages threatened, endangered, sensitive and G1-G3 plant species (identified by NatureServe) under the statutory authority of the National Forest Management Act (NFMA) and the Endangered Species Act (ESA; USFWS, 1988). In this study species of management concern to the Forest Service will be collectively referred to as TES species.

NFMA requires the Forest Service to address goals and objectives for conservation of TES species and their habitats through land and resource management planning. NFMA is implemented through the 1982 and 2005 planning regulations (USDA, 1982; USDA, 2005). The National Environmental Protection Act (NEPA) requires the Forest Service to address impact to TES species during project work (NEPA, 1986).

Typically, land mangers conduct pre-field analysis and field surveys for TES species in support of project work. Land managers and botanists concerned with the conservation and protection of TES species are faced with a daunting task. Habitat associations for many rare plant species have not been well defined. Element occurrence data, which consists of an incidence of a population, community, or ecological system in a specific location, is often opportunistically acquired and may not be a full reflection of species distribution. Limited resources often prevent biologists from conducting intensive searches for TES species or surveying large areas. As a result, habitat modeling is an increasingly important tool to assist land managers and botanists in determining whether habitat for TES species is likely present within a proposed project area. Habitat modeling increases the efficiency of agency resources for project support and in determining whether field surveys and/or mitigation are needed.

Advancements in Geographic Information Systems (GIS) have revolutionized predictive habitat mapping by significantly improving land managers' abilities to do detailed resource inventories, analysis, and management (Vogiatzakis, 2003). The increasing availability of environmental information in digital formats and refinement of various GIS-based techniques offer an opportunity to improve and test quantitative mapping of species distributions (Brotons et al., 2004). Associations between plant species and their environment (and predictive maps based upon these associations) have significantly improved efforts for plant conservation and management (e.g., Box et al., 1993; Wiser et al., 1998; Elith and Burgman, 2002; Fertig and Reiners, 2002; Fleishman et al., 2002).

The purpose of this research was to test a methodology for predicting rare plant habitat and occurrence at a broad scale including multiple species over a large extent. Twenty-one diverse plant species listed on the Forest Service Region One Regional Forester's Sensitive Species List were selected for this initial effort (USDA Forest Service, 2004). The potential habitats and occurrence of these species were predicted within three National Forests in western Montana and north-central Idaho. The DOMAIN model (Carpenter et al., 1993), a simple biophysical envelope, was chosen to identify the potential habitat of each species. The algorithm uses a computerized procedure that calculates a Gower similarity index for each pixel in the study area based upon how closely the environmental values at that point correlate with the environmental values at points of known occurrences. User-defined thresholds designated areas of suitable habitat for each species. The resulting map products were then given to Forest Service botanists who used the potential habitat maps in combination with their knowledge of the target species to conduct field surveys within the high probability areas. The collected field data were utilized to assess model performance. The model was evaluated by examining: (1) the percentage of known occurrences within areas of predicted potential habitat, (2) whether botanists found potential habitat within predicted areas, and (3) whether new occurrences were found within predicted areas. We anticipate this approach will be able to model 85% of known occurrences for one-half of the species, an acceptable level of prediction (Anderson et al., 1976).

This study was a pilot project to identify data availability and limitations, examine strengths and weaknesses of the DOMAIN algorithm, provide new location observations acquired through field survey to refine and improve the accuracy of subsequent efforts, and to improve our understanding of the relationships between these rare plants and their habitats in USFS Region One.

2. BACKGROUND

2.1. Rare Plant Species

The 2005 NFMA Planning Rule requires the Forest Service to conserve the diversity of plant and animal communities through the application of “Ecosystem Diversity” and “Species Diversity” concepts. Forest plan components for Ecosystem Diversity are intended to contribute to an adequate representation and arrangement of ecological conditions and vegetative communities in the planning area. Ecosystem Diversity components include management for community types, successional stages, ecological parameters, and disturbance processes important for maintaining sustainable populations of wildlife, fish, and plant species within a planning area. For TES plant species, species’ needs are to be compared to Ecosystem Diversity components to determine if adequate conservation measures are present (USDA, 2005).

Species Diversity, under the 2005 Planning Rule, is intended to complement management under Ecosystem Diversity by providing a species-by-species approach to analyzing species’ habitat needs. Species Diversity provides for the additional management needs of certain species such as regional endemics, threatened and endangered plant species, or other species-at-risk. In addition, Species Diversity is intended to provide protection for those species with specialized habitat niches. Application of Species Diversity concepts require the evaluation of rare or TES species by ecosystem conditions and plan components, at the appropriate scale, as context for management.

Regional Foresters are responsible for identifying and conserving TES species occurring within their Regions (USDA, 1991). The Regional Forester's Sensitive Species List for Region One currently includes 205 plant species (USDA Forest Service, 2004). The conservation status of a species is designated by a number from one to five, preceded by a letter reflecting the appropriate geographic scale of the assessment (G = Global, N = National, and S = State). The numbers have the following meaning:

1 = critically imperiled
2 = imperiled
3 = vulnerable to extirpation or extinction
4 = apparently secure
5 = demonstrably widespread, abundant, and secure.

These status assessments are based on the best available information, and consider a variety of factors such as abundance, distribution, population trends, and threats (Master et al., 2000). The Regional Forester's Sensitive Species List includes local and regional endemics (G1-G3), as well as numerous species that are rare at the state or regional level (global ranks of G4-G5, and state ranks of S1-S2).

To achieve management goals for conserving TES species and their habitats, the Forest Service conducts pre-field analysis along with field surveys to assess project impacts. Pre-field analysis varies widely and may consist of an examination of known populations of TES plant species within or adjacent to the project area, habitat assessment utilizing aerial photography, or basic GIS overlay analysis. Typically field surveys are conducted in areas where pre-field analysis indicates suitable habitat may be present. However, these techniques are often time consuming and are not statistically based. Habitat modeling can provide a consistent method that can assist botanists in determining whether habitat for TES species is likely present within a proposed project area. Habitat modeling can increase the efficiency of agency resources for project support and in determining whether field surveys and/or mitigation are needed.

2.2. Predictive Habitat Models

Statistical algorithms which spatially examine species-habitat relationships are the most widely employed method for predicting potential habitat (Wu and Smeins, 2000; Elith and Burgman, 2002; Fertig and Thurston, 2003; Beauvais et al., 2004; Decker et al., 2005). Predicting potential habitat and species occurrence relies upon finding broad-scale associations between taxonomic distributions and combinations of readily available environmental variables (James and McCulloch, 2002). Integrating statistical algorithms and spatial analysis in a GIS provides a means to rapidly review the distribution and the status of a species even when information is poor or non-existent and can be used to predict potential habitat from limited field data (Austin, 1998).

Predictive habitat models do not directly model habitat or distribution of a target species – they model the distribution of environmental conditions believed to be suitable for occupation, and assume that results reflect the actual distribution of an element. The foundation of these models is the basic ecological principal that there are biotic and abiotic factors that constrain where species can and cannot exist in the context of their own biogeographic and evolutionary histories (Pulliam, 2000). Predictive habitat models seek to describe those limits by correlating known occurrences with environmental factors that represent or approximate those limits.

Numerous methods have been utilized in developing predictive habitat maps. A major difference between methods involves the form of occurrence data needed for the algorithm, either presence-only or presence and absence. Methods such as generalized linear models (GLMs) and general additive models (GAMs), which require reliable presence-and-absence data, are used extensively in species' distribution modeling because of there strong statistical foundation and ability to realistically model ecological relationships (Austin, 2002). GAMs use non-parametric, data-defined smoothers to fit non-linear functions, whereas GLMs fit parametric terms, usually some combination of linear, quadratic and/or cubic terms (Elith et al., 2006). Another well-established presence-and-absence modeling technique, called genetic algorithm for rule-set prediction (GARP), implements a genetic algorithm to select a set of rules (e.g. adaptations of regression and range specifications) that best predicts the species distribution (Stockwell and Peters, 1999).

In a study conducted by Brotons et al. (2004), results show that using both presence and absence data (GLM) predicted the distribution of songbird bird species with higher accuracy than presence-only data (ENFA). This supports the view that species use available habitats proportionally to their suitability, making absence data reliable and useful to enhance model calibration (Hirtzel et al., 2000). Recently, Zaniewski et al. (2002) showed that although presence-absence based methods were more discriminate than presence-only techniques, they appeared to be less suitable to identify areas with high conservation concern. For example, if the objective were to protect rare or endangered species overestimating areas of potentially elevated biodiversity might be preferable than underestimating their existence, therefore, making presence-only methods useful (Zaniewski et al., 2002). While presence-only methods might not perform as well in all situations, they are by far the most common type of analysis for modeling rare species for which limited data are available (Godown and Peterson, 2000; Beauvais et al., 2003; Beauvais and Smith, 2005; Decker et al., 2006).

The vast majority of species data available for both plants and animals consist of presence-only records collected in an unsystematic fashion. Therefore, another set of techniques have been developed to use these types of data. BIOCLIM utilizes an environmental envelope algorithm to identify locations which have environmental conditions that fall within the environmental range recorded for known locations (Nix, 1986). Specifically the minimum and maximum values for each environmental predictor are identified to define the multidimensional environmental "box" of conditions in which the element is known to occur. Study area sites that have environmental conditions within the boundaries of the multidimensional box are predicted as potential sites of occupancy. Maximum entropy models (MAXENT) estimates species' distributions by finding the distribution of maximum entropy (i.e. closest to uniform) subject to the constraint that the expected value of each environmental variable (or its transform and/or interactions) under this estimated distribution matches its empirical average (Phillips et al., 2006). Ecological Niche Factor Analysis (ENFA) is based on the ordination of data in a multivariate space. This technique is based on the computation of the factors explaining the major part of species environmental distribution. Extracted factors are uncorrelated and have biological significance: the first factor is the marginality factor, which describes how far the species optimum is from the mean environmental profile in the study area; the second is a tolerance factor, which is sorted by decreasing amount if explained variance and describe how specialized the species is by reference to the available range of environments in the study area (Hirzel, 2001). This approach is implemented using BIOMAPPER (Hirzel, 2001) software to produce habitat suitability maps. Mahalanobis distance is defined by having equal Mahalanobis distance to a vector of 'optimal' conditions, with 'optimum' being defined as the mean conditions of all the observations available for target species (Farber and Kadmon, 2003). When applied to species prediction, an underlying assumption of the Mahalanobis distance technique is that the mean vector represents optimal conditions for the species.

The DOMAIN method uses a distance-based algorithm which assesses areas of interest in terms of their environmental similarity to sites of known locations (Carpenter et al., 1993). This procedure computes potential distributions based on a range-standardized, point-to-point similarity metric (Gower, 1971) and provides a simple, robust method for modeling potential distributions of rare species. DOMAIN offers advantages over similar methods in its ability to operate effectively using a limited number of biophysical attributes. The graded nature of habitat similarity scores can facilitate the use of the DOMAIN model as a prioritization tool through the use of the user-defined thresholds required to obtain predictions of habitat. It also performs well with small sample sizes of occurrence data, an advantage when dealing with rare species.

This algorithm was chosen for this study based upon a number of factors: utilization of this modeling technique for rare species by other state heritage programs such as Colorado (Decker et al., 2006) and Wyoming (Beauvais et al., 2004; Beauvais and Smith, 2005), ability to use limited occurrence data (Elith et al., 2006), availability of software for public as well as Forest Service use, ability of the software to use categorical data, and the ease by which output can be integrated into a GIS.

2.3. Study Area Description

US National Forest System lands in Region One include thirteen National Forests and Grasslands encompassing 25 million acres across the states of Washington, Idaho, Montana, North Dakota, and South Dakota. The Region extends from the tall grass prairies of the Dakotas, extending west through sagebrush communities and montane Douglas fir (*Pseudotsuga menziesii* (Mirbel) Franco), lodgepole pine (*Pinus contorta* Dougl. ex Loud.), ponderosa pine (*Pinus ponderosa* C. Lawson) forests of Montana, to the western red cedar (*Thuja plicata* Donn ex D. Don) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) forests of northern Idaho.

The study area (Figure 1) focuses on the western half of Region One in Montana and Idaho and includes three of the twelve National Forests: Beaverhead-Deerlodge, Bitterroot, and Nez Perce. The Forests (Figure 1) were selected based upon their location within a similar ecological province and the availability of skilled and knowledgeable staff botanists to conduct field surveys for model validation.

Figure 1 shows a portion of the Middle Rocky Mountain Steppe-Coniferous Forest-Alpine Meadow Ecological Province that occurs in Region One. The total area covers all ownerships and encompasses 23 million acres. An ecological province is a broad scale, homogeneous natural subdivision having a distinct combination of geologic features and ecological sites (Bailey, 1993). Ecological provinces are commonly used as analysis boundaries for modeling and assessment at a regional level. Although the forests share broadly similar bioclimatic ecological conditions, Table 1 briefly describes each forest's distinct combination of climate, topography, and vegetation. For this study, known plant occurrences were selected based on the extent of the ecological province.

This was done for homogeneity and to obtain as many known occurrence records as possible for model input.

3. METHODS

3.1. Data Acquisition

3.1.1. Element Occurrences

NatureServe, an international non-profit conservation organization, is a network of member programs which are the leading source for information about rare and endangered species and threatened ecosystems. Natural Heritage Programs (or Conservation Data Centers) operate throughout the United States and other countries to collect, analyze, and distribute detailed scientific information about the biological diversity found within their jurisdictions. Natural Heritage Programs and Conservation Data Centers are the leading sources of information on the precise locations and conditions of rare and threatened species and ecological communities.

Element occurrence data for TES species were obtained from the Idaho Conservation Data Center and the Montana Natural Heritage Program. Element occurrence data consist of individual species or plant communities known from direct observations with a defined level of certainty regarding the spatial location of the feature. An element occurrence can define a subpopulation or a population of a species. Adjacent, spatially separated clusters may be considered as subpopulations and may be grouped within an element occurrence (e.g., the subpopulations occur in ecologically similar habitats and within approximately one mile of one another; MNHP, 2006).

All element occurrence records that occurred within the Middle Rocky Mountain Steppe-Coniferous Forest-Alpine Meadow ecological province boundary were examined. The data were then manipulated to generate a set of observations useful for the GIS approach used here. First, element occurrence multi-part polygons were separated so that each polygon would represent a single occurrence rather than a grouped species subpopulation. Polygons were converted to point locations, the number of occurrence records for each plant species calculated, and those species with more than 20 element occurrence records were selected. Statistically, more observations should be available for input into a predictive model, however, these rare species have a dearth of known location records. Table 2 displays the 21 rare plant species that were included in the study.

3.1.2. Environmental Variables

The selection of environmental variables to predict species distributions should include those variables that modulate physical processes and biological response (Poon and Margules, 2004). Seven variables were chosen based upon general biophysical processes and availability of datasets with spatial coverage across the study area. They reflect the climate (mean annual precipitation and mean May temperature), physiography (elevation, slope, aspect, and parent material), and main vegetation types (tree-dominance) within the study area, all of which can affect the distribution of a species (Nix, 1982). GIS data layers were obtained from the Forest Service Northern Region Geospatial Library and several additional internet data sources.

Elevation, slope, and aspect were derived from 30-meter Digital Elevation Model (USDAFS Geospatial Group, 2007) using the ArcMap 9.2 Spatial Analyst extension (ESRI, 2007). Geologic parent material was acquired from the 1:100,000 land-type association layer (GNF, 2004). This layer was created by Forest Service soil scientists using a regionally consistent legend for dominant groups of landforms and geologic materials occurring in repeatable patterns on National Forest System lands and was intended to support broad-scale watershed and landscape level assessments (Table 3). The land-type association layer was chosen to replace soils data which were not available for the entire study area at the time of writing. The Soil Survey Geographic Database is scheduled for completion during 2008 (NRCS, 2007). Future modeling efforts should include soil variables important to plant growth and habitat selection such as soil texture, pH, percent organic matter, soil bulk density, and depth to limiting factor.

The tree-dominance layer was developed by reclassifying the VMAP Version 6 Tree Dominance (vegetation classification for the Nez Perce National Forest and Bitterroot National Forest) and SILC3 Covertype (vegetation classification for the Beaverhead-Deerlodge National Forest) vegetation classification datasets (Table 4). This was done to obtain a consistent vegetation layer across the study area. The VMAP tree dominance is a multi-source and multi-classifier hierarchical landcover dataset which was created using multiresolution segmentation on Landsat ETM+ satellite imagery (USDAFS Geospatial Group, 2006). The SILC3 dataset was derived from sixteen Landsat TM images (2000-2002) of eastern Montana. Each Landsat image was delineated into regions in an unsupervised classification, and each of the regions was assigned a land-cover class in a supervised classification (WSAL, 2002).

Mean annual precipitation and mean May temperature (1971-2000) were derived from PRISM data. PRISM data sets were specifically created to capture the spatial characteristics of climatic data in mountain environments and is the United States Department of Agriculture’s official source for climatological data (Daly et al., 1994; PRISM, 2006). Temperature is one of the major factors limiting the distribution of plants (Monsen et al., 2004). Mean May temperature was chosen because many plants examined in the study (most associated with the lower valley and mid-montane zones) begin to initiate growth during this time of year.

All datasets were processed to a geographic projection as this is the only projection in which DOMAIN can operate. The layers were then clipped to the ecological province boundary, resampled as necessary, manipulated for alignment between layers and converted to ASCII file format. As rare plant habitat can vary a great deal over fine scales, a 30 × 30 m cell size was initially preferred for analysis of habitat requirements. Hardware computational restraints, however, limited resolution to a 60 × 60 m cell size.

When ASCII files are open in DOMAIN the program assumes all datasets are continuous. Layers which included categorical data were manipulated using a Hex Editor which enabled DOMAIN to differentiate between the two data types. First the ASCII grid is converted to DOMAIN grid file (.grd) format. When a grid is saved as a .grd file the flag variable (byte 00000034) is automatically set to 4 (Figure 2). Using a Hex Editor, the flag variables were set to the proper values (for continuous data the flag is set to 0, and for categorical data the flag is set to 2 (Figure 3)).

3.2. DOMAIN Model

The Gower-similarity approach (Gower, 1971), as implemented in DOMAIN (v 1.6; http://clearwater.com.au/domain/), was used. DOMAIN uses the Gower similarity metric to assign a value to a potential site (pixel) based upon its proximity in statistical environmental space to the most similar occurrence location. The output is a new grid where cell values reflect the multivariate distance to the nearest known set of conditions where the species occurs. This is equivalent to a continuous similarity surface, where the highest values (approaching 1) represent areas most similar to known occurrence conditions and low values are most unlike occurrence locations (Decker et al., 2006). The values do not represent probability estimates, but can be interpreted as a measure of classification confidence (Carpenter et al., 1993). Because the statistical surface does not give a discrete boundary for mapping potential habitat, user-defined thresholds are required to map potential species habitat.

The Gower metric provides a means of quantifying similarity between sites. The algorithm uses range standardization to equalize the contribution from each biophysical attribute. This method of standardization is preferred over variance standardization in this application because it is less susceptible to bias arising from dense clusters of sample points (Carpenter et al., 1993). By evaluating the complementary similarity measure and the maximum similarity for all grid points in the study area, a matrix of continuously varying similarity values is generated. DOMAIN defines no discrete boundary for the biophysical envelope. All candidate points are assigned similarity values and user-defined thresholds determine the boundaries for suitable habitat.

Environmental layers along with the locations known species occurrences were inputted into DOMAIN, and the model was run for each of the 21 species. Algorithm output was a grid coverage of the study area, with each cell assigned a Gower metric value. Figure 4 shows an example of the grid coverage for Coville Indian paintbrush. The DOMAIN output grid was converted to a floating-point ASCII grid then converted to integer grid and values were scaled by 100 to maintain an accuracy of two decimal places. Then, thresholds were selected to define potential habitat for each species. Threshold values may be based on expert knowledge or a number of subjective thresholds may be used to reveal relative trends. Theoretically, values above the defined threshold indicated suitable environmental conditions (i.e., within the potential range of species), and values below the threshold indicated less suitable environmental conditions. In this case, threshold values were chosen based on previous studies (Beauvais et al., 2004; Beauvais and Smith, 2005; Decker et al., 2006) which suggest using certain distributions of predicted Gower similarity values; similarity values attributed to the top 2.5% of pixel values (between 97.5 and 100%) were labeled 'most likely' habitat. Pixel values between 95 and 97.4% indicated 'likely' habitat. This percentage rule allowed for definition of predicted range in a standardized fashion for all species.

Approximately 140 maps were produced to assess the model predictions. For each species, an overview map was created which showed predicted potential habitat within each forest (Table 5; Figure 5). Multiple smaller-scale maps showing the potential habitat layer overlaid onto the standard Forest Visitor Map were produced to illustrate travel routes and ownership for easy field navigation (Figure 6). In addition, to increase the efficiency of field surveys, a species density map was also generated for each forest (Figure 7). Potential habitat grids were combined to highlight areas that potentially contained multiple target species.

3.3. Field Evaluation

In general, the most robust way to statistically test a model is to utilize stratified random sampling over the study area (Vaughan and Ormerod, 2003). However, models are not often evaluated in this manner due to lack of time, money, and manpower. A classic validation was not performed due to the large extent of the study area which would have required much greater funding than was available for this study. In a previous study, USFS botanists have observed that this technique had not been successful at locating new rare plant occurrences (Hammet, 2005). Most plant species have uneven distributions due to natural selective influences, the spatial heterogeneity of the environment, and the seasonal nature of some species. Therefore, a survey to determine absolute presence or absence of rare plants is problematic.

The goal for the field sampling effort was to: (1) have experienced field botanists evaluate areas defined as suitable habitat, and (2) find new rare plant populations. Professional field botanists conducted assessments following the standard Forest Service protocol for rare plant surveys (USDA Forest Service, 1988). The botanists participating in the study possess a high degree of expertise and have a combined experience of forty years working within the Rocky Mountain ecosystem. Each of them was asked to conduct rare plant surveys in their respective forest within geographic areas identified by the model as potential habitat for target species. Botanists were instructed to utilize their knowledge of species habitat requirements and to survey high likelihood habitat for the designated species. Predicted habitat served as a primary guide to direct botanists into areas of potential habitat. Once at these locations, botanical knowledge, discretion, and analytic skills contributed to “in situ” assessment. At each survey site, botanists documented target survey species, existing suitable habitat for each predicted species, and a detailed description of biophysical site features (Figure 8). If a new rare plant occurrence was located, site location information was documented with a global positioning system (GPS) device or drawn on a topographic map. Habitat information was also documented in the same fashion for sites where target species were not observed.

During the predictive process, no distinctions were made for species associated with macrohabitats and those with an affinity to microhabitat conditions. The study was purposefully broad-scale; therefore, the predictive process was intrinsically designed to work best for species with macrohabitat affiliations. Table 6 lists the dominant macrohabitats included in the study area as defined by the VMAP tree dominance layer (USDAFS Geospatial Group, 2006). Microhabitat types typically found within the study area include riparian swales and seeps, rock outcrops, canyon walls, footslopes, disturbed sites (e.g., recently burned areas and roadside habitats), and bare soil sites. Botanists were asked to use their field knowledge of species to locate microhabitat types within predicted macrohabitat areas. Surveyed areas were downloaded or digitized within the GIS and site information was used for model evaluation.

3.4. Prediction Assessment

The most commonly used method in predictive rare plant studies is to evaluate the predictions with independent occurrence data (Fertag and Thurston, 2003; Rushton et al., 2004; Decker et al., 2006). Several metrics are also commonly used to summarize model success using an error matrix (Fielding and Ball, 1997; Guisan and Zimmerman, 2000).

For this study, model performance was evaluated using a multi-layered approach. The percentages of known occurrences, referred to as the “known occurrence accuracy,” located within defined ‘likely’ and ‘most likely’ thresholds were examined. Known occurrence records used as model inputs were used as opposed to an independent dataset to verify if environmental variables are adequate predictors for selected species.

Error matrices for each species were constructed to assess algorithm habitat prediction accuracy based on field assessment. Each error matrix displays the relationship between the predicted and observed habitats. Each matrix or table includes the number of pixels that were correctly and incorrectly predicted (as assessed by the field botanists), and model performance is expressed with percentages of error of omission (exclusion) and commission (inclusion). Pixels that were properly predicted are entered along the major diagonal of the table (upper left to lower right). The habitat prediction accuracy for a species can be found by summing the diagonal and dividing by the total number of cells examined. All non-diagonal components in the table represent errors of omission or commission. Omission errors correspond to non-diagonal row elements and commission errors are represented by non-diagonal column elements. Percentage errors of omission were computed by dividing the number of correctly classified pixels (on the major diagonal) by the total number of pixels that were visited in that category (row total). Percentage errors of commission were calculated by dividing the number of correctly classified pixels by the total number of pixels that were visited (column total). This figure indicates the percentage of pixels classified correctly.

An additional matrix was produced if a new population was found where the percentage of new occurrences found within defined ‘likely’ and ‘most likely’ predicted areas, referred to as new occurrence accuracy, was calculated. This table also displays a pixel count of predicted and found occurrences, as well as errors of omission and commission calculated in the same manner as described above.

4. RESULTS

The results for the DOMAIN process and field verification are examined below by species. A total of forty-four new TES plant element occurrences, including two new state occurrence records (tapered-root orogenia and Coville Indian paintbrush) in Idaho, were located using the habitat predictions. Results were evaluated using the multi-layered approach: (1) percentage of known occurrences within defined thresholds, referred to as the known occurrence accuracy, (2) habitat prediction accuracy of the algorithm based on field assessment, and (3) percentage of new occurrences found within predicted areas, or new occurrence accuracy.

Table 7 displays the number of new element occurrences found, known occurrence accuracy (percentage of known element occurrence that fell within defined 'likely' and 'most likely' habitat), and amount of predicted habitat by Forest. Idaho Douglasia, surveyed in the Nez Perce National Forest, had the most occurrences located with 16 new records. All known occurrence records for Constance's bittercress, Pacific dogwood, and short-styled columbine fell within predicted habitat. The majority of species had known occurrence accuracies between 83 and 98%. The species with the lowest known occurrence accuracy was Lemhi beardtongue with 43%. Coville Indian paintbrush, Missoula phlox, sapphire rockcress and small onion also displayed low known occurrence accuracies ranging from 63-74%.

Field surveys were successfully conducted on two of the three pilot forests participating in the study, the Bitterroot National Forest and Nez Perce National Forest. Unfortunately, an unusually early growing season and drought-like conditions in 2007 on the Beaverhead-Deerlodge National Forest constrained effective field surveys for the target species. As a result, the habitat predictions for Jove's buttercup, Missoula phlox, and sapphire rockcress were not assessed further in this study. Two other species anticipated to occur within the Bitterroot National Forest (short-styled columbine and northern rattlesnake-plantain) were also excluded from field sampling. The botanist noted these two species are closely tied to limestone, sandstone, shale, or calcareous soils, none of which occur within the Bitterroot National Forest.

4.1. Broad-fruit Mariposa

Broad-fruit mariposa's known distribution includes Idaho, Washington, and Oregon. Within Idaho, it is known to be associated with the greater Palouse area including both grasslands and moist swales occurring between adjacent hills. The soils in these areas are primarily loess and alluvium. It prefers 10 to 30% slopes, elevations between 1500 and 6400 ft (450-2000 m), and habitat dominated by perennial bunchgrasses and deciduous shrubs.

Three areas predicted as potential habitat were surveyed in the Nez Perce National Forest and two new populations were located. Known occurrence accuracy for broad-fruit mariposa was 95% (Table 7). Within the areas visited, the botanist reported that the model performed well in predicting mariposa grassland and swale macrohabitat and at limiting predictions to the geographic areas where the species is known to occur. A total of 53 pixels were assessed during field survey. Field assessment produced a habitat prediction accuracy of 75.5% (Table 8). The two new populations were found within the 'most likely' predicted habitat (Table 9). Since this species has an affinity for Palouse areas with loess and alluvium soils, inclusion of soil attributes could further refine habitat and potentially produce an even more accurate assessment of habitat requirements.

4.2. Clustered Lady's Slipper

Clustered lady's slipper distributional range includes most of the western United States: California, Colorado, Idaho, Oregon, Utah, Wyoming, and Montana. Within Idaho, this species is found across a wide range of macrohabitats. It primarily occurs in various successional stages of habitat types including mixed stands of drier Douglas fir, grand fir, and western red cedar to old growth cedar. The known occurrence accuracy for Clustered lady's slipper was 88% (Table 7). Fourteen areas of predicted habitat were visited in the Nez Perce National Forest and two new occurrences were located.

Field assessment results supported model habitat classification for this species. A total of 245 pixels were assessed on the ground and, according to the botanist, only 36 were misclassified producing an overall accuracy of 85% (Table 10). Both of the new occurrence records were found in areas predicted to be suitable habitat (Table 11).

4.3. Constance's Bittercress

Constance's bittercress is found along river breaks and stream terraces in areas associated with warm and moist environments of low elevation river canyons between 2,000 and 4,000 feet (610 to 1200 meters) of elevation. It prefers western red cedar and western hemlock habitat types. Its distribution range extends throughout Idaho.

Thirteen areas were visited within the Nez Perce National Forest. No new occurrences for Constance's bittercress were found. All of the known element occurrences fell within predicted habitat, producing a known occurrence accuracy of 100% (Table 7). The predicted habitat reflected the warm and moist conditions required by the species. The botanist observed that the algorithm captured the known species range of the Selway River Corridor but it also included southern portions of the forest outside its known distribution. Although there is a well established elevational range in which this species will occur, much of the modeled habitat exceeded this substantially.

Field results show that of the 293 pixels surveyed, 98 were misclassified (Table 12). While a 95% omission error for unsuitable classification was also found, this reflects that there were a large number of pixels misclassified as potential habitat.

4.4. Coville Indian Paintbrush

Coville Indian paintbrush's distribution ranges from Idaho to Montana. This species occupies stony soils on slopes and summits in the montane and subalpine zones. A total of eighteen areas identified as potential habitat were visited. The known occurrence accuracy for Coville Indian paintbrush was low at 67% (Table 7). Five sites were surveyed within the Nez Perce National Forest and seven new occurrences were found. Thirteen sites were visited in the Bitterroot National Forest and four new occurrences were located.

This species was not previously documented in Idaho but it was suspected that the species distribution extended into the state (IFG, 2007). Within the Nez Perce National Forest in Idaho, the botanist found it at several locations predicted not to be suitable habitat. The new occurrences were found while conducting surveys in an area predicted as suitable habitat for Idaho Douglasia in the eastern portion of the forest. During field assessment, the botanist found that habitats for Idaho Douglasia and tapered-root orogenia often overlapped and the two plants were occasionally found together. The surveyed area predicted to be habitat was much lower in elevation and of a different forest community. Habitat predictions for this species in Idaho were based on known occurrences in Montana, but species can occur in very different habitat types across their ranges. More knowledge about this species' habitat in Idaho will improve future predictions.

Within the Bitterroot National Forest in Montana, Coville Indian paintbrush is endemic to the Bitterroot Mountains and was originally found in open, rocky subalpine/alpine areas near the Idaho border up to 8780 feet (2600 meters). Recently its habitat and elevational range were broadened when new occurrences were found during an unrelated survey in open Ponderosa pine and grassland macrohabitats on the West Fork Ranger District of the Bitterroot National Forest. These new occurrences were used as model input; this may be why the algorithm included habitats ranging from bunchgrass communities to subalpine fir/beargrass (*Xerophyllum* Michx.) groups. The biophysical envelope approach led the botanist to some new insights into potential habitat as several occurrences were found in the transition zone between Douglas fir/pinegrass (*Calamagrostis rubescens* Buckley) and Ponderosa pine/bunchgrass habitats previously believed to be unsuitable habitat.

Field results for Coville Indian paintbrush revealed a 39% habitat prediction accuracy (Table 13). In almost 3/4 of the areas surveyed, the model excluded potential habitat. The percentage error of commission for unsuitable habitat, 76%, was also large, indicating that pixels classified as suitable do not represent suitable habitat on the ground. New occurrence locations, which had an overall accuracy of only 20%, were mostly located in areas designated as unsuitable habitat suggesting that much work remains to improve predictions of habitat for this species (Table 14). The new occurrence located in this study will assist future efforts.

4.5. Evergreen Kittentail

The known distribution of evergreen kittentail is within Idaho. This species occupies habitats that include grand fir, subalpine fir, and mountain hemlock, and occasionally western red cedar macrohabitat types. Its range is strongly associated with grand fir mosaic forests and the botanist believed the predicted habitat was very good within zones of that forest type. The known occurrence accuracy for evergreen kittentail was 83% (Table 7).

Eleven areas predicted as suitable habitat were visited in the Nez Perce National Forest and four new occurrences were located. None were visited on the Bitterroot National Forest as it is believed to be outside the plant's range, though the model predicted 17,978 acres (7,275 ha) of suitable habitat. Field assessment results showed a habitat prediction accuracy of only 38% (Table 15). An 82% error of omission was calculated for unsuitable habitat indicating that the algorithm was not including all potential habitats. Within areas surveyed, pixels classified as suitable had a 71% commission error, indicating that a pixel classified as suitable habitat does not necessarily represent suitable habitat on the ground. Promisingly, all new occurrences were found within areas predicted as suitable habitat (Table 16). The botanist suggested that future iterations of the model should include soil as an environmental input variable with a focus on soil types that are limited to the grand fir mosaic forest type.

4.6. Hall's Rush

The distribution of Hall's rush extends from Montana and Idaho southward into Wyoming, Utah, and Colorado. Within Montana, Hall's rush is known to occur only on National Forest System lands east of the continental divide. It is found within the

Beaverhead-Deerlodge, Helena, and Lewis and Clark National Forests. This species is not known to occur within the Bitterroot National Forest and the botanist did not have previous observations of habitat affiliation for the species upon which to refer. However, DOMAIN predicted suitable habitat within the Bitterroot National Forest and four survey sites were visited. Typically Hall's rush occurs in moist to dry meadows and slopes from valleys to montane zones. The model did select several sites on the Forest that are known to contain wetlands. The botanist focused on these areas but no new locations were discovered.

The known occurrence accuracy for Hall's rush was 83% (Table 7). An 83% error of commission was calculated for suitable habitat suggesting there is poor probability that pixels classified as suitable habitat were found to be suitable. The error of omission for suitable habitat was 65% indicating that more than half of the time the model was not capturing suitable habitat accurately (Table 17). As mentioned previously, Hall's rush is not known to occur in the Bitterroot National Forest. Unfortunately, habitat predictions in the Beaverhead-Deerlodge National Forest, within the species' known distribution, were not field verified. Assessing predicted habitat within these areas could provide information on if the algorithm was accurately capturing the species bioclimatic envelope.

4.7. Hollyleaf Clover

Hollyleaf clover's distribution range extends throughout the west, excluding Washington State. Within Region One, it occurs in open woodlands and slopes, usually in dry soil of sagebrush steppe to ponderosa pine forest in the foothills to the lower montane zone. The known occurrence accuracy for this species was 83% (Table 7).

Fourteen sites predicted as potential habitat were surveyed in the Bitterroot National Forest. Within the Forest, hollyleaf clover has only been found in the vicinity of Painted Rocks Reservoir. The botanist noted the biophysical algorithm identified good habitat in other regions of the forest and surveyed in these areas, but no occurrences were located.

A total of 348 pixels were assessed and 255 were found to be misclassified (Table 18). All habitats surveyed by the botanist were identified as potentially suitable. Seventy three percent of these pixels had been identified as unsuitable by the algorithm. As noted above, this species may have a geographical limitation. The botanist was unaware of the environmental factors limiting this species to the Painted Rocks Reservoir and was greatly interested in examining possible soil associations. Additional modeling efforts should include soil information to enhance and refine habitat predictions.

4.8. Howell's Gumweed

Howell's gumweed is a regional endemic known to occur only in two counties in Montana, and one county in Idaho. In Montana, populations occur in a variety of natural habitats, but often the species prefers disturbed sites. This species is associated with microhabitat types which include moist, lightly-disturbed soil adjacent to ponds and marshes as well as other disturbed habitats such as roadsides and grazing pastures. Howell's gumweed is also known to prefer sites located along the transition zone between lower elevation grassland and intermixed lower forest macrohabitat types. The known occurrence accuracy for this species was 90% (Table 7).

Seven sites predicted as suitable habitat were surveyed in the Bitterroot National Forest. Field assessment of predicted habitat found that of the 503 pixels surveyed, 116 were misclassified (Table 19). The algorithm underestimated suitable habitat, according to the botanist's assessment, resulting in an error of commission of 93%. Despite this species having microhabitat associations, the model was correctly classifying a substantial amount of potential habitat. Future modeling efforts should be conducted at the forest-level and should include fine-scale data related to disturbance conditions such as grazing allotments and roads as well as soil variables.

4.9. Idaho Douglasia

Idaho Douglasia is endemic to the mountains of central Idaho with populations distributed in a series of isolated, widely separated clusters extending from the upper Selway River corridor southward to the Trinity Mountains. The species occurs within subalpine vegetation characterized by open, forb-dominated communities as well as woodlands dominated by whitebark pine and subalpine fir. The known occurrence accuracy for Idaho Douglasia was 95% (Table 7).

Six areas predicted to be suitable habitat were surveyed in the Nez Perce National Forest and sixteen new occurrence records were located. The botanist originally thought the predictions were overly broad and many areas predicted as suitable habitat were not appropriate (generally forested habitat types). However, during survey work, he found that areas predicted as habitat were often suitable on the ground. Focusing on areas predicted as suitable, the botanist twice extended the known range of this species a total of 16 miles (25 km) to the west.

Within the areas surveyed, the model missed 27% of the habitat the expert found and predicted habitat in a similarly large area where no suitable habitat was located. Habitat prediction accuracy for Idaho Douglasia was 60% (Table 20). New occurrence records were found within areas predicted to be unsuitable 32% of the time (Table 21).

Thus, the new occurrences confirmed that the species occupies broad amplitude of habitats and that we can increase our knowledge of species habitat relationships through field surveys.

4.10. Idaho Strawberry

Idaho strawberry is another endemic restricted to north-central Idaho and the far western regions of Montana. The species occurs in open, cool, moist forest types from toe to mid-slopes in western red cedar, grand fir, and subalpine fir zones at elevations between 4,000 and 5,000 feet (1,219 to 1,524 meters). Occasionally, it does occur in rich mesic and warmer sites. Idaho strawberry requires specific ecological conditions which causes it to occur within four distinct geographic areas in north-central Idaho. However, its occurrences are more broadly distributed than many other endemics in this area. The known occurrence accuracy for Idaho strawberry was 98% (Table 7).

Sixteen survey sites of predicted habitat were assessed in the Nez Perce National Forest and one new element occurrence was found. Field assessment revealed that more than one-half of the area identified as suitable was not suitable, and thus the algorithm was not adequately capturing habitat requirements for this species though it was including almost all the known sites. Habitat prediction accuracy was only 45% (Table 22). Only 8% of the time did the algorithm include pixels of suitable habitat. However, the new occurrence was found within predicted suitable habitat (Table 23). It can be extremely difficult to define the habitat requirements of Idaho strawberry due to its affinity for cool, moist microhabitats. Future modeling efforts for this species should include higher resolution datasets for the environmental variables to reflect microhabitat parameters. Also, including a topographic wetness index should be considered to help capture the moist microhabitats which this species prefers.

4.11. Lemhi Beardtongue

Lemhi beardtongue is a regional endemic of Lemhi County, Idaho, and Beaverhead, Deer Lodge, Ravalli, and Silverbow Counties, in Montana. In Montana, Lemhi beardtongue occurs on moderate to steep, east to southwest facing slopes, often on open soils. It prefers sites below or near the lower extent of Douglas fir and/or lodgepole pine forest in habitats dominated by sagebrush and bunchgrasses. This species is not restricted to any particular geological substrate and has been found on granitic soils as well as limestone and other sedimentary substrates. It is most commonly found on gravelly loams, however soil texture can be variable and range from sand to fine clay. Lemhi beardtongue is known to respond favorably to disturbance regimes that leave bare soil, and it declines in undisturbed communities as vegetative succession proceeds toward advanced stages. The known occurrence accuracy for Lemhi beardtongue was 43% (Table 7). Ten survey areas predicted to be potential habitat were visited and one new population was located within the Bitterroot National Forest. Field results showed that the algorithm missed three times as much suitable habitat as it correctly identified (Table 24). Predicted habitat areas included subalpine/beargrass habitat types which are not considered classic habitats for this species. The botanist believed the algorithm appropriately identified the open canopy and grassland macrohabitat types preferred by the species. The new population was found in an area which was predicted to be unsuitable (Table 25).

As discussed earlier, Lemhi beardtongue is associated with disturbed habitats in the early seral stages of succession, but the model did not include a variable that described successional stages and disturbance regimes. Including disturbance variables such as wildfire, grazing, and roads, as well as soil type and texture, could further refine potential habitat predictions.

4.12. Pacific Dogwood

Pacific dogwood is a Pacific coastal disjunct species found in northern Idaho. The principal distribution of this species is west of the Cascade/Sierra crest from southwestern British Columbia to southern California. A disjunction exists when a population segment is separated by some distance from the main or principal population. In Idaho, this species is ecologically restricted to the Lochsa-Selway River corridors and lower elevations of the western red cedar zone. In Region One it inhabits brushfields, rather dense mature forests, and stream banks. Slopes vary from flat to greater than 60% and plants can be found growing on all aspects though southern aspects support the highest concentrations. Pacific dogwood ranges in elevation from 1,600 to 2,800 feet (487 to 853 meters) and is found in moderately developed spodosols with good drainage and humus surface. The species grows in a variety of habitats ranging from secondary succestional stages induced by fire to near climax. Most communities are mid-successional and dominated by seral such as Douglas fir, western larch, and grand fir.

The known occurrence accuracy for Pacific dogwood was 100% (Table 7). Thirteen survey areas predicted as potential habitat were visited in the Nez Perce National Forest and one new occurrence was located. The botanist felt the algorithm correctly identified the warm and moist climatic requirements of this species. Field assessment of habitat predictions found that, of the 257 pixels assessed, only 24 were classified incorrectly (Table 26). Overall, the model preformed well predicting habitat for this species. The new occurrence was located within an area defined as ‘most likely’ habitat (Table 27). However, the model included areas outside its known local geographical distribution along Lochsa-Selway River corridors. Thus, finding a methodology to include this limitation could have improved habitat predictions.

4.13. Payson’s Milkvetch

Payson’s milkvetch is a regional endemic of the Clearwater Mountains of north-central Idaho, the Palisades Reservoir area of east-central Idaho, and the Wyoming, Salt River, and Gros Ventre ranges of western Wyoming. Payson’s milkvetch is ruderal in nature. It occupies cooler grand fir habitats in early seral stage of succession, and is commonly is found on roadsides, clearcuts, and in other disturbed microhabitats. It is usually found on sandy soils with low cover of forbs and grasses. The known occurrence accuracy for Payson’s milkvetch was 92% (Table 7).

Fifteen survey sites predicted to be potential habitat were visited on the Nez Perce National Forest. The botanist found it difficult to assess whether an area was potential habitat due to the difficulty of determining the gradual temperature gradient between cooler grand fir and warmer grand fir forests. Within the sites surveyed, the botanist found the algorithm was over predicting habitat, resulting in 51% error of commission (Table 28). Habitat prediction accuracy was a low 47% (Table 28). The botanist suggested refining the input environmental parameters for this species to include road corridors in grand fir forests over 4,000 feet (1,219 meters) elevation and regeneration harvest units less than 20 years old in grand fir forests above 4,000 feet elevation (1,219 meters).

4.14. Puzzling Halimolobos

Puzzling halimolobos distribution extends from Washington into Idaho. In Idaho, it is regionally endemic to the Salmon River watershed. Like Payson's milkvetch, it is an early seral species requiring disturbance and bare soil to become established. Its habitat is gravelly, sandy, or grassy slopes adjacent to rock outcrops in open ponderosa pine and Douglas fir forests. The known occurrence accuracy for puzzling halimolobos was 83% (Table 7).

Six survey sites predicted as suitable habitat were visited on the Nez Perce National Forest. Puzzling halimolobos had the second lowest habitat prediction accuracy at 28% (Table 29). None of the habitat surveyed was assessed by the botanist as being suitable. Areas which had been predicted to be unsuitable was assessed that way as well. Predicted habitat often included forested areas where grasslands were severely reduced due to disturbance or completely lacking. However, the model did reflect the species' ecological limit along the Salmon River Corridor. This species is strongly associated with specific soil types. Including finer resolution data and additional environmental variables, such as soil types and disturbed areas, could improve algorithm performance.

4.15. Small Onion

Small onion distribution includes California, Idaho, Montana, Nevada, Oregon, and Utah. This species is found in dry, open forests, woodlands or grasslands and generally on predominantly south-facing slopes in the montane zone. Fifteen survey areas were visited in the Bitterroot National Forest and one new population was located using model output. The known occurrence accuracy for small onion was 74% (Table 7).

Field verification found the algorithm predicted habitat appropriately in Douglas fir/pinegrass and subalpine fir/beargrass forested habitat types but could not differentiate suitable understory types. The vegetation layer used as an input variable was too coarse in resolution to distinguish grassland types.

The habitat prediction accuracy for small onion was 85% (Table 30). Field results showed a 93% error of commission for unsuitable habitat. However, the new population was located in an area predicted to be suitable, in classic habitat of dry, rocky, south-facing slope with bare soil (Table 31). Inclusion of soils attributes could help future refine habitat predictions for this species.

4.16. Tapered-root Orogenia

The distribution range for the tapered-root orogenia ranges from California through Oregon and into Idaho and Montana. In the northern Rocky Mountains, it is known to occur on open slopes, ridges, and meadows from the lower foothills to the mid-montane zone. A total of nineteen areas predicted as potential habitat were surveyed. Three areas were visited in the Nez Perce National Forest where one new occurrence was found, and thirteen areas in the Bitterroot National Forest where four new occurrences were found. Known occurrence accuracy for tapered-root orogenia was 84% (Table 7).

Within the Bitterroot National Forest, the tapered-root orogenia has a broad amplitude of habitats ranging from grasslands, open ponderosa pine/bunchgrass to Douglas fir/pinegrass, and mixed conifer stands. The model did correctly predict several macrohabitat types where this species is expected to be found including dry grasslands and opening in ponderosa pine and Douglas fir forests. Four new occurrence locations were discovered in predicted areas of the Douglas fir/pinegrass habitat type.

One new element occurrence on the Nez Perce National Forest was found while surveying for Idaho Douglasia. Like Coville Indian paintbrush, habitat predictions for this species in Idaho were based on known occurrences in Montana but species can occur in very different habitat types across their ranges. While there was predicted habitat in this region, it was not where the new population was found. The predicted Gower similarity values for pixels where the new occurrence was found ranged from 40 to 43. This was quite different than the similarity values which defined suitable habitat. Values which defined ‘most likely’ threshold ranged from 94 to 99, while values in the ‘likely’ threshold ranged from 81 to 84. The population located was a new state record for Idaho and extends the known geographic range of the species according to ICDC and NatureServe records (IFG, 2007). This new occurrence in Idaho changes our understanding of this species’ habitat requirements and will help to refine future predictions of potential habitat.

The broad range of habitat types in which this species is known to occur made it somewhat difficult to model. Areas predicted as suitable by the model included different habitats and lower elevations compared to where it was found. It is evident that the algorithm did not adequately capture the species’ biophysical envelope. The habitat prediction accuracy of survey sites was 48% (Table 32). This could explain why errors of omission and commission were extremely high for unsuitable habitat (70% and 73% respectively). Further research on the species’ habitat requirements, and introducing additional environmental parameters, could help refine predictions. New occurrences were located within suitable habitat in half the pixels visited; this resulted in a 50% error of omission rate which indicates that a great deal of suitable habitat pixels was not classified accurately (Table 33).

5. DISCUSSION AND FUTURE RESEARCH

The method of evaluation was based on a multi-layered approach: (1) percentage of known occurrences within defined thresholds, referred to as the known occurrence accuracy, (2) habitat prediction accuracy of the algorithm based on field assessment, and (3) percentage of new occurrences found within predicted areas. Field evaluation of the habitat assessment by expert field botanists provided insight and valuable information on modeling rare species. The modeling process also revealed algorithm strengths and weaknesses.

Some plants lend themselves well to the biophysical envelope model approach. Several species had high known occurrence accuracies in which most of the known occurrences fell within areas defined as 'likely' and 'most likely' potential habitat. These species include Constance's bittercress, Pacific dogwood, and short-styled columbine. More than two thirds of the species (16 of 21) had overall accuracy values ranging from 83% to 98% (Table 7), including broad-fruit mariposa, clustered lady's slipper, evergreen kittentail, Hall's rush, hollyleaf clover, Howell's gumweed, Idaho Douglasia, Idaho strawberry, Payson's milkvetch, puzzling halimolobos and tapered-root orogenia. This method was close to the hypothesized estimate that this approach would be able to predict habitat correctly at 85% accuracy for known occurrences for more than one-half of the species. Twelve of 21 species had accuracies of 85% or greater.

After examining the Gower metric values of known occurrences outside the thresholds defining potential habitat, it became clear that extending the threshold values to include the highest 10% or 15% would increase overall prediction accuracies for some species. For example, Idaho Douglasia and Idaho strawberry had one known occurrence that did not fall within potential predicted habitat. The Gower similarity values at these locations were close to the threshold cutoff values for areas defined as ‘likely’ habitat. Therefore, extending threshold values would improve known occurrence accuracy and presumably habitat predictions. Lemhi beardtongue had the lowest known occurrence accuracy at 43% (Table 7). More research about Lemhi beardtongue’s habitat requirements and associated environmental variables is needed. For this species, 153 known occurrences were inputted into the model, which would raise the expectation that predicted habitat would be well defined. However, the model did not adequately define its environmental envelope. Figure 8 displays the number of found element occurrences verses the number of known input element occurrences used in the model. As presented in the graph, species with large sets of known element occurrence records used as inputs did not necessarily increase the chance of finding new occurrence records. For instance Idaho Douglasia, which had the most new records located, had the least number of known element occurrence records (Table 7).

Field assessment of predicted habitat showed Pacific dogwood was predicted best, with habitat prediction accuracy of 91% (Table 26); clustered lady’s slipper and small onion shared the second highest classification accuracy of 85% (Table 10; Table 30). These species are associated with macrohabitat types which the algorithm distinguished across the landscape using the seven input variables. The botanist found that the predicted habitat was usually suitable on the ground and all new occurrence records for these species were found in predicted habitat.

On the other hand, the predicted habitat for several species was found to be inaccurate or overestimated. Misclassification of suitable and unsuitable habitat is inevitable in any habitat modeling procedure and sources of error may be caused by inherent problems in the modeling process or complications arising from an organism's ecology (Luck, 2002). Some of these pitfalls include: microhabitat associations not adequately resolved, inadequate environmental parameters used as input, or an unpredictable distribution pattern due to evolutionary reasons (Skov, 2000). Hollyleaf clover, Lemhi beardtongue, and puzzling halimolobos had the lowest habitat classification accuracy, ranging from 25% to 27% (Table 18; Table 24; Table 29). Hollyleaf clover has a geographical limitation due to unknown ecological reasons that led to an over prediction of habitat. Lemhi beardtongue and puzzling halimolobos had low habitat classification accuracies most likely due to inadequate environmental variables used as input. These species have an affinity towards disturbed habitats in early seral stages of succession. No layer describing these variables was included and thus biophysical envelopes for these species were inadequate.

The biophysical envelope was calculated at a 60 × 60 m scale over a substantial region, making it virtually impossible to identify microhabitat variations and accurately assess site suitability for some plant species. A number of species that were associated with microhabitat types had poor habitat classification accuracies. These species include: Howell's gumweed, Hall's rush, Idaho strawberry, and Payson's milkvetch. Technical limitations prevented microhabitats from being described and measured on a regional scale. Species with microhabitat associations should be modeled at the forest level using 15 × 15 m pixel size. However, modeling at the forest level would result in a compromise in the number of known occurrences used as model inputs as well as size of the study area. Suggestions for future research include prescreening for marcohabitat verses microhabitat associations, as well as species with affinities for disturbance and early successional stages, and model accordingly at the appropriate scale. These species may occur across a wide variety of habitat types and should only be modeled when GIS layers describing these factors are included.

Habitats for Coville Indian paintbrush, Idaho Douglasia, Lemhi beardtongue, and small onion were not adequately predicted. The development of a habitat model should always rely on the understanding of the ecology of the species (Wu and Smeins, 2000). Variables for this study were chosen based on available datasets and consistency across the region and were not tailored to specific species habitat requirements. Because these plants species are rare, quite often botanists are not aware of their specific habitat requirements beyond the very general. The algorithm seemed to be selecting the appropriate overstory habitats but did not accurately distinguish differences in understory microhabitats. Since the layers were analyzed by the algorithm at a 60 × 60 m pixel size, it may be that there was not enough variation to differentiate past broad habitat requirements. Future efforts could employ procedures for variable selection, such as principal components analysis (PCA). A PCA of all variable values in the study area will indicate which variables explain the most variation and which variables are inter-correlated for each species.

Other species were inaccurately predicted due to lack of available data at a regional scale. This included broad-fruit mariposa, tapered-root orogenia, evergreen kittentail, and hollyleaf clover. These species all have a high affinity for certain soil types not included as environmental variables in the algorithm. Soil parameters could not be included due to a lack of complete data within National Forest System lands across the study area. For all four species, the lack of consistent regional soils datasets was a limiting factor in estimating suitable habitat. In future efforts, it may be cost effective to fund digitization of printed soil maps. In addition to soils, other environmental parameters should be considered which could refine a species biophysical envelope such as: number of frost-free days, annual growing degree days, precipitation frequency (proportion of wet days), and evapotransporation.

Experts also noted that certain species have specific ecological limitations governing where they are known to occur, which resulted in over-prediction of suitable habitat by the model. Constance's bittercress, hollyleaf clover, Idaho strawberry and puzzling halimolobos all have ecological limits. Some of these factors remain unknown while others are due to a specific soil type or river corridor. These ecological and geographic limitations should be investigated further and included in subsequent efforts. However, using the model to identify geographic areas outside the known range and surveying within these areas should be pursued because the known range might be extended for the species. This could be done for all four of these species.

A number of additional potential pitfalls that may affect the accuracy of a presence-only model must be considered. First, occurrence records may be biased. They are often correlated with the nearby presence of roads, rivers, or other access conduits (Reddy and Davalos, 2003). The location of occurrence records may also be limited to one region (e.g., specimens collected from several near-by locations in a restricted area) which may result in the perception that they grow under certain conditions when other areas were simply not examined. Similarly, mapping intensity and sampling methods often vary widely across a study area. In addition, errors may exist in occurrence data due to transcription error or species misidentification. Selected environmental variables may not be sufficient to describe all the parameters of species habitat requirements. Finally, errors may be included within predictor variables themselves, perhaps due to data manipulation, inaccuracies in the generation of the environmental layers, or interpolation of lower-resolution data (Phillips et al., 2006).

DOMAIN offers advantages over similar methods in its ability to operate effectively using presence-only records and a limited number of biophysical attributes. The graded nature of habitat similarity scores can facilitate the use of the DOMAIN model as a prioritization tool through the use of the user-defined thresholds required to obtain predictions of occurrence. The model is user friendly and can easily be represented as a prediction map within a GIS. Another major advantage in terms of rare plant modeling is that this algorithm is known to perform well with small sample sizes of occurrence data.

However, as with all modeling procedures, DOMAIN does have its limitations. One disadvantage is that it does not address potential correlations and interactions among environmental variables. All environmental predictors are given equal weight. In addition, there is no way to investigate the influence each environmental predictor actually has on the species' distribution pattern. Lastly, there is no procedure for variable selection other than the layers included as inputs.

6. CONCLUSION

A prerequisite to developing a strategy for the conservation of rare plant species is an understanding of the habitats in which the populations of the species occur (Wiser et al., 1998). In this study, the goal was to predict the distribution of habitats for rare species for which limited ecological information is available. Additionally, because these are rare plants, it was important to locate new occurrences to enhance knowledge of their habitat requirements. With 44 new populations located and two new state occurrence records for Idaho, results demonstrate the DOMAIN biophysical approach proved to be a simple, efficient technique for predicting rare plant potential habitat at a broad-scale. The algorithm predicted habitat well for some species but for others further refinement of input variables is needed. Implementing this procedure at the Forest level could improve habitat predictions, aid botanists in locating new plant occurrences, and become a useful tool in the management of rare plant and animal species. This study was an initial attempt to predict habitat for rare plants within Region One and is the beginning of an iterative procedure whereby the development, validation, refinement and re-validation of this algorithm, or other presence-only modeling techniques, will continue until consistent patterns of habitat use are identified.

The biophysical envelope procedure explored in this study demonstrates that opportunistically-collected occurrence data can produce usable predictions of species distribution over a large region. This conclusion is supported by other studies as well (e.g., Elith et al., 2006 and Phillips et al., 2006). The DOMAIN algorithm provided a simple method to incorporate limited occurrence data and environmental predictor variables to predict potential habitat across a landscape. This method can be utilized for both common and rare species to increase knowledge of species habitat requirements, assist botanists in efficient field sampling efforts during project work, and help conservation managers in decision making and project evaluation.

A broad-scale habitat-based approach to conservation assessment has associated benefits. By identifying locations of potential habitat for rare species using environmental factors, measures can be taken for their management and protection. The complexity of nature and, in particular, the variation of species interactions and their environment, make habitat prediction a difficult task. DOMAIN provides a useful choice for potential habitat mapping, and it is particularly well-suited to applications where available site location records or environmental data are limited.

These predictions are not intended as substitutes for field survey and should not provide the sole basis for management decisions. Rather, they should be used as spatially-explicit predictions on the distribution of the target species based on current knowledge of occurrence in the region. As with all models, the predictions are approximations of the true distribution of each species rather then a direct mapping. Predictive habitat maps must be tested rigorously in the field to identify methodological flaws, incorrect assumptions, and faulty input data so that future iterations can be improved. Plant and animal distributions are dynamic in both space and time necessitating careful interpretation, re-evaluation, and updating of range maps as new information becomes available.

REFERENCES

Anderson, J.R., Hardy, E.E., Roach, J.T., Witmer, R.E., 1976. A Land Use and Land Cover Classification System for Use with Remote Sensor Data. U.S. Geological Survey. Professional Paper 964, Washington, DC.

Austin, M.P., 1998. An Ecological Perspective on Biodiversity Investigations: Examples from Australian Eucalypt Forests. Ann. Mo. Bot. Gard. 85 (1), 2-17.

Austin, M.P., 2002. Spatial Prediction of Species Distribution: An Interface Between Ecological Theory and Statistical Modeling. Ecol. Modell.157 (2-3), 101-118.

Bailey, R.G. 1993. Description of the Ecoregions of the United States. USDA Forest Service Misc. Publ. No 1391.

Beauvais, G., Keinath, D., Thurston, R., 2003. Predictive Range Maps for 15 Species of Management Concern in the Rocky Mountain Region of the USDA Forest Service. Wyoming Natural Diverse Database, University of Wyoming, Laramie, Wyoming. Unpublished document. http://uwadmnweb.uwyo.edu/wyndd/.

Beauvais, G., Keinath, D., Thurston, R., 2004. Predictive Range Maps for Five Species of Management Concern in Southwestern Wyoming. Wyoming Natural Diverse Database, University of Wyoming, Laramie, Wyoming. Unpublished document. http://uwadmnweb.uwyo.edu/wyndd/Reports/pdf_beauvais/U04BEA03WYUS.pdf.

Beauvais, G., Smith, R., 2005. Predictive Range Maps for 54 Species of Management Concern in the Rocky Mountain Region of the USDA Forest Service. Wyoming Natural Diverse Database, University of Wyoming, Laramie, Wyoming. Unpublished document. http://uwadmnweb.uwyo.edu/WYNDD/Reports/pdf_beauvais/PMJM_report_2001.pdf.

Box, E.O., Crumpacker D.W., Hardin, E.D., 1993. A Climatic Model for Location of Plant Species in Florida, USA. J. Biogeogr. 20 (6), 629-644.

Brotons, L., Thuiller, W., Araujo, M.B., Hirzel, A.H., 2004. Presence-Absence Verses Presence-Only Modeling Methods for Predicting Bird Habitat Suitability. Ecography 27 (4), 437-448.

Carpenter, G., Gillison, A.N., Winter, J., 1993. DOMAIN: A Flexible Modeling Procedure for Mapping Potential Distributions of Plants and Animals. Biodivers. Conserv. 2 (6), 667-680.

Daly, C., Neilson, R.P., Phillips, D.L., 1994. A Statistical-Topographic Model for Mapping Climatological Precipitation over Mountainous Terrain. J. Appl. Meteorology 33 (2), 140-158.

Decker, K., Lavender, A., Handwerk, J., Anderson, D.G., 2005. Modeling the Potential Distribution of *Phacelia scopulina var. submutica* (Debeque phacelia) and *Astragalus debequaeus* (Debeque milkvetch) in Western Colorado. Report prepared for U.S. Fish and Wildlife Service by the Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado. Unpublished document. http://www.cnhp.colostate.edu/documents/2005/Modeling_Phacelia_submutica_and_Astragalus_debequaeus.pdf.

Decker, K., Lavender, A., Handwerk, J., Anderson, D.G., 2006. Modeling the Potential Distribution of Three Endemic Plants of the Northern Piceance and Uinta Basins. Report prepared for U.S. Fish and Wildlife Service by the Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado. Unpublished document. http://www.cnhp.colostate.edu/documents/2006/PEGR_LECO_PHOB_report.pdf.

Elith, J., Burgman, M., 2002. Predictions and Their Validation: Rare Plants in the Central Highlands, Victoria, Australia. In: Scott, J.M., Heglund, P.J., Morrison, M.L., Haufler, J.B., Rapheal, M.G., Wall, W.A., Sampson, F.B. (Eds.), Predicting Species Occurrence: Issues of Accuracy and Scale. Island Press, Covello, CA, p 303-313.

Elith, J., Graham, C.H., Anderson, R.P., Dudik, M., Ferrier, S., Guisan, A., Hijmans, R.J., Huettmann, F., Leathwick, J.R., Lehmann, A., Li, J., Lohmann, L.G., Loiselle, B.A., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., McC. Overton, J., Peterson, A.T., Phillips, S.J., Richardson, K., Scachetti-Pereira, R., Schapire, R.E., Soberon, J., Williams, S., Wisz, M.S., Zimmermann, N.E., 2006. Novel Methods to Improve Prediction of Species' Distributions from Occurrence Data. Ecography 29 (2), 129-151.

Environmental Systems Research Institute, Inc, 2007. ArcMap v9.2, Spatial Analyst Extension. Redlands, California.

Farber, O., Kadmon, R., 2003. Assessment of Alternative Approaches for Bioclimatic Modeling with Special Emphasis on the Mahalanobis Distance. Ecol. Model. 160 (1-2), 115-130.

Feilding, A.H., Bell J.F., 1997. A Review of Methods for the Assessment of Prediction Errors in Conservation Presence/Absence Models. Environ. Conserv. 24 (2), 38-49.

Fertig, W., Reiners, W.A., 2002. Predicting Presence/Absence of Plant Species for Range Mapping: A Case Study from Wyoming. In: Scott, J.M., Heglund, P.J., Morrison, M.L., Haufler, J.B., Rapheal, M.G., Wall, W.A., Sampson, F.B. (Eds.), Predicting Species Occurrence: Issues of Accuracy and Scale. Island Press, Covello, CA, p 483-490.

Fertig, W., Thurston, R., 2003. Modeling the Potential Distribution of BLM Sensitive and USFWS Threatened and Endangered Plant Species in Wyoming. Report prepared for the Bureau of Land Management Wyoming State Office, by the Wyoming Natural Diverse Database, University of Wyoming, Laramie, Wyoming. Unpublished document. http://uwadmnweb.uwyo.edu/wyndd/Reports/pdf_fertig/U03FER01WYUS.pdf.

Fleishman E., Murphy, D.D., Sjogren-Gulve, P., 2002. Modeling Species Richness and Habitat Suitability for Taxa of Conservation Interest. In: Scott, J.M., Heglund, P.J., Morrison, M.L., Haufler, J.B., Rapheal, M.G., Wall, W.A., Sampson, F.B. (Eds.), Predicting Species Occurrence: Issues of Accuracy and Scale. Island Press, Covello, CA, p 507-518.

Gallatin National Forest, 2004. Landtype Associations of the Northern Region, accessed April 2006. Available from http://www.fs.fed.us/r1/gis/thematic_data/landtype_associations_r1_100k.htm.

Godown, M.E., Peterson, A.T., 2000. Preliminary Distributional Analysis of US Endangered Bird Species. Biodivers. Conserv. 9 (9), 1313-1322.

Gower, J.C., 1971. A General Coefficient of Similarity and Some of its Properties. Biometrics 27 (4), 857-74.

Guisan, A., Zimmermann, N.E., 2000. Predictive Habitat Distribution Models in Ecology. Ecol. Model. 135 (2-3), 147-186.

Hammet, A.E., 2005. Rare Elements Pilot Inventory Study Summary of Findings. Unpublished document.

Hirzel, A.H., Helfer, V., Metral, F., 2001. Assessing Habitat Suitability Models With a Virtual Species. Ecol. Model. 145 (2-3), 111-121.

Hirzel, A.H., Hausser, J., Chessel, D., Perrin, N., 2002. Ecological-niche Factor Analysis: How to Compute Habitat-Suitability Maps Without Absence Data? Ecology 83 (7), 2027-2036.

Idaho Fish and Game, 2007. Idaho's Special Status Vascular Plants (A-D), accessed April 2007. Available from http://fishandgame.idaho.gov/cms/tech/CDC/plants/vascular_plants_status_a-d.cfm.

James, F.C., McCulloch, C.E., 2002. Predicting Species Presence and Abundance. In: Scott, J.M., Heglund, P.J., Morrison, M.L., Haufler, J.B., Rapheal, M.G., Wall, W.A., Sampson, F.B. (Eds.), Predicting Species Occurrence: Issues of Accuracy and Scale. Island Press, Covello, CA, p 461-466.

Luck, G.W., 2002. The Habitat Requirements of the Rufous Treecreeper (*Climacteris rufa*). 2. Validating Predictive Habitat Models. Biol. Conserv. 105 (3), 395-403.

Manel, S., Dias, J.M, Buckton, S.T., Ormerod, S.J., 1999. Alternative Methods for Predicting Species Distribution: An Illustration with Himalayan River Birds. J. Appl. Ecol. 36 (5), 734-747.

Master, L.L., Stein, B.A., Kutner, L.S., and Hammerson, G.A. 2000.Vanishing Assets: Conservation Status of US Species. In: Stein, B.A., Kutner, L.S., and Adams, J.S. (Eds). Precious Heritage: The Status of Biodiversity in the United States. Oxford University Press, New York, NY.

Monsen, S.B., Stevens, R., Shaw, N.L., 2004. Restoring Western Ranges and Wildlands. USDA Forest Service, General Technical Report RMRS-GTR-136-vol. 1.

Montana Natural Heritage Program, 2006. Plant Species of Concern. MTNHP, Helena.

National Environmental Policy Act, 1986. 40 CFR Parts 1500-1508.

National Resources Conservation Service, 2007. US General Soil Map (STATSGO). Accessed December 2007. Available from http://www.ncgc.nrcs.usda.gov/products/dataasets/statsgo.

NatureServe. 2007. NatureServe Conservation Status. Accessed September 6, 2007. Available from http://www.natureserve.org/explorer/ranking.htm.

Nix, H.A., 1982. Environmental Determinates of Biogeography and Evolution in Terra Australia. In: Baker, W.R., Greensdale, P.M.J. (Eds.), Evolution of the Flora and Fauna of Arid and Australia. Peacock Publishers, Adelaide, Australia.

Nix, H.A., 1986. A Biogeographic Analysis of Australian Elapid Snakes. In: Longmore, R. (Eds.), Australian Flora and Fauna Series Number 7. Australian Government Publishing Service, Canberra, Australia.

Phillips, S.J., Anderson, R.P, Schapire, R.E, 2006. Maximum Entropy Modeling of Species Geographic Distributions. Ecol. Model. 190 (3-4), 231-259.

Poon, E.L., Margules, C.R., 2004. Searching for New Populations of Rare Plant Species in Remote Locations. In: Thompson, W.L. (Eds.), Sampling Rare or Elusive Species: Concepts, Designs, and Techniques for Estimating Population Parameters. Island Press, Washington.

PRISM Group, Oregon State University, accessed April, 2006. Available from http://www.prismclimate.org.

Pulliam, R., 2000. On the Relationship Between Niche and Distribution. Ecol. Lett. 3 (4), 349-361.

Reddy, S., Davalos, L.M., 2003. Geographical Sampling Bias and its Implications for Conservation Priorities in Africa. J. Biogeogr. 30 (11), 1709-1727.

Rushton, S.P., Ormerod, S.J., Kerby, G., 2004. New Paradigms for Modeling Species Distributions? J. Appl. Ecol. 41 (2), 193-200.

Schemske, D.W., Husband, B.C., Ruckelshaus, M.H., Goodwillie, C., Parker I.M., Bishop, J.G., 1994. Evaluating Approaches to the Conservation of Rare Plants and Endangered Plants. Ecology 75 (3), 584-606.

Skov, F., 2000. Potential Plant Distribution Mapping Based on Climatic Similarity. Taxon 49 (3), 503-515.

Stockwell, D., Peters, D., 1999. The GARP Modeling System: Problems and Solutions to Automated Spatial Prediction. Int. J. Geogr. Inf. Sci. 13 (2), 143-158.

United States Department of Agriculture, 1982. National Forest System Land and Resource Management Planning (36 CFR 219.9), accessed December 2007. Available from http://www.fs.fed.us/emc/nfma/includes/nfmareg.html#Forest%20planning--resource.

United States Department of Agriculture, 1991. Sensitive and Endangered Species. Forest Service Manual 2672.11.

United States Department of Agriculture, 2005. National Forest System Land Management Planning 36 CFR Part 219: Final Rule. Federal Register vol.3.

United States Department of Agriculture, 2008. Natural Resources Conservation Service, Plants Database, accessed March 2008. Available from http://plants.usda.gov/index.html.

United States Department of Agriculture, Forest Service, 1988. Sensitive Plant Survey Methods. Unpublished document.

United States Department of Agriculture Forest Service, 2004. Regional Forester's Sensitive Species List. Unpublished document.

United States Department of Agriculture Forest Service Geospatial Group, 2006. VMAP Tree Dominance Type, accessed April 2006. Available from http://www.fs.fed.us/r1/gis/thematic_data/vmap_treedominancetype_wr1_v06.htm.

United States Department of Agriculture Forest Service Geospatial Group, 2007. 30-meter Digital Elevation Model. Unpublished data.

United States Fish and Wildlife Service, 1988. Endangered Species Act of 1973 as amended through the 100th Congress. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C., USA.

Vaughan I.P, Ormerod, S.J., 2003. Improving the Quality of Distribution Models for Conservation by Addressing Shortcomings in the Field Collection of Training Data. Conserv. Biol. 17 (6), 1601-1611.

Vogiatzakis, I., 2003. GIS-Based Modeling and Ecology: A Review of Tools and Methods. Geographical Paper No. 170.

Wildlife Spatial Analysis Lab-The Univerisity of Montana, 2002. Vegetation (SILC 2 and 3-Covertype) for eastern Montana, accessed April 2006. Available from http://www.fs.fed.us/r1/gis/thematic_data/vegetation_silc_2_3_covertype_e_mt.htm.

Wiser, S.K., Peet, R.K., White, P.S., 1998. Prediction of Rare-Plant Occurrence: A Southern Appalachian Example. Ecol. Appl. 8 (4), 909-920.

Wu B.X., Smeins, F.E., 2000. Multiple-Scale Habitat Modeling Approach for Rare Plant Conservation. Landscape and Urban Plan. 51 (1), 11-28.

Zaniewski, A.E., Lehman, A., Overton, J., 2002 Predicting Species Spatial Distributions Using Presence-Only Data: A Case Study of Native New Zealand Fern. Ecol. Model. 157 (2-3), 261-280.

Table 1. Brief description of physiographic, vegetative, and climatic characteristics for each forest located within the study area. Descriptions are based upon Bailey's (1993) ecological sections and species scientific nomenclature follows the USDA Plants Database listings (USDA, 2008).

	Beaverhead-Deerlodge NF	**Bitterroot NF**	**Nez Perce NF**
Physiography	High, steep mountains, glacial and fluvial valleys, and alluvial terraces and flood plains. Elevation ranges from 2,500 to 6,500 ft (763 to 1,983 m) in valleys to 4,000 to 10,000 ft (1,220 to 3,000 m) in the mountains.	High glaciated mountains with alpine ridges and lacustrine basins at lower elevations. Elevation ranges from 2,500 to 6,000 feet (763 to 2,440 m) in basins to 3,000 to 10,000 ft (915 to 3,000 m) in the mountains.	Large U-shaped valleys extending to mountains with alpine ridges and cirques. Elevation ranges from 3,000 to 10,000 ft (900 to 3,000 m).
Vegetation	Sagebrush steppe with small areas of alpine vegetation above 9,500 ft (2,880 m), and Douglas fir forest in elevations 1,000 to 1,500 ft (300 to 450 m). Typical steppe species include big sagebrush (*Artemisia tridentate* Nutt.), fescues, wheatgrass (*Agropyron* Gaertn.), and needlegrass (*Achnatherum* P. Beauv.). Douglas fir, limber pine (*Pinus flexilis* James), and lodgepole pine are common tree species.	Douglas fir, western larch (*Larix occidentalis* Nutt.), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), and ponderosa pine. Lower valleys are dominated by bluebunch wheatgrss (*Pseudoroegneria spicata* (Pursh) A. Löve), Idaho fescue (*Festuca idahoensis* Elmer), and rough fescue (*Festuca campestris* Rydb).	Common tree species include grand fir (*Abies grandis* (Douglas ex D. Don) Lindl.), Douglas fir, Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), and ponderosa pine.
Climate	Precipitation ranges from 10 to 15 in (250 to 1,270 mm). Winters are cold, and growing season conditions are dry. Soil moisture is not sufficient for tree growth on some south and west aspects below timberline; hence, grasslands often extend from the valley to mountain tops. Climate is cold dry continental. Temperature averages 36 to 46°F (2 to 8°C).	Precipitation ranges from 14 to 80 in (360 to 2,030 mm). Climate is cool temperate with some maritime influence. Temperature averages 36 to 46°F (2 to 8°C).	Precipitation ranges from 20 to 80 in (510 to 2,030 mm). Maritime-influenced, cool temperatures ranging from 35 to 46°F (2 to 7°C) with dry summers.

Table 2. Species used for habitat prediction, including the state status, the global and state rank, and number of occurrences used as input. Species scientific nomenclature follows the USDA Plants Database listings (USDA, 2008), common names follow state natural heritage lists (MNHP, 2006; IFG, 2007). Species designated with two ranks are assessed as agreeing with both ranking classifications.

Species	State Listed	Global Rank	State Rank	Number of Occurrences
Broad-fruit mariposa (*Calochortus nitidus* Dougl.)	ID	G3	S3	261
Tapered-root orogenia (*Orogenia fusiformis* S. Wats.)	MT	G5	S2	69
Clustered lady's slipper (*Cypripedium fasciculatum* Kellogg ex S. Wats.)	ID/MT	G4	S3/S2	81
Constance's bittercress (*Cardamine constancei* Detling)	ID	G3	S3	74
Coville Indian paintbrush (*Castilleja covilleana* Henderson)	MT	G3G4	S2	86
Evergreen kittentail (*Synthyris platycarpa* Gail & Pennell)	ID	G3	S3	83
Hall's rush (*Juncus hallii* Engelm.)	MT	G4G5	S2	24
Hollyleaf clover (*Trifolium gymnocarpon* Nutt.)	MT	G5	S2	47
Howell's gumweed (*Grindelia howellii* Steyermark)	MT	G3	S2S3	100
Idaho Douglasia (*Douglasia idahoensis* D. Henderson)	ID	G2	S2	20
Idaho strawberry (*Waldsteinia idahoensis* Piper)	ID	G3	S3	45
Jove's buttercup (*Ranunculus jovis* A. Nels.)	MT	G4	S2	27
Lemhi beardtongue (*Penstemon lemhiensis* (Keck) Keck & Cronq.)	MT	G3	S3	153
Missoula phlox (*Phlox kelseyi* var. *missoulensis* Wherry)	MT	G2	S2	25
Northern rattlesnake-plantain (*Goodyera repens* (L.) R. Br. Ex Ait. F.)	MT	G5	S2S3	133
Pacific dogwood (*Cornus nuttallii* Audubon ex Torr. & Grey)	ID	G5	S1	99
Payson's milkvetch (*Astragalus paysonii* (Rydb.) Barneby)	ID	G3	S3	190
Puzzling halimolobos (*Halimolobos perplexa* (Henerson) Rollins var. *perplexa*)	ID	G4	S3	42
Sapphire rockcress (*Arabis fecunda* Rollins)	MT	G2	S2	43
Short-styled columbine (*Aquilegia brevistyla* Hook.)	MT	G5	S2	47
Small onion (*Allium parvum* Kellogg)	MT	G5	S2S3	102

Table 3. List of the major geologic parent materials attributed in the Region One Land-type Association layer.

Land-type Association- Geologic Parent Material
Alluvium
Alluvium, deltaic sediments
Gneiss, schist
Granitics
Granitics, highly weathered
Granitics, weakly weathered
Loess
Mixed geology
Metasediments
Metasediments, glacial till
Quartzite, calc-silicates
Carbonates
Shale, siltstone, sandstone
Soft sedimentary
Sandstone, shale
Tertiary sediments
Volcanics
Wind deposited sediments

Table 4. Reclassification table for VMAP and SILC3 vegetation cover grids. The grids were reclassified to obtain a consistent vegetation layer for the study area. Species scientific nomenclature follows the USDA Plants Database listings (USDA, 2008).

VMAP	**SILC3**	*Reclassification*
Grass/forb dominated	Very low cover grassland	Grassland
	Low/moderate cover grassland	
	Moderate/high cover grassland	
Shrub dominated	Mesic shrub	Mesic shrub
	Sagebrush/xeric shrublands	Xeric shrub
	Aspen (*Populus tremuloides* Michx.)	Broadleaf forest
	Mixed broadleaf/ cottonwood forest	
Ponderosa pine	Ponderosa pine	Ponderosa pine
Douglas fir	Douglas fir	Douglas fir
Western larch	Western larch	Western larch
Lodgepole pine	Lodgepole pine	Lodgepole pine
Subalpine fir	Subalpine fir/spruce	Subalpine fir/ Engelmann spruce
Engelmann spruce		
Western red cedar		Western red cedar
Mountain hemlock (*Tsuga mertensiana* (Bong.) Carriére)	Whitebark pine (*Pinus albicaulis* Engelm.)	Whitebark pine/ mountain hemlock
Shade-intolerant mixed conifer	Mixed xeric conifer forest	Shade-intolerant mixed conifer
Shade-tolerant mixed conifer (subalpine fir, Engelmann spruce, mountain hemlock)	Mixed upper subalpine conifer forest	Shade-tolerant mixed conifer (subalpine fir, Engelmann spruce, mountain hemlock)
Shade-tolerant mixed conifer (grand fir, western red cedar)	Mixed lower subalpine conifer forest	Shade-tolerant mixed conifer (grand fir, western red cedar)
	Rocky mountain juniper (*Juniperus scopulorum* Sarg.)	Rocky mountain juniper/limber pine
	Limber pine	
	Douglas fir/lodgepole pine	Douglas fir/lodgepole pine
	Douglas fir/ponderosa pine	Douglas fir/ponderosa pine
	Burned area	Burned area
	Water	Water
	Rock	Rock
	Mines/quarries	Non-vegetated
	Urban or developed lands	
	Agriculture-dry	
	Agriculture-irrigated	
	Snow	
	Cloud	
	Cloud shadow	

Table 5. Species surveyed within each National Forest.

Beaverhead-Deerlodge NF	Bitterroot NF	Nez Perce NF
Tapered-root orogenia	Tapered-root orogenia	Broad-fruit mariposa
Coville Indian paintbrush	Coville Indian paintbrush	Tapered-root orogenia
Hall’s rush	Hall’s rush	Clustered lady’s slipper
Hollyleaf clover	Hollyleaf clover	Constance’s bittercress
Jove’s buttercup	Howell’s gumweed	Coville Indian paintbrush
Lemhi beardtongue	Lemhi beardtongue	Evergreen kittentail
Missoula phlox	Northern rattlesnake- plantain	Idaho Douglasia
Sapphire rockcress	Short-styled columbine	Idaho strawberry
	Small onion	Pacific dogwood
		Payson’s milkvetch
		Puzzling halimolobos

Table 6. Macrohabitat types of Region One (USDAFS Geospatial Group, 2006).

Macrohabitat Types	
Grand fir	Lodgepole pine
Subalpine fir	Ponderosa pine
Grassland/shrub dominated	Douglas fir
Western larch	Western red cedar
Engelmann spruce	Mountain hemlock

Table 7. The number of new element occurrences located through field surveys, known occurrence accuracy (percentage of known EO that fell within predicted habitat), and amount of predicted habitat in both ‘likely’ and ‘most likely’ thresholds by Forest.

Species	**New Occurrences**	**Known Occurrence Accuracy**	**Acreage (Hectares) of Potential Predicted Habitat**	
			Nez Perce NF	***Bitterroot NF***
Broad-fruit mariposa	2	95%	304,173 (123,094)	13,068 (5,288)
Tapered-root orogenia	5	84%	67,624 (27,366)	258,823 (104,741)
Clustered lady’s slipper	2	88%	542,224 (219,430)	24,767 (10,022)
Constance’s bittercress	0	100%	552,866 (223,736)	13,425 (5,432)
Coville Indian paintbrush	11	67%	75,823 (30,684)	225,597 (91,295)
Evergreen kittentail	4	83%	586,778 (237,460)	17,978 (7,275)
Hall’s rush	0	83%	4,964 (2,008)	52,690 (21,322)
Hollyleaf clover	0	83%	5,539 (2,241)	63,393 (25,654)
Howell’s gumweed	0	90%	2,145 (868)	62,776 (25,404)
Idaho Douglasia	16	95%	179,061 (72,463)	237,956 (96,297)
Idaho strawberry	1	98%	531,617 (215,137)	41,361 (16,738)
Jove’s buttercup	Not surveyed	96%	557 (225)	7,279 (2,945)
Lemhi beardtongue	1	43%	3,391 (1,372)	71,542 (28,952)
Missoula phlox	Not surveyed	52%	1,478 (598)	15,954 (6,456)
Northern rattlesnake-plantain	Not surveyed	89%	11,287 (4,567)	82,700 (33,467)
Pacific dogwood	1	100%	552,866 (223,736)	13,425 (5,432)
Payson’s milkvetch	0	92%	596,401 (241,354)	12,520 (5,066)
Puzzling halimolobos	0	83%	385,235 (155,899)	130,160 (52,673)
Sapphire rockcress	Not surveyed	76%	196 (79)	24,486 (9,909)
Short-styled columbine	Not surveyed	100%	100 (40)	108,749 (44,009)
Small onion	1	74%	26,950 (10,906)	231,776 (93,796)

Table 8. Results from field verification of predicted habitat for broad-fruit mariposa. Table shows the number of pixels as assessed by the botanist.

		Predicted Habitat			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Habitat	Suitable	38	2	0	40
	Unsuitable	9	4	0	13
	Total	53		0	53

Habitat Prediction Accuracy = 40/53 = 75.5%

Error of Commission	Error of Omission
Suitable = (13/53) = 25%	Suitable = (0/40) = 0%
Unsuitable = (0/0) = 0%	Unsuitable = (0/13) = 0%

Table 9. The table presents predicted occurrence vs. found occurrence for broad-fruit mariposa.

		Predicted Occurrence			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Occurrence	Suitable	18	0	0	18
	Unsuitable	0	0	0	10
	Total	18		0	18

New occurrence accuracy = 18/18 = 100%

Error of Commission	Error of Omission
Suitable = (18/18) = 0%	Suitable = (18/18) = 0%
Unsuitable = (0/0) = 0%	Unsuitable = (0/0) = 0%

Table 10. Results from field verification of predicted habitat for clustered lady's slipper. Table shows the number of pixels as assessed by the botanist.

		Predicted Habitat			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Habitat	Suitable	156	53	27	236
	Unsuitable	9	0	0	9
	Total	218		27	245

Habitat Prediction Accuracy = 209/245 = 85%

Error of Commission	Error of Omission
Suitable = (9/218) = 4%	Suitable = (27/236) = 11%
Unsuitable = (0/27) = 0%	Unsuitable = (9/9) = 100%

Table 11. The table presents predicted occurrence vs. found occurrence for clustered lady's slipper.

		Predicted Occurrence			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Occurrence	Suitable	2	1	0	3
	Unsuitable	0	0	0	0
	Total	3		0	3

New occurrence accuracy = 3/3 = 100%

Error of Commission	Error of Omission
Suitable = (0/3) = 0%	Suitable = (0/3) = 0%
Unsuitable = (0/0) = 0%	Unsuitable = (0/0) = 100%

Table 12. Results from field verification of predicted habitat for Constance's bittercress. Table shows the number of pixels as assessed by the botanist.

		Predicted Habitat			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Habitat	Suitable	114	76	12	202
	Unsuitable	27	59	5	91
	Total	276		17	293

Habitat Prediction Accuracy = 195/293 = 67%

Error of Commission	Error of Omission
Suitable = (86/276) = 31%	Suitable = (12/202) = 6%
Unsuitable = (12/17) = 71%	Unsuitable = (86/91) = 95%

Table 13. Results from field verification of predictive habitat for Coville Indian paintbrush. Table shows the number of pixels as assessed by the botanist.

		Predicted Habitat			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Habitat	Suitable	89	44	158	291
	Unsuitable	100	30	50	180
	Total	263		208	471

Habitat Prediction Accuracy = 183/471 = 39%

Error of Commission	Error of Omission
Suitable = (130/263) = 49%	Suitable = (158/291) = 54%
Unsuitable = (158/208) = 76%	Unsuitable = (130/180) = 72%

Table 14. The table presents predicted occurrence vs. found occurrence for Coville Indian paintbrush.

		Predicted Occurrence			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Occurrence	Suitable	6	2	33	41
	Unsuitable	0	0	0	0
	Total	8		33	41

New occurrence accuracy = 8/41 = 20%

Error of Commission	Error of Omission
Suitable = (0/8) = 0%	Suitable = (33/41) = 80%
Unsuitable = (33/33) = 100%	Unsuitable = (0/0) = 0

Table 15. Results from field verification of predictive habitat for evergreen kittentail. Table shows the number of pixels as assessed by the botanist.

		Predicted Habitat			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Habitat	Suitable	33	9	0	42
	Unsuitable	63	40	22	125
	Total	145		22	167

Habitat Prediction Accuracy = 64/167 = 38%

Error of Commission	Error of Omission
Suitable = (103/145) = 71%	Suitable = (0/42) = 0%
Unsuitable = (0/22) = 0%	Unsuitable = (103/125) = 82%

Table 16. The table presents predicted occurrence vs. found occurrence for evergreen kittentail.

		Predicted Occurrence			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Occurrence	Suitable	8	6	0	14
	Unsuitable	0	0	0	0
	Total	14		0	14

New occurrence accuracy = 14/14 = 100%

Error of Commission	Error of Omission
Suitable = (0/14) = 0%	Suitable = (0/14) = 0%
Unsuitable = (0/0) = 0%	Unsuitable = (0/0) = 0%

Table 17. Results from field verification of predicted output for Hall’s rush. Table shows the number of pixels as assessed by the botanist.

		Predicted Habitat			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Habitat	Suitable	9	13	40	62
	Unsuitable	59	49	277	385
	Total	130		317	447

Habitat Prediction Accuracy = 299/447 = 67%

Error of Commission	Error of Omission
Suitable = (108/130) = 83%	Suitable = (40/62) = 65%
Unsuitable = (40/317) = 13%	Unsuitable = (108/385) = 28%

Table 18. Results from field verification of predictive habitat for hollyleaf clover. Table shows the number of pixels as assessed by the botanist.

		Predicted Habitat			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Habitat	Suitable	45	48	255	348
	Unsuitable	0	0	0	0
	Total	93		255	348

Habitat Prediction Accuracy = 93/348 = 27%

Error of Commission	Error of Omission
Suitable = (0/93) = 0%	Suitable = (255/348) = 73%
Unsuitable = (255/255) = 100%	Unsuitable = (0/0) = 0%

Table 19. Results from field verification of predicted habitat for Howell’s gumweed. Table shows the number of pixels as assessed by the botanist.

		Predicted Habitat			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Habitat	Suitable	300	78	116	494
	Unsuitable	0	0	9	9
	Total	378		125	503

Habitat Prediction Accuracy = 387/503 = 77%

Error of Commission	Error of Omission
Suitable = (0/378) = 0%	Suitable = (116/494) = 23%
Unsuitable = (116/125) = 93%	Unsuitable = (0/9) = 0%

Table 20. Results from field verification of predicted habitat for Idaho Douglasia. Table shows the number of pixels as assessed by the botanist.

		Predicted Habitat			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Habitat	Suitable	292	39	124	455
	Unsuitable	99	9	15	123
	Total	439		139	578

Habitat Prediction Accuracy = 346/578 = 60%

Error of Commission	Error of Omission
Suitable = (108/439) = 25%	Suitable = (124/455) = 27%
Unsuitable = (124/139) = 89%	Unsuitable = (108/123) = 88%

Table 21. The table presents predicted occurrence vs. found occurrence for Idaho Douglasia.

		Predicted Occurrence			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Occurrence	Suitable	58	9	32	99
	Unsuitable	0	0	0	0
	Total	67		32	99

New occurrence accuracy = 67/99 = 68%

Error of Commission	Error of Omission
Suitable = (0/67) = 0%	Suitable = (32/99) = 32%
Unsuitable = (32/32) = 100%	Unsuitable = (0/0) = 0%

Table 22. Results from field verification of predictive habitat for Idaho strawberry. Table shows the number of pixels as assessed by the botanist.

		Predicted Habitat			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Habitat	Suitable	101	53	14	168
	Unsuitable	143	53	15	211
	Total	350		29	379

Habitat Prediction Accuracy = 169/379 = 45%

Error of Commission	Error of Omission
Suitable = (196/350) = 56%	Suitable = (14/168) = 8%
Unsuitable = (14/29) = 48%	Unsuitable = (196/211) = 93%

Table 23. The table presents predicted occurrence vs. found occurrence for Idaho strawberry.

		Predicted Occurrence			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Occurrence	Suitable	3	0	0	3
	Unsuitable	0	0	0	0
	Total	3		0	3

New occurrence accuracy = 3/3 = 100%

Error of Commission	Error of Omission
Suitable = (0/3) = 0%	Suitable = (0/3) = 0%
Unsuitable = (0/0) = 0%	Unsuitable = (0/0) = 0%

Table 24. Results from field verification of predictive habitat for Lemhi beardtongue. Table shows the number of pixels as assessed by the botanist.

		Predicted Habitat			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Habitat	Suitable	72	19	272	363
	Unsuitable	0	0	0	0
	Total	91		272	363

Habitat Prediction Accuracy = 91/363 = 25%

Error of Commission	Error of Omission
Suitable = (0/91) = 0%	Suitable = (272/363) = 75%
Unsuitable = (272/272) = 100%	Unsuitable = (0/0) = 0%

Table 25. The table presents predicted occurrence vs. found occurrence for Lemhi beardtongue.

		Predicted Occurrence			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Occurrence	Suitable	0	0	2	2
	Unsuitable	0	0	0	0
	Total	0		2	2

Predicted Occurrence Accuracy = 0/2 = 0%

Error of Commission	Error of Omission
Suitable = (0/0) = 0%	Suitable = (2/2) = 100%
Unsuitable = (2/2) = 100%	Unsuitable = (0/0) = 0%

Table 26. Results from field verification of predicted output for Pacific dogwood. Table shows the number of pixels as assessed by the botanist.

		Predicted Habitat			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Habitat	Suitable	101	132	17	250
	Unsuitable	4	3	0	7
	Total	240		17	257

Habitat Prediction Accuracy = 233/257 = 91%

Error of Commission	Error of Omission
Suitable = (7/240) = 3%	Suitable = (17/250) = 7%
Unsuitable = (17/17) = 100%	Unsuitable = (7/7) = 100%

Table 27. The table presents predicted occurrence vs. found occurrence for Pacific dogwood.

		Predicted Occurrence			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Occurrence	Suitable	1	0	0	1
	Unsuitable	0	0	0	0
	Total	1		0	1

New occurrence accuracy = 1/1 = 100%

Error of Commission	Error of Omission
Suitable = (0/1) = 0%	Suitable = (0/1) = 0%
Unsuitable = (0/0) = 0%	Unsuitable = (0/0) = 0%

Table 28. Results from field verification of predictive habitat for Payson's milkvetch. Table shows the number of pixels as assessed by the botanist.

		Predicted Habitat			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Habitat	Suitable	114	64	9	187
	Unsuitable	147	41	0	188
	Total	366		9	375

Overall = 178/375 = 47%

Error of Commission	Error of Omission
Suitable = (188/366) = 51%	Suitable = (9/187) = 5%
Unsuitable = (9/9) = 100%	Unsuitable = (188/188) = 100%

Table 29. Results from field verification of predictive habitat for puzzling halimolobos. Table shows the number of pixels as assessed by the botanist.

		Predicted Habitat			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Habitat	Suitable	0	0	0	0
	Unsuitable	81	46	49	176
	Total	127		49	176

Habitat Prediction Accuracy = 49/176 = 28%

Error of Commission
Suitable = (127/127) = 100%
Unsuitable = (0/49) = 0%

Error of Omission
Suitable = (0/0) = 0%
Unsuitable = (127/176) = 72%

Table 30. Results from field verification of predictive habitat for small onion. Table shows the number of pixels as assessed by the botanist.

		Predicted Habitat			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Habitat	Suitable	135	50	137	322
	Unsuitable	16	1	17	28
	Total	202		148	350

Habitat Prediction Accuracy = 209/245 = 85%

Error of Commission
Suitable = (17/202) = 8%
Unsuitable = (137/148) = 93%

Error of Omission
Suitable = (137/322) = 43%
Unsuitable = (17/28) = 61%

Table 31. The table presents predicted occurrence vs. found occurrence for small onion.

		Predicted Occurrence			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Occurrence	Suitable	1	0	0	1
	Unsuitable	0	0	0	0
	Total	0		0	1

New occurrence accuracy = 1/1 = 100%

Error of Commission
Suitable = (0/0) = 0%
Unsuitable = (0/0) = 0%

Error of Omission
Suitable = (0/1) = 0%
Unsuitable = (0/0) = 100%

Table 32. Results from field verification of predicted habitat for tapered-root orogenia. Table shows the number of pixels as assessed by the botanist.

		Predicted Habitat			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Habitat	Suitable	154	33	139	326
	Unsuitable	98	21	52	171
	Total	306		191	497

Habitat Prediction Accuracy = 239/497 = 48%

Error of Commission	Error of Omission
Suitable = (119/306) = 39%	Suitable = (139/326) = 43%
Unsuitable = (139/191) = 73%	Unsuitable = (119/171) = 70%

Table 33. The table presents predicted occurrence vs. found occurrence for tapered-root orogenia.

		Predicted Occurrence			
		Suitable		Unsuitable	Total
		97.5%	95%		
Found Occurrence	Suitable	4	0	4	8
	Unsuitable	0	0	0	0
	Total	4		4	8

New occurrence accuracy = 4/8 = 50%

Error of Commission	Error of Omission
Suitable = (0/4) = 0%	Suitable = (4/8) = 50%
Unsuitable = (0/0) = 0%	Unsuitable = (0/0) = 0%

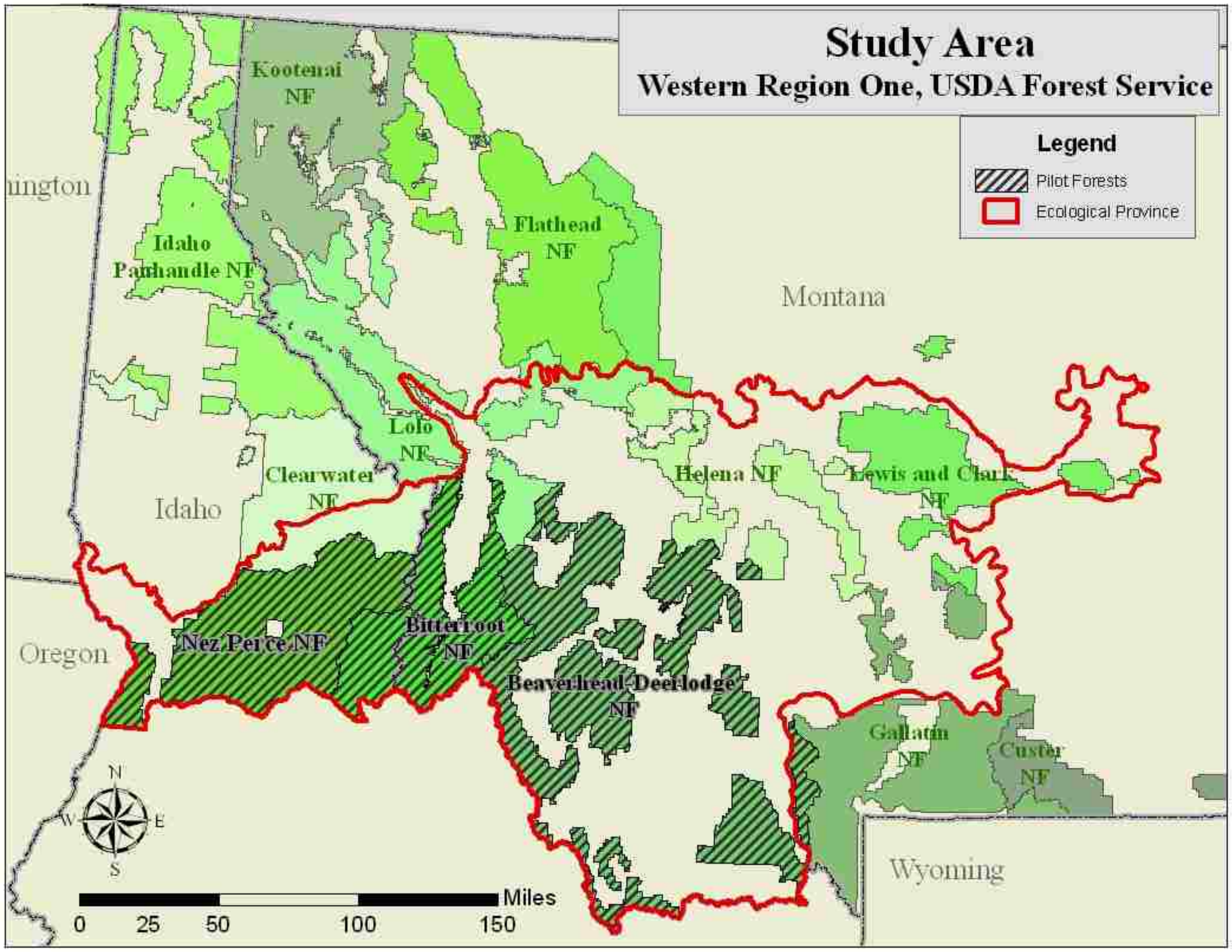

Figure 1. The study area occurs in the western half of Region One in Montana and Idaho and includes three of the twelve NF: Beaverhead-Deerlodge, Bitterroot, and Nez Perce (shown in black hatch). The red polygon represents a portion of the Middle Rocky Mountain Steppe-Coniferous Forest-Alpine Meadow Ecological Province.

```
00000000:    fa  ca  00  00  38  00  00  00  cc  36  00  00  6c  1f  00  00
00000010:    a4  70  3d  0a  d7  c3  5b  c0  1f  85  eb  51  b8  7e  44 40
00000020:    fc  a9  f1  d2  4d  62  40  3f  fc  a9  f1  d2  4d  62  40  3f
00000030:    00  3c  1c  c6  04  00  00  00  00  3c  1c  c6  00  3c  1c  c6
```

Figure 2. Original header for DOMAIN grid file when opened within a Hex Editor. Flag variable (byte 00000034) is automatically set to 4.

```
dem.grd
00000000:    fa  ca  00  00  38  00  00  00  cc  36  00  00  6c  1f  00  00
00000010:    a4  70  3d  0a  d7  c3  5b  c0  1f  85  eb  51  b8  7e  44 40
00000020:    fc  a9  f1  d2  4d  62  40  3f  fc  a9  f1  d2  4d  62  40  3f
00000030:    00  3c  1c  c6  00  00  00  00  00  3c  1c  c6  00  3c  1c  c6
```

```
landtype.grd
00000000:    fa  ca  00  00  38  00  00  00  cc  36  00  00  6c  1f  00  00
00000010:    a4  70  3d  0a  d7  c3  5b  c0  1f  85  eb  51  b8  7e  44 40
00000020:    fc  a9  f1  d2  4d  62  40  3f  fc  a9  f1  d2  4d  62  40  3f
00000030:    00  3c  1c  c6  02  00  00  00  00  3c  1c  c6  00  3c  1c  c6
```

Figure 3. Using a Hex Editor the flag variables were set to the proper values, continuous data the flag is set to 0, and categorical data the flag is set to 2.

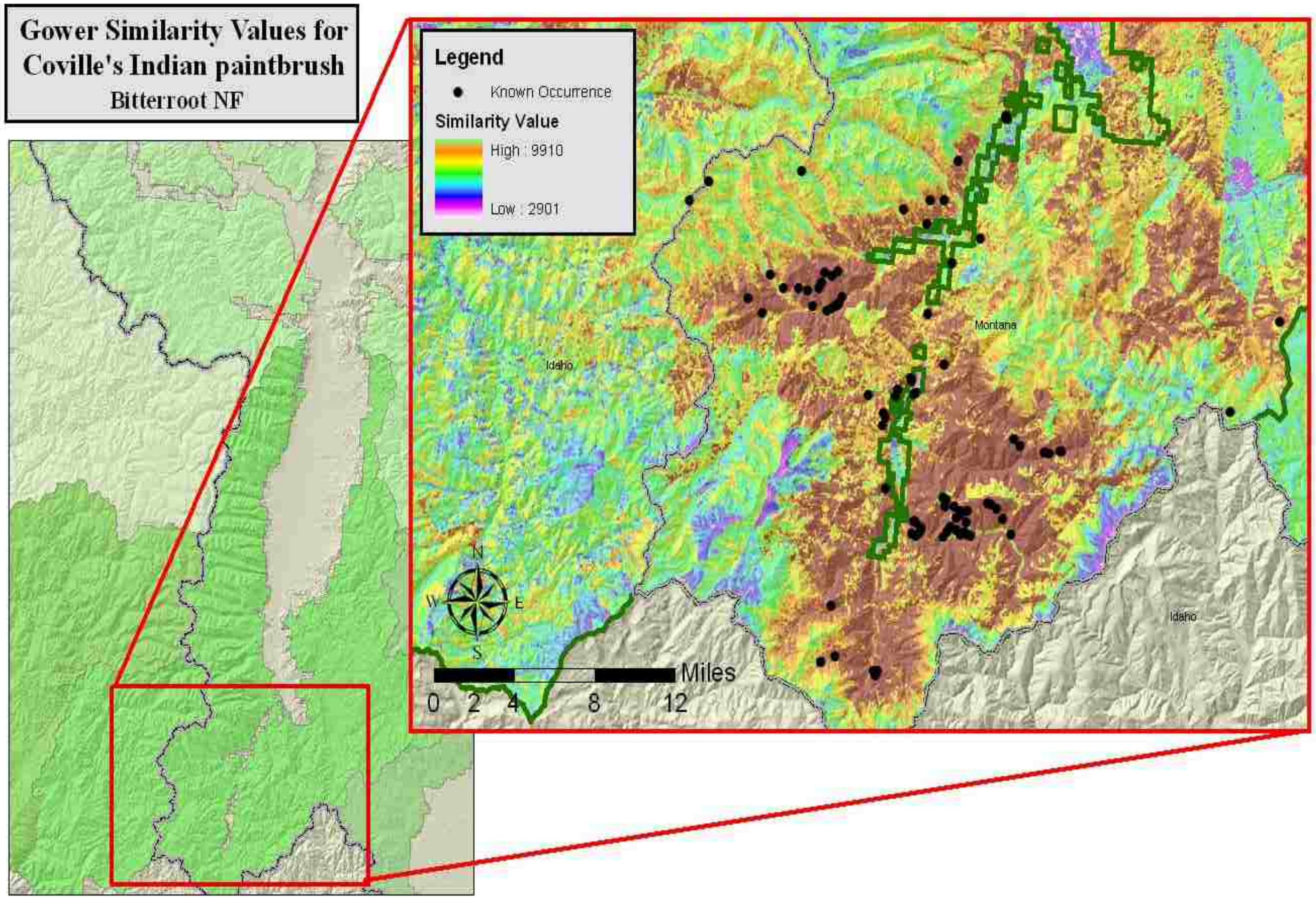

Figure 4. Computed Gower similarity values for Coville Indian paintbrush. Areas displayed in red have the highest similarity to known locations, while areas in blue have the lowest similarity values. Known locations are shown in black.

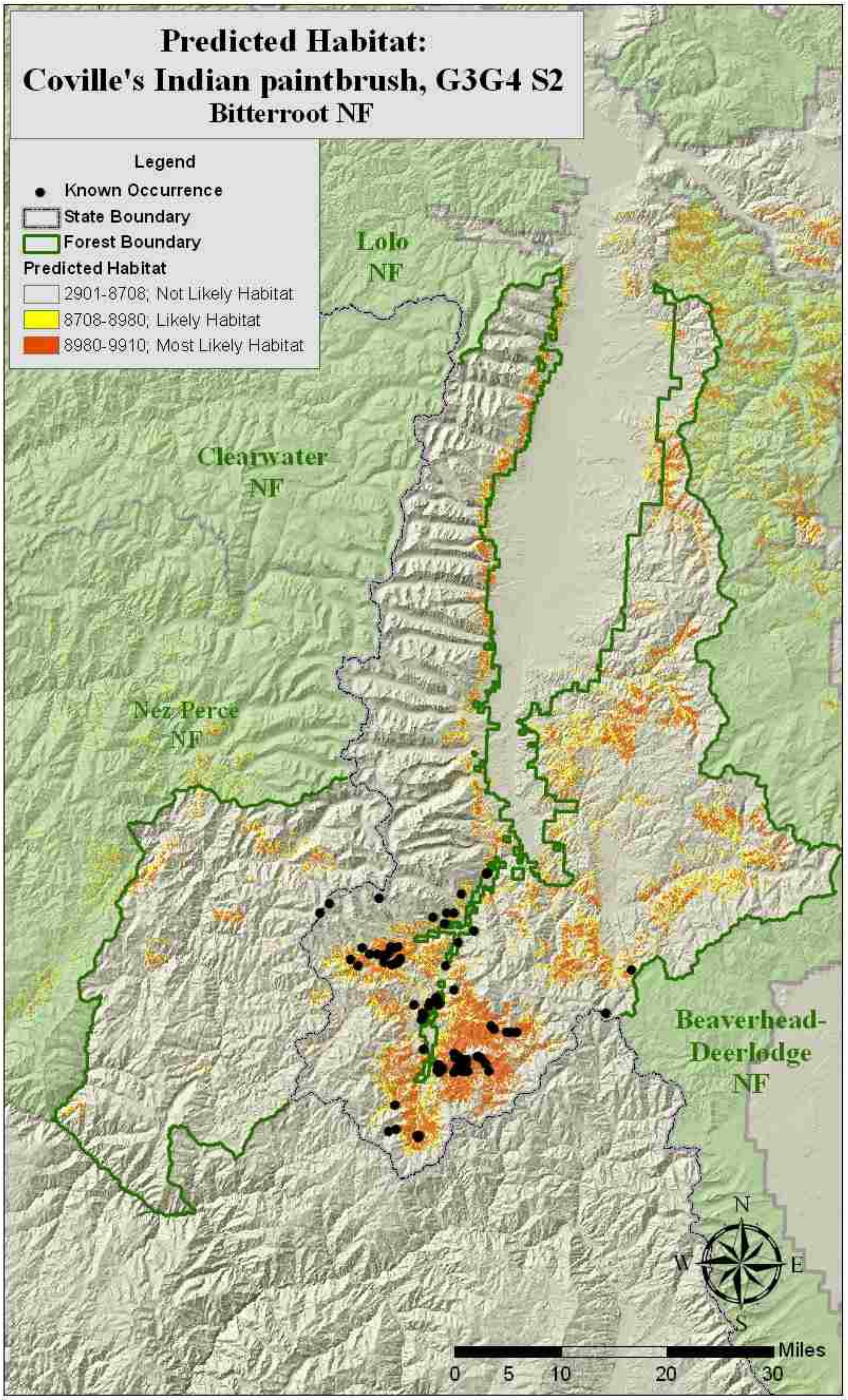

Figure 5. Map of predicted habitat in the Bitterroot National Forest for Coville Indian paintbrush.

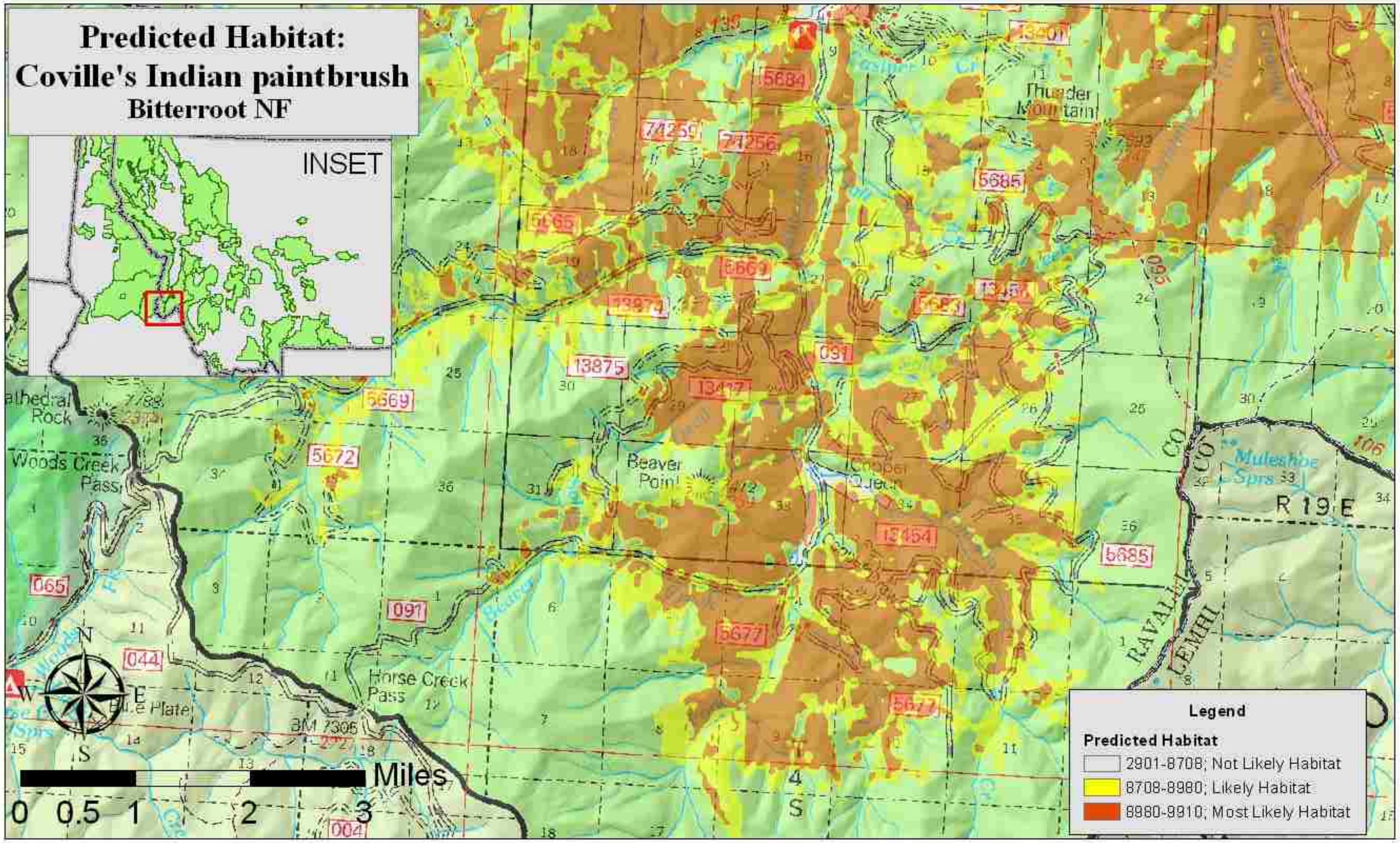

Figure 6. Potential habitat for Coville Indian paintbrush overlaid on the standard Forest Visitor Map, showing travel routes and ownership for easy field navigation.

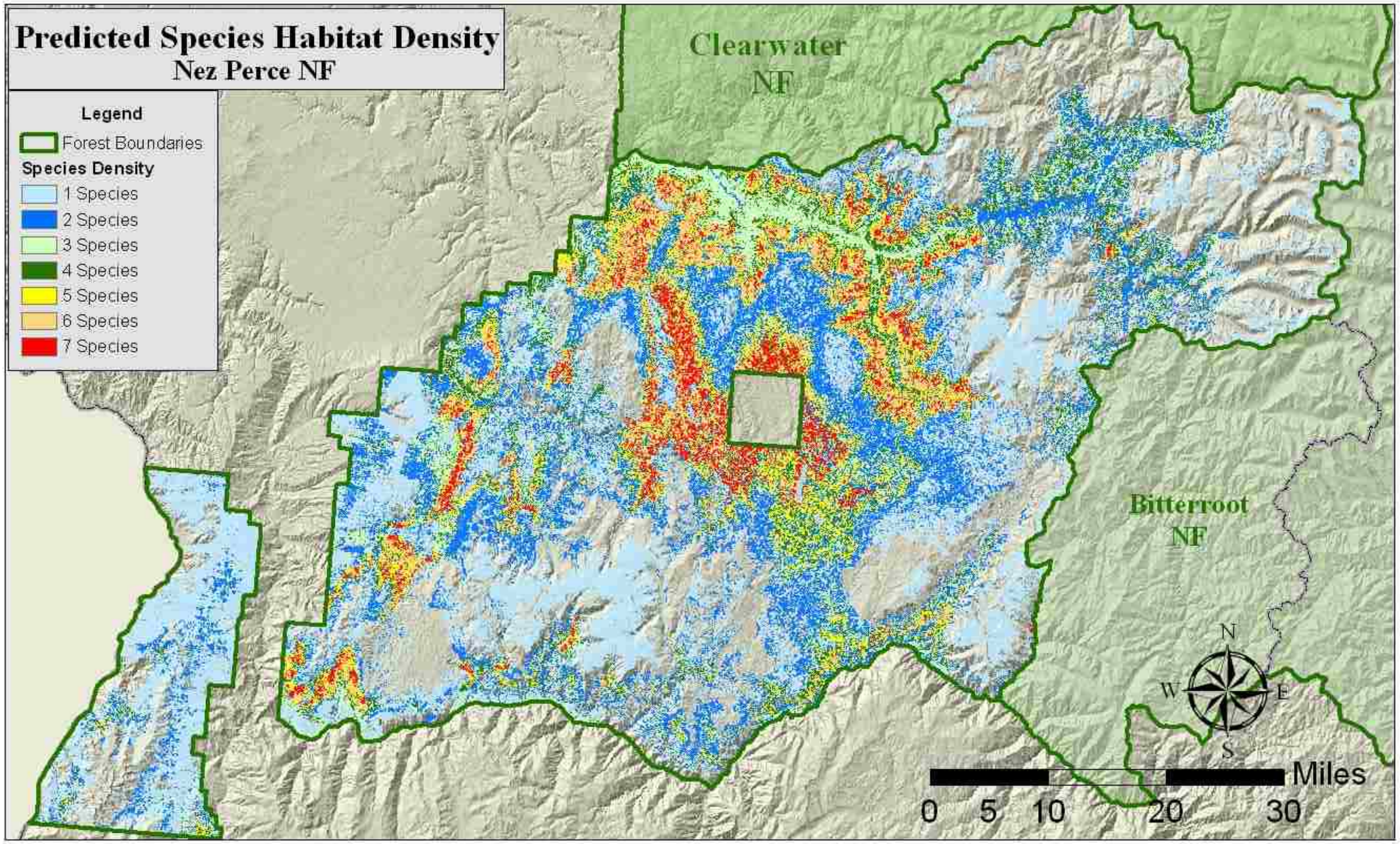

Figure 7. Rare species predicted habitat density on the Nez Perce NF. Map was created to direct botanist into areas where multiple species had predicted habitat.

Predictive Model Field Site Form

Date:

National Forest:

Surveyor (s):

Target rare plant species:

Location data (GPS coordinates):

Presence/Absence data:

Was habitat present for any target species? If yes, briefly describe the habitat.

Were any rare plant populations located? If yes, which species?

Biophysical features of survey area:

Briefly describe primary habitat (dominant/co-dominant species):

Presence of microsites as inclusions within the primary habitat?
(Please circle any that are present)

riparian swales, riparian seeps, rock outcrops, canyon walls, footslopes, disturbed sites, bare soil sites, recently burned areas, roadside habitat

Other microsites (please list):

Figure 8. Predictive model site evaluation form used during field verification of model predictions.

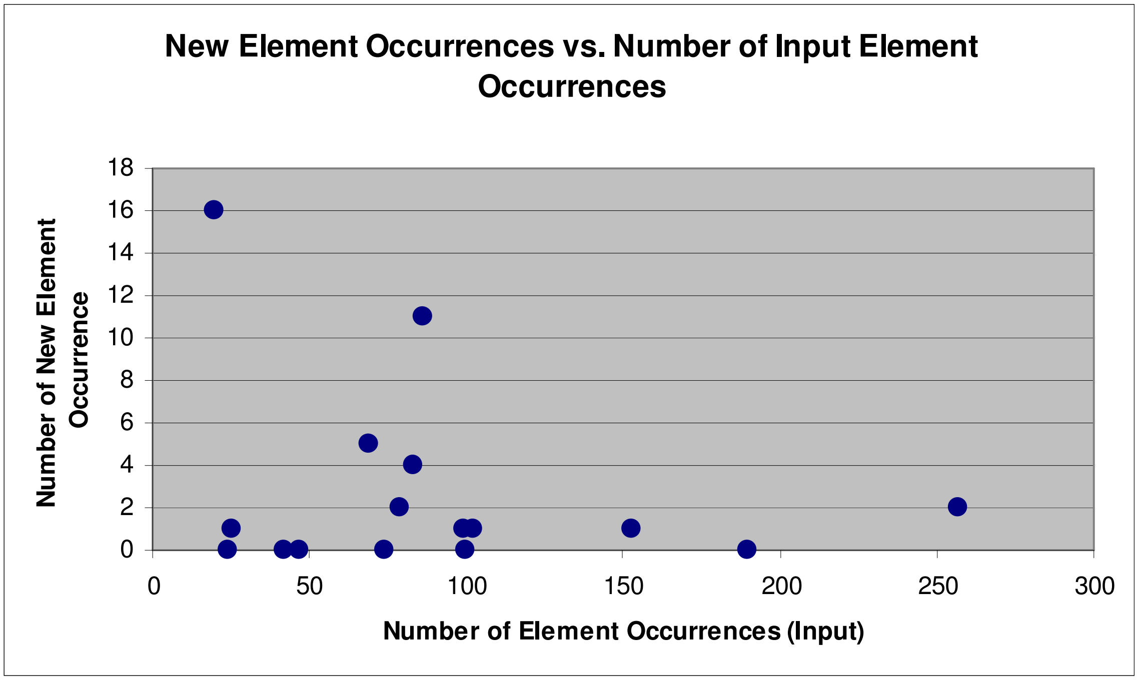

Figure 9. Number of new element occurrence vs. the number of element occurrences used as input into the model.