Habitat Characteristics of Mexican Spotted Owls (Strix occidentalis lucida) in the Canyonlands of Southern Utah

Leah R. Lewis
Utah State University

Follow this and additional works at: https://digitalcommons.usu.edu/etd
Part of the Ecology and Evolutionary Biology Commons

Recommended Citation
Lewis, Leah R., "Habitat Characteristics of Mexican Spotted Owls (Strix occidentalis lucida) in the Canyonlands of Southern Utah" (2014). All Graduate Theses and Dissertations. 3335.
https://digitalcommons.usu.edu/etd/3335

This Thesis is brought to you for free and open access by the Graduate Studies at DigitalCommons@USU. It has been accepted for inclusion in All Graduate Theses and Dissertations by an authorized administrator of DigitalCommons@USU. For more information, please contact digitalcommons@usu.edu.
HABITAT CHARACTERISTICS OF MEXICAN SPOTTED OWLS (*STRIX OCCIDENTALIS LUCIDA*) IN THE CANYONLANDS OF SOUTHERN UTAH

by

Leah R. Lewis

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Ecology

Approved:

_____________________________  ______________________________
Eugene Schupp  Frank Howe
Major Professor  Committee Member

_____________________________  ______________________________
David Koons  Mark McLellan
Committee Member  Vice President for Research and Dean of the School of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

2014
I studied the habitat characteristics of Mexican Spotted Owls (*Strix occidentalis lucida*), a federally threatened species, in the canyonlands region of southern Utah. Vegetative and geologic features were measured within 10m wide belt plots at each current or historic nest/roost site. Based on our findings, past research, and species life history characteristics, I constructed a species distribution model (SDM) predicting Mexican Spotted Owl distribution in Utah for the Colorado Plateau region. The SDM was generated using the following inputs as important habitat variables: elevation, aspect, surface ratio, curvature, slope, geology, and vegetation. Program R was used for model development and generation. The SDM was generated using an ensemble model approach by combining three modeling techniques: random forest, logistic regression, and maximum entropy. This study combines measured habitat characteristics, with
sophisticated geographic information system (GIS) tools and SDMs to provide managers with an informative and useful toolkit for Mexican Spotted Owl conservation.

Chapter 2 discusses modeling techniques and SDM development. I detail how individual models were constructed using random forest, logistic regression, and maximum entropy and how these were combined into an ensemble model. Final models indicated that several vegetative and geologic characteristics were considered important habitat characteristics for predicting Mexican Spotted Owl presence within the Colorado Plateau. The SDMs produced eight distribution maps predicting Mexican Spotted Owl presence and probability of occurrence in Utah for the Colorado Plateau region.

Chapter 3 explains the use of SDMs by managers and synthesizes findings of measured habitat characteristics for southern Utah. For habitat characteristics I measured a combination of vegetative and geologic features within 10m wide belts at current and historic Mexican Spotted Owl sites. Vegetative features measured included: height and species of all trees and shrubs, position of tree or shrub within plot, presence of canopy cover, and tree diameter at breast height (DBH). Geologic features measured included: geologic formation type, wall height, structure type, number of caves, and number of solution cavities. I found that canyon width and density of vegetation > 2.5 m tall were significantly correlated with Mexican Spotted Owl presence.
Habitat Characteristics of Mexican Spotted Owls (*Strix occidentalis lucida*) in the Canyonlands of Southern Utah

by Leah R. Lewis

Mexican Spotted Owls are considered a threatened species by the US Fish and Wildlife Service. Therefore, they must be properly managed and protected by federal and state agencies. In this study I explored the habitat characteristics used by Mexican Spotted Owls in the canyonlands region of southern Utah. I spent three summer field seasons (May–September) from 2010 – 2013 locating Mexican Spotted Owl sites and measuring vegetative and geologic features at these sites. I found that canyon width and very tall vegetation influenced Mexican Spotted Owl presence, suggesting that these owls prefer narrow canyons that are vegetated with trees.

Based on habitat features and species life history characteristics several species distribution models (SDM) were generated for Mexican Spotted Owls in Utah. These models produce maps showing where Mexican Spotted Owls are likely to occur within Utah’s Colorado Plateau region. In order to predict Mexican Spotted Owl presence we used several vegetative and geologic variables including: elevation, aspect, surface ratio, curvature, slope, geology, and vegetation. Of these variables elevation, surface ratio, curvature, geology, and vegetation were most important in predicting where Mexican Spotted Owls occur. The variables curvature, which indicates the presence of canyons, and surface ratio, which identifies steep cliffs and walls, indicated that Mexican Spotted
Owls prefer steep and narrow canyons, as opposed to flat tablelands that show little
topographic variability.

These distribution maps can be used by managers to help conserve, protect, and
manage Utah’s population of Mexican Spotted Owls. Managers can use the distribution
maps to select new areas to survey for owls by identifying areas of potential owl
occurrence. They can also identify areas of suitable habitat and designate important
habitat areas, to provide protection to zones threatened with human disturbance or
resource extraction. Such distribution maps can be a vital component in future
conservation efforts and management of threatened and endangered species.

Chapter 1 of my thesis provides an introduction to Mexican Spotted Owls and
the goals of my research project. Chapter 2 explains the construction of the SDMs and
distribution maps. Chapter 3 synthesizes data on Mexican Spotted Owl habitat and how
managers can effectively and efficiently employ the distribution maps presented in
Chapter 2. Chapter 4 provides a conclusion to my research and future conservation
implications for Mexican Spotted Owls and the respective SDMs.
I would first like to thank my advisor, Dr. Eugene Schupp, for accepting me as his student two years into my project. I faced many challenges with this research and Geno’s guidance and support helped me stay motivated and reach my goals. Secondly, I would like to thank Dr. Thomas Edwards who provided much needed support, advice, and guidance on my research. Without Tom’s dedication, extensive expertise, and unparalleled advice, completion of a quality research project would not have been possible. I would also like to thank my committee members, Dr. David Koons and Dr. Frank Howe, for their insightfulness and support with this research. Many thanks to Dr. Michael Kuhns, Dr. Johan du Toit, Marsha Bailey, Lana Barr, Cecelia Melder, and Stephanie White for their continued support and help.

Thank you to the Utah Division of Wildlife Resources (UDWR) and Bureau of Land Management (BLM) for funding my research. Thanks to The Nature Conservancy Canyonlands Research Center for providing accommodations during the summer. Also, special thanks to the Redd Family for their great hospitality while living on the ranch.

I would like to thank my field technicians Jessica Belcher, Chelsea DeMarco, and Melanie Renell for all their help and support in the field. Special thanks to my family for all of their support through my master’s program and challenging times. Finally, very special thanks to my husband, Matt, for his never-ending support, love, reassurance, and patience. Without his continued support I would have never finished this thesis.

Leah R. Lewis
## CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>.................................................................</td>
<td>ii</td>
</tr>
<tr>
<td>PUBLIC ABSTRACT</td>
<td>.................................................................</td>
<td>iv</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>.................................................................</td>
<td>vi</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>.................................................................</td>
<td>viii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>.................................................................</td>
<td>ix</td>
</tr>
<tr>
<td>CHAPTER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2.</td>
<td>MODELING MEXICAN SPOTTED OWL (<em>STRIX OCCIDENTALIS LUCIDA</em>) HABITAT: REFINING SPECIES DISTRIBUTION MODELS FOR A THREATENED SPECIES</td>
<td>10</td>
</tr>
<tr>
<td>3.</td>
<td>MEXICAN SPOTTED OWL (<em>STRIX OCCIDENTALIS LUCIDA</em>) HABITAT: MANAGEMENT AND CONSERVATION IMPLICATIONS FOR A THREATENED SPECIES IN THE COLORADO PLATEAU OF UTAH</td>
<td>64</td>
</tr>
<tr>
<td>4.</td>
<td>CONCLUSION</td>
<td>107</td>
</tr>
<tr>
<td>APPENDIX</td>
<td></td>
<td>110</td>
</tr>
</tbody>
</table>
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Predictor variables used in modeling probability of presence for Mexican Spotted Owls</td>
<td>45</td>
</tr>
<tr>
<td>2.2</td>
<td>Original and re-classified Landfire vegetative attributes</td>
<td>45</td>
</tr>
<tr>
<td>2.3</td>
<td>Original and re-classified geologic attributes</td>
<td>46</td>
</tr>
<tr>
<td>2.4</td>
<td>Accuracy metrics for logistic regression, random forest, and maximum entropy predicting probability of presence for Mexican Spotted Owls</td>
<td>48</td>
</tr>
<tr>
<td>2.5</td>
<td>Variable coefficients (SE), z-statistic, and p-values for logistic regression step model predicting probability of presence for Mexican Spotted Owls as a function of habitat characteristics</td>
<td>49</td>
</tr>
<tr>
<td>2.6</td>
<td>Model comparison showing percent Mexican Spotted Owl sites captured within the species distribution model prediction layer</td>
<td>50</td>
</tr>
<tr>
<td>2.7</td>
<td>Model Overlap showing the percentage of cells that overlap between models</td>
<td>50</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>Map of Mexican Spotted Owl study area for Mexican Spotted Owls .......... 51</td>
<td></td>
</tr>
<tr>
<td>2.2</td>
<td>Map of habitat envelope for Mexican Spotted Owls that was used to select pseudo-absence points ................................................................. 52</td>
<td></td>
</tr>
<tr>
<td>2.3</td>
<td>Map of random forest species distribution classification model for Mexican Spotted Owls ................................................................. 53</td>
<td></td>
</tr>
<tr>
<td>2.4</td>
<td>Map of logistic regression species distribution classification model for Mexican Spotted Owls ................................................................. 54</td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>Map of maximum entropy species distribution classification model for Mexican Spotted Owls ................................................................. 55</td>
<td></td>
</tr>
<tr>
<td>2.6</td>
<td>Map of random forest species distribution probability model for Mexican Spotted Owls ................................................................. 56</td>
<td></td>
</tr>
<tr>
<td>2.7</td>
<td>Map of logistic regression species distribution probability model for Mexican Spotted Owls ................................................................. 57</td>
<td></td>
</tr>
<tr>
<td>2.8</td>
<td>Map of maximum entropy species distribution probability model for Mexican Spotted Owls ................................................................. 58</td>
<td></td>
</tr>
<tr>
<td>2.9</td>
<td>Probability map of ensemble species distribution model for Mexican Spotted Owls ................................................................. 59</td>
<td></td>
</tr>
<tr>
<td>2.10</td>
<td>Map of ensemble uncertainty ................................................................. 60</td>
<td></td>
</tr>
<tr>
<td>2.11</td>
<td>Classification map for ensemble species distribution model for Mexican Spotted Owls ................................................................. 61</td>
<td></td>
</tr>
<tr>
<td>2.12</td>
<td>Concordance chart showing the number of predicted presence cells that overlap between the random forest, maximum entropy, and logistic regression distribution models ................................................................. 62</td>
<td></td>
</tr>
<tr>
<td>2.13</td>
<td>Variable Importance plots for random forest model ................................................................. 63</td>
<td></td>
</tr>
<tr>
<td>3.1</td>
<td>Map of Mexican Spotted Owl study area for Mexican Spotted Owls .......... 89</td>
<td></td>
</tr>
</tbody>
</table>
3.2  Placement of vegetative and geologic belt transects within the canyon........... 90
3.3  Ten meter wide belt with center transect (dotted line)................................. 91
3.4  Mean canyon width(± SE) for presence and absence sites ............................. 92
3.5  Mean percent canopy cover (± SE) for presence and absence sites ................. 93
3.6  Mean DBH (± SE) for trees in size class 2 (15.2 cm – 30.5 cm) per 10 m² for 
    presence and absence sites ........................................................................... 94
3.7  Mean DBH (± SE) for trees in size class 2 (15.2 cm – 30.5 cm) per 10 m² for 
    presence and absence sites ........................................................................... 95
3.8  Comparing tree density (± SE) per 10 m² for presence and absence plots by 
    height class ................................................................................................. 96
3.9  Comparing vegetation density (± SE) per 10 m² for presence and absence 
    plots by height class .................................................................................... 97
3.10 Mean number of live shrubs (± SE) per 10 m² for presence and absence 
    sites ............................................................................................................. 98
3.11 Mean vegetation (± SE) (trees and shrubs combined) per 10 m² for 
    presence and absence sites ......................................................................... 99
3.12 Mean number of caves (± SE) for presence and absence sites ..................... 100
3.13 Mean number of solution cavities (± SE) for presence and absence sites ...... 101
3.14 Mean number of ledges (± SE) for presence and absence sites ...................... 102
3.15 Mean wall height (± SE) for presence and absence sites. ............................. 103
3.16 Example of Cross-Canyon Transect Tool (CCTT) in ArcMap ....................... 104
3.17 Digital model of Unknown Canyon created from CCTT measurements......... 105
3.18 Plots showing elevation and distance from center point for each transect 
    of the Cross-Canyon Transect Tool within Unknown Canyon ..................... 106
CHAPTER 1
INTRODUCTION

Identifying site-specific characteristics associated with occupied sites can inform species distribution modeling and influence future monitoring and management decisions. These predictive species distribution models are vital to conservation and management of rare and endangered species (Guisan and Zimmermann 2000, Margules and Pressey 2000, Austin 2002). Given vast and ecologically diverse landscapes, identifying habitat characteristics driving a species distribution can be challenging. Researchers are presented with a constantly changing landscape and numerous ecological characteristics that influence the habitats species select. For threatened species like the Mexican Spotted Owl (*Strix occidentalis lucida*), it is important to identify key habitat characteristics to guide managers with the conservation of suitable and potential habitat. The goal of this study was to identify habitat characteristics of Mexican Spotted Owls in the canyonlands region of southern Utah and use them to create a species distribution model.

The Mexican Spotted Owl, a subspecies of the Spotted Owl, was listed as a threatened species by the U.S. Fish and Wildlife Service in 1993 (USFWS 1993). Mexican Spotted Owl populations are found throughout the southwestern United States and into Mexico as far as Michoacan (Gutierrez et al. 1995, Willey 1998). These populations are faced with a multitude of potential threats throughout their range including timber
harvest, catastrophic wildfires, habitat fragmentation, and disturbance from recreational activities (USFWS 2012).

The USFWS consider “Critical Habitat” elements in canyons to include: presence of water; clumps or stringers of mixed-conifer \((Pseudotsuga menziesii, Pinus ponderosa, Pinus edulis, Picea engelmannii)\); pine-oak \((Pinus edulis, Quercus gambelii)\); pinyon-juniper \((Pinus edulis, Juniperus osteosperma)\); riparian vegetation \((Populus spp., Salix spp.)\); canyon walls with crevices, ledges, and caves; and a high percentage of woody debris and litter (USFWS 2004). In Utah, Spotted Owls inhabit a variety of canyon terrain throughout the Colorado Plateau (Ganey and Balda 1994, Seamans and Gutierrez 1995, Willey 1998). Utah’s Spotted Owl habitat is typically dominated by steep, narrow canyons with limited canopy cover. Vegetation in these canyons is patchy and sparse. Typical vegetation types include deciduous riparian \((Populus spp., Salix spp.)\), pinyon-juniper \((Pinus edulis, Juniperus osteosperma)\), ponderosa pine \((Pinus ponderosa)\) and mixed conifer \((Abies spp., Picea, spp., Pseudotsuga menziesii)\) (Rinkevich and Gutierrez 1996, Willey 1998). In contrast, habitat characteristics for owls located in Arizona and New Mexico include cool and moist areas with dense, mixed-conifer species and pine-oak canopies along steep, rocky slopes (Ganey and Benoit 2002, Mullet and Ward 2010). These two contrasting habitat types present a need for more research on potential Mexican Spotted Owl habitat in Utah (Ganey and Benoit 2002).

Microclimate has been suggested as an important factor for Mexican Spotted Owl habitat preference (Rinkevich and Gutierrez 1996, Ganey and Benoit 2002, Ganey 2004). Differences in microclimate are created by a variety of factors including
elevation, canopy cover, and canyon morphology (Mullet and Ward 2010). Occupied canyons are believed to have higher absolute humidity and lower temperatures facilitated by canyon structure and vegetative cover in combination with the presence of water (Ganey 2004). However, Ganey (2004) has suggested that thermal cover by itself may not determine habitat selection directly and its significance may vary depending on interactions with location and elevation of occupied sites, as well as other factors such as prey abundance and protective cover. Therefore, thermal microclimates in isolation may not be the essential feature to determine occupied canyon sites (Ganey 2004), but merely one of several.

Utah’s unique canyonland environment provides a new challenge in both describing and predicting potential Spotted Owl habitat. This especially holds true for southern Utah where one of the largest expanses of these canyon systems exists. Microhabitat features within canyons have not been rigorously measured and need to be identified and quantified (Mullet and Ward 2010). For this study, microhabitat refers to the finer-scaled features used by the owl within a canyon (Hall et al. 1997). These site-specific features include caves, ledges, roost perches, and water sources. Mullet and Ward (2010) suggested quantifying site-specific features near roost and nest locations in order to distinguish the important microhabitat features within the canyon from larger macrohabitats. Their recent study (2010) measured eight geomorphic features and a combination of vegetative variables at historically occupied nest and roost sites. These features included width and depth of the selected canyon, aspect of the site and canyon drainage, and the elevation at the canyon bottom (Mullet and Ward...
In our study we measured similar canyon features at a more detailed scale and included measurement of geomorphic structuring of canyon walls. Measurements of these finer scaled features provide a description of the owl’s microhabitat and canyon morphology.

Mullet and Ward (2010) measured canyon habitat features in the Guadalupe Mountain range of west Texas and southeastern New Mexico. Their study suggested that nest and roost sites were typically located in dense patches of mid-story vegetation within deep and narrow canyons. Many owls nesting in Utah canyons are found in caves (Willey 1998) rather than in the dense patches of vegetation described by Mullet and Ward (2010). They also found no significant correlation between the amount of bare ground, vegetative cover, tree diameter, tree layer height, or tree species composition and occupancy, and suggested these may not be important habitat features for canyon owls in their study. They further suggested owls may select roosting and nesting sites based on their proximity to forage and prey resources. Mullet and Ward (2010) indicated that sites in their study had similarities to canyon sites located in southern Utah, the Grand Canyon, and Colorado; however, additional research needs to be done to determine which features are common to canyon habitats occupied by Mexican spotted owls across their range.

Currently, the majority of studies on Mexican Spotted Owls have focused on populations inhabiting forested areas. While these studies provide detailed descriptions of habitat, prey, roost behavior, and predictive habitat models for these areas (Ganey et al. 2003, Hathcock and Haarmann 2008), they may not be suitable for use in canyon
habitats found in Utah (Ganey and Benoit 2002, Mullet 2008). Relatively few published studies are available on Mexican Spotted Owls and their habitat preference in Utah (but see Rinkevich and Gutierrez 1996, Willey and van Riper 2007). This may be due to the challenging terrain of Utah’s canyonlands where these owls are found (Rinkevich and Gutierrez 1996, Willey and van Riper 2007). Currently, information concerning specific microsite habitat characteristics and geomorphic features found within occupied Utah canyons is limited (USFWS 2012).

The current habitat models for Mexican Spotted Owls in Utah were developed by Willey and Spotskey in 1996 and 2000 (Willey and Spotskey, Montana State University, unpublished data). These models incorporated the variables slope, elevation, curvature, and vegetation characteristics. The 1996 model captured 55.3% of current and historic owl locations within the predicted habitat layer, while the 2000 model only captured 4.3% of owl locations. Unfortunately, the 1996 model overestimates suitable owl habitat, while the 2000 model drastically underestimates suitable habitat. Since these models were developed, new information has been gathered and improved geographic information systems (GIS) techniques have been developed, both of which I have used to improve prediction of Spotted Owl habitat in Utah.

Creating a landscape based model to predict owl habitat across Utah’s diverse canyon terrain can be daunting. However, habitat models built on a smaller scale, will allow for further refinement of larger landscape-scaled models (Hathcock and Haarmann 2008). In order to construct such a model, research should focus on increased data collection at the microhabitat scale to allow a finer-scaled model to
detect canyons occupied by owls. Data collection should focus on canyon structure and features, dominant vegetation, and climate variables such as temperature and humidity (USFWS 1995). Combining these data from a macro and micro scale will provide a comprehensive assessment of suitable habitat and further aid in the construction of an accurate species distribution model for southern Utah.

The goals of this thesis were to identify habitat features associated with occupied canyons in southern Utah and create a species distribution model for Mexican Spotted Owls. Chapter 2 outlines a descriptive species distribution model for Mexican Spotted Owl habitat at the macro scale in Utah. Chapter 3 provides a microhabitat description of the vegetative and geologic structures associated with Mexican Spotted Owl territories in the canyonlands of southern Utah and discusses management implications and future model applications. Chapter 4 synthesizes model use, overall results, and management implications. The research presented in this thesis will help guide future management decisions and further research of Mexican Spotted Owl habitat throughout the Colorado Plateau.

REFERENCES


Mullet, T. C. 2008. Evaluation of two GIS habitat models and initial characterization of
nesting and breeding-season roosting microhabitat for mexican Spotted Owls in
the Guadalupe mountains. Sul Ross State University.

Mullet, T. C., and J. P. Ward. 2010. Microhabitat features at Mexican spotted owl nest
and roost sites in the Guadalupe Mountains. Journal of Raptor Research 44:277-
285.

Rinkevich, S. E., and R. J. Gutierrez. 1996. Mexican Spotted Owl habitat characteristics in

Seamans, M. E., and R. J. Gutierrez. 1995. Breeding habitat of the Mexican Spotted Owl

U.S. Fish and Wildlife Service. 1993. Endangered and threatened wildlife and plants:
final rule to list the Mexican Spotted Owl as a threatened species. Federal
Register 58:14248-14271.

final designation of critical habitat for the Mexican Spotted Owl; final rule in
USDI, editor. Federal Register, Albuquerque, New Mexico.

U.S. Fish and Wildlife Service. 2012. Final recovery plan for the Mexican Spotted Owl,

USDI Fish and Wildlife Service. 1995. Recovery plan for the Mexican Spotted Owl (Strix

CHAPTER 2

MODELING MEXICAN SPOTTED OWL (*STRIX OCCIDENTALIS LUCIDA*) HABITAT: REFINING SPECIES DISTRIBUTION MODELS FOR A THREATENED SPECIES

**Abstract.** Mexican Spotted Owls (*Strix occidentalis lucida*) are a threatened species found in a variety of habitat types. Identifying habitat characteristics within these occupied sites can be challenging, making it difficult to produce an accurate species distribution model (SDM). With rare and elusive species, such as the Mexican Spotted Owl, constructing a distribution model with presence only data might be the best option, especially when absence data are limited. Here we constructed an ensemble of SDMs that decrease predictive uncertainty associated with the identification of suitable habitat for the owls. We first constructed three different species distribution models using background points as pseudo-absences: random forest, logistic regression, and maximum entropy. Area under the curve (AUC) and specificity for all models were comparable, suggesting high model performance. The logistic regression model indicated elevation, curvature, and surface ratio were significant variables affecting Spotted Owl presence. Curvature is a measure of tablelands, cliff tops, and canyons across the landscape. Surface ratio is a measure of topographic roughness and was used to identify areas with steep canyons. The logistic regression model also indicated deciduous forest, coniferous forest, and piñon-juniper woodland as significant vegetation types for predicting Spotted Owl presence. The random forest model selected surface ratio and curvature as the best variables for
predicting Mexican Spotted Owl presence. Maximum entropy ranked surface ratio, curvature, and geology as the most important predictor variables. The individual SDMs were then combined to generate a final ensemble model, which combines presence predictions for all three SDMs. The ensemble model provides robust predictions and allows managers to focus on areas of high conservation priority. These distribution models are the first step in designing effective sampling schemes for Mexican Spotted Owls in Utah. Managers are encouraged to use these distribution models for the selection of survey locations and conservation planning for Mexican Spotted Owls.

INTRODUCTION

Conservation strategies of threatened and endangered species should begin with the identification of occupied and productive habitat (Margules and Pressey 2000). Identifying environmental characteristics associated with occupied and unoccupied sites can lead to ecologically-based species distribution models (SDM). SDMs highlight a proposed species distribution based on environmental and spatial characteristics drawn from known occurrence locations (Elith and Leathwick 2009). These distribution models are a vital tool for conservation and management of threatened and endangered species (Austin 2002, Guisan et al. 2013).

SDMs are used for a variety of purposes including management of biological invasions, selection of species reserves, guiding species translocation or re-introduction efforts, and identification and protection of important habitat areas for threatened and endangered species (Franklin 2013, Guisan et al. 2013). However, SDMs are of particular
importance when used by managers in conservation. In general, SDMs are capable of predicting regions of species occupancy, which allows managers to target specific areas for management, monitoring, and surveys (Guisan et al. 2013). Researchers and managers can then implement habitat protection for these regions, which may lead to reduction of harmful impacts to the species and its habitat, such as human disturbance or resource extraction (Guisan et al. 2013). The use of SDMs is a cost effective approach and prevents managers from wasting time and resources on less favorable habitats. These SDMs can also influence managers to survey new regions and locate additional populations that were previously undocumented (Franklin 2013). Over time, consistent use of SDMs can lead to the acquisition of improved data through adaptive management and survey techniques (Guisan et al. 2013). This high-quality data then can be used to refine and reconstruct the SDM, leading to improved models and changes in management objectives (Guisan et al. 2013).

The application of distribution models can depend on the ultimate goal and construction method used for generating the SDM. With rare and elusive species the problem of accurate and sufficient data acquisition arises, making these models difficult to construct. For rare species, it is more efficient to survey a higher number of units, with less repeat visits, than it is to survey fewer units with more visits (Mackenzie and Royle 2005). For this reason, many managers are left with presence only data and lack quality absence data. This is especially true for species that are logistically difficult to survey, such as the Mexican Spotted Owl (Strix occidentalis lucida).
The Mexican Spotted Owl, a subspecies of the Spotted Owl (*S. occidentalis*), was listed as threatened by the U.S. Fish and Wildlife Service (USFWS) in 1993 (USFWS 1993). Currently, this species is faced with numerous threats throughout their range including timber harvest, catastrophic wildfires, habitat fragmentation, and disturbance from recreational activities (USFWS 2012). Managing these threats can be challenging due to the different habitat types used by Mexican Spotted Owls across their range (Willey 1998). This study focused on the greater canyonlands region of southern Utah, where Mexican Spotted Owl habitats are typically dominated by steep and narrow canyons, and have limited canopy cover and vegetative structure (Rinkevich and Gutierrez 1996, Willey 1998). These unique habitat characteristics require new habitat models to help guide the management of Utah’s population of Mexican Spotted Owls.

Past research has led to the development of several predictive habitat models for Mexican Spotted Owls across their range. Willey and Spotskey (1997, 2000) generated several GIS models for canyon habitats based on vegetation and topographic variables such as slope, curvature, aspect, soil moisture, and surface temperature. Further refinement of these models indicated that variables such as percent slope, elevation, and vegetation were positively associated with Mexican Spotted Owl presence (Willey et al. 2007). Ganey (1994) developed a predictive habitat model for forest habitats in northern Arizona. His model indicated slopes >15% and dense mixed-conifer, ponderosa pine, or deciduous forest were important variables in predicting Mexican Spotted Owl presence on National Forest lands in northern Arizona. Mullet used occupancy sampling to evaluate the performance of two existing GIS habitat
models and their ability to correctly predict Mexican Spotted Owl occurrence. Mullet further characterized breeding habitat by quantifying microhabitat features within canyon habitats of the Guadalupe Mountains (Mullet 2008). In my study, I have used additional data, a different modeling approach, improved GIS techniques, and new methods in species distribution modeling in an attempt to improve upon previous owl distribution models.

The use of presence only data to construct a species distribution model is a cost-effective tool for conservation managers and can be valuable in poorly surveyed areas (Guisan and Zimmermann 2000, Austin 2002). Due to southern Utah’s rugged terrain and harsh conditions, surveying for Mexican Spotted Owls can prove challenging and cause acquisition of large datasets to be time consuming and costly. For this reason, our study uses a presence only dataset based on historic and current locations of Spotted Owls throughout Utah’s Colorado Plateau. To accommodate our lack of absence data we use pseudo-absences. Using pseudo-absences, or background points, has been shown to improve model quality and prevent over prediction of species distributions, especially for rare and distribution-limited species (Brotons et al. 2004, Engler et al. 2004). Incorporating pseudo-absence points allows for the use of multiple modeling techniques (Zaniewski et al. 2002, Engler et al. 2004). Zaniewski et al. (2002) suggested that using pseudo-absences paired with presence data will create SDMs that better reflect the species habitat.

However, the method used for selecting pseudo-absence points can impact the strength of the final model (Engler et al. 2004, Zarnetske et al. 2007, Barbet-Massin et
Engler et al. (2004) indicated that using pseudo-absences selected from a weighted ENFA provided significantly better results compared to randomly selected pseudo-absences. Zarnetske et al. (2007) showed that selecting pseudo-absences from a habitat envelope led to better models compared to models that did not use a habitat envelope. The habitat envelope is a simple distribution model constructed from pre-defined habitat characteristics that are drawn from published literature and knowledge of species-specific life history characteristics. The goal of using the habitat envelope is to constrain the selection of pseudo-absence points to ecologically-based regions within the species’ distribution, while excluding known presence locations from the selection process (Zarnetske et al. 2007). Zarnetske et al. (2007) indicated that the use of habitat envelopes, compared to no envelope models, led to greater sensitivity and specificity, more competing top models, and improved classification of highly suitable habitat within a designated range of identified habitat. Each of these studies supports the need for selecting pseudo-absence points from low-suitability habitat maps, while excluding areas of known presence from the pseudo-absence point selection process (Zaniewski et al. 2002, Engler et al. 2004, Zarnetske et al. 2007).

Our presence and pseudo-absence data were used to construct three individual models that were ultimately combined to create an ensemble model predicting Mexican Spotted Owl occurrence. Ensemble models are created by combining several individual models to create a final model with increased accuracy in predicting species occurrence across the range (Araújo and New 2007, Marmion et al. 2009). This approach is based on the concept that all models are flawed, but by combining several techniques (models)
into an ensemble model some of the variability seen amongst the individual models will be averaged out (Araújo and New 2007). Marmion et al. (2009:63) tested eight different single modeling techniques against the combined results of the ensemble model and found “significantly more robust predictions” with the ensemble approach. They further suggested that the weighted average proved the best predictive indicator for model accuracy.

In this study we combine multiple modeling techniques that use presence and pseudo-absence data in order to model suitable Mexican Spotted Owl habitat found in Utah. The goal of this study is to construct an ensemble model that will: (1) generate a species distribution model (SDM) with increased accuracy that focuses on identifying suitable habitat and, (2) decrease our predictive uncertainty, with the ultimate goal of providing managers with a tool to assist in the conservation of Mexican Spotted Owls in Utah.

METHODS

Study Species

The Spotted Owl has been extensively studied, and is known for generating substantial political controversy. Spotted Owls have three subspecies; Northern Spotted Owls (S. o. caurina) found throughout the northwest, California Spotted Owls (S. o. occidentalis) found only in California, and Mexican Spotted Owls (S. o. lucida) found in parts of Arizona, New Mexico, Colorado, Utah and central Mexico (Gutierrez et al.)
Mexican Spotted Owls have received considerably less study compared to the Northern Spotted Owl. Here, we focus on Mexican Spotted Owl populations in Utah’s portion of the Colorado Plateau.

Mexican Spotted Owls use a variety of habitat and nesting structures depending on their geographic location. Throughout Arizona and New Mexico owls inhabit coniferous forests and use abandoned raptor nests made of sticks for their nesting structure (Ganey and Benoit 2002). In contrast, Mexican Spotted Owls in Utah occupy steep and narrow canyons that are sparsely vegetated, with limited canopy cover. Instead of using a stick nest, they nest inside caves or along sheltered canyon ledges (Willey 1998).

**Study Area**

The study area encompasses Utah’s Colorado Plateau with the majority of owl sites found throughout the greater canyonlands region of southern Utah (Fig. 2.1). Mexican Spotted Owls are found regularly in Canyonlands, Capitol Reef, and Zion National Parks. They are also found within the Grand Staircase-Escalante National Monument and other Bureau of Land Management (BLM) districts that surround these National Parks (L. Lewis personal observation, unpublished data). Elevation for the study areas ranges from 1,525 to 2,745 m. Many of these sites are characterized as having narrow canyons, steep canyon walls, and unique geologic formations such as arches and spires. Mean annual precipitation ranges from 19.7 cm to 39.9 cm, with annual
temperatures ranging from -6°C to 46°C (21°F to 115°F) (Utah Climate Center and Utah State University 2006-2011).

**Site Selection**

Historic survey records of Mexican Spotted Owls in Utah were compiled from USFWS, Utah Division of Wildland Resources (UDWR), U. S. Forest Service (USFS), National Park Service (NPS), and BLM. There are a total of 1,729 Mexican Spotted Owl presence records dating from 1928-2012, from approximately 472 sample locations, referred to as sites. Sites were selected for use only if they had a presence record within the past 25 years during the breeding season and coordinates for the owl’s location. A 25 year timeframe was selected based on the assumption that model predictor variables, such as elevation, geology, and dominant vegetation type, remained unchanged over this period. A total of 94 sites met the < 25 year measurement age and reliable location coordinates criteria within the Colorado Plateau of Utah (Fig. 2.1, see Appendix for 94 presence points).

**Habitat Envelope**

Our method of generating a habitat envelope and selecting pseudo-absence points followed procedures outlined in Zarnetske et al. (2007). Our final habitat envelope was based on factors from three raster layers: elevation, vegetation, and geology (Table 2.1 for sources).
We used elevation as our first limiting factor for the habitat envelope. First we extracted elevation values for our 94 presence points using digital elevation models (DEM). Elevations of these presence points ranged from 1,245 m to 2,322 m. Since it is unlikely these values represent the true elevational limits we then arbitrarily added and subtracted 10% to the maximum and minimum elevation values for presence points, respectively, which resulted in a final elevational range of 1,121 m – 2,554 m that is more likely to fully capture the species geographic and environmental niche. We then used the “raster calculator” in ArcMap to select elevations within this range from our DEM. From this calculation a new raster layer was created, providing an elevational range for Mexican Spotted Owls within Utah.

The vegetation and geology layers were composed of 37 and 38 categorical variables, respectively (see Table 2.1 for sources). We chose to reclassify, or condense, these layers for several reasons: (1) reduce the number of categorical variables from our models, (2) simplify vegetative descriptors to select for community type as opposed to species type, and (3) eliminate non-critical categorical variables from the habitat model. The vegetation layer was reclassified by combining individual species into community types (e.g. white fir (*Abies concolor*) and lodgepole pine (*Pinus contorta*) were reclassified as “coniferous forest”) (Table 2.2). Unlikely owl habitat types such as grassland species (e.g. grama) and water were reclassified as “other”. The geology layer was reclassified using a similar technique. However, rather than condensing variables as was done with the vegetation layer, we removed variables (or geologic layers) that were non-critical to Mexican Spotted Owls by classifying them as “other” (e.g. surficial
deposits and volcanic rock) (Table 2.3). Reclassification of these raster layers was performed using the “reclassify” tool in ArcMap. After reclassification we masked out the “other” category from both layers, eliminating vegetative and geologic types unlikely to be used by owls.

With the masked layers (i.e. elevation, vegetation, geology) we used the “raster calculator” in ArcMap to create a new raster layer from the intersection of these three layers (i.e. elevation \( \cap \) vegetation \( \cap \) geology = new raster). The output layer was then clipped, using the “clip” tool in ArcMap, to the Colorado Plateau and Utah boundaries. The final raster output was used as our habitat envelope and served as a boundary for selecting our pseudo-absence points (Fig. 2.2).

**GIS Layer Preparation**

Our modeling approach included random forest (Breiman 2001), logistic regression (McCullagh and Nelder 1989), and maximum entropy (maxent) (Phillips et al. 2006). Based on studies by Chefaoui and Lobo (2008) and Lobo (2011), we generated ten times the number of pseudo-absence points from our habitat envelope as we had presence points. Thus our models were constructed using 94 presence points and 940 pseudo-absence points.

The first step in running the statistical models was to prepare seven GIS raster layers as variables. These included the three layers used to construct the habitat envelope previously, elevation, geology, and vegetation, as well as aspect, surface ratio, curvature, and slope (Table 2.1). Surface ratio can be considered a measure of
topographic roughness, defined as changes in slope and aspect along the terrain surface. A high surface ratio value (such as 10) indicates increased topographic roughness, such as mountains and canyons, where a low value (such as 1) indicates low topographic roughness, such as valleys, plateaus, and grasslands (Jenness 2013).

Curvature represents the flow of the landscape; it identifies areas with rapid changes in slope or aspect. Flat areas, such as tablelands are represented by values of 0, areas that are highly convex, such as cliff tops, are represented by values closer to 1, and areas that are highly concave, such as canyons are represented by values closer to -1. Slope, aspect, and curvature were generated in ArcMap from a DEM with 30 m resolution.

Surface ratio was generated from the DEM using an add-on tool set called DEM Surface Tools, by Jenness Enterprises (Jenness 2013).

Focal statistics were calculated in ArcMap for slope, elevation, surface ratio, curvature, vegetation, and aspect. Focal statistics calculate the average value from surrounding cells or pixels, within a predefined neighborhood or area, and assign the average value to the cell. For slope, elevation, surface ratio, and curvature, new rasters were derived using the “focal statistics” tool in ArcMap in order to better describe the average value for owl sites. A new raster layer was calculated for each variable using a 3 x 3 cell (where each cell represents 30 m x 30 m) square neighborhood. For our focal statistics we took the mean of the values in the 3 x 3 cell neighborhood and assigned this mean value to the cell in the center of the neighborhood, which allowed the raster layers to be generalized and smoothed for future extraction methods. For vegetation, a new layer was created with the same techniques, but the majority vegetation was
assigned to the center cell within a 5 x 5 cell (where each cell represents 30 m x 30 m) neighborhood. For example, if “piñon-juniper woodland” was the most abundant, or majority category within the 5 x 5 neighborhood, then it was assigned to the central cell. A larger neighborhood was used to avoid ties of majority values between two different vegetation categories. The vegetation layer was then reclassified by combining individual species into the same community types as done with the habitat envelope (Table 2.2). Aspect was transformed before applying the “focal statistics” tool. We transformed aspect from a scale of 0 to 360 to a scale of -1 to 1 using the R package “labdsv” (Roberts 2013). This created a new raster layer where all northerly aspects were easily identifiable. Finally, we ran the “focal statistics” tool across the aspect raster with a 3 x 3 cell neighborhood and calculated the mean within each neighborhood. Lastly each of the raster layers was clipped to the Colorado Plateau within Utah.

Data extraction was performed across all seven variable raster layers for each of the 940 pseudo-absence points and 94 presence points. To extract data associated with each point the “extract multi values to points” tool was used in ArcMap. After data extraction, each of the 1,034 points was associated with a value for: presence/absence (1/0), elevation, aspect, surface ratio, curvature, slope, geology, and vegetation. This created a final dataset of 1,034 points that was exported as a data file for future use with statistical packages in R (R Development Core Team 2013).
Descriptive statistics were calculated for each of the seven variables to test for variable correlation. Variable correlation was determined because collinearity is not addressed internally with each of the modeling methods and we wanted to ensure each model had consistent variable inputs. Any two variables were considered dependent if the Pearson correlation value between them was $\geq 0.7$. Of the seven variables only surface ratio and slope were highly correlated ($r = 0.87$). Due to the high correlation and potential for collinearity between these variables, slope was removed as a variable from future modeling. We retained surface ratio because it was likely a better indicator of owl presence and provided a measure of canyon roughness and features across the landscape. The reclassified vegetation and geology layers were used for all statistical models (Tables 2.2 – 2.3).

The random forest model was constructed using package “randomForest” (Breiman 2001, R Development Core Team 2013). Model inputs were presence/absence (1,034 points) as a function of curvature, aspect, elevation, surface ratio, geology, and vegetation. Random forest internally ranks and weights variables by importance, therefore placing minimal to no weight on the least important variables (Breiman 2001). The logistic regression model was also based on a binomial response (presence/absence) with a logit link (McCullagh 1989) and was constructed using package “glm” in R (R Development Core Team 2013). For this model, we used the backwards step method, where all six predictors (curvature, aspect, elevation, surface
ratio, geology, and vegetation) were put into the model and removed one by one in order to determine maximum variable importance. Variable retention (or removal) was based on AIC; critical level for retention (removal) was 0.15. Based on this step method, aspect was removed as a variable and not considered to be an important model input. The five remaining variables from the logistic regression model (curvature, elevation, surface ratio, geology, and vegetation) were used as inputs for our maximum entropy model. The variable inputs were based on our step logistic regression model because maximum entropy does not internally perform a backwards step-wise function. The maximum entropy model was constructed using package “dismo” in R (Phillips 2006). All R code and the original dataset are found in the Appendix.

We selected “max sensitivity + specificity” as our model threshold for all three models. Our goal was to maximize the proportion of presences and absences correctly predicted across the landscape. This threshold fit the needs of our species best, especially when considering its rarity (Franklin et al. 2009).

Accuracy metrics were also calculated for each model using package “PresenceAbsence” (Freeman 2013, R Development Core Team 2013). These included: area under the curve (AUC), percent correct classification (PCC), sensitivity, specificity (Fielding and Bell 1997), and true skill statistic (TSS) (Allouche et al. 2006) These metrics were used for comparing model performance.
Species Distribution Models

To develop species distribution maps from our statistical models we used package “raster” in program R. To begin, we imported each of the six raster layers (curvature, aspect, elevation, surface ratio, geology, and vegetation) into “raster”. A raster stack was created by stacking each of the predictor variables (raster layers) on top of each other to form one final raster object with all variables attached. For each of the three models (random forest, logistic regression, and maximum entropy) we predicted species distribution (presence) as both a probability function (between 0 and 1) and a classification function (0 or 1). These prediction maps were generated by combining the raster stack of model input variables with the designated statistical model (i.e. random forest, logistic regression, or maximum entropy) (Figs. 2.3-2.8).

We then generated two different ensemble maps, based on the ensemble model. First we generated a probability map by stacking the random forest, logistic regression, and maximum entropy probability distribution maps on top of each other. From this stack an average probability was generated for each cell (sum of probabilities/3) producing a final ensemble probability map (Fig. 2.9). Standard deviation was then calculated for each cell in the ensemble probability map and a new ensemble uncertainty map showing standard deviation was derived (Fig. 2.10). We then created an ensemble classification map using a similar process. The random forest, logistic regression, and maximum entropy classification maps were stacked on top of each other as before. However, with this map the sum of the values for each
overlapping cell in the stack was calculated, producing final values ranging from 0 to 3 (Fig. 2.11). A concordance table was calculated using the ensemble classification map showing the amount of overlap between the three individual models (Fig. 2.12).

RESULTS

Statistical Models

The random forest model performed well with an AUC = 0.903 and TSS = 0.653 (Table 2.4). The PCC for the random forest model was 0.833, meaning 83% of presence and absence points combined were correctly classified. Model sensitivity, or the proportion of observed presences that were predicted as presences, was 0.819. While model sensitivity was relatively high, the model also did a good job predicting observed absences with a specificity = 0.834.

The random forest variable importance plots indicated two variables were of particular importance in predicting Spotted Owl presence (Fig. 2.13). Both plots indicated that surface ratio, our measure of topographic roughness, was the most important variable for predicting Spotted Owl presence. The Mean Decrease Gini Plot indicated that curvature was the second most important variable for Mexican Spotted Owl distribution (Fig. 2.13). In particular, as surface ratio (topographic roughness) increases, such as with the presence of canyons, Mexican Spotted Owl presence also increases. The relationship with curvature indicated that Mexican Spotted Owls prefer steep canyons (negative curvature values), while avoiding tablelands (curvature values
near 0). There did not appear to be any significant differences between variable importance for the remaining four variables.

The logistic regression model performed slightly better than the random forest model on several different metrics. Model AUC = 0.910 with a TSS = 0.689. The PCC (0.805) and the specificity value (0.796) were slightly lower compared to the random forest model. However, the sensitivity (0.894) was slightly higher compared to the random forest Model (Table 2.4).

The logistic regression model indicated several variables of significant importance for predicting Mexican Spotted Owl distribution. Elevation and curvature had significant negative effects on predicting Spotted Owl presence (Table 2.5). Therefore, at relatively high elevations (> 2100 m) the likelihood of Mexican Spotted Owl presence decreases. For curvature, the negative effect indicates that as curvature becomes more strongly negative, indicating steep canyons, Mexican Spotted Owl presence increases. Surface ratio (topographic roughness) had a significant positive correlation with Spotted Owl presence, meaning that as topographic roughness increases (e.g. the presence of canyons, steep walls, or mountains), the likelihood of Mexican Spotted Owl presence also increases.

Of the 15 vegetative and geologic variables, six were significant in the logistic regression model (Table 2.5). Deciduous forest was negatively correlated with Spotted Owl presence, while coniferous forest and piñon-juniper woodland were positively correlated to Spotted Owl presence (Table 2.5). The Cedar Mesa, Glen Canyon, and
Oquirrh geology types all were significantly, positively correlated to Spotted Owl presence (Tables 2.5 and 2.6).

The maximum entropy model performed slightly better across several metrics when compared with both the random forest and logistic regression models. The maximum entropy model had the highest AUC (0.927) and TSS (0.754) values (Table 2.4). However, the sensitivity value (0.826) was lower compared to the logistic regression model. In contrast, the maximum entropy specificity (0.928) was the highest of all models. The maximum entropy model ranked surface ratio, curvature, and geology as the three most important variables for Mexican Spotted Owl distribution. Surface ratio and curvature were positively correlated with presence, meaning as the landscape becomes more rough and complex, the likelihood of Mexican Spotted Owl presence increases. As a categorical variable, the importance of geology indicated that several geologic formations were of importance to Mexican Spotted Owls. These formations are not specifically specified within the maximum entropy model, but defined in the logistic regression model.

Species Distribution Models

Although the accuracy metrics were similar between all three models, the species distribution maps were quite different in the amount of probable habitat predicted by each model and quantity of presence points captured. The random forest model predicted the largest distribution area, with 14,696 km² (Table 2.6 and Fig. 2.3). This model also captured the greatest amount of presence points at 96.8%, which was
likely due to the larger predicted distribution for Spotted Owls. The logistic regression model predicted less than half of the area identified by the random forest model (Table 2.6 and Fig. 2.4), but performed poorer compared to the random forest model, capturing 60.6% of known owl sites. The maximum entropy model predicted the least amount of Spotted Owl habitat across the three models, predicting only 4,467 km$^2$, but captured 77.7% of owl sites, an intermediate value (Table 2.6 and Fig. 2.4).

The ensemble model does not provide the same accuracy metrics as the individual models; however, comparisons in performance can still be made. The ensemble probability map shows the mean probability of presence for all three models combined (Fig. 2.9). The mean probability ranges from nearly 0 to 0.935. This map can be compared with the ensemble uncertainty map, which shows the range of standard deviation for the ensemble probabilities (Figs. 2.10 and 2.9). Standard deviations for the ensemble probability map were ± 5.1e-6 – 0.47, meaning areas with higher standard deviation values (e.g. > 0.25) would indicate higher model uncertainty when predicting presence. Some higher standard deviation values were likely due to the variability between the random forest model and the logistic regression and MatEnt models.

The ensemble classification map highlights model overlap between the three different classification models by taking the sum of the three model values, where a value of 1 indicates no model overlap, a value of 2 indicates two models overlap, and a value of 3 indicates all models (three) overlap (Fig 2.11). This model overlap is compared using a concordance chart. The concordance chart shows the number of cells that overlap between the three models (Fig. 2.12). This emphasizes how differently each of
the models predicted Spotted Owl habitat. Approximately 10 million cells were classified as 1, 2, or 3 in the ensemble classification map. Of these cells, 53% had no overlap between the models and 47% of the cells had overlap between two of the given models. Only 32% of the cells had overlap between all three models. Table 2.7 is a matrix constructed to show the percentage of individual model overlap. As seen in the matrix, models one and three (random forest and maximum entropy, respectively) have the least overlap with only 32%. Models two and three (logistic regression and maximum entropy, respectively) have the greatest amount of overlap with 68%. Cells in models one and two (random forest and logistic regression, respectively) had 47% overlap.

DISCUSSION

The goal of this study was to improve species distribution models for Mexican Spotted Owls in Utah. Our models incorporate a variety of improved modeling techniques, combined with detailed GIS data to provide a robust forecast of Mexican Spotted Owl distribution. Our ensemble approach further provides eight potential distribution maps to assist managers tasked with the conservation and monitoring of Utah’s Mexican Spotted Owls (Figs. 2.3-2.11).

Previous Mexican Spotted Owl habitat models (Willey and Spotskey 1997, 2000) have laid the groundwork for our modeling efforts. Similar variables, such as curvature, were important in both the Willey and Spotskey models and our models. Our models have, however, improved predictions for Mexican Spotted Owl habitat in Utah compared to Willey and Spotskey (1997, 2000). The 1996 model, a supervised
classification model designed to predict "Prime Breeding Habitat" at the 1:100,000 scale, only captured 55.3% of our 94 presence sites used in this study, but also predicted significantly more habitat (9,409 km²) compared to our logistic regression (60.6% of sites captured and 6,255 km² habitat) and maximum entropy (77.7% of sites captured and 4,467 km²) models (Table 2.6). Although our random forest model predicted more habitat than the 1996 model it captured a much higher percent of known sites (14,696 km² and 96.8%). When comparing the results of the maximum entropy and 1996 models, it can be noted that the maximum entropy model improved overall predictability by capturing more owl sites in half the predicted area. The Willey and Spotskey 2000 model (1:250,000 scale) added thermal intensity and duration to the previous 1996 model in an attempt to identify cooler canyons. This model performed quite poorly, capturing only 4.3% of our 94 presence sites used in this study, while predicting nearly the same amount of habitat as our logistic regression model. An increase in known owl locations and incorporation of advances in GIS technology and new modeling approaches have resulted in substantial improvements to Mexican Spotted Owl habitat modeling and predictive capabilities compared to past models.

Overall, model performance for the random forest, logistic regression, and maximum entropy was comparable. While accuracy metrics were not precisely the same for all models, they were relatively similar (Table 2.4). According to AUC and specificity metrics maximum entropy performed best in predicting Mexican Spotted Owl distribution. The maximum entropy model also captured a large percentage (77.7%) of known owl sites while predicting the least amount of potential owl habitat (Table 2.6).
This suggests the model was both relatively precise and accurate, while not overestimating Spotted Owl presence for the region.

According to the concordance chart (Fig. 2.12) there was little overlap between the three models. This may be due in part to model inputs for individual model. While model inputs remained the same for the logistic regression and maximum entropy models, inputs were slightly different for the random forest model. Due to the modeling procedure for random forest, we used all six variable inputs including aspect. For the logistic regression and maximum entropy models aspect was removed as a variable due to insignificance determined by the step-wise model. This factor could have contributed to some of the variation seen between the three models. Overall, the random forest approach predicted two to three times the amount of habitat compared to the other two models (Table 2.6), which contributes to the low concordance between maps.

Habitat characteristics for Mexican Spotted Owls are variable throughout their range. Our logistic regression model showed that coniferous forest (typically dominated by *P. ponderosa*, *Abies* spp., and *Pseudotsuga menziesii*) and piñon-juniper (*Pinus* spp. and *Juniperus* spp.) woodlands had a significant positive correlation with Mexican Spotted Owl presence (Table 2.5). While many studies have considered coniferous forests an important feature of Mexican Spotted Owl habitat (Johnson 1997, May and Gutierrez 2002, Hathcock and Haarmann 2008), few studies have mentioned the importance of piñon-juniper woodlands (Ganey 2004, Mullet and Ward 2010). Furthermore, other studies have indicated tall trees, with large diameters (DBH) provide extensive amounts of canopy cover, and are considered critical components of nesting
habitat (Peery et al. 1999, May et al. 2004). Ganey (2004) found that mixed coniferous stands provide not only cover from predators, but also create a microclimate for owls that is vital in regulating temperatures of nest and roost sites. The sparsely distributed piñon-juniper woodlands of southern Utah do not likely provide the same overhead thermal cover described by Ganey and others (Ganey 2004, May et al. 2004). While some coniferous forest can be found in parts of southern Utah, such as Zion National Park and Cedar Mesa, many areas of the owls range (ex. Canyonlands National Park) are dominated by piñon-juniper landscapes that offer little usable vegetative cover for Spotted Owls. In these regions it is likely that the maze of canyon walls, slot canyons, and complex geomorphology provide the necessary cover and thermoregulation (Rinkevich and Gutierrez 1996, Willey 1998). Our study indicated that underlying topographic characteristics such as roughness and curvature are important for breeding Mexican Spotted Owls. These canyons may serve a similar purpose as forest canopies by providing thermal regulation, protection from predators, and nesting structure (Willey 1995, Willey 1998). Therefore, coniferous forest may not be a required habitat characteristic for Mexican Spotted Owls in all of Utah, and piñon-juniper woodlands should be considered an important habitat feature.

As suggested, canyon morphology is an important factor to consider when predicting Mexican Spotted Owl distributions, especially for those owls that do not use coniferous forest as nesting structures. Our logistic regression model showed surface ratio (topographic roughness) and curvature were significantly correlated with Mexican Spotted Owl presence (Table 2.5). A positive correlation with surface ratio indicates that
as the landscape becomes more complex, such as canyon formations, Spotted Owl presence increases. A negative correlation of curvature suggests that increased topographic concavity from the presence of canyons, significantly increase the probability of Mexican Spotted Owl presence. This supports the idea that Mexican Spotted Owls within the Colorado Plateau prefer steep, narrow, complex canyons for nest and roost sites (Rinkevich and Gutierrez 1996, Willey 1998, Willey and van Riper 2007). Cedar Mesa, Glen Canyon, and Oquirrh geology types were all positively correlated with Mexican Spotted Owl presence in the logistic regression model (Table 2.5). Of these formation types, Cedar Mesa Sandstone and Glen Canyon Group comprise the majority of southern Utah’s canyon landscapes and National Parks. Cedar Mesa Sandstone can be seen across southern Utah, and is most predominant in the Needles District of Canyonlands National Park. The Glen Canyon Group consists of the Wingate Sandstone, Kayenta Formation, and Navajo Sandstone formations. These formations can be found throughout southern Utah, where Navajo Sandstone is the most recognized in Capitol Reef and Zion National Park. These geologic formations are important for Mexican Spotted Owl habitat, because they comprise the majority of complex canyon structures across southern Utah, including steep, narrow slot canyons, such as “The Narrows” of Zion National Park. Again, these narrow and steep canyons are thought to provide thermoregulation for the owls, keeping them cool during extreme desert temperatures in the summer. Information on habitat quality, characteristics, and
productivity will further guide active adaptive management by state and federal agencies tasked with Mexican Spotted Owl conservation.

CONSERVATION AND MANAGEMENT IMPLICATIONS

Understanding habitat relationships is a crucial step in effective management of species populations at multiple scales. Relatively few Mexican Spotted Owl studies have focused on the arid canyonlands region of southern Utah. Insight into this landscape and its unique attributes will benefit management and conservation practices for this threatened species.

The use of a single distribution model for management practices introduces both uncertainty and risk factors, especially for conservation planning (Jones-Farrand et al. 2011). While this uncertainty is difficult to quantify, it can be seen when comparing model overlap (Fig. 2.11 – 2.12). Each model presented in this chapter is predicting habitat or species distribution slightly differently, presenting some uncertainty as to where managers should prioritize conservation efforts. While the random forest model broadly predicted Mexican Spotted Owl distribution, the maximum entropy model restricted owl distribution to a much tighter range. Each modeling approach analyzed the data slightly differently based on underlying mathematical equations (Segurado and Araújo 2004, Elith and Graham 2009). Therefore, caution should be taken when choosing a model for management and conservation planning, because different models may lead to different conservation strategies (Jones-Farrand et al. 2011). Managers can minimize the risks accompanied with using a single model by implementing an ensemble
model. Ensemble models provide robust predictions, especially when underlying model accuracy metrics are comparable, which was the case with each of our three individual models (Jones-Farrand et al. 2011).

While all of these models performed well, with reasonably high accuracy metrics (Table 2.4), their application will ultimately depend on conservation and management goals. Managers need to use their best judgment in selecting an appropriate model that is suited for their region of interest. The predictive distribution models provided here can be used to identify potential Mexican Spotted Owl sites. For example, managers can use the ensemble probability distribution map to select future sites for breeding Mexican Spotted Owl occupancy surveys. This can easily be accomplished by selecting a region of interest, such as Capitol Reef National Park, and looking for areas with, for example, a probability > 0.75, suggesting a high likelihood of Mexican Spotted Owl presence or suitable habitat. However, probability thresholds are set at the manager’s discretion according to project needs. By prioritizing regions with high probability, managers can optimize their survey efforts, especially when funding is limited. These distribution models will allow managers to better survey, monitor, and manage Utah’s population of Mexican Spotted Owls.

Managers should remember that species distribution models are a simplified representation of a complex ecological system. Therefore, they will always have errors and never fully explain complex biological relationships. However, they can be a useful tool for inference and conservation management by providing insight on where to focus survey efforts and habitat protections.
Future studies and management of Mexican Spotted Owls should focus on the development of a suitable sampling scheme designed to collect reliable occupancy data (presence and absence) that will allow for unbiased modeling. Opportunistic collection of occupancy or habitat data should be avoided and researchers should focus on establishing a sampling framework that will adequately survey the target species and suitable habitat (Yackulic et al. 2013). Managers should use these models for selection of sampling sites for Mexican Spotted Owls in order to develop a comprehensive occupancy sampling scheme (USFWS 2012). Application of these models for management purposes is discussed further in Chapter 3. In addition, understanding the owl’s productivity, prey base, and winter movements in Utah will provide insights into population dynamics and species limitations. Emphasis should also be given to studying the microclimates within these canyons. Researchers can use current technologies, such as data loggers, to capture temperature and humidity in canyon floodplains, roost locations, and nest caves. Focusing future research on these topics will aid in the long-term conservation and management of Mexican Spotted Owls in Utah.

REFERENCES


Environmental Systems Research Institute. 2010. ArcGIS 10.0. ESRI, Redlands, California, USA.


Guisan, A., R. Tingley, J. B. Baumgartner, I. Naujokaitis-Lewis, P. R. Sutcliffe, A. I. T. Tulloch, T. J. Regan, L. Brotons, E. McDonald-Madden, C. Mantyka-Pringle, T. G.
Wintle, O. Broennimann, M. Austin, S. Ferrier, M. R. Kearney, H. P. Possingham,
and Y. M. Buckley. 2013. Predicting species distributions for conservation

The birds of North America Online, Ithaca: Cornell Lab of Ornithology.
http://bna.birds.cornell.edu/bna/species/179

habitat of the Mexican Spotted Owl in northern New Mexico. Southwestern
Naturalist 53:34-38.


Johnson, C. L. 1997. Distribution, habitat, and ecology of the Mexican Spotted Owl in

Jones-Farrand, D. T., T. M. Fearer, W. E. Thogmartin, F. R. Thompson, M. D. Nelson, and
conservation planning: the benefit of ensemble prediction. Ecological

Lobo, J. M., and M. F. Tognelli. 2011. Exploring the effects of quantity and location of
pseudo-absences and sampling biases on the performance of distribution models


Peery, M. Z., R. J. Gutierrez, and M. E. Seamans. 1999. Habitat composition and
configuration around Mexican Spotted Owl nest and roost sites in the Tularosa

http://www.cs.princeton.edu/~schapire/maxent/


R Development Core Team. 2013. R: A language and environment for statistical

Rinkevich, S. E., and R. J. Gutierrez. 1996. Mexican Spotted Owl habitat characteristics in

version 1.6-1.


U.S. Fish and Wildlife Service. 1993. Endangered and threatened wildlife and plants:
final rule to list the Mexican Spotted Owl as a threatened species. Federal
Register. 58:14248-14271.

U.S. Fish and Wildlife Service. 2012. Final recovery plan for the Mexican Spotted Owl
(Strix occidentalis lucida), First Revision, Albuquerque, New Mexico, USA.

Utah Climate Center and Utah State University. 2006-2011. Utah Climate Center
Willey, D. W. 1995. Movements and habitat ecology of Mexican Spotted Owls in southern Utah. Utah Division of Wildlife Resources, Salt Lake City, Utah, USA.


Willey, D. W., and D. Spotskey. 2000. GIS habitat model for Mexican Spotted Owl habitat in Utah. Unpublished report, Utah Division of Wildlife Resources, Salt Lake City, Utah, USA.


TABLE 2.1. Predictor variables used in modeling probability of presence for Mexican Spotted Owls.

<table>
<thead>
<tr>
<th>Variable (raster)</th>
<th>Units</th>
<th>Resolution</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation (DEM)</td>
<td>meters</td>
<td>30 x 30</td>
<td><a href="http://www.gis.utah.gov">www.gis.utah.gov</a></td>
</tr>
<tr>
<td>Aspect</td>
<td>meters</td>
<td>30 x 30</td>
<td>derived from 30m DEM</td>
</tr>
<tr>
<td>Curvature</td>
<td>meters</td>
<td>30 x 30</td>
<td>derived from 30m DEM</td>
</tr>
<tr>
<td>Surface Ratio</td>
<td>meters</td>
<td>30 x 30</td>
<td>derived from 30m DEM</td>
</tr>
<tr>
<td>Vegetation</td>
<td>meters</td>
<td>30 x 30</td>
<td><a href="http://www.landfire.gov">www.landfire.gov</a></td>
</tr>
<tr>
<td>Geology</td>
<td>meters</td>
<td>1800 x 1800</td>
<td><a href="http://www.geology.utah.gov/maps">www.geology.utah.gov/maps</a></td>
</tr>
</tbody>
</table>

TABLE 2.2. Original and re-classified Landfire vegetative attributes. The “other” category was excluded from modeling because these types were highly unsuitable owl habitat.

<table>
<thead>
<tr>
<th>Re-classified Vegetative Attribute</th>
<th>Landfire Vegetative Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chaparral</td>
<td>Curleaf Mountain-Mahogany</td>
</tr>
<tr>
<td>Other</td>
<td>Developed</td>
</tr>
<tr>
<td>Coniferous Forest</td>
<td>Engelmann Spruce-Subalpine Fir</td>
</tr>
<tr>
<td>Chaparral</td>
<td>Gambel Oak</td>
</tr>
<tr>
<td>Other</td>
<td>Grama-Galetta</td>
</tr>
<tr>
<td>Sagebrush Steppe</td>
<td>Grama-Tobosa Shrub</td>
</tr>
<tr>
<td>Riparian</td>
<td>Great Plains Riparian</td>
</tr>
<tr>
<td>Coniferous Forest</td>
<td>Interior Douglas-Fir</td>
</tr>
<tr>
<td>Coniferous Forest</td>
<td>Interior Ponderosa Pine</td>
</tr>
<tr>
<td>Other</td>
<td>Introduced Upland Vegetation-Herbaceous</td>
</tr>
<tr>
<td>Riparian</td>
<td>Introduced Woody Wetlands and Riparian Vegetation</td>
</tr>
<tr>
<td>Pinyon-Juniper Woodland</td>
<td>Juniper-Pinyon Pine Woodland</td>
</tr>
<tr>
<td>Pinyon-Juniper Woodland</td>
<td>Juniper-Pinyon Woodland</td>
</tr>
<tr>
<td>Coniferous Forest</td>
<td>Limber Pine</td>
</tr>
<tr>
<td>Coniferous Forest</td>
<td>Lodgepole Pine</td>
</tr>
<tr>
<td>Original Geologic Attribute</td>
<td>Re-classified Geologic Attribute</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Sagebrush Steppe</td>
<td>Low Sagebrush</td>
</tr>
<tr>
<td>Chaparral</td>
<td>Mesquite</td>
</tr>
<tr>
<td>Sagebrush Steppe</td>
<td>Mountain Big Sagebrush</td>
</tr>
<tr>
<td>Mixed Desert Shrubland</td>
<td>Palo Verde-Cactus</td>
</tr>
<tr>
<td>Other</td>
<td>Recently Burned-Herbaceous</td>
</tr>
<tr>
<td>Riparian</td>
<td>Riparian</td>
</tr>
<tr>
<td>Other</td>
<td>Rough Fescue-Bluebunch Wheatgrass</td>
</tr>
<tr>
<td>Other</td>
<td>Rough Fescue-Idaho Fescue</td>
</tr>
<tr>
<td>Mixed Desert Shrubland</td>
<td>Salt Desert Shrub</td>
</tr>
<tr>
<td>Mixed Desert Shrubland</td>
<td>Saltbush-Greasewood</td>
</tr>
<tr>
<td>Sagebrush Steppe</td>
<td>Sandsage Prairie</td>
</tr>
<tr>
<td>Pinyon-Juniper Woodland</td>
<td>Sideoats Grama-Sumac-Juniper</td>
</tr>
<tr>
<td>Other</td>
<td>Snow-Ice</td>
</tr>
<tr>
<td>Sagebrush Steppe</td>
<td>Sparsely Vegetated</td>
</tr>
<tr>
<td>Other</td>
<td>Tall Forb</td>
</tr>
<tr>
<td>Other</td>
<td>Transitional Herbaceous Vegetation</td>
</tr>
<tr>
<td>Other</td>
<td>Water</td>
</tr>
<tr>
<td>Chaparral</td>
<td>Western Live Oak</td>
</tr>
<tr>
<td>Other</td>
<td>Wheatgrass-Bluestem-Needlegrass</td>
</tr>
<tr>
<td>Coniferous Forest</td>
<td>White Fir</td>
</tr>
<tr>
<td>Coniferous Forest</td>
<td>Whitebark Pine</td>
</tr>
<tr>
<td>Sagebrush Steppe</td>
<td>Wyoming Big Sagebrush</td>
</tr>
</tbody>
</table>

TABLE 2.3. Original and re-classified geologic attributes. The “other” category was excluded from modeling because these types were highly unsuitable owl habitat.
<table>
<thead>
<tr>
<th>Other</th>
<th>Duchesne River, Uinta, Bridger, Crazy Hollow and other Forms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other</td>
<td>Evanston, North Horn, Currant Creek, Canaan Peak and other Forms</td>
</tr>
<tr>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moenave Forms) and Nugget Ss</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moenave Forms) and Nugget Ss</td>
</tr>
<tr>
<td>Other</td>
<td>Great Blue, Humbug, Deseret and other Forms</td>
</tr>
<tr>
<td>Other</td>
<td>Green River, Fowkes and other Forms</td>
</tr>
<tr>
<td>Other</td>
<td>high-level alluvial deposits</td>
</tr>
<tr>
<td>Other</td>
<td>Indianola, Mancos, Frontier, Straight Cuffs, Iron Springs and other Forms</td>
</tr>
<tr>
<td>Other</td>
<td>intrusive rocks-Tertiary</td>
</tr>
<tr>
<td>Other</td>
<td>Kaibab, Toroweap, Park City and other Forms</td>
</tr>
<tr>
<td>Other</td>
<td>Mesaverde Group, Price River, Kaiparowits, Echo Canyon and other Forms</td>
</tr>
<tr>
<td>Other</td>
<td>metamorphic rocks</td>
</tr>
<tr>
<td>Moenkopi, Dinwoody, Woodside, Thaynes and other Forms</td>
<td>Moenkopi, Dinwoody, Woodside, Thaynes and other Forms</td>
</tr>
<tr>
<td>Other</td>
<td>Morgan, Round Valley, Honaker Trail, Paradox, Ely and other Forms</td>
</tr>
<tr>
<td>Other</td>
<td>Morrison Form</td>
</tr>
<tr>
<td>Other</td>
<td>Playa</td>
</tr>
<tr>
<td>Other</td>
<td>Prospect Mountain, Tintic, Ignacio, Geertsen Canyon and other Forms</td>
</tr>
<tr>
<td>Other</td>
<td>Redwall, Madison, Gardison, Ludgepole and other Forms</td>
</tr>
<tr>
<td>Other</td>
<td>Salt Lake Form and other valley-filling alluvial, lacustrine, and volcanic units</td>
</tr>
<tr>
<td>Other</td>
<td>sedimentary and metasedimentary Forms</td>
</tr>
<tr>
<td>Other</td>
<td>Sevier River, Browns Park, Castle Valley Forms</td>
</tr>
<tr>
<td>Summerville, Entrada, Carmel, Arapien, Twin Creek and other Forms</td>
<td>Summerville, Entrada, Carmel, Arapien, Twin Creek and other Forms</td>
</tr>
<tr>
<td>Other</td>
<td>surficial alluvium and colluvium</td>
</tr>
<tr>
<td>Other</td>
<td>surficial eolian deposits</td>
</tr>
<tr>
<td>------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>Other</td>
<td>surficial glacial deposits</td>
</tr>
<tr>
<td>Other</td>
<td>surficial Lake Bonneville deposits</td>
</tr>
<tr>
<td>Other</td>
<td>surficial landslide deposits</td>
</tr>
<tr>
<td>Other</td>
<td>surficial older alluvium and colluvium</td>
</tr>
<tr>
<td>Other</td>
<td>volcanic rocks</td>
</tr>
<tr>
<td>Other</td>
<td>volcanic rocks-basalt, rhyolite, andesite, tuffaceous rocks</td>
</tr>
<tr>
<td>Other</td>
<td>volcanic rocks-mostly basalt</td>
</tr>
<tr>
<td>Other</td>
<td>volcanic rocks-rhyolite</td>
</tr>
<tr>
<td>Other</td>
<td>volcanic rocks-Tertiary</td>
</tr>
<tr>
<td>Wasatch, Cotton, Flagstaff, Claron, White Sage and other Forms</td>
<td>Wasatch, Cotton, Flagstaff, Claron, White Sage and other Forms</td>
</tr>
<tr>
<td>Other</td>
<td>Water</td>
</tr>
</tbody>
</table>

TABLE 2.4. Accuracy metrics for logistic regression, random forest, and maximum entropy predicting probability of presence for Mexican Spotted Owls as a function of the following habitat variables: slope, elevation, surface ratio, curvature, vegetation, and aspect.

<table>
<thead>
<tr>
<th>Model</th>
<th>PCC</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>AUC</th>
<th>TSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random Forest</td>
<td>0.833</td>
<td>0.819</td>
<td>0.834</td>
<td>0.903</td>
<td>0.653</td>
</tr>
<tr>
<td>Logistic Regression</td>
<td>0.805</td>
<td>0.894</td>
<td>0.796</td>
<td>0.910</td>
<td>0.689</td>
</tr>
<tr>
<td>Maximum Entropy</td>
<td>0.925</td>
<td>0.826</td>
<td>0.928</td>
<td>0.927</td>
<td>0.754</td>
</tr>
</tbody>
</table>

PCC = percent correct classification, AUC = area under the curve, TSS = true skill statistic (sensitivity + specificity -1)
TABLE 2.5. Variable coefficients (SE), z-statistic, and p-values for logistic regression step model predicting probability of presence for Mexican Spotted Owls as a function of habitat characteristics.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>SE</th>
<th>z-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-10.200</td>
<td>1.880</td>
<td>-5.41</td>
<td>&lt; 0.01*</td>
</tr>
<tr>
<td>Elevation</td>
<td>-0.0027</td>
<td>0.0006</td>
<td>-4.27</td>
<td>&lt; 0.01*</td>
</tr>
<tr>
<td>Curvature</td>
<td>-0.0441</td>
<td>0.1360</td>
<td>-3.26</td>
<td>&lt; 0.01*</td>
</tr>
<tr>
<td>Surface Ratio</td>
<td>7.3700</td>
<td>0.7530</td>
<td>9.80</td>
<td>&lt; 0.01*</td>
</tr>
<tr>
<td>Vegetation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barren</td>
<td>0.5250</td>
<td>0.8070</td>
<td>0.65</td>
<td>0.5151</td>
</tr>
<tr>
<td>Chaparral</td>
<td>0.1340</td>
<td>0.1570</td>
<td>0.85</td>
<td>0.3935</td>
</tr>
<tr>
<td>Deciduous Forest</td>
<td>-4.2300</td>
<td>1.6600</td>
<td>-2.55</td>
<td>&lt; 0.01*</td>
</tr>
<tr>
<td>Coniferous Forest</td>
<td>2.8900</td>
<td>1.2200</td>
<td>2.37</td>
<td>&lt; 0.05*</td>
</tr>
<tr>
<td>Mixed Desert Shrubland</td>
<td>0.7130</td>
<td>0.7950</td>
<td>0.90</td>
<td>0.3698</td>
</tr>
<tr>
<td>Pinyon-Juniper Woodland</td>
<td>2.4900</td>
<td>0.8080</td>
<td>3.08</td>
<td>&lt; 0.01*</td>
</tr>
<tr>
<td>Riparian</td>
<td>1.1700</td>
<td>1.3700</td>
<td>0.85</td>
<td>0.3964</td>
</tr>
<tr>
<td>Geology</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chinle</td>
<td>-0.5532</td>
<td>1.5859</td>
<td>-0.35</td>
<td>0.7272</td>
</tr>
<tr>
<td>Cedar Mesa</td>
<td>4.0400</td>
<td>1.1400</td>
<td>3.54</td>
<td>&lt; 0.01*</td>
</tr>
<tr>
<td>Glen Canyon</td>
<td>2.7100</td>
<td>1.1200</td>
<td>2.42</td>
<td>&lt; 0.05*</td>
</tr>
<tr>
<td>Moenkopi</td>
<td>0.5400</td>
<td>1.5900</td>
<td>0.34</td>
<td>0.7337</td>
</tr>
<tr>
<td>Oquirrh</td>
<td>3.4500</td>
<td>1.3200</td>
<td>2.60</td>
<td>&lt; 0.01*</td>
</tr>
<tr>
<td>Summerville</td>
<td>0.5440</td>
<td>1.2800</td>
<td>0.43</td>
<td>0.6697</td>
</tr>
<tr>
<td>Wasatch</td>
<td>1.8200</td>
<td>1.1800</td>
<td>1.53</td>
<td>0.1249</td>
</tr>
</tbody>
</table>

* Indicates significance; Major geologic variable listed, see Table 2.3 for full geologic descriptions.
TABLE 2.6. Model comparison showing percent Mexican Spotted Owl points captured within the species distribution model prediction layer. All models compared using the 94 presence points in our study.

<table>
<thead>
<tr>
<th>Model</th>
<th>Total Owl Points</th>
<th>Owl Points Captured</th>
<th>Owl Points Captured (%)</th>
<th>Total Predicted Distribution Area (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random Forest (classification)</td>
<td>94</td>
<td>91</td>
<td>96.8</td>
<td>14,696</td>
</tr>
<tr>
<td>Logistic Regression (classification)</td>
<td>94</td>
<td>57</td>
<td>60.6</td>
<td>6,255</td>
</tr>
<tr>
<td>Maximum Entropy (classification)</td>
<td>94</td>
<td>73</td>
<td>77.7</td>
<td>4,467</td>
</tr>
<tr>
<td>1996 Model¹</td>
<td>94</td>
<td>52</td>
<td>55.3</td>
<td>9,409</td>
</tr>
<tr>
<td>2000 Model¹</td>
<td>94</td>
<td>4</td>
<td>4.3</td>
<td>6,617</td>
</tr>
</tbody>
</table>


TABLE 2.7. Model Overlap showing the percentage of cells that overlap between models. Where RF= random forest, LR= logistic regression, and ME= maximum entropy.

<table>
<thead>
<tr>
<th></th>
<th>Model 1 (RF)</th>
<th>Model 2 (LR)</th>
<th>Model 3 (ME)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1 (RF)</td>
<td>100%</td>
<td>47%</td>
<td>32%</td>
</tr>
<tr>
<td>9,722,424 cells</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 2 (LR)</td>
<td>47%</td>
<td>100%</td>
<td>68%</td>
</tr>
<tr>
<td>4,579,429 cells</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 3 (ME)</td>
<td>32%</td>
<td>68%</td>
<td>100%</td>
</tr>
<tr>
<td>3,092,842 cells</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FIG. 2.1. Map of Mexican Spotted Owl study area in Utah.
FIG. 2.2. Map of habitat envelope for Mexican Spotted Owls that was used to select pseudo-absence points.
FIG. 2.3. Map of random forest species distribution classification model for Mexican Spotted Owls, where a value of 0 indicates absence and a value of 1 indicates presence.
FIG. 2.4. Map of logistic regression species distribution classification model for Mexican Spotted Owls, where a value of 0 indicates absence and a value of 1 indicates presence.
FIG. 2.5. Map of maximum entropy species distribution classification model for Mexican Spotted Owls, where a value of 0 indicates absence and a value of 1 indicates presence.
FIG. 2.6. Map of random forest species distribution probability model for Mexican Spotted Owls, where a value of 0 indicates absence and a value of 0.99 indicates a high probability of presence.
FIG. 2.7. Map of logistic regression species distribution probability model for Mexican Spotted Owls, where a value of 0 indicates absence and a value of 1 indicates a high probability of presence.
FIG. 2.8. Map of maximum entropy species distribution probability model for Mexican Spotted Owls, where a value of 0 indicates absence and a value of 0.98 indicates a high probability of presence.
FIG. 2.9. Probability map of ensemble species distribution model for Mexican Spotted Owls, where a value of 0 indicates absence and a value of 0.94 indicates a high probability of presence.
FIG. 2.10. Map of ensemble uncertainty. Shows range of standard deviation when compared to model mean of ensemble probability model (Fig. 2.8).
FIG. 2.11. Classification map for ensemble species distribution model for Mexican Spotted Owls, where a value of 0 indicates absence and a value of 3 indicates a high likelihood of presence. Also shows model overlap where a value of 1 indicates no model overlap, a value of 2 indicates two models overlap, and a value of 3 indicates all models (three) overlap.
FIG. 2.12. Concordance chart showing the number of predicted presence cells that overlap between the random forest, maximum entropy, and logistic regression distribution models. A value of 1 indicates number of cells with no overlap, a value of 2 indicates number of cells where 2 models overlapped, and a value of 3 indicates number of cells where all 3 models overlapped.
FIG. 2.13. Variable Importance plots for random forest model (pa~curve+asp+elev+surf+geo+veg). Where curv=curvature, asp=aspect, elev=elevation, surf=surface ratio, geo=geology, and veg=vegetation. These plots are interpreted by reading top-down, from right to left and looking for any natural “breaks” or gaps that occur between points (indicated by vertical lines). Therefore, the Mean Decrease Accuracy plot on the left indicates that surface ratio (surf) is the most important variable for predicting Mexican Spotted Owl presence. The Mean Decrease Gini plot indicates that surface ratio (surf) is the most important variable for predicting Mexican Spotted Owl presence with curvature (curve) as the second most important variable for predicting Mexican Spotted Owl presence.
CHAPTER 3
MEXICAN SPOTTED OWL (STRIX OCCIDENTALIS LUCIDA) HABITAT: MANAGEMENT AND
CONSERVATION IMPLICATIONS FOR A THREATENED SPECIES IN THE COLORADO
PLATEAU OF UTAH

Abstract. Mexican Spotted Owls (Strix occidentalis lucida) are a threatened
species found in the southwestern United States, including the canyonlands of the
Colorado Plateau. Although their range extends into Arizona, New Mexico, Colorado,
and central Mexico, this study focuses on owls in the canyon regions of southern Utah.
While owl habitat throughout most of their range is better understood, canyon habitats
have received little study. Therefore, to help guide future management decisions, more
information on these unique canyon habitats is required. We measured vegetation and
geology variables at 27 Mexican Spotted Owl sites across southern Utah. While logistic
modeling was inconclusive, paired t-tests allowed for mean comparisons between
variables of presence and absence sites. Occupied sites had significantly narrower
canyon width (or mean belt area), greater canopy cover, and higher vegetation density
in areas of taller vegetation (> 2.5 m) compared to unoccupied sites. This study suggests
pairing previous distribution models, presented in Chapter 2, with the newly developed
Cross-Canyon Transect Tool to aid managers in model refinement and survey efforts.
Combining these newly developed tools with habitat descriptions will allow for better
management and conservation of Mexican Spotted Owls.
Managers face a variety of challenges in managing Mexican Spotted Owls (*Strix occidentalis lucida*) throughout the Colorado Plateau. Mexican Spotted Owl surveys can be demanding and time consuming, especially when much of their habitat is rugged canyon terrain. Furthermore, little is known about their specific habitat characteristics, making it difficult for managers to decide where to survey, particularly when faced with an extensive maze of canyon walls. These owls are considered rare and elusive across the landscape and detection is not always guaranteed. Establishing management priorities for this species is crucial, since it is listed as a threatened species by the U.S. Fish and Wildlife Service (USFWS) (USFWS1993). One of the first steps in managing a threatened species, such as Mexican Spotted Owls, is identifying habitat characteristics.

Studies by Rinkevich (1991), Willey (1998), and Willey and van Riper (2007) describe several main habitat characteristics; however few studies have quantified vegetation and geology aspects associated with occupied Mexican Spotted Owl sites in canyon environments. This may be due, in part, to the difficulty of accessing some of these sites and establishing a method conducive to measuring vegetation and geology structures within small canyons.

Studies on Mexican Spotted Owl habitat, in both canyon and mountain regions, have suggested a variety of habitat requirements. Hathcock and Haarmann (2008) studied Mexican Spotted Owl habitat in northern New Mexico, where owls prefer forests and stick nests for breeding. They suggested that tree height and density, canopy
cover, and shrub density were all positively correlated with Spotted Owl occupancy, while density of snags was negatively correlated. Of these characteristics they indicated that tree diversity was the most significant vegetation characteristic of occupied sites. Mullet and Ward (2010) measured Mexican Spotted Owl characteristics near nest and roost sites in the Guadalupe Mountains of New Mexico and Texas. Their study found no statistically significant difference in tree diameter, tree layering, or species composition, and suggested that these characteristics may not be important on a microhabitat scale, especially for canyon dwelling owls. They further indicated that owl nests were typically located in dense patches of vegetation and generally found within the mid-story canopy located near the end of deep, narrow canyons (Mullet and Ward 2010). Although all Mexican Spotted Owl nests were stick nests located in dense canopies within canyons in their study, Mexican Spotted Owls in Utah have never been documented nesting within a stick nest or in a dense canopy.

Mexican Spotted Owl habitat within Utah may have some similarities to the studies outlined above; however, more extensive research is needed for these unique sites. Studies on home range and ecology of Mexican Spotted Owls in Utah suggest they prefer extremely narrow and deep canyons (Rinkevich and Gutierrez 1996). Typically, occupied canyon sites in Utah have very little canopy structure and vegetation is found in patches or stringers, with the presence of large conifers being rare (Willey 1998, Mullet and Ward 2010).

The research and models presented in Chapter 2 indicated there are several important habitat variables for canyon dwelling owls in the Colorado Plateau.
Topographic roughness was positively correlated with owl presence, indicating that the presence of steep walled canyons is an important habitat factor for Mexican Spotted Owls within the Colorado Plateau, as has also been shown Mullet and Ward (2010). Our study also indicated that coniferous forest and piñon-juniper woodlands are important vegetation for canyon dwelling Mexican Spotted Owls. While it is unclear what benefits piñon-juniper landscapes provide for Mexican Spotted Owls, this vegetation should be considered an important habitat element throughout much of their range in the Colorado Plateau within Utah.

Species distribution models (SDM), paired with habitat descriptions, are an important tool for management and conservation of threatened species (Guisan and Zimmermann 2000, Guisan et al. 2013). There are many benefits to the use of SDMs in conservation and species management. SDMs can provide information useful for the management of biological invasions, selection of species reserves, decisions on translocation or re-introduction, and identification or protection of important habitat areas (Franklin 2013, Guisan et al. 2013). Since SDMs predict regions of species occupancy, managers can use them to target specific areas for monitoring and surveys, thereby saving time and money when establishing a new survey plan (Guisan et al. 2013). This approach is a cost effective tool that prevents managers from spending time and money in less favorable habitats and may lead to discovery of previously undocumented sites or populations (Franklin 2013, Guisan et al. 2013). Over time, this newly acquired data can be used to refine current SDMs, which may lead to improved models and new management objectives (Guisan et al. 2013). How these models are
applied depends on their construction methods and management objectives. Increased knowledge and improved data on how managers employ SDMs are needed to further support these benefits within the scientific literature (Guisan et al. 2013).

This Chapter will discuss Mexican Spotted Owl habitat in southern Utah and how managers can combine the use of habitat descriptions and geospatial information system (GIS) tools, with the SDMs presented in Chapter 2. By combining SDMs with habitat descriptions managers will be able to implement adaptive management strategies for Mexican Spotted Owls in Utah. Chapter 3 will specifically cover: (1) Mexican Spotted Owl surveys and measurement of vegetation and geology at occupied and unoccupied sites, (2) application of the Cross-Canyon Transect Tool (CCTT) within ArcMap 10.1 (Environmental Systems Research Institute 2010, Crabb et al. 2012), (3) use of SDMs with the CCTT, and (4) future management and conservation implications for Mexican Spotted Owls.

METHODS

Study Species

There are three subspecies of Spotted Owls within North America: Northern Spotted Owls (*S. o. caurina*), found in the Northwest region of the United States, California Spotted Owls (*S. o. occidentalis*), found in California, and Mexican Spotted Owls (*S. o. lucida*) found throughout Arizona, New Mexico, Colorado, Utah and central Mexico (Gutierrez et al. 1995). While there has been extensive research conducted on
Northern Spotted Owls and their habitat, little attention has been given to Mexican Spotted Owls, especially in Utah.

Mexican Spotted Owls perform a variety of calls that can sometimes vary depending on individuals. Their calls are typically composed of a variety of hoots, barks, and whistles (Forsman et al. 1984). The most common calls given by Spotted Owls include the “four-note location call” and the “contact call.” While some owls will perform variations of the four-note call, including a two or three note call, the location call is typically given to reveal the owl’s location to a mate. It can also be given to indicate territory rights. The contact call is typically given by females and juveniles in response to a location call. This call allows the female to provide their location to a male Spotted Owl (Forsman et al. 1984).

Study Area

The study area encompasses the greater canyonlands region of southern Utah, where Mexican Spotted Owls are frequently detected (Fig. 3.1). Study sites were located within Canyonlands, Capitol Reef, and Zion National Parks. The Grand Staircase-Escalante National Monument and the Bureau of Land Management (BLM) districts surrounding the National Parks were also included. These areas range in elevation from approximately 1,525 m to 2,745 m and are characterized by steep rock formations and complex canyon structures. Mean annual precipitation for study sites range from 19.7 cm to 39.9 cm. Sites are characterized by desert temperatures ranging from -6°C to 46°C (21°F to 115°F) (Utah Climate Center and Utah State University 2006-2011).
Site Selection

Site selection was based on historical Mexican Spotted Owl occupancy records provided by National Park Service (NPS), BLM, Fish and Wildlife Service (USFWS), and Utah Division of Wildlife Resources (UDWR). An occupancy database was created with this data using Microsoft Access to organize all Mexican Spotted Owl records. Survey sites were selected if they had a Mexican Spotted Owl presence record within the last 25 years. Sites that were logistically difficult or too dangerous to access were eliminated from final selection. Based on these restrictions, 37 sites were used for this study.

Mexican Spotted Owl Surveys

Occupancy sampling was conducted within canyon habitats to locate Mexican Spotted Owls. Survey canyons were selected based on: (1) historical occupancy data and (2) a historical predictive habitat model (Willey and Spotskey 2000).

We conducted a total of 67 surveys at the 37 different canyon sites during the 2011 field season. During the 2012 field season, Mexican Spotted Owl surveys were conducted opportunistically at 27 historic sites during vegetation and geology surveys. Each canyon was surveyed using a standard occupancy sampling scheme. For rare species, it is more efficient to survey a higher number of sites, with fewer repeat visits, than it is to survey fewer canyons with more visits (Mackenzie and Royle 2005). A potential problem is biased occupancy estimates that result when a species is not detected within the sampling unit, but is actually present. These “false absences”
underestimate the true occupancy for a particular habitat. In order to minimize false
absences, canyons were sampled with two repeat visits within a short timeframe
(Mackenzie and Royle 2005). In addition, a removal sampling design was incorporated
into this standard design. Thus, selected canyons were surveyed with a maximum of 2
visits per canyon. However, if a Mexican Spotted Owl was detected on the first visit,
surveys ended for that canyon (removal design). If a Mexican Spotted Owl was not
detected on the first visit, a second survey was performed (standard design).

Methods described by USFWS (2003) were used to detect Mexican Spotted Owls.
Survey design included a single calling route for each canyon with three to six calling
stations (or call points) depending on canyon length. Calling routes began up canyon
and ended down canyon. Calling stations were dispersed along calling routes
approximately 0.4 - 0.8 km apart. Surveys were conducted during the two hours after
dusk or two hours prior to dawn, as this is when owls are most vocally active (Forsman
et al. 1984). Spotted Owl calls were imitated by the surveyor to provoke a response
from owls. A variety of whistles, four-note, and agitated bark calls were used to attract
owls. This “hoot ing” procedure was conducted at each calling station for 20 - 30
minutes. During this time, 10 - 15 minutes were devoted to hooting, and the remaining
10 - 15 minutes were used to listen for a response. Hooting and listening were
alternated in 3 - 5 minute intervals during the calling period. If an owl was detected at
any point during the survey, the sex, species, call type, time, and location were
recorded. If a Mexican Spotted Owl was detected, the survey ended for that canyon. If a
Great Horned Owl (Bubo virginianus) was detected, the survey was terminated to avoid
potential confrontation between competing owl species (U.S. Fish and Wildlife Service 2003). As noted, if a Mexican Spotted Owl was detected during a survey, no additional nighttime surveys were performed. However, a follow-up daytime visit was conducted within seven days of the detection, during which a comprehensive search was performed in combination with continuous calling to locate the owl’s nest or roost site. Sites were classified as either a presence, when a Mexican Spotted Owl was detected, or an absence, when no Mexican Spotted Owls were detected.

**Vegetation Sampling**

Vegetation surveys were conducted at a total of 27 sites across three National Parks and two BLM districts. Mexican Spotted Owls were not detected at twelve of these sites and the remaining 15 were classified as owl presence sites. Vegetation surveys were conducted at three sampling belts for every canyon site using 10-meter wide belt transects (Fig. 3.2). For occupied canyons, the center belt was located at the nest or roost site. For unoccupied canyons, the center belt was placed at the historic location of the nest or roost site. If the historic nest/roost site was unknown, then the center sampling belt was placed at a randomly selected survey point, which was used during prior owl surveys (e.g. a canyon was previously inventoried for an owl using 4 calling stations and one of these stations was randomly selected and treated as the “nest/roost” site). The two remaining vegetation belts were placed 200 m above and 200 m below the center belt.
The following methods were applied for each vegetation sampling station. First, the aspect of the canyon was recorded and a line perpendicular (i.e. 90° and 270°) to the aspect was established along the floodplain using a 50 m tape. The perpendicular line extended the entire width between the canyon walls; therefore; transect length was dependent on canyon width and varied between transects and canyon sites. This perpendicular line served as the center transect for the 10 m wide belt, creating a bounded strip of 5 m on each side (Fig. 3.3). Dominant vegetation that fell within the 10-m-wide belt was recorded. If vegetation crossed the outer boundary of the belt, it was only measured if more than 50% of the vegetative mass fell within the belt.

Presence of canopy cover was recorded along the center line. Species, height, diameter at breast height (DBH), and tree or shrub condition (dead or live) were recorded for every tree and shrub within the belt. Tree DBH was measured and placed into one of five size classes: (1) < 15.2 cm (<6 in), (2) 15.2 – 30.5 cm (6 – 12 in), (3) 30.5 – 45.7 cm (12 – 18 in), (4) 45.7 – 61 cm (18 – 24 in), (5) > 61 cm (>24 in). Transect length (total length of transect), meter mark (location of plant), and distance from the center line to vegetation was also recorded for every tree or shrub within the belt.

In order to accommodate a wide variety of canyons and conditions, additional methods were established for selected belt transects. For areas with dense vegetation, that was either too thick to travel or see through, the total belt width was reduced from 10 m to 5 m, with the center line at the 2.5 meter mark. For canyons with only one wall, the belt terminated at the nearest channel edge of the floodplain.
Geology Sampling

Geology surveys were also performed at these 27 sites. Geology surveys were conducted at each of the three vegetation belt transects as well as at two additional geology transects established 100 m up canyon and 100 m down canyon from the center sampling belt. This resulted in five geology belt transects, spaced 100 m apart (Fig. 3.2). Vertical sight lines were established on canyon walls by extending the vegetation sampling belt up from the base of the canyon wall. Using a rangefinder and clinometer, a baseline measurement of distance and angle was taken for the base of the canyon wall, while standing on the center line in the floodplain. The canyon wall was then classified using seven predefined structural features: (1) “bench”- a horizontal surface > 1 m wide and 1 m deep, (2) “cave”- an opening > 1 m high x 1 m wide x 1 m deep, (3) “cliff”- a vertical or near vertical surface with a slope of 80° - 90°, (4) “ledge”- a horizontal surface 0.3 - 1 m wide, (5) “overhang”- a surface with an angle > 90°, (6) “solution cavity”- a rounded, shallow opening < 0.3 m deep, and (7) “slope”- an angled surface > 5° but < 80° and more than 1 m wide. These features were selected because they offer perching, nesting, and protection opportunities for Mexican Spotted Owls in canyons. Using the rangefinder and clinometer, the distance and angle for each of these structural changes, along the perpendicular line, were recorded. The total number of caves, solution cavities, and ledges was counted within the approximately 10-m-wide belt for the entire height of the canyon wall. Where possible, nest cave dimensions were also measured. Using a clinometer, compass, and rangefinder, the aspect, height,
width, and distance were recorded for all nest caves. This process was repeated for both
canyon walls. Before leaving a sampling site, four digital photographs were taken at the
belt transect. The direction of the photos corresponded with up canyon, down canyon,
and each canyon wall.

**Analysis**

Statistical analysis and modeling methods were limited due to the small sample
size (15 presence and 12 absence sites). The high variability of vegetation and geology
between canyons reduced the ability to compare presence and absence sites using
logistic regression techniques. Due to data limitations, t-tests were used to compare
means of vegetation and geology variables for presence and absence sites.

Since vegetation belt transect lengths varied among belts and between sites,
variables were adjusted for further comparison. First, total belt area for each vegetation
belt transect was calculated by multiplying belt width (10 m) by belt length (varied).
Belts that were reduced to 5 m in width were assumed to be 10 m wide and variable
measurements were doubled (a total of 3 belts, at 2 different sites). Belt area was then
divided by 10 to provide an estimate of density/10 m². Finally, these estimates were
totaled for all vegetation belts at the site to provide a final estimate of belt area for each
site. This approach allowed for vegetation density comparisons between sites or
canyons of varied widths. To calculate mean canyon width the total mean transect
length was calculated for each site and then the mean was calculated for presence and
absence sites combined.
For vegetation measurements, shrubs and trees were binned based on height into five classes: small = height < 0.15 m, low = 0.15 m < height < 0.5 m, medium = 0.5 m < height < 1.5 m, tall = 1.5 m < height < 2.5 m, and very tall = height > 2.5 m. For vegetation analysis, the means of several variables were compared between presence and absence sites. Bar charts were created and two sample t-tests were performed for the following variables: mean belt length (mean canyon width), mean DBH of trees in class 1 (< 15.2 cm), mean DBH of trees in class 2 (15.2 cm – 30.5 cm), mean vegetation density by height class, mean tree density by height class, mean live shrub density, mean live tree density, mean total vegetation density, and mean percent canopy cover. Analysis for DBH classes 3 – 5 were omitted due to a significantly small sample size of trees within these classes. The two sample t-tests were used to determine whether there were significant differences between the variable means for presence and absence sites.

The same process was repeated for select geology variables at presence and absence sites. These variables included: mean number of caves, mean number of solution cavities, mean number of ledges, and mean canyon wall height.

RESULTS

Mexican Spotted Owl Surveys

During the 2011 field season a total of 26 Mexican Spotted Owls were detected at 11 sites (Canyonlands NP: 9, Capitol Reef: 1, BLM: 1); nests were located at 4 sites. Of
the 26 owls, 12 were male, six were female, and eight were juveniles. All female owls were detected with a male and they were presumed to be a nesting pair. Single male detections were presumed to be solitary males. Reproductive status was assessed during daytime visits where a pair of owls was detected. The eight juveniles were detected at three different sites; one had a single juvenile detected, two had two juveniles each, and the third had three juveniles. Three juveniles at a single site is a rare occurrence, as the typical number of young produced is two. It was assumed that all juveniles successfully fledged from the nesting sites, as no remains were recovered and all juveniles were observed doing well at 3 - 4 months of age. Two additional sites where pairs of owls were detected earlier in the season were presumed abandoned. These sites were re-visited approximately three weeks later and there was no longer any evidence of owl presence within the apparent nesting caves.

During the 2012 field season a total of 10 Mexican Spotted Owls were detected at five sites (Canyonlands NP: 2 sites, Capitol Reef NP: 1 site, Zion NP: 2 sites) three of which contained nests. Of these, five were male, three were female, and two were juveniles. Pairs were detected at four of these sites (Canyonlands NP: 1 site, Capitol Reef NP: 1 site, Zion NP: 2 sites) and juvenile owls were detected at two of the sites (Capitol Reef NP: 1 site, Zion NP: 1 site).

**Vegetation and Geology**

Several vegetation characteristics showed significant difference between mean values for presence and absence sites. Mean canyon width for presence sites = 21.71 ±
3.05 m and for absence sites = 46.08 ± 9.11 m (Fig. 3.4); these differences were significant (t = -2.54, df = 13.46, p < 0.05). There was a significant difference in mean percent canopy cover between presence and absence sites, with presence sites having significantly more canopy cover (t = 4.36, df = 15.80, p < 0.01) (Fig. 3.5). The mean DBH of trees in class 1 (< 15.2 cm; p = 0.29) and class 2 (15.2 cm – 30.5 cm; p = 0.95) did not differ significantly between presence and absence sites (Fig. 3.6 – 3.7). There were no significant differences in tree density between presence and absence sites for any tree height class (p > 0.5; Fig. 3.8). However, when looking at total vegetation density (trees and shrubs) by height there was a significant difference between presence and absence sites only for vegetation >2.5 m tall, with a greater density in presence sites (t = 3.16, df = 19.12, p < 0.01; Fig. 3.9). Neither live shrub density (p = 0.94; Fig. 3.10) nor live vegetation density (p = 0.30; Fig. 3.11) differed significantly between presence and absence sites.

Means for geology variables (bench, cave, cliff, ledge, overhang, solution cavity, slope) showed no significant differences between presence and absence sites. While the mean number of caves for presence sites (0.53) was slightly greater than the number for absence sites (0.33), this was not significant (Fig. 3.12). The mean number of solution cavities for presence and absence sites was nearly identical with means of 5.4 and 5.0 respectively (Fig. 3.13). The mean number of ledges was also nearly identical between presence and absence sites (presence sites = 14.63, absence sites = 14.77; Fig. 3.14). Mean wall height for presence sites (106.1 m) was less than mean wall height for absence sites (147.3 m) (Fig. 3.15), although this was not significant.
DISCUSSION

Our efforts measuring vegetation and geology variables for Mexican Spotted Owl habitat was difficult and led to inconclusive results. Our study indicated that Mexican Spotted Owls in the Colorado Plateau prefer narrow canyons, higher canopy cover and a higher density of very tall (> 2.5 m) vegetation. Past research on Mexican Spotted Owl habitat has also supported that occupied canyons are generally narrow and deep with steep vertical cliffs (Rinkevich and Gutierrez 1996, Willey and van Riper 2007). A study in northern New Mexico by Hathcock and Haarmann (2008) also indicated that occupied owl sites were positively correlated to greater tree height, tree density, and canopy cover when compared to unoccupied sites. Our lack of additional significant findings, however, may be due to a small sample size. This study may have failed to measure characteristics that are important to Mexican Spotted Owl habitat selection, such as prey abundance or temperature and humidity conditions in canyons. Raptor species, especially owls, will not continue to occupy a territory lacking sufficient prey. Mexican Spotted Owls depend on woodrats (Neotoma spp.) as their primary prey source (Willey 2013). Fluctuations in local woodrat populations could cause Mexican Spotted Owls to leave a previously occupied canyon. Future studies should focus on this relationship and prey abundance in occupied versus unoccupied sites.

Determining differences between presence and absence sites for Mexican Spotted Owls can be problematic because variability in vegetation and geology is limited between canyon sites. Much of the desert canyon landscape in southern Utah is
dominated by similar vegetative communities, such as piñon-juniper with Gambel oak. Furthermore, sites labeled as absent could potentially be suitable Mexican Spotted Owl habitat. Therefore, it is plausible that at least some of the unoccupied canyons may be suitable for Mexican Spotted Owl nesting; however, if the population is sufficiently low then it is impossible for all suitable canyons to be occupied. With a healthy and increasing population, one might expect to see the majority of suitable habitat occupied and the landscape saturated with Mexican Spotted Owls.

Combining habitat characteristics, such as those presented in this chapter, with species distribution models, such as those presented in Chapter 2, can aid managers in identifying quality habitat for Mexican Spotted Owls. The SDMs provide managers with a macro view of Mexican Spotted Owl habitat. However, when combined with habitat descriptions, managers can assess habitat quality at a more micro scale. Combining field measurements and descriptions with SDM models can allow managers to further identify and refine Mexican Spotted Owl habitat models. In order to aid managers in easily identifying microsite characteristics before heading into the field, a GIS tool called the Cross-Canyon Transect Tool (CCTT) was developed (Crabb et al. 2012). The CCTT can be implemented on a site-by-site basis, and we encourage managers to combine the habitat descriptions (Chapter 2 and Chapter 3), with species distribution models (Chapter 2), and the Cross-Canyon Transect Tool (Chapter 3) to properly identify and classify Mexican Spotted Owl habitat. This approach is further discussed in the following sections.
The Cross-Canyon Transect Tool (CCTT) was developed at Utah State University by GIS specialists to meet project needs for identifying Mexican Spotted Owl habitat in canyon terrain (Crabb et al. 2012). The CCTT can be used with ArcMap 10.1 to assist in data collection of vegetation and geospatial variables associated with Mexican Spotted Owl canyon sites. The tool accomplishes this by establishing transects, with a designated number of regular sampling points, perpendicular to the canyon floor. The perpendicular transects are established by using the canyon flowline as a guide. This tool allows data for a narrow or wide canyon, with any number of desired transects and sampling points to be extracted. The CCTT can extract data from any underlying raster layers and allow the user to determine canyon rim elevation, canyon bottom elevation, average canyon wall slope, canyon wall aspect, and canyon width for every transect.

Use of the CCTT is relatively easy and straightforward, making it a viable tool for managers to use before selecting Mexican Spotted Owl survey sites. Data provided by this tool allows managers to better identify and quantify Mexican Spotted Owl site characteristics before or after field surveys. Data acquired with the CCTT can then be compared to habitat descriptions provided in Chapter 2 and Chapter 3. This allows managers to look at microsite characteristics and easily identify vegetation or geomorphic characteristics for any occupied or unoccupied site.
Several Mexican Spotted Owl distribution models were developed and presented in Chapter 2. These models are intended to assist managers in decision making, surveying, and habitat classification for Mexican Spotted Owls. The models presented are considered a macro-scale approach to predicting Mexican Spotted Owl distribution. Therefore, these macro-scale models should be paired with a micro-scale approach in order to provide optimal use and results.

A total of eight distribution maps were constructed from three different models, which allows managers to choose a map that is best suited for their needs (Fig. 2.3-2.11). Three different classification maps were created using three different modeling techniques (see Chapter 2 for details). The classification maps provide a measure of presence (indicated by a value of 1) or absence (indicated by a value of 0). These maps are a simple raster layer that highlights the likely distribution of Mexican Spotted Owls. The ensemble classification model takes all three individual classification models and stacks them on top of each other (Fig. 2.11) resulting in a single map. The result is a map with values ranging from 0 to 3. A value of 3 indicates that all three models predicted Mexican Spotted Owls were present, while a value of 0 indicates all three models predicted absence. The ensemble classification map can be considered a more robust prediction of habitat when compared to the maps created from the individual models.

The probability maps differ from classification maps because they provide the manager with a probability, or likelihood of presence, between 0 and 1. Therefore,
when looking at each of the three probability maps a manager can easily identify areas with high probability (e.g. >0.75) for Mexican Spotted Owls and compare those regions to areas with low probability (e.g. < 0.40) for Mexican Spotted Owls. The ensemble probability map takes each of the individual probability models and stacks them on top of each other. This provides a combined probability of Mexican Spotted Owl distribution (Fig. 2.9). The ensemble probability map is interpreted the same way as the other three probability maps, but offers a more restrictive and robust habitat suitability map for managers.

Managers are encouraged to use the SDMs, paired with the CCTT, to refine habitat descriptions and survey efforts. Managers can choose a species distribution map that they feel is best suited for their region and needs. After selecting the appropriate map, regions of high presence probability can be easily identified using the desired probability threshold, and later surveyed for breeding Mexican Spotted Owls. Managers can prioritize survey efforts by surveying sites with high probabilities first, which can be helpful when staffing and funding are limited. A description of Mexican Spotted Owl habitat, as presented in Chapter 2 and 3, can be used during surveys to determine if the canyon is suitable habitat. For example, managers should focus on canyon width, vegetation height, and composition of vegetation communities including species, while surveying areas for Mexican Spotted Owls.

The SDMs from Chapter 2 can be used to identify areas of high MSO occurrence probability. The CCTT can be used to determine whether specific canyons, and even portions of canyons, have the habitat characteristics demonstrated by the Mexican
Spotted Owl models. Managers can implement the use of the CCTT on the existing map raster layers, using ArcMap, to determine canyon width, elevation, and dominant vegetation, all of which are important factors for Mexican Spotted Owl habitat (Chapters 2 and 3). The combination of SDMs and the CCTT could be used in establishing a sampling plan for monitoring Mexican Spotted Owl populations in canyon habitats. Such an approach would conform to the suggestions provided in USFWS (2012). The CCTT could also be applied post-survey to obtain geospatial or vegetation information that can later be paired with survey data (presence, nesting success, productivity) to validate and improve habitat models for canyon-dwelling spotted owls. The Mexican Spotted Owl distribution maps paired with the CCTT provide a valuable resource for managers in monitoring Mexican Spotted Owl populations.

Application of the CCTT on a narrow canyon nest site for breeding Mexican Spotted Owls, suggests that this tool performs fairly accurately when compared to field measurements of canyon width at the nest site. For this example, we evaluated the CCTT on a remote canyon site where canyon width was measured on the ground at and near the nesting location as described in the Methods. The CCTT was applied to the canyon by establishing a total of 64 transects, 200 m apart, above and below the nest site along the length of the canyon’s flowline within ArcMap (Fig. 3.16). Canyon elevation and width of the floodplain and rim were calculated along each transect by the CCTT. A digital model of the canyon was then created in Program R based on measurements from the 64 transects. The model provides an overall view of the canyon’s structure (Fig. 3.17). Next, cross-sections were generated for each transect in
Program R; these cross-sections provide a visual of canyon elevation and structure (or width) at each transect location (Fig. 3.18). Based on measurements provided by the CCTT the average canyon width at the nest site was 20 m. This measurement was very comparable to our field measurement, which indicated average canyon width was 17 m at the nest site. This cursory test supports the functionality of the CCTT in correctly identifying canyon width, which is an important Mexican Spotted Owl habitat characteristic. The estimates provided by the CCTT for this nesting location closely match our study results for canyon width at presence sites (≤ 21.71 m). Therefore, the CCTT serves as a helpful tool for measuring and selecting narrow canyons to survey.

Management Implications and Conservation

Species distribution models are the first step in identifying potential habitat for Mexican Spotted Owls. Using these models, managers should focus on establishing and maintaining a consistent survey scheme to determine occupancy in canyon habitats (USFWS 2012). With increased and more accurate occupancy data, managers can determine population health and associate habitat needs with occupied sites.

Species distribution models, such as those presented in Chapter 2, are the first step in managing a rare species. These models should serve as a tool used by managers for future decision making, especially when resource extraction is a threat. With model use, managers can implement efficient and meaningful surveys for Mexican Spotted Owls across the Colorado Plateau. This provides a great resource for model testing in
the future. With survey and occupancy data collected over time, adjustments can be made to these models in order to improve their predictability.

With Utah’s Mexican Spotted Owl population managers should ask themselves whether all suitable habitat is saturated. Meaning, are there regions where Mexican Spotted Owls can persist, but are not currently occupied. According to the models, there are an abundance of canyons suited for Mexican Spotted Owls that are not occupied. For conservation purposes, it is important to understand why these canyons remain unoccupied. While it could be due to low population abundance, it may be related to other factors, such as disturbance from humans, resource extraction, or low prey abundance. Understanding these connections is crucial for conserving Utah’s population of Mexican Spotted Owls.

REFERENCES


Guisan, A., R. Tingley, J. B. Baumgartner, I. Naujokaitis-Lewis, P. R. Sutcliffe, A. I. Tulloch, T. J. Regan, L. Brotons, E. McDonald-Madden, C. Mantyka-Pringle, T. G. Martin, J.


Rinkevich, S. E. 1991. Distribution and habitat characteristics of Mexican Spotted Owls in Zion National Park, Utah. Humboldt State University, Arcata, California, USA.


U.S. Fish and Wildlife Service. 2012. Final recovery plan for the Mexican Spotted Owl (Strix occidentalis lucida), First Revision, Albuquerque, New Mexico, USA.


FIG. 3.1. Map of Mexican Spotted Owl study area for Mexican Spotted Owls.
FIG. 3.2. Placement of vegetative and geologic belt transects within the canyon. Each belt was 10 m wide with a center line (dotted line). Belts were distributed 100 m apart from the center line.
FIG. 3.3. Ten meter wide belt with center transect (dotted line).
FIG. 3.4. Mean canyon width (± SE) for presence and absence sites. * Indicates significance (p < 0.05).
Fig. 3.5. Mean percent canopy cover (± SE) for presence and absence sites. * Indicates significance (p < 0.05).
FIG. 3.6. Mean number of size class 1 (DBH < 15.2 cm) trees (± SE) per 10 m² for presence and absence sites.
FIG. 3.7. Mean DBH (± SE) for trees in size class 2 (15.2 cm – 30.5 cm) per 10 m² for presence and absence sites.
FIG. 3.8. Comparing tree density (± SE) per 10 m$^2$ for presence and absence plots by height class.
FIG. 3.9. Comparing vegetation density (± SE) per 10 m$^2$ for presence and absence plots by height class. * Indicates significance (p < 0.05).
FIG. 3.10. Mean number of live shrubs (± SE) per 10 m² for presence and absence sites.
FIG. 3.11. Mean vegetation (± SE) (trees and shrubs combined) per 10 m² for presence and absence sites.
FIG. 3.12. Mean number of caves (± SE) for presence and absence sites.
FIG. 3.13. Mean number of solution cavities (± SE) for presence and absence sites.
FIG. 3.14. Mean number of ledges (± SE) for presence and absence sites.
FIG. 3.15. Mean wall height (± SE) for presence and absence sites.
FIG. 3.16. Example of Cross-Canyon Transect Tool (CCTT) in ArcMap. This map shows the application of the CCTT at a Mexican Spotted Owl nest site. The floodplain transects (yellow) take measurements along the canyon floor, while the rim transects (red) take measurements across the top of the canyon.
FIG. 3.17. Digital model of Unknown Canyon created from CCTT measurements.
FIG. 3.18. Plots showing elevation and distance from center point for each transect of the Cross-Canyon Transect Tool within Unknown Canyon.
CHAPTER 4

CONCLUSION

Management and conservation of Mexican Spotted Owls (*Strix occidentalis lucida*) requires knowledge of their population dynamics, habitat characteristics, and local distribution. However, varied habitat characteristics across their range, such as sparsely vegetated canyons and dense forest patches, present managers with the challenge of describing breeding owl habitat and predicting where owls may occur. It is critical for managers to identify differences in breeding habitat in order to better survey for Mexican Spotted Owls. Increased survey efforts and detailed data can aid in monitoring local and regional population dynamics and influence future conservation needs. Managers should focus on linking population dynamics, such as occupancy surveys, with specific habitat characteristics in order to improve future distribution models for Mexican Spotted Owls.

Several Mexican Spotted Owl distribution maps and a brief description of broad habitat characteristics for the Colorado Plateau in Utah were presented in this thesis. The two data chapters presented in this thesis are closely related and allow for underlying methods to be applied to a broad range of threatened species and management objectives. Chapter 2 outlines the importance, creation, and application of species distribution models through the implementation of an ensemble model approach. A total of eight distribution maps were created using three modeling methods: random forest (Breiman 2001), maximum entropy (Phillips 2006), and logistic
regression (McCullagh and Nelder 1989). Each method produced a classification model and a probability model predicting Mexican Spotted Owl distribution. The combination of all three models produced an additional ensemble classification map and ensemble probability map. The results indicated that all models performed well with high accuracy metrics that were similar between each of the models. Similarity between model accuracy metrics supports the idea that our ensemble model approach was robust in predicting Mexican Spotted Owl distribution. These results emphasized the need for accurate species distribution models and the benefits of using an ensemble modeling approach for future conservation of threatened species.

Chapter 3 presented the use of species distribution models, from Chapter 2, paired with regional habitat descriptions for management of Mexican Spotted Owls. This chapter discussed typical habitat characteristics for Mexican Spotted Owls occupying canyon regions in the Colorado Plateau. Our results indicated that Mexican Spotted Owls preferred narrow, steep canyons with tall (> 2.5 m), coniferous or pinyon-juniper vegetation. This chapter also presented managers with several options for using the Mexican Spotted Owl distribution and ensemble maps. Some of these options included occupancy surveys, habitat protection, and resource extraction planning. Benefits of distribution models were further discussed, emphasizing the need for combining these models with active adaptive management to protect and preserve threatened species.

The results of our study presented in this thesis provide a better understanding of canyon habitats used by Mexican Spotted Owls in the Colorado Plateau. Our models
performed substantially better when compared to past models that also attempted to predict Mexican Spotted Owl distribution. The current models provide managers with a new conservation tool that can be implemented in regions within Utah for predicting Mexican Spotted Owl presence. Managers should focus on using the ensemble maps to increase site selection accuracy with future occupancy survey efforts. Understanding how each model was created, along with their differences, benefits, and application will allow managers to select the proper model to use in their region. Understanding habitat characteristics is a critical component for conservation of threatened and endangered species. This knowledge can be implemented both in the field and in various modeling approaches to create robust species distribution models, such as those presented in our study. These models serve as an invaluable tool for management and conservation of threatened species, such as Mexican Spotted Owls.

REFERENCES


Appendix: Program R Code and Data for Species Distribution Models

LINEAR REGRESSION MODEL

library(verification)
library(MASS)
library(PresenceAbsence)

#read data from csv file
mso=read.csv('All_GISdata_FIN2013_code.csv', header=T, sep=',')
head(mso)
str(mso)

# Fix Sagebrush Steppe variable
mso$geo=as.factor(mso$geo)

# Fix Chinle variable
mso$veg=as.factor(mso$veg)

####### MODEL 1 ###################
#build initial model:
### MODEL 1: full - slp; 6 var
#Determine which veg and geo variable to fix
# Fix Sagebrush Steppe variable
table(mso$pa, mso$veg)
# Fix Chinle variable
table(mso$pa, mso$geo)

mso.lrfull = glm(pa~elev+curve+surf+asp+geo+veg, family=binomial, data=mso)
summary(mso.lrfull)

#model fit - obtain values from summary
mso.lrfull.fit=100*(1-mso.lrfull$deviance/mso.lrfull$null.deviance)
mso.lrfull.fit

#predicted values for observations
mso.lrfull$fitted.values
mso.lrfull.pred=predict(mso.lrfull, type="response")
mso.lrfull.pred

#resubstitution confusion matrix
mso.confusemat.resub=table(mso$pa, factor(round(mso.lrfull.pred), 0:1, c("NonNest", "Nest")))
mso.confusemat.resub

min(mso.lrfull.pred)
max(mso.lrfull.pred)
AUC calculated from roc.area (obs, pred) and then plotted

MODEL 1

mso.roc=(as.integer(as.character(mso$pa))) #pa must be numeric not factor for this analysis
str(mso.roc)
mso.roc

mso.auc1=roc.area(mso.roc, mso.lrfull.pred)
mso.auc1=mso.auc1$A
mso.auc1

plot=(1:1034)
plot
mso2=cbind(plot, mso$pa, mso.lrfull.pred)
mso2

mod.cut=optimal.thresholds(mso2, opt.methods=c("MaxSens+Spec"))
out.mso3=capture.output(mod.cut)
out.mso3
#cat(out.mso3, file="sppMAXKAPPA_msoRF.txt", sep="\n", append=T)

#generate confusion matrix and output to txt file
mod1.cfmat=table(mso2[,2], factor(as.numeric(mso2[,3]>=mod.cut[1,2])))
mod1.cfmat

#generate model accuracies and output to txt file
mso.acc=presence.absence.accuracy(mso2, threshold=mod.cut[1,2])
tss=mso.acc$sensitivity+mso.acc$specificity-1
mso.acc=cbind(mso.acc[1:7], tss)
mso.acc

#plot AUC
roc.plot(mso.roc, mso.lrfull.pred, ylab= "Sensitivity (True Positive)",
        xlab="1-Specificity (False Positive)", main= "AUC Plot")

mso.xvs=sample(rep(c(1:10), length=nrow(mso)))
mso.xval.pred=rep(0,length=nrow(mso))
for (i in 1:10){
  tr=mso[mso.xvs!=1,]
to=mso[mso.xvs==i,]
  fit=glm(pa~elev+curve+surf+asp+geo+veg, family=binomial, data=tr)
mso.xval.pred[mso.xvs==i]=predict(fit,to,type="response")
}
mso.confusemat.xval=table(mso$pa, round(mso.xval.pred))
mso.confusemat.xval
mso.xval.acc

########################################################################
#Stepwise model
mso.lrstep=step(mso.lrfull, family=binomial)

summary(mso.lrstep)

###model for prob map
mso.step = glm(pa~curve+elev+surf+geo+veg, family=binomial, data=mso)

pl#Model fit compared
mso.lrfull.fit
mso.lrstep.fit=100*(1-mso.lrstep$deviance/mso.lrstep$null.deviance)
mso.lrstep.fit

#model prediction
mso.lrstep.pred=predict(mso.lrstep, type="response")
mso3=cbind(plot, mso$pa, mso.lrstep.pred)
mso3

mod.cut=optimal.thresholds(mso3, opt.methods=c("MaxSens+Spec"))
out.mso3=capture.output(mod.cut)
out.mso3

#resubstitution confusion matrix
mso.confusemat.resub.step=table(mso$pa, factor(round(mso.lrstep.pred), 0:1, c("NonNest", "Nest")))
mso.confusemat.resub.step

#ACC
mso.acc=presence.absence.accuracy(mso3, threshold=mod.cut[1,2])
tss=mso.acc$sensitivity+mso.acc$specificity-1
mso.acc=cbind(mso.acc[1:7], tss)
mso.acc
RANDOM FOREST MODEL

library(randomForest)
library(verification)
library(PresenceAbsence)

# read data from csv file
mso=read.csv('All_GISdata_FIN2013_code.csv', header=T, sep=',')
head(mso)
dim(mso)

str(mso)
mso$geo=as.factor(mso$geo)
mso$veg=as.factor(mso$veg)
#mso$pa=as.factor(mso$pa)
#mso.w=na.omit(mso) # omit NA value from dataset

## RF model 1: FULL
# set response variable (pa) as a factor *Omit slope and use surf instead (topographic roughness)
mso.rf1 = randomForest(as.factor(pa) ~
curve+asp+elev+surf+geo+veg, importance=T, keep.forest=T, data=mso)

## Apply RF model 1 and predict
## Calculate out-of-bag confusion matrix and cross validation accuracy
mso.pred.oob = predict(mso.rf1, type="prob") [,2]
mso.pred.oob

## determine best threshold using PresenceAbsence package Sec7.1
### generate prevalence and output to txt file
plotID=(1:1034)
plotID
mso2=cbind(plotID, mso$pa, mso.pred.oob)
mso2
mod.cut=optimal.thresholds(mso2, opt.methods=c("MaxSens+Spec"))
out.mso3=capture.output(mod.cut)
out.mso3
#cat(out.mso3, file="sppMAXKAPPA_msoRF.txt", sep="\n", append=T)

### generate confusion matrix and output to txt file
mod1.cfmt=table(mso2[,2], factor(as.numeric(mso2[,3]>=mod.cut[1,2])))
mod1.cfmt
## generate model accuracies and output to txt file

```r
mso.acc = presence.absence.accuracy(mso2, threshold = mod.cut[1, 2])
tss = mso.acc$sensitivity + mso.acc$specificity - 1
mso.acc = cbind(mso.acc[1:7], tss)
mso.acc
```

### PLOTS

## Plot AUC using roc.plot function

```r
par(fin = c(4, 4))
msospa = as.integer(as.character(mso$pa))
roc.plot(msospa, mso$pred.oob, ylab = "Sensitivity (True Positive)",
xlab = "1-Specificity (False positive)", main = "AUC: Cross-Validation")
```

## variable importance plots

```r
par(fin = c(2, 2))
varImpPlot(mso.rf1, main = "Variable Importance Plots", cex = 1)
```

## partial plots, different n.pt for comparison

```r
par(mfrow = c(1, 1))
# partialPlot(mso.rf1, mso$w, geo, which.class = "1",
# n.pt = 21, main = "PA Partial Plot: n.t=20")
# partialPlot(mso.rf1, mso$w, veg, which.class = "1",
# main = "PA Partial Plot:n.pt=51")
# partialPlot(veg.rf1, veg, v1, which.class = "1",
# n.pt = 72, main = "PA Partial Plot: n.pt=70")
## partialPlot(geo.rf1, geo, v1, which.class = "1",
## n.pt = 20, main = "Partial Dependence: Geology")
partialPlot(mso.rf1, mso$w, surf, which.class = "1",
            n.pt = 20, main = "Partial Dependence: Topographic Roughness")
partialPlot(mso.rf1, mso$w, curv, which.class = "1",
            n.pt = 20, main = "Partial Dependence: Curvature",
            ylab = "Logit(Presence)"
partialPlot(mso.rf1, mso$w, surf, which.class = "1",
            n.pt = 20, main = "Partial Dependence: Topographic Roughness",
            ylab = "Logit(Presence)"
partialPlot(mso.rf1, mso$w, veg, which.class = "1",
            n.pt = 20, main = "Partial Dependence: Vegetation",
```
```
partialPlot(mso.rf1, mso.w, elev, which.class="1",
    n.pt=20, main="Partial Dependence: Elevation",
    ylab="Logit(Presence)")
#partialPlot(veg.rf1, veg, v6, which.class="1",
# n.pt=20, main="Partial Dependence: Total Belt Area",
# ylim=c(0,1.0))

par(mfrow=c(1,1))

partialPlot(mso.rf1, mso.w, surf)

MAXIMUM ENTROPY MODEL

library(ROCR)
library(vcd)
library(boot)
library(PresenceAbsence)
library(dismo)
library(rJava)

mso=read.csv('All_GISdata_FIN2013_code.csv', header=T, sep=',')
str(mso)
mso$geo=as.factor(mso$geo)
mso$veg=as.factor(mso$veg)
mso.x=mso[, -1]
mso.x=mso.x[, -2]
mso.x=mso.x[, -2]

mso.p=mso[, -1]
mso.p=mso.p[941:1034,]
mso.p=mso.p[,2:3]

mso.b=mso[, -1]
mso.b=mso.b[1:940,]
mso.b=mso.b[2:3]

setwd("H:/Habitat_Model_Data/R/MSO/Preds/IMG") #Leah's
asp=raster("asp.img")
curve=raster("curve.img")
elev=raster("elev.img")
```
surf=raster("surf.img")
veg=raster("veg.img")
geo=raster("geo.img")
mx.stack=stack(curve,elev,surf,veg,geo)
names(mx.stack)=c("curve","elev","surf","veg","geo")

max=maxent(mx.stack, mso.p, a=mso.b, factors=c('geo','veg'))  #run MaxEnt model

presence=read.csv('mso_samplePredictions.csv') #read in samples file
background=read.csv('mso_backgroundPredictions.csv') #read in background file
pp=presence$Logistic.prediction # get column of predictions
testpp=pp[presence$Test.or.train=="test"] #select only test points
trainpp=pp[presence$Test.or.train=="train"] #select only test points
bb=background$logistic
combined=c(testpp, bb) #combine into a single vector
label= c(rep(1,length(testpp)), rep(0,length(bb))) #labels: 1=present, 0=random
pred=prediction(combined, label) #labeled predictions
perf=performance(pred, "tpr", "fpr") #True/false positives, for ROC curve
plot(perf, colorize=TRUE) #show the ROC curve
performance(pred, "auc")@y.values[[1]] #calculate AUC

#Threshold
pred
combined
dim(combined)
plotID=(1:963)
msos=cbind(plotID, label, combined)
msos
mod.cut=optimal.thresholds(msos, opt.methods=c("MaxSens+Spec"))
out.mso6=capture.output(mod.cut)
out.mso6

##generate confusion matrix and output to txt file
mod1.cfm=table(msos[,2], factor(as.numeric(msos[,3]>=mod.cut[1,2])))
mod1.cfm

##generate model accuracies and output to txt file
msos.acc=presence.absence.accuracy(msos, threshold=mod.cut[1,2])
tss = mso.acc$sensitivity + mso.acc$specificity - 1
mso.acc = cbind(mso.acc[1:7], tss)
mso.acc

ENSEMBLE MODELS

##### generate probability surfaces for each model

### load all predictors
setwd("F:/Habitat_Model_Data/R/MSO/Preds/IMG")
setwd("H:/Habitat_Model_Data/R/MSO/Preds/IMG")  # Leah's
asp = raster("asp.img")
asp = raster("aspcalc.img")
curve = raster("curve.img")
elev = raster("elev.img")
surf = raster("surf.img")
veg = raster("veg.img")
geo = raster("geo.img")
geo = ("geo_ext.img")
c = raster("H:/Habitat_Model_Data/R/MSO/Preds/curve.grd")

## RF

load("F:/Habitat_Model_Data/R/MSO/Workspace/RF_MSO")
load("H:/Habitat_Model_Data/R/MSO/Workspace/RF_MSO")  # Leah's
preds.rf = stack(surf, geo, curve, elev, asp, veg)
names(preds.rf) = c("surf", "geo", "curve", "elev", "asp", "veg")

mod.rf = get("mso.rf1")

prob.rf = predict(preds.rf, mod.rf, type = 'prob', filename = "prob.rf2.img",
fun = predict, index = 2, overwrite = TRUE)  # NOTE: in case of memory issues, try-
setwd("F:/Habitat_Model_Data/R/MSO/Maps")
setwd("H:/Habitat_Model_Data/R/MSO/Maps")  # Leah's
writeRaster(prob.rf, filename = "prob.rf.img", format = "HFA")
writeRaster(clas.rf, filename = "clas.rf.img", format = "HFA")

plot(prob.rf)
plot(clas.rf)
zoom(prob.rf)

#prob.rf=predict(test.r,mod.rf,type="prob",fun=predict,index=2,overwrite=TRUE)
#NOTE: in case of memory issues, try filename=

## MAX
library(dismo)

mod.mx=get("max")
pred.mx=stack(curve, elev, surf, geo, veg)
names(pred.mx)=c("curve","elev","surf","geo","veg")

prob.max=predict(pred.mx,mod.mx,filename="prob.max.img",type="response",fun=predict,index=2,overwrite=TRUE)

clas.mx=prob.max >= 0.36
setwd("H:/Habitat_Model_Data/R/MSO/Maps") #Leah's
writeRaster(prob.max,filename="prob.max.img", format="HFA")
writeRaster(clas.mx,filename="clas.mx.img", format="HFA")

## LR
library(rgdal)
load("H:/Habitat_Model_Data/R/MSO/Workspace/LR_MSO")
preds.lr=stack(curve, elev, surf, geo, veg)
names(preds.lr)=c("curve","elev","surf","geo","veg")
pmod.lr=get("mso.step")
prob.lr=predict(preds.lr,pmod.lr,type="response",fun=predict,filename="prob.lr2.img",index=2,overwrite=TRUE)
writeRaster(prob.lr, filename="probb.lr3.img")
prob.lr2=raster("probb.lr_ext.img")

#prob.lr=predict(preds.lr,pmod.lr,type='prob',filename="prob.lr.img", fun=predict,index=2,overwrite=TRUE) #original code

clas.lr=prob.lr2 >= 0.08
setwd("H:/Habitat_Model_Data/R/MSO/Maps") #Leah's
writeRaster(prob.lr2,filename="prob.lr_fin.img", format="HFA")
writeRaster(clas.lr,filename="clas.lr.img", format="HFA")

### ensemble
clas.rf=raster("clas.rf.img")
clas.mx=raster("clas.mx.img")
clas.lr=raster("clas.lr.img")
clas=stack(clas.rf,clas.lr,clas.mx)
prob.rf=raster("prob.rf.img")
prob.mx=raster("prob.max.img")
prob.lr=raster("prob.lr_fin.img")
probs=stack(prob.rf,prob.lr,prob.mx)

## generate average probability for each cell
ep.a=sum(probs)/3
writeRaster(ep.a,filename="env.prob.img", format="HFA")
t=raster("env.prob.img")

## generate standard deviation of probabilities for each cell
##Write function for calculating SD ###
sd.fun=function(x, m1,m2,m3){sqrt(((x-m1)^2 + (x-m2)^2 + (x-m3)^2)/2)}
##Test function
x=0.5
m1=1
m2=2
m3=3
test=sd.fun(x, m1,m2,m3)

### Stack probability models and calculate mean
probs=stack(prob.mx, prob.rf, prob.lr)
mean.prob=mean(probs)

###Calculate sd for ensemble probability stack
m1=prob.mx
m2=prob.rf
m3=prob.lr
ep.sd=sd.fun(mean.prob,m1, m2, m3)
writeRaster(ep.sd,filename="ep.sd.img", format="HFA")
save(ep.sd, file="epsd.rdata")

### Convert sd raster to data frame
dfsd=as.data.frame(ep.sd)

test=cellStats(probs, 'sd')
ep.s=calc(probs,sd, filename="env.sd.img")
writeRaster(ep.s,filename="env.sd.img", format="HFA")
#epsd is the sd map created on Matt's computer
epsd=raster("ep.sd.img")
dfsd=as.data.frame(epsd)
save(dfsd, file="dfsd.rdata")
dfsd$bins=cut(dfsd$ , breaks=c(0.15, 0.3), labels=c("<0.15", "0.16-0.3")))

b=c(-2.5,-1.5,0,1.5,2.5)
r=cut(epsd, b)
r=as.data.frame(r)

binsd=cut(epsd, breaks=c(0.15, 0.3, 0.45))

## sum classified maps (concordance map)
ec.s=sum(clas)
writeRaster(ec.s,filename="env.clas.img", format="HFA")

# area comparison table
setwd("H:/Habitat_Model_Data/R/MSO/Maps")
ens.clas=raster("env.clas.img")
clas.lr=raster("clas.lr.img")
clas.mx=raster("clas.mx.img")
clas.rf=raster("clas.rf.img")
ens.prob=raster("env.prob_ext.img")
prob.mx=raster("prob.max.img")
prob.rf=raster("prob.rf.img")
prob.lr=raster("probb.lr_ext.img")

# import owl point shapefile
owl=shapefile("H:/ARC/MSO/Shapefiles/Owl_Points/Owl_pts_2013")
# extract data to owl points
cs.lr=extract(clas.lr, owl)
table(cs.lr)
cs.mx=extract(clas.mx, owl)
table(cs.mx)

# concordance table
setwd("H:/Habitat_Model_Data/R/MSO/Maps")
ens.clas=raster("env.clas.img")
ens.clas=as.data.frame(ens.clas)
freq(ens.clas)
ens.clas=nrow(20737580, 9722424, 4579429, 3092842)
value=c(0,1,2,3)
x=matrix(nrow=1, ncol=4)
colnames(x)=value
x[1,1]=20137580
x[1,2]=9722424
\[ x[1,3] = 4579429 \]
\[ x[1,4] = 3092842 \]
\[ x = x[1,2:4] \]

map = c(1, 2, 3)
cells = c(20137580, 9722424, 4579429, 3092842)

color()

hist(x, main = "Total Number of Predicted Presence Cells")
barplot(x, ylim = c(0, 1e+06), main = "Number of Predicted Presence Cells Showing Model Overlap",
       xlab = "Number of Models Overlapping",
       ylab = "Number of Cells", col = c("gold", "darkorange2", "palegreen4"))

# Ensemble uncertainty map
epsd = raster("epsd.img")
sd = as.data.frame(epsd)

freq(epsd)

# writeRaster(asp,"asp");writeRaster(curve,"curve");writeRaster(surf,"surf");writeRaster(veg,"veg");writeRaster(geo,"geo");writeRaster(elev,"elev")

### CROSS-CANYON TRANSCET TOOL PLLOTS

## Script: plotting_canyon_transects.r  June 2012
## Purpose: visualize the results of sampling transects perpendicular to a canyon bottom or river flowline
## created using the 'Cross-Canyon Transect Sampling Tool' script tool in ArcGIS 10
## contact: Ben Crabb bcrabb@gmail.com

library(foreign) # load this library to read .dbf files
## read in the .dbf from the sampling_points shapefile created by the transect tool. Ensure it includes an 'elev' field.
## Make sure to have double slashes in the pathnames.
tbl = read.dbf("H:\\ARC\\MSO\\CCT\\NEW_REFR\\points.dbf")
head(tbl) # look at the first six lines of the table to ensure it read in correctly

plot_3d_in_color = "yes" # enter "yes" or "no" to render the 3d plot in color ("yes") or to just plot the transects in 3d ("no")
vert_factor = 1 # vertical relief factor for plot
canyon_name = "Unknown" # name to use in plot title
sub_title = "sub title"

save_to_file = "no" # enter "yes" to save the plots as .png files to the png_dir directory. Enter "no" to view the plots before saving to file.
## if save_to_file = "yes", .png files will be saved to the following location. Make sure to have double slashes in the pathnames.
png_dir = "H:/Habitat_Model_Data/CCTT"

# sets the working directory. the plots created by this script will be written as .png files to this location
setwd(png_dir)
ppi = 200 # resolution of .png files to be written

# turn off current graphics devices
current_device = dev.cur()
while (current_device > 1){
  dev.off()
  current_device = dev.cur()
}

# order the table by distance from transect center points. Points on the left have a negative distance.
tbl = tbl[with(tbl, order(tbl$dist_cntr2)),]

## Create a 3-d plot to superimpose the transects upon. This plot, and the transects superimposed on it,
## are not accurate in true geographic space - they show a straightened version of the canyon.
## Transects may overlap in true geographic space but will never overlap in these plots.
## to project the canyon in a custom continuum of colors, use this code.
jet.colors = colorRampPalette( c("blue", "green") )
colors1 = jet.colors(100)

## to project the canyon in terrain colors, use this code.
number_of_colors = 100
colors1 = terrain.colors(number_of_colors)

# Compute the z-value at the facet centres
z = xtabs(tbl$elev ~ tbl$dist_cntr2 + tbl$dist_canyn)
zfacet = z[-1, -1] + z[-1, -ncol(z)] + z[-nrow(z), -1] + z[-nrow(z), -ncol(z)]

# Recode facet z-values into color indices
facetcol = cut(zfacet, number_of_colors)

## user preference determines whether 3d plot will be in color or in white
if(plot_3d_in_color == "yes"){
  color=colors1[facetcol]
} else {color="white"}

number_of_transects = length(unique(tbl$Transect))

## plot the entire straightened canyon in 3d.
windows(8.5, 11)
if(save_to_file == "yes"){
  png(filename = paste(canyon_name, "_3d_plot_of_straightened_canyon.png", sep=""),
       units="in", width=8.5, height=11, res=ppi)}

par(mfrow=c(1, 1))
par(mar = c(5, 5, 4, 2))

pmat = persp(x = sort(unique(tbl$dist_cntr2)), y = sort(unique(tbl$dist_canyn)), z,
            theta = 15, phi = 40, # angles specifying the viewing direction. theta gives the azimuthal direction and phi the colatitude.
expand = vert_factor, border = c('gray'),
xlim = c(min(tbl$dist_cntr2), max(tbl$dist_cntr2)),
ylim = c(min(tbl$dist_cany), max(tbl$dist_cany)),
zlim = c(min(tbl$elev), max(tbl$elev)),
ticktype = "detailed",
main = paste("View down straightened canyon: ", canyon_name),
sub = sub_title,
xlab = "Distance from flowline",
ylab = "Distance along flowline at center point",
zlab = "Elevation",
col = color,
scale = FALSE)

########
## Plot transects superimposed on 3d plot. if within canyon, transect is in red
for(trnsct in 1:number_of_transects){
  # plot whole transect in 3d in black
  transect_i_tbl = subset(tbl, Transect == trnsct)
  transect_line = trans3d(transect_i_tbl$dist_cntr2, transect_i_tbl$dist_cany,
                          transect_i_tbl$elev, pmat)
  lines(transect_line, col = "black", lwd = 1)

  # plot portion of transect in canyon in 3d in red, if the 'in_canyon' field exists/is-populated
  if(length(tbl$in_cany) > 0){
    in_canyon_transect_i_tbl = subset(tbl, Transect == trnsct & in_canyon == "Yes")
    if(nrow(in_canyon_transect_i_tbl) > 0){
      in_canyon_transect_line = trans3d(in_canyon_transect_i_tbl$dist_cntr2,
                                         in_canyon_transect_i_tbl$dist_cany, in_canyon_transect_i_tbl$elev, pmat)
      lines(in_canyon_transect_line, col = "red", lwd = 2, xlab = "", ylab = "")
    }
  }
}

if(save_to_file == "yes"){
  dev.off()
}

#################################################################################
## take 9 transects at a time and plot that section of the straightened canyon in 3d, and plot the transect cross-sections in 2d
#################################################################################

number_of_subplots_per_plot = 9
number_of_plots = ceiling(number_of_transects/number_of_subplots_per_plot)
i = 0
while(i < number_of_plots){
    transects_to_plot = 1:number_of_subplots_per_plot+(number_of_subplots_per_plot*i)
    sub_tbl = subset(tbl, Transect>=min(transects_to_plot) & Transect<=max(transects_to_plot))
    number_of_transects_being_plotted = min(number_of_subplots_per_plot - (max(transects_to_plot) - number_of_transects), number_of_subplots_per_plot)

    # 3d plot of subset of transects
    windows(8.5, 11)
    close.screen(all.screens=TRUE)
    if(save_to_file == "yes"){
        png(filename = paste(canyon_name, "_plot_", i+1, "_of_", number_of_plots, ".png", sep=""), units="in", width=8.5, height=11, res=ppi)}
    ## Split the screen into 3 rows and 1 columns, defining different plotting screens
    screen_matrix = matrix(c(0,1,0.67,1, 0,1,0,0.67), nrow = 2, ncol=4, byrow=TRUE, dimnames = list(c("screen1", "screen2"), c("left", "right", "bottom", "top")))
    split.screen(figs = screen_matrix) # split into two screens: top third, and bottom 2 thirds
    split.screen(figs = c(3,3), screen=2) # split the bottom 2 thirds of the plotting space into 3 rows and 3 cols
    screen(1) # plot 3d of subset of transects in screen 1 (NW)
    par(mar = c(3, 1, 2.5, 1))

    if(number_of_transects_being_plotted > 1){

        # Compute the z-value at the facet centres
        z = xtabs(sub_tbl$elev ~ sub_tbl$dist_cntr2 + sub_tbl$dist_canyn)
        zfacet = z[-1, -1] + z[-1, -ncol(z)] + z[-nrow(z), -1] + z[-nrow(z), -ncol(z)]
        # Recode facet z-values into color indices
        facetcol = cut(zfacet, number_of_colors)

        pmat = persp(x = sort(unique(sub_tbl$dist_cntr2)), y = sort(unique(sub_tbl$dist_canyn)), z,
                     theta = 15, phi = 40, # angles specifying the viewing direction. theta gives the azimuthal direction and phi the colatitude.
                     expand =vert_factor, border=c('gray'), 
                     # Add further arguments as needed for persp
        )
xlim=c(min(sub_tbl$dist_cntr2), max(sub_tbl$dist_cntr2)),
ylim=c(min(sub_tbl$dist_canyn), max(sub_tbl$dist_canyn)),
zlim=c(min(sub_tbl$elev), max(sub_tbl$elev)),
ticktype = "simple",
main = paste("View down straightened canyon: ", canyon_name, 
\nTransects", min(transects_to_plot), "through", min(max(transects_to_plot), number_of_transects)),
#sub = sub_title,
xlab="Distance from flowline",
 ylab="Dist down canyon",
zlab="Elevation",
col=color,
scale=FALSE)

#########
# 3d plot of s
ubset of transect lines
for(trnsct in transects_to_plot){
  # plot whole transect in 3d in black
  if(trnsct <= number_of_transects){
    transect_i_tbl = subset(sub_tbl, Transect == trnsct)
    transect_line = trans3d(transect_i_tbl$dist_cntr2, transect_i_tbl$dist_canyn,
    transect_i_tbl$elev, pmat)
    lines(transect_line, col="black", lwd=1)
  }
  # plot the portion of the transect within canyon in 3d in red, if the in_canyon field
  exists/is populated
  if(length(sub_tbl$in_canyon) > 0){
    in_canyon_transect_i_tbl = subset(sub_tbl, Transect == trnsct & in_canyon == "Yes")
    if(nrow(in_canyon_transect_i_tbl) > 0){
      in_canyon_transect_line = trans3d(in_canyon_transect_i_tbl$dist_cntr2,
      in_canyon_transect_i_tbl$dist_canyn, in_canyon_transect_i_tbl$elev, pmat)
      lines(in_canyon_transect_line, col="red", lwd=2)
    }
  }
}
if(number_of_transects_being_plotted == 1){
  screen(1)
mtext(paste(canyon_name, ":\nTransect ", number_of_transects, " of ", number_of_transects,":\nSingle Transect; No 3D plot available.", sep=""), side=3, line=-
5, cex=1.5)

### Produce line plots of elevation values which show cross-sections of the canyon along transects  
###  
screens = c(3,4,5,6,7,8,9,10,11)

j=1
for(n in transects_to_plot){
  if(n <= number_of_transects){
    screen(screens[j])
    par(mar = c(2, 2, 0.5, 0.5))
    one_transect_tbl = subset(tbl, Transect == n)
    plot(one_transect_tbl$dist_cntr2, one_transect_tbl$elev, type='l', ylab="Elevation", xlab="Distance from center", cex=0.8, ylim=c(min(tbl$elev), max(tbl$elev)), xlim=c(min(tbl$dist_cntr2), max(tbl$dist_cntr2)), tcl=-0.1, cex.axis=0.8, mgp=c(1,0.2,0))
    text(0, 9/10*(max(tbl$elev)-min(tbl$elev))+min(tbl$elev), labels=paste("Transect", n)) # put label at x=0 and most of the way up the plot

    if(length(one_transect_tbl$in_canyon) > 0){
      in_canyon_one_transect_tbl = subset(one_transect_tbl, in_canyon == "Yes")
      if(nrow(in_canyon_one_transect_tbl) > 0){
        lines(in_canyon_one_transect_tbl$dist_cntr2, in_canyon_one_transect_tbl$elev, type="l", ylab="", xlab="", cex=0.8, ylim=c(min(tbl$elev), max(tbl$elev)), xlim=c(min(tbl$dist_cntr2), max(tbl$dist_cntr2)), lwd=3, tcl=-0.1, cex.axis=0.8, mgp=c(0,0.2,0))
      }
      j = j+1
    }
  }
}
i=i+1
if(save_to_file == "yes"){
  dev.off() # write the .png to file
}
}

if(save_to_file == "yes"){
# turn off graphics devices

```r
current_device = dev.cur()
while (current_device > 1){
  dev.off()
  current_device = dev.cur()
}
```
### DATA FOR 94 PRESENCE POINTS

<table>
<thead>
<tr>
<th>Site</th>
<th>Owl Detected</th>
<th>Year</th>
<th>Curvature</th>
<th>Slope</th>
<th>Aspect</th>
<th>Surface Ratio</th>
<th>Elevation</th>
<th>Geology</th>
<th>Vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S</td>
<td>2008</td>
<td>-4.09</td>
<td>39.00</td>
<td>0.28</td>
<td>1.66</td>
<td>1818.07</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>2</td>
<td>P</td>
<td>2010</td>
<td>-2.70</td>
<td>47.44</td>
<td>0.15</td>
<td>2.00</td>
<td>1648.18</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Barren</td>
</tr>
<tr>
<td>3</td>
<td>S</td>
<td>2003</td>
<td>2.00</td>
<td>25.08</td>
<td>0.16</td>
<td>1.23</td>
<td>1773.13</td>
<td>Oquirrh Group, Wells, Weber, Ely, Callville and o</td>
<td>Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>4</td>
<td>S</td>
<td>2003</td>
<td>-0.39</td>
<td>34.11</td>
<td>0.85</td>
<td>1.33</td>
<td>1849.27</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
<td>Mixed Desert Shrubland</td>
</tr>
<tr>
<td>5</td>
<td>S</td>
<td>2003</td>
<td>-0.13</td>
<td>21.15</td>
<td>-0.05</td>
<td>1.10</td>
<td>1630.70</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
<td>Mixed Desert Shrubland</td>
</tr>
<tr>
<td>6</td>
<td>S</td>
<td>2010</td>
<td>-1.01</td>
<td>46.71</td>
<td>0.91</td>
<td>1.57</td>
<td>1909.67</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Barren</td>
</tr>
<tr>
<td>7</td>
<td>U</td>
<td>1991</td>
<td>-0.39</td>
<td>42.04</td>
<td>0.71</td>
<td>1.69</td>
<td>1848.89</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Barren</td>
</tr>
<tr>
<td>8</td>
<td>S J</td>
<td>2011</td>
<td>0.55</td>
<td>37.56</td>
<td>-0.64</td>
<td>1.51</td>
<td>1871.88</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Barren</td>
</tr>
<tr>
<td>9</td>
<td>P</td>
<td>1996</td>
<td>-1.81</td>
<td>21.69</td>
<td>0.40</td>
<td>1.15</td>
<td>1295.08</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
<td>Mixed Desert Shrubland</td>
</tr>
<tr>
<td>10</td>
<td>P</td>
<td>2009</td>
<td>-1.37</td>
<td>19.04</td>
<td>-0.40</td>
<td>1.12</td>
<td>1710.16</td>
<td>Summerville, Entrada, Carmel, Arapien, Twin Creek</td>
<td>Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>11</td>
<td>S</td>
<td>2008</td>
<td>0.30</td>
<td>17.72</td>
<td>0.87</td>
<td>1.06</td>
<td>2031.86</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>12</td>
<td>S</td>
<td>2009</td>
<td>0.49</td>
<td>47.56</td>
<td>0.70</td>
<td>1.70</td>
<td>1733.81</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Barren</td>
</tr>
<tr>
<td>13</td>
<td>P J</td>
<td>2011</td>
<td>-1.86</td>
<td>47.15</td>
<td>0.80</td>
<td>1.75</td>
<td>1948.22</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>14</td>
<td>S</td>
<td>2010</td>
<td>0.02</td>
<td>5.36</td>
<td>0.93</td>
<td>1.01</td>
<td>1726.83</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
<td>Mixed Desert Shrubland</td>
</tr>
<tr>
<td>15</td>
<td>S</td>
<td>2012</td>
<td>0.49</td>
<td>15.84</td>
<td>-0.44</td>
<td>1.05</td>
<td>1463.79</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>16</td>
<td>P J</td>
<td>2010</td>
<td>-0.38</td>
<td>17.15</td>
<td>0.96</td>
<td>1.06</td>
<td>1645.02</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>17</td>
<td>S</td>
<td>2009</td>
<td>0.16</td>
<td>17.45</td>
<td>0.55</td>
<td>1.06</td>
<td>2260.88</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
<td>Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>18</td>
<td>S</td>
<td>2003</td>
<td>1.69</td>
<td>30.93</td>
<td>-0.34</td>
<td>1.22</td>
<td>1832.31</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
<td>Barren</td>
</tr>
<tr>
<td>19</td>
<td>P</td>
<td>2003</td>
<td>-0.53</td>
<td>17.36</td>
<td>0.21</td>
<td>1.09</td>
<td>1245.52</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
<td>Mixed Desert Shrubland</td>
</tr>
<tr>
<td>20</td>
<td>P</td>
<td>1995</td>
<td>-0.17</td>
<td>8.15</td>
<td>0.52</td>
<td>1.02</td>
<td>1534.07</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
<td>Mixed Desert Shrubland</td>
</tr>
<tr>
<td>21</td>
<td>P J</td>
<td>2012</td>
<td>-1.11</td>
<td>50.31</td>
<td>-0.93</td>
<td>1.65</td>
<td>1853.20</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Mixed Coniferous Forest</td>
</tr>
<tr>
<td>22</td>
<td>P</td>
<td>2012</td>
<td>-1.87</td>
<td>31.99</td>
<td>0.49</td>
<td>1.27</td>
<td>1690.97</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>23</td>
<td>S</td>
<td>2011</td>
<td>-3.36</td>
<td>39.72</td>
<td>0.39</td>
<td>1.52</td>
<td>1692.35</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Barren</td>
</tr>
<tr>
<td>24</td>
<td>P J</td>
<td>2011</td>
<td>-1.82</td>
<td>23.11</td>
<td>-0.22</td>
<td>1.17</td>
<td>1635.96</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
<td>Barren</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>P</td>
<td>1996</td>
<td>-0.43</td>
<td>14.26</td>
<td>-0.23</td>
<td>1.04</td>
<td>2120.64</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>26</td>
<td>S</td>
<td>2009</td>
<td>-0.52</td>
<td>42.58</td>
<td>-0.35</td>
<td>1.40</td>
<td>1801.86</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
<td>Barren</td>
</tr>
<tr>
<td>27</td>
<td>P</td>
<td>2011</td>
<td>-0.80</td>
<td>9.35</td>
<td>0.15</td>
<td>1.03</td>
<td>1683.60</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
<td>Riparian</td>
</tr>
<tr>
<td>28</td>
<td>P J</td>
<td>2012</td>
<td>-2.57</td>
<td>36.49</td>
<td>-0.33</td>
<td>1.39</td>
<td>1914.80</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Barren</td>
</tr>
<tr>
<td>29</td>
<td>P J</td>
<td>2010</td>
<td>-3.78</td>
<td>37.89</td>
<td>-0.02</td>
<td>1.66</td>
<td>1522.88</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Deciduous Forest</td>
</tr>
<tr>
<td>30</td>
<td>P J</td>
<td>2010</td>
<td>-2.58</td>
<td>29.01</td>
<td>0.06</td>
<td>1.39</td>
<td>1707.01</td>
<td>Summerville, Entrada, Carmel, Arapien, Twin Creek</td>
<td>Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>31</td>
<td>S</td>
<td>2011</td>
<td>0.54</td>
<td>24.12</td>
<td>0.26</td>
<td>1.14</td>
<td>1430.71</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
<td>Mixed Desert Shrubland</td>
</tr>
<tr>
<td>32</td>
<td>S</td>
<td>1996</td>
<td>-1.18</td>
<td>48.85</td>
<td>0.71</td>
<td>1.98</td>
<td>1717.40</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Sagebrush Steppe</td>
</tr>
<tr>
<td>33</td>
<td>P</td>
<td>2011</td>
<td>-0.25</td>
<td>21.85</td>
<td>-0.90</td>
<td>1.13</td>
<td>1744.86</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>34</td>
<td>S</td>
<td>2010</td>
<td>-0.89</td>
<td>63.52</td>
<td>0.26</td>
<td>2.51</td>
<td>1760.80</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Barren</td>
</tr>
<tr>
<td>35</td>
<td>S</td>
<td>2009</td>
<td>-0.13</td>
<td>11.50</td>
<td>-0.89</td>
<td>1.02</td>
<td>1676.80</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>36</td>
<td>S</td>
<td>2001</td>
<td>-2.53</td>
<td>37.74</td>
<td>-0.95</td>
<td>1.47</td>
<td>1629.85</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
<td>Barren</td>
</tr>
<tr>
<td>37</td>
<td>P</td>
<td>2001</td>
<td>2.37</td>
<td>42.16</td>
<td>0.39</td>
<td>1.46</td>
<td>1738.81</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
<td>Mixed Desert Shrubland</td>
</tr>
<tr>
<td>38</td>
<td>P</td>
<td>1996</td>
<td>1.37</td>
<td>51.90</td>
<td>0.87</td>
<td>1.73</td>
<td>1916.29</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Mixed Coniferous Forest</td>
</tr>
<tr>
<td>39</td>
<td>S</td>
<td>2003</td>
<td>-0.26</td>
<td>37.37</td>
<td>-0.07</td>
<td>1.51</td>
<td>1366.11</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
<td>Barren</td>
</tr>
<tr>
<td>40</td>
<td>U</td>
<td>1991</td>
<td>4.75</td>
<td>53.30</td>
<td>-0.23</td>
<td>2.04</td>
<td>1936.13</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>41</td>
<td>U</td>
<td>1993</td>
<td>0.46</td>
<td>54.47</td>
<td>0.41</td>
<td>1.86</td>
<td>1903.43</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>42</td>
<td>P</td>
<td>1995</td>
<td>0.94</td>
<td>11.69</td>
<td>0.30</td>
<td>1.05</td>
<td>1267.27</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
<td>Mixed Desert Shrubland</td>
</tr>
<tr>
<td>43</td>
<td>S</td>
<td>2003</td>
<td>0.13</td>
<td>10.45</td>
<td>-0.96</td>
<td>1.03</td>
<td>1850.07</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
<td>Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>44</td>
<td>P</td>
<td>2011</td>
<td>0.70</td>
<td>18.03</td>
<td>-0.34</td>
<td>1.09</td>
<td>1389.29</td>
<td>Moenkopi, Dinwoody, Woodside, Thaynes and other Fms</td>
<td>Mixed Desert Shrubland</td>
</tr>
<tr>
<td>45</td>
<td>P J</td>
<td>2011</td>
<td>-0.88</td>
<td>10.88</td>
<td>-0.20</td>
<td>1.05</td>
<td>1635.36</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
<td>Barren</td>
</tr>
<tr>
<td>46</td>
<td>S J</td>
<td>1991</td>
<td>-1.82</td>
<td>21.70</td>
<td>0.10</td>
<td>1.17</td>
<td>1614.74</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Mixed Desert Shrubland</td>
</tr>
<tr>
<td>47</td>
<td>P</td>
<td>2001</td>
<td>-0.22</td>
<td>41.82</td>
<td>0.17</td>
<td>1.37</td>
<td>1389.11</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Mixed Desert Shrubland</td>
</tr>
<tr>
<td>48</td>
<td>S</td>
<td>1995</td>
<td>1.38</td>
<td>38.58</td>
<td>0.66</td>
<td>1.38</td>
<td>1675.71</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Mixed Desert Shrubland</td>
</tr>
<tr>
<td>49</td>
<td>S</td>
<td>2009</td>
<td>0.44</td>
<td>23.34</td>
<td>0.55</td>
<td>1.11</td>
<td>1368.11</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
<td>Barren</td>
</tr>
</tbody>
</table>

131
<table>
<thead>
<tr>
<th>Page</th>
<th>Author</th>
<th>Year</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
<th>Value 4</th>
<th>Value 5</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>51</td>
<td>PJ</td>
<td>2003</td>
<td>0.36</td>
<td>17.95</td>
<td>0.09</td>
<td>1.07</td>
<td>1327.27</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
</tr>
<tr>
<td>52</td>
<td>S</td>
<td>2008</td>
<td>-0.11</td>
<td>7.61</td>
<td>-0.67</td>
<td>1.01</td>
<td>1521.25</td>
<td>Chinle, Ankareh Fms</td>
</tr>
<tr>
<td>53</td>
<td>S</td>
<td>2009</td>
<td>-0.45</td>
<td>41.41</td>
<td>-0.33</td>
<td>1.60</td>
<td>1515.05</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
</tr>
<tr>
<td>54</td>
<td>PJ</td>
<td>2012</td>
<td>0.35</td>
<td>22.12</td>
<td>0.08</td>
<td>1.09</td>
<td>1547.70</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
</tr>
<tr>
<td>55</td>
<td>PJ</td>
<td>2010</td>
<td>-1.29</td>
<td>47.25</td>
<td>0.14</td>
<td>2.04</td>
<td>1559.90</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
</tr>
<tr>
<td>56</td>
<td>PJ</td>
<td>2010</td>
<td>-2.41</td>
<td>43.75</td>
<td>0.19</td>
<td>1.67</td>
<td>1675.83</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
</tr>
<tr>
<td>57</td>
<td>S</td>
<td>2011</td>
<td>-1.97</td>
<td>19.88</td>
<td>-0.30</td>
<td>1.22</td>
<td>1607.50</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
</tr>
<tr>
<td>58</td>
<td>S</td>
<td>2008</td>
<td>-0.29</td>
<td>22.21</td>
<td>-0.57</td>
<td>1.12</td>
<td>2219.17</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
</tr>
<tr>
<td>59</td>
<td>P</td>
<td>2010</td>
<td>1.49</td>
<td>47.12</td>
<td>0.59</td>
<td>1.54</td>
<td>1782.98</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
</tr>
<tr>
<td>60</td>
<td>PJ</td>
<td>2011</td>
<td>-0.55</td>
<td>42.71</td>
<td>-0.87</td>
<td>1.53</td>
<td>1426.42</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
</tr>
<tr>
<td>61</td>
<td>PJ</td>
<td>2012</td>
<td>-2.14</td>
<td>39.42</td>
<td>-0.22</td>
<td>1.73</td>
<td>1576.41</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
</tr>
<tr>
<td>62</td>
<td>S</td>
<td>2008</td>
<td>-5.87</td>
<td>48.61</td>
<td>0.13</td>
<td>2.09</td>
<td>1638.38</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
</tr>
<tr>
<td>63</td>
<td>P</td>
<td>2011</td>
<td>0.34</td>
<td>29.43</td>
<td>-0.53</td>
<td>1.16</td>
<td>1615.28</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
</tr>
<tr>
<td>64</td>
<td>P</td>
<td>2003</td>
<td>-0.16</td>
<td>22.61</td>
<td>0.83</td>
<td>1.15</td>
<td>1742.76</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
</tr>
<tr>
<td>65</td>
<td>S</td>
<td>2003</td>
<td>0.74</td>
<td>16.75</td>
<td>-0.14</td>
<td>1.06</td>
<td>1799.06</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
</tr>
<tr>
<td>66</td>
<td>S</td>
<td>2003</td>
<td>-0.29</td>
<td>23.24</td>
<td>-0.29</td>
<td>1.13</td>
<td>1813.22</td>
<td>Oquirrh Group, Wells, Weber, Ely, Callville and o</td>
</tr>
<tr>
<td>67</td>
<td>P</td>
<td>2001</td>
<td>1.72</td>
<td>39.24</td>
<td>0.38</td>
<td>1.36</td>
<td>1618.32</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
</tr>
<tr>
<td>68</td>
<td>S</td>
<td>2002</td>
<td>-0.70</td>
<td>11.12</td>
<td>0.60</td>
<td>1.03</td>
<td>1568.49</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
</tr>
<tr>
<td>69</td>
<td>P</td>
<td>2003</td>
<td>0.34</td>
<td>33.88</td>
<td>0.83</td>
<td>1.23</td>
<td>1357.54</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
</tr>
<tr>
<td>70</td>
<td>P</td>
<td>2008</td>
<td>-0.24</td>
<td>23.50</td>
<td>0.70</td>
<td>1.10</td>
<td>1947.71</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
</tr>
<tr>
<td>71</td>
<td>S</td>
<td>2003</td>
<td>-1.42</td>
<td>39.34</td>
<td>-0.86</td>
<td>1.47</td>
<td>1453.83</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms</td>
</tr>
<tr>
<td>72</td>
<td>S</td>
<td>2011</td>
<td>-2.40</td>
<td>34.60</td>
<td>0.82</td>
<td>1.31</td>
<td>1665.77</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
</tr>
<tr>
<td>73</td>
<td>PJ</td>
<td>1996</td>
<td>0.62</td>
<td>25.55</td>
<td>-0.39</td>
<td>1.18</td>
<td>2152.57</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
</tr>
<tr>
<td>74</td>
<td>PJ</td>
<td>2008</td>
<td>-2.25</td>
<td>54.14</td>
<td>0.83</td>
<td>1.86</td>
<td>1709.17</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
</tr>
<tr>
<td>75</td>
<td>P</td>
<td>1996</td>
<td>-2.84</td>
<td>31.75</td>
<td>-0.67</td>
<td>1.40</td>
<td>1903.28</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena)</td>
</tr>
<tr>
<td>76</td>
<td>P</td>
<td>2010</td>
<td>-1.00</td>
<td>18.53</td>
<td>0.66</td>
<td>1.09</td>
<td>2178.13</td>
<td>Summerville, Entrada, Carmel, Arapien, Twin Creek</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>77</td>
<td>PJ</td>
<td>2003</td>
<td>-0.21</td>
<td>13.80</td>
<td>-0.40</td>
<td>1.05</td>
<td>1638.99</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms Mixed Desert Shrubland</td>
</tr>
<tr>
<td>78</td>
<td>P</td>
<td>2010</td>
<td>0.51</td>
<td>12.75</td>
<td>-0.10</td>
<td>1.04</td>
<td>1715.17</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>79</td>
<td>U</td>
<td>1989</td>
<td>0.09</td>
<td>31.17</td>
<td>0.95</td>
<td>1.22</td>
<td>1632.82</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena Mixed Desert Shrubland</td>
</tr>
<tr>
<td>80</td>
<td>S</td>
<td>2006</td>
<td>-0.67</td>
<td>47.66</td>
<td>0.33</td>
<td>1.57</td>
<td>2010.58</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena Mixed Coniferous Forest</td>
</tr>
<tr>
<td>81</td>
<td>PJ</td>
<td>2009</td>
<td>0.94</td>
<td>32.19</td>
<td>0.98</td>
<td>1.21</td>
<td>2322.43</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena Mixed Coniferous Forest</td>
</tr>
<tr>
<td>82</td>
<td>S</td>
<td>2011</td>
<td>-1.23</td>
<td>36.40</td>
<td>0.97</td>
<td>1.31</td>
<td>1845.98</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>83</td>
<td>S</td>
<td>2011</td>
<td>-0.17</td>
<td>11.68</td>
<td>-0.72</td>
<td>1.08</td>
<td>1688.47</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms Mixed Desert Shrubland</td>
</tr>
<tr>
<td>84</td>
<td>P</td>
<td>2012</td>
<td>-1.40</td>
<td>44.66</td>
<td>0.31</td>
<td>1.69</td>
<td>1802.06</td>
<td>Glen Canyon Group (Navajo, Kayenta, Wingate, Moena Barren</td>
</tr>
<tr>
<td>85</td>
<td>P</td>
<td>2003</td>
<td>0.75</td>
<td>17.90</td>
<td>0.65</td>
<td>1.15</td>
<td>1758.12</td>
<td>Cedar Mesa, Diamond Creek, Arcturus and other Fms Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>86</td>
<td>P</td>
<td>2011</td>
<td>2.77</td>
<td>37.51</td>
<td>0.74</td>
<td>1.42</td>
<td>1815.06</td>
<td>Oquirrh Group, Wells, Weber, Ely, Callville and o Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>87</td>
<td>P</td>
<td>2006</td>
<td>-0.31</td>
<td>42.13</td>
<td>-0.83</td>
<td>1.37</td>
<td>1524.33</td>
<td>Wasatch, Cotton, Flagstaff, Claron, White Sage and Barren</td>
</tr>
<tr>
<td>88</td>
<td>S</td>
<td>2010</td>
<td>-1.57</td>
<td>27.74</td>
<td>-0.49</td>
<td>1.28</td>
<td>1497.08</td>
<td>Wasatch, Cotton, Flagstaff, Claron, White Sage and Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>89</td>
<td>P</td>
<td>2010</td>
<td>0.27</td>
<td>44.47</td>
<td>0.81</td>
<td>1.44</td>
<td>1621.87</td>
<td>Wasatch, Cotton, Flagstaff, Claron, White Sage and Sagebrush Steppe</td>
</tr>
<tr>
<td>90</td>
<td>P</td>
<td>2002</td>
<td>1.00</td>
<td>43.23</td>
<td>0.12</td>
<td>1.41</td>
<td>1562.39</td>
<td>Wasatch, Cotton, Flagstaff, Claron, White Sage and Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>91</td>
<td>P</td>
<td>1998</td>
<td>1.41</td>
<td>52.96</td>
<td>0.96</td>
<td>1.73</td>
<td>1580.05</td>
<td>Wasatch, Cotton, Flagstaff, Claron, White Sage and Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>92</td>
<td>P</td>
<td>1997</td>
<td>-1.92</td>
<td>46.66</td>
<td>0.81</td>
<td>1.58</td>
<td>1624.10</td>
<td>Wasatch, Cotton, Flagstaff, Claron, White Sage and Pinyon-Juniper Woodland</td>
</tr>
<tr>
<td>93</td>
<td>P</td>
<td>2010</td>
<td>-1.40</td>
<td>15.88</td>
<td>0.29</td>
<td>1.09</td>
<td>1553.04</td>
<td>Wasatch, Cotton, Flagstaff, Claron, White Sage and Sagebrush Steppe</td>
</tr>
<tr>
<td>94</td>
<td>U</td>
<td>2010</td>
<td>0.45</td>
<td>42.85</td>
<td>-0.62</td>
<td>1.41</td>
<td>1638.04</td>
<td>Wasatch, Cotton, Flagstaff, Claron, White Sage and Barren</td>
</tr>
</tbody>
</table>

*Detection: S= single, P= pair, J= juvenile, U= unknown*