CONSERVATION POTENTIAL OF
BARN OWLS (*Tyto alba*) IN PENNSYLVANIA

by

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ABSTRACT

Though once prolific, the barn owl (Tyto alba) is now considered vulnerable in Pennsylvania and vulnerable-to-critically imperiled in all surrounding states. Barn owls are charismatic animals. They are wide-ranging generalists, so they are seldom the target of species-specific conservation efforts. Barn owls thrive in open habitats, so their North American extent expanded extensively in the early 1900 with the increased deforestation brought by intensified farming. Farming practices in the northern range of the United States subspecies (T. alba pratincola) are changing, and barn owl populations appear to be responding. Across Pennsylvania, open pastures are being replaced by smaller, row crop fields that have the decrease barn owl hunting habitat. With the exception of a several nesting box companies, few people are actively working towards conservation of barn owls. Statistically accurate descriptions of their specific habitat requirements are rare as a result of their wide range and general disinterest in studying the species.

Radio-transmitted data from 16 barn owl fledglings released from Pittsburgh, Pennsylvania, was used to determine preferred habitat and climatic conditions. Owl dispersal paths spanned the eastern United States. Dispersal patterns consisted of bursts of rapid dispersal as well as heavy use of home ranges of 320 km². The most heavily used point within each established home range used by a successful owl was compared to locations of mortalities using envelope, generalized linear, and classification and regression tree spatial models. The most heavily used habitat was low-lying, flat, and open with temperatures seldom dipping below freezing. The maps created by these models were compared using Pennsylvania as the focal region. The envelope model likely underestimated existing habitat due to its simplicity. Less than 5,000 km² of Pennsylvania was deemed habitat, an area that could support fewer than 100 owls. The other models estimated that 50-60% of land cover both in Pennsylvania and across the eastern United States could be functional habitat. These estimates are likely more realistic for a generalist species like the barn owl.

Given the breadth of the estimated habitat, populations should be more robust. It is more likely that a lack of nesting sites or a decline in prey numbers caused the present situation. Agricultural trends also favor increased pesticide use which would diminish prey populations as well as improved building conditions. This could remove potential nesting spots in the eaves of barns and silos. The acceptable temperature range does not extend into northern Pennsylvania, and nearing that range, survival necessitates increasingly sheltered nest sites, like buildings. A straightforward conservation approach would be placing artificial nesting boxes in areas of low pesticide use such as vineyards and organic farms.
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INTRODUCTION

The common barn owl (Tyto alba) is unique among nocturnal raptors in that it is able to thrive in areas of anthropogenic influence (Colvin 1985). Barn owls are native to coastal marshlands which provide similar habitat to agricultural areas (Colvin 1985, Jemson and Chabreck 1961). The expanses of short, non-woody vegetation supply the owls with suitable hunting grounds, and the rafters of poorly sealed barns, sheds, and silos resemble favored natural nesting sites (Taylor 1994).

Barn owls preferentially nest in tree cavities but have been known to use other predatory birds’ nests (Anderson 1996, Taylor 1994) or ground-nests (Quigley 1954, Tewes 1984). Barn owls have been observed to share nests, though only between females of polygamous reproductive trios (Marti 1990). Human destruction of natural nest sites combined with construction of surrogate sites alter wild nesting preferences. Mardi and Denne (1979), Newton (1979), Radley and Bednarz (2005) agree that viable nest sites limit the species’ success but the influx of agriculture and the associated buildings often provide owls with densely available nest sites. Barn owls were rare in Pennsylvania prior to widespread conversion of forest to agriculture in the early twentieth century (DCNR 2010).

Twentieth century Pennsylvania land cover rapidly transitioned from virgins forests to vast expanses of open farmland (DCNR 2010). Barn owl populations flourished, but by the mid 1900s the national tendency was to convert open grassy farmland to row crop fields (Laub et al. 1979). This required less acreage, and specialized livestock farms, predecessors to modern factory farms (Laub et al. 1979). Changes in land use along with winter mortality, pesticide use and prey cycles, are used
in attempt to explain the current vulnerable status of barn owls in Pennsylvania (Colvin 1985, DCNR 2010, Mineau et al. 1999). This trend is mirrored in all surrounding states but has not universally raised concern.

The current range of the American barn owl spans most of the United States and continues through all of South America (Taylor 1994). Subspecies exist elsewhere, but even those within the Americas are not clearly delineated possibly because of documented opportunities for interaction (Taylor 1994). It is not fully understood how American subspecies interact or how local extinctions could alter the success of the species as a whole (Stewart 1952, Taylor 1994).

A primary cause of the lack of subspecies delineation is the irregularity of barn owl dispersal patterns. Barn owls have been observed to disperse long distances, but at varying temporal intervals. The factors influencing when and where the owls travel remains relatively unknown. Some studies suggest owls settle at nesting sites found by chance (Colvin 1985) whereas others suggest that barn owls have predictable migration patterns (Stewart 1952). Observed breeding dispersal of banded individuals ranged from under ten kilometers to over 1600 (Bolen 1978, Marti 1999, Soucy 1985, Stewart 1952). Dispersal observations typically utilize banding and recapture which operates on the assumption that tagged owls located near a previously occupied site never left. Moreover, many noted ‘rediscoveries’ were of deceased owls, often killed as a result of vehicle collisions, shootings, or other human actions. The dispersal patterns of barn owls can more accurately be inferred from numerous sightings of live individuals.

Many would assume that knowing so little about such an accessible species’ preferred habitat would prompt innumerable studies, but even as localized populations
declined, the ubiquitous nature seems to have avoided any momentous attention. The currently prevalent theory is that increasing agricultural intensity decreases barn owl habitat, which is logical but remains statistically unproven. This study uses satellite tracking using radio transmitters to track barn owl dispersal patterns. This study sought to quantify barn owl habitat preferences and climatic range as well as identify potential habitat. With a better awareness of dispersal and habitat preferences, conservation efforts can become more effective.

**METHODS**

*Data collection*

In 2005 the Pittsburgh Zoo & PPG Aquarium and Moraine State Park jointly funded the rearing of 16 barn owls. Captive breeding pairs raised the chicks to fledglings with minimal human interaction. Prior to release, the fledglings were fitted with satellite transmitters. The transmitter rode in the center of the owl’s dorsal side with tubular nylon fastened around the owl’s ventral side, similar to the way a parachute is fastened. By the release dates, all owls had preened the transmitters so that only the antennae could still be seen. The owls were moved to a 9.1m x 3.7m x 3.7m outdoor enclosure for a minimum of ten days prior to release. During this time, live mice were provided to simulated hunting experience within the enclosure. Release occurred in mid-September, which mimicked the timing of natural fledging.

The Argos-certified transmitters could transmit the owls’ locations for a total of 400 hours, limiting the transmission schedule. Initial dispersal and breeding season were of greatest interest, so transmitters were programmed to transmit locations every two
days in the fall, every ten days in the winter, and every seven days in the spring at a frequency of 401.650MHz ± 30kHz. Polar orbiting satellites of the National Oceanic and Atmospheric Administration (NOAA-15, NOAA-16, NOAA-17, and NOAA-18) recorded transmissions and simultaneously sent owl locations and altitudes to an Argos receiving station in Wallops Island, Virginia, USA.

The Argos processing center in Largo, Maryland, USA filtered and corrected erroneous data before forwarding it to the Pittsburgh Zoo & PPG Aquarium via their ArgosDirect program. Raw data was made available, however only professionally rectified data was considered. This service was provided as a part of transmitter purchase and taken advantage in order to ensure accuracy. The platforms also doubled as radio transmitters, allowing for manual verification of owl locations. Verification was conducted randomly at Pittsburgh-area locations to check accuracy of the Argos data. There were no discrepancies found, so this data is not included in these analyses.

Dispersal routes were estimated in ArcGIS given owl locations using Hawth’s tools, buffering all locations by a minimum of 20km to determine the area of interest. Non-continental boundaries were then made rectangular in order to simplify data download (figure 1). The 30m 2001 National Land Cover Dataset (NLCD) was downloaded from the U.S. Geological Survey (USGS) Seamless Server. Additional wetland and agricultural data were downloaded from the U.S. Fish and Wildlife Service’s National Wetlands Inventory and the U.S. Department of Agriculture’s National Agricultural Statistical Service respectively. The 90m Satellite Radar Topography Mission (SRTM) digital elevation model (DEM) provided a coarse resolution DEM which was necessary given the broad spatial scope of the analyses. Temperature,
isothermality, and precipitation data from WorldClim were downloaded to examine barn owl seasonal habitat use. Mark Browning, of the Pittsburgh Zoo & PPG Aquarium, assembled the owl location points as an Excel file which was imported into Arc. All data were projected into the 1983 North American Datum (NAD83) Albers equal area projection.

*Physical Habitat Analysis*

The low temporal resolution of the owl location data complicated the determination of permanent habitat versus transitional, migratory habitat. A minimum stay of ten days was required to guarantee that a habitat was suitable and non-migratory. Habitat was then classified as area where two of these ten-day stays had been recorded. One instance of a bird roosting in one location for 22 days was removed due to mortality at that site. Twenty locations qualified as sample habitats. Land cover type, elevation, slope, aspect, and distance from agriculture, wetlands, moving water, grasslands, and urbanization were determined for each of these habitat points (Appendix A). Specific agricultural and wetland classifications, such as riverine or paulustrine wetlands, were extracted to points located in either broad land cover type.

Similar methods were used to distinguish poor barn owl habitat. Thirteen owls died during the course of this study, and the locations of their deaths were assumed to be in unsuitable habitat. All analyses included these points except the envelope method of species distribution modeling.

Each numerical variable was examined for statistically significant differences between suitable and unsuitable sites using independent two-tailed t-tests with the
intention of weighting significantly different factors more heavily in a later determination of suitable habitat. Aspect and land cover were not factors in these preliminary statistical analyses but were intended to be considered in the physical habitat analysis. Aspect, while it can be described in numerical angular units, is more comprehensible statistically as a string variable. Secondary compass headings (north, northeast, east, southeast, south, southwest, west, and northwest) were compared using Pearson’s χ² test. This was done once to compare areas heavily used by successful and unsuccessful birds and once to compare heavily used areas and sites of mortalities. Aspect was also reduced to primary compass headings to increase observations per category for another Pearson’s χ² test. A Pearson’s χ² test was used to assess the non-numeric land cover classifications as well. The length of stay was compared to the ultimate fate of the individual birds using a Pearson’s χ² test in order to better estimate the habitat impact.

A generalized linear model (GLM) was used for assessing factor interaction between both numeric and non-numeric factors. GLM uses multiple models for the specific response variables, checking for significant differences between the models (Qian 2009). Prior to fitting GLMs, significantly correlated variables were reduced to one representative variable. One GLM was created using the number of days spent at each location as the response variable. It initially included all variables and was fit to the lowest Akaike’s Information Criterion (AIC) by removing the least significantly influential variable. This was done until all variables in the GLMs were statistically significant (p < 0.05) and of the fit with the lowest AIC was accepted.

The owl location data appeared clustered in many areas. One point used over an extended period would be surrounded by other areas of interspersed brief use. This
suggests that barn owls set up home ranges. The ArcGIS point density function weighted by the number of days between transmissions determined the average successful home range radius to be 10.1km (figure 2). Given the large raster cell size (as large as 1km) and temporal data gaps, no meaningful statistical analyses could be performed, but they would aid in the understand of how proximal habitats affect barn owl success.

*Climatic Influence Analysis*

Most noteworthy weather data must be considered at a fine temporal scale; however some of the study owls dispersed hundreds of kilometers in a matter of days. The inaccuracy of assessing isolated storm events limited daily climatic factors considered. In order to avoid extraneous interpolations from insufficient data, WorldClim’s professionally mapped climatic averages from 1950 to 2000 was substituted for individual climate station records. Mean annual temperature, mean diurnal temperature range, isothermality, annual temperature extremes, annual temperature range, mean annual precipitation, precipitation extremes, and seasonality served as general weather indicators (Appendix B). Numerical values were extracted from each weather indicator raster using representative points from the home ranges assessed in the physical habitat analysis.

A GLM was run with all climatic variables as independent variables and the length of stay as the dependent variable to predict how long an owl resided at that location. The season of stay was added as a string variable because many of the climatic variables were seasonal. Interacting variables were reduced to one representative variable to reduce covariation. Seasonal classification was determined by the median
date of stay and its relationship to the 2005 winter solstice. Due to the small number of qualifying sites, the birds’ ultimate success or death was not considered.

Seasonal habitat preferences were looked at using two-tailed independent t-tests in order to differentiate physical and climatic factors. Factors considered during the physical habitat analysis were compared again but on the basis of which season the bird showed longer periods of successful use.

Existing Habitat Analysis

Three separate model types were used to estimate existing habitat: envelope model, GLM, and classification and regression tree (CART) model.

The envelope model is one of the most basic forms of species distribution modeling. The range of tolerance of numerical factors, such as elevation and mean annual temperature, were considered habitat within the maximum and minimum of the observed values. For non-numerical factors, such as land cover type and aspect, only values observed in areas of long-term use (greater than 20 days) were considered. Envelope model was used to estimate barn owl distribution including all heavily used areas.

GLM acts as a flexible least squares regression using maximum-likelihood estimation. Each factor maintains its variability. When combined using a simple linear function, the variability values of each factor are weighted and combined to give an overall probability layer. Suitable habitat was determined based on the spatial relationship to habitat and mortality sites.
CART models were created with the R 2.9.1 statistical software package. CART explains suitability by using the most influential variables to determine characteristics of suitable and non-suitable habit. This also restricts the model to the fewest factors necessary to explain habitat and non-habitat differences.

This study focused on habitat in Pennsylvania. All aforementioned analyses are quantified to greater detail within Pennsylvania.

RESULTS

Physical Habitat Analysis

Twenty heavily used habitat areas were apparent. Nine were use by surviving birds, while eleven were used by birds that died. The independent t-test yielded no significant differences when comparing preferred habitat by successful versus unsuccessful owls (Table 1). The Pearson’s χ² test also yielded no significant results (Table 1).

No single environmental variable could describe the differences in survivorship, but in order to verify that all heavily used areas were synonymous with preferred habitat, factor interactions were considered.

Finding physical differences between sustained habitat and the locations of mortalities was intended to differentiate suitable and unsuitable habitat traits that may have contributed to the mortalities; however no environmental qualities varied consistently between locations of extended use and locations of mortalities (Table 2). The locations of mortalities did not differ from heavily used habitat; and this implies that the decline in barn owl populations may not be solely attributable to changes in habitat.
Interactions between the physical variables were not significant, so they all were used as primary inputs to the physical habitat analysis (Table 3). The envelope model of the ranges of observed habitat found 35.5 percent of the study area to be suitable barn owl habitat (Figure 3). GLM of the length of stay resulted in a final model fit using only elevation, but the model comprised of elevation and distance to streams had the best fit (Table 4). The GLM estimated viable habitat at 80.4 percent, more than twice as much as the envelope model (Figure 4). CART prioritized distance to flowing water, urbanization, wetlands and agriculture as the most important factors for distinguishing viable and non-viable habitat (Figure 5). When mapped, the CART model predicted 61.7 percent of the study area to be suitable physical habitat (Figure 6).

Within Pennsylvania, the envelope model predicted only 11.3 percent suitable habitat, which is 13,289 km² (Figure 7). GLM estimated 34.3 percent or 40,290 km² of Pennsylvania possessed the physical characteristics necessary for barn owl success (Figure 8). CART identified 62.9 percent or 73,757 km² (Figure 9).

**Climatic Influence Analysis**

As an exploratory test, the ultimate success of the individual birds was compared with the season using a Pearson’s χ² test, and while there were no significant results, the resulting p-value of 0.078 showed trends towards significance. This preliminarily suggested that climatic variables associated with changing season could play a larger role in barn owl survivorship.

As with physical habitat, there were no significant differences between the climates of areas used by successful and unsuccessful owl. (Table 5). The only climatic
variable that differed significantly between sites of extended use and mortality sites was mean annual temperature, but the general trend was towards more significant variation than found between successful and unsuccessful birds (Table 6).

Using an envelope model, approximately 46.6 percent of the eastern United States was found to be within the climatic range of barn owls (Figure 10). GLM indentified suitable habitat incorporating 76.7 percent of the study area (Figure 11), whereas the CART model only included 46.1 percent (Figure 12). GLM included annual temperature range, maximum temperature, mean diurnal range, and seasonality (Table 7). CART included winter precipitation, minimum temperature, seasonality, and annual temperature range (Figure 13).

All climate models estimated a possible climatic range that included parts of Pennsylvania. The envelope method estimated 10.0 percent (11,768km$^2$) of Pennsylvania was within the barn owl’s climatic range (Figure 7). GLM estimated 45.3 percent (53,172km$^2$, Figure 8) whereas CART estimated 74.7 percent (87,582km$^2$, Figure 9) of Pennsylvania is within a usable range.

Seasonal environmental preferences were also considered. Substituting prior grouping by survivorship with grouping by the season of inhabitation, elevation, slope, distance to grasslands, distance to wetlands, and land cover type all varied significantly with season (Table 8). Long periods of occupancy favored lower (Figure 14, p < 0.001) and flatter (Figure 15, p = 0.011) territories in the winter. This is consistent with preferences transitioning from deciduous forest to pasture or hay agricultural fields (p = 0.002) as farm land typically covers flat lands in lower watersheds. The distance to natural grasslands and to wetlands also related to season. Fall habitats were typically
closer to natural grasslands than winter habitats \( (p = 0.04) \), although during both seasons, natural grasslands remained within the owls’ average home range (Figure 16). Conversely, overwintering barn owls tend to stay closer to wetlands than they did in the fall (Figure 17, \( p = 0.01 \)).

**Existing Habitat Analysis**

The combination of physical factors and climatic range was simplest with the envelope model. The strict constraints of that method limited physically and climatically acceptable habitat to within the bounds of every variable tested. The resulting area included only 19.3 percent of the study area (Figure 18). Conversely, GLM and CART identified usable habitat over 50 percent, though the areas included are different (Figures 19 and 20). GLM included annual temperature range, distance to grassland, moving water, and wetlands, elevation, mean annual temperature and precipitation, maximum temperature, minimum precipitation, seasonality, slope, winter precipitation, and land cover type (Table 9). It estimated that 52.0 percent of the area of interest could serve as habitat; however, the habitat patches were consistently small, speckling the landscape and giving an overall appearance of connectivity (Figure 19). CART identified habitat which was more connected, being based on more climatic variables, winter precipitation, minimum precipitation, and mean diurnal range, but only one physical factor: distance to moving water (figures 20 and 21). The combination of these factors identified that 56.8 percent of the study area was functional habitat.

Within Pennsylvania, the resulting percentages were much more variable. The envelope model limited habitat to 4.2 percent of Pennsylvania \( (4,899 \text{km}^2, \text{Figure 7}) \).
GLM of Pennsylvania left 75,132km² or 64.9% (Figure 8). CART was more climate-dependent and only identified 51.9 percent (60,880km², Figure 9).

The number of times an area within Pennsylvania was deemed habitat was also mapped for conservation potential (Figure 22).

**DISCUSSION**

Prior to radio telemetry, bird banding was the ideal form of studying wild birds over extended periods of time (Stewart 1952). Radio tracking has long been known to come with some intrinsic error, particularly when the subjects were raised in captivity (Mech 1983, Millspaugh and Marzluff 2001). Even decades prior to this study, atypical animal behavior was observed when fitted with radio collars or other transmitting devices (Mech 1983). Similarly, the tendency of captive-bred individuals to tolerate human presence more readily than wild populations was well documented (Millspaugh and Marzluff 2001). The owlets raised for this study had minimum contact with people, but some degree of acclimation could not be avoided. In addition, owlets from captive breeding pairs were difficult to come by, so the study owls were obtained from zoos and other breeding programs as far away as Arizona. They were all of the North American subspecies, but there is no telling how dramatically their birthplace influenced their dispersal patterns.

**Physical Habitat Analysis**

Barn owls’ regular use of more open land cover types is common knowledge among ornithologists. Their heavy reliance on agriculture, wetlands, and natural
grasslands has been well established (Colvin 1984, Hegdal and Blaskiewicz 1984). The owls in this study were regularly found in deciduous forests. Salvati et al. (2002) cites deciduous forest to be secondary habitat to open lands, especially in rural areas. Typical habitat was taken into account with envelope model but not with GLM or CART. The extracted distance rasters, like distance to moving water, accounted for land cover in GLM and CART. Because envelope model included variables only within the observed ranges, it likely underestimated existing habitat. Its inconsistency with the other two models further corroborates this theory. GLM and CART reduce variables to only include the most meaningful ones. The persistence of distance rasters in these models affirms that barn owls establish home ranges in order to accumulate all survival necessities.

The estimated home range size was larger than others suggest. Some approximations have been made as low as 8km² (Taylor 1994). This estimate was made in Scotland, so any number of situational differences could account for the discrepancies in home range size. For example the Scottish subspecies may be better adapted to restricted areas or nest site availability could be limiting American populations (Salvati et al. 2002). Regardless, similar habitat types were noted among the Scottish owls (Taylor 1994). The mortality rate in this study, 81.3 percent, was comparable to typical wild fledgling mortality rates. The southern U.S. averages a mortality rate of approximately 47 percent, but the northern U.S. tends to be closer to 70 percent among fledglings in their first year (Henny 1969). Starvation is the primary cause of barn owl death (Taylor 1994). Prey species populations and hunting abilities are linked to physical habitat characteristics, although a clearer link is to vehicular collisions, the second most
prevalent cause of death (Taylor 1994). Distance to roads was not a variable in this study. It was not considered as the study focus was on owl survivor necessities rather than mortality causes.

The physical variables that were included were not consistent across all models. Envelope and GLM omitted the Appalachian Mountains from potential habitat (Figures 3 and 4), but CART failed to make the distinction between lowland habitat and upland non-habitat (Figure 6). CART identified the distance to flowing water in its first two regression branches (Figure 5). This was unanticipated as no previous studies have observed this trend. One of the 13 mortalities occurred in the Allegheny River near Fox Chapel, Pennsylvania which may have skewed the results. Moreover, the primary CART decision was based on a distance of 10.4km from flowing water. This is unexpected similar to the home range estimated in this study (10.1km). The two numbers were calculated independently but it appears that access to water may be a critical component to the home range and as thus, an important determinant in home range size. Evaluating the fit of CART is not possible using the data put into it (Chipman et al. 1998). The limited number of habitat and mortality locations did not make withholding points for an accuracy assessment an option. Envelope models consistently underestimate habitat and AIC values are easy to calculate from GLMs, but no practical approach to limited input CARTs exist (Chipman et al. 1998).

The physical habitat GLM only contained two variables: distance to streams and elevation. The simplicity of this model could have negated its accountability, but both factors may have been representative of other physical habitat qualities. Elevation, for example, has been used for a proxy for mean annual temperature (Millspaugh and
The physical habitat AIC value was the lowest obtained, but 323.85 was an order of magnitude higher than the existing habitat AIC, 30.72. The dramatic difference implies a strong trend of climate-dependent habitat use.

Climatic Influence Analysis

Starvation has been shown to be the leading cause of death in barn owls (Taylor 1994). Snow is the most often quoted impediment to barn owls’ abilities to hunt (Chabreck 1961, Marti and Wagner 1985, Taylor 1994). Prolonged below-freezing temperatures also leave barn owls susceptible to freezing (Speirs 1940). All models provided a stark climatic range that extended east-to-west through Pennsylvania (Figures 7, 8, and 9). The envelope model was very restrictive along the northern range (Figure 10). Limiting the acceptable range strictly to the observed range provides the most conservative estimate; however, it does not take into account that the northern mortalities were not immediately north of the successfully used habitat.

The climatic GLM AIC value of 310.21 was on scale with the physical habitat AIC value, suggesting a nearly equal ability of physical habitat or climate to explain variation in owl success, though climate GLM, too, was an order of magnitude higher than the existing habitat AIC. Existing literature suggested that snow has impeded barn owl hunting abilities and increased mortalities in prolonged cover (Handrich et al. 1993, Marti and Wagner 1985). Minimum temperature was strongly correlated with mean annual temperature and maximum temperature, so it was removed from analysis. Though removing it from the model was a statistically sound choice, it may have removed some ecological importance as well. The use of minimum temperature in CART further
affirms the error in removing minimum temperature. CART’s first decision branch partitions off areas of high winter precipitation as habitat (Figure 13). This was not contradictory to barn owls’ incompatibility with snow as areas receiving high winter precipitation were southern and thus avoided the harsh temperatures in the northern part of the range (Appendix B). As the climatic range extending into freezing minimum temperatures, measures of temperature buffering became more important in CART (Figure 13). Owl survival in areas with freezing temperatures was only possible in areas of low annual and mean diurnal temperature ranges (Figure 13).

The WorldClim climatic data used was created from averaging 50 years of data together. The winter of this study, 2005-2006 was an unusually snowy winter, and hurricanes and other extreme weather persisted throughout the year, possibly affecting barn owl behavior. Conversely, global climate change shows trends towards increasing temperatures that would extend the northern range of the barn owl. An increasing range would imply increasing populations. As this is not the case, climate could not be used to explain the northern population decline. It did, however, provided an estimate of the previously unknown northern range and therefore of the range of viable habitat worth considering in potential conservation efforts.

Existing Habitat Analysis

Envelope estimated less than 5 percent of Pennsylvania as habitat (Figure 7). Most was constrained in a few small patches in the southwest surrounding the release site. The birds had not been able to fly long distances while being raised, so the initial tendency to stay near the release site was predictable (Millspaugh and Marzluff 2001).
This error was inevitable. The owls were purposefully released in areas consistent with known barn owl preferences in attempt to mimic natural dispersal and curb mortality rates; however, this may have resulted in the artificial inflation of the importance of both physical and climatic habitat metrics typical of southwestern Pennsylvania.

**Conservation Recommendations**

Neither physical habitat nor climatic range could explain the differing successes between owls in this study, though they interacted. Conservation efforts should be focused in the more temperate regions of the United States, within the range at which barn owls have previously been observed. This study could not conclusively tie the decline in barn owl populations to a lack in viable habitat, but it was able to distinguish the most suitable habitat in Pennsylvania which is where conservation efforts have the greatest probability of success. Additional surveys of potential conservation areas to determine the presence of nesting sites and prey would be more helpful in validating habitat viability.

Conservation efforts could be more efficient if there was a better spatial understanding of prey distributions and nest site locations. Coastal marshlands are lacking in Pennsylvania, but agricultural fields with low pesticide use should have sufficient prey to sustain breeding pairs. Such areas would likely include vineyards and organic farms that would also reap the benefit of a natural pest control. Such sites may lack a proper nesting site. This can be remedied relatively easily with the use of artificial nesting boxes. Several companies already produce barn owl nesting boxes which be fit onto existing buildings or stand alone. Boxes associated with buildings
provide better protection from extreme weather but are more cost and labor intensive. Freestanding boxes are a less restricted as they can be erected anywhere and do not require the modification of buildings. Intelligently located nesting boxes could maintain populations at sustainable densities, furthering the benefits of natural pest control. In areas of high prey availability, barn owls become less territorial and may share nesting sites though this is not ideal do to overcrowding and disease (Keith 1964, Marti 1990). Placing boxes in vineyards and organic farms could aid in both owl conservation and pest control. Landowners would be more receptive to barn owl boxes if they barn owl is present as a valuable agrarian tool. This coupling of conservation and anthropogenic benefit would be the most efficient and effective conservation approach.

ACKNOWLEDGEMENTS

I would like to thank the Pittsburgh Zoo & PPG Aquarium and Moraine State Park for providing the means to conduct this study. In particular, I want to thank Mark Browning for spearheading the project and for generously allowing access to this data. I would like to thank my advisor, Dr. Curt Richardson, as well as the rest of the Nicholas School faculty whom added input throughout this process, especially Jennifer Swenson, John Fay, Song Qian, and Gaby Katul. My peers, also, have been a huge source of encouragement. Michelle Stogner, Lisanne Petracca, and Brian Tarpinian were just a few of my pillars of support. Finally, I would like to thank my family. Without the enduring support offered by these people, this report would have been a skeleton of its current form. They are sincerely appreciated.
REFERENCES


Table 1. *Comparison of habitat used by surviving versus non-surviving owls.* No significant differences were detected.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
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<td>161</td>
<td>230</td>
</tr>
<tr>
<td>Slope (degrees)</td>
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<td>0.91</td>
</tr>
<tr>
<td>Distance to Agriculture (km)</td>
<td>0.54</td>
<td>0.41</td>
</tr>
<tr>
<td>Distance to Natural Grassland (km)</td>
<td>3.77</td>
<td>4.11</td>
</tr>
<tr>
<td>Distance to Moving Water (km)</td>
<td>9.23</td>
<td>7.45</td>
</tr>
<tr>
<td>Distance to Urbanization (km)</td>
<td>2.93</td>
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</tr>
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<td>Distance to Wetlands (km)</td>
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<table>
<thead>
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</tr>
<tr>
<td>E-W Aspect</td>
<td>East</td>
<td>West</td>
</tr>
<tr>
<td>Land Cover</td>
<td>Deciduous Forest, Pasture/Hay</td>
<td>Deciduous Forest</td>
</tr>
<tr>
<td>Season</td>
<td>Winter</td>
<td>Fall</td>
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Table 2. *Comparison of habitat and mortality sites.* No physical variable varied significantly between sites.

<table>
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<td>Slope (degrees)</td>
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</tr>
<tr>
<td>Distance to Natural Grassland (km)</td>
<td>3.96</td>
</tr>
<tr>
<td>Distance to Moving Water (km)</td>
<td>8.25</td>
</tr>
<tr>
<td>Distance to Urbanization (km)</td>
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<tr>
<td>Distance to Wetlands (km)</td>
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<td><strong>Pearson’s χ²</strong></td>
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</tr>
<tr>
<td>Aspect</td>
<td>North, Northwest, Southeast</td>
</tr>
<tr>
<td>N-S Aspect</td>
<td>East</td>
</tr>
<tr>
<td>E-W Aspect</td>
<td>East, West</td>
</tr>
<tr>
<td>Land Cover</td>
<td>Deciduous Forest</td>
</tr>
</tbody>
</table>

Table 3. *Physical variable interactions.* No significant interactions occurred, so all variables remained in the analyses.

<table>
<thead>
<tr>
<th>Distance to Agriculture</th>
<th>Distance to Grasslands</th>
<th>Distance to Streams</th>
<th>Distance to Urbanization</th>
<th>Distance to Wetlands</th>
<th>Elevation</th>
<th>Slope</th>
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<td>Distance to Agriculture</td>
<td>1.000</td>
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<td></td>
<td></td>
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<td></td>
</tr>
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<td>Distance to Grasslands</td>
<td>0.336</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
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<td>Distance to Streams</td>
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<td>-0.007</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Distance to Urbanization</td>
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<td>0.150</td>
<td>0.355</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance to Wetlands</td>
<td>0.591</td>
<td>0.245</td>
<td>-0.090</td>
<td>-0.134</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Elevation</td>
<td>0.220</td>
<td>0.047</td>
<td>0.220</td>
<td>-0.281</td>
<td>0.616</td>
<td>1.000</td>
</tr>
<tr>
<td>Slope</td>
<td>0.470</td>
<td>0.238</td>
<td>-0.207</td>
<td>-0.152</td>
<td>0.832</td>
<td>0.481</td>
</tr>
</tbody>
</table>

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Table 4. *Physical habitat GLM inputs.* The best fit physical habitat GLM had an AIC of 323.85 and only one statistically significant variable.

| Factor             | Estimate | Standard Error | t-value | Pr (>|t|) |
|--------------------|----------|----------------|---------|----------|
| Intercept          | 39.051   | 10.377         | 3.763   | 0.001    |
| Distance to Streams| 0.001    | 0.001          | 1.491   | 0.146    |
| Elevation          | -0.099   | 0.040          | -2.487  | 0.019    |
| AIC Value          |          |                |         | 323.85   |

Table 5. *Comparison of climatic variables and habitat success.* No significant differences in climatic variables were found between owls that survived and did not survive the study.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Successful</th>
<th>Unsuccessful</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Temperature Range (C)</td>
<td>33.111</td>
<td>34.773</td>
<td></td>
<td>0.214</td>
</tr>
<tr>
<td>Isothermality</td>
<td>38.667</td>
<td>37.364</td>
<td></td>
<td>0.546</td>
</tr>
<tr>
<td>Mean Annual Precipitation (mm)</td>
<td>125.467</td>
<td>121.009</td>
<td></td>
<td>0.653</td>
</tr>
<tr>
<td>Mean Annual Temperature (C)</td>
<td>15.389</td>
<td>13.082</td>
<td></td>
<td>0.215</td>
</tr>
<tr>
<td>Maximum Precipitation (mm)</td>
<td>13.533</td>
<td>13.264</td>
<td></td>
<td>0.821</td>
</tr>
<tr>
<td>Maximum Temperature (C)</td>
<td>31.556</td>
<td>30.318</td>
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<td>0.237</td>
</tr>
<tr>
<td>Mean Diurnal Range (C)</td>
<td>12.822</td>
<td>13.045</td>
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<td>0.534</td>
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<tr>
<td>Minimum Precipitation (mm)</td>
<td>6.944</td>
<td>6.909</td>
<td></td>
<td>0.937</td>
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<tr>
<td>Minimum Temperature (C)</td>
<td>-4.455</td>
<td>-1.556</td>
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<td>0.210</td>
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<tr>
<td>Seasonality</td>
<td>7.401</td>
<td>7.905</td>
<td></td>
<td>0.304</td>
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<tr>
<td>Winter Precipitation (mm)</td>
<td>30.844</td>
<td>28.582</td>
<td></td>
<td>0.595</td>
</tr>
</tbody>
</table>

Table 6. *Comparison of climatic and mortalities.* Isothermality, seasonality, mean annual precipitation, mean diurnal range, and winter precipitation would have been significant at p=0.1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Habitat</th>
<th>Mortality</th>
<th>p-value</th>
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</thead>
<tbody>
<tr>
<td>Annual Temperature Range (C)</td>
<td>34.025</td>
<td>35.446</td>
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<td>0.141</td>
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<tr>
<td>Isothermality</td>
<td>37.950</td>
<td>34.692</td>
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<td>0.057</td>
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<tr>
<td>Mean Annual Precipitation (mm)</td>
<td>123.015</td>
<td>108.569</td>
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<td>0.066</td>
</tr>
<tr>
<td><strong>Mean Annual Temperature (C)</strong></td>
<td><strong>10.712</strong></td>
<td><strong>15.994</strong></td>
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<td>&lt;0.001</td>
</tr>
<tr>
<td>Maximum Precipitation (mm)</td>
<td>13.385</td>
<td>12.185</td>
<td></td>
<td>0.276</td>
</tr>
<tr>
<td>Maximum Temperature (C)</td>
<td>30.875</td>
<td>29.746</td>
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<td>0.130</td>
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<tr>
<td>Mean Diurnal Range (C)</td>
<td>12.945</td>
<td>12.385</td>
<td></td>
<td>0.081</td>
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<tr>
<td>Minimum Precipitation (mm)</td>
<td>6.925</td>
<td>6.346</td>
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<td>0.169</td>
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<tr>
<td>Minimum Temperature (C)</td>
<td>-3.150</td>
<td>-5.700</td>
<td></td>
<td>0.128</td>
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<tr>
<td>Seasonality</td>
<td>7.678</td>
<td>8.335</td>
<td></td>
<td>0.078</td>
</tr>
<tr>
<td>Winter Precipitation (mm)</td>
<td>29.600</td>
<td>23.562</td>
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<td>0.059</td>
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</table>
Table 7. *Climatic range GLM inputs*. The best fit climatic GLM had an AIC of 310.21, which was only marginally better than the physical habitat GLM.

| Factor                      | Estimate | Standard Error | t-value | Pr (>|t|) |
|-----------------------------|----------|----------------|---------|-----------|
| Intercept                   | 33.367   | 275.973        | 0.121   | 0.905     |
| Annual Range in Temperature | 133.646  | 30.901         | 4.325   | < 0.001   |
| Maximum Temperature         | 7.877    | 5.759          | 1.368   | 0.182     |
| Mean Diurnal Range          | -126.667 | 27.693         | -4.574  | < 0.001   |
| Seasonality                 | -410.42  | 91.308         | -4.495  | < 0.001   |

| AIC Value                   | 310.21   |

Table 8. *Comparison of physical habitat variables seasonally*. The high number of significantly different variables implies that under different climatic conditions barn owl preferences vary.

<table>
<thead>
<tr>
<th>Independent t-test</th>
<th>Mean</th>
<th>Fall</th>
<th>Winter</th>
<th>p-value</th>
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</thead>
<tbody>
<tr>
<td>Variable</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elevation (m)</td>
<td>306.55</td>
<td>67.67</td>
<td>&lt; 0.001</td>
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<tr>
<td>Slope (degrees)</td>
<td>1.12</td>
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<td>0.011</td>
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<td>Distance to Agriculture (km)</td>
<td>0.51</td>
<td>0.41</td>
<td>0.718</td>
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<tr>
<td>Distance to Natural Grassland (km)</td>
<td>2.32</td>
<td>5.95</td>
<td>0.040</td>
<td></td>
</tr>
<tr>
<td>Distance to Moving Water (km)</td>
<td>8.74</td>
<td>7.65</td>
<td>0.763</td>
<td></td>
</tr>
<tr>
<td>Distance to Urbanization (km)</td>
<td>1.40</td>
<td>4.95</td>
<td>0.053</td>
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</tr>
<tr>
<td>Distance to Wetlands (km)</td>
<td>14.47</td>
<td>2.37</td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td>Length of Stay (days)</td>
<td>30.27</td>
<td>58.22</td>
<td>0.095</td>
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<table>
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<tbody>
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</tr>
<tr>
<td>N-S Aspect</td>
<td>Northeast,</td>
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<td></td>
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</tr>
<tr>
<td>E-W Aspect</td>
<td>West</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Land Cover</td>
<td>Deciduous Forest</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Pearson’s $\chi^2$          |                          |        |         |           |
|                            | Deciduous Forest         |        |         |           |
|                            | Pasture/Hay              |        |         |           |

|                         |                          |        |         |           |
|---|------------------|--------------------------|--------|---------|-----------|
|    | Pearson’s $\chi^2$ | Northeast,               |        |         |           |
|    |                  | Northwest                |        |         |           |
|    |                  | East                      |        |         |           |
|    |                  | South                     |        |         |           |
|    |                  | West                      |        |         |           |
|    |                  | Pasture/Hay               |        |         |           |

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Table 9. *Potential habitat GLM inputs.* The all-inclusive GLM had the overall lowest AIC value at 30.719.

| Factor             | Class             | Estimate | Standard Error | t-value | Pr (>|t|) |
|--------------------|-------------------|----------|----------------|---------|----------|
| Intercept          |                   | -43.840  | 18.580         | -2.359  | 0.035    |
| Annual Temperature | Range             | -1.259   | 0.632          | 1.990   | 0.068    |
| Distance to        | Grasslands        | -0.00004 | 0.00003        | -2.515  | 0.026    |
| Distance to        | Water             | 0.00004  | -0.00003       | 1.624   | 0.128    |
| Distance to        | Wetlands          | 0.00006  | 0.00002        | 3.193   | 0.007    |
| Elevation          |                   | 0.011    | 0.005          | 2.170   | 0.049    |
| Mean Annual        | Precipitation     | 0.161    | 0.007          | 2.435   | 0.030    |
| Mean Annual        | Temperature       | -1.641   | 1.149          | -1.427  | 0.177    |
| Maximum Temperature|                   | 3.100    | 1.375          | 2.255   | 0.042    |
| Minimum Precipitation|               | -1.109   | 0.290          | -3.820  | 0.002    |
| Seasonality        |                   | 1.169    | 0.921          | 1.270   | 0.226    |
| Slope              |                   | -0.307   | 0.144          | -2.133  | 0.053    |
| Winter Precipitation|                | -0.245   | 0.125          | -1.963  | 0.071    |
| Land Cover         | Coniferous Forest | -1.120   | 0.722          | -1.551  | 0.145    |
|                    | Developed Open    |          |                |         |          |
|                    | Space             | -0.290   | 0.324          | -0.896  | 0.387    |
|                    | Deciduous Forest  | -0.646   | 0.282          | -2.294  | 0.039    |
|                    | Open Water        | -0.774   | 0.500          | -1.547  | 0.146    |
|                    | Pasture Crops     | -1.899   | 6.641          | -2.962  | 0.011    |
|                    | Woody Wetlands    | -2.110   | 0.780          | -2.705  | 0.018    |

AIC Value: 30.72
Figure 1. *Area of Interest.* There was little consistency in individual owls’ dispersal patterns.
Figure 2. *Home Ranges*. The average home rang radius was approximately 10.1km, spanning 320km².
Figure 3. *Envelope model physical habitat*. Potentially, 35.5 percent of land cover within the study owls’ ranges could serve as barn owl habitat.
Figure 4. *GLM physical habitat.* GLM estimated 80.4 percent of the study area could be within the climatic range.
Figure 5. Physical habitat CART input. All decisions were made based on numbers within or nearly within the average home range radius.
Figure 6. CART physical habitat. Over half, 61.7 percent of the eastern United States could serve as barn owl habitat.
Figure 7. *Pennsylvania envelope model.* Potentially, 11.3 percent of Pennsylvania could physically serve as habitat (yellow), 10.0 percent is within the climatic range (blue), and 4.2 percent is both physically and climatically suitable (green).

Figure 8. *Pennsylvania GLM.* The physical factors, climatic factors, and all factors GLMs estimated 34.3 percent (40,290km²), 45.3 percent (53,172km²), and 64.9 percent (76,132km²) of Pennsylvania within the usable range of barn owls. Only 12.6 percent (14,790km²) of Pennsylvania was not considered habitat under any of the three GLMs, and 9.5 percent (10,354km²) was in all GLMs.
Figure 9. *Pennsylvania CART*. CART estimated 62.9 percent (73,757km$^2$), 74.7 percent (87,582km$^2$), and 51.9 percent (60,880km$^2$) of Pennsylvania as viable when using physical variables only, climatic variables only, and both, respectively. These models all overlapped on 41.6 percent (48,824km$^2$) of Pennsylvania’s area.
Figure 10. *Envelope model climatic range.* Mapped envelope ranges estimated 46.5 percent of the study area to be within the climatic range.
Figure 11. *GLM climatic range.* GLM of climatic variables encompasses 76.7 percent of the eastern United States.
Figure 12. *CART climatic range.* CART model of climatic ranges divides the eastern U.S. in two, though it still estimated 74.7 percent of the area of interest.
Figure 13. *Climatic range CART input.* The classification and regression tree of climatic variables found winter precipitation to be the most telling climatic variable.
Figure 14. *Seasonal habitat elevation.* Barn owls spent winters at lower elevations than fall.

Figure 15. *Seasonal habitat slope.* Barn owls used generally flat terrain, particularly during winter months.
Figure 16. *Seasonal Distance to Grasslands.* Barn owls use natural grasslands less during winter months.

Figure 17. *Seasonal distance to wetlands.* Barn owls stayed significantly closer to wetlands while overwintering.
Figure 18. Envelope model existing habitat. Only 19.3 percent of the study remained viable after combining physical and climatic envelope models.
Figure 19. *GLM existing habitat*. Innumerable small patches of viable habitat comprise 52.0 percent of the landscape, according to the GLM, giving the appearance of connectedness.
Figure 20. *Existing habitat CART input.* The CART primary decision for all possible habitat, physical and climatic, was winter precipitation. Most factors were climatic rather than physical though.
Figure 21. CART existing habitat. Large, cohesive patches of habitat take up 56.8 percent of the landscape.
Figure 22. *Pennsylvania model frequency.* Areas near the release sites appeared in most modeled habitat. Southeastern Pennsylvania also frequented predictions despite having no study owls disperse there.
Aspect

Projection: Albers Equal Area
North American Datum 1983
Prepared by: Aldia Burtner
Duke University, 2/7/2010
Distance to Agriculture

Projection: Albers Equal Area
North American Datum 1983
Prepared by: Aldia Burkner
Duke University, 2/27/2010
APPENDIX B: Climatic Range Variables

Mean Annual Temperature

Projection: Albers Equal Area
North American Datum 1983
Prepared by: Alida Butner
Duke University, 2/27/2010
Isothermality

Projection: Albers Equal Area
North American Datum 1983
Prepared by: Alida Burkner
Duke University, 2/27/2010
Minimum Temperature

Projection: Albers Equal Area
North American Datum 1983
Prepared by: Alida Busnher
Duke University, 2/27/2010
Annual Range - Temperature

Projection: Albers Equal Area
North American Datum 1983
Prepared by: Alycia Butner
Duke University, 2/27/2010
Precipitation - Wettest Month

Projection: Albers Equal Area
North American Datum 1983
Prepared by: Alida Butner
Duke University, 2/7/2010