GIS Analysis of Potential Bald Eagle Nesting Habitats along the Mississippi River and the Pacific Northwest (USA)

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Abstract

The purpose of this project was to determine if potential bald eagle nest habitat can be identified using GIS analysis. A second objective was to observe differences among nesting habit of bald eagles in five different study areas. Bald eagles (*Haliaeetus leucocephalus*) were on the verge of extinction before being placed on the endangered species list in 1975. Eagles were impacted by habitat destruction, hunting, lead poisoning, and DDT/DDE. Nest sites and habitat are crucial in order to maintain a healthy population of bald eagles. A hindrance to this is human disturbance, thus human disturbances continue to need to be monitored. Data were collected by examining eagle nest habitat, territories, geospatial relationships, and human disturbances. A 100 meter (m) buffer was applied to known and random nest locations in an effort to correct error from GPS data collection. Results found 38% of nests were located within 1000 m of a railroad or major roadway. In addition, trees > 25 m in height occupied 5% of the total area. Tree cover ranging from 30-70% occupied 51% of the total area. Selected tree species accounted for 27% of the total area.

Introduction

Toxicants including DDT (dichlorodiphenyltrichloroethane) and DDE (dichlorodiphenyldichloroethylene) nearly caused extinction of bald eagle populations due to chemical reactions that caused extremely low reproduction rates and egg shell thinning (Grier, 1982). These chemicals are so powerful that a half-life was unable to be determined which led to environmental problems and ultimately the Environmental Protection Agency banning them from further use (Grier). Bald eagle populations were depleted to a mere 417 breeding pairs in 1963, but have since rebounded to approximately 11,040 pairs in the continental United States (Suckling and Hodges, 2007). Since the reduction of bald eagles, numerous studies have focused on their populations, nest selections, and disturbances. Because eagles were on the brink of extinction their populations have been and continue to be monitored closely to ensure their population continues to thrive and rebound.

With bald eagle habitats being destroyed, an increase of lead poisoning, and human interference, models can used to predict and prevent certain outcomes by using geospatial analysis. Using geospatial data can help interpolate data collected and produce graphic displays for tests and

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information collected. Using information collected and displayed through ArcMap can have ecological validity (Craig, Craig, Huettmann, and Fulle, 2009).

Nest site selection is crucial to maintaining a healthy bald eagle population. Along the Mississippi River, bald eagles nest in a floodplain forest dominated by silver maples (*Acer saccharinum*) and eastern cottonwoods (*Populus deltoides*) (Mundahl, Bilyes, and Mass, 2013). Within these forests, eagles preferred to select the tallest trees that protruded through the canopy of the forest. Eagles were found to select eastern cottonwood trees more frequently than any other tree (Mundahl *et al.*, 2013). Pacific Northwest bald eagle nests were also found in supercanopy trees such as ponderosa pine (*Pinus ponderosa),* mixed conifer, Douglas-fir (*Pseudotsuga menziesii*), and sitka spruce (*Pseudotsuga menziesii*)/ western hemlock (*Tsuga heterophylla)* forests (Anthony, Knight, Allen, McClelland, and Hodges, 1982). Bald eagles, as a species, "finds optimum habitat for breeding . . . in old growth Douglas-fir forests in western Oregon and Washington," declares Meslow (1981).

Along the Mississippi River, trees that contained active nests had an average of 28 meters in height and 84 cm breast height with the highest and largest nests located in eastern cottonwoods. Large, isolated trees in dense forests were found to contain the most active nests. Nest trees were significantly taller and had a notably larger diameter at breast height than other trees located in the same forest plot. Nest trees were found to be considerably larger in both height and diameter at breast height than the next largest tree (Mundahl *et al.*, 2013). Nests are found in dominant or co-dominant tree species within a forest throughout the Pacific Northwest (Anthony *et al.*, 1982).Tree height has a significantly positive relationship to active bald eagle nests (Suring, 1998).

Despite recovering populations, eagles are still under watch. Eagle deaths are closely monitored to ensure their safety and make sure there is no sign of poaching, fowl-play, or chemical interference. The Wisconsin Department of Natural Resources (2011) found collisions with motor vehicles to be the leading cause of eagle deaths in 2011. Data from banding records analyzed by Keran (1981) indicated mortality from vehicular collisions can be a significant cause of mortality for some raptor species. Information from 273 encounter records of banded raptors indicated 42.5% of the human-caused mortalities were from road kills. Raptors foraging along roadside habitats or on road-killed carcasses increase the potential for raptor-vehicle collisions (Howard, 1975). Illner (1992) documented 21 times greater vehicle-owl collisions along roads with car speeds of more than 50 mph than on roads with slower traffic. Also, eagle deaths have been caused by electrocution, eagle vs. eagle fights, and wing injuries (Wisconsin DNR, 2011). Improperly constructed power lines can result in the electrocution of raptors attempting to utilize these structures for perching and nesting sites (Harness and Wilson, 2001). Along the Mississippi River, successful nests were located farther away from potential transportation disturbances (Mundahl *et al.*, 2013).

Broley (1947) states, "Human disturbances around nest sites during the nesting season can negatively influence nesting success." Eagle nests that are located in a dense forest provide the most shelter from human disturbances and have been showing nesting success (Anthony *et al.*, 1982).

Populations in the Pacific Northwest, Wyoming, Montana, Idaho, and Central Oregon have not fully recovered from the DDT outbreak. Bald eagle nests were observed in each of these areas and latitude, longitude data were obtained (Nadeau, 2012). Also, according to Watson and Rodrick (2001), it was found the majority of eagle nests are located within 805 m (.5 miles) of a major waterbody. The purpose of this study was to determine if a bald eagle nest habitat model can be developed using GIS analysis and to observe the differences of nesting habits of bald eagles in 5 different areas. Using previous research, five criteria were considered and then analyzed to construct the best potential bald eagle nest habitat model. The criteria established were: forest type (cottonwoods, maples, oaks, pines, mixed conifer, Douglas-fir, Sitka spruce/western hemlock), tree cover (30-70%), tree height (> 25 m), 100 m away from railroads or major roadways, and with 805 m of a major waterbody (Table 1).

Table 1. List of five criteria used to develop potential bald eagle nest location models.

Criteria
100 m away from human disturbance (roads, railroads)
Within 805 m of a waterbody
Forests must have between 30-70% tree cover
Trees must be > 25 m in height
Tree species must be cottonwoods, maples, oaks, pines, mixed conifer, Douglas-fir, Sitka spruce/western hemlock

Eagle nests were located along pools (impoundments) 4, 5, 5a, and 6 of the Mississippi river, Lake Cascade in Idaho, Upper Klamath Lake, and Agency Lake in Oregon. Once data were collected, GIS analysis was undertaken using ArcMap 10.2.2.

Study Area

A total of five areas were examined ranging from Oregon, Idaho, Wyoming, to Minnesota (Figure 1). The Mississippi study area is a floodplain habitat that serves as a major migratory route for bald eagles. The Upper Mississippi Wildlife Refuge contains the Mississippi River, off channel areas, and floodplain forests. This area contains the most eagle nests in the continental United States. This study included river pools (impoundments) 4, 5, 5a, and 6, which are located in the upper-most portion of the Upper Mississippi Wildlife Refuge. Nests in this location are located on both public and private land and all nest points were collected by wetland biologists working for the United States Fish and Wildlife Service. Nest points were checked for accuracy and nests with large GPS approximations were not included in this study to ensure accurate results. Data points of 121 active and non-active nests were analyzed and included in this study. Active and non-active nests were studied because bald eagles have been known to reoccupy abandoned nests up to 17 years later (Whittington and Allen, 2008).

A 6437 m (4 mile) buffer was created around pools 4, 5, 5a, and 6 to establish a study area to analyze eagles in this location. It was found eagles nest near large bodies of water (Watson, 2001) and no nests were located farther than 6437 m away from water. The total area (in hectares) was 324,726 and 32,267 of that was open water. After the 100 m buffer

(Table 1) was applied, the study area was reduced to 377 hectares which was dominated by cottonwoods, maples, and, oaks 10-25 m in height.

The study area in Idaho was a 6437 m buffer around Lake Cascade, Idaho. Lake Cascade is a reservoir located along the Payette River.

The area around Lake Cascade included the Cascade Mountains, which contained many of the specific tree species required for bald eagle nests. A total of 15 nests were analyzed here and the study area totaled 87,915 hectares, with open water occupying 10,078 of that area. After the 100 m buffer was applied, the total area was reduced to 47 hectares. Pines, mixed conifer, Douglas-fir, Sitka spruce/western hemlock ranging 10-25 m dominated the landscape.

The Snake River is the main waterbody flowing through the Wyoming study area. When a 6437 m buffer (four miles) was applied, the results showed alpine terrain, pines, mixed conifer, Douglas-fir, Sitka spruce/western hemlock, pristine ponds, and the Teton Mountain Range consisted of dominant vegetation types. A total of six nests were located in this study area. The study area totaled 330,058 hectares. Open water occupied only 6622 hectares. After the 100 m buffer was applied, the total area was reduced to 18 hectares. There were no supercanopy trees with the majority of trees including pines, mixed conifer, Douglas-fir, Sitka spruce/western hemlock extending between 10-25 m.

Study areas in Oregon were located around Upper Klamath Lake (known as Oregon South in this study), 132,959 hectares and Agency Lake (known as Oregon North in this study), 106,422 hectares, which includes wetlands and marshes as well as the largest freshwater body (Upper Klamath Lake) west of the Rocky Mountains. When the 100 m buffer was applied study areas were reduced to 28 hectares in the Southern study area and 28 hectares in the Northern Study area. Like most mountainous habitats, this area was inhabited by pines, mixed conifer, Douglas-fir, Sitka spruce/western hemlock ranging from 10-25 m in height.

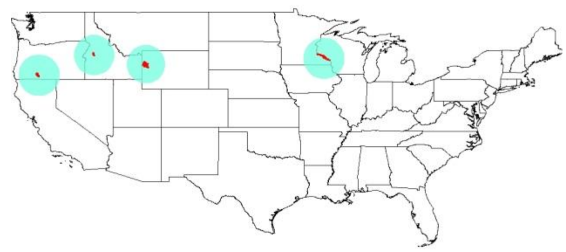

Figure 1. Map of the Continental United States showing the study areas (in red) focused on during this research.

Methods

Bald eagle nest locations along the Mississippi River were obtained from the United States Fish and Wildlife Service. The remaining nest locations were obtained from Nadeau (2012) in the form of latitude and longitude. Using ArcMap 10.2.2 the latitude and longitude of each nest location was converted to a point file with a projected coordinate system of Albers NAD 1983. These locations were then used for analysis throughout the study.

ArcMap 10.2.2 was used to analyze bald eagle habitats along the Mississippi River. Preliminary data were downloaded from the U.S.G.S Landfire online database. The data included vegetation species, height, and density. Shapefiles were then obtained from the U.S Census Bureau, which included primary roads and railroads.

The data for each study area were clipped to fit the 6437 m buffer around major waterbodies. From there, each raster file containing vegetation height, type, or density was reclassified. Reclassification divided each raster file into criteria (Table 1) used to develop potential bald eagle nest habitats. Height was reclassified to only contain tree species that were > 25 m, type was reclassified to include only cottonwoods, maples, oaks, pines, mixed conifer, Douglas-fir, Sitka spruce/western hemlock, and density was reclassified to allow for only forests with a tree density or 30-70%. Once reclassified, new data were processed with the raster calculator to produce a true/false statement. This conversion allows for the data to be converted from a raster file to a vector file.

The reclassified criteria were then converted into polygons in order to be analyzed using geoprocessing methods. After the height, type, and cover were converted to polygons, the final two criteria (Table 1) could be applied since they were in vector form to begin with. An 805 m buffer was created around major waterbodies in each study area based on U.S.F.W.S and findings from Watson and Rodrick (2001), bald eagle nests are located within 805 m of a waterbody. The final criterion was to create a 100 m buffer around primary roads. The newly reclassified vegetation criteria were then applied to the 805 m buffer and 100 m human disturbance buffer. Clipping the vegetation layers to the 805 m water layer allowed for the final criteria to be executed. The remaining polygons were then clipped from the 100 m road layer to ensure no nests were located near a human disturbance. The combination of all criteria produces a potential bald eagle nesting habitat.

The 100 m buffer was then applied to each existing nest location to analyze vegetation height, cover, and type in each location. A 100 m buffer was created because multiple locations were approximated and each GPS unit has an approximate error distance (Figure 2).

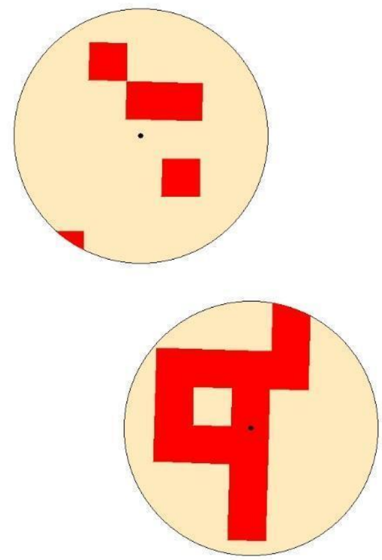

Figure 2. A detailed picture of existing nest locations and the 100-m buffer that was applied to the nest. The polygons within the buffer represent potential bald eagle nest locations.

Random nest locations were then generated using a randomization generator in ArcMap. These were created to test if criteria used were accurately portrayed. After buffers were created, polygons of the criteria were clipped to the 100 m buffer and analyzed.

Distances of nests to disturbances, water, and to nearest nest were measured with a Euclidian or straight line using the measure tool in ArcMap.

Analyses

Potential bald eagle nest sites were analyzed by individual characteristics, vegetation height, type, and cover, and distance to water, disturbances, and nearest nests. They were also analyzed as a unit. A series of independent sample Student t-tests were performed for each study area to determine if the criteria established within buffers around the existing nests were significantly different than that of the buffer around the random nest locations. An Average Nearest Neighbor test was performed on existing and random nest locations to determine if the nests were random, clustered, or dispersed throughout the study area. This test also analyzed the distances between each nest. The Average Nearest Neighbor Distance tool measures the Euclidian distance between each feature centroid and its nearest neighbor's centroid location. It then averages all these nearest neighbor distances. If the average distance is less than the average for a hypothetical random distribution, the distribution of the features being analyzed are considered clustered. If the average distance is greater than a hypothetical random distribution, the features are considered dispersed. The index is expressed as the ratio of the observed distance divided by the expected distance (expected distance is based on a hypothetical random distribution with the same number of features covering the same total area) (Ebdon, 1985). The individual data for height, type, and cover were observed and recorded to show if the criteria selected were the dominant selection in each study area based on percentages.

Results

There were 160 bald eagle nests that were tested as well as 160 randomly generated nest points. The Minnesota study area contained 121 nests, Idaho contained 15, Wyoming contained 6, Oregon South and Oregon North each contained 9 nests. Individual nest sites were observed separately for vegetation height, type, and density. The criteria were also analyzed as a unit (all five criteria combined) to observe if this way of testing could also be used. The Minnesota study area had no nests intersecting potential nesting areas. Idaho had 2 nests intersecting nesting areas, while Wyoming had no nests. In addition, Oregon South had 4 nests and Oregon North had 6 nests intersect nesting areas. The intersection tool was used to show if existing nests were located in an area created by the potential habitat model that was created. Minnesota, Wyoming, and Idaho had poor results after the model was developed and run.

Individual Criteria

The 100 m buffer areas around each nest were observed first (Figure 2). The buffer areas around nests in Minnesota were found to be 377 hectares. Of the 377 hectares 169 hectares were open water and were not included in the study due to the fact that eagles cannot nest in open water. It was found tree density between 30-70% inhabited 45% (94.3 hectares) of the study area. Tree height between 10-25 m dominated the study area with 71% (147 hectares). Floodplain vegetation inhabited

83% (171 hectares) of the study area (Figures 3-5).

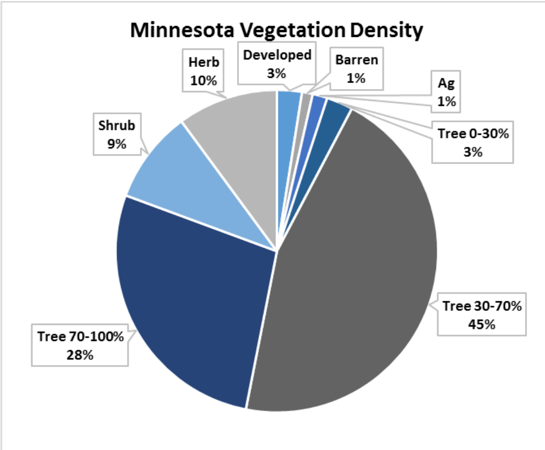

Figure 3. Percent of vegetation density located in Minnesota study area.

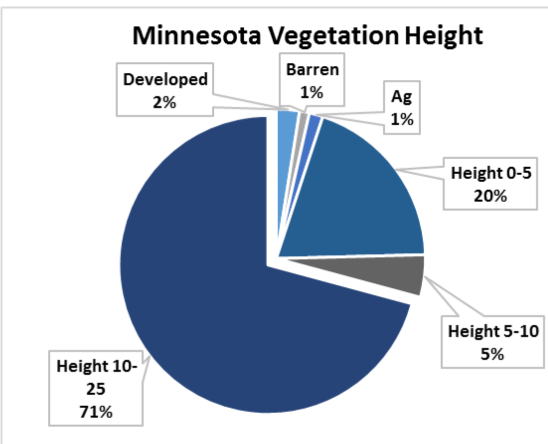

Figure 4. Percent of vegetation height located in Minnesota study area.

In Idaho, 47 hectares was the total area around bald eagle nests with open water inhabiting 12 hectares. Tree density ranging from 30-70% occupied 47% (21 hectares) of the total area. Tree heights between 0-5 m were found to be the most common with 53% (24 hectares) of the total area. Vegetation type was dominated by cottonwoods, maples, oaks, pines, mixed conifer, Douglas-fir, Sitka spruce/western hemlock, with a result of 55% (25 hectares) (Figures 6-8).

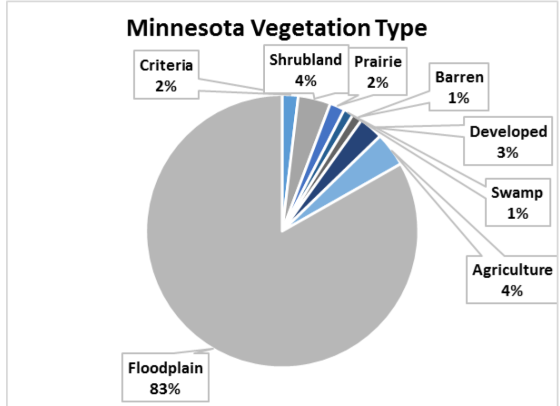

Figure 5. Percent of vegetation type in Minnesota study area.

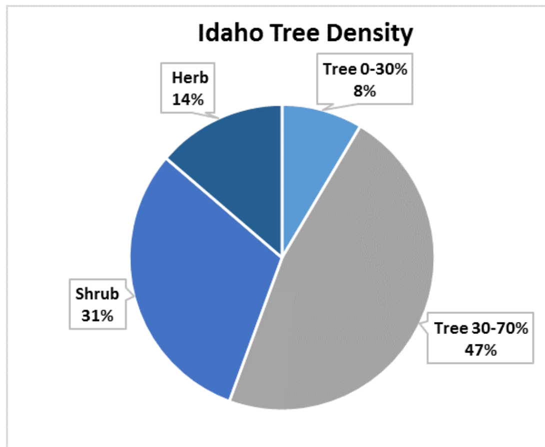

Figure 6. Percent of vegetation density in Idaho study area.

Buffers around the Wyoming nest sites totaled 18 hectares with open water occupying 1.4 hectares. Vegetation cover between 30-70% inhabited 55% (10 hectares) of the total area. Tree height ranging between 10-25 m totaled 62% (11 hectares). The criteria of cottonwoods, maples, oaks, pines, mixed conifer, Douglas-fir, Sitka spruce/western hemlock inhabited 66% (12 hectares) of the total area (Figures 9-11).

The Oregon South study area totaled 28 hectares with open water occupying .8 hectares. It was found that tree density between 30-70% totaled 82%

(22 hectares). Tree height ranging from 10-25 m occupied 51% (14 hectares) of the total study area. Cottonwoods, maples, oaks, pines, mixed conifer, Douglas-fir, Sitka spruce/western hemlock inhabited 94% (26 hectares) of the total area (Figures 12-14).

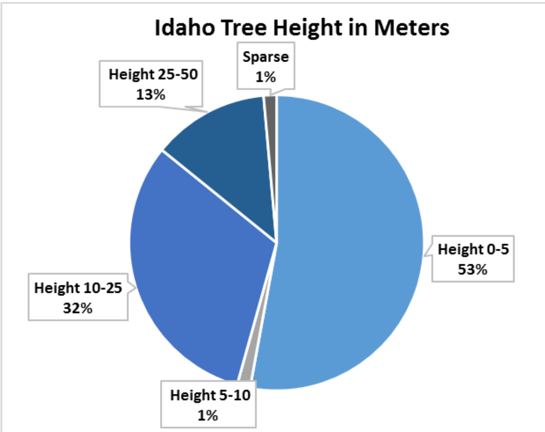

Figure 7. Percent of vegetation height in Idaho study area.

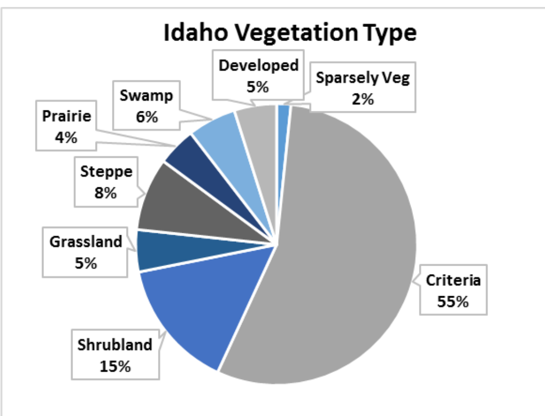

Figure 8. Percent of vegetation type in Idaho study area.

The Oregon North study area also totaled 28 hectares with open water occupying .7 hectares. Tree density between 30-70% inhabited 70% (19 hectares) of the total area. Tree heights ranging from 10-25 m inhabited 50% of the total area. The criteria of cottonwoods, maples, oaks, pines, mixed conifer, Douglas-fir, Sitka spruce/western hemlock dominated the total area with 80% (22 hectares) cover (Figures 15-17).

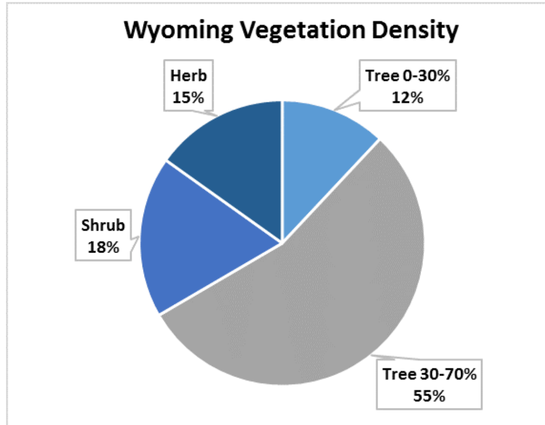

Figure 9. Percent of vegetation density in Wyoming study area.

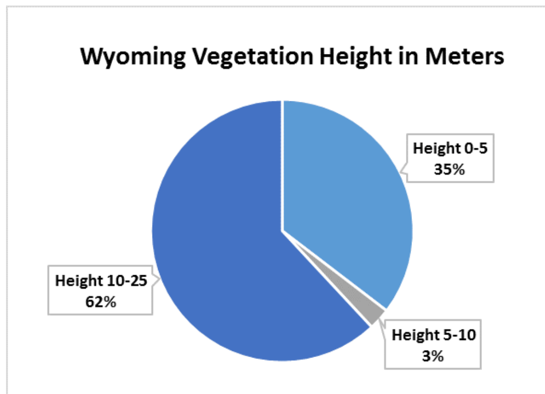

Figure 10. Percent of vegetation height in Wyoming study area.

Distance Measurements

Nests were measured in a Euclidian or straight line to the nearest human disturbance, body of water, and nearest nest. In Minnesota 6 (5%) nests were located within the 100 m buffer around human disturbance. Forty-nine (40%) nests were between 100-1000 m from a disturbance; distances between 1001-2000 m found 44 (36%) nests. Eighteen nests (15%) were located between 2001-3000 m away from disturbances; three nests (3%)

were located between 3001-4000 m, while one nest (1%) was located between 4001-10000 m.

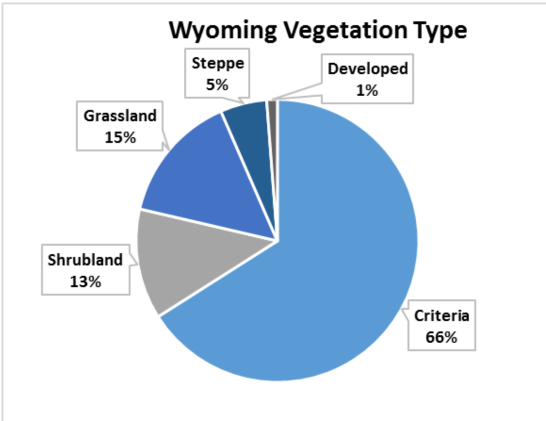

Figure 11. Percent of vegetation type in Wyoming study area.

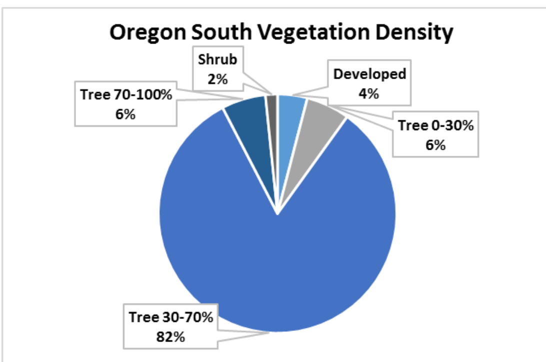

Figure 12. Percent of vegetation density in Oregon South study area.

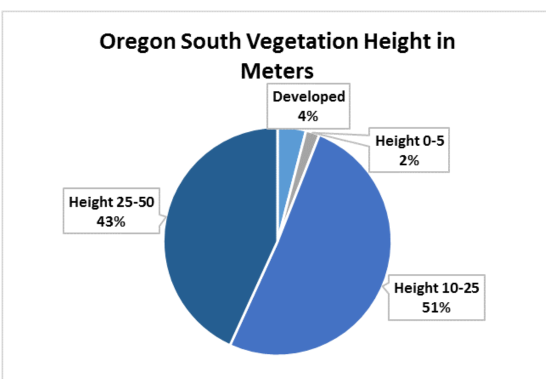

Figure 13. Percent of vegetation height in Oregon South study area.

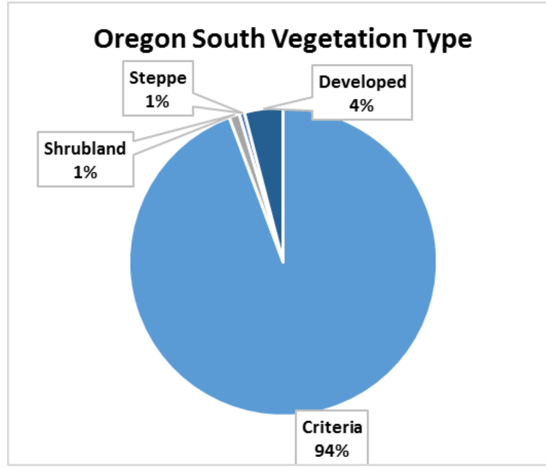

Figure 14. Percent of vegetation type in Oregon South study area.

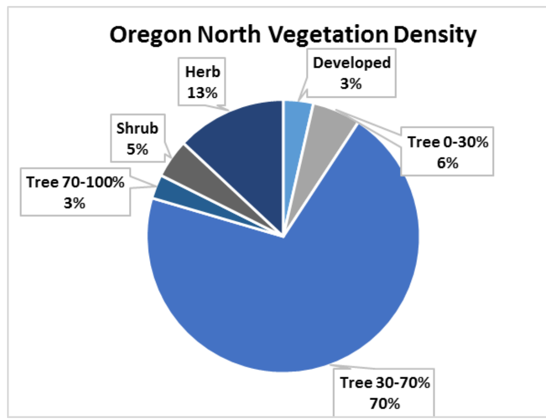

Figure 15. Percent of vegetation density in Oregon North study area.

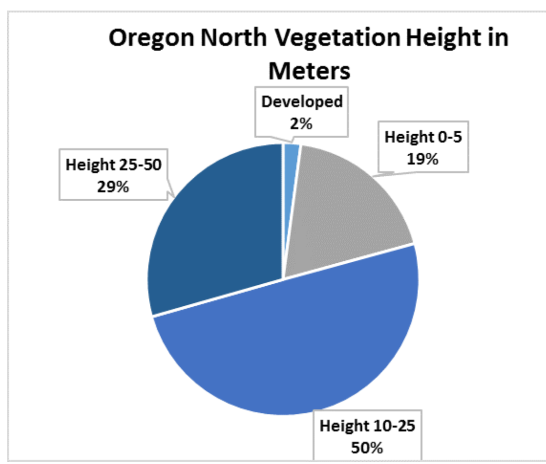

Figure 16. Percent of vegetation height in Oregon North study area.

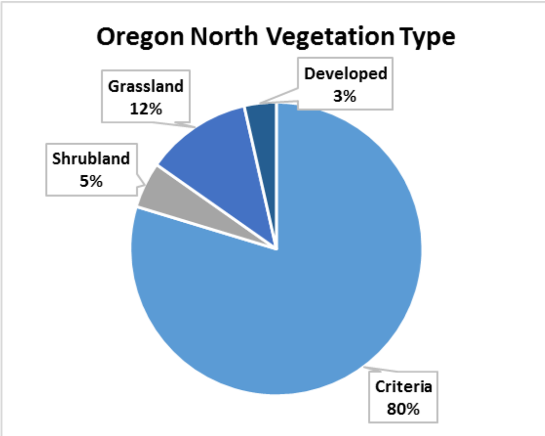

Figure 17. Percent of vegetation type in Oregon North study area.

In Idaho, 3 (20%) nests were located between 101-1000 m away from a disturbance. Two nests (13%) were found between 1001-2000 m away from a disturbance, while one nest (7%) was 2001-3000 m from a disturbance. Three (20 %) nests were found to be 3001-4000 m to the nearest disturbance. Six (40%) nests were between 4001-10000 m away from a disturbance.

A single (17%) nest site in Wyoming was found between 101-1000 m from the nearest disturbance. One (17%) nest site was located between 1001-2000 m. Two (33%) were 2001-3000 m away and 2 (33%) were 10001-20000 m away from a disturbance.

Oregon South saw 1 (11%) nest 101-1000 m away from a disturbance; 2 nests (22%) 1001-2000 m away, 4 (45%) 4001-10000 m away, and lastly 1 (11%) nest 10001-20000 m away.

Oregon North had 1 (11%) nest 101-1000 m away from a disturbance, 1 (11%) nest 4001-10000 m away, and 7 (79%) nests between 20001-28000 m away from a disturbance (Figure 18).

In Minnesota, ninety-three (77%) nests were located between 0-50 m of water; 10 (8%) nests were 51-100 m away from a waterbody, 8 (7%) nests were 101-200 m away from a waterbody, 4 (3%) nests were 201-300 m away from a waterbody, and 6 (5%) were 301-805 m away from a waterbody.

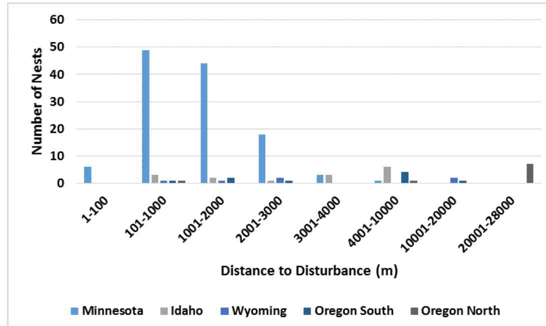

Figure 18. Total distance of nests to disturbances in each study area.

Idaho had 8 (53%) nests within 0-50 m from a major water body, 1 (7%) nest 101-200 m away from a waterbody, 1 (7%) nest 201-300 m away, 1 (7%) nest 301-805 m away from a waterbody, and 4 (26%) 806-5600 m from a waterbody.

A single (17%) nest in Wyoming was located between 51-100 m from a waterbody, 1 (17%) nest was 101-200 m away from a waterbody 1 (17%) nest was 301-805 m away from a waterbody, and 3 (50%) nests were 806-5600 m from the nearest body of water.

Oregon South saw 2 (22%) nests within 0-50 m of a major waterbody, 1 (11%) nest 51-100 m away from a waterbody, 2 (22%) nests 101-200 m away from a waterbody, 1 (11%) nest 201-301 m from a waterbody, 1 (11%) nest 301-805 m from a waterbody, and 2 (22%) nests 806-5600 m from a body of water.

Oregon North had 1 (11%) nest 0-50 m away from water, 1 (11%) nest 101-200 m away from a waterbody, 2 (22%) nests 201-300 m away from a waterbody, and 5 (56%) nests 301-805 m away from a waterbody (Figure 19).

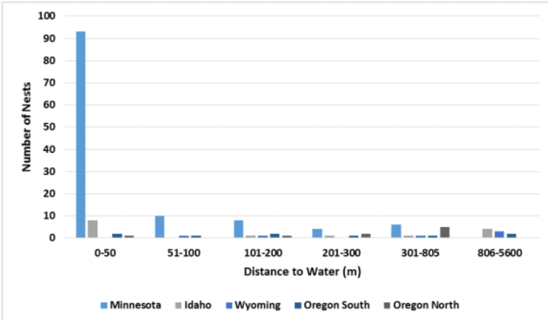

Figure 19. Total distance of nests to nearest waterbody.

The Average Nearest Neighbor was used in ArcMap to analyze Euclidian distances between nest locations to determine mean distances, and if the nest locations were random, clustered, or dispersed throughout the study area.

In Minnesota, the mean distance between nests was 887 meters and the nests were clustered together. Given the z-score of -13.8, there is less than 1% likelihood that this clustered pattern could be the result of random chance. Nest sites in Idaho were on average 3345 meters from each other and tended towards an even dispersion throughout the study area. Given the z-score of 2.2, there is less than 5% likelihood this dispersed pattern could be the result of random chance.

Wyoming nest sites were, on average, 10,217 meters away from each other and were randomly distributed throughout (z score = -.6). The nests in Oregon South had a mean distance of 3009 meters between nests and were clustered together. Given the z-score of -2.9, there is less than 1% likelihood this clustered pattern could be the result of random chance. Nest sites in Oregon North averaged 6259 meters from each other and were randomly dispersed (z score = 1.1).

All Criteria

In order to observe if the model created combining 5 criteria to predict potential bald eagle nest habitats was significant, data were analyzed with an independent sample Student's t-test. The null hypothesis was "100 m buffers around existing nests have similar areas (in hectares) of all 5 criteria combined as 100 m buffers around randomly generated points." Total areas of criteria within the buffer zones were collected and analyzed (Figure 20).

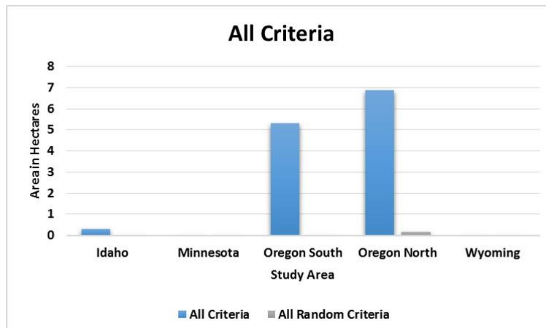

Figure 20. Total area in hectares of existing and random nest locations.

In Minnesota and Wyoming, the null hypothesis could not be tested due to the fact no nests or random points fell within the parameters of the potential bald eagle nests locations. In Idaho, the null hypothesis was not rejected (2-tailed, p = 0.196). In Oregon South, the null hypothesis was rejected (2-tailed, p = 0.045.). In Oregon North, the null hypothesis was again rejected (2-tailed, p = 0.028) (Table 2).

Discussion

Since 2007, when bald eagles were removed from the Endangered Species List, their populations have steadily increased through the Mississippi floodplain and across the Pacific Northwest. This study provides important information about bald eagles and proposes a method to predict and preserve areas crucial to their nesting habitats. The model proposed in this study shows that it is possible to successfully predict potential nesting areas. Criteria developed (Table 2) from previous research determined bald eagles tend to nest in supercanopy cottonwoods, maples, oaks, pines, mixed conifer, Douglas-fir, Sitka spruce/western hemlock > 25 m in height within a high density forest. In addition, eagles tend to nest near major waterbodies and away from major roads.

Table 2. Comparisons of all 5 criteria were analyzed using an independent sample Student's t-test. Values of t represent the observed values. Values under df are the degrees of freedom used for the test. The Sig. (2-tailed) represents the P-value where any number < .05 significantly differ from each other. In this test all 5 criteria were combined and tested between existing and random nest locations. X represents areas were tests were not performed due to the lack of criteria in existing and random locations.

Study Area	t	df	Sig. (2-tailed)
Idaho	1.326	28	0.196
Minnesota	x	x	x
Oregon South	2.205	14	0.045
Oregon North	2.414	16	0.028
Wyoming	x	x	x

This study found tree cover between 30-70% was ideal location for bald eagle nests, which was one of the selected criteria used. Eagles tend to nest in dense forests with plenty of cover. Eagle nests located in a dense forest provide the most shelter from human disturbances and exhibited strong nesting success (Anthony *et al.*, 1982) (Figure 21).

Previous research found eagles preferred to select the tallest trees protruding through canopy of forests. Nests in the Pacific Northwest are normally found in dominant or co-dominant tree species within a forest (Anthony *et al.*, 1982). However, data from this study found nests were located in areas that had trees ranging between 10-25 m instead of predicted criteria of > 25 m (Figure 22).

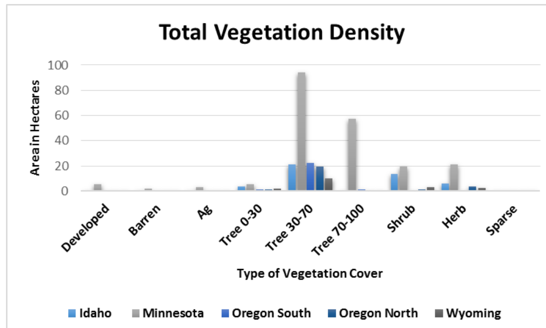

Figure 21. Total vegetation density in all study areas.

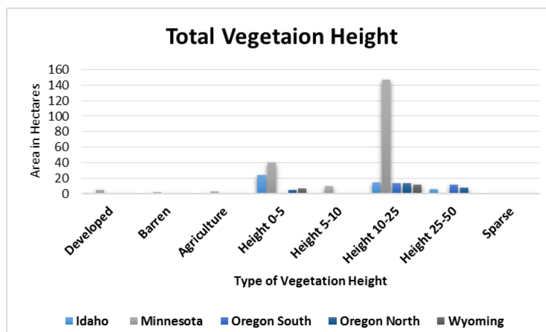

Figure 22. Total vegetation height in all study areas.

Bald eagles tend to nest in a floodplain forest dominated by silver maples and eastern cottonwoods whereas in the Pacific Northwest, bald eagle nests were found in ponderosa pine mixed conifer, Douglas-fir and sitka spruce/ western hemlock forests (Figure 23).

The greatest cause of bald eagles deaths today is collisions with cars.

Because most collisions occur on roads with a speed limit greater than 50 mph, only major roads were used in this study. In this study, in the Minnesota study area, only 6 nests were located within the 100 m recommended buffer zone from human disturbances (roads, railroads). Human disturbances continue to negatively affect bald eagle nests, however literature suggests some birds have learned to adapt to disturbance (Wood, Edwards, and Collopy, 1989). Eagles tended to nest farther away from disturbances in the other 4 study areas.

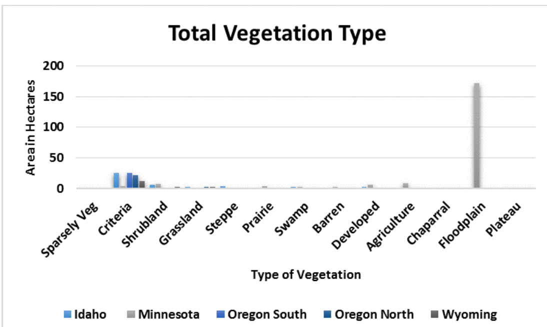

Figure 23. Total vegetation type in all study areas.

The Minnesota and Idaho study area found that nests were located more closely to a major waterbody totaling 77% and 53% of their nests respectively. The Oregon study areas found the eagles nesting further away from the major waterbodies. Nests located further from water may be due to human disturbances around waterbodies. Boat traffic has been found to cause eagles to abandon nests and move farther away from water to avoid human contact (Steidl and Anthony, 1996). Along the Mississippi River there is heavy commercial and private boat use that eagles in the area are apparently accustomed to. Here, the constant use of the river may actually cause eagles nest closer to disturbances.

A bald eagle territory can be defined as "an area defended against competing members of the same species from the time of mating until young are independent" (Hensel and Troyer, 1964). An adult pair protects their territory by sending out threat vocalizations, perching on top of dominant trees, performing circling displays, and territorial chases (Stinson, Watson, and McAllister, 2001). Adult eagles will fight off intruding species to protect their nesting territory. In the Minnesota study area, nests were located, on average, 887 m away from each other. This may be due to the high populations of eagles in the area and high food production of the Mississippi River. Each year, a nesting pair of eagles will occupy one nest, but can have up to 8 alternate nests. In western Washington alternate nests were, on average, 1050 feet from active nests (Grubb, 1976). Eagles will return to a nest that has the most reliable food source each year (Stinson *et al.*, 2001). Eagles locate territories that have multiple dominant trees to help serve as replacement nest trees if damage occurs to the original tree (Stinson *et al.*, 2001). In other study areas, nests were more dispersed, and this might contribute to the lower population of eagles in the area or larger established territories and alternate nest locations from each breeding pair.

This study found 4 of the 5 criteria matched previous research: tree density, tree type, distance away from disturbances, and distance to water. However, predicted tree height criteria did not match the findings in this study. Findings suggest eagle nests were located in areas with tree heights ranging between 10-25 m. Because of this, potential habitat areas were adjusted to include tree heights > 10 m (Figure 24).

This was applied because the purpose of this study was to find the best potential bald eagle nesting habitats. After this change was applied to the data, 4 out of 5 study areas rejected the null hypothesis, which was "100 m buffers around existing nests have similar amount (in hectares) of all 5 criteria combined as 100 m buffers around randomly generated points," with Idaho being the only study area not rejecting it (Table 3).

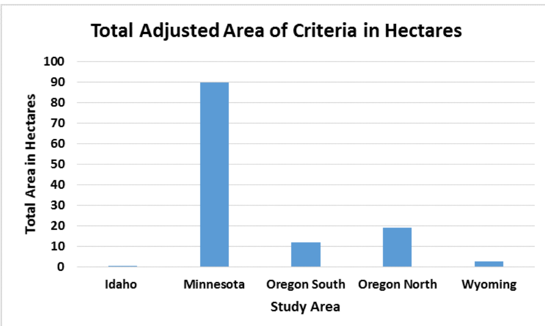

Figure 24. Total area of adjusted criteria in all study areas.

Table 3. Comparisons of all 5 criteria were analyzed using an independent sample Student's t-test. Values of t represent the observed values. Values under df are the degrees of freedom used for the test. The Sig. (2-tailed) represents the P-value where any number < .05 significantly differ from each other. In this test all 5 criteria were combined and tested between existing and random nest locations.

Study Area	t	df	Sig. (2-tailed)
Idaho	1.522	28	0.139
Minnesota	8.337	240	0
Oregon South	3.587	16	0.002
Oregon North	6.245	16	0
Wyoming	0.078	10	0.939

The study areas where the null hypothesis was rejected indicate areas where all 5 criteria (Table 1) have more of all 5 criteria than random nest locations and that the criteria selected are reasonable for nest selection. Rejecting the null hypothesis determined it is possible to use ArcMap and various GIS tools to accurately predict bald eagle nest habitats. This model can be applied to help preserve crucial nesting habitats in areas where bald eagles tend to nest (Figures 25-29).

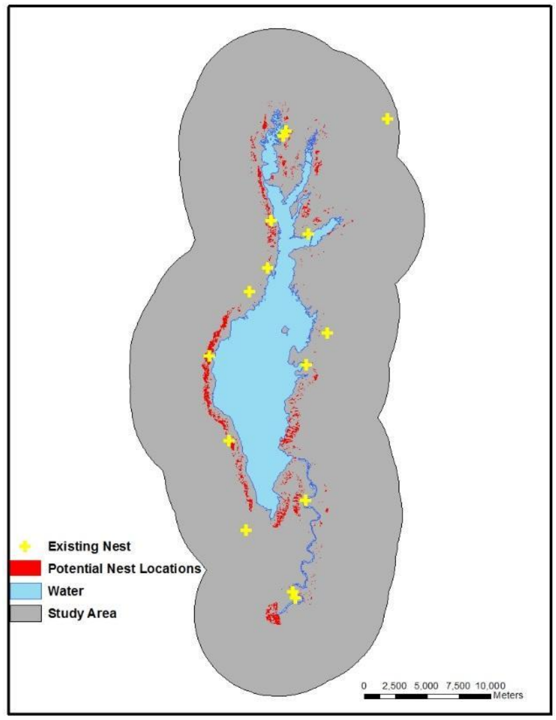

Figure 25. Figure representing potential bald eagle nest locations in Idaho study area. Polygons represent best predicted nest locations. Existing nest locations are represented by circles to show existing locations vs. predicted locations.

The criteria set up in this study were based on previous findings that portray eagle nest habitats and behavior. Like most living organisms, eagles will adapt to their surroundings in order to survive. Because of this, no specific criteria will match each eagle population perfectly. In the end, eagles will nest in close proximity to any source of food. Also, eagles will choose the best tree location that fits their need in a specific area. There are no set guidelines for what cover, type, or height of tree eagles can nest in which means no perfect set of criteria can be developed. Criteria can only be selected based on trends and previously documented research.

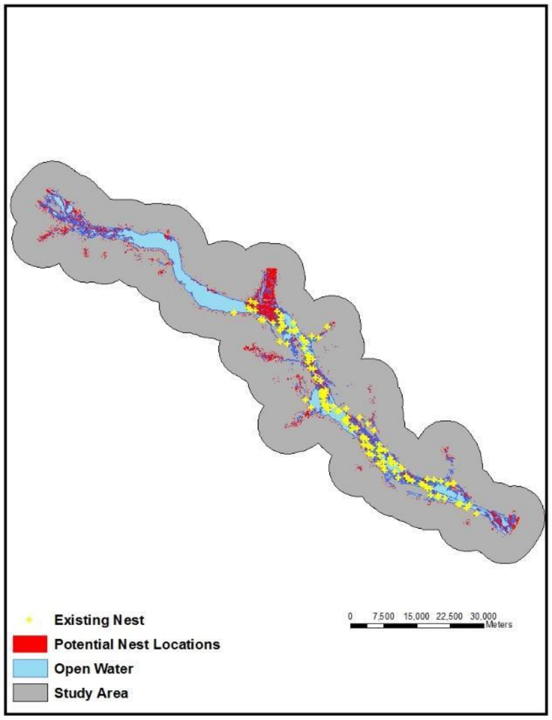

Figure 26. Figure representing potential bald eagle nest locations in Minnesota study area. Polygons represent best predicted nest locations. Existing nest locations are represented by circles to show existing locations vs. predicted locations.

This study could be improved if nest located were located more accurately with reduced GPS error. If nest locations were confidently mapped, a buffer would not have been needed and data could be more accurately studied. Also, accurately defining projected coordinate systems and maintaining the same coordinate system throughout the study is essential. This study is a beginning for the development of a model to map potential areas of bald eagle nest habitats.

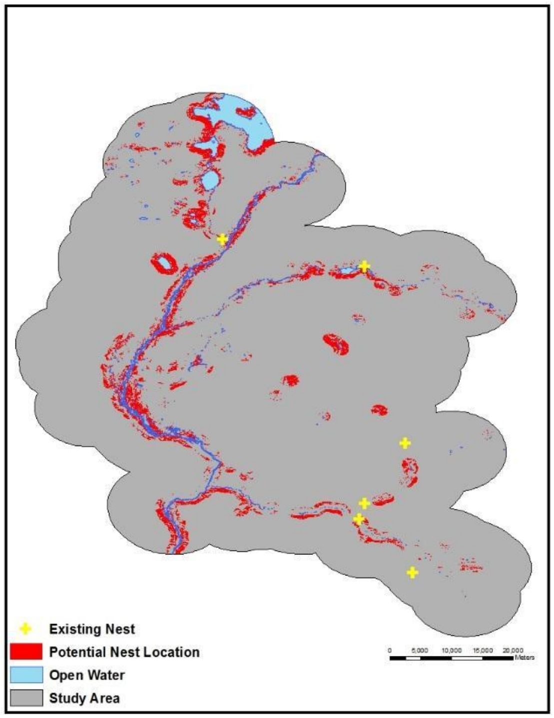

Figure 27. Figure representing potential bald eagle nest locations in Wyoming study area. Polygons represent best predicted nest locations. Existing nest locations are represented by circles to show existing locations vs. predicted locations.

If future researchers were able to obtain tree species of actual nest trees, many more studies could be performed. The more information collected about nest locations will provide a more accurate the model.

Conclusions

The purpose of this work was to determine if a model predicting bald eagle nest habitat could be developed using GIS analysis and to observe the differences of nesting habits of bald eagles in 5 different study areas in the United States.
After data were analyzed it was found eagles tended to nest closer to water in Minnesota and Idaho and farther away in both Oregon Study areas. In Minnesota, eagles tended to nest closer to disturbances

and apparently have learned to live close to human interaction.

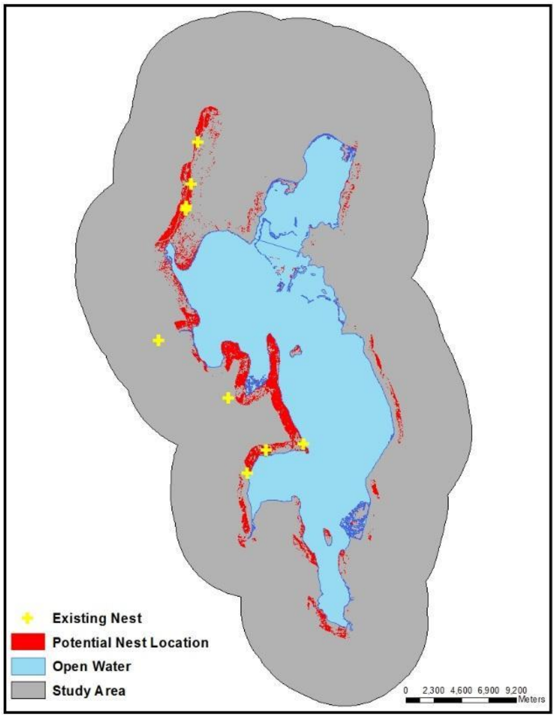

Figure 28. Figure representing potential bald eagle nest locations in Oregon South study area. Polygons represent best predicted nest locations. Existing nest locations are represented by circles to show existing locations vs. predicted locations.

This differs from Mundahl *et al.*, (2013) who found successful nests tend to be further away from human disturbances. This may be due to the fact that even though there are human disturbances along the Mississippi River, bald eagles need food for survival. The abundance of prey and food sources along the Mississippi River may draw a larger population of eagles closer to the food source and allow them to disregard human disturbances. This study found a much greater number and a more dense population of nests along the Mississippi River compared to the other four areas. Bald eagle's exhibit high natal fidelity, so when they come back to breed at maturity it is often in relatively close proximity to their original nest. Eagle populations in Idaho are recently recovering from near extinction and nests are limited to water sources and reservoirs. These recently found populations in the Pacific Northwest will then lead to smaller numbers of nests in an area (Nadeau, 2012).

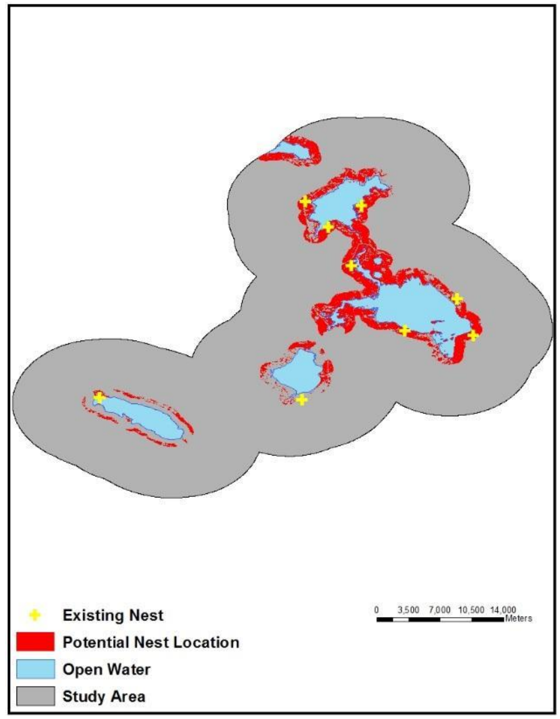

Figure 29. Figure representing potential bald eagle nest locations in Oregon North study area. Polygons represent best predicted nest locations. Existing nest locations are represented by circles to show existing locations vs. predicted locations.

U.S.F.W.S employees have monitored nest locations along the Mississippi River closely to locate every nest within their district. Idaho's bald eagle population are also closely monitored to study for a population bottleneck so all nests were also accounted for in this area. However, in the Oregon and Wyoming areas, nests were only observed by volunteers in 2007 meaning multiple nests could have been formed since then or nests could not have been recorded at all.

Because nest locations have been monitored so closely in Idaho and Minnesota it is likely good. With missing or unreliable data in the remaining areas, this may not be so. This study was set up to determine if nest habitat and locations could be accurately modeled based on information that was provided.

Throughout each study area, nest tree height needed to be adjusted to > 10 m due to the lack of supercanopy trees in the data collected. The rest of the predicted criteria of tree type and cover were found to be correct. After testing the null hypothesis, “100 m buffers around existing nests have similar areas (in hectares) of all 5 criteria combined as 100 m buffers around randomly generated points,” findings concluded this model can correctly predict bald eagle nest habitats.

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