Surveys

Bald Eagle Nesting Habitats in the Upper Mississippi River National Wildlife and Fish Refuge

Neal D. Mundahl,* Anthony G. Bilyeu, Lisa Maas

N.D. Mundahl, A.G. Bilyeu
Department of Biology, Winona State University, Winona, Minnesota 55987
Present address of A.G. Bilyeu: Mayo Clinic, 200 First Street SW, Rochester, Minnesota 55905

L. Maas
U.S. Fish and Wildlife Service, Upper Mississippi River National Wildlife & Fish Refuge–McGregor District and Driftless Area National Wildlife Refuge, 401 Business Highway 18N, McGregor, Iowa 52157

Abstract

This study examined habitat variables associated with 53 active bald eagle *Haliaeetus leucocephalus* nest sites in the Winona District of the Upper Mississippi River National Wildlife and Fish Refuge, Minnesota and Wisconsin. The Refuge is the most heavily visited refuge in the United States, where breeding eagle populations have been increasing dramatically. During February–April 2009, nest trees were identified and measured, nest heights were determined, distances to nearest water bodies were assessed, and forest inventories were conducted for the standing timber surrounding the nest trees. Nest densities and spacing were assessed within each navigation pool, and land cover types were examined within 100- and 1,000-m radii around known eagle nest sites and random points within the Refuge. Ninety-three percent of nest sites had supercanopy eastern cottonwoods *Populus deltoides* and silver maples *Acer saccharinum* as the nest trees. Potential human disturbances from highways, railroads, and commercial barge and recreational boat traffic were present within 400 m of 90% of known nest sites. Eagle nest sites were located an average of 1.52 km from the next nearest nest, with nest densities ranging from 0.32 to 9.72 nests/100 km^2 among the four navigation pools of the Winona District. Land cover types around known nest sites and random points differed significantly at both 100- and 1,000 m scales, with wet forest and open water significantly more abundant and agricultural and developed lands significantly less abundant than around randomly selected points. Successful nests that fledged at least one young were spaced significantly further away from other active nests and were located in areas with lower tree density than were unsuccessful nests. Floodplain-nesting bald eagles tended to select the tallest, dominant trees for nest sites, placing nests near the height of the surrounding canopy. Human presence within the Refuge does not appear to be limiting the expansion of nesting bald eagles in this riverine habitat.

Keywords: breeding eagles; floodplain; forest inventory; habitat; *Haliaeetus leucocephalus*; nest sites

Received: January 21, 2012; Accepted: September 6, 2013; Published Online Early: September 2013; Published: December 2013

Citation: Mundahl ND, Bilyeu AG, Maas L. 2013. Bald Eagle Nesting Habitats in the Upper Mississippi River National Wildlife and Fish Refuge. *Journal of Fish and Wildlife Management* 4(2): 362-376; e1944-687X. doi: 10.3996/012012-JFWM-009

* Corresponding author: nmundahl@winona.edu

Introduction

Bald eagle *Haliaeetus leucocephalus* numbers have increased dramatically in Minnesota and Wisconsin during recent decades (Miller and Pfannmuller 1991; Baker et al. 2000; Guinn 2004; Eckstein et al. 2012). Although eagles have continually inhabited the northern lakes regions of these states, the species disappeared from the lower portions of both states during the early 1900s because of habitat destruction, shooting, and the use of dichlorodiphenyltrichloroethane (DDT; Kumlien and Hollister 1903; Robbins 1991; Buehler 2000). Populations rebounded in both states after DDT was banned, restoration programs were undertaken, and eagles were given greater legal protection in the 1970s (Miller and Pfannmuller 1991; Alsop 2002; Guinn 2004; Eckstein et al. 2012). Major breeding populations now occur throughout the northern lakes regions, as well as along major river systems to the south and west (Baker et al. 2000; Guinn 2004; Eckstein et al. 2012).

Bald eagles typically nest in old-growth or mature forests, constructing nests in a variety of supercanopy coniferous trees in remote locales (Peterson 1986; Stalmaster 1987; Garrett et al. 1993). As eagle populations expand beyond these typical habitats, availability of suitable nesting sites may limit nesting populations in some areas (Bowerman et al. 2005). However, nesting eagles currently are expanding into areas previously thought to be suboptimal, establishing nests more frequently near human activity (Guinn 2004). Human activity near nest sites has been considered a major threat to nesting and foraging eagles (Mathisen 1968; Anthony et al. 1982; Peterson 1986; Stalmaster 1987; Steidl and Anthony 2000; Grubb et al. 2002), but bald eagles are now breeding successfully in some highly developed areas (Garrett et al. 1993; Guinn 2004; Nelson 2005; Baker and Monstad 2006).

In Minnesota, numbers of nesting bald eagles are expanding most rapidly in the floodplains of large rivers in the southern portion of the state (Baker and Monstad 2006). These systems often lack the extensive forests and large conifers that typify eagle nesting habitats in northern Minnesota and Wisconsin (Guinn 2004; Bowerman et al. 2005; Haskell and Eckstein 2007), and they have much higher levels of human activity (e.g., agriculture, recreational and commercial boat traffic, railroads, highways, cities). The objective of this project was to assess bald eagle nest sites along a busy portion of the Upper Mississippi River in Minnesota and Wisconsin (regular commercial and recreational boat traffic, two high-volume [>1,000 railcars/d] railways, state and national highways). We used a combination of on-site assessments of the immediate habitat at each nest location and broader geospatial assessments of land use and potential human disturbance around nest sites and random sites to determine what habitat characteristics are associated with nesting eagles within this type of ecosystem.

Study Site

The Upper Mississippi River National Wildlife and Fish Refuge (hereafter Refuge) includes habitats in 19 counties in Minnesota, Wisconsin, Iowa, and Illinois. It encompasses 972 km^2 of Mississippi River channels, backwaters, and floodplain habitats (including 206 km^2 of floodplain forest, 194 km^2 of marsh, 23 km^2 of grasslands and native prairie), extending 420 km from Wabasha, Minnesota, to near Rock Island, Illinois. This reach includes 11 navigation locks and dams and all or part of 12 navigation pools (4, 5, 5A, 6–14) maintained to facilitate commercial shipping via barges. Bald eagles use the Refuge as a migration corridor (average of 2,953 birds during peak of spring migration, 2006–2008; L. Reid, Refuge, personal communication), as an important overwintering area (>1,000 birds; Steenhoff et al. 2008) and as nesting habitat (313 occupied nests in 2012; B. Stemper, Refuge, personal communication). Overall, the Refuge hosts more eagles and nests than any refuge in the United States outside of Alaska and is the most heavily visited refuge in the U.S. National Wildlife Refuge System, with 3.7 million human visitors annually (Hultman 2006). The Refuge was designated as a ''Wetland of International Importance'' by the U.S. Department of Interior in 2009.

This study was conducted on only the upstream-most portion of the Refuge (Winona District), from the confluence of the Mississippi and Chippewa rivers (rkm 1228; 44°24′35″N, 92°05′03″W) in Pool 4 downstream to Lock & Dam 6 (rkm 1149; 43°59′55″N, 91°26′20″W), a distance of 79 rkm (Figure 1). This reach forms the border between southeastern Minnesota and west central Wisconsin. For simplicity, we divided the Winona District into four sections based on navigation pools, and we refer to each section (water and land) by its pool designation (4, 5, 5A, 6; Table 1). Data for Pool 6 also included nests in the 25.2-km^2 Trempealeau National Wildlife Refuge, a separate parcel located in the river floodplain adjacent to the Refuge. The Refuge staff monitors all known bald eagle nests on Refuge lands, as well as those nearby on both public and private property. Between 1990 and 2012, 151 different bald eagle nest sites had been documented in the four-pool study area within and nearby the Refuge. During the 2009 study, 53 of these sites were determined to be active. Most (46 sites, 87%) of these active nest sites were first established after 1999 (including 12 sites first used in 2009), although three sites were first used as early as 1991.

In addition to the main river channel and impounded navigation pools, the Winona District of the Refuge is characterized by a labyrinth of secondary channels, backwaters, islands, and marshes, a large portion of which are in public ownership (Refuge and other entities; Figure 1). Shorelines and islands are forested with stands of mature deciduous trees such as silver maple *Acer saccharinum*, eastern cottonwood *Populus deltoides*, American elm *Ulmus americana*, slippery elm *Ulmus rubrea*, green ash *Fraxinus pennsylvanica*, white ash *Fraxinus americana*, black willow *Salix nigra*, swamp white oak *Quercus bicolor*, and river birch *Betula nigra*. Conifers are rare within these floodplain forests. The Refuge also is situated within a major transportation corridor, with commercial barge (>10 million tons of cargo shipped through annually) and recreational boat traffic (>10,000 pleasure craft lock through the system annually) on the river (USACE 2012) and railways and roadways along both sides. Nine villages and cities border the Winona District.

Methods

Nest site assessments

We used recent records (map coordinates, written descriptions, sightings) of nest sites and recent (2005–2008) satellite images to determine approximate locations

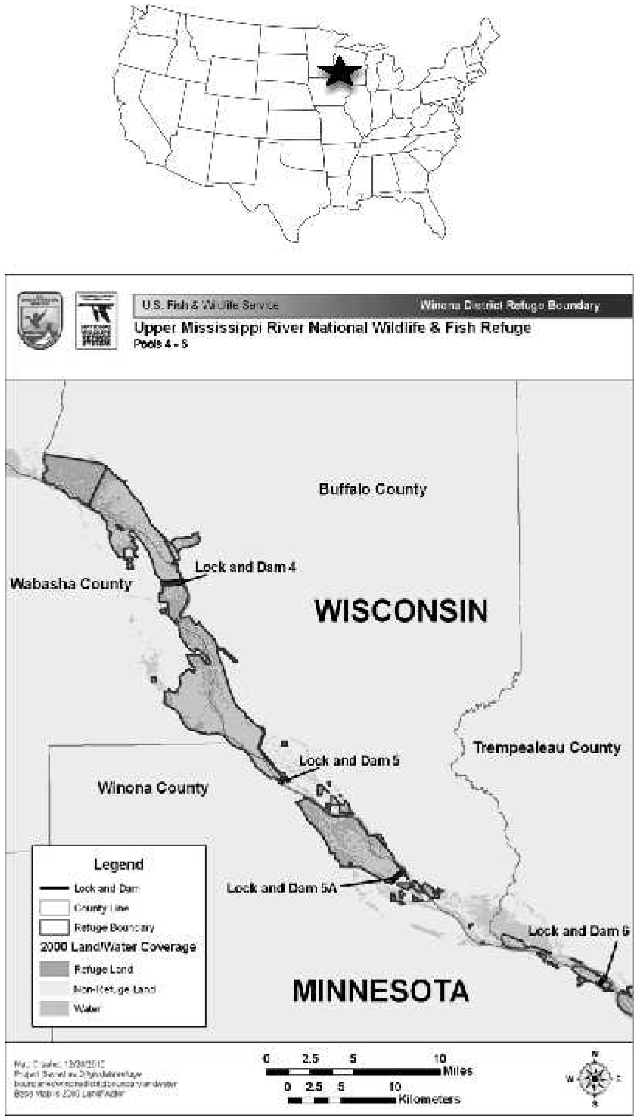

Figure 1. Map of study area in the Upper Mississippi River National Wildlife & Fish Refuge (star), Winona District, February–April 2009. Map provided by the U.S. Fish and Wildlife Service, Upper Mississippi River National Wildlife & Fish Refuge, Winona District.

for all known, active bald eagle nest sites ($n = 53$) within only the Winona District of the Refuge. It is possible that additional nest sites (previously known sites or new sites) may have been active during 2009, but they were not detected during this study. Therefore, data gathered for this study must be considered as opportunistic.

Field visits to nest sites began in early February 2009 and continued through mid-April 2009. Although late winter and early spring may not the optimal time to visit nest sites because of potential disturbance, late summer (dense foliage), fall (waterfowl hunting and closed areas [no boat traffic permitted] of the Refuge to protect waterfowl), and early winter (scheduling and logistic problems) visits were not possible. Nest sites typically are visited annually during the late winter–early spring period to check on eagle activity at nests, so having one person collect both the nest activity and site data was a one-time activity (one person, one visit per site) judged by Refuge staff to have minimal disturbance on eagles (B. Pember, Refuge, personal communication). We used an airboat to access most sites, due to remoteness of many sites and presence of ice or unstable river conditions during this period. Unfortunately, eight active nest sites were not accessible during 2009. On-site data were not collected for these sites, but sites were included in all other analyses.

At each nest site, we recorded information about the nest tree and the surrounding forest. Nest tree location was recorded with a GPS unit (Universal Transverse Mercator coordinate system); species of the nest tree was determined; and two photographs of the nest were taken with a digital camera from a distance of 50 m, making note of compass bearings. Nest tree diameter at breast height (DBH) was measured with a girthing tape, tree height, and nest height were measured with a clinometer and logger's tape, and distance to the nearest body of water (river channel, backwater) was determined with a range finder. We inventoried standing timber around each nest tree with the aid of a forester's angle gauge (basal area factor = 10) and a variable radius plot procedure (Bitterlich method; Grosenbaugh 1952), thereby producing a stand density estimate based on basal area (square meters per hectare) around each nest tree. For each tree within each plot, we determined species, DBH, and height as described above. This procedure resulted in approximately 0.4 ha of floodplain forest being surveyed around each nest tree, and quantified stands immediately surrounding eagle nests in a manner directly comparable to previous forest assessments conducted within the Refuge.

Distances between active bald eagle nests and distance from each nest to the nearest potential human

Table 1. Pool-by-pool listing of habitat area, and abundance and spacing of bald eagle *Haliaeetus leucocephalus* nests within the Winona District of the Upper Mississippi River Wildlife & Fish Refuge, February–April 2009. Area/nest calculations include open water areas. Nest spacing (mean ± SD) is based on a nearest-neighbor assessments for each nest.

River pool	Total area (ha)	% of total area	Area excluding open water (ha)	No. of eagle nests	rkm/nest	km^2/nest	Nest spacing (km)
4	378,008	79.3	22,681	12	4.10	315.0	1.66 (0.51)
5	49,345	10.4	11,793	13	1.81	38.0	1.80 (1.24)
5A	16,457	3.5	6,929	16	1.24	10.3	0.97 (0.79)
6	32,591	6.8	13,916	12	1.90	27.2	1.81 (0.58)
Totals	476,401	100	55,319	53			

disturbance (highways, railways, main river channel [barge traffic, recreation and fishing boats], side river channel [fishing boats]) were measured using recent (2005–2008) satellite images. Measurements were made in a straight line between active nest sites, and from the nest site to the center of the nearest highway, railway, or river channel.

Geospatial assessments

We used geospatial techniques to assess habitats at two different scales around each active eagle nest and random sites. All geospatial assessments were completed using ArcMap 10.0 and Excel (Microsoft). To begin, year 2000 land cover maps were downloaded from the U.S. Geological Survey Upper Midwest Environmental Science Center's on-line database for Pool 4, 5, 5A, and 6 (http://www.umesc.usgs.gov/data_library/land_cover_use/land_cover_use_data.html). Various land cover classifications are included in the attribute table of these maps. We used the Class_15 land cover classification scheme that includes the following 15 habitat categories: agriculture, deep marsh, developed, grass/forbs, open water, road/levee, rooted floating aquatics, sand/mud, scrub/shrub, shallow marsh, submerged aquatic vegetation, upland forest, wet forest, wet meadow, and wet shrub. This scheme was selected because it differentiates between key habitats (e.g., upland vs. wet forest) of biological relevance without getting too complicated (e.g., by subdividing forest types based on tree density and height) and protecting against reductions in classification accuracy as the number of cover classes increases. Acreage for each polygon of land cover also was included in the attribute tables of these maps. Using these data, we determined land cover percentages for each pool in Excel, summing acreage in each land cover class and dividing by the total acreage in the pool.

Land cover around active eagle nests in the Refuge was compared to cover around randomly generated points within the Refuge to examine habitat types possibly selected or avoided by eagles. Map (Universal Transverse Mercator) coordinates for all 53 active eagle nests were obtained from Refuge databases. Because three nest sites were located beyond the boundary of the available land cover database, land cover analyses were restricted to the 50 active nest sites encompassed by the database. An equal number of random points (50) within the Refuge and database coverage area were generated using Geospatial Modeling Environment. Random points were generated on a pool-by-pool basis, with the number of random points per pool equal to the number of active nests per pool. Open water was excluded from random point generation because this habitat type has no potential for eagle nesting. We created 100- and 1,000-m radius buffers around each active eagle nest and random point using the buffering feature in ArcMap 10.0 and then used these buffers and the clipping feature to clip out an area of habitat from the pool land cover map. The calculate geometry tool in ArcMap allowed us to calculate the area of land cover in each "clipped, buffered" polygon around each eagle nest and random point. We then summed the acreages in each land cover class around each individual eagle nest and random point in Excel.

Analyses

Bald eagle nest site data were summarized and analyzed as an aggregate as well as by species of the nest tree. Nest tree variables were summarized for presentation purposes using means ± SD. We compared nest tree heights, nest tree DBHs, nest heights, and distances to water among nest tree species with single-factor analysis of variance (ANOVA). Distances from nests or random points to potential disturbances were compared among potential disturbance types with single-factor ANOVA, and distances from nests and random points to potential disturbances were compared to each other with a *t*-test. Nest tree heights and DBHs were compared to those of surrounding trees with *t*-tests. Nest heights were compared to nest tree height and nest tree DBH with simple linear regressions. To determine whether there was any pattern to eagle nest placement within trees as tree size varied, we examined nest height as a percentage of nest tree height across the range of nest tree heights with simple linear regression where X is nest tree height and Y is nest height as a percentage of nest tree height. We assessed possible selection of nest tree species by bald eagles by comparing the distribution of nests among tree species to the community composition of forests around nest trees with a χ^2 contingency table test. We also used Ivlev's selectivity index (Krebs 1989) to individually assess selection for or against certain species of trees for nesting.

Geospatial data were analyzed to compare land coverages between active eagle nests and random points and to compare nest spacing among river pools. A series of *t*-tests were used to compare land coverage classifications between active nest sites and random sites, using both 100- and 1,000-m buffers. A Bonferroni correction ($\alpha = 0.05/n$) was applied when multiple tests were used within the same data set. Nest spacing (nearest-neighbor approach) was compared among river pools with a single-factor ANOVA.

Refuge staff and volunteers determined the success of active nests at or near the end of the 2009 nesting season. Nests that successfully fledged one or more young were termed successful ($n = 33$). Nests that produced no young or where success could not be determined were termed unsuccessful ($n = 20$). Twenty-five of the successful nests and all 20 of the unsuccessful nests were included in the on-site assessments. Successful and unsuccessful nest sites were compared with respect to nest tree preference (χ^2 contingency table), nest tree height, nest tree DBH, nest height, distance to water, distance to nearest neighbor, distance to potential disturbance, and land coverages within 100 and 1,000 m of nest sites (all *t*-tests).

Results

The 53 known active bald eagle nest sites (Tables S1–S3, *Supplemental Material*) were distributed throughout the four pools comprising the Winona District study reach (Table 1). Successful nests were located in each pool, but success rates and numbers of young fledged varied substantially among pools (Pool 4: 83% nest success rate, 13 young fledged; Pool 5: 46% nest success rate, 7 young fledged; Pool 5A: 38% nest success rate, 10 young fledged; Pool 6: 92% nest success rate, 17 young fledged). However, the number of young fledged/successful nest (1.42 ± 0.50 young/successful nest) did not differ significantly among pools (ANOVA: $F_{3,29} = 1.47$; $P = 0.24$). Within the study area overall, nest success rate was 62% and the rate of reproduction was 0.89 young fledged/occupied breeding area.

Densities of known nests varied >30-fold among pools (Pool 4 = 0.32 nests/100 km^2, Pool 5 = 2.63 nests/100 km^2, Pool 5A = 9.72 nests/100 km^2, Pool 6 = 3.68 nests/100 km^2), and nest spacing (straight line distance to nearest neighboring nest) differed significantly (ANOVA: $F_{3,49} = 3.38$; $P = 0.03$) among pools (Table 1). Only 26% (14 of 53 nests) of active nests were located within 1 km of another active nest, and only two of these 14 nests were successful. Successful nests were located significantly ($t_{51} = 3.64$, $P < 0.001$) further from other active nests (1.84 ± 0.85 km) than were unsuccessful nests (1.01 ± 0.72 km). Overall, active bald eagle nests were distributed every 1.24 to 4.10 rkm within the Mississippi River reaches covered in this study, based on total nests per pool and main river channel length in each pool. Refuge pool area/active eagle nest was <40 km^2 except in Pool 4, where open water dominated (94%) total pool area (Table 1).

Most (42 nests, 79%) active bald eagle nests in the Winona District of the Refuge were located on islands or island complexes within the Mississippi River corridor, but these and several additional nests (48 nests total, 90%) were all in proximity (within 400 m) to potential disturbances from various modes of transportation. One-third (18 nests, 34%) of all active nests were located near or immediately (<50 m) adjacent to the main river (shipping) channel, 40% (21 nests) were near side channels or backwaters frequented by fishing boat traffic, and the remainder were closest to highways (nine nests; U.S. Highway 61, Wisconsin State Highways 25 and 35) or railways (five nests; Canadian Pacific Railway, Burlington Northern-Santa Fe Railway). Some nest sites were located near three potential disturbances: within 400 m of the river channel, a railroad, and a four-lane highway. Two nest sites were located within 400 m of busy commercial river locks. Average distances from nest sites to potential transportation disturbance did not differ significantly (ANOVA: $F_{3,49} = 1.58$; $P = 0.206$) among the different transportation corridors. Similarly, distance from random sites within the Refuge to potential transportation disturbance did not differ significantly (ANOVA: $F_{3,49} = 0.09$; $P = 0.963$) among the different transportation corridors. However, average distance from nest sites to potential transportation disturbance (226 ± 107 m) was significantly less ($t_{104} = 4.31$, $P < 0.001$) than average distance from random sites to potential transportation disturbance (366 ± 210 m). Successful nests (242 ± 104 m) were slightly, but not significantly ($t_{51} = 1.41$, $P = 0.163$), further from potential transportation disturbance than were unsuccessful nests (200 ± 108 m).

Nest trees

Active bald eagle nests (Figure 2) were located in trees representing four different deciduous species (Table 2). Eastern cottonwood (71%) and silver maple (22%) were the most common nest tree species, whereas swamp white oak (4.5%) and red oak (2%) each held small numbers of eagle nests. Only one nest was located in a dead tree (swamp white oak). All nests in swamp white oaks and red oaks were in Pool 4 and Pool 5, where they represented 17 and 8% of all active eagle nests surveyed in those sections, respectively. All 28 nests in Pool 5A and Pool 6 were located in cottonwood or silver maple trees. Nest distribution among tree species did not differ significantly ($\chi^2_2 = 1.40$, $P = 0.497$) between successful and unsuccessful nests.

Bald eagle nest trees with active nests averaged 28 m in height, 89 cm in DBH, and 64 m from a shoreline throughout the Winona District, with nests built an average of 19 m off the ground (Table 3). Ninety percent of nests were built in trees within 100 m of a shoreline, with a majority (58%) located between 10 and 40 m from water (Figure 3). The various species of nest trees did not differ significantly in DBH (ANOVA: $F_{3,41} = 0.49$; $P = 0.69$) or distance from shoreline (ANOVA: $F_{3,41} = 0.43$; $P = 0.73$), but cottonwood nest trees were significantly (ANOVA: $F_{3,41} = 9.41$; $P < 0.001$) taller than the other species used as nest trees (Table 3). Nest height also varied significantly (ANOVA: $F_{3,41} = 5.86$; $P = 0.002$) among nest tree species, with nests placed several meters higher in cottonwood and red oak trees than in maples and swamp white oaks (Table 3). Nest height was strongly positively correlated (nest height = 0.551 tree height + 3.422; $r^2 = 0.63$; $F_{1,43} = 73.81$; $P < 0.001$) to tree height, but not to tree DBH ($F_{1,43} = 0.61$; $P = 0.44$). When expressed as a percentage of nest tree height, nests were placed at positions ranging from 51 to 85% of the nest tree's total height. Nest height percentage ([nest height/tree height] × 100) was not significantly related ($F_{1,43} = 3.61$; $P = 0.064$) to tree height, although there was a tendency for nests to be constructed relatively lower in taller trees than in shorter trees.

Successful nests did not differ significantly from unsuccessful nests in nest tree height, nest tree DBH, nest height, or distance from water (Bonferonni correction $\alpha = 0.0125$; Table 4). However, successful nests had a strong tendency to be further from water (89 vs. 33 m) than unsuccessful nests.

Forest inventory

Floodplain forest stands surrounding bald eagle nest trees contained at least 12 different species of deciduous trees (some individual trees could not be identified with certainty when lacking leaves, so were recorded as unidentified). Of the 380 trees we inventoried around bald eagle nests, silver maples (42%) and eastern cottonwoods (30.5%) were most common (Table 2). No other species represented >7% of the forest trees. Some eagle nests had as many as five different tree species in the immediate vicinity, but we inventoried three or fewer tree species at 91% of the nest sites. Forest stands surrounding nest trees averaged 19.4 m^2 of basal area/

Figure 2. Bald eagle *Haliaeetus leucocephalus* nest in Catfish Slough area, Pool 4, Upper Mississippi River National Wildlife & Fish Refuge, March 2009. Airboat in foreground was used to access nest sites during the study.

ha, ranging from 2.3 to 48.2 m^2/ha (Figure 4). Bald eagles built nests in isolated trees and in dense stands of tall trees, but the majority (60%) of nest trees were located in stands with basal areas between 11 and 30 m^2/ha. Successful eagle nests were significantly more likely ($\chi^2_1 = 3.87$, $P = 0.049$) to have surrounding forest basal area densities $<$20 m^2/ha compared with unsuccessful nests (Figure 4).

We observed that bald eagle nest trees at most (67%) sites were the tallest trees in the immediate area. Both DBHs ($t_{423} = 10.59$, $P < 0.001$) and heights ($t_{423} = 8.08$, $P < 0.001$) of nest trees were significantly greater than those of surrounding trees, with nest trees averaging 41 cm (85%) greater DBH and 8 m (40%) greater height than surrounding trees (Figure 5). Nest trees also were significantly (paired $t_{43} = 2.85$, $P = 0.007$) taller (28.2 vs. 26.3 m) than the next largest trees in the plots immediately around nest trees. On average, bald eagle nests were placed at heights in nest trees (18.9 m) just slightly below the tops of the surrounding forest trees (20.1 m).

At 15 nest sites (33%), the nest tree was not the tallest tree in the immediate vicinity (0.4-ha plot). For these locations, nest trees were significantly ($t_{14} = 7.39$, $P < 0.001$) shorter (averaging 2.9 m shorter) than at least one other tree nearby. Cottonwoods were the nest tree at 10 of these sites, and the taller trees nearby these nests also were all cottonwoods. At the remaining five sites, non-cottonwoods were the nest trees and also were the taller trees nearby, except in one instance (red oak nest tree, taller cottonwood nearby).

Nest tree selectivity

Bald eagles appear to select nest trees nonrandomly from among the species available. The distribution of nests among tree species differed significantly ($\chi^2_4 = 33.12$, $P < 0.001$) from the community composition of forests around nest trees, with a far larger proportion of cottonwoods and a much smaller proportion of silver maples selected as nest trees than expected (Table 2). Positive Ivlev's selectivity values for cottonwood, swamp white oak, and red oak suggest that these species were selected as nest trees two to six times more frequently than expected, whereas the negative selectivity value for silver maple indicates choice as nest trees 40% less frequently than expected (Figure 6).

Geospatial assessments

Land cover varied among the four pools of the Refuge's Winona District (Figure 7; Table S4, *Supplemental Material*). Five of the 15 land cover classes (agriculture, developed, roads/levees, wet forest, open water) repeat-

Table 2. Species composition of bald eagle *Haliaeetus leucocephalus* nest trees and surrounding forest trees, Upper Mississippi River National Wildlife & Fish Refuge, Winona District, February–April 2009.

Common name and species	Nest trees		Forest trees	
	No.	%	No.	%
Eastern cottonwood *Populus deltoides*	36	71.1	116	30.5
Silver maple *Acer saccharinum*	10	22.2	161	42.4
Swamp white oak *Quercus bicolor*	2	4.5	6	1.6
Red oak *Quercus rubra*	1	2.2	1	0.3
Green ash *Fraxinus pennsylvanica*	—	—	27	7.1
American basswood *Tilia americana*	—	—	3	0.8
Box-elder *Acer negundo*	—	—	25	6.6
Sugar maple *Acer saccharum*	—	—	5	1.3
American elm *Ulmus americana*	—	—	7	1.8
Hackberry *Celtis occidentalis*	—	—	3	0.8
River birch *Betula nigra*	—	—	15	3.9
Black willow *Salix nigra*	—	—	2	0.5
Unidentified	—	—	9	2.4
Totals	45	100.0	380	100.0

edly appeared as the most important either due to high percentages of cover, or large differences between pools, eagle nests, or random points. Consequently, the remaining 10 land cover classes were lumped together as ''Other'' to simplify further analyses. Developed and roads/levees cover classes were combined to form a single category. Open water was the dominant cover type in all pools, but other land cover types varied among pools. For example, the relative abundance of wet forest in Pool 5A was three times greater than in any other pool, whereas relative abundance of developed lands/roads/levees was eight times higher in Pool 6 than in other pools. Agricultural lands were low in abundance (<7%) in all pools.

Land cover around eagle nests in the Winona District was distinctly different than that around randomly selected points on land (Figure 8; Table S5, *Supplemental Material*). Wet forest and open water were the dominant cover types (combined 71% of total) within 100 m of nests, with agriculture and developed lands collectively making up only 1%. Wet forest and open water also dominated (combined 64% of total area) within 1,000 m of eagle nests, with agricultural and developed lands making up <8% of habitats at this scale. Land cover classes around active eagle nests and random points differed significantly from each other at both the 100 and 1,000 m scales (Table 5). Open water habitats were two–five times more abundant around eagle nest sites than around random points, whereas agricultural and developed lands combined were 3–30 times more common around random points than around nest sites. Wet forest habitat was twice as common around nest sites compared with random sites at the 100-m scale but did not differ between nest and random sites at the 1,000-m scale. Land cover classes around successful nests did not differ from those around unsuccessful nests at either the 100- or 1,000-m scale (Table 6).

Discussion

With populations of nesting bald eagles increasing faster in the Upper Mississippi River floodplain than anywhere else in Minnesota (Baker and Monstad 2006), our study provides important information about the characteristics of nesting sites now being used by eagles in this habitat. Although our nesting data are opportunistic and may not include every active eagle nest within the Winona District of the Refuge, many clear patterns are evident. Eagles are nesting exclusively in deciduous trees, especially eastern cottonwood and silver maple, selecting nest trees of a size and nearness to water that is typical for the species in many non-floodplain habitats. Nest sites often are located near transportation corridors, but away from other human developments and agricultural land. Densities of active nest sites and nest spacing within the upper Mississippi River floodplain are similar to those in other floodplain and non-floodplain habitats. Successful nests are spaced further away from other active nests and are located in areas with lower tree density compared with unsuccessful nests.

Eagles in the Winona District nested exclusively in deciduous trees. Although bald eagles typically choose various conifers as nest trees in more northern forests,

Table 3. Characteristics of bald eagle *Haliaeetus leucocephalus* nest trees, Upper Mississippi River National Wildlife & Fish Refuge, Winona District, February–April 2009. Values are means ± SD, with ranges in parentheses. *n* is sample size and DBH is diameter at breast height.

Tree	*n*	Tree height (m)	DBH (cm)	Nest height (m)	Nest height/tree height (%)	Distance to water (m)
Eastern cottonwood	32	30.1 ± 3.7 (22.6–38.7)	90 ± 23 (53–152)	20.0 ± 2.7 (15.2–26.5)	66.9 ± 7.1 (51.0–85.0)	61.5 ± 84.6 (12–354)
Silver maple	10	23.9 ± 4.1 (17.1–29.3)	90 ± 25 (66–135)	16.0 ± 3.1 (11.6–20.4)	62.7 ± 7.2 (58.5–82.1)	85.8 ± 126.7 (10–418)
Swamp white oak	2	22.3 ± 0.9 (21.6–22.9)	72 ± 9 (66–79)	16.0 ± 1.9 (14.6–17.4)	71.8 ± 5.9 (67.6–76.0)	15.5 ± 2.1 (14–17)
Red oak	1	22.9 —	76 —	18.6 —	81.3 —	21.0 —
Combined	45	28.2 ± 4.7 (17.1–38.7)	89 ± 23 (53–152)	18.9 ± 3.3 (11.6–26.5)	67.5 ± 7.2 (51.0–85.0)	64.0 ± 92.7 (10–418)

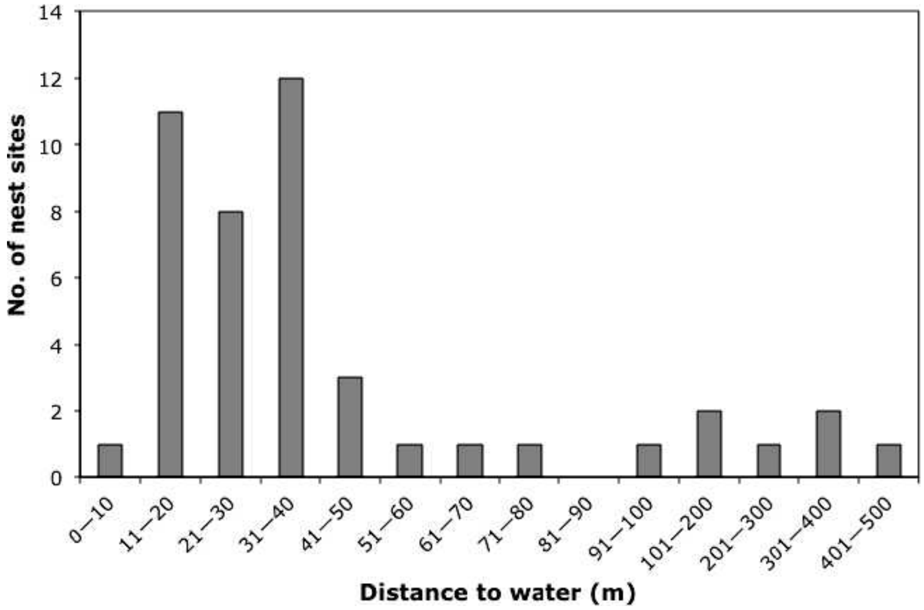

Figure 3. Distribution of bald eagle *Haliaeetus leucocephalus* nest distances from water, Upper Mississippi River National Wildlife & Fish Refuge, Winona District, February–April 2009. *n* = 45.

southern forests, mountainous regions, and along seacoasts (Anthony et al. 1982; Peterson 1986; Harris et al. 1987; Stalmaster 1987; Packham 2005), deciduous trees regularly are selected for nesting, especially in river floodplains (Thompson and McGarigal 2002; Guinn 2004; Haskell and Eckstein 2007; Suring 2010). As in the present study, cottonwoods (eastern or black [*Populus trichocarpa*]) are the most common deciduous trees used by nesting eagles in river floodplains, although at least 12 other deciduous species have been reportedly used as nest trees (Thompson and McGarigal 2002; Guinn 2004; Haskell and Eckstein 2007; Suring 2010; present study). Cottonwoods typically are the supercanopy tree of the floodplain, making them the floodplain equivalent of the large conifers used for nesting by eagles in northern, southern, and mountain forests (Anthony et al. 1982; Harris et al. 1987; Wood et al. 1989; Packham 2005; Suring 2010).

Nest sites (tree species, height, DBH, distance to water) selected by bald eagles in the Winona District of the Upper Mississippi River Refuge were typical of those used by eagles nesting along rivers in many regions of North America (Hansen et al. 1986; Thompson and McGarigal 2002; Nelson 2005; Packham 2005; Suring 2010). Characteristics of these nest sites also were very similar to those of eagles that nest in nonriverine environments (Peterson 1986; Grubb et al. 2003; Bowerman et al. 2005), suggesting common species needs regardless of geographic area (Anthony et al. 1982).

Most (90%) of the eagle nests in the Refuge were located in proximity (<400 m) to some form of regular human activity (i.e., boat traffic, highways, railways), although only three nests (all unsuccessful) had any developed or agricultural lands within 100 m of the nest tree. Human developments and activities typically are low in abundance around eagle nest sites (Peterson 1986; Harris et al. 1987; Grubb et al. 2003), although eagles will tolerate human activities with increasing distance from the nest (Peterson 1986; Harris et al. 1987; Grubb et al. 2002). Eagles may nest near some disturbances such as railroads that they do not directly associate with humans (Peterson 1986), but frequent boat traffic, marinas, boat launches, and heavily traveled highways usually are not tolerated by nesting eagles (Peterson 1986; Grubb et al. 2003). Despite past and current evidence demonstrating significant, negative effects of human activities on nesting eagles (Mathisen 1968; Fraser et al. 1985; Grubb et al. 1992; Steidl and Anthony 2000; Grubb et al. 2002; Fraser and Anthony 2010), birds in some locales apparently can adapt to

Table 4. Characteristics of successful and unsuccessful bald eagle *Haliaeetus leucocephalus* nest trees, Upper Mississippi River National Wildlife & Fish Refuge, Winona District, February–April 2009. Values are means ± SD. *N* is sample size and DBH is diameter at breast height. Student's *t* values and associated *P* values comparing successful and unsuccessful nests are included.

Nest success	*n*	Tree height (m)	DBH (cm)	Nest height (m)	Distance to water (m)
Successful	25	27.8 ± 4.2	90 ± 21	19.1 ± 2.9	89.1 ± 118.7
Unsuccessful	20	28.6 ± 5.4	89 ± 25	18.8 ± 3.7	32.6 ± 14.4
Student's *t*		0.590	0.084	0.312	2.112
P		0.558	0.933	0.757	0.041

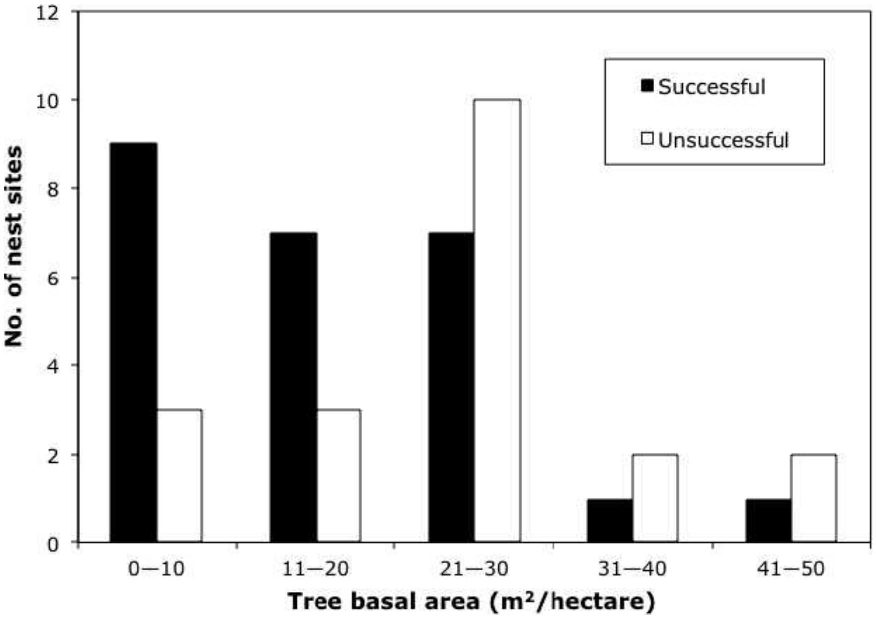

Figure 4. Distribution of tree densities (based on trunk cross-sectional area, square meters per hectare in floodplain forest stands) around successful ($n = 25$) and unsuccessful ($n = 20$) bald eagle *Haliaeetus leucocephalus* nests, Upper Mississippi River National Wildlife and Fish Refuge, Winona District, February–April 2009.

humans (Wood et al. 1989; McGarigal et al. 1991; Berry et al. 1998; Thompson and McGarigal 2002; Thompson et al. 2005; Elliott et al. 2006) and are nesting successfully even in more developed or urbanizing environments (Johnson 1990; Sorensen 2003; Guinn 2004; Millsap et al. 2004; Nelson 2005; Baker and Monstad 2006). For example, occupied nests in the Minneapolis–St. Paul, Minnesota, metropolitan area more than doubled (from 35 to 78) between 2000 and 2005 (Baker and Monstad 2006), even while the human population of the region was expanding by nearly 170,000 people (U.S. Census Bureau statistics). It has been speculated that bald eagle populations may be experiencing generational habituation in some areas, becoming desensitized to human presence as successive generations nest successfully in areas of increasing human activity (Guinn 2004; Millsap et al. 2004; Hager

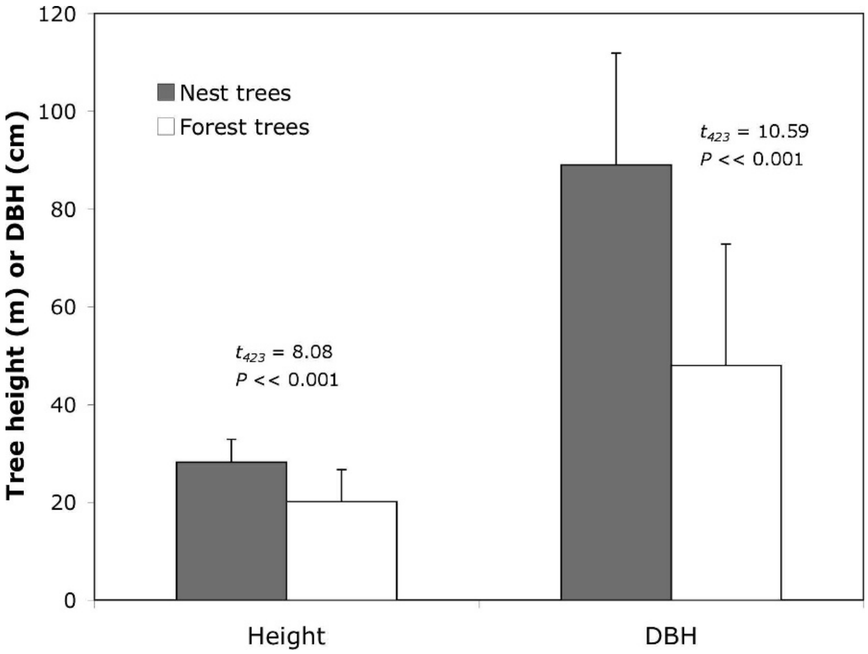

Figure 5. Mean ± SD bald eagle *Haliaeetus leucocephalus* nest tree heights and diameters (diameter at breast height, DBH) compared with heights and diameters of nearby trees in the floodplain forest, Upper Mississippi River National Wildlife and Fish Refuge, Winona District, February–April 2009. $n = 45$ for nest trees, $n = 380$ for forest trees.

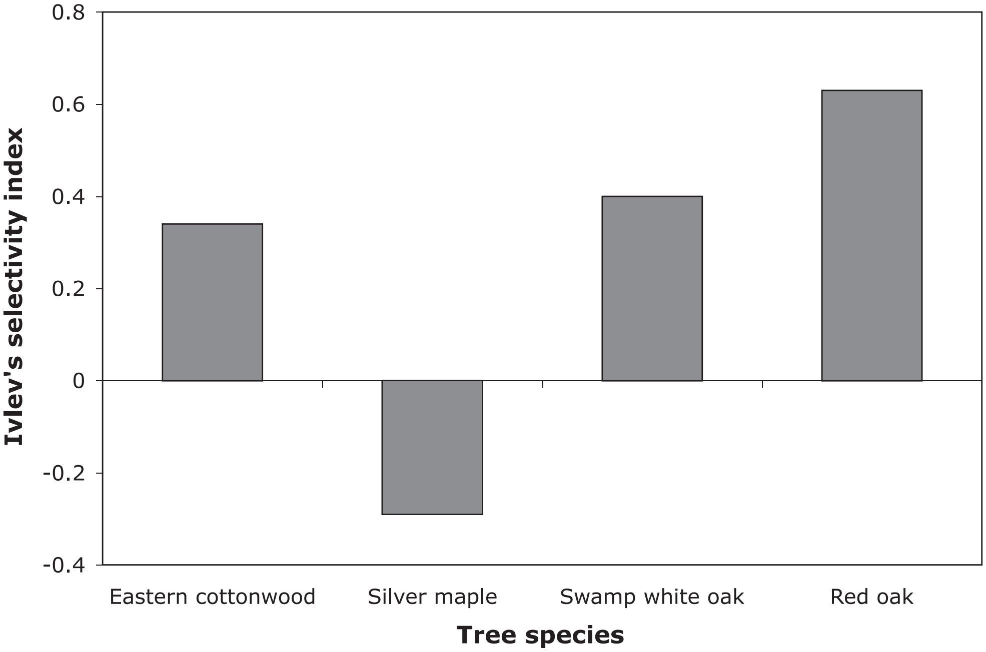

Figure 6. Selection by bald eagles *Haliaeetus leucocephalus* in the Upper Mississippi River National Wildlife and Fish Refuge, Winona District, February–April 2009, for or against certain species of trees for nesting, based on Ivlev's selectivity index. Values > 0 indicate positive selection, 0 indicates random use, and values < 0 indicate negative selection.

2009). Reproductive success of bald eagles within the Refuge was assessed during the 2005 nesting season, when 167 occupied nests were estimated to have fledged 279 eaglets (1.67 eaglets/nest; D. Hultman, Refuge [retired], personal communication).

The density and spacing of bald eagle nest sites in the Winona District of the Refuge appear similar to those reported for bald eagles in other large riverine systems in North America. Bald eagle nests were distributed every 1.24–4.10 rkm within the Mississippi River reaches covered in our study (based on total nests per pool and main river channel length in each pool), similar to the 3.2–10.6 km of river shoreline spanned by bald eagle home ranges along the Columbia and Hudson rivers (Garrett et al. 1993; Thompson and McGarigal 2002). Bald eagle home range areas (5.1–47.3 km^2) in these same two systems (Garrett et al. 1993; Thompson and McGarigal 2002) and the presumed minimum habitat area required for bald eagles (8.66 km^2; Peterson 1986) also agree with the areas/eagle nest (10.3–38.0 km^2) observed in three of the four Mississippi River Refuge pools examined in the present study. The much larger area/eagle nest value for Pool 4 (315 km^2/nest) was, in part, the result of the large proportion (94%) of open

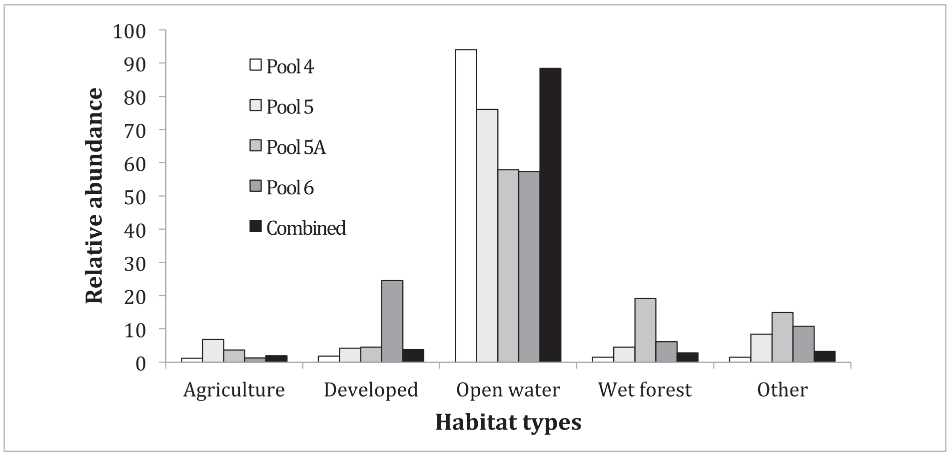

Figure 7. Relative abundance of land cover (habitat types) within each of the four individual pools making up the Upper Mississippi River National Wildlife and Fish Refuge, Winona District, and for all pools combined. Data are based on year 2000 land cover maps. The Developed category includes developed and road/levee cover types. The category Other combines the following 10 cover types: deep marsh, grass/forbs, rooted floating aquatics, sand/mud, scrub/shrub, shallow marsh, submerged aquatic vegetation, upland forest, wet meadow, and wet shrub.

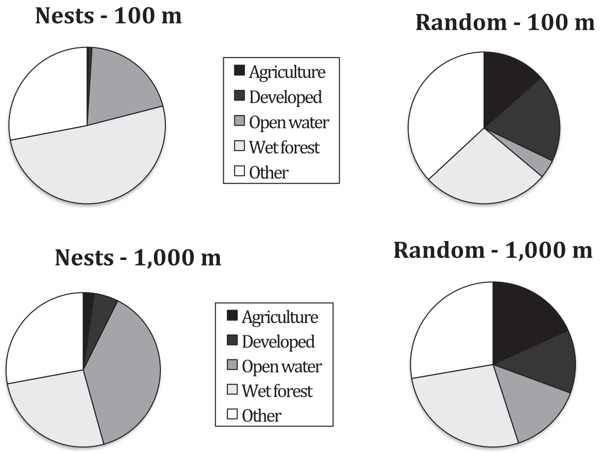

Figure 8. Relative abundance of land cover types within 100- and 1,000-m radii of 50 active bald eagle *Haliaeetus leucocephalus* nests and 50 random points (non-open water) in the Upper Mississippi River National Wildlife and Fish Refuge, Winona District. Data are based on year 2000 land cover maps. The Developed category includes developed and road/levee cover types. The category Other combines the following 10 cover types: deep marsh, grass/forbs, rooted floating aquatics, sand/mud, scrub/shrub, shallow marsh, submerged aquatic vegetation, upland forest, wet meadow, and wet shrub.

water habitat in this pool (area/nest excluding open water habitat = 18.9 km^2). Nearest-neighbor spacing (average 1.52 km) between eagle nests in the Winona District of the Refuge was much less than the average distances of 4.7 and 7.1 km between occupied nests reported along the Columbia and Hudson rivers (Garrett et al. 1993; Thompson and McGarigal 2002). It remains unclear how near riverine-nesting eagles might tolerate another occupied nest, with previous studies indicating that lake-nesting eagles may defend shoreline habitats from other eagles for up to 2 km from the nest site (Corr 1974; Gerrard et al. 1983; Mahaffy and Frenzel 1987; Garrett et al. 1993).

Eagle nests in the Refuge that were successful in fledging at least one young were spaced significantly further away from other active nests (1.84 vs. 1.01 km) and were located in areas with lower tree density than were unsuccessful nests. Successful nests also exhibited a strong tendency to be located further from water than were unsuccessful nests. All other characteristics of nest sites observed in our study (nest tree species, tree size, distance to potential transportation disturbance, land cover surrounding nests) did not differ between successful and unsuccessful nests. Taken together, these observations suggest that eagles nesting in more isolated, less dense floodplain forests have a greater chance of fledging young. In the present study, 79% (31 of 39) of nest sites $>$1 km from another active nest were successful, whereas 86% (12 of 14) of nest sites $<$1 km from another active nest were unsuccessful. With a nest success rate of 62% and a rate of reproduction of 0.89 young fledged/occupied breeding area, the Refuge population of bald eagles represents a healthy expanding population (Sprunt et al. 1973; Grier et al. 1983).

Bald eagle populations likely will continue to expand in the riverine regions of southern and western Minnesota (Minnesota and Red rivers) and southern Wisconsin (Wisconsin River) where habitat is suitable. In addition to nesting within the Mississippi River floodplain, eagles are nesting more frequently along rivers (e.g., Minnesota, Cannon, Zumbro, Whitewater, Root, Wisconsin, Black, Chippewa) tributary to the Mississippi River in Minnesota (Guinn 2004; Baker and Monstad 2006) and Wisconsin (Haskell and Eckstein 2007). These river systems support a rich diversity of fish prey (Delong 2005), and nearby woodlots, highways, and farmlands are a source of bird and mammal carrion (NDM, personal observations). Bald eagles may tolerate human activities associated with farming, highways, river recrea-

Table 5. Comparisons of land cover types at 100- and 1,000-m scales surrounding active bald eagle *Haliaeetus leucocephalus* nests (N = 50) and random points (N = 50), Upper Mississippi River National Wildlife & Fish Refuge, Winona District, 2009. Values (in hectares) are means, with SD in parentheses. Student's t values and associated P values comparing nests and random points are included. Bonferroni corrected α = 0.01 for significance. Bold type denotes P values $<$ 0.01. Degrees of freedom (df) were adjusted following an F-test for inequality of variances.

Scale/land use	Nests	Random points	t	P	Adjusted df
100-m radius					
Agriculture	0.009 (0.061)	0.423 (0.924)	3.16	**0.0027**	49
Developed/roads	0.022 (0.148)	0.584 (0.963)	4.08	**0.0002**	51
Wet forest	1.586 (0.791)	0.847 (1.125)	3.80	**0.0003**	88
Open water	0.624 (0.617)	0.128 (0.404)	4.76	**<0.0001**	85
Other	0.872 (0.797)	1.157 (1.229)	1.37	0.1738	84
1,000-m radius					
Agriculture	7.249 (25.320)	57.108 (83.046)	4.06	**0.0001**	58
Developed/roads	16.176 (13.096)	38.878 (51.943)	3.00	**0.0041**	55
Wet forest	83.074 (53.328)	85.710 (71.124)	0.21	0.8344	91
Open water	120.114 (63.336)	45.339 (58.153)	6.15	**<0.0001**	98
Other	87.501 (50.514)	86.980 (64.800)	0.04	0.9643	92

Table 6. Comparisons of land cover types at 100- and 1,000-m scales surrounding successful ($N = 30$) and unsuccessful ($N = 20$) active bald eagle *Haliaeetus leucocephalus* nests, Upper Mississippi River National Wildlife & Fish Refuge, Winona District, 2009. Values (in hectares) are means with SD in parentheses. Student's *t* values and associated *P* values comparing successful and unsuccessful nests are included. Bonferroni corrected $\alpha = 0.01$ for significance. Degrees of freedom (df) were adjusted following an F-test for inequality of variances.

Scale/land use	Successful nests	Unsuccessful nests	*t*	*P*	Adjusted df
100-m radius					
Agriculture	0.000 (0.000)	0.022 (0.097)	1.00	0.3299	19
Developed/roads	0.000 (0.000)	0.054 (0.234)	1.03	0.3144	19
Wet forest	1.508 (0.855)	1.702 (0.686)	0.85	0.3995	48
Open water	0.664 (0.705)	0.564 (0.464)	0.60	0.5505	48
Other	0.924 (0.888)	0.796 (0.654)	0.55	0.5849	48
1,000-m radius					
Agriculture	3.313 (8.500)	13.154 (38.500)	1.13	0.2739	20
Developed/roads	18.079 (11.623)	13.323 (14.895)	1.27	0.2102	48
Wet forest	81.539 (56.145)	85.377 (50.135)	0.25	0.8037	48
Open water	114.123 (67.956)	129.101 (56.169)	0.82	0.4163	48
Other	97.064 (59.962)	73.157 (27.055)	1.91	0.0626	43

tion, and small cities to access productive foraging areas (McGarigal et al. 1991; Thompson and McGarigal 2002; Guinn 2004). Past problems associated with contaminants in these riverine systems appear to be diminishing, with eagles now exhibiting reproductive rates in these areas indicative of healthy populations (Dykstra et al. 2010).

As bald eagle populations continue to expand into river floodplain areas that have not supported this species in many decades, suitable habitats may need additional protection to ensure the success of breeding eagles. Unfortunately, determining suitable nesting habitats may be difficult for two reasons. First, habitat suitability models developed for bald eagles are designed for use in lake and estuarine habitats (e.g., Peterson 1986; Grubb et al. 2003; Bowerman et al. 2005), not the river floodplains where populations are expanding dramatically in Minnesota and Wisconsin. These suitability models need to be modified to make them applicable to riverine systems, or new models may need to be devised specifically for these types of habitats. Expanding eagle populations along the Mississippi River may be able to locate and use additional, isolated nesting sites free of development and agricultural lands, but these types of habitats may be far less abundant in the floodplains along smaller rivers. Second, possible changing tolerances of bald eagles to human activity (Thompson and McGarigal 2002; Guinn 2004) point to a need to reassess the potential effects of this form of disturbance (especially heavy commercial and recreational boat traffic) on nesting eagles along river floodplains, because human disturbance has always been an important component in habitat suitability models for eagles (Peterson 1986; Bowerman et al. 2005). The expansion of bald eagles in Minnesota and Wisconsin has been dramatic during the past 30 y, but greater efforts are needed to ensure that we clearly understand the needs and tolerances of these birds living in ever-closer proximity to us.

Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

Reference S1. Baker R, Monstad Y. 2006. 2005 Minnesota bald eagle surveys. St. Paul: Minnesota Department of Natural Resources, Nongame Wildlife Program Report.

Found at DOI: http://dx.doi.org/10.3996/012012-JFWM-009.S1; also available at http://files.dnr.state.mn.us/eco/nongame/projects/eagle_report_2005.pdf (1093 KB PDF).

Reference S2. Bowerman WW, Grubb TG, Bath AJ, Giesy JP, Weseloh DV. 2005. A survey of potential bald eagle nesting habitat along the Great Lakes shoreline. Fort Collins, Colorado: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Research Paper RMRS-RP-56WWW.

Found at DOI: http://dx.doi.org/10.3996/012012-JFWM-009.S2; also available at http://www.fs.fed.us/rm/pubs/rmrs_rp056.html (2.4 MB PDF).

Reference S3. Eckstein R, Goltz D, Glenzinski B, Johansen K, Bacon B, Magana R, Grossman E, Easterly S, Nelson J, Manthey P, Meyer M. 2012. Wisconsin bald eagle and osprey surveys 2011. Madison: Wisconsin Department of Natural Resources Report.

Found at DOI: http://dx.doi.org/10.3996/012012-JFWM-009.S3; also available at http://dnr.wi.gov/topic/WildlifeHabitat/documents/reports/eagleospreysurv.pdf (296 KB PDF).

Reference S4. Grubb TG, Bowerman WW, Bath AJ, Giesy JP, Weseloh DV. 2003. Evaluating Great Lakes bald eagle nesting habitat with Bayesian inference. Fort Collins, Colorado: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Research Paper RMRS-RP-45.

Found at DOI: http://dx.doi.org/10.3996/012012-JFWM-009.S4; also available at http://www.fs.fed.us/rm/pubs/rmrs_rp045.html (461 KB PDF).

Reference S5. Hultman D. 2006. Upper Mississippi River National Wildlife and Fish Refuge comprehensive conservation plan. U.S. Fish and Wildlife Service.

Found at DOI: http://dx.doi.org/10.3996/012012-JFWM-009.S5; also available at http://www.fws.gov/midwest/planning/uppermiss/CCP/CCP.pdf (7.5 MB PDF).

Reference S6. Peterson A. 1986. Habitat suitability index models: bald eagle (breeding season). Washington, D.C.: National Ecology Center, U.S. Department of the Interior. U.S. Fish & Wildlife Service Biological Report 82(10.126).

Found at DOI: http://dx.doi.org/10.3996/012012-JFWM-009.S6; also available at http://www.nwrc.usgs.gov/wdb/pub/hsi/hsi-126.pdf (3.9 MB PDF).

Reference S7. U.S. Army Corps of Engineers. 2012. Upper Mississippi River-Illinois waterway system: locks and dams. USACE Mississippi Valley Division.

Found at DOI: http://dx.doi.org/10.3996/012012-JFWM-009.S7; also available at http://www.mvr.usace.army.mil/Portals/48/docs/CC/FactSheets/Miss/Mississippi%20River%20Locks%20and%20Dams%20(2012).pdf (5.0 MB PDF).

Table S1. Bald eagle (*Haliaeetus leucocephalus*) nest tree data, Upper Mississippi River Wildlife and Fish Refuge, Winona District, February–April 2009.

Found at DOI: http://dx.doi.org/10.3996/012012-JFWM-009.S8 (21 KB XLS)

Table S2. Forest inventory data for areas surrounding bald eagle (*Haliaeetus leucocephalus*) nest trees, Upper Mississippi River Wildlife and Fish Refuge, Winona District, February-April 2009.

Found at DOI: http://dx.doi.org/10.3996/012012-JFWM-009.S9 (50 KB XLS)

Table S3. Nearest-neighbor distances for each of 53 bald eagle (*Haliaeetus leucocephalus*) nest sites and distances to potential disturbance for nest sites and 53 random points (non-open water) within the Upper Mississippi River Wildlife and Fish Refuge, Winona District, February-April 2009.

Found at DOI: http://dx.doi.org/10.3996/012012-JFWM-009.S10 (47 KB XLSX)

Table S4. Land coverages for each of 15 river floodplain habitat types within the Upper Mississippi River Wildlife and Fish Refuge, Winona District. Data were generated from geospatial assessments of year 2000 land cover maps, and are presented for each individual area polygon within each of the four river pools.

Found at DOI: http://dx.doi.org/10.3996/012012-JFWM-009.S11 (242 KB XLSX)

Table S5. Land coverages within 100-m and 1,000-m radii of 50 bald eagle (*Haliaeetus leucocephalus*) nests and 50 random points (non-open water) within the Upper Mississippi River National Wildlife and Fish Refuge, Winona District. Data were generated from geospatial assessments of year 2000 land cover maps, and are presented on four separate tabs.

Found at DOI: http://dx.doi.org/10.3996/012012-JFWM-009.S12 (89 KB XLSX)

Acknowledgments

We greatly appreciate the assistance of the staff of the Upper Mississippi River National Wildlife & Fish Refuge, Winona, Minnesota, especially Brian Pember, Lisa Reid, Brian Stemper, and Mary Stefanski. The Refuge provided personnel, airboats, and all equipment used during field assessments. We also thank Maria Fosado (Fergus Falls Wetland Management District, Fergus Falls, Minnesota) for assistance during this project. The manuscript benefitted from the constructive comments of the Journal Subject Editor and three anonymous reviewers. The findings and conclusions in this article are those of the author(s) and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

References

Alsop FJ. 2002. Birds of North America. New York: DK Publishing.

Anthony RG, Knight RL, Allen GT, McClelland BR, Hodges JI. 1982. Habitat use by nesting and roosting bald eagles in the Pacific Northwest. Pages 332–342 in Sabol K, editor. Transactions of the 47th North American Wildlife and Natural Resources Conference. Washington D.C., Wildlife Management Institute.

Baker R, Galli J, Nelson S. 2000. 2000 Minnesota bald eagle survey. St. Paul: Minnesota Department of Natural Resources. Nongame Wildlife Program Report. Available: http://www.dnr.state.mn.us/eco/nongame/projects/baldeagle_survey2000.html (October 2012).

Baker R, Monstad Y. 2006. 2005 Minnesota bald eagle surveys. St. Paul: Minnesota Department of Natural Resources, Nongame Wildlife Program Report (see *Supplemental Material*, Reference S1, http://dx.doi.org/10.3996/012012-JFWM-009.S1); also available: http://files.dnr.state.mn.us/eco/nongame/projects/eagle_report_2005.pdf (October 2012).

Berry ME, Bock CE, Haire SL. 1998. Abundance of diurnal raptors on open space grasslands in an urbanized landscape. Condor 100:601–608.

Bowerman WW, Grubb TG, Bath AJ, Giesy JP, Weseloh DV. 2005. A survey of potential bald eagle nesting habitat along the Great Lakes shoreline. Fort Collins, Colorado: U.S. Department of Agriculture, Forest

Service, Rocky Mountain Research Station. Research Paper RMRS-RP-56WWW (see *Supplemental Material*, Reference S2, http://dx.doi.org/10.3996/012012-JFWM-009.S2); also available: http://www.fs.fed.us/rm/pubs/rmrs_rp056.html (October 2012).

Buehler DA. 2000. Bald eagle (*Haliaeetus leucocephalus*). Pages 1–40 in Poole A, Gill F, editors. The birds of North America, no. 506. Philadelphia, Pennsylvania: The Birds of North America, Incorporated.

Corr PO. 1974. Bald eagle (*Haliaeetus leucocephalus alascanus*) nesting related to forestry in southeastern Alaska. Master's thesis. Fairbanks: University of Alaska.

Delong MD. 2005. Upper Mississippi River basin. Pages 327–373 in Benke AC, Cushing CE, editors. Rivers of North America. Burlington, Massachusetts: Elsevier Academic Press.

Dykstra CR, Route WT, Meyer MW, Rasmussen PW. 2010. Contaminant concentrations in bald eagles nesting on Lake Superior, the upper Mississippi River, and the St. Croix River. Journal of Great Lakes Research 36:561–569.

Eckstein R, Goltz D, Glenzinski B, Johansen K, Bacon B, Magana R, Grossman E, Easterly S, Nelson J, Manthey P, Meyer M. 2012. Wisconsin bald eagle and osprey surveys 2011. Madison: Wisconsin Department of Natural Resources Report (see *Supplemental Material*, Reference S3, http://dx.doi.org/10.3996/012012-JFWM-009.S3); also available: http://dnr.wi.gov/topic/WildlifeHabitat/documents/reports/eagleospreysurv.pdf (October 2012).

Elliott KH, Duffe J, Lee SL, Mineau P, Elliott JE. 2006. Foraging ecology of bald eagles at an urban landfill. Wilson Journal of Ornithology 118:380–390.

Fraser JD, Anthony RG. 2010. Human disturbance and eagles. Pages 306–314 in Wright BA, Schempf P, editors. Bald eagles in Alaska. Surrey, British Columbia: Hancock House Publishers.

Fraser JD, Frenzel LD, Mathisen JE. 1985. The impact of human activities on breeding bald eagles in north-central Minnesota. Journal of Wildlife Management 49: 585–592.

Garrett MG, Watson JW, Anthony RG. 1993. Bald eagle home range and habitat use in the Columbia River estuary. Journal of Wildlife Management 57:19–27.

Gerrard JM, Gerrard PN, Bortolotti BR, Whitfield DWA. 1983. A 14-year study of bald eagle reproduction on Besnard Lake, Saskatchewan. Pages 47–57 in Bird DM, editor. Biology and management of bald eagles and ospreys. Sainte Anne de Bellevue, Quebec: Harpell Press.

Grier JW, Elder JB, Gramlich FJ, Green NF, Kussman JB, Mathisen JE, Mattsson JP. 1983. Northern states bald eagle recovery plan. Washington, D.C.: U.S. Department of the Interior, Fish and Wildlife Service.

Grosenbaugh LR. 1952. Plotless timber estimates—new, fast, easy. Journal of Forestry 50:32–37.

Grubb TG, Bowerman WW, Bath AJ, Giesy JP, Weseloh DV. 2003. Evaluating Great Lakes bald eagle nesting habitat with Bayesian inference. Fort Collins, Colorado: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Research Paper RMRS-RP-45 (see *Supplemental Material*, Reference S4, http://dx.doi.org/10.3996/012012-JFWM-009.S4); also available: http://www.fs.fed.us/rm/pubs/rmrs_rp045.html (October 2012).

Grubb TG, Bowerman WW, Giesy JP, Dawson GA. 1992. Responses of breeding bald eagles, *Haliaeetus leucocephalus*, to human activities in northcentral Michigan. Canadian Field-Naturalist 106:443–453.

Grubb TG, Robinson WL, Bowerman WW. 2002. Effects of watercraft on bald eagles nesting in Voyageurs National Park, Minnesota. Wildlife Society Bulletin 30: 156–161.

Guinn JE. 2004. Bald eagle nest site selection and productivity related to habitat and human presence in Minnesota. Doctoral dissertation. Fargo: North Dakota State University.

Hager SB. 2009. Human-related threats to urban raptors. Journal of Raptor Research 43:210–226.

Hansen AJ, Dyer MI, Shugart HH, Boeker EL. 1986. Behavioral ecology of bald eagles along the Pacific Northwest coast: a landscape perspective. Oak Ridge, Tennessee: Oak Ridge National Laboratory. Environmental Sciences Division Publication 2548.

Harris JO, Zwank PJ, Dugoni JA. 1987. Habitat selection and behavior of nesting bald eagles in Louisiana. Journal of Raptor Research 21:27–31.

Haskell D, Eckstein R. 2007. Bald eagle (*Haliaeetus leucocephalus*). In Kreitinger K, Paulios A, editors, The Wisconsin all-bird conservation plan, version 1.0. Madison: Wisconsin Department of Natural Resources, Wisconsin Bird Conservation Initiative. Available: www.wisconsinbirds.org/plan/species/baea.htm (October 2012).

Hultman D. 2006. Upper Mississippi River National Wildlife and Fish Refuge comprehensive conservation plan. U.S. Fish and Wildlife Service (see *Supplemental Material*, Reference S5, http://dx.doi.org/10.3996/012012-JFWM-009.S5); also available: http://www.fws.gov/midwest/planning/uppermiss/CCP/CCP.pdf (September 2012).

Johnson NP. 1990. Nesting bald eagles (*Haliaeetus leucocephalus*) in urban areas of southeast Alaska: assessing highway construction and disturbance impacts. Transportation Research Record 1279:60–68.

Krebs CJ. 1989. Ecological methodology. New York: Harper & Row.

Kumlien L, Hollister N. 1903. The birds of Wisconsin. Bulletin of the Wisconsin Natural History Society 3:1–143.

Mahaffy MS, Frenzel LD. 1987. Elicited territorial responses of northern bald eagles near active nests. Journal of Wildlife Management 51:551–554.

Mathisen JE. 1968. Effects of human disturbance on nesting bald eagles. Journal of Wildlife Management 32:1–6.

McGarigal K, Anthony RG, Isaacs FB. 1991. Interactions of humans and bald eagles on the Columbia River estuary. Wildlife Monographs 115:1–47.

Miller M, Pfannmuller L. 1991. Bald eagle population in Minnesota. Loon 63:268–271.

Millsap B, Breen T, McConnell E, Steffer T, Phillips L, Douglass N, Taylor S. 2004. Comparative fecundity and survival of bald eagles fledged from suburban and rural natal areas in Florida. Journal of Wildlife Management 68:1018–1031.

Nelson ZR. 2005. Using geographic information systems to determine potential bald eagle nesting sites in Washington County, MN. Endeavor 1:16–25.

Packham R. 2005. Bald eagle nest site and nest tree characteristics in select biogeoclimatic zones of the 100 Mile House Forest District, British Columbia. British Columbia Journal of Ecosystem Management 6:1–7.

Peterson A. 1986. Habitat suitability index models: bald eagle (breeding season). Washington, D.C.: National Ecology Center, U.S. Department of the Interior. U.S. Fish & Wildlife Service Biological Report 82(10.126) (see *Supplemental Material*, Reference S6, http://dx.doi.org/10.3996/012012-JFWM-009.S6); also available: http://www.nwrc.usgs.gov/wdb/pub/hsi/hsi-126.pdf (October 2012).

Robbins SD Jr. 1991. Wisconsin birdlife, population and distribution, past and present. Madison: University of Wisconsin Press.

Sprunt A, Robertson WB, Postupalsky S, Hensel RJ, Knoder CE, Ligas FJ. 1973. Comparative productivity of six bald eagle populations. Transactions of the North American Wildlife and Natural Resources Conference 38:96–106.

Stalmaster MV. 1987. The bald eagle. New York: Universe Books.

Steenhof K, Bond L, Dunn LL. 2008. The midwinter bald eagle survey results and analysis 1986–2005. Corvallis, Oregon: U.S. Geological Survey, National Biological Information Infrastructure, and Northwest Alliance for Computational Science and Engineering. Available: http://www.nacse.org/nbii/eagles (February 2011).

Steidl RJ, Anthony RG. 2000. Experimental effects of human activity on breeding bald eagles. Ecological Applications 10:258–268.

Sorensen E. 2003. Majestic bald eagle adapting to urban life. The Seattle Times (January 27): . Available: http://community.seattletimes.nwsource.com/archive/?date=20030127&slug=eagle27m (September 2012).

Suring LH. 2010. Habitat relationships of bald eagles in Alaska. Pages 106–116 in Wright BA, Schempf P, editors. Bald eagles in Alaska. Surrey, British Columbia: Hancock House Publishers.

Thompson CM, McGarigal K. 2002. The influence of research scale on bald eagle habitat selection along the lower Hudson River, New York (USA). Landscape Ecology 17:569–586.

Thompson CM, Nye PE, Schmidt GA, Garcelon DK. 2005. Foraging ecology of bald eagles in a freshwater tidal system. Journal of Wildlife Management 69:609–617.

[USACE] U.S. Army Corps of Engineers. 2012. Upper Mississippi River-Illinois waterway system: locks and dams. USACE Mississippi Valley Division (see *Supplemental Material*, Reference S7, http://dx.doi.org/10.3996/012012-JFWM-009.S7); also available: http://www.mvr.usace.army.mil/Portals/48/docs/CC/FactSheets/Miss/Mississippi%20River%20Locks%20and%20Dams%20(2012).pdf (June 2013).

Wood PB, Edwards TC Jr, Collopy MW. 1989. Characteristics of bald eagle nesting habitat in Florida. Journal of Wildlife Management 53:441–449.