BALD EAGLE NEST SITE SELECTION AND PRODUCTIVITY RELATED TO HABITAT AND HUMAN PRESENCE IN MINNESOTA

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Title

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JEREMY EUGENE GUINN

The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

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Degree Granted

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ABSTRACT

Guinn, Jeremy Eugene, Ph.D., Department of Biological Sciences, College of Science and Mathematics, North Dakota State University, May 2004. Bald Eagle Nest Site Selection and Productivity Related to Habitat and Human Presence in Minnesota. Major Professor: Dr. James W. Grier.

Removal of the bald eagle from the federal Endangered and Threatened Species List has been proposed but delayed, pending consideration of habitat needs and the development of a population-monitoring plan. This project evaluated the species' use of nesting habitat in Minnesota, where a large population of bald eagles nests across several different ecoregions and near varying levels of human activity. A total of 24 habitat and human-presence variables were measured at a sample of 120 active nest sites and 166 random sites. Measurements within 100 m of nests were taken on site while variables up to 1,000 m were measured by analyzing remote-sensing data and aerial photographs. Discriminant Analysis separated nest sites from random sites primarily on the basis of tree diameter and distance from shoreline. Information-theoretic Model Selection showed little relationship of productivity at each nest to the characteristics of the site. Within the range of basic requirements (proximity to water, substantial trees for nest support, and an adequate prey base), eagle habitat was highly variable and not specialized. The rebound of bald eagle populations did not occur with concurrent increases in habitat. Rather, it appears that recent population trends were the result of demographic factors that were probably not related directly to habitat or human presence. As long as the public does not harass the birds or impact eagle reproduction and survival, nesting bald eagles appear to coexist satisfactorily with humans in close proximity. The

continued welfare of bald eagles depends most importantly on protection of the birds themselves, via continuing education of the public and enforcement of existing regulations. While bald eagle nesting habitat should not be ignored, there is little evidence from this study that it is currently a major concern in the state of Minnesota.

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CHAPTER 1. INTRODUCTION

Bald eagle populations have risen sharply since the banning of DDT and the administration of new laws limiting harassment of eagles and destruction of their nest sites. Gains in nesting bald eagle populations over the last two decades led to a proposed delisting of the bald eagle from the federal Endangered and Threatened Species List (Fish & Wildlife Service 1999; Bednarz 2000). Bald eagles are currently protected in the United States by the Bald and Golden Eagle Protection Act, the Migratory Bird Treaty Act, the Lacey Act, and the Endangered and Threatened Species Act. A substantial amount of protection for eagle habitat would vanish under the current delisting proposal (Bednarz 2000; Barth 1999).

Concern about eagle habitat requirements expressed by both experts and the general public resulted in delaying a change in the listing status of the bald eagle. Some groups recommended that delisting not occur unless provisions for habitat protection were first implemented (Bednarz 2000; Barth 1999). However, bald eagle habitat has been difficult to define. In many areas, populations have recently expanded their ranges into new habitat types.

Over the last decade, bald eagles have shown the ability to successfully nest in many areas that were previously thought to be sub-optimal habitat (pers. observations and corresp. with U. S. and Canadian eagle experts). For these reasons, re-evaluation of bald eagle nesting habitat was deemed necessary to determine the importance of habitat features within a context of varying levels of human presence. This project examined habitat use, including degrees of isolation from human activity, by breeding bald eagles in the state of Minnesota.

The primary factor influencing the survival of many wildlife species today is habitat loss. Animals must have certain essential environmental features available to them for sufficient food, water, and shelter for themselves and their offspring. Identifying these essential habitat features allows for the design of more effective management strategies. Several raptor species show varying degrees of decreased reproductive success due to contact with human activities (Fyfe & Olendorf 1976; Stalmaster 1987; Gerrard & Bortolotti 1988). These concerns need to be more fully examined in order to create an accurate view of the habitat requirements of nesting bald eagles and the factors limiting successful breeding.

The role of human activity near nest sites, once considered to be the primary threat to nesting and foraging eagles (Mathisen 1968; Evans 1982; Green 1985; Herkert 1992), should be re-examined. The number of eagles successfully nesting near human activity appears to be increasing. Bald eagle populations in Minnesota have increased in the face of increasing human populations since 1970 (Fig. 1). Observing a pair of eagles nesting near human activity has become a relatively common occurrence rather than an exceptional case.

Many questions can be considered concerning current eagle populations. How tolerant are eagles of humans intruding into their territory? What level of disturbance does a hiker walking along a trail cause, compared to the activities that occur in an agricultural field? Are eagles able to successfully breed within close proximity to human activity? Are buffer zones, which were designed to protect eagle nests from potential human intrusions, really necessary? What activities should be prohibited or controlled within these zones? Do eagles only

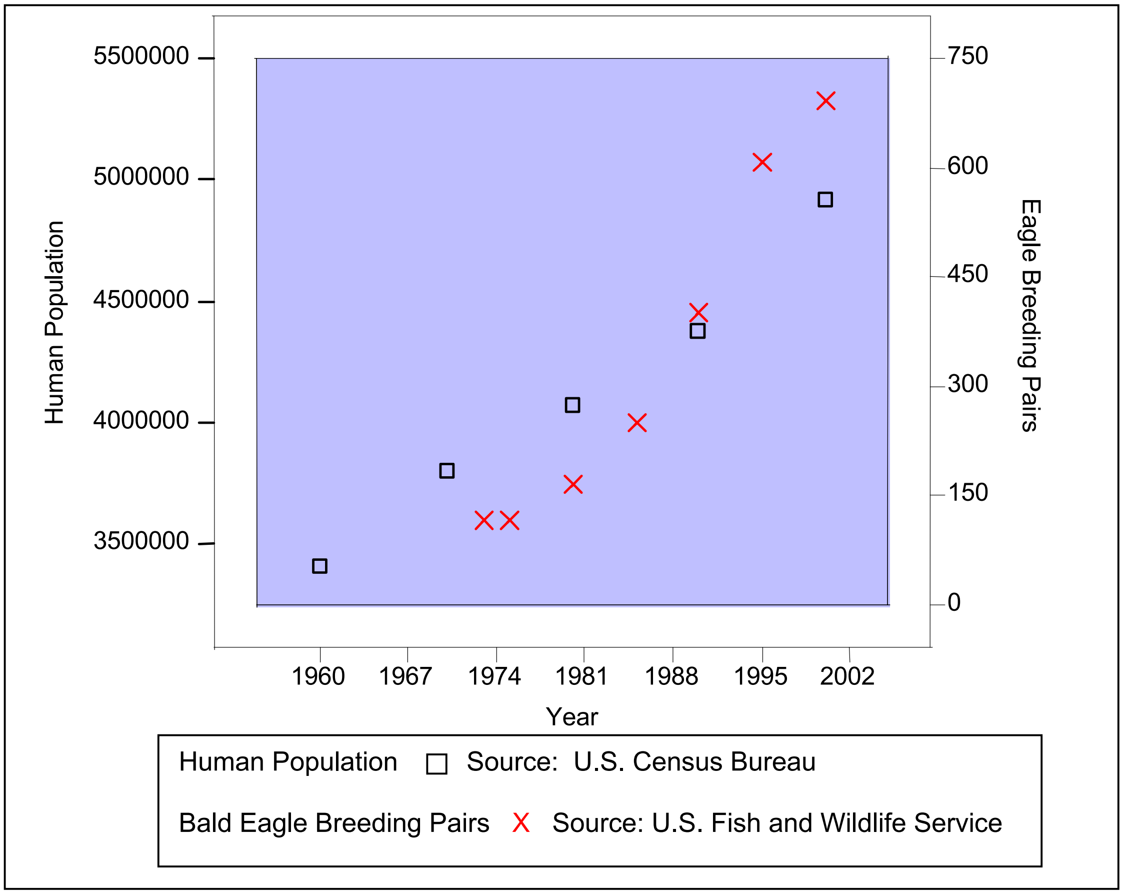

Figure 1. Comparative increases in populations of humans and bald eagles in Minnesota between 1960 and 2000.

nest in certain types of trees within certain types of forests? Is proximity to a sizable body of water a necessary requirement?

It is essential that managers have accurate data concerning these issues in order to design management strategies that will provide sufficient habitat, seclusion, and protection for eagles in the future. Many investigators have proposed the use of site-specific management for every nest (Mathisen et al. 1977; Fraser et al. 1985; Grubb & King 1991). However, as the number of eagle nesting sites continues to rise, this becomes financially and logistically unfeasible. Nests on private land are particularly difficult to manage. Future management plans for large populations must consider regional differences in habitats and land-use patterns (Wood et al. 1989).

The state of Minnesota contains one of the largest breeding populations of bald eagles in the contiguous United States. During the year 2000, the Minnesota Department of Natural Resources, Nongame Wildlife Program (MN DNR) sponsored the Millennium Bald Eagle Survey (M.B.E. Survey), an initiative to gain information on the locations and activity of all known eagle nests in the state (Baker et al. 2000). The survey's goal was to locate, map, and gather nesting information on every eagle nest across the state. The information gathered during the M.B.E. Survey facilitated examination of nesting habitat. A major subset of all known active nests located during the M.B.E. Survey was examined for this project. The original set of sample nests represented a very large sample size (n = 180) and were spread across a broad spectrum of habitat types and human presence throughout the state of Minnesota. A large sample size provided the ability to obtain good estimates of variability and range, permitted the statistical separation of the role(s) of various factors involved, and allowed for comparisons of the factors relative to the productivity of each nest.

Eagle nests across the entire state of Minnesota were examined. The state has been subdivided according to ecological habitat types into four major ecoregions (Henderson et al. 1997) (Fig. 2). The largest ecoregion, the Laurentian Mixed Forest, includes the central and northeast portions of the state. This area consists mainly of large aspen/conifer forests, numerous large lakes, and peatlands. Most of the Southern and Eastern portions of the state are considered

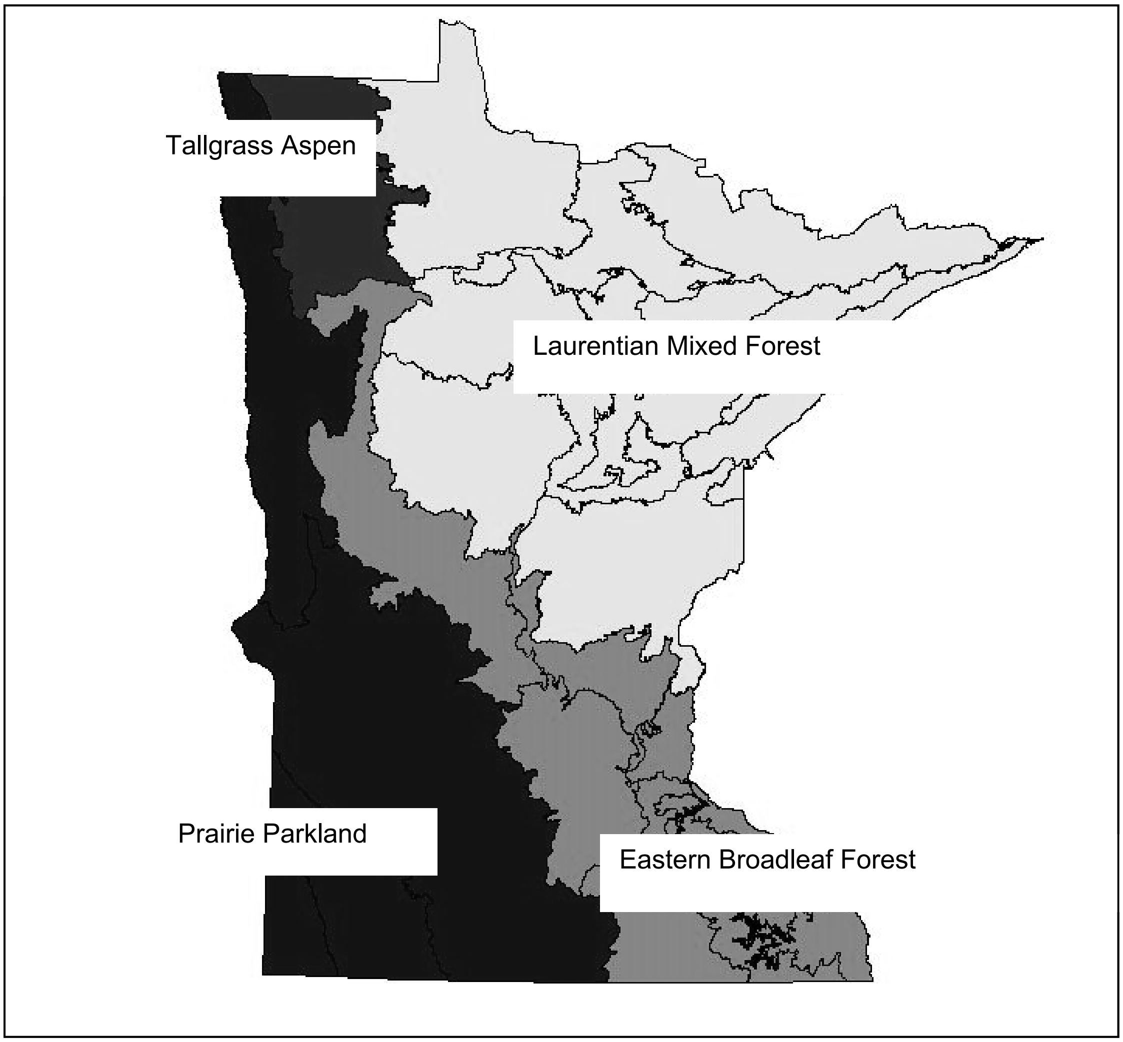

Figure 2. Geographic ecoregions found in Minnesota.

Eastern Broadleaf Forest (also known as the hardwood forest transition zone), which is composed of deciduous forests. The Western portion is considered Prairie Parkland. This area is the typical shortgrass prairie found in the Mid-western states, which consists of large expanses of grassland interspersed with small pothole wetlands. The smallest ecoregion, the Tallgrass Aspen, is found in the Northwest portion of the state. It is characterized by open terrain with many marshy areas and scattered aspen wood lots. Regional habitats were evaluated and assigned to an ecoregion by the Minnesota DNR (Henderson et al. 1997).

Project Objectives

The objectives of this project were designed to evaluate habitat features and human presence features near bald eagle nests. Initial objectives were to (1) obtain 2001 productivity, habitat, and (potential) disturbance data for a sample of bald eagle nests and random sites in Minnesota; and (2) analyze the relationship between bald eagle productivity and habitat and human disturbance variables.

Each objective was subdivided into several tasks: objective 1: (a) conduct survey flights at a subset of the eagle nests identified in 2000; (b) obtain remote sensing measurements for each sample nest and for other, random sites; (c) obtain on-site habitat measurements for each sample nest and random site; objective 2: (a) conduct GIS-based spatial analyses of data and (b) employ Information-theoretic Model Selection analysis to investigate the relationship between productivity and habitat and potential disturbance features. Additional objectives included using Discriminant Analysis to compare nest and random sites and disseminating these findings through a dissertation, professional journal articles, and presentations at national professional conferences.

CHAPTER 2. LITERATURE REVIEW

The bald eagle is a member of the genus *Haliaeetus*, which contains eight species of sea eagles around the world. The bald eagle is the only member of the genus found in North America and occurs only in North America. Large breeding populations occur throughout Canada, Alaska, Minnesota, Wisconsin, Michigan, Maine, Washington, and Florida (Stalmaster 1987). Smaller nesting populations occur across much of the remainder of the continent. The bald eagle was previously partitioned into two subspecies, or races, a Northern race (*H. leucocephalus alascarius*) of larger birds north of the 40^{th} parallel and a Southern race (*H. leucocephalus leucocephalus*) of smaller birds south of the 40^{th} parallel. However, there is much variation in body size and inter-mixing of birds; therefore, racial delineation of subspecies is generally not currently accepted (Gerrard & Bortolotti 1988).

Eagles are viciously territorial during the breeding season. Aggression in defense of a territory can be observed as loud calling, displaying, chasing, and/or physically attacking an intruder. Physical altercations with intruders often result in serious injuries or death.

Aggressive reactions are typically directed at adult conspecifics (Fischer 1985; Hackl 1994); however, bald eagles may be aggressive toward sub-adults and juveniles of their species as well as toward ospreys (Gerrard & Bortolotti 1988; Watt et al. 1995). In some cases, eagles have harassed ospreys to the point that ospreys were driven from a particular lake because they simply could not compete with the larger, more powerful eagles. Ospreys often attempt to establish nests in areas that eagles have deserted, possibly to avoid the presence of eagles. This situation occurs in regions that have been abandoned by eagles supposedly because of human disturbances (Stalmaster 1987; Gerrard & Bortolotti 1988). If eagle populations continue to spread into areas of high human activity, the future success of ospreys in regions where they coexist with eagles could be jeopardized.

Nests

Bald eagles build one of the largest, most conspicuous nests of any North American bird (Stalmaster 1987). The largest nest on record was 9 ft in diameter, 18 ft deep, and weighed over 2 tons (Broley 1947). Average nests are typically 1-2 m in diameter and 1 m in depth (Stalmaster 1987), although much variation exists. Nests are built with branches and sticks that interlock to form a large, sturdy platform structure (Stalmaster 1987; Gerrard & Bortolotti 1988). The supporting structure partially determines the shape of the nest (Stalmaster 1987). The platform of the nest is lined with grasses, moss, and other soft vegetation to form a complete mat on which to lay the eggs (Gerrard & Bortolotti 1988).

Nests are typically used for several successive years, with as much as 1 to 2 ft of new nest material being added each year (Broley 1947). The longevity of an eagle nest varies tremendously. Extremely sturdy nests may last up to 30-40 years, although most do not survive that long (Stalmaster 1987). Nest trees are especially vulnerable to wind, lightning, and disease, as well as being weakened from supporting the large and heavy nest structure. Grier (unpubl. data) suggests that some areas of Northern Ontario annually lose more than 10% of nests because of weather and tree condition issues.

Nest Sites

Foraging habitat is one of the primary determinants of raptor breeding site distributions (Newton 1979). Eagles choose nest areas with a constantly available food resource (Hansen 1987; Canton et al. 1992), tending to place their nests near a sizable body of water with fish as the primary food source (Stalmaster 1987; Anthony & Isaacs 1989; Hackl 1994). An available food source near nesting sites is essential to provide sufficient food for their young (Todd et al. 1982; Hansen 1987; Anthony & Isaacs 1989; Livingston et al. 1990; Canton et al. 1992; Hackl 1994). Nesting rarely occurs more than 3 km from water and is usually much closer (Gerrard & Bortolotti 1988).

Several studies have investigated nest site selection in various areas across the bald eagle's range (Murphy 1965; Mathisen 1968; Whitfield et al. 1974; McEwan & Hirth 1979; Andrew & Mosher 1982; Fraser et al. 1985; Anthony & Isaacs 1989; Livingston et al. 1990; Dzus & Gerrard 1993; Cornutt & Robertson 1994; Wood 1999). Comparisons of the results of these studies, however, have shown a high amount of variation in habitat use. Some researchers suggest that suitable nesting trees and a degree of seclusion from human disturbance may influence nest locations (Stalmaster 1987; Livingston et al. 1990). Currently, there are no methods sufficient for evaluating eagle nests over their entire range to facilitate recommendations for management.

Determining patterns of nest site selection by bald eagles and the effects of potential human disturbances has long been problematic for managers and researchers. According to Martin & Roper (1988), habitat characteristics likely effect nest placement by avian species at two different levels. The first level is the area immediately surrounding the nest. The second level involves a larger area surrounding the nest. Several researchers have examined nest site habitat and human disturbances for bald eagles (Mathisen 1968; McEwan & Hirth 1979; Andrew & Mosher 1982; Fraser et al. 1985; Anthony & Isaacs 1989; Livingston et al. 1990; Dzus & Gerrard 1993; Wood 1999). The majority of these researchers, both within and among their various studies, suggest that eagles exhibit wide variation in nest site selection.

Large variation in nesting habitat and the effects of potential human disturbances may be the result of several project-design factors including sample size and habitat heterogeneity within and among different study areas. Some studies looked at a limited number of nests (Mathisen 1968; McEwan & Hirth 1979; Andrew & Mosher 1982; Dzus & Gerrard 1993; Fraser et al. 1985; Wood 1999) and usually only in a small area of land or in one continuous habitat (Mathisen 1968; Whitfield et al. 1974; McEwan & Hirth 1979; Andrew & Mosher 1982; Fraser et al. 1985; Anthony & Isaacs 1989; Dzus & Gerrard 1993; Wood 1999). High variability observed when comparing studies of nesting habitat may be the result of examining nests in completely different habitat types. It is logical to believe that a nest site in a deciduous forest will appear much different from one in a coniferous forest. Therefore, identifying nest site selection in one particular small area does little for managers working outside that specific area or habitat type. For example, Cornutt and Robertson (1994) reported bald eagles nesting in mangroves of Florida Bay. Their results are quite relevant for that specific habitat. However, their study area is quite different from nest sites and potential sites that must be managed in Minnesota, Arizona, Alaska, or Canada.

Livingston et al. (1990) provides the most comprehensive previous evaluation of eagle nesting habitat. Their study area in Maine included a large sample of nests, a large area of land, and they identified nest site criteria across multiple habitats. Their study included nests primarily located along coastal maritime habitat, with only a few nests located along inland bodies of water.

McEwan and Hirth (1979) related productivity data to nest site selection. Their study site was a small area in north central Florida. Aerial surveys were used to determine nest activity and the number of hatchlings present in each nest. Habitat types within 0.5 km of each nest were determined using aerial photographs. Human disturbances were measured within concentric circles with radii of 0.5, 1.0, and 1.5 km. Disturbance values, road use, and habitat alterations were arbitrarily assigned a disturbance rating from 0-5. They found that productivity was negatively correlated with the distance nest trees were located from water. Productivity was positively correlated with the distance other active nests were from the nest, suggesting intraspecific interference competition between nesting pairs.

Andrew and Mosher (1982) quantified habitat features at nest sites around the Chesapeake Bay, Maryland. They used aerial surveys to initially locate nests and measured variables at random sites to provide a measure of the habitat that was available to eagles. They found no relationship between the number of young fledged and the distance the nest was from water.

Anthony and Isaacs (1989) described characteristics of eagle nesting habitat in three different forest types in Western Oregon. Characteristics of nesting habitat were divided into three categories: nest tree, forest stand, and human activity. They stratified their samples into three different forest habitats. They found that nest trees were always dominant or co-dominant in terms of height within a forest stand and were always associated with large bodies of water. The majority of nests were located in live trees. Nest trees in each forest type were taller and also larger in diameter than the trees in the surrounding stand.

Cornutt and Robertson (1988) described eagle nest sites in subtropical areas of Florida Bay, Florida. Eagles were observed to nest in live and dead mangroves and on the ground. Nest trees averaged 33.4 cm in diameter and 4.08 m in height. Nest height averaged 3.96 m and was positively correlated with tree height.

Variation in Nesting Habitat

Nesting habitat has previously been studied in many areas of the country, including Alaska (Corr 1974), California (Lehman 1980), Florida (Broley 1947; McEwan & Hirth 1979; Cornutt & Robertson 1994), Maine (Todd 1979), Minnesota (Mathisen 1968; Juenemann 1973; Fraser et al. 1985), and Washington (Grubb 1976). Across the continent, studies have shown a high amount of variability in describing bald eagle nest sites. Suitable nesting habitat includes trees at least 20 cm in diameter located within 1 km of open water (Andrew & Mosher 1982). In Northern areas, eagle nests tend to be located near areas where ice breaks up early each spring (Gerrard & Bortolotti 1988). Of more than 2,700 nests in Alaska, 99% were within 200 m of water with an average of less than 40 m (Robards & Hodges 1977). In Minnesota, half of 43 nests were within 500 m and the average was approximately 600 m away from water, possibly due to lack of suitable trees along the shoreline (Fraser 1981). In areas of Saskatchewan and Manitoba, 90% of nests were within 183 m of a lake or river (Whitfield et al. 1974; Henny et al. 1974). Thelander (1973) found that 75% of nests were within ¼ mile of the shoreline. Hehnke (1973) reported that all nests found on the Alaskan Peninsula were within 50 yards (units as originally published) of shore. McEwan (1977) found that 66% of 61 nests were within 1 km of water. Todd (1979) found that 67% of nests were within 100 m and 81% were within 250 m. Corr (1974) found that 99% of nests were located within 200 m. Gerrard et al. (1975) found that eagles nested within 220 yards of shore. Mathisen (1963) found that only 8% of 48 nests were located further than 1 mile from shore. The variation across studies could be due to variation in techniques used to locate nests (Fraser 1981). A more extensive review of nests in relation to water can be found in Fraser (1981).

Eagles typically place their nests high in one of the largest trees in a forest stand (Stalmaster 1987). A term popularly used to describe the nest tree of a bald eagle in some areas is “super canopy.” Super canopy trees are those that are substantially taller than the other trees in the surrounding forest stand, rising above the general canopy. In some areas, super canopy trees are preferentially chosen as nest trees by bald eagles (Fraser 1981; Stalmaster 1987; Retfalvi 1965). Eagles tend to pick tall and especially sturdy trees (Gerrard et al. 1975). Super canopy trees may provide good vantagepoints for watching prey and intruding eagles or ospreys (Johnson 1981; Stalmaster 1987; Gerrard & Bortolotti 1988). In Virginia, nest trees averaged 29 m in height while the surrounding trees averaged just 24 m (Stalmaster 1987). Mean nest tree height varies according to the species of tree in which the nest is placed (Retfalvi 1965; Hensel & Troyer 1964). In Chippewa National Forest, Minnesota, nests were higher than the surrounding trees or the nest tree was situated at a habitat edge (Fraser 1981).

Hackl (1994) states that nest trees are an overall average of 25 m tall. Because large eagles have trouble maneuvering in dense forests, tall nest trees allow for unobstructed landing flights to the nest and provide a location to display to intruders (Stalmaster 1987). Selecting a tall, sturdy structure increases the support for a large nest, provides an open flight path to and from the nest, and allows for a panoramic view of the surrounding terrain for defense and display purposes (Stalmaster 1987). Nests are usually placed a few meters below the top of the tree, rather than at the very top (Lehman 1979; Andrew & Mosher 1982; Stalmaster 1987; Gerrard & Bortolotti 1988). Nest trees, regardless of species, are usually stout for their height (Fraser 1981; Anthony et al. 1982; Andrew & Mosher 1982) and have large crowns (Gerrard & Bortolotti 1988). Nest trees in 14 areas around the country ranged from mean values of 20-60 m in height and 50-190 cm in diameter (Stalmaster 1987).

The tree species appears to vary according to the available trees in the stand and selection is likely to be an opportunistic choice (Palmer 1988). Further investigation on this matter is needed (Gerrard & Bortolotti 1988; Hackl 1994). Many studies have reported a strong preference for pine trees. Cornutt and

Robertson (1994) reported that in Florida until 1994, "nearly all nest trees described had been conifers." Wood et al. (1989) reported that 112 of 116 nests in Florida were located in pine trees. McEwan and Hirth (1979) reported that all of the 18 nest trees measured were in pines. Of 140 nests observed, Broley (1947) found 134 nests in pines. Mathisen (1963) reported that 79% of 48 nests were in red and white pines. Nesbitt et al. (1975) reported a similar preference for pine trees. However, this may not be the situation in many other parts of the country.

It is common to find one or more additional alternate, or supernumerary, nests within a few hundred meters of each other inside of a single breeding territory (Broley 1947; Hensel & Troyer 1964; McGahan 1968). Only one of the nests is used for producing eggs and young each year, but different ones may be used during different years. There are several potential reasons for a pair to build supernumerary nests. This act may fulfill an urge to build a nest before laying eggs or serve as insurance in case of the destruction of the primary nest (Newton 1979). The pair may avoid long-lived ectoparasites by alternating nests (Newton 1979). Supernumerary nests may serve as additional advertisement of the occupancy status of a breeding territory (Newton 1979). Regardless of the reason, supernumerary nests within the same breeding territory seem to be a common phenomenon in many areas across the continent. In areas of high nesting density, determining single breeding territories for monitoring research and management purposes is often difficult because of the presence of supernumerary nests.

Historical Populations

When European settlers first arrived in North America, there may have been between 250,000 and 500,000 bald eagles on the continent, occurring in areas covered by at least 45 current states (Fyfe & Olendorf 1976; Gerrard & Bortolotti 1988). As of 1972, occupied nests had been eliminated in at least 14 of those states (Fyfe & Olendorf 1976). Ninety percent of occupied nests were found in just 10 states (Fyfe & Olendorf 1976). Howell (1965) indicated a 75% loss in occupied sites between the 1930s and 1962.

In 1985, estimates placed the bald eagle population in North America at between 70,000 and 80,000 eagles (Stalmaster 1987). About 13,000 eagles wintered in the lower 48 states in the 1980s, and there were around 1,400 breeding pairs (Stalmaster 1987). For reasons discussed below, the number of known breeding pairs reported in the lower 48 states increased steadily from 417 in 1963; to 1,188 in 1981; 2,475 in 1988; 3,014 in 1990 (Kjos 1992); 4,016 in 1993 (Fish & Wildlife Service 1994); 4,452 in 1994 (Fish & Wildlife Service 1995); and 5,748 by 1998 (Baker et al. 2000). The population is currently thought to be well over 7,000 nesting pairs (Baker et al. 2000).

Sources of Mortality

After fledging, bald eagles have no natural predators, although many species may feed on dead or injured eagles, and many eagles are casualties of intraspecific aggression. Winter is thought to be a high period of highest natural mortality due to decreased availability of prey and increased energy needs during periods of extreme cold and migration. During the winter months, starvation may be a major natural cause of death. Eagles are also vulnerable to a variety of other natural events. Eagles are occasionally struck by lightning while on the nest (Howell 1941; Broley 1947; Broley 1952). Territorial fights with other eagles during the breeding season can be injurious and may either directly or indirectly cause death (Prouty et al. 1977). Injuries caused by fights are increasing as population densities in many areas continue to increase (pers. comm. Leland Grim).

A variety of animals may prey on eagle eggs and young. Raccoons are often suspected of preying on eggs and/or young hatchlings (Nash et al. 1980; Fyfe & Olendorf 1976). In fact, eagle nesting success dramatically increased after a disease decimated the raccoon population on the San Juan Islands, WA (Nash et al. 1980). Other nest invaders and potential predators include bobcats, magpies, crows, gulls (Hensel & Troyer 1964; Fyfe & Olendorf 1976), and wolverines (Doyle 1995). Even black bears have been observed sitting in eagle nests, although there was speculation over whether the bear had actually attacked the young (McKelvey & Smith 1979; McEwan & Hirth 1979). Adult eagles will usually flee the nest when a large predator approaches. Older, pre-fledging young may jump from the nest and glide to an ungraceful landing near the base of the tree, after which the adults typically feed the young on the ground until they are able to fly (pers. comm. J. Grier).

Humans have either directly or indirectly caused high rates of mortality for bald eagles, as with many wildlife species. Until 1975, as many as 500 or more eagles died annually because of various types of interactions with humans (Braun et al. 1975). Of 200 eagles admitted to one rehabilitation center in the U.S., 76%

had traumatic injuries caused by gunshots, traps, collisions, electrocution, or other human-related accidents (Redig et al. 1983). Impacts with cars, airplanes, towers, trains (Stone et al. 2001) and power lines are frequent occurrences (Stalmaster 1987). Eagles may also become entangled in traps and eat poisoned carrion that has been set as bait for other predators, such as wolves or coyotes. Eagles have been observed in flight dangling a leg-hold trap from one leg after binding to the bait animal (Gerrard & Bortolotti 1988; Durham 1981). Trapping injuries and fatalities, however, have now been largely eliminated by changes in trapping regulations that prohibit open-view baiting.

Chemical pollutants have had a tremendous impact on raptor populations. Contaminants such as insecticides, herbicides, and industrial wastes are major concerns due to the fact that eagles are directly exposed to both air and water pollution. Biomaginificiaton and bioaccumulation of many chemical substances as they move through the food chain have been detrimental to eagle populations. Eagles are vulnerable to lead poisoning because they often rely heavily on wounded birds or avian carrion for food (Mulhern et al. 1970, Pattee & Hennes 1983, Hennes 1985). Lead shot from waterfowl hunters was found in 43% of all living adult Canada Geese in Swan Lake National Wildlife Refuge, Missouri (Griffin et al. 1980). Lead accumulation in bald eagles has been found at concentrations high enough to cause mortality (Kaiser et al. 1980, Reichel et al. 1984).

Other mortality factors are best classified as accidental. Some eagle chicks have been impaled on fishing hooks that were brought by the adults to the nest still attached to fish (Stalmaster 1987) and eagles of all ages have become entangled in monofilament fishing line, causing a variety of disabilities. Each year many eagles are injured and killed by collisions with automobiles. Of particular danger to eagles are road-cuts in hillsides with steep banks where eagles are attracted by road kills, but do not have the space needed to escape an oncoming vehicle (pers. comm. Lilian Anderson). Eagles have been injured and electrocuted by being struck by lightning while incubating eggs or otherwise on the nest (Howell 1941).

Historically, one of the biggest sources of eagle mortality has been by gunshot wounds. Until the last few decades, many farmers did not hesitate to shoot raptors on sight because they assumed they were foraging on livestock. Of 198 eagles treated at the Minnesota Raptor Center from 1972-1980, 54 were admitted due to gunshot wounds (P. Redig, pers. comm.). Many more are found injured beyond the point of rehabilitation. In 1984, Reichel et al. (1984) reported that shooting was the cause of as many as 20% of the total eagle deaths across the nation. Another study showed the number to be as high as 60% (Fraser et al. 1985). Stalmaster (1987) reported that 43% of 374 eagles died due to gunshot wounds from 1960 to 1977. Shooting of eagles appears to vary greatly from year to year and across different regions of the country. An outbreak of shootings in a particular area for a short period of time appears to be the trend. In such an instance, the person(s) responsible are either brought to justice or the act loses its thrill. In some areas, over 50% of all fledgling eagles have been shot (Retfalvi 1965). Juvenile eagles, which have mottled plumage, are often mistaken for hawks or other raptors and are thus killed (even though all birds of prey are currently protected).

Included in the above records are several isolated, but organized hunting campaigns. Some private groups hunted down eagles by the hundreds. One of these groups included several ranchers that mistakenly blamed eagles for killing a large portion of their livestock. In the 1930s, sheep ranchers in California shot several hundred golden eagles each year (Stalmaster, 1987). In the 1970s, eagles were even hunted from helicopters and airplanes. O'Gara (1982) determined that eagles often fed on the carcasses of livestock animals, but were not predatory on living livestock.

Another group causing eagle mortalities involves persons who sell eagle parts for profit on the black market. Native Americans can legally possess and use eagle feathers and other body parts in rituals and as dance ornamentation. However, they must obtain eagle parts from governmental suppliers. In 1982, 300 birds were killed by a group of professional eagle harvesters who then sold their bounty to Native American groups (Seattle-Post Intelligencer 1983). In the early 1980s, over 50 people were indicted for killing 200-300 eagles in South Dakota to supply "authentic" Indian artifacts to tourists. In the past, the black market for eagle parts has been very lucrative. In 1987, a whole carcass could draw $1,000, a tail feather fan $500, and a single eagle feather as much as $25. In more recent times, authorities have tightened enforcement of the illegal sale of eagle parts.

At present, human activities in and around eagle nest sites, foraging areas, and wintering areas are often cited as being the largest threat to the species' survival. In some areas, feeding efficiency declines as the frequency of human encounters increases (Knight & Knight 1984). However, this is not consistent with the findings of McGarigal et al. (1991), who reported that there was no evidence that eagles modified their foraging activity levels in relation to daily fluctuations in human activity. In many areas, fish discarded by sport and commercial fishermen and other sources of carcasses such as road-killed or hunter-injured deer, may provide a major or supplementary source of food for bald eagles.

In some areas of the country, logging activities present a serious concern for bald eagle habitat. Welchsler (1971) reports that logging within ¼ mile of a nest may cause desertion of the nest site. In some areas, logging has resulted in nest abandonment (Welchsler 1971; Juenemann 1973) or relocation (Thelander 1973). However, proper management strategies attempt to avoid these situations. Continuous year-round disturbance associated with developed areas may have a greater negative impact on bald eagle populations than periodic disturbances such as timber operations, particularly if logging coincides with the non-breeding season.

Reasons for Decline

Bald eagle populations showed dramatic losses from the time Europeans settled in the New World until about the 1980s. Population numbers dropped significantly after colonization, but began to rebound in the 1940s (Gerrard & Bortolotti 1988). In 1890 on the Chesapeake Bay, there was reported to be a bald eagle nest for every mile of shoreline (Gerrard & Bortolotti 1988). By 1936 that number had dropped to between 600 and 800 breeding pairs (Gerrard & Bortolotti 1988).

There are many reasons for the decline in eagle population numbers over the last two centuries. A few of the primary reasons have been directly related to humans. The Raptor Research Foundation Bald Eagle De-listing Committee felt that “although there are some data suggesting that eagles can habituate to some levels of human development, essentially all peer-reviewed, published scientific data indicate that eagle populations have been and will continue to be impacted adversely by habitat alterations” (Bednarz 2000). Losses of habitat, human disturbances, and shooting have all taken a large toll on eagle populations (Broley 1958; Howell & Heinzmann 1967; Sprunt 1969, Retfalvi 1965; Fraser et al. 1985). Among these factors are destruction of territories, cutting of nest trees, collecting of eggs, killing of young and adults (Broley 1952), and human development of nesting sites.

Stalmaster (1987) provides five major causes for eagle population declines: killing, poisoning, habitat destruction, prey base change, and disturbance by humans. Frequent small alterations to the habitat result in a large cumulative impact on bald eagles (Stalmaster 1987). Stalmaster (1987) suggests that it is undeniable that humans have been a significant force in changing many features of eagle habitat and have driven the eagle from many of its former territories through direct persecution. As humans depleted aquatic food stocks and other prey sources, eagles had more difficulty finding an adequate meal (Stalmaster 1987). Many prey populations have been decimated. Salmon were once plentiful, but populations have now been reduced. Channelization projects in several areas for controlling floods have reduced the amount of prey available and in each case, eagle populations in these areas have declined (Stalmaster 1987; Steenhof 1978; Shapiro et al. 1982).

Another hypothesis suggests that declines in eagle populations during the 1800s may have been linked to the near extermination of the huge bison population that provided winter food for eagles in many areas (Andrew & Mosher 1982). Along with bison population declines, there was intensive hunting pressure on large flocks of waterfowl (Andrew & Mosher 1982). The loss of these two major sources of food likely impacted eagle populations.

Biocides such as insecticides and other pesticides have also been proven to be detrimental to eagle populations (Krantz et al. 1970). Among these, DDT (Dichlorodiphenylethane trichloride) caused the most problems. Broley (1958) determined that DDT was responsible for decreasing the number of chicks produced in Florida. He was one of the first researchers to voice concern that the bald eagle was not reproducing at a sustainable rate. In 1942, eagles in Broley's (1958) study areas showed a nest success rate of 89%. By 1952, nest success had plummeted to 14% (Broley 1958).

DDT was widely used throughout North American to control insects, especially mosquitoes, from the end of World War II until it was banned in 1972 (Stalmaster 1987). DDT disrupts calcium metabolism in bald eagles and many other species, causing thin eggshells (Stickel 1973; Stalmaster 1987). As few as a couple parts per million of DDT may cause problems in eggshell development (Stalmaster 1987).

Around the same time, Fawks (1961 & 1974) was finding similar decreases in eagle numbers during winter surveys along the Mississippi River in Illinois and Iowa. Carson (1962) took up the battle against environmental contaminants with the writing of *Silent Spring*, a powerful book discussing the woes of DDT. DDT was proven to reduce the thickness of eggshells, making them much easier to break than before its introduction in 1946 (Anderson & Hickey 1972; Grier 1982). Many eagles were unable to hatch a viable chick due to effects of DDT.

Researchers working in many areas of the country reported drastic declines in nesting success from the mid-1940s to the mid-1970s due to the depression of eagle nesting success and productivity (Sprunt 1969; Nye 1977; Dunstan 1978; Green 1985). Eagles, ospreys, and many other avian species were negatively affected by DDT exposure. Even with substantial contrary evidence, the impacts of DDT have recently been questioned by industry-related groups (Edwards 1992; Jukes 1994; Hecht 2002). Grier (1980) suggested that DDT was not singularly responsible for drastic declines in eagle populations. Rather, it was likely that a combination of several factors, including both reduced productivity and high mortality, was likely to blame.

Reasons for Recovery

Between 1974 and 1995, the number of occupied breeding areas in the lower 48 states increased 462% (Fish & Wildlife Service 1999). Between 1990 and 1995, breeding areas increased 47% (Fish & Wildlife Service 1999). Although the growth rate is slowing as areas become saturated with eagles, the breeding population of bald eagles in the contiguous United States has approximately doubled every 6-7 years since 1970 (Fish & Wildlife Service 1999).

There are many reasons for the dramatic increase in populations of eagles in North America in the last two to three decades. Recovery has been assisted by intensive management that includes systematic monitoring, increased protection, enforcement of laws, captive breeding, relocation of wild birds, and public awareness of the eagles' plight (Matthews & Mosely 1990). Productivity has increased since the ban of DDT in 1972 (Grier 1982). The construction of locks, dams, and reservoirs on the Mississippi and Missouri Rivers, begun in the 1920s and 1930s, has improved wintering habitat for bald eagles (Sprunt & Ligas 1966; Spencer 1976; Gerrard & Bortolotti 1988). Eagles gather in large concentrations just downstream of many dams along the Mississippi River (Musselman 1949; Southern 1963, 1964), particularly between Minneapolis, Minnesota and St. Louis, Missouri. Eagles also find late-winter foraging habitat along the Missouri River in North Dakota and South Dakota (pers. observations).

Programs designed to restore eagle populations by breeding eagles in captivity and releasing young eagles hatched and raised by humans (known as hacking) have increased populations in some areas (Gerrard & Bortolotti 1988). In Alaska, a bounty on eagles was finally eliminated in 1952 and eagles have reproduced relatively free from human disturbances since that time (Stalmaster 1987). In Glacier National Park, an introduced run of Kokanee salmon fed the densest concentration of wintering eagles in the lower 48 states (McClelland et al. 1981). The human image of the bald eagle has changed dramatically and respect for eagles has been passed along to younger generations. For most members of today's generation, it would be unthinkable to shoot an eagle purely for sport. Changes in human perception have been important for protection of eagles from direct persecution and also for fund-raising ventures and land acquisitions for protecting eagle nest sites and roosting habitat.

Human Dimensions

Human activities have, without a doubt, had detrimental effects on a variety of wildlife populations. Some studies have reported that some eagle nest failures were clearly associated with human disturbances (Hunt et al. 1992). However, bald eagle responses to different types of human activities vary widely (Grier 1969; McGarigal et al. 1991; Steidl and Anthony 1996).

Several studies have associated lowered productivity and site desertion with nest disturbances (Murphy 1965; Retflavi 1965; Juenemann 1973; Weekes 1974; Fyfe & Olendorf 1976; Grubb 1976; Fraser 1981; Anthony & Isaacs 1989). Murphy (1965), Thelander (1973), Fraser (1981), and Fraser et al. (1985) suggest that eagles choose new nest sites farther away from shorelines because of human activities. Often these sites are in what was considered to be less favorable habitat areas for eagles (Hunt et al. 1992). However, others have found little or no evidence of nest failures being caused by human activity (Mathisen 1968; Grier 1969; Swenson 1975; McEwan & Hirth 1979; Fraser 1981; Bangs et al. 1982). Fraser (1981) found that less than 4.5% of failed nesting attempts could be attributed to human disturbance.

With increasing development and recreational use of shorelines and waterways, it is important to better understand human interactions with eagles.

Very often the highest public use areas consist of prime foraging and/or nesting habitat for bald eagles (Hunt et al. 1992). The distance to roads or buildings has been used as an indicator of human disturbance (Wood et al. 1989). The distance human activity occurs relative to an eagle is often the most important aspect of a disturbance (Grubb & King 1991). Predictive models must be developed that broadly apply beyond the local scales (Grubb et al. 1993) and that include many types of disturbances in many different habitats.

There are several different views about whether bald eagles are affected by human activities. At one end of the spectrum of opinions, bald eagles are thought to avoid human presence in their nesting and foraging activities completely. This view suggests that eagles flush from perches, leave the area, and do not return in response to any human encroachment. On the other extreme is the view that eagles are not affected by human activities and that they forage and nest in close proximity to human presence with no adverse affects. In reality, free-living bald eagles appear to fall somewhere in the middle of these extremes and show much variability between individual pairs. Some degree of seclusion seems to be necessary for eagles to carry out their daily activities, but this has been difficult to evaluate and may be changing through time.

There are many accounts of eagles placing a nest directly above a summer cabin, along a river within a metropolitan area, or in other areas with high human activity. One large winter concentration of eagles occurs along the Mississippi River on islands and shorelines near Rock Island, Illinois and Davenport, Iowa (Fawks 1961). Eagles in this area are frequently observed flying a few meters over heavily traveled interstate bridges. In some areas of the country, eagles appear to be highly disturbed by human activities and avoid interactions at all costs, including abandonment of nestlings, while others appear not to be affected by human activity and actually seem to seek out sites near human structures (e.g. lakeside cabins).

Human activity has in the past been negatively correlated with eagle reproduction (Broley 1947; Murphy 1965; Mathisen 1968). Investigations of the actual effects of human disturbances have evolved along with technology and research techniques. Livingston et al. (1990) suggested that isolation from humans might be the most important factor in the selection of islands as a nest site. Mathisen (1968) examined human disturbances as a potential cause of nesting failure among bald eagles on the Chippewa National Forest in North-central Minnesota. He evaluated the effectiveness of buffer zones established in 1963 by the U. S. Forest Service to protect eagle nests from human disturbances. A Wilderness Factor was developed for each nest site. He rated four factors (human activity, roads, modified habitat, and difficulty getting to/finding nests) on an arbitrary scale of High, Moderate, and Low disturbance. He also gathered productivity data, but did not relate it to nest site selection. Andrew and Mosher (1982) identified land-use practices that may influence the status of eagle populations. Juenemann (1973), Thelander (1973), and Gerrard et al. (1975) reported the importance of vegetation as a buffer for creating a visual barrier between human activity and the nest.

Most management has been directed at restricting human activities near eagle use areas (Mathisen et al. 1977; Stalmaster 1982; Grier et al. 1983). Fraser et al. (1985) used random sites as a measure of the available, potential eagle habitat and gathered productivity data through aerial surveys. They examined flushing distance as a measure of disturbance. Human activities were categorized as being either within 500 m or further than 500 m from the nest. They found no evidence that human activities had a major impact on bald eagle reproduction at occupied nests. Disturbance may result in increased energy expenditures due to avoidance flights and decreased energy intake because of interference with feeding activity (Stalmaster 1987). However, starvation makes up a small percentage of the overall mortality of adult bald eagles, especially during the breeding season. Disturbance is a difficult factor to evaluate for any animal species.

Anthony and Isaacs (1989) assessed the possible effects of human disturbance on eagle productivity. Human activity and man-made structures within 1.6 km were used as an indication of potential human disturbance and were arbitrarily ranked on a scale from 1-5 (Anthony & Isaacs 1989). In another study and area, nests were 80-120 m from water in areas with shoreline houses, 10-400 m in areas without houses, and 600-4,800 m from clusters of houses (Fraser et al. 1985). This study suggested that eagles were more disturbed by higher levels of human activity and chose to place their nests in more isolated locations.

Wood et al. (1989) reported that eagles were fairly tolerant of limited disturbances in the secondary protection zone, because many active nests in each region were in close proximity to roads or buildings within the zone. Fraser et al. (1985) found no evidence that human activity within 500 m of occupied nests significantly affected reproduction. The question concerning factors that actually cause a disturbance to eagles remains controversial. This project examines the tolerance of nesting eagles near varying levels of human presence.

CHAPTER 3. MATERIALS AND METHODS

Study Area

Minnesota offered a unique opportunity to study nesting bald eagles. The state has a large breeding population of bald eagles (n ~ 700 breeding pairs), four distinct habitat regions, varying amounts of human activity near nest sites, and a history of monitoring bald eagle populations. It was essential to examine a large number of nests in a large study area to eliminate potential biases that have resulted from past studies that investigated smaller land areas and/or had small sample sizes. The habitat available for eagles in the state varies dramatically among the four ecoregions (Fig. 2): Laurentian Mixed Forest, Eastern Broadleaf Forest, Prairie Parkland, and Tallgrass Aspen (Henderson et al. 1977).

Scale of Measurements

Habitat features of each site were measured at two scales: a 100 m radius plot (primary zone) and a 1,000 m radius plot (secondary zone) (Fig. 3). This terminology purposely corresponded closely with management terminology used in determining restrictions of human activity near nest sites. Primary and secondary zones correspond to proximal characteristics and landscape concerns, respectively. Several habitat and human presence variables (discussed later) were measured at each nest site. Primary zone evaluation consisted predominantly of measurements of trees within 100 m of nest trees. Analysis of the larger secondary zone consisted of evaluating land management activities and human presence using aerial photographs and land-use maps (MN DNR Data Deli 2001) for each selected nest site and random site.

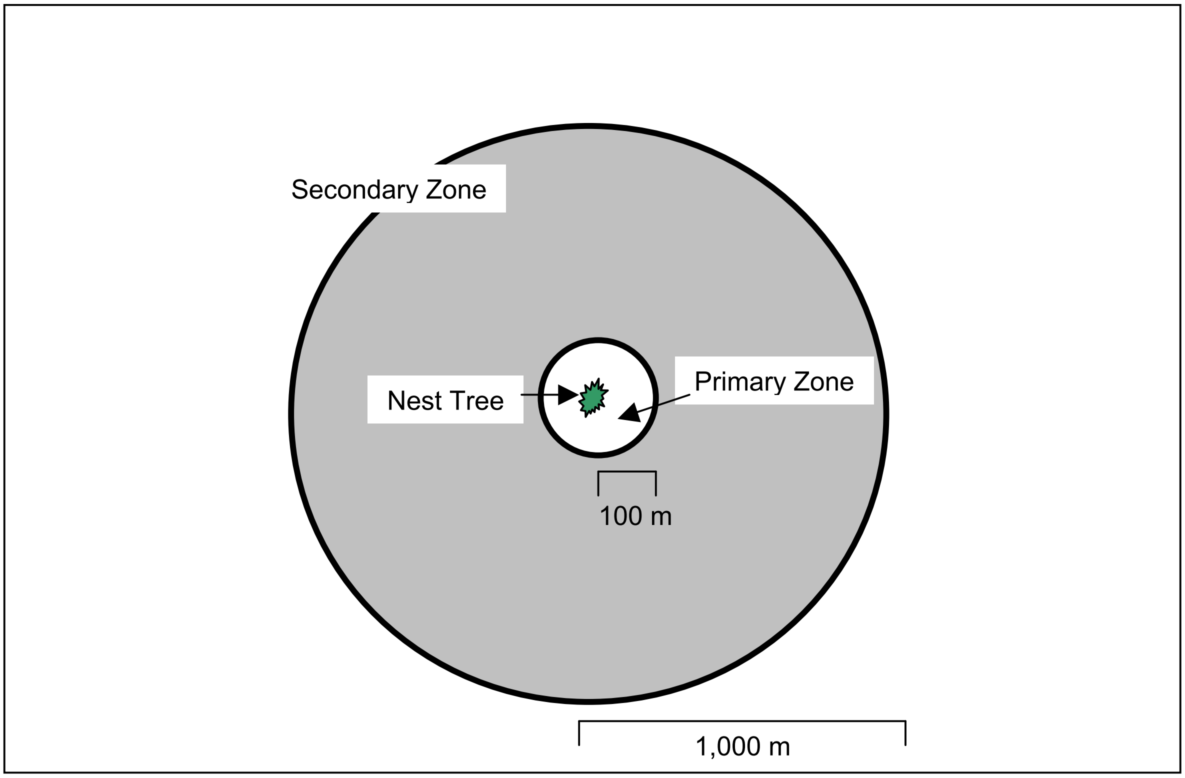

Figure 3. Scales for examining bald eagle nesting habitat and human presence.

Data Collection

Measurements of features within 100 m of the nest tree were taken on-site. Aerial photographs and land-use maps of each nest site were used to determine secondary zone features within 1,000 m of each nest tree. Human presence may affect bald eagles at greater distances than 100 m (Fraser et al. 1985; Anthony & Isaacs 1989). Therefore, examining human presence within 1,000 m provides a more thorough evaluation of potential disturbance factors. Human presence at sample sites was evaluated utilizing ArcView GIS (Geographical Information System) to examine aerial photographs and land-use maps (MN DNR Data Deli Online GIS data). A description of each feature measured during the physical inspections of the primary zone of each nest and random sites is recorded below (Table 1).

Table 1. Measurements at the primary zone

FEATURE	DESCRIPTION
Location	Measured at the base of the nest tree or the mid-point of random habitat sites using a hand-held Garmin GPS 3+. Waypoint averaging of locations was used to accurately determine the location of each site.
Species	Species of nest tree.
Height	Measurement of the distance from the base of the tree to the top of the highest branch. Measurement taken with clinometer to nearest foot and converted to meters.
Diameter at Breast Height	Diameter of tree at 1.4 m from the ground. Measured in centimeters using Ben Meadows Company 5 m/160 cm Diameter Tape
Canopy Elevation	Average height measurement of overall canopy in area taken measured using a clinometer. Comments on slope of terrain and height of canopy compared to nest and nest tree.
Ground to nest	Measurement of distance from the ground at the base of the nest tree to the bottom of the nest. Measurement taken with Brunton Survey Master Clinometer to nearest foot and converted to meters.
Nest to top	Measurement of distance from the top of the nest to the top of the nest tree. Measurement taken with clinometer to nearest foot and converted to meters.
Nest Site	Measurements were taken of trees greater than 20 cm dbh within a 10m radius of the nest tree. Measurements taken of each tree were: species, height, and diameter at breast height, as above.
Additional Sites	Additional sites were chosen at a random distance and direction from the nest tree. Measurements were taken of trees greater than 20 cm dbh within a 10 m radius extending from the random point.

Table 1. (continued)

FEATURE	DESCRIPTION
Human Presence	Comments on location, size, distance, and type of human activity in area.
Distance to Active Nest	Distance to nearest known or visible active nest.
Shoreline Distance	Distance to closest known or visible shoreline.
Shoreline Description	Comments on closest visible shoreline features.

Sample nests (Fig. 4) for the study were selected from the group of all active nests observed during the M.B.E. Survey. For analytical purposes, active nests were stratified according to the four ecoregions. The vast majority of known eagle nests in Minnesota were located in the Eastern Broadleaf Forest and Laurentian Mixed Forest ecoregions. There were relatively few nests in the Prairie Parkland and Tallgrass Aspen ecoregions. Therefore, the nests included in the sample set were every known, active nest in the Prairie Parkland (~40 nests) and the Tallgrass Aspen (~20 nests) ecoregions and a random sample of the total known, active nests in the Eastern Broadleaf Forest (~60 nests) and Laurentian Mixed Forest (~60 nests) ecoregions.

Sites chosen by eagles as nest sites were compared to the available habitat in each ecoregion by evaluation of a number of random sites, equal to the anticipated number of sample nests within each ecoregion (n = 180). The sample number of nests was reduced due to nest losses during the study or incorrect site locations resulting in some nests not being found. Identical habitat variable

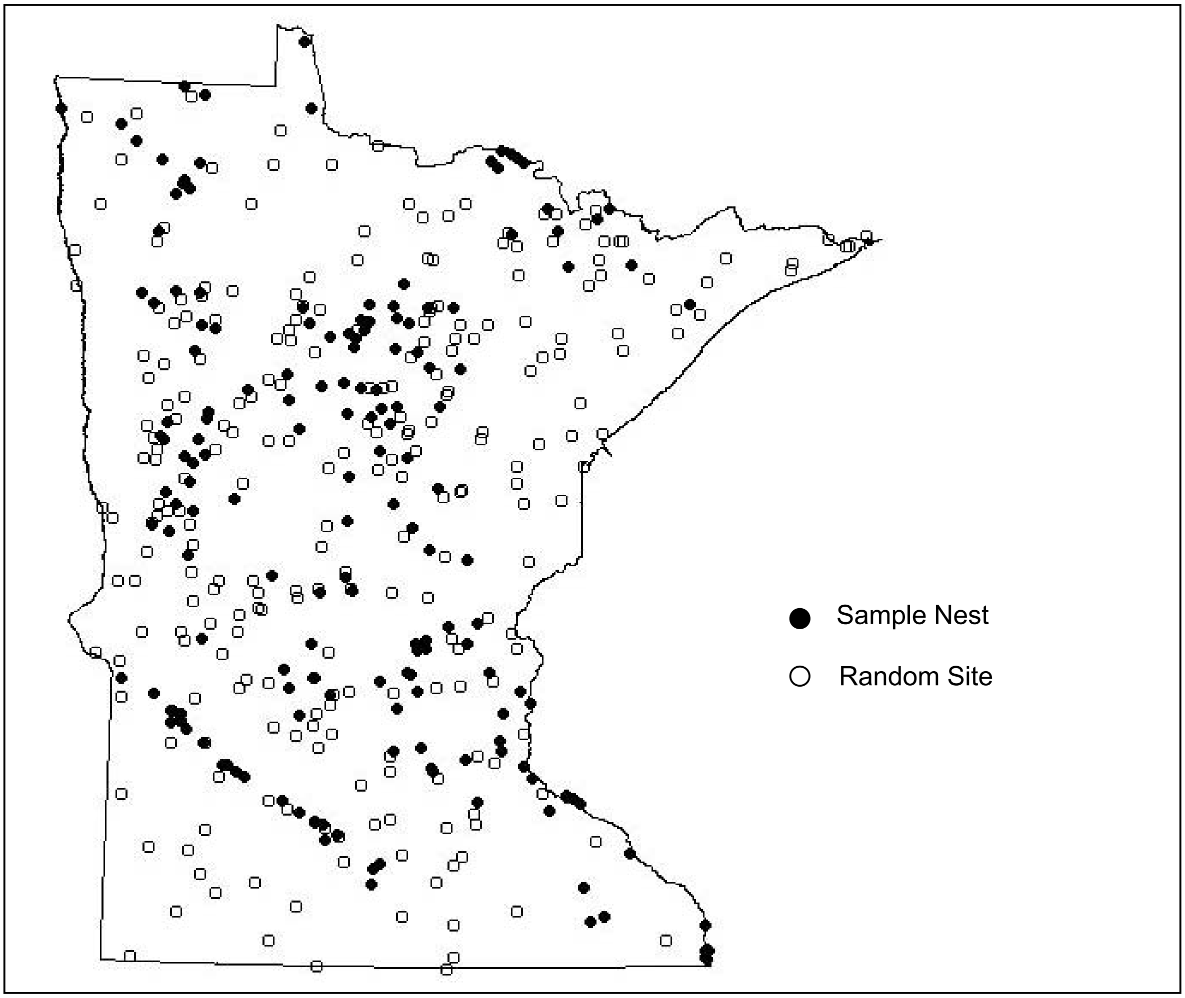

Figure 4. Sample bald eagle nests and random sites examined in Minnesota.

measurements were taken at random sites and compared to those measured at each nest site. Random sites were selected using criteria that restricted sites to areas that would include the shoreline zone in which nearly all nests are found. The most important criterion was proximity to water. Livingston et al. (1990) found that 107 of 115 eagle nests occurred within 1 km of a major body of water. Fraser et al. (1985) found that, in the Chippewa National Forest, Minnesota, the mean distance of nests to the shoreline was less than 1 km. Likewise, in Alaska (Corr

1974) and Canada (Whitfield et al. 1974; Gerrard et al. 1975), the mean distance from water was less than 330 m (also, see Literature Review).

Random sites were selected according to two main criteria. Potential sites were (1) restricted to being within 1 km of a major water body and (2) required to include trees larger than 20 cm in diameter. To meet the first criterion, a grid of 1 km^2 cells was developed to overlay the entire state using ArcView GIS (ESRI 1999). A 1 km buffer (Fig. 5) was then selected to border all major water bodies. Any grid cell that contained an amount of the buffered area (i.e., all areas of land within 1 km of a major body of water) was considered a potential random site. From that set, random sites were selected using ArcView Spatial Analysis Extension corresponding to the number of nest sites within each ecoregion. Each habitat cell was then examined manually and omitted if it did not include usable eagle nesting substrate (e.g., if the cell was entirely water or in the middle of a metropolitan area with no trees). The total number of random sites chosen from each ecoregion was equal to the initial number of sampled nest sites within that ecoregion. The closest tree to the mid-point of the grid cell was designated to symbolize the "mid-point tree" of a random site. Habitat measurements were initiated from that mid-point tree, and all relevant measurements were taken.

At each nest site and random site, measurements were taken within a total of four-10 m radius circular plots (Fig. 6). The initial plot used the nest tree (or the mid-point of a random site) as the center of the circular plot. The other three plots were chosen at a random compass direction and random distance within 100 m of the nest tree. Compass degrees were selected randomly using a random numbers

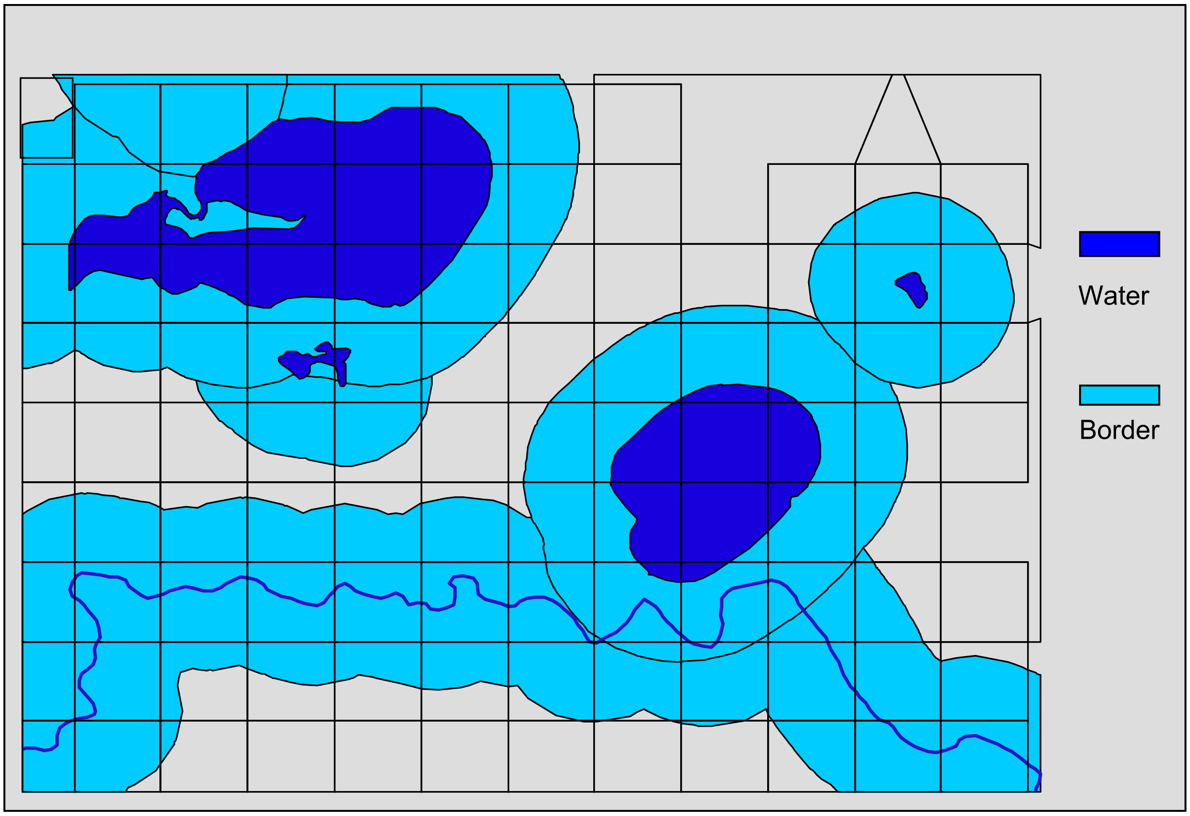

Figure 5. Water body buffer and 1 km^2 cells grid system for selection of random sites (Not to scale).

table to determine the direction of each additional site from the nest tree. Distance was constrained to >10 m (to avoid overlapping with the initial site closest to the nest tree) and <100 m (the limit of primary zone evaluation). Measurements taken at sites 1, 2, and 3 were considered to be measurements of the surrounding stand trees. Measurements taken within the primary zone are listed in Table 1.

Access to each site was gained via automobile, foot, canoe, boat, or air-boat and was facilitated by a variety of federal and state agency personnel (see Acknowledgments). Visits to each nest area were limited to less than 45 minutes to reduce any possible researcher-induced disturbances to nesting eagles.

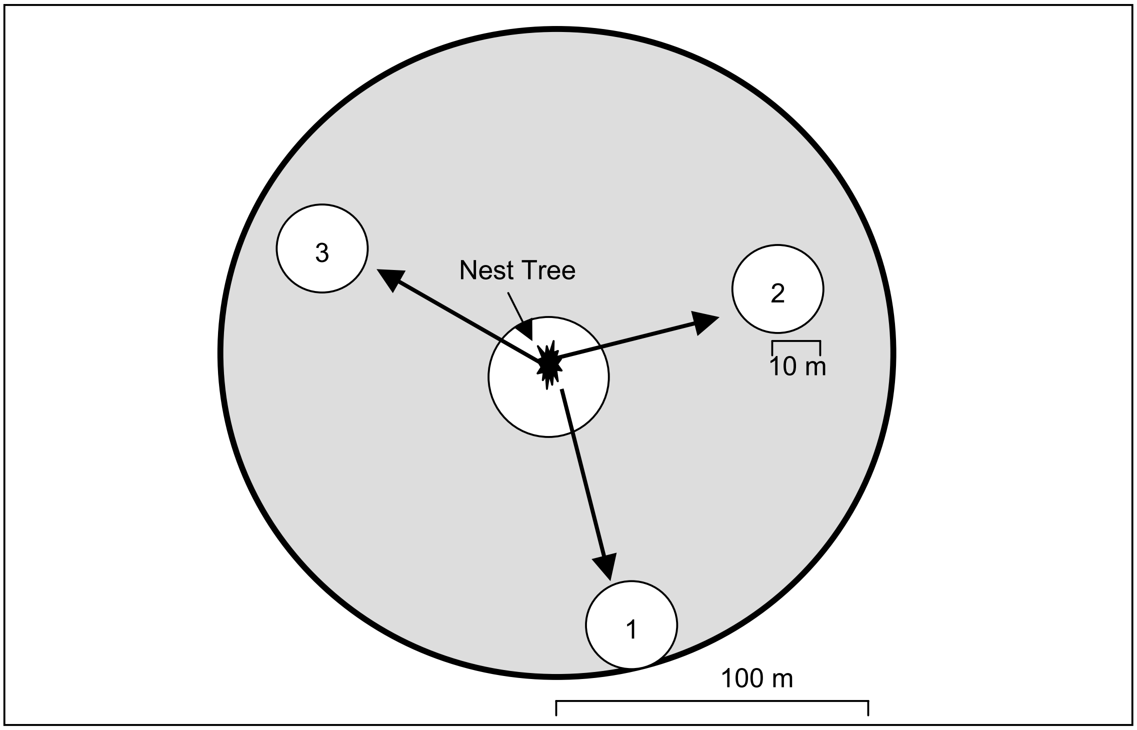

Figure 6. Sampling strategy for measurement of the primary zone. Stand measurements taken at sites 1, 2, and 3 (Not to scale).

Measurements were not initiated until after 15 June of each year, as an additional precaution against possible disturbances during the most critical part of the breeding season (March-May) (Fish & Wildlife Service 1990; Fraser 1981). Measurements were taken between 15 June 2001 and 15 December 2001 and between 15 June 2002 and 10 August 2002.

To identify and gather data at random habitat sites, some rules of priority were followed (1) All sites had to include several measurable (i.e., >20 cm in diameter) trees and (2) Measurements had to be taken for each site selected. To ensure all sites contained measurable trees, the mid-point for the random site needed to be adjusted in several special cases. I traveled to the designated mid-point of the site using a hand-held GPS unit. If the site contained trees larger than

20 cm in diameter, then measurements were taken as normal using the tree closest to the mid-point of the site as the mid-point tree. If the site did not contain measurable trees, I moved in the direction of the closest water body to the nearest stand of measurable trees. The closest tree larger than 20 cm in diameter within that stand was chosen as the mid-point tree. Measurements were taken at the site in the usual manner. If the original site was completely (unexpectedly) water, I moved to the closest trees along the nearest shoreline. The closest tree larger than 20 cm within that stand was designated as the mid-point tree and measurements were taken as usual.

Eagles often nest close to shore; therefore, shoreline areas required special attention in this study. In many instances nests were located less than 100 m from water, requiring adjustment of my sampling methods to avoid biases when examining tree densities (Fig. 7). For random sites, the following rules applied. If the site contained only a small band of trees along the perimeter of a lake or stream, then the tree (>20 cm) closest to the middle point of the site was designated as the mid-point tree. A coin flip determined the direction of travel for each of the additional habitat sites. If the sites that were chosen overlapped in any way, the second site was eliminated and a replacement site was chosen at random. Measurements of the sites were then taken as usual. For nest sites, the nest tree was located and directions were followed as above.

If the nest tree (or mid-point of a random site) was less than 10 m from the water in a more heavily forested area, a different approach was taken. I moved 10 m from the shoreline in the opposite direction of the shoreline (i.e. into the forest)

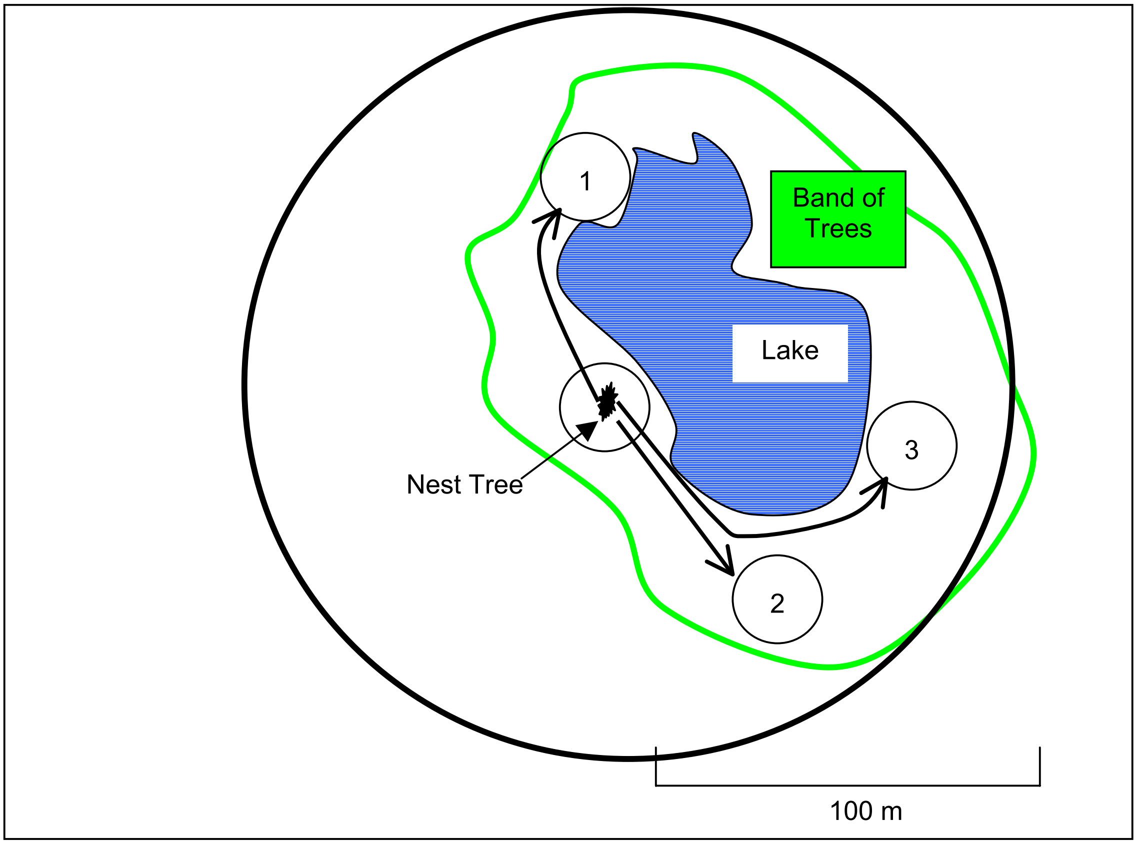

Figure 7. Strategy for measuring primary zone at sites with one band of trees surrounding water. Additional habitat sites are numbered 1, 2, and 3 (Not to scale).

and used that point as the center of the initial plot (Fig. 8). All other measurements were taken as usual, taking a random distance and direction from the actual nest tree (or the actual middle point of a random site).

Some variables were measured utilizing ArcView GIS data provided by the Minnesota DNR including aerial photographs and land-use maps. Habitat and disturbance factors that were not measured via ArcView GIS were verified or gathered by direct measurement in the field. Nests and random site locations were marked with a hand-held GPS (Global Positioning System) unit. Secondary

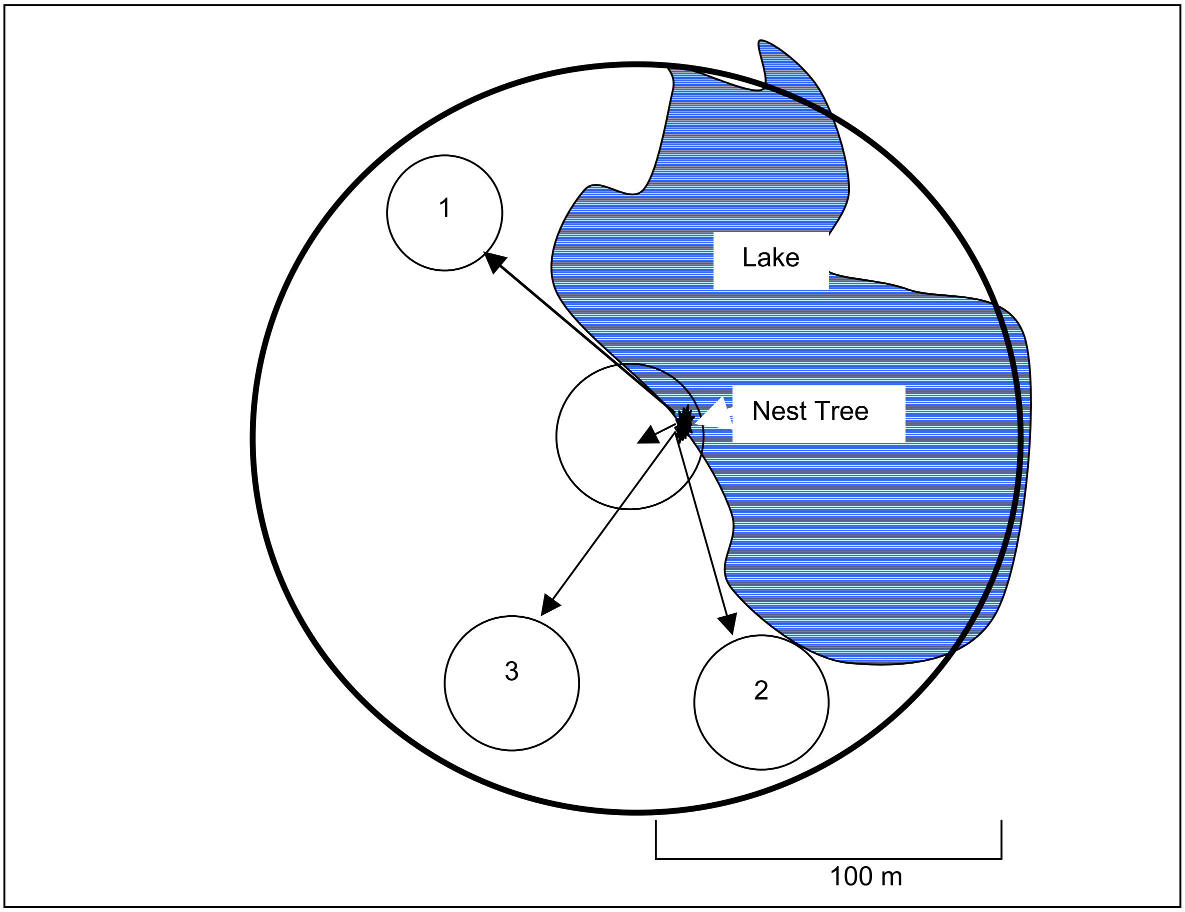

Figure 8. Strategy for measuring the primary zone at sites located within 10 m of water (Not to scale).

zone evaluation consisted of examining aerial photographs and land-use maps of nest sites and random sites. The proportion of land area consisting of certain habitat categories and potential human disturbances was evaluated within the secondary zone. Features that were examined for each site are listed in Table 2.

Data concerning nesting activity and productivity were gathered using aerial surveys according to Grier et al. (1981). Aerial surveys are the traditional method for locating and censusing bald eagles and their nests (King et al. 1972; Hodges et al. 1984; Fuller & Mosher 1987). Aerial survey data for 2000 was obtained during

Table 2. Measurements at the secondary zone

FEATURE	DESCRIPTION
Distance to Forest	Distance (m) to nearest forested land as shown on land-use maps and/or aerial photographs.
Distance to Water	Distance (m) to nearest body of water as shown on land-use maps and/or aerial photographs.
Distance to Bog	Distance (m) to nearest bog, marsh, fen, or swamp as shown on land-use map.
Distance to Grassland	Distance (m) to nearest grassland as shown on land-use maps or aerial photographs.
Distance to Cultivated Field	Distance (m) to nearest cultivated field as shown on land-use maps or aerial photographs.
Distance to Roads	Distance (m) to nearest road as shown on aerial photographs.
Distance to Structures	Distance (m) to nearest structures as shown on aerial photographs.
Distance to Brushland	Distance (m) to brushland as shown on land-use maps and aerial photographs.
Density of Roads	Number of roads within 1,000 m as shown on aerial photographs.
Density of Structures	Number of structures within 1,000 m as shown on aerial photographs.
Density of Land-use Types	Number of land-use types within 1,000 m as shown on land-use maps.

the MN DNR's M.B.E. Survey. Aerial surveys were performed as part of this project to gather productivity figures for 2001. Two years of productivity data reduced the chance of bias due to annual fluctuations in nest productivity.

All nests were surveyed from single engine, fixed-wing airplanes (Cessna 185 or similar aircraft) in April to determine nest occupancy and again in June to determine the productivity (number of nestlings present) of the nest. Few nestlings perish after the late stage of nesting; therefore, the number of nestlings observed during the final stage of nesting is usually accepted as the number of birds that will fledge (pers. corresp. with experts in Canada and the U.S.).

Experienced eagle survey workers from the MN DNR and/or North Dakota State University (NDSU) recorded aerial survey data. Fraser (1981) and Fraser et al. (1983) suggested a high amount of error when surveys are taken at an inappropriate time during the breeding season. Attempts were made to avoid sampling error by consulting pilots, managers, and other researchers familiar with nesting schedules in each part of the state. The general trend is for eagles in the Southern part of the state to initiate nesting earlier than eagles in the North. Pilots from the MN DNR or other governmental agencies flew aerial surveys in their specific areas, recorded data, and reported findings to the DNR and/or directly to me.

Data collected during aerial surveys included the presence or absence of adult eagles at nest sites, a description of the location and activity of any eagles at the nest (i.e. incubating, brooding, perching in nest tree or nearby tree), presence of juvenile eagles, general notes on the terrain, and position of the nest in the nest tree. The terminology used to describe nest usage and occupancy was according to Postupalsky (1974). All survey data were recorded immediately on data forms and collated and analyzed by the specific agency, the DNR, or myself. Aerial survey data from across the state were made available to me for use in this study.

Data Analysis

Data analysis was conducted using PC SAS (Version 8.02, SAS Institute, Inc.) and JMP (Version 5.0.1a, SAS Institute, Inc.). Data spreadsheets were maintained in Microsoft Excel (Version 97 SR 1, Microsoft Corporation). Descriptive statistics were used to examine species composition, tree diameter, tree height, and distance measurements. Multivariate analyses were essential to investigate the simultaneous effects of habitat and human presence features on productivity. Discriminant Function Analysis (DFA) (McGarigal et al. 2000) was used to compare nest sites to random sites. DFA provided a method to determine if habitat variables could distinguish between nest sites and random sites.

Information-theoretic Model Selection (Burnham & Anderson 2002) was used to select the most parsimonious models to describe the relationship between habitat features and the productivity of each nest site. The measured variables (Tables 1 and 2) were selected *a priori* based on a thorough review of the literature (Mathisen 1963, Andrew & Mosher 1982, Stalmaster 1987, Anthony & Isaacs 1989, Livingston et al. 1990) and previous applied experience with nesting bald eagle populations (J. Grier and T. Dunstan, pers. corresp.). Additional screening of variables for exclusion from our model sets was accomplished by testing for correlation and examining the distribution of each explanatory variable.

Several variables were highly correlated (Appendices F and G) and others showed highly skewed distributions (Appendices H and I) with little range or spread of values, thus, providing little information. In the former case, a variable that was explained by another variable was eliminated from the model set. In the latter case, the variable was transformed using a $\log_e$ transformation in an attempt to provide a distribution with a more useful spread, in order to facilitate the detection of any possible effects. If transformation was unsuccessful in providing a less-skewed distribution, the variable was considered unlikely to provide any explanatory value (due to extremely small spread) and eliminated from consideration. In this manner, the final variables included in the models were selected.

The full data set (including data collected at both nest sites and random sites) was used to determine differences between nest sites and random sites. Five of the original variables were eliminated based on their lack of biological importance and/or to avoid overlapping variables. Overlapping variables were those determined to be too closely related to provide sufficient information. In addition, five were eliminated due to inappropriate distributions and four were eliminated due to being highly correlated with other variables. A categorical variable, “NestorRandom”, was used as the response variable for determination of a discriminant function. A Discriminant Analysis plot of the final variable set (Table 3) was used to discriminate between nest sites and random sites.

A validation step was established, setting aside 20% of the data as the *Validation Set*. The *Validation Set* was chosen by selecting sites from both the extremes and the median portions of the data to enhance the evaluation of the chosen models (analogous to designing treatments in a controlled experiment).

Table 3. Variables chosen for Discriminant Function Analysis

Variable	Description
Stand Height	Height of Trees within Primary Zone
LnDBH	Natural Log of Diameter of Nest Trees and Mid-point Trees
Ln DRoad	Natural Log of Distance to Nearest Road
LnDUrban	Natural Log of Distance to Nearest Urban Area
LnDEdge	Natural Log of Distance to Nearest Terrestrial Edge
LnDNest	Natural Log of Distance to Nearest Nest
LnDWater	Natural Log of Distance to Shoreline
Land1000	Density of Land-use Types 1000 m
Houses1000	Density of Houses within 1000 m

The *Exploratory Set* (remaining 80% of data) was used to discriminate between nest sites and random sites. Using the most important vectors from the exploratory Discriminant Analysis, the *Validation Set* was used to evaluate the discriminant function. The sites were analyzed to examine the percent of sites that were mis-classified by the discriminant function. If the discriminant function is a good approximator of the data, the mis-classification percentage should be relatively low.

The process for modeling productivity utilized data only from the nest sites; therefore, the final variables selected are slightly different. For modeling productivity, five of the original twenty-three measured variables were eliminated by our first *a priori* screening process. These variables were removed based on lack of potential biological significance and/or to avoid overlapping variables. In addition, seven variables were screened from our set due to inappropriate correlation and/or distribution concerns. The remaining variables (Table 4) were examined using an initial variable-interaction technique.

Table 4. Variables chosen for initial interaction assessment by Mallow's C_p

Variable	Description
LnNtoTop	Log_e Distance from Nest to Top of Tree
LnDWater	Log_e Distance to Shoreline
LnDBH	Log_e Nest Tree Diameter at Breast Height
LnStandDBH	Log_e Average Diameter at Breast Height of Trees Measured within 100 m of the Nest Tree
Nland1000	Number of Land-use Types within 1,000 m
Nroads1000	Number of Roads within 1,000 m
LnDHouse	Log_e Distance to Nearest Structure
Durban	Distance to Nearest Urban Area (designated by city streets)
LnDCultv	Log_e Distance to Nearest Cultivated Field
LnDGrass	Log_e Distance to Nearest Grassland
LnDActive	Log_e Distance to Nearest Active Nest

The 11 variables and each of their 2-way comparisons were examined using SAS PROC REG to determine Mallow’s Selection Criterion (C_p) to identify the best fitting interactions. The “best” interactions were then analyzed by SAS PROC GENMOD to determine the log-likelihood of each model. Next, the log-likelihood values were used to calculate Akaike’s Information Criterion (AIC_c)

values and the associated Akaike weights (W_i) to arrive at the best approximating models for the data set (Burnham & Anderson 2002). AIC_c, Δi , and W_i were calculated using equations from Burnham & Anderson (2002). AIC_c was calculated using the formula as follows:

$$AIC_c = -2\,log(\mathcal{L}\Theta) + 2k\left(\frac{n}{n-k-1}\right),$$

where $\mathcal{L}\Theta$ equals the Likelihood of the model, k equals the number of estimable parameters in the model, and n equals the number of samples. The Δi values were calculated using the formula as follows:

$$\Delta i = AIC_{ci} - \text{minimum } AIC_c,$$

where the minimum AIC_c is the smallest AIC_c value from the previous equation. The W_I values were calculated using the formula as follows:

$$w_i = \frac{\exp(-1/2\Delta i)}{\sum \exp(-1/2\Delta i)}.$$

Using a similar strategy as above, the exploratory model-building process utilized 80% of the data (*Exploratory Set*). The remaining 20% of the data (*Validation Set*) was set aside to cross validate the models. The *Validation Set* was chosen by selecting sites from both the extremes and the median portions of the data to enhance the evaluation of the chosen models. The Root Mean Square Error (RMSE) was calculated and evaluated as a comparison between the two sets. The RMSE is a single standard deviation for multiple variables in a model, estimating the common within-group standard deviation.

The response variable for these models was the productivity of the eagles at individual nests. Productivity was the number of chicks produced from a nest. Two years of productivity data, 2000 and 2001, were obtained. For each year, productivity ratings were determined (Table 5). A Productivity Rank for each nest site was obtained by summing the annual productivity ratings for each nest. The result of productivity ranking is a normally-distributed response variable on a scale from 2 to 10. All nests used in data analysis were active in both 2000 and 2001.

Table 5. Annual productivity ratings for bald eagle nests

Annual Productivity Rating	Description
1	Nest Not Active
2	Nest Active, Productivity = 0 chicks fledged
3	Nest Active, Productivity = 1 chick fledged
4	Nest Active, Productivity = 2 chicks fledged
5	Nest Active, Productivity = 3 chicks fledged

Appropriate Statistical Techniques

Significance values are not included in this dissertation. Rather, a different and relatively newer paradigm of data analysis, Information-theoretic Model Selection, has been incorporated. Although studies of this type have traditionally been associated with null hypothesis (i.e. significance testing) and p-values (e.g., $p > 0.05$), I agree with D. H. Johnson (1999) and D. R. Anderson et al. (2000) that "significance values are not appropriate for field studies of this nature." W. L. Thompson (http://www.cnr.colostate.edu/~anderson/thompson1.html) provides a thorough bibliography of sources which question the indiscriminate use of hypothesis testing in observational studies. Likewise, Anderson et al. (2000) reports a dramatic increase in the number of articles in various disciplines that contest the use of null hypothesis testing in research that does not involve controlled experiments. Carver (1978), Cohen (1994), and Nester (1996) offer some of the most aggressive statements concerning the use of null hypothesis testing.

The main issue is that null hypothesis testing is useful and appropriate for strictly controlled experiments, but not for observational studies. "Results from null hypothesis testing have led to relatively little increase in understanding and divert attention from the important issues—estimation of effect size, its sign and its precision, and meaningful mechanistic modeling of predictive and causal relationships" (Anderson et al. 2000).

The use of significance testing in an uncontrolled, non-experimental project design is not appropriate because it only offers one alternate hypothesis. In practice if the null hypothesis is rejected, the single alternative hypothesis is often accepted as truth and management strategies are devised accordingly. However, due to the nature of observational studies, there are often many alternate hypotheses that can be associated with a single null hypothesis.

Null hypothesis testing requires that the researcher assume complete ignorance of the system. Information-theory, on the other hand, allows the researcher to use previous information obtained through personal observations, prior investigations, and the published literature. Information-theoretic Model

Selection places the emphasis on formulating a proper research question (Burnham & Anderson 2002). Information-theory finds its basis in Likelihood Theory and includes ideas such as the Principle of Parsimony and Kullback-Leibler Information, two fundamental principals of modern statistical theory. Model Selection allows for multi-modal inference, making inferences based on several models instead of a single model that is assumed to be the best (Burnham & Anderson 2002). For the purposes of this project, null hypothesis testing was avoided in favor of more appropriate statistical techniques.

CHAPTER 4. RESULTS

Nest Site Descriptions

Nests were located in living and dead trees of a variety of species. Eleven tree species and one man-made structure were used by bald eagles as nesting substrate (Table 6). Sample nests were most frequently located in cottonwood trees. Use of this species was particularly important in the Eastern Broadleaf Forest and Prairie Parkland ecoregions (Table 7). Red and white pines were also well represented as nest trees, especially in the Laurentian Mixed Forest ecoregion. This was consistent with earlier reports of the importance of pine trees as eagle nesting trees in the same area of the state (Fraser 1981; Mathisen 1963). However, other tree species were used across the eagles' range in Minnesota (Table 7).

Nest trees were placed into five *a posteriori* categories to facilitate univariate analyses. Nest tree categories included Coniferous, Cottonwoods, Quaking Aspen, Other Deciduous, and Steel. Productivity rankings were similar across all tree categories (Fig. 9), except for Steel, which represented only one, highly productive nest. Productivity rankings were similar in different ecoregions across the state (Fig. 10). An overall comparison of productivity ranks among tree categories and ecoregions show no differences across tree types and habitat regions (Fig. 11).

Nests were generally located in large, tall trees in each ecoregion. On average, nest trees in the Eastern Broadleaf Forest ecoregion were the largest in diameter (Fig. 12), while nest trees in the Laurentian Mixed Forest ecoregion were the tallest (Fig. 13). Similarly, the nest structure was located farthest from the

Table 6. Characteristics of bald eagle nests (n = 120) in Minnesota

Tree Species	N	Percent of Nest Trees	Tree DBH (cm) Mean	SE	Tree Height (m) Mean	SE	Nest Height (m) Mean	SE
Cottonwood	39	32.5	59.95	4.83	24.66	0.76	19.58	0.72
White Pine	35	29.2	45.94	2.86	26.21	0.99	21.87	0.92
Quaking Aspen	17	14.2	49.4	15.31	21.84	1.55	18.98	1.41
Red Pine	10	8.3	43.75	8.29	25.73	1.12	21.66	1.41
Silver Maple	4	3.3	55.7	26.01	17.84	0.83	14.70	0.93
Slippery Elm	4	3.3	45.35	9.99	17.68	1.23	13.79	1.83
Green Ash	3	2.5	54.5	17.75	16.51	2.90	13.56	3.69
White Oak	3	2.5	45.94	2.86	23.83	5.08	17.79	4.11
White Poplar	2	1.7	43.8	7.6	21.80	1.37	19.65	1.37
Paper Birch	1	0.8	36.2	--	23.17	--	17.37	--
Sugar Maple	1	0.8	41.3	--	25.30	--	23.77	--
Steel	1	0.8	54	--	16.62	--	16.61	--
All Structures	120	100.0	51.56	2.97	23.99	0.52	19.78	0.48

ground in the Laurentian Mixed Forest ecoregion (Fig. 14). On average, nests were located in the upper 20% of the nest tree (Table 7) at an average height of 19.78 m.

In comparison to trees in the surrounding stand (i.e. within 100 m), nest trees were larger in diameter and height than nest stand trees (Table 8). Nest trees were the tallest trees measured at only 65 of 120 (54.2%) nest sites. On the other hand, the nest tree was larger in diameter than stand trees at 97 of 120 (80.1%) nest sites.

Table 7. Bald eagle nest tree species within ecoregions

Tree Species	Eastern Broadleaf	Laurentian Mixed Forest	Prairie Parkland	Tallgrass Aspen
Cottonwood	19	--	17	3
White Pine	5	27	2	1
Quaking Aspen	3	6	--	8
Red Pine	--	10	--	--
Silver Maple	2	--	2	--
Slippery Elm	--	3	--	1
Green Ash	1	--	1	1
White Oak	1	--	2	--
White Poplar	--	1	1	--
Paper Birch	--	1	--	--
Sugar Maple	--	1	--	--
Steel	1	--	--	--

In the Laurentian Mixed Forest ecoregion, nests were taller than stand trees (Fig. 15). This is consistent with Fraser (1981) who reported that bald eagles nest in super canopy trees in the same area of Minnesota. However, in the Eastern Broadleaf Forest and Prairie Parkland ecoregions, nests were just slightly (i.e., < 1 m) taller while, in the Tallgrass Aspen ecoregion, nests were shorter than stand trees (Fig. 15). Overall, nests were taller than stand trees at only 25 of 120 sites.

On average, nest sites were closer than 160 m to water (Table 9). This is substantially closer than reported distances of approximately 600 m in the

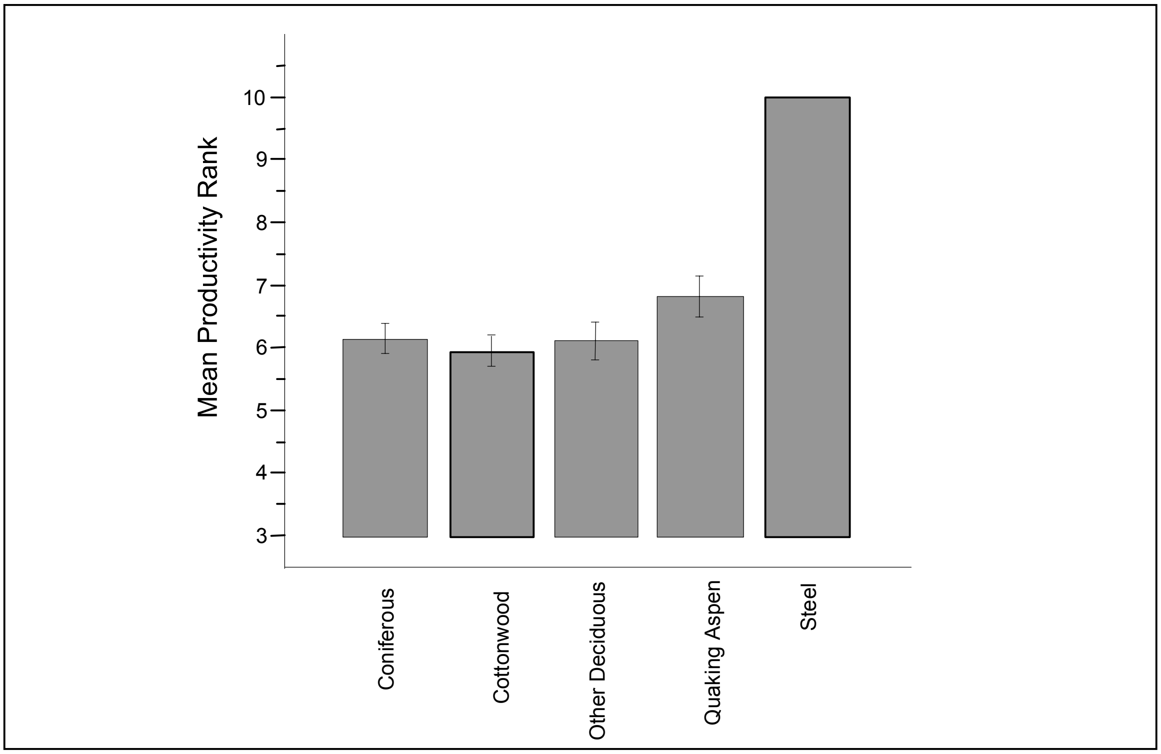

Figure 9. Mean bald eagle productivity ranks (+ standard error) within tree categories.

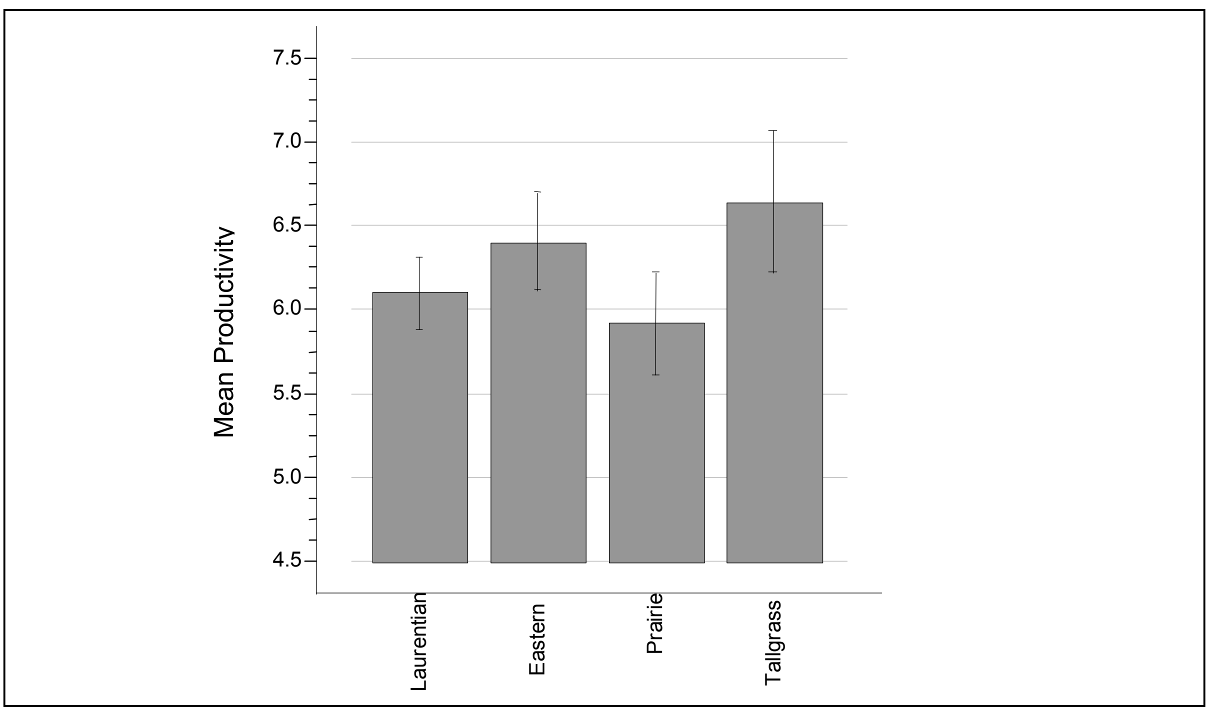

Figure 10. Mean bald eagle productivity ranks (+ standard error) within ecoregions.

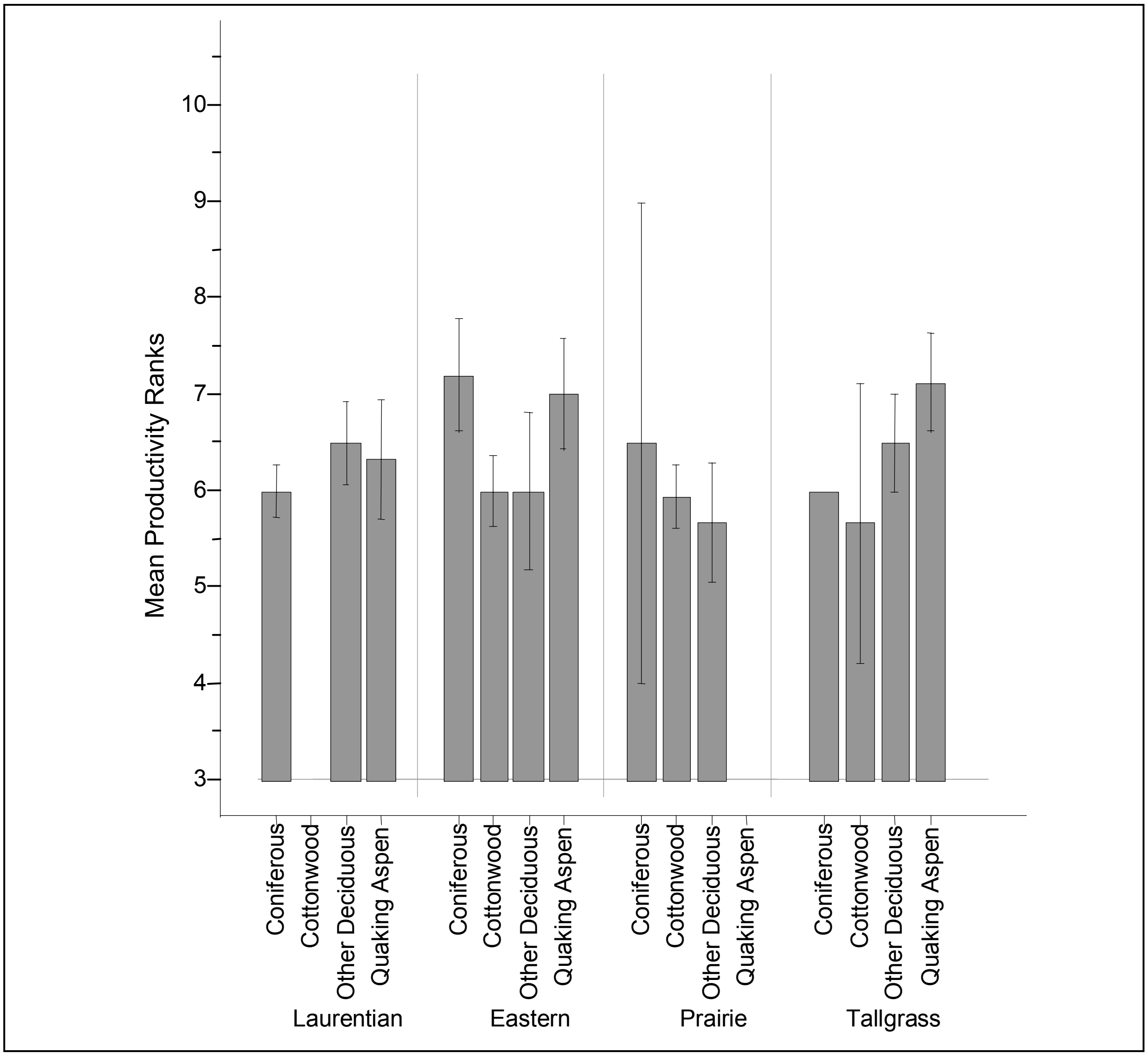

Figure 11. Mean bald eagle productivity ranks (± standard error) within categories within ecoregion.

Chippewa National Forest area (Fraser 1981). Fraser (1981) suggested that eagles avoided shoreline development in these areas and, therefore, were forced to nest farther away from the shoreline. The sample nests for this study were not located in areas devoid of human presence (Table 9).

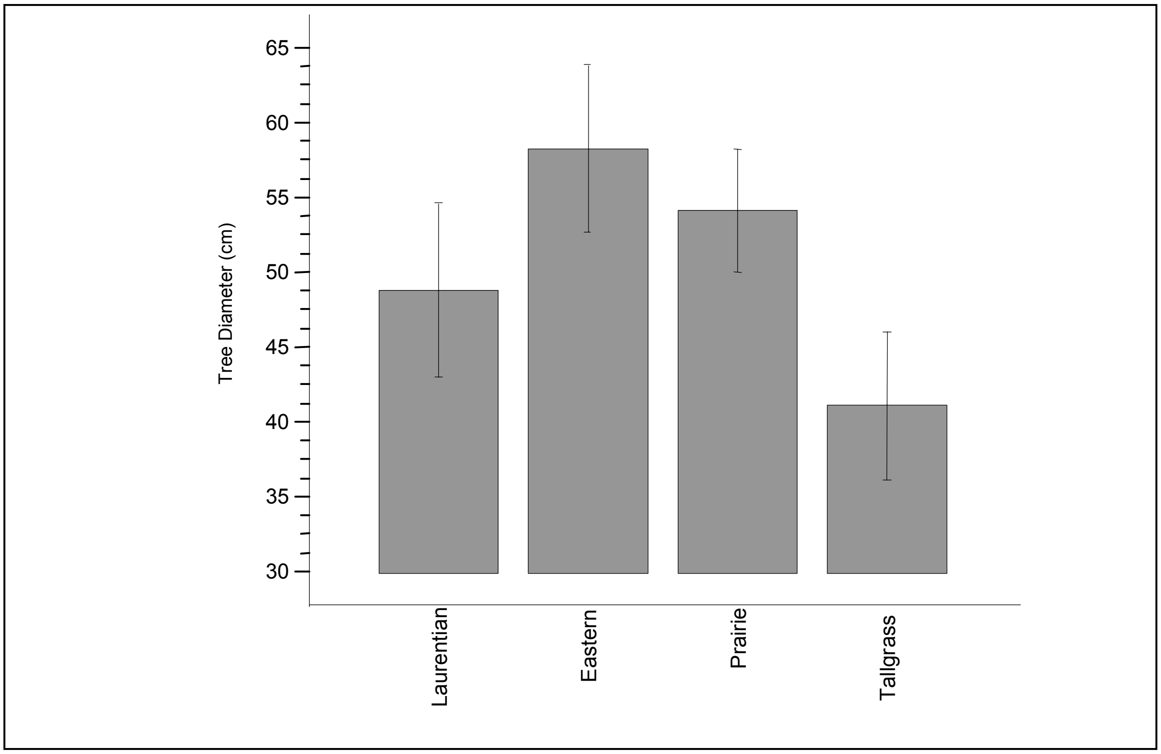

Figure 12. Mean bald eagle nest tree diameter (± standard error) within ecoregions.

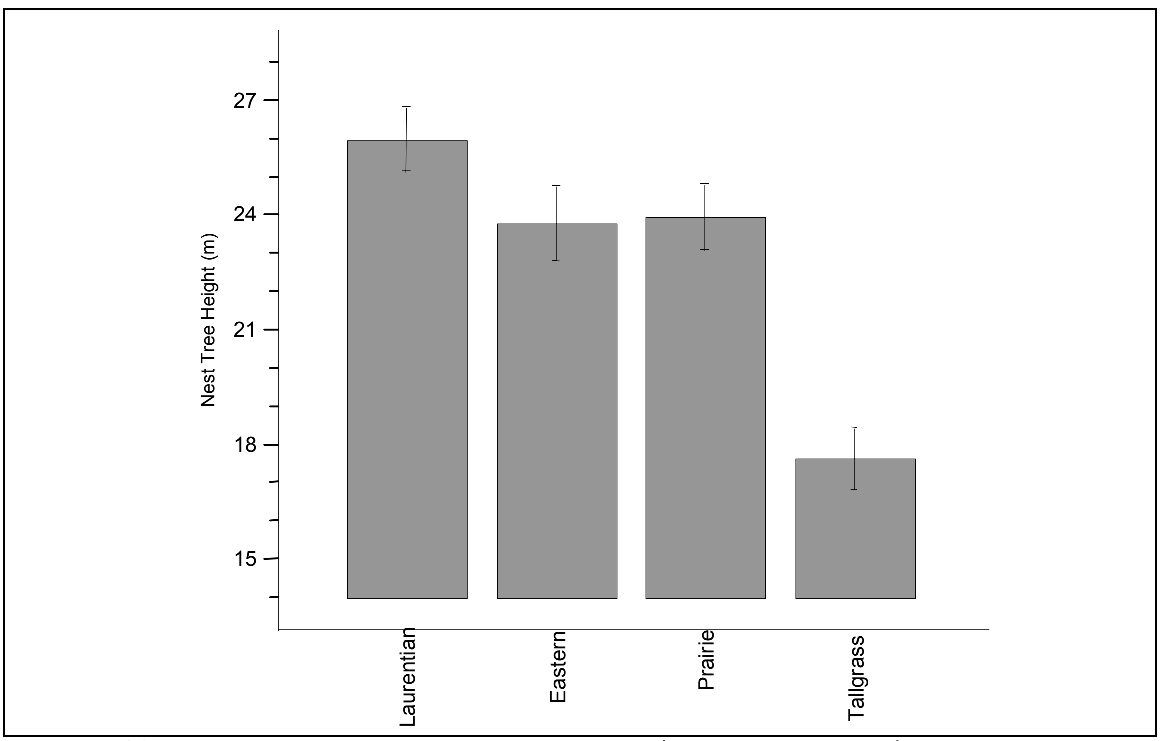

Figure 13. Mean bald eagle nest tree height (± standard error) within ecoregions.

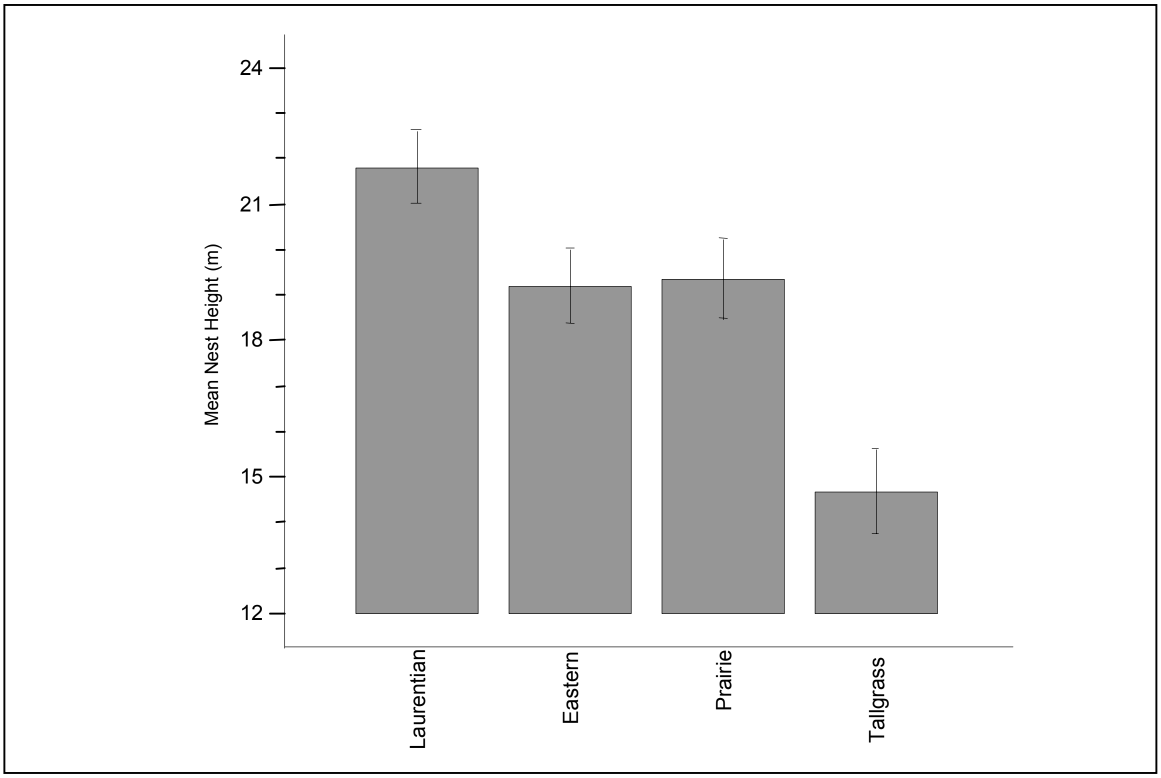

Figure 14. Mean bald eagle nest height (± standard error) within ecoregions.

Table 8. Mean height and diameter of bald eagle nest trees and trees in the surrounding stand within 1,000 m

	Nest Tree	Stand Trees
Mean Tree Height (m)	23.99	18.55
(SE)	(0.52)	(0.39)
Mean Tree Diameter (cm)	51.56	31.41
(SE)	(2.97)	(0.83)

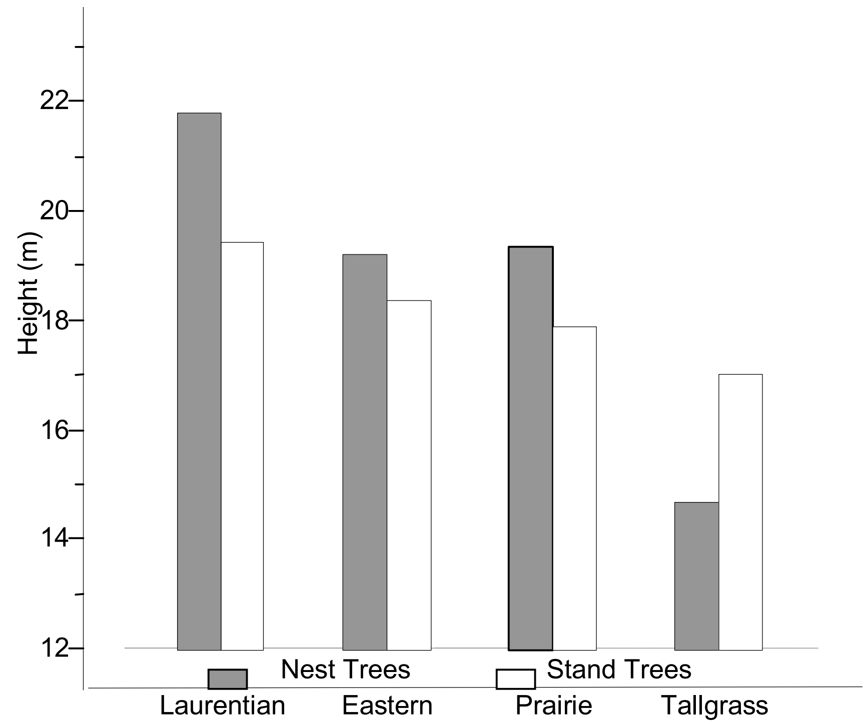

Figure 15. Mean height of nest trees and associated stand trees (+ standard error) within ecoregions.

Table 9. Mean characteristics of bald eagle nest sites (n = 120) in Minnesota

Variable	Mean (SE)
Distance (m) to Nearest Active Nest	8876.58 (813.74)
Distance (m) to Water	159.28 (27.57)
Distance (m) to Nearest House	6147.60 (1455.98)
Distance (m) to Nearest Road	668.88 (170.20)
Distance (m) to Urban Area	9752.03 (710.90)
Distance (m) to Cultivated Fields	6128.97 (1325.73)
Distance to Terrestrial Edge	413.68 (66.04)
Number of Land-use Types in 1000m	5.47 (0.12)
Number of Roads in 1000 m	4.58 (0.34)
Houses in 1000 m	12.42 (2.93)

Nest Sites vs. Random Sites Comparison

Univariate comparisons between nest sites and random sites within ecoregions are shown in Figures 16-22. Differences associated with each ecoregion were primarily attributed to extreme differences in habitat types between the four areas. For example, distances to the nearest body of water were much greater in the Prairie Parkland ecoregion than in the Laurentian Mixed Forest ecoregion. This is to be expected because of the geological events that have occurred and the nature of the biomes that exist in each area. Similarly, on average, there were few land-use types (and, therefore, greater distances from terrestrial edges) in the Laurentian Mixed Forest ecoregion because this area contains large tracts of protected forests with little agricultural activities or open grasslands. Mean distance to the nearest active nest was much greater for random sites in the Prairie Parkland ecoregion because nearly all of the nests in this region were associated with the Minnesota River. The river was located a great distance from many of the randomly chosen sites, while sample nests were relatively close to one another.

Nest trees were larger in diameter and height than mid-point trees of random sites (Table 10). The number of species observed was similar between nest trees (12 species) and mid-point trees (16 species); however, their frequency distributions were much different. Nest sites were closer to water (Fig. 18) andcloser to other active nests than random sites. Human-presence variables showed minimal differences between nest and random sites with a large amount of variation among sites (Figs. 20 and 21).

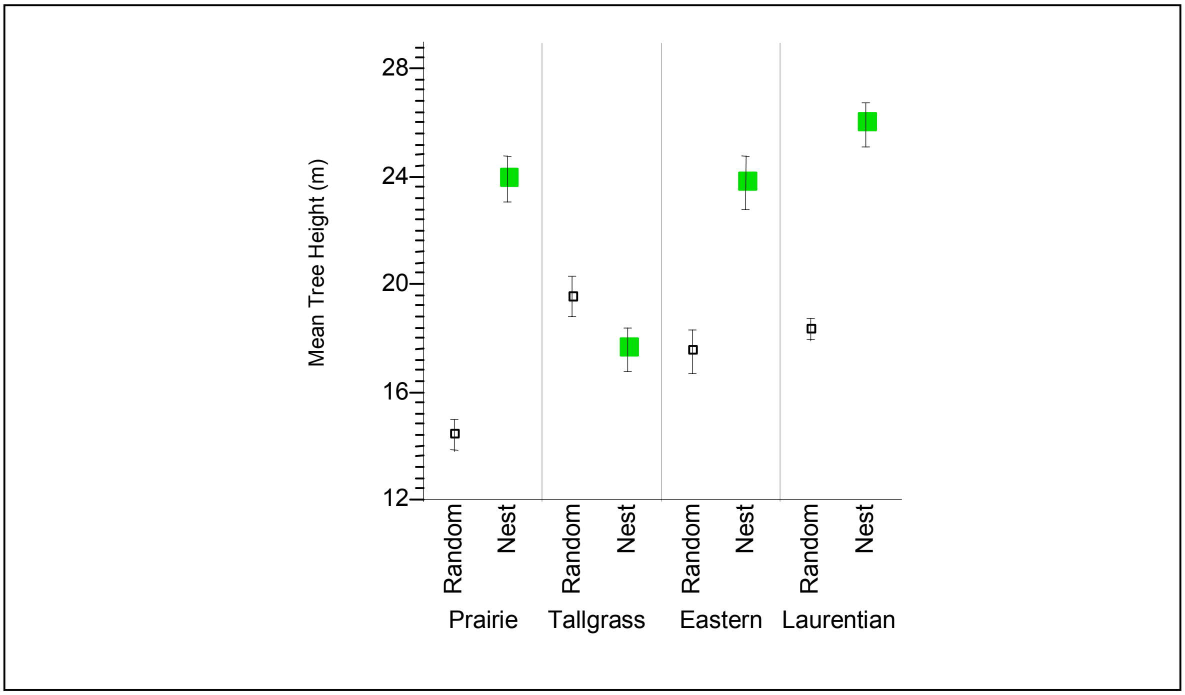

Figure 16. Tree height at nest sites and random sites (± standard error) within ecoregions.

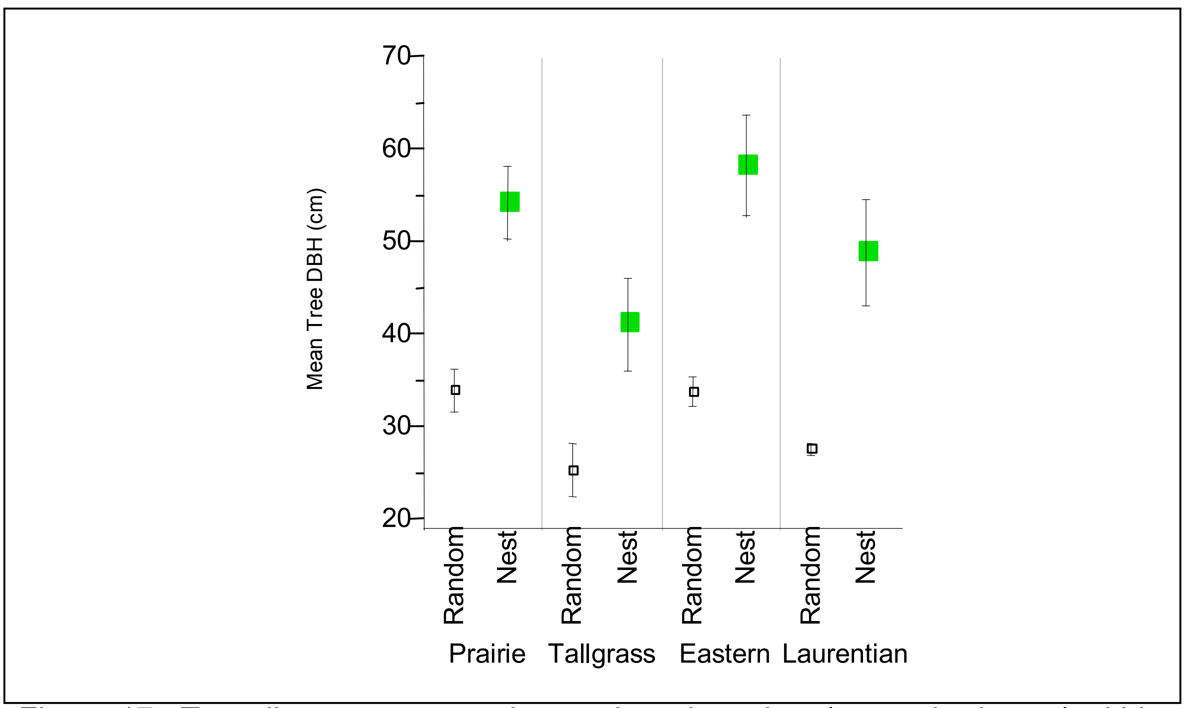

Figure 17. Tree diameter at nest sites and random sites (± standard error) within ecoregions.

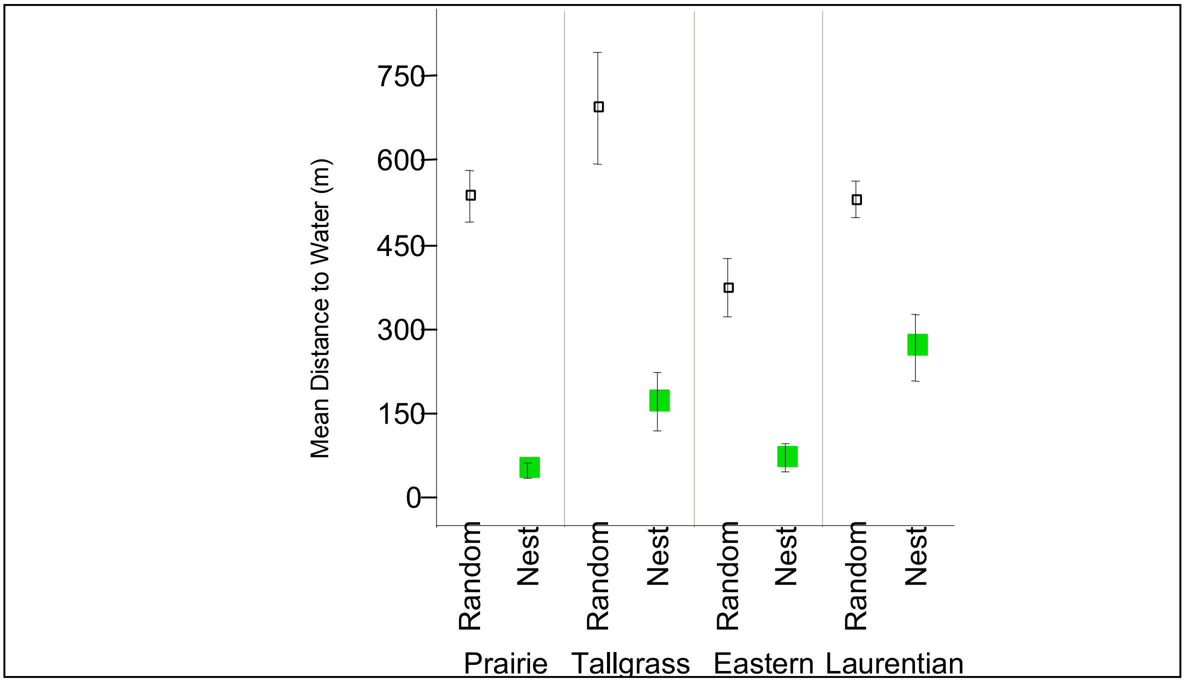

Figure 18. Distance to shoreline at nest sites and random sites (± standard error) within ecoregions.

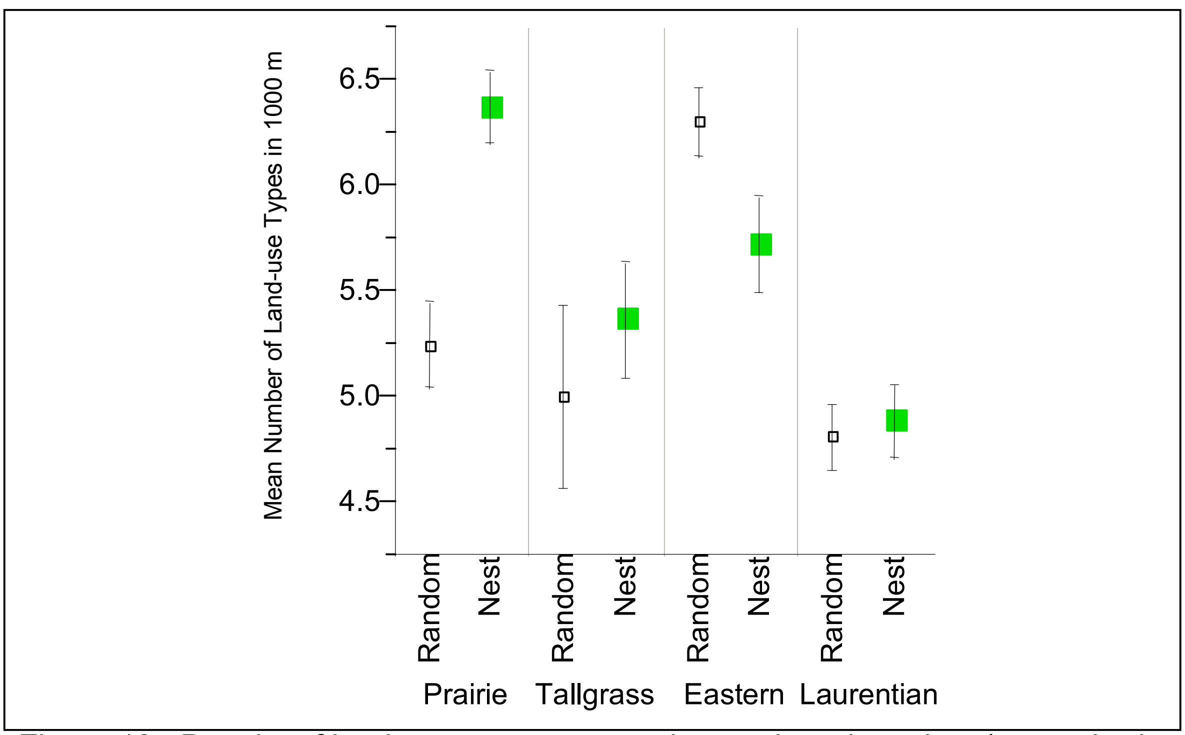

Figure 19. Density of land-use types at nest sites and random sites (± standard error) within ecoregions.

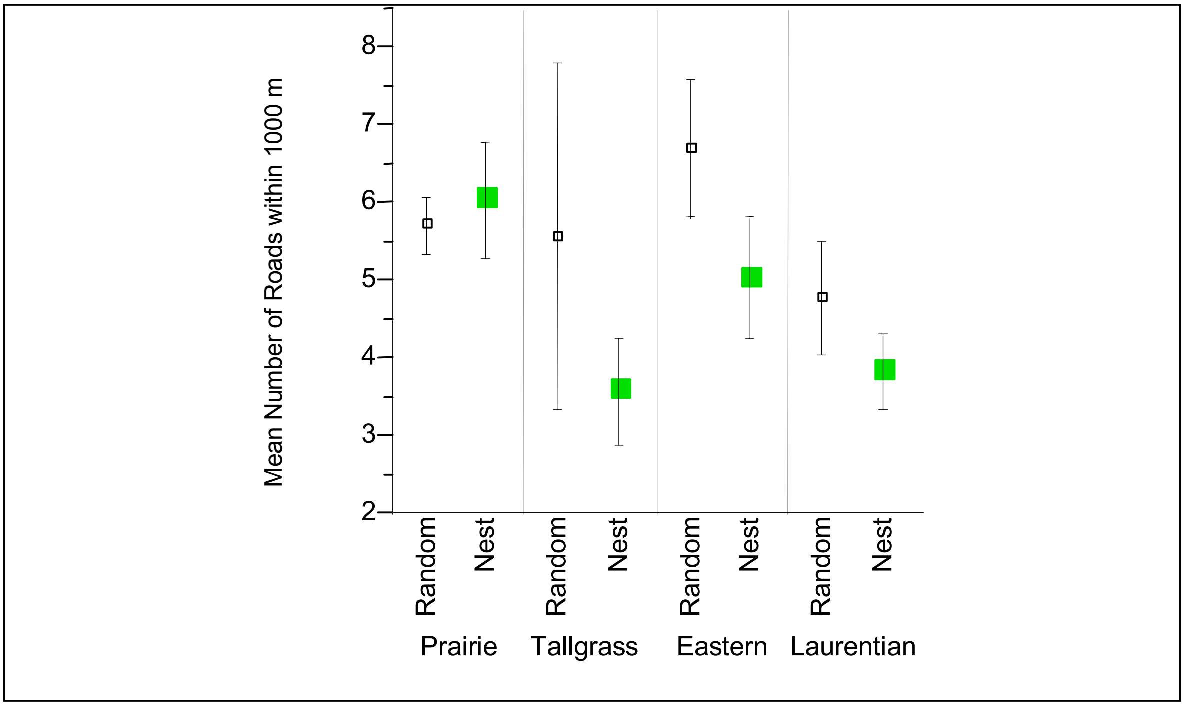

Figure 20. Density of roads at nest sites and random sites (± standard error) within ecoregions.

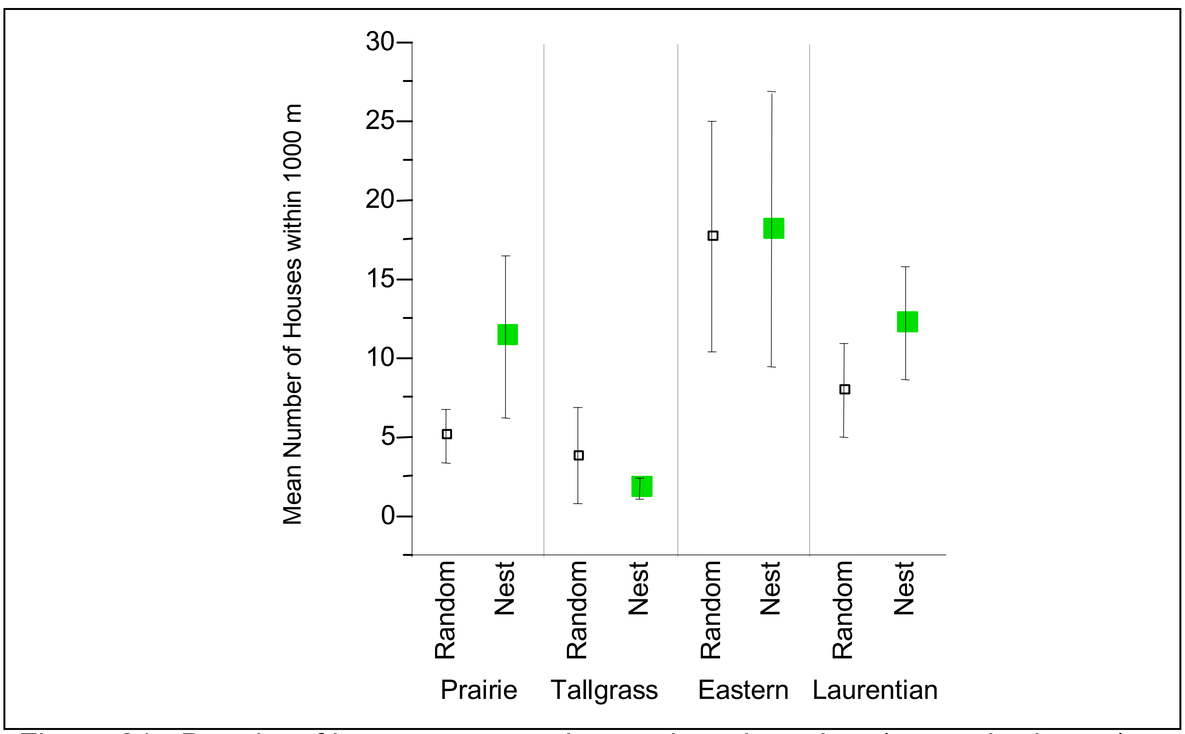

Figure 21. Density of houses at nest sites and random sites (± standard error) within ecoregions.

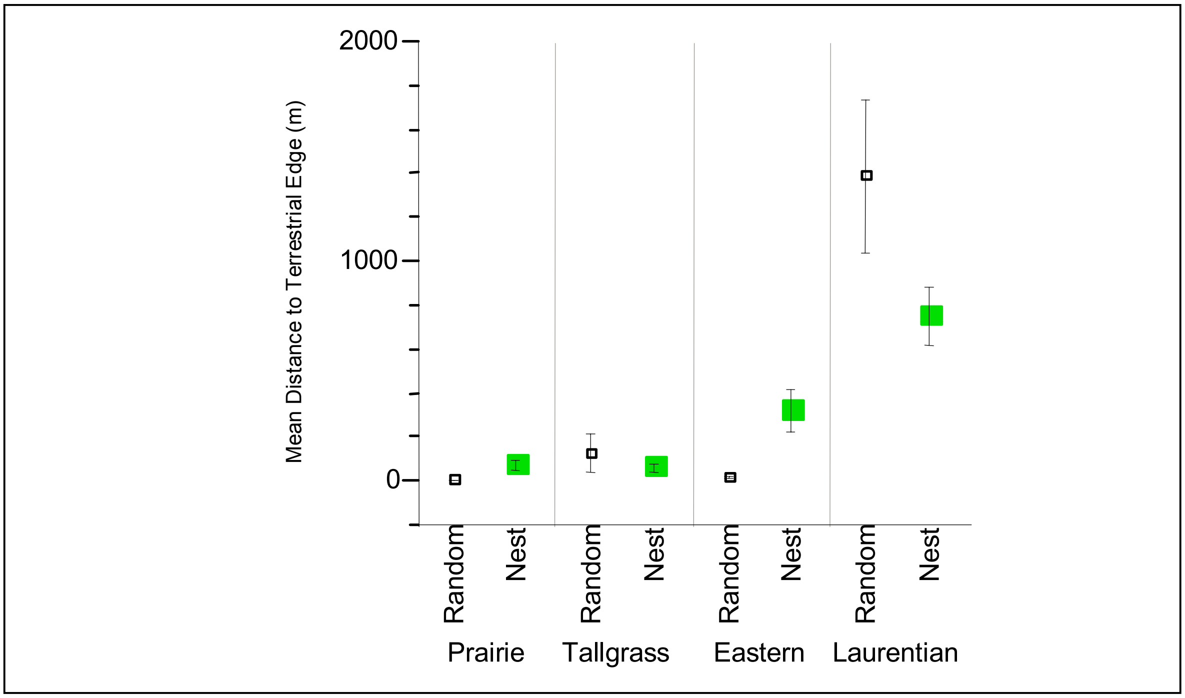

Figure 22. Mean distance bald eagle nests were located from the nearest terrestrial edge (± standard error).

Table 10. Characteristics of nest trees, random sites, and their associated stand trees

Variable or Tree Species	Nest Sites (n =120) Nest Tree	Stand	Random Sites (n = 166) Mid pt.	Stand	All Sites Combined
Mean Diameter (SE)	51.56 (2.97)	31.41 (0.83)	30.33 (0.80)	27.30 (0.56)	34.22 (0.99)
Mean Height (SE)	23.99 (0.52)	18.55 (0.39)	17.22 (0.34)	15.97 (0.29)	18.59 (0.30)
Species (% of total species)	12 (31.0)	30 (78.9)	16 (42.1)	29 (76.3)	38 (100)
Number of Trees (% of total trees)	120 (5.1)	865 (36.8)	162 (6.9)	1206 (51.3)	2353 (100)

Nests were farther from the nearest house and slightly farther from the nearest road than random sites. However, the density of houses was greater for nest sites than random sites, and the distance to the nearest urban area was less for nest sites. Eagles chose sites close to a terrestrial edge (Fig. 22).

Tree height (Fig. 16) might appear to be an important factor, but it is confounded with tree diameter, making its importance is misleading. This issue will be developed further in the next section. Mean nest tree diameter was much greater than the diameter of either trees in the surrounding stand or random site trees. The mean tree height between these groups was similar. Tree height was slightly greater for nest trees, but this represented a small difference. Tree diameter (Fig. 17) and distance to water (Fig. 18) represented the only valid univariate differences between nest sites and random sites that would show statistical significance overall (if that were considered a valid approach, see Appropriate Statistical Methodology in Methods and Materials section). Nest trees were much larger in diameter than either the trees in the surrounding stand or the trees sampled at random sites (Fig. 23).

Removing the ecoregion variable from the analysis allowed trends that were more important for management of nesting habitat across a broader range to become evident. Nest sites and random sites were similar in their distances from most of the human presence variables measured (Figs. 24-27). Distance to the nearest house (Fig. 24) showed the largest difference with nest sites being farther from houses than random sites. However, the density of houses (Fig. 27), roads (Fig. 28), and land-use types (Fig. 29) associated with each site was similar for nest sites and random sites.

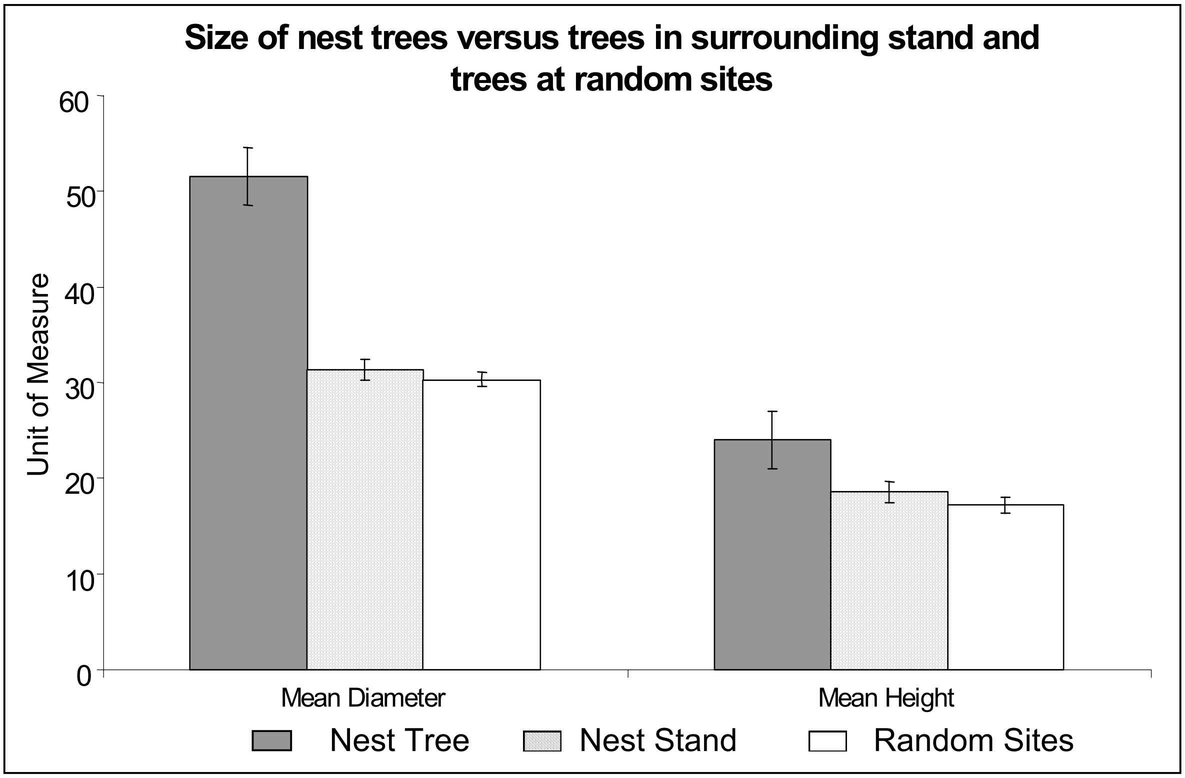

Figure 23. Mean height and diameter of bald eagle nest trees, trees within the surrounding stand, and trees at random sites (± standard error).

Figure 24. Mean distance bald eagle nest sites and random sites were located from the nearest house (± standard error).

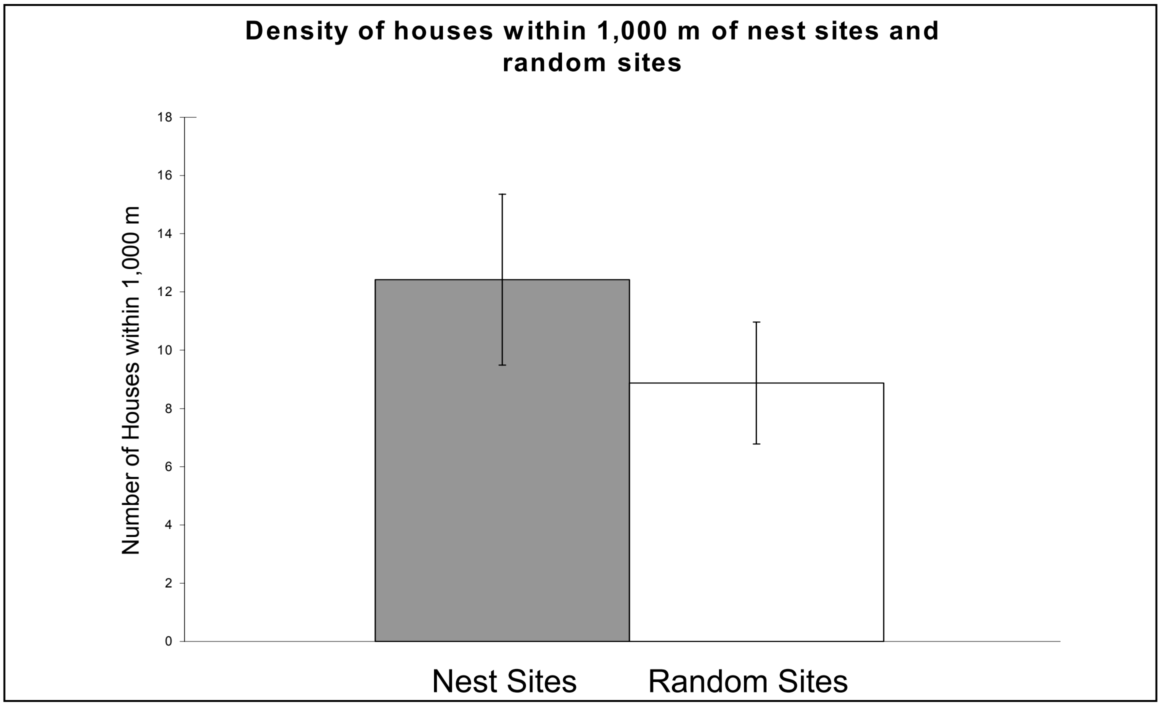

Figure 25. Mean density of houses within 1,000 m of bald eagle nest sites and random sites (± standard error).

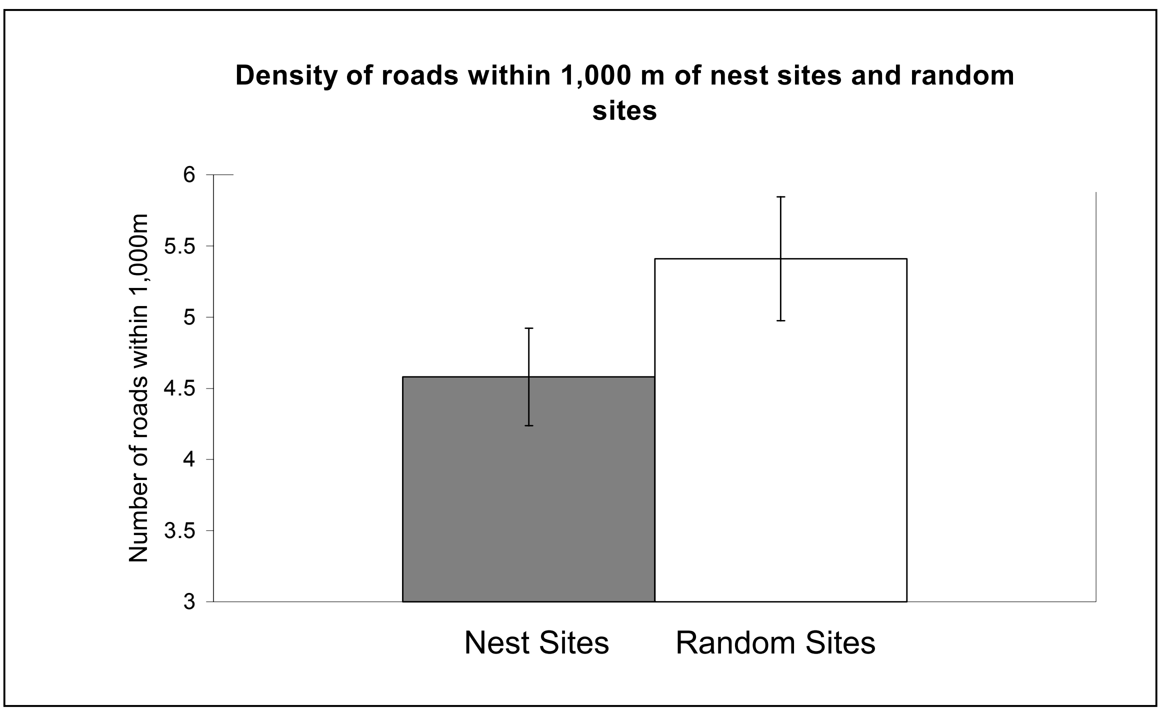

Figure 26. Mean density of roads within 1,000 m of bald eagle nest sites and random sites (± standard error).

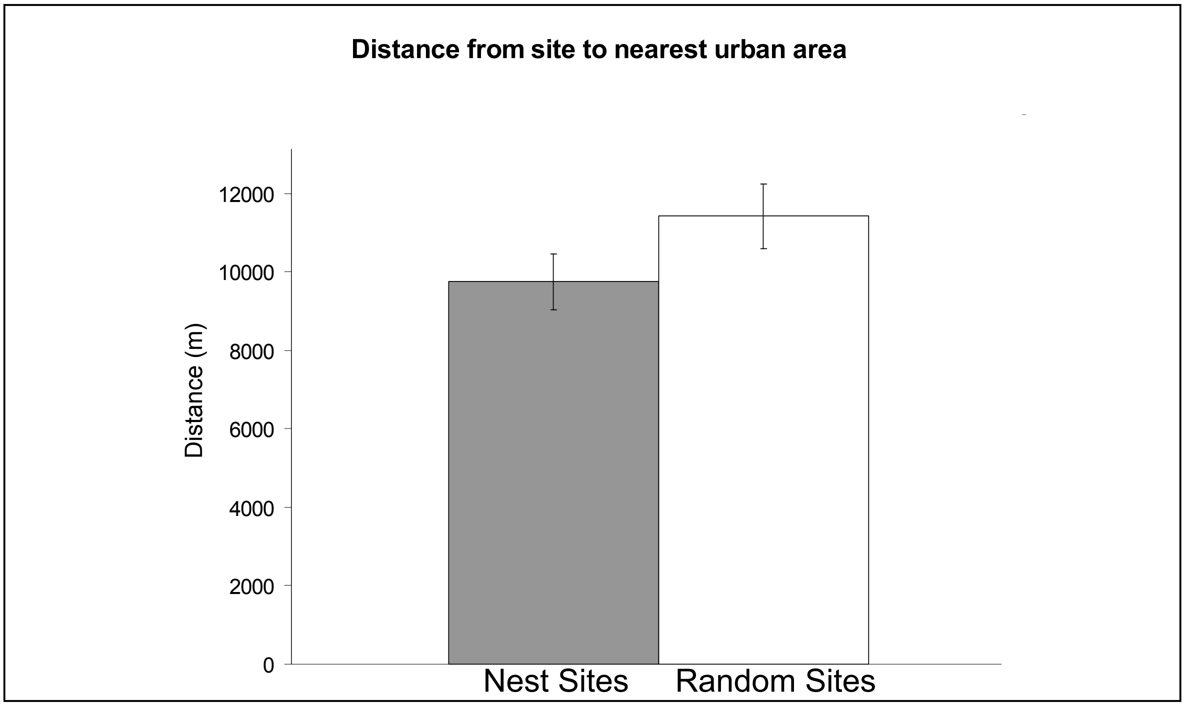

Figure 27. Mean distance bald eagle nest sites and random sites were located from the nearest urban area (+ standard error).

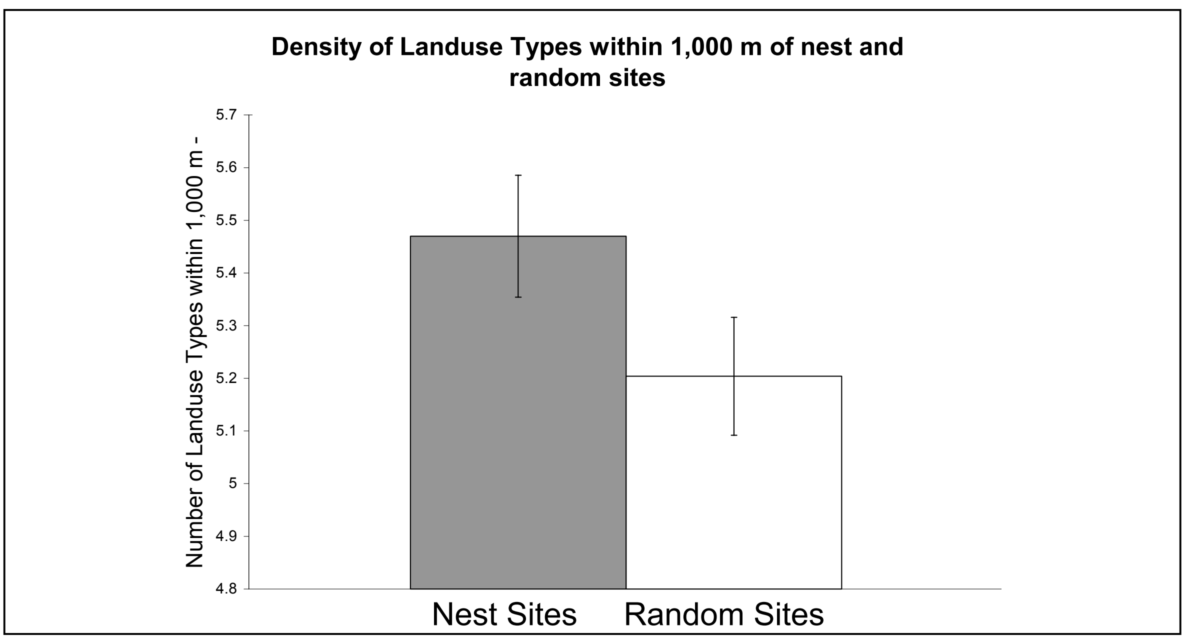

Figure 28. Mean density of land-use types within 1,000 m of bald eagle nest sites and random sites (+ standard error).

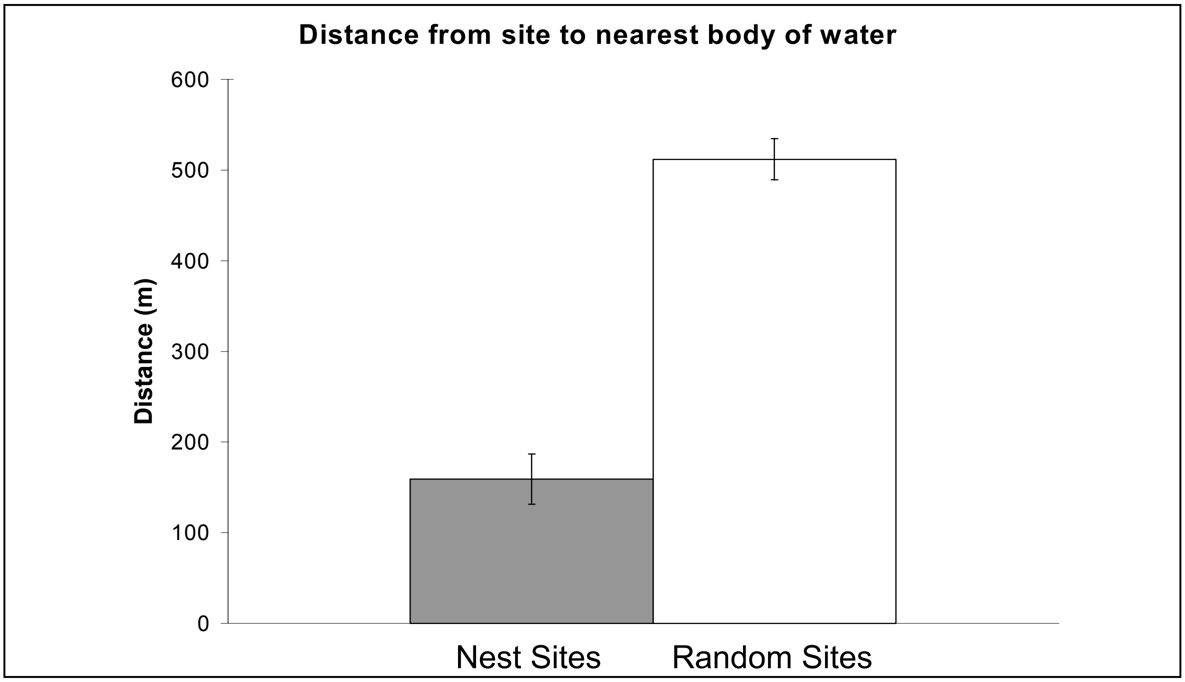

Figure 29. Mean distance bald eagle nest sites and random sites were located from the nearest body of water (± standard error).

Bald eagle nests were located closer to terrestrial edges than random sites (Fig. 30). In many cases, nests were located within 20 m of an open edge. This suggests that bald eagles do not require large tracts of continuous forests. Eagles are large-bodied birds and may choose nest sites close to edges to take advantage of open flight lanes. Sample nests were located closer to other active nests than random sites (Fig. 31). This was primarily because of high-density nesting locations in some parts of the state. High-density nesting is likely associated with quality food sources.

Discriminant Analysis

Multivariate analyses were utilized to examine correlations between habitat variables and productivity, and to determine multi-dimensional differences between

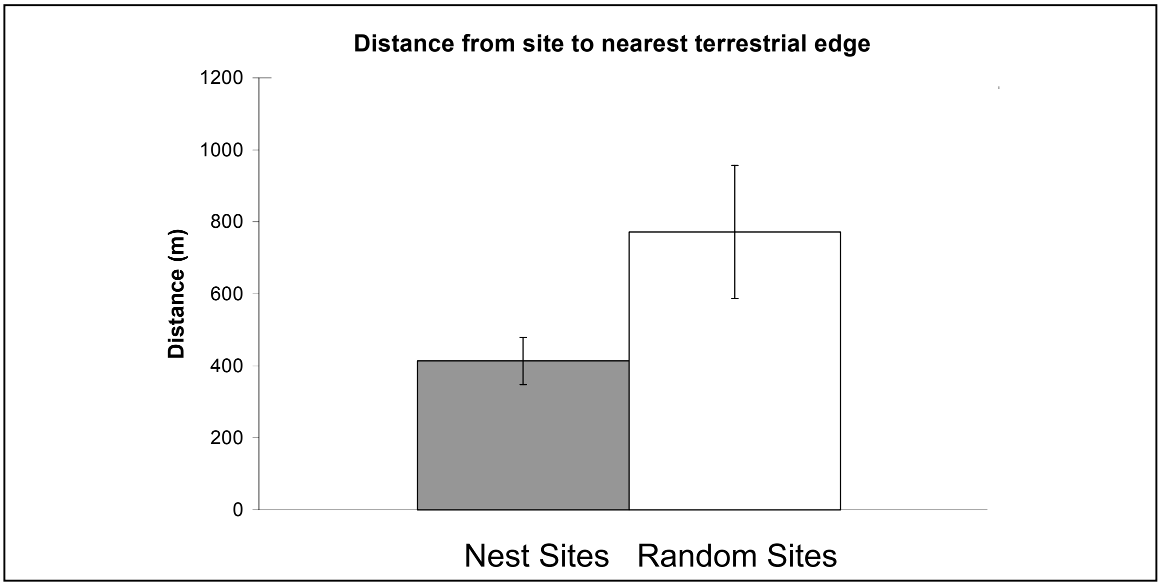

Figure 30. Mean distance bald eagle nest sites and random sites were located from the nearest terrestrial edge (± standard error).

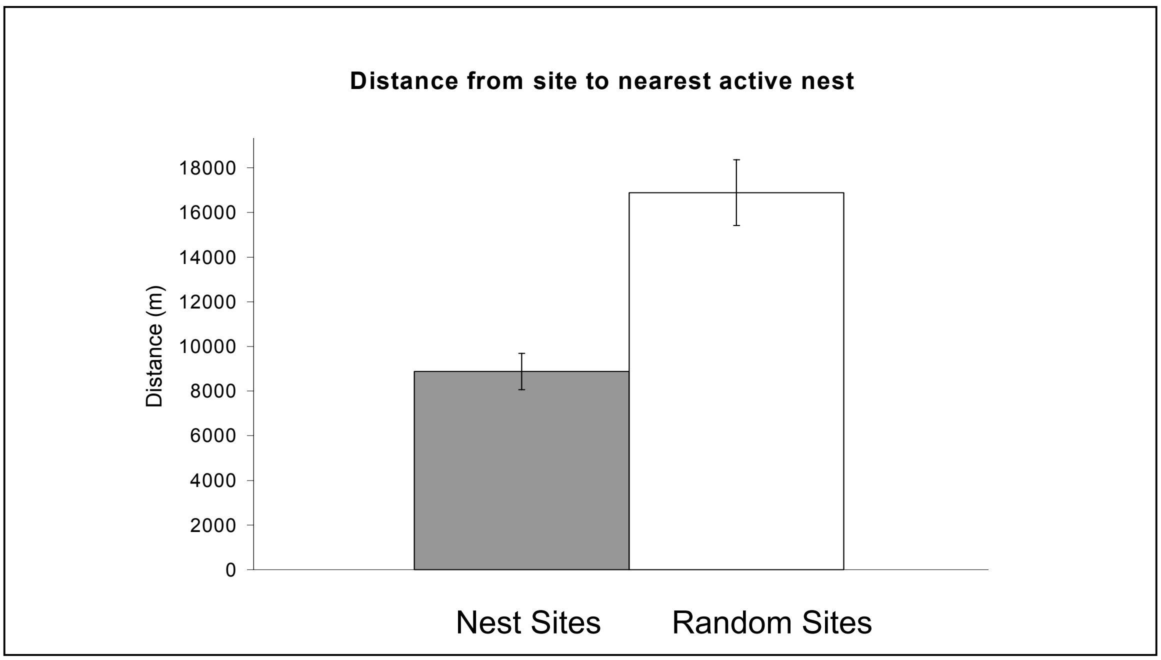

Figure 31. Mean distance bald eagle nest sites and random sites were located from the nearest active bald eagle nest (± standard error).

nest sites and random sites. For multivariate analyses in this study, it was necessary to examine the data as two separate sets. The first set was the entire body of data collected at random sites and nest sites. The second set consisted of data gathered at only nest sites. Each multivariate analysis utilized a separate, reduced list of variables. In other words, within each data set, each variable was intensely screened in order to obtain a short list of variables that were not confounded with other variables and that had appropriately distributed ranges to be analytically meaningful.

Data for the productivity modeling process consisted of only nest sites, while comparing nest sites and random sites utilized a data set comprised of nest site and random site data. Variables were separately screened for multiple correlations for Discriminant Analysis (Appendix F) and for productivity modeling (Appendix G). Variables were separately screened for limited range distributions for Discriminant Analysis (Appendix H) and for productivity modeling (Appendix I). Variables that possessed an appropriate range distribution and that were not tightly correlated to other variables were selected for use in the associated multivariate process.

Discriminant Function Analysis (DFA) is a technique used for assessing the differences between pre-defined groups, in this case nest sites and random sites. DFA is comprised of both descriptive and predictive sections, making it ideal for examining separations in data sets containing a categorical grouping variable such as nesting activity. The measured variables were rigorously screened before being selected as potential discriminating variables. The measured variables and their reasons for acceptance or removal from the preliminary procedures of DFA are shown in Table 11.

Table 11. Acceptance or exclusion status of variables for Discriminant Analysis

Variable	Acceptance Status
Species	Excluded: multiple correlations
Nest Tree Height	Excluded: multiple correlations
Nest Tree Diameter	Accepted with $\log_e$ transformation
Canopy Elevation	Excluded: difficult to measure in the field
Stand Diameter	Excluded: multiple correlations
Stand Height	Accepted with $\log_e$ transformation
Distance to Active Nest	Accepted with $\log_e$ transformation
Distance to Shoreline	Accepted with $\log_e$ transformation
Distance to Roads	Accepted with $\log_e$ transformation
Density of Roads	Excluded: multiple correlations
Distance to House	Excluded: multiple correlations
Density of Houses	Accepted
Distance to Urban	Accepted
Distance to Forest	Excluded: distribution showed few extreme values
Distance to Grassland	Accepted with $\log_e$ transformation: Combined to form Distance to Terrestrial Edge
Distance to Bog	Excluded: distribution showed few extreme values
Distance to Brushland	Accepted with $\log_e$ transformation: Combined to form Distance to Terrestrial Edge
Distance to Cultivation	Accepted with $\log_e$ transformation: Combined to form Distance to Terrestrial Edge
Density of Land-use Types	Accepted

Discrimination between nest sites and random sites using the selected explanatory variables (Table 11) was possible (Fig. 32). Nest sites and random sites were clearly represented as separate, non-overlapping circles. The length and direction of Eigenvectors represent the relationships among variables. A strong association existed between nest sites and trees with large diameters. In other words, the diameter of trees (also see Table 10 and Fig. 23) was a discriminating variable with larger trees observed at nest sites. A strong association was also observed for random sites and greater distances to shorelines. Other variables including the distance to the nearest terrestrial edge and the height of stand trees had weak associations with nest sites.

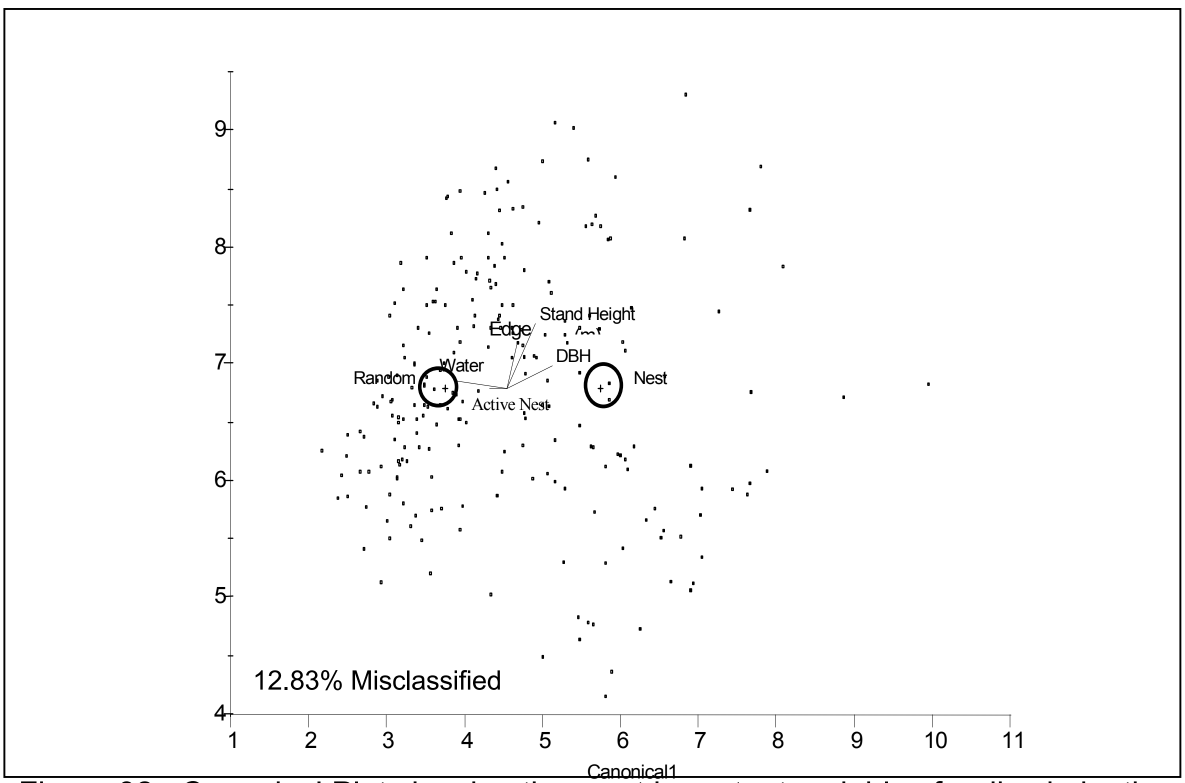

Figure 32. Canonical Plot showing the most important variables for discriminating nest sites and random sites (Exploration Set).

The *Validation Set* was analyzed to evaluate the utility of the discriminant function. The discriminant function was successful in discriminating between nest sites and random sites using the *Validation Set* (Fig. 33). Discriminant Analysis was then conducted utilizing only the two most important variables (Tree Diameter and Distance to Water). These two variables were nearly as successful in discriminating between nest sites and random sites (Fig. 34) as the full model (Fig. 33). Therefore, the most important differences between nest sites and random sites appear to be diameter of trees and distance from the shoreline.

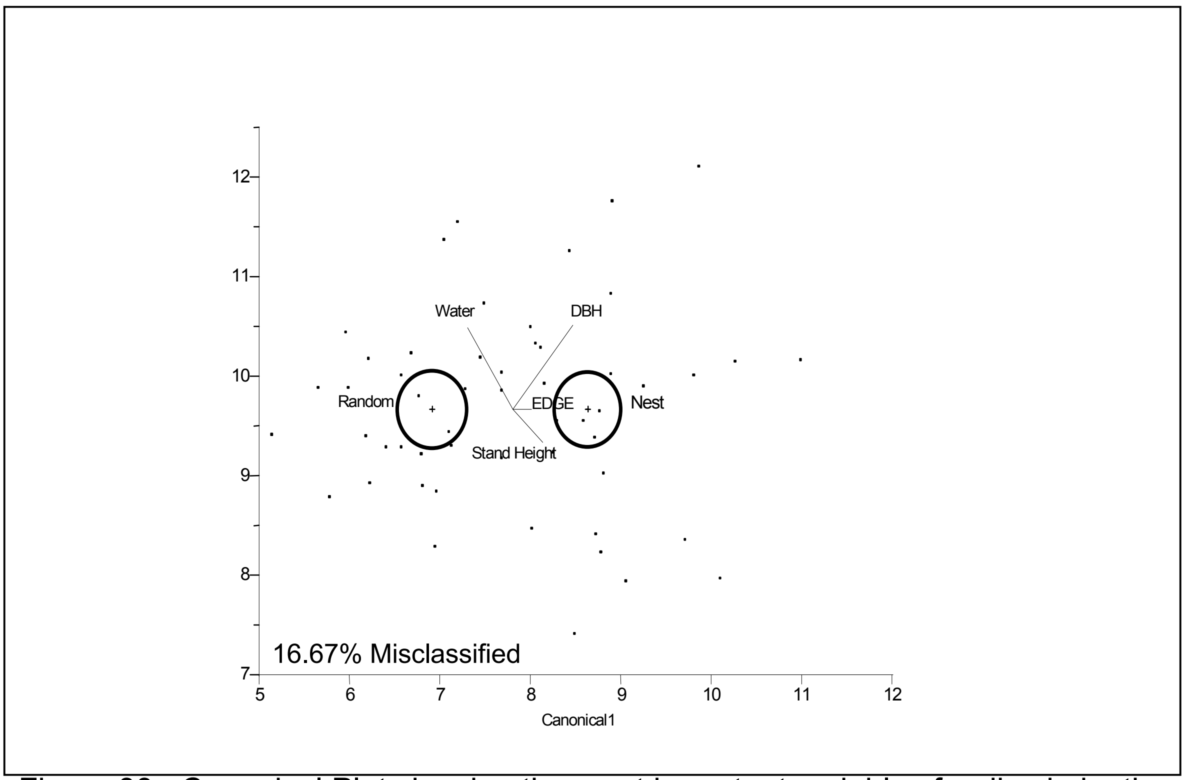

Figure 33. Canonical Plot showing the most important variables for discriminating between nest sites and random sites (Validation Set).

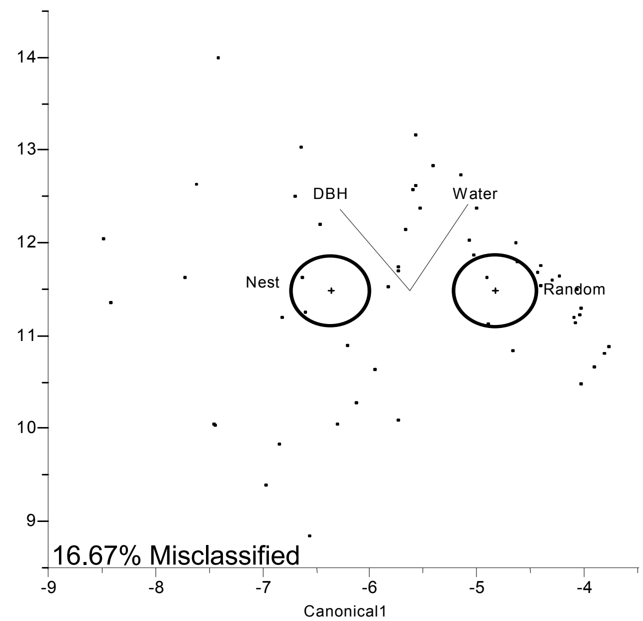

Figure 34. Canonical Plot showing the distance to water and tree diameter discriminating between nest sites and random sites (Validation Set).

Productivity Modeling

Model selection techniques were employed to determine the effects of habitat features on productivity. Variables were rigorously screened as described previously. The process consisted of four steps. The first three were (1) reducing overlapping and biologically unimportant variables, (2) eliminating variables with limited range distribution, and (3) eliminating variables with many correlations. Each measured variable and the reasons for exclusion or acceptance from the first three steps are reported in Table 12.

After the initial three screening steps, the accepted variables were examined to determine any interactions among the variables using Mallow's

Table 12. Reasons for accepting or rejecting measured variables for Model Selection Analysis

Variable	Acceptance Status
Nest Height	Excluded: correlations and distribution
Nest to top	Accepted with $\log_e$ transformation
Species	Excluded: correlations, confounding factor
Nest Tree Height	Excluded: confounding correlations
Nest Tree Diameter	Accepted with $\log_e$ transformation
Canopy Elevation	Excluded: difficult to measure in the field
Stand Diameter	Accepted with $\log_e$ transformation
Stand Height	Excluded: distribution showed few extreme values
Distance to Active Nest	Accepted with $\log_e$ transformation
Distance to Shoreline	Accepted with $\log_e$ transformation
Distance to Roads	Excluded: confounding correlations
Density of Roads	Accepted
Distance to House	Accepted with $\log_e$ transformation
Density of Houses	Excluded: distribution showed few extreme values
Distance to Urban	Accepted
Distance to Forest	Excluded: distribution showed few extreme values
Distance to Grassland	Accepted with $\log_e$ transformation
Distance to Bog	Excluded: distribution showed few extreme values
Distance to Brushland	Excluded: confounding correlations
Distance to Cultivation	Accepted with $\log_e$ transformation
Density of Land-use Types	Accepted

Selection Criterion. The important variables and interactions developed with Mallow's Selection Criterion were used to develop the final candidate set of models (Table 13). Although some of the listed variables (Table 12) appeared to offer some information about the system and were accepted to be examined with Mallow's Selection Criterion, not all of them provided support for inclusion in the candidate set. The candidate set of models created using the results of Mallow's Selection Criterion was then ranked in order of importance as described in the next section.

AIC_c values and their associated log-likelihood values were calculated to determine the best approximating models for the data set (Table 14). AIC provides a method for evaluating the likelihood of a model given the data and comparing the usefulness of multiple models. AIC uses maximum likelihood estimation to rank the models in the candidate set in order of importance. It is unlikely that one model is the single best model for the system. Therefore, it is usually necessary to acknowledge several models that represent the system well.

For this data set, it was appropriate to use AIC_c (a correction for smaller sample sizes) rather than AIC because the n/K ratio (ratio of number of sample and number of parameters in our models) was relatively small (Burnham & Anderson 2002). The AIC W_i-values (Akaike weights) were essential for comparing the relative importance of the models. Larger Akaike weights represented a greater likelihood of the model being the best in the Candidate Set. The number of estimable parameters in the model was designated as *K*.

Table 13. The Candidate Set of Models used for Information-theoretic Model Selection

Model	Model Description
E(y) = Bo + B1(lnStandDBH) + B2(lnDGrass) + B3 (lnStandDBH*lnDGrass)	Diameter of Stand Trees and Distance to Grassland
E(y) = Bo + B1(Nland1000)	Density of Land-use Types within 1000 m
E(y) = Bo + B1(lnDGrass)	Distance to Grassland
E(y) = Bo + B1(lnDBH)	Nest Tree Diameter
E(y) = Bo + B1(lnDBH) + B2(lnDGrass) + B3 (lnDBH*lnDGrass)	Nest Tree Diameter and Distance to Grassland
E(y) = Bo + B1(lnDBH) + B2(Nland1000) + B3(lnDBH*Nland1000)	Nest Tree Diameter and Density of Land-use Types within 1000 m

Table 14. AIC-values for models describing effects of habitat features on productivity

Model	Cp	r^2	LogL	K	AIC_c	Delta AIC_c	W_i
Diameter Stand Trees and Distance to Grassland	-1.938	0.054	-171.26	5	353.046	0	0.6006
Density of Land-use Types within 1000 m	-2.688	0.040	-174.88	3	355.9732	2.9268	0.1390
Distance to Grassland	-2.555	0.039	-175.22	3	356.6565	3.6101	0.0988
Nest Tree Diameter	-2.115	0.034	-175.34	3	356.8873	3.8409	0.0880
Nest Tree Diameter and Distance to Grassland	-2.763	0.063	-173.96	5	358.4387	5.3926	0.0405
Nest Tree Diameter and Density of Land-use Types within 1000 m	-2.012	0.055	-174.16	5	358.8465	5.8001	0.0330

Although the candidate set was selected using the best available information, none of the resulting models explained more than 7% of the variation in the system (see r^2 values). In other words, productivity did not appear to vary in response to any of the variables examined, even after careful consideration of the candidate factors (alone and in combination). Although the first model is the best model given the Candidate Set, it is still a poor model for productivity, explaining less than 6% of the variation.

Unusual Nesting Substrate

Many sample nests would have once been termed, “abnormal”, according to descriptions of bald eagle nest sites in previous studies. In particular, bald eagles in many areas of Minnesota did not reflect the “wilderness bird” description depicted by Stalmaster (1987) and others. One nest area possessed many contrary traits of modern bald eagle nests. Although some aspects of this nesting territory were highly unusual or represented the initial occurrence for bald eagles, many aspects are becoming more frequent traits of bald eagle nesting sites in Minnesota.

Bald eagles typically nest in large coniferous and deciduous trees. In some areas, bald eagles also nest on cliffs (Arizona, Saskatchewan), pinnacles of rock (Alaska), on the ground (Northern Canada), rarely on large cacti (California), and recently in a goose nest tub (Ohio). Nesting attempts on artificial nest platforms have been observed in some areas. Artificial nests are more readily accepted by eagles if the structure is a replacement for a nest that was destroyed earlier in the same breeding season, rather than the structure being erected before the initiation of the season. In many of the cases of alternative nest substrate use, suitable nest trees were not locally available (see Stalmaster [1987] and Gerrard & Bortolotti [1988] for nest substrate review).

Bald eagle populations in most areas of Minnesota do not appear to be limited by suitable nest trees. Eagles in Minnesota take advantage of the availability of many large trees, such as white pines, red pines, and cottonwoods. The population has grown dramatically over the past two decades, and currently, many pairs nest close to human activity. Recently, one pair of eagles in Minnesota chose an alternative nesting substrate, a high-voltage transmission tower. The transmission tower provided a flat platform on one end and a perch site 2 m above the platform on the other end (Fig. 35).

Figure 35. Transmission tower structure used as nesting substrate by bald eagles in western Minnesota.

The transmission tower nesting area was located in the western edge of the Minnesota and nearing “atypical” eagle habitat, characteristic of the western and southwestern parts of the state. However, there was certainly not a lack of potential nest trees in this area. The transmission lines at this site were cut directly through a forested area, leaving a mowed buffer of 30 m on each side of the tower. It was approximately 730 m from (but within site of) a divided highway, 1250 m from two small farmhouses, and within 50 m of cattle grazing. The particular tower chosen for the nest was at the pinnacle of a rounded hill, making the nest the tallest point in the immediate area. Ospreys frequently nest on transmission towers and telephone poles, but bald eagles have never been reported to use these types of structures. Nests assumed to be inhabited by ospreys should be observed more closely, especially during aerial surveys.

Bald eagles and osprey utilize similar habitats for foraging and nesting. Bald eagles are very aggressive toward ospreys within their breeding territory. Continual harassment at nests and klepto-parasitization attempts at foraging sites by eagles are common and may result in decreased osprey productivity (Stalmaster 1987). For these reasons, it is uncommon for eagles and ospreys to nest within close proximity to each other (Mackenzie 1986). However, nesting attempts at the transmission tower nesting area provide additional information on the relationship between these two species and allude to possible population trends in areas where they overlap.

The transmission tower nesting area (Fig. 36) was initially reported in 1995 and censused by the Minnesota Department of Natural Resources in 1995, 1996, 1997, and 2000. In three of the four study seasons, bald eagles were active at the nest site (Nest Site 1) (Fig. 35); however no productivity surveys were conducted during these years. Information about the nest area was then provided to me for this study.

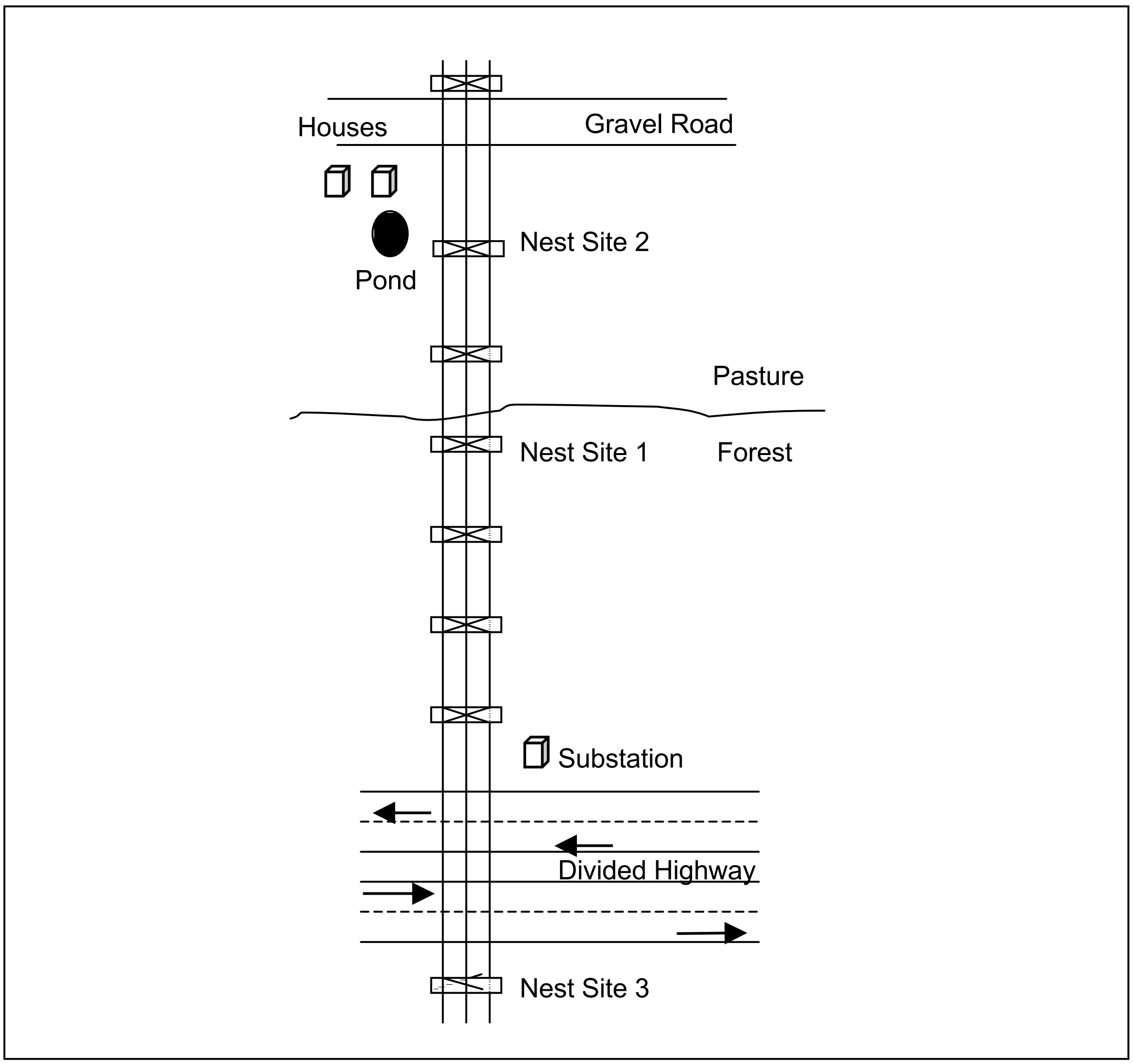

Figure 36. Transmission tower nesting area used by bald eagles and ospreys in western Minnesota (Not to scale).

In 2001, the nest was surveyed from fixed-wing aircraft by Department of Natural Resources pilot, A. Buchert and J. Grier on 24 April and 28 June. The nest was active and contained three full-grown bald eagle chicks. The nest was ground-checked on 10 July. Three full-grown bald eagle chicks were observed on the nest. A remnant of a nest was located on a nearby transmission tower (Nest Site 2) within 20 m of a farmhouse. The landowner reported that an osprey had built a substantial nest structure at that site earlier in the season. The landowner witnessed an altercation at Nest Site 2 between the osprey and an adult bald eagle on 15 April. During the altercation, the eagle repeatedly dove at the osprey, eventually chasing it from the area. The eagle then returned within 5 min. and destroyed the osprey's nest by grasping the sticks in its talons and pulling it apart until only a few sticks remained. An adult eagle was often observed perched at Nest Site 2 during this breeding season.

In 2002, the nesting area was ground-checked on 3 July. I observed an active nest at Nest Site 1, with three eagle chicks present, and no nest structure at Nest Site 2. One nestling flushed from the nest and flew from the area, suggesting that the juvenile had recently fledged from the nest, which brought the total to three chicks produced for the second consecutive year.

In 2003, the nest area was ground-checked on 31 July. As soon as visual contact with Nest Site 1 was made, an adult osprey flushed from the nest and began an alarm/defense call. The osprey circled, called, and swooped at the intruding researcher the entire 10 min. period he was within site of the nest. Although chicks were not visible in the nest, the osprey's actions were consistent with behaviors related to protecting chicks on a nest. The timing of the visit was also consistent with the nesting chronology of ospreys, as osprey chicks do not fledge until mid-August in this area (Dunstan 1973). A large nest was also observed at Nest Site 2 (Fig. 37) containing two juvenile eagles. Another juvenile eagle was observed perched in a tree within 30 m of the nest. As the nest was approached, one juvenile flew to a tree approximately 60 m away. Upon leaving the area, a third active nest was observed at Nest Site 3. At least three osprey chicks were visible in this nest, while two adult ospreys circled and called as the nest was approached. This was the initial nesting attempt recorded at Nest Site 3.

Figure 37. Transmission tower nest site used by bald eagles in western Minnesota during the 2003 breeding season.

This nesting area is worthy of discussion because of the close nesting proximity, the unusually high productivity of the nests (Table 15), and the use of transmission towers by bald eagles. The three active nests were within a total of 1210 m of each other. Nest Site 1 and 2 were within 384 m of each other. The eagle pair nested at Nest Site 1 between 2000 and 2002, but built and used another nest at Nest Site 2 in 2003. Nest Site 2 was much closer to houses, roads, and cattle activities and was in an open cattle pasture. Nest Site 1, on the other hand, was in a forested area and on the pinnacle of a hill. This pair of eagles not only chose an artificial nesting substrate, but also moved closer to human activity and farther from forested areas.

Table 15. Transmission tower nesting area history

Year	Nest Site	Resident	Productivity
2001	1	Bald Eagles	3
2001	2	Osprey	Abandoned (chased by eagles)
2001	3	None	0
2002	1	Bald Eagles	3
2002	2	None	0
2002	3	None	0
2003	1	Osprey	3+
2003	2	Bald Eagles	3
2003	3	Osprey	4

Distance to Houses

The variable Distance to Houses was re-evaluated *a posteriori* due to concerns about removing the variable from the Discrimant Analysis when univariate analyses showed strong differences between nest and random sites. For example, eagle nests were located much farther from the nearest house than random sites (Fig. 24). However, the variable was eliminated before the Discriminant Analysis due to multiple correlations with other variables and limited range distribution of the data. This variable required additional attention due to its importance for management strategies. Further development of this variable included examining differences between productivity, ecoregions, and minimum nesting distances.

Productivity did not appear to be related to the number of houses within the Primary Zone (100 m), Secondary Zone (1000 m), and an Intermediate Zone (500 m) of nests (Table 16). Many of the highest productivity values were observed within high house densities. However, few nests were located within 100 m of houses (n = 7), four of which had only one house within 100 m. And, no sample nests were located within 30 m of a house. Although my sampling method did not detect house density effects on productivity, there appeared to be a minimum nesting distance for the majority of eagle nests.

The area of the state within which the nest was located may have an effect on the distance a nest is located from a house because of the varying densities of houses between the ecoregions. It was assumed that the Laurentian Mixed Forest Ecoregion would have the greatest mean Distance to Nearest House values

Table 16. Productivity ranks in relation to distance to and number of houses

Productivity Rank	N	Houses within 100 m	Houses within 500 m	Houses within 1000 m
3	6	0 (-)	0.333 (0.2118)	1.667 (0.7601)
4	11	0.091 (0.0909)	2.273 (1.6900)	32.455 (22.9043)
5	21	0.095 (0.0952)	2.333 (1.0336)	11.714 (5.7218)
6	32	0.125 (0.0745)	0.625 (0.1944)	8.313 (3.5711)
7	21	0 (-)	1.000 (0.4254)	5.238 (2.2792)
8	23	0.044 (0.0453)	1.783 (0.9023)	10.957 (4.2512)
9	5	0.400 (0.4)	4.200 (1.4629)	49.000 (25.706)
10	1	1.000 (-)	2.000 (-)	4.000 (-)

because of the large amount of state and federally protected forests in the northeastern section of the state. Similarly, it was thought that nests in the Eastern Broadleaf Ecoregion would be observed closest to houses because of the many developed and urban areas in that part of the state.

However, nests in the Tallgrass Prairie Ecoregion were observed to be located much farther from houses than in other parts of the state (Fig. 38). Nests in this area were located primarily in and around the Agassiz National Wildlife Refuge. This ecoregion was one of the least developed areas of the state, but did not contain as much public land as the Laurentian Mixed Forest. Nests in the Laurentian Mixed Forest Ecoregion were located the next farthest distance, while nests in the Prairie Parkland Ecoregion were located the closest to roads. The Prairie Parkland Ecoregion was primarily agricultural lands with many section roads and farm buildings, therefore nests were seldom located a great distance from a house.

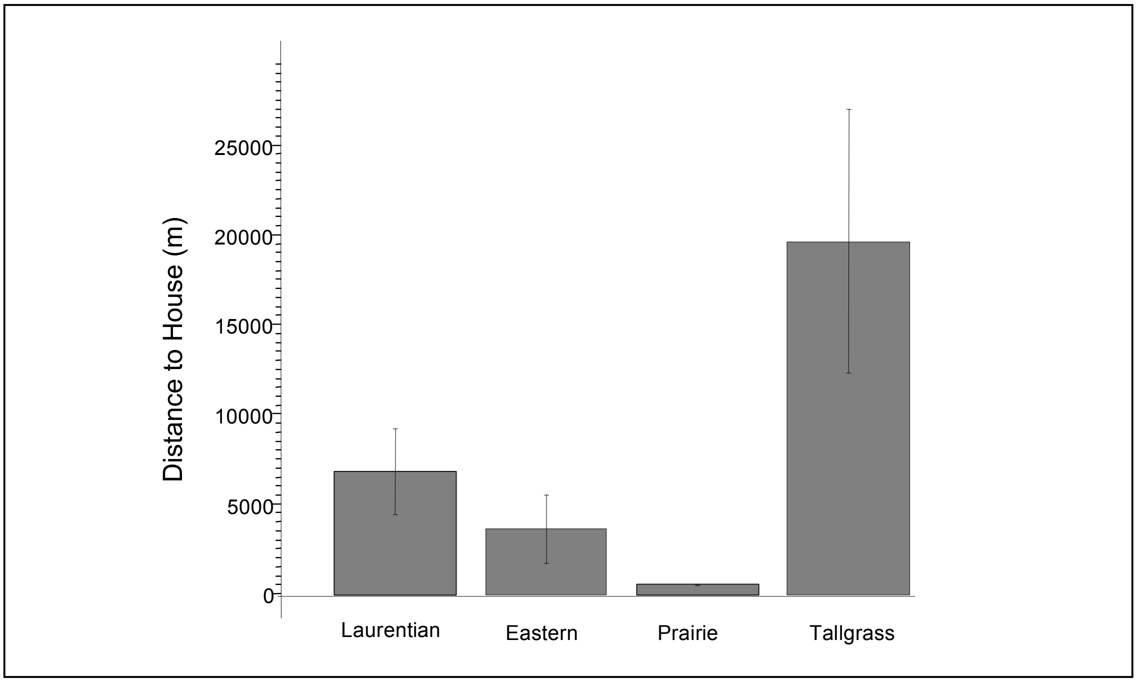

Figure 38. Distance eagle nests were located from the nearest house within ecoregions.

The variable Distance to House was re-inserted into the Discriminant Analysis *a posteriori* to examine the differences between nest sites and random sites. When inserted into the Discriminant Analysis, the $\log_e$ transformed Distance to House values did not show a strong association with either nest sites or random sites (Fig. 39). Although the length of the igenvector suggests that the variable represented some importance to the system, it did not appear to drive the separation between nest sites and random sites. Distance to water and diameter of trees remained the most important differences between nest sites and random sites.

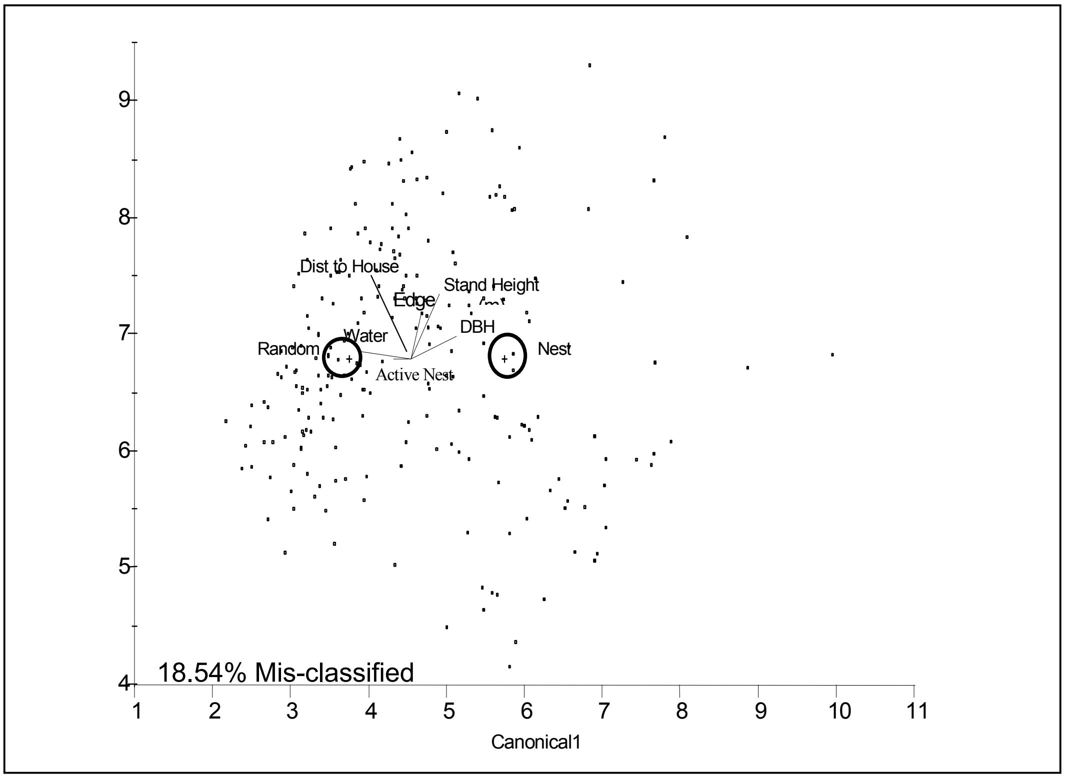

Figure 39. Canonical Plot with Distance to House variable inserted.

CHAPTER 5. DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Bald eagles in Minnesota utilize many different trees for nesting. Cottonwoods are more important as nest trees than previously reported for eagles in the state. This probably reflects the scale of this project. Examining a large range of habitats enabled the detection of nest tree species other than the pine trees that have been traditionally reported. The species of trees does not seem to be important to eagles; rather, selection of the nest tree appears to be driven by searching for structures based on size (primarily diameter). My data support Palmer (1988) who reported that the species of nest tree is likely to be an opportunistic choice. Nests in the northern ecoregions were typically found in pines, while nests in the southern and western ecoregions were typically located in cottonwoods or other deciduous trees. The choice of nest tree species corresponded to the availability and frequency of occurrence of trees in each ecoregion.

Bald eagles in Minnesota choose the largest trees (as measured in diameter) available in an area for nesting. Nest trees on average are taller and larger in diameter than those in the surrounding stand and trees at random sites, with diameter being the more important of the two variables. Although nest tree height is slightly greater, my data support both Cornutt and Robertson (1994) and Wood et al. (1989) who found that nest trees were taller at only 2 of 12 sites and 19 of 98 sites, respectively. On the other hand, nest trees were usually much bigger in diameter than those in the stand. If fact, once I was inside the tree stand, searching for large diameter trees became a useful method for finding nests that were otherwise camouflaged from view from the ground. Tree choice is likely driven by the requirements of supporting a large, heavy nest structure.

There was no evidence that bald eagles require large expanses of continuous forests for nesting purposes. Several nests were located in isolated trees on small islands or in small band of trees bordering a lake or river. Additionally, many other nests were located very close to some type of edge.

Being within close proximity of a body of water appeared important for eagle nests as suggested by prior studies. Nest sites were located much closer to water than random sites. This was a powerful trend considering that the random sites were limited to being within 1,000 m of water by product of my sampling methods. However, there was no evidence of a trend relating productivity to distance from shoreline.

Protection of large diameter, older growth trees within 1 km of a water body may be helpful for nesting eagles as nest sites both for the present and for potential nest sites in the future. This is especially important as the eagle population continues to grow and expand into new areas. Large trees seem to be necessary for nesting eagles. However, most of our sample nest trees were not "super canopy" trees (Stalmaster 1987, Fraser 1981, Retfalvi 1965). Nest trees at sample sites were usually one of the tallest, but seldom towered above the surrounding tree stand. These data are somewhat limited in that only a sample of trees within 100 m was measured. If every tree in the primary zone were measured, it is likely that the nest tree would not be the tallest in the zone at many sites. I often observed trees in the primary zone of comparable height to the nest tree that were not measured because they were not inside of one of the sampling plots.

Interactions among eagles and defense of breeding territories has been previously suggested to result in lowered productivity, apparently acting as a density dependent effect of increasing eagle populations (pers. corresp. Leland Grim, Voyageur's National Park, others). Analysis of these data suggested that nest sites were closer to other active nests than were random sites, therefore there was little support for a trend relating productivity to the distance to the nearest active nest. Additional analyses of edge-of-range nests may show that nests on the edge of a local population have higher productivity than nests within the dense core of the population, but this study was not designed to detect that situation.

Transmission Tower Nesting Area

The transmission tower nests described in this study were the first occurrences of the use of transmission towers as nesting substrate by bald eagles; however, this situation may occur in other areas with similarly designed towers. There are several possible reasons for bald eagles to use transmission towers as nest sites in areas where suitable nesting trees exist. (1) Transmission lines are often cut along ridges between two or more lakes, providing elevated structures near prime foraging locations. (2) Transmission towers are often larger and taller than the trees in the immediate area, providing support and tall perches that may be preferred for displaying or for good visibility of the surrounding area.
(3) Transmission towers offer open flight lanes for large-bodied eagles to approach and leave the nest. (4) Transmission towers of this design provide stable perch locations near the nest for adults to watch the nest and for chicks just prior to

fledging. For this reason, I believe the design of the transmission tower is important in that it allows a perch site several meters above the nest.

(5) Transmission towers are much more stable than natural trees. In some areas, weather damage and disease destroy more than 10% of nest trees each year (Grier, unpublished data).

This nesting situation may be the result of continued generational habituation (see Generational Habituation below) by bald eagle populations to human presence and structures in breeding areas. This nest site is located in an area with many potential nesting trees. Nesting on transmission towers may offer a substantial advantage for bald eagles over using traditional tree nests and may become a more frequent occurrence. Eagles nesting on transmission towers potentially face the danger of electrocution, but the design of this particular tower makes that risk slight. No evidence was found to suggest that electrocution had occurred during any of the study seasons.

Recommendations

Our best approximating models explained only a small percentage of the variation in the data. This suggests that the variables measured, the best and most obvious ones for bald eagles, were not good predictors of eagle productivity. These variables were chosen after careful consideration and provided a thorough picture of eagle habitat and human presence factors. Previous work (Fraser 1981) suggested that only 4.5% of nest failures could be attributed to human disturbances. My data support Fraser (1981) in that human presence near nests did not appear to have an effect on bald eagle productivity. Eagle habitat was not well defined according to specific features of the habitat within the primary or secondary zones.

Bald eagles have proven to be more adaptable to different habitats and human presence levels than previously considered and I do not believe that habitat or the physical presence of humans, per se, is a limiting factor for nesting bald eagles in the state of Minnesota. Current effects of human development did not appear to be limiting for the occurrence of nesting bald eagles. As a consequence, there are few recommendations for nesting habitat management beyond insuring the continued existence of large diameter trees within a relatively close distance to a body of water. However, human development of shoreline property in Minnesota and other states is increasing and could become important at higher levels in the future. It should remain a constant concern in spite of the current situation.

The rebound of the eagle population did not result from large changes (increases) in habitat factors, but most likely occurred from changes in eagle demographic factors (reproduction and survival). The essential needs for nesting bald eagles are large trees in which to place a nest in close proximity to lakes or rivers with an adequate available food source. A landscape comprised of trees and lakes is the image for which Minnesota has become known, but development is continually changing the landscape of Minnesota. Aside from habitat factors, although not a component of this project, it seems obvious that protection of the species depends most importantly on protection of the birds themselves, through continuing education of the public and enforcement of established regulations.

Generational Habituation

Habituation has been defined as a decrease in an animal's responsiveness upon repeated exposure to a stimulus (Hinde 1970). During habituation, an animal learns not to perform a characteristic behavior because the stimulus has been shown to be harmless and is not associated with a threat (Clark 1960; Hinde 1970). The adaptive benefit of habituation is a reduction in energy used during responses to frequently occurring stimuli that have no detrimental effect on the animal's welfare. At the same time, significant and/or dangerous stimuli continue to elicit responses without diminished reactions (Hinde 1970).

Although traditionally thought of as a bird of wilderness areas (Stalmaster 1987; Gerrard & Bortolotti 1988), bald eagles have shown an ability to successfully nest in areas close to human activity (Fraser et al. 1985). When compared to several decades ago, bald eagles are currently nesting in relatively high densities near human presence in many areas of the United States and Canada. Growing eagle populations and increases in recreation and development along the shorelines of lakes and rivers within prime eagle habitat have resulted in more frequent interaction between our species. Many studies have attempted to quantify habituation of eagles to human activities with varying and often contrasting results (Mathisen 1968; McEwan & Hirth 1979; Fraser et al. 1985; Anthony & Isaacs 1989).

The purpose of this section of the dissertation is to address the issue of possible eagle habituation to human presence over generations of eagles. It may be important to incorporate a generational habituation hypothesis in future eagle management strategies. Generational habituation concerns particular events during which habituation is carried over to subsequent generations.

Buehler et al. (1991) suggested that eagles become more tolerant of human activity as the breeding season progresses. However, individuals that appear tolerant of human activities may actually be increasing defense and attentiveness of their young as opposed to defending eggs during the incubation stage, or even defending an empty nest prior to egg laying. In other words, the adult has invested more energy in raising a chick to the point of fledging and therefore, may be less likely to abandon the nest in the presence of similar disturbance. Steidl and Anthony (1996) found no evidence of eagle habituation to repeated approaches throughout the breeding season, but agreed with Russel (1980) and Knight and Knight (1984) that eagles in high human activity areas either habituate to human presence or relocate to areas with lower levels of human presence.

Animal habituation to human presence, resulting in desensitization to disturbance over time, is well studied in controlled laboratory environments (Clark 1960; Rushforth 1965; Carew & Kandel 1973; Bonardi et al. 1991). It is important to recognize that habituation only occurs when human presence is not accompanied by any harmful activity (Grier 1984). Observations of the acceptance of human activities near nest sites by some bald eagle pairs led to reports that an eagle pair becomes habituated to human presence throughout the course of their lives, or perhaps, during a single breeding season. Previous research has concentrated on quantifying an eagle’s response to human activity through direct observations over a limited amount of time.

However, the question is not whether a single individual (or breeding pair) becomes desensitized to human activity. The central issue requires consideration of eagle responses on a much larger scale. The important question is whether the bald eagle population is becoming habituated, not just at one finite point in time, but rather over several generations. In other words, have increasing numbers of eagles in the population become habituated to human presence over the last three decades, which has seen a dramatic increase in the number of individuals.

A chick that has hatched and fledged in an area close to human activity will probably identify with that type of nesting area and choose a similar situation when it becomes part of the breeding population. The nest-selection image is likely to be neither innate nor obtained through a period of trial and error, but rather established while on the nest. The initial step in generational habituation is imprinting on a nest site and utilizing a similar breeding site later in life. This process might occur in several ways.

The following example is one hypothetical, but potential situation. A breeding pair returns to a traditionally wilderness nest site and lays eggs. At the time of hatching (or, perhaps later in the season), some form of human activity begins (construction, recreational activity, a seasonal cabin becomes occupied, etc.). The adults, although possibly annoyed or disturbed by the presence of this activity, may continue to care for the chicks until after fledging. If the process of choosing a nest location is acquired by the young through imprinting or some other learned behavior, and not innately, then the chicks may choose a nest site without avoiding human activity when they become mature. Chicks from the second generation that are raised in areas of high human activity without negative incident will likely choose to nest in a similar area when they become adults. The process continues as successive generations of chicks choose nest sites in close proximity to human activity.

The generational habituation hypothesis might be testable in an experimental field project. A study consisting of a group of nests within several different disturbance regimes could be designed and implemented, with either naturally occurring or researcher-induced disturbances and exchanging chicks from different areas of human presence. Generational habituation would be detected by following chicks from those disturbance regimes until reproductive age and examining their nest site choices. In reality, however, this study could be difficult, if not impossible, to see through to completion. Low survival of eagles entering the breeding population would be a major problem requiring a large number of chicks within each disturbance regime to be banded. Following juvenile eagles for 4-5 years until maturity would also be difficult due to logistics, funding, and technological limitations. In addition, the mechanism controlling a pair's nest-site choice is not well understood and would confound the study to a greater extent. For example, if one gender is responsible for choosing the nest site, the other gender simply complies. Complexities arise due to collective selection if both genders contribute.

I suspect that generational habituation of bald eagle populations is widespread and occurring in many areas of the continent including Minnesota, where bald eagles are increasingly nesting close to human presence. It is likely that humans no longer pose a strong threat association for bald eagles, as habituation focuses the attention and energy of the animal on the important aspects of the environment such as prey and territory defense (Leibrecht & Askew 1980). However, the need for certain protective measures near nest sites is still necessary as there is a likely a threshold distance for eagle tolerance of human activity, particularly early in the nesting season.

Generational habituation is not limited to bald eagles, or even to bird species. Many species thrive in urban areas with constant interactions with human activity. The adaptation of a species to human presence may be associated with innate knowledge and/or learned experience. However, there is an important aspect of learning positioned between these two areas that seems to be overlooked by many researchers. This type of habituation to human activities is based on one generation being exposed to human activity at an early age, with little or no harmful experiences. Behavioral responses to those activities are then passively "passed on" to the next generation.

Identifying this type of developmental learning at the population level is more important than quantifying habituation within a single individual. A population that is undergoing generational habituation is more important, in an ecological and management sense, than a single individual that has become habituated to a disturbance. During individual habituation, each individual from every successive generation must become habituated to human presence. In effect, individual habituation is the same as starting over with the birth of each new generation. In generational habituation, each successive generation is more habituated to human presence from the beginning of life because of experience gained by prior generations. Generational habituation may be responsible for faster changes in behavioral responses to human activities. Under increasing pressures from human encroachment and habitat fragmentation, generational habituation may be a primary means by which animals adapt to human presence.

Future management strategies for bald eagle populations would benefit from incorporating the generational habituation hypothesis. It is important for managers to recognize that generational habituation is a continuing process. We do not believe that eagle populations, at this time, are fully habituated to human presence, although data collected during this study suggest that eagles do not avoid areas of human activity. Generational habituation provides a method for explaining previous trends in eagle biogeography associated with human presence and predicts future changes in the behavior of individuals of the population.

Limitations of Study

There were two main limitations of this study. (1) Prey densities and availability potentially may affect productivity. However, it was not within the scope of this project to examine prey bases for eagles at individual nests. Bald eagles are considered to be generalists in their prey selection and will readily switch prey; therefore, they are not especially affected by the loss of particular prey species at a nest site. A specific prey base likely does not have a large effect on bald eagle productivity, although more study of that aspect would be useful. (2) Productivity at any given nest typically varies over time. Although I obtained only two years of productivity data, I used a very large number of nests and, thus, should have detected any habitat or human presence effects that were present.

Nest distance from houses remains a concern, with no clear relationship being determined relating productivity and density of houses at several distance levels. No clear relationship could be determined concerning distance from houses based and productivity or comparisons between nest sites and random sites. The issue of nest distance from houses is discussed below (see Future Research).

Future Research

Further research should investigate the generational habituation hypothesis and its usefulness in management strategies. Additionally, research should focus on developing an effective and efficient population-monitoring program for bald eagles and examining the effects of seasonal changes in human presence on a landscape scale. The temporal effect of seasonal human activities of humans on nesting eagles was not within the scope of this project. Eagles may respond differently to seasonally-active versus continually-active structures. Continuing development and changes in trends of development may have a greater impact on bald eagle populations in the future. Currently, bald eagles do not appear to be limited by the number of nesting areas in Minnesota. However, increased development of shoreline areas may shift the carrying capacity of the species.

Primary prey sources of bald eagles have been impacted by human activities in the past and are likely to continue to be locally effected by pollutants and over harvesting. Bald eagles are opportunistic foragers and have the ability to change their diet when certain species are not available. However, if prey species remain available (although somehow compromised by pollutants or disease), bald eagles will likely continue to choose those prey items that are readily available. Therefore, bioaccumulation of chemical pollutants in prey species remains a concern for many eagle populations.

Additionally, many diseases have the potential to cause sudden declines in bird populations. West Nile Virus has recently decimated several bird populations in Mid-western States and has been observed to cause serious health problems in captive eagles (pers. corresp. J. Grier). Currently, wild eagle populations do not appear to be greatly effected by West Nile Virus, although researchers in many parts of the country are testing eagle populations for the virus. It is essential that monitoring programs continue in the future to ensure early detection of any sudden changes in eagle populations.

Bald eagle populations have made a dramatic recovery since the 1960's due in part to biological and ecological research, active management strategies, and the dedication of hundreds of people. The future of the population depends on protecting and cultivating the public's opinion, pride, and concern for eagles, especially for those nesting in close proximity to human presence. In many cases, wilderness nests are likely receiving sufficient protection through current forestry management mandates concerning bald eagles. Nests in areas that are designated as recreational sites or that are located on private land are likely to be more of a concern. Many eagle pairs appear to have adjusted satisfactorily to current human presence near nest sites. However, in Minnesota, there is still likely a threshold distance or disturbance level within which eagles will not nest, but which was not detected in this study.

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APPENDIX A. SCIENTIFIC NAMES FOR ALL SPECIES

COMMON NAME	SCIENTIFIC NAME
American Crow	*Corvus brachyrhynchos*
Bald Eagle	*Haliaeetus leucocephalus*
Bison	*Bos bison*
Black Bear	*Ursus americanus*
Bobcats	*Lynx rufus*
Canada Geese	*Branta canadensis*
Cottonwood	*Populus deltoides*
Golden Eagle	*Aquila chrysaetos*
Green Ash	*Fraxinus pennsylvanica*
Gulls	*Larus sp.*
Kokanee Salmon	*Oncorhynchus nerka*
Magpies	*Pica sp.*
Osprey	*Pandion haliaetus*
Paper Birch	*Betula papyrifera*
Quaking Aspen	*Populus tremuloides*
Raccoon	*Procyon lotor*
Red Pine	*Pinus resinosa*
Salmon	*Oncorhynchus and Salmon sp.*
Silver Maple	*Acer saccharinum*
Slippery Elm	*Ulmus rubra*
Sugar Maple	*Acer saccharum*
White Oak	*Quercus alba*
White Pine	*Pinus strobus*
White Poplar	*Populus alba*
Wolverines	*Gulo gulo*

APPENDIX B. LAND-USE DATA INFORMATION

Minnesota Land Use and Cover - A 1990's Census of the Land

This data set integrates six different source data sets to provide a simplified overall view of Minnesota's land-use / cover. The six source data sets covered different parts of the state, were in differing formats, and used different legend classifications. The Minnesota Department of Natural Resources developed a simplified 8-category legend and translated each source data set's original detailed classification into the 8-category system. They also standardized the data to 30-meter grid cells.

Categories

1 - Urban and Rural Development
2 - Cultivated Land
3 - Hay/Pasture/Grassland
4 - Brushland
5 - Forested
6 - Water
7 - Bog/Marsh/Fen
8 - Mining
9 - Unclassified

Source: Minnesota Department of Natural Resources. 2000. Minnesota.data, vol. 1 and 2. State of Minnesota, St. Paul, MN 55155.

APPENDIX C. DATA FORM FOR PRIMARY ZONE ANALYSIS

Minnesota Bald Eagle Nest Habitat Survey—Field Survey Data

#_____ Lat_________ Long__________ Date _____
Log.____

Nest: grnd2:_____ 2top______ cond._________
comm.____

Nest Tree: species______ height _________ dbh_________ cond.____________
elev.____________________________

Nest Site:____
____

Surr Area: canopy______ Description ____________________________________

Site 1: dir______ dist______
____
____

Site 2: dir______ dist______
____
____

Site 3: dir______ dist______
____
____

Human dist:
____
Nearby Nest:_____________ Shoreline: dist__________ dir____________
description____
Additional Comments:

APPENDIX D. DATA FORM FOR SECONDARY ZONE EVALUATION

Variable	Number	Cat.	< 100m	Cat.	<500m	Cat.	<1,000m	Cat.
Landuse Types	{X}	{X}						
Number of Roads	{X}	{X}						
Number of Houses	{X}	{X}		{X}		{X}		{X}
Distance to Nearest Road			{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest House		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest Lake		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest River		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest Railroad		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest Urban Area (as designated by city roads)		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest Cultivated Land *(brownish)*		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest Hay, Pasture, Grassland *(orangish)*		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest Brushland *(greenish)*		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest Forest *(dark blue)*		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest Bog, Marsh, Fen *(purple)*		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest Mining *(white)*		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Amount of Urban/Rural Devel. *(pale yellow)*	{X}	{X}		{X}		{X}		{X}
Amount of Cultivated Land *(brownish)*	{X}	{X}		{X}		{X}		{X}
Amount of Hay, Pasture, Grassland *(orangish)*	{X}	{X}		{X}		{X}		{X}
Amount of Brushland *(greenish)*	{X}	{X}		{X}		{X}		{X}
Amount of Forest *(dark blue)*	{X}	{X}		{X}		{X}		{X}
Amount of Water *(light blue)*	{X}	{X}		{X}		{X}		{X}
Amount of Bog, Marsh, Fen *(purple)*	{X}	{X}		{X}		{X}		{X}
Amount of Mining *(white)*	{X}	{X}		{X}		{X}		{X}
Amount of Roads	{X}	{X}		{X}		{X}		{X}
Distance to Other		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Other		{X}	{X}	{X}	{X}	{X}	{X}	{X}
Distance to Nearest Active Nest		{X}	{X}	{X}	{X}	{X}	{X}	{X}

APPENDIX E. SAS PROGRAM CODE FOR VARIABLE EVALUATION AND PRODUCTIVITY MODELING

```
PROC UNIVARIATE DATA=Eagle PLOT;
  VAR NestorRandom Dwater lnDwater DBH lnDBH Height lnHeight StandDBH
lnStandDBH StandHeight lnStandHeight Nland1000 lnNland1000 Nroads1000
lnNroads1000 Nhouses1000 lnNhouses1000 droad lndroad dhouse lndhouse
Durban lnDurban Dcultv lnDcultv Dgrass lnDgrass Dactive lnDactive Dforest
lnDforest;
RUN;

PROC CORR DATA=Eagle;
        VAR NestorRandom Dwater lnDwater DBH lnDBH Height lnHeight
StandDBH lnStandDBH StandHeight lnStandHeight Nland1000 lnNland1000
Nroads1000 lnNroads1000 Nhouses1000 lnNhouses1000 droad lndroad dhouse
lndhouse Durban lnDurban Dcultv lnDcultv Dgrass lnDgrass Dactive lnDactive
Dforest lnDforest;
RUN;

PROC REG DATA=eagle;
  TITLE 'MODEL ALL POSSIBLE';
  MODEL ProdRank = lnNtoTop lnDWater lnDBH lnStandDBH  Nland1000
NRoads1000 lnDhouse Durban lnDCultv lnDGrass lnDactive / selection = cp;
RUN;

***** TAKE THE BEST MODELS FROM ABOVE AND RUN THROUGH GENMOD
TO GET LOG-LIKELIHOOD VALUES.**********

PROC GENMOD DATA=eagle;
  TITLE 'MODEL lnDiameter lnDistancetoGrassland';
  MODEL ProdRank =  lnDBH lnDGrass / DIST=NORMAL LINK=ID P;

PROC GENMOD DATA=eagle;
  TITLE 'MODEL DensityofLanduseTypes';
  MODEL ProdRank = Nland1000 / DIST=NORMAL LINK=ID P;

PROC GENMOD DATA=eagle;
  TITLE 'MODEL lnDistancetoGrassland';
  MODEL ProdRank = lnDGrass / DIST=NORMAL LINK=ID P;

PROC GENMOD DATA=eagle;
  TITLE 'MODEL lnDiameter';
  MODEL ProdRank = lnDBH / DIST=NORMAL LINK=ID P;

PROC GENMOD DATA=eagle;
  TITLE 'MODEL lndiameter DensityoflanduseTypes';
```

```
  MODEL ProdRank = lnDBH Nland1000 / DIST=NORMAL LINK=ID P;

PROC GENMOD DATA=eagle;
  TITLE 'MODEL lnStandDiameter lnDistancetoGrassland';
  MODEL ProdRank = lnStandDBH lnDGrass / DIST=NORMAL LINK=ID P;

RUN;
```

APPENDIX F. MULTI-CORRELATION SCREENING OF VARIABLES FOR DISCRIMINANT ANALYSIS

Table 17 presents pairwise correlation coefficients and significant correlations between each variable. Coefficients summarize the strength of the linear relationship between each response variable. These data were used in screening variables for Discriminant Analysis. Significant probabilities are arranged in descending order. Values less than 0.05 are highly correlated.

Table 17. Evaluation of variables for Discriminant Analysis

VARIABLE	BY VARIABLE	CORRELATION	SIGN. PROB.
Landuse 1000m	Distance to Forest (m)	0.00023585	0.99685394
Roads 1000m	Stand Diameter (cm)	-0.0014297	0.98093083
Stand Diameter (cm)	Nest to Top Distance (m)	-0.0028308	0.97552063
Distance to Nearest Nest (m)	Tree DBH (cm)	-0.0022357	0.97018377
Distance to Nearest House (m)	Tree Height (m)	0.00308786	0.95882848
Roads 1000m	Distance to Brushland (m)	-0.0036715	0.95105611
Distance to Nearest Nest (m)	Distance to Brushland (m)	0.00372455	0.95034918
Houses 1000m	Tree Height (m)	0.00389145	0.94812733
Roads 1000m	Nest Height (m)	-0.0066751	0.94231715
Distance to Terrestrial Edge (m)	Tree Height (m)	0.00435384	0.94197397
Distance to Water (m)	Distance to Cultivation (m)	0.00609958	0.91877624
Houses 1000m	Distance to Bog (m)	-0.0063919	0.91489808
Distance to Water (m)	Distance to Railroad (m)	-0.0064635	0.91394775
Distance to Brushland (m)	Stand Height (m)	0.0067812	0.9097362
Distance to Nearest House (m)	Stand Diameter (cm)	-0.0072124	0.90402281
Distance to Bog (m)	Nest to Top Distance (m)	-0.0123118	0.89382763
Distance to Water (m)	Distance to Bog (m)	-0.0090191	0.88014381
Distance to Railroad (m)	Tree DBH (cm)	-0.0101522	0.8652218
Distance to Brushland (m)	Distance to Railroad (m)	-0.0104216	0.86167986
Roads 1000m	Distance to Water (m)	0.01204538	0.84039738
Tree DBH (cm)	Nest Height (m)	-0.0203732	0.82519808
Houses 1000m	Stand Height (m)	-0.0135928	0.82022267
Stand Height (m)	Nest to Top Distance (m)	0.02186671	0.81261106
Distance to Bog (m)	Stand Diameter (cm)	-0.0146895	0.80599469
Distance to Nearest House (m)	Tree DBH (cm)	0.01565975	0.79346028
Distance to Bog (m)	Distance to Nearest Roads (m)	-0.0158253	0.79132718
Distance to Water (m)	Distance to Brushland (m)	-0.016023	0.78878118
Distance to Forest (m)	Nest to Top Distance (m)	-0.0286399	0.75616998
Houses 1000m	Stand Diameter (cm)	0.02047793	0.73205634

Table 17. (continued)

VARIABLE	BY VARIABLE	CORRELATION	SIGN. PROB.
Landuse 1000m	Tree Height (m)	-0.0209752	0.72580819
Distance to Railroad (m)	Stand Height (m)	-0.0211082	0.72413963
Distance to Brushland (m)	Stand Diameter (cm)	0.02142496	0.72017164
Roads 1000m	Tree DBH (cm)	-0.0217766	0.71577599
Distance to Nearest Nest (m)	Stand Diameter (cm)	-0.0240124	0.68804902
Distance to Brushland (m)	Tree Height (m)	-0.024519	0.68182316
Roads 1000m	Nest to Top Distance (m)	-0.0418776	0.64972535
Houses 1000m	Nest to Top Distance (m)	-0.0425151	0.64475335
Distance to Bog (m)	Tree DBH (cm)	0.0281115	0.63830611
Distance to Cultivation (m)	Nest to Top Distance (m)	0.04417577	0.6318745
Distance to Nearest Roads (m)	Stand Diameter (cm)	0.02926256	0.62461228
Houses 1000m	Tree DBH (cm)	0.02940296	0.62295064
Landuse 1000m	Distance to Nearest Nest (m)	-0.0312137	0.60169334
Distance to Water (m)	Nest Height (m)	0.04945014	0.59171149
Distance to Brushland (m)	Distance to Nearest House (m)	-0.0320999	0.59141077
Distance to Water (m)	Distance to Forest (m)	-0.0354069	0.55376535
Distance to Water (m)	Distance to Nearest Roads (m)	-0.0357438	0.54999676
Houses 1000m	Nest Height (m)	-0.0555856	0.54650704
Distance to Water (m)	Distance to Terrestrial Edge (m)	0.03701654	0.53587376
Roads 1000m	Distance to Nearest Nest (m)	0.0370461	0.53554801
Distance to Forest (m)	Stand Diameter (cm)	0.03842204	0.52049197
Distance to Nearest Roads (m)	Nest to Top Distance (m)	0.06007818	0.51451467
Distance to Nearest Roads (m)	Nest Height (m)	-0.0603392	0.51268569
Stand Diameter (cm)	Nest Height (m)	0.06283013	0.49540366
Houses 1000m	Distance to Forest (m)	-0.0409894	0.49299096
Houses 1000m	Distance to Grassland (m)	-0.0420331	0.48203615
Distance to Forest (m)	Tree DBH (cm)	0.04256564	0.47649796
Distance to City Roads (m)	Nest to Top Distance (m)	0.06632541	0.47168099
Distance to Water (m)	Distance to Grassland (m)	0.04306778	0.4713077
Houses 1000m	Distance to Terrestrial Edge (m)	-0.043722	0.46459191
Nest to Top Distance (m)	Nest Height (m)	-0.0689634	0.4541943
Distance to Brushland (m)	Nest Height (m)	-0.0727205	0.42992437
Distance to Nearest Roads (m)	Tree DBH (cm)	0.04894697	0.4129009
Distance to Nearest Nest (m)	Nest to Top Distance (m)	-0.0778868	0.39779733
Distance to Railroad (m)	Stand Diameter (cm)	-0.0518442	0.38576173
Landuse 1000m	Stand Height (m)	-0.0518521	0.38568987
Distance to Forest (m)	Distance to Nearest Roads (m)	-0.0521955	0.38254622
Distance to Forest (m)	Distance to Grassland (m)	-0.0540692	0.36567444
Distance to Railroad (m)	Nest to Top Distance (m)	0.08804952	0.33892203
Distance to Nearest House (m)	Nest to Top Distance (m)	-0.0901989	0.32721658
Distance to Forest (m)	Distance to Nearest House (m)	-0.0589674	0.32379416
Distance to Railroad (m)	Nest Height (m)	0.09084674	0.32373966

Table 17. (continued)

VARIABLE	BY VARIABLE	CORRELATION	SIGN. PROB.
Distance to Brushland (m)	Distance to City Roads (m)	0.05959743	0.31864197
Distance to Bog (m)	Nest Height (m)	-0.0918641	0.31832786
Distance to Grassland (m)	Nest to Top Distance (m)	0.09382914	0.30804198
Distance to Bog (m)	Tree Height (m)	-0.0615321	0.3031571
Distance to Forest (m)	Distance to Terrestrial Edge (m)	-0.0620233	0.29930663
Distance to Railroad (m)	Distance to Nearest House (m)	0.06241628	0.29624913
Distance to Grassland (m)	Stand Diameter (cm)	-0.0635976	0.28718364
Distance to Terrestrial Edge (m)	Stand Height (m)	0.06655218	0.26533393
Distance to Brushland (m)	Distance to Grassland (m)	0.06669159	0.26433182
Distance to Nearest Roads (m)	Tree Height (m)	0.06708716	0.26150272
Distance to Bog (m)	Distance to Nearest House (m)	-0.0684394	0.25198905
Distance to Nearest Nest (m)	Distance to Nearest House (m)	-0.0694255	0.24520437
Roads 1000m	Distance to Forest (m)	-0.0695841	0.24412508
Distance to Nearest Nest (m)	Distance to Nearest Roads (m)	-0.0696238	0.24385566
Distance to Grassland (m)	Tree Height (m)	0.07039727	0.23864398
Distance to Grassland (m)	Tree DBH (cm)	-0.0706018	0.23727933
Roads 1000m	Stand Height (m)	-0.0707567	0.23624935
Distance to Nearest Nest (m)	Distance to Grassland (m)	-0.0715437	0.23106439
Landuse 1000m	Nest to Top Distance (m)	0.11090387	0.22785653
Distance to Nearest House (m)	Stand Height (m)	0.07205776	0.22772127
Distance to Forest (m)	Nest Height (m)	-0.1179483	0.19948564
Distance to Nearest Nest (m)	Distance to City Roads (m)	-0.0768443	0.19823117
Houses 1000m	Distance to Cultivation (m)	-0.0782465	0.19014312
Distance to Bog (m)	Distance to Grassland (m)	-0.0792344	0.18459206
Distance to Nearest Nest (m)	Distance to Railroad (m)	-0.0793481	0.18396084
Distance to Bog (m)	Distance to Terrestrial Edge (m)	-0.0811545	0.17414485
Distance to Terrestrial Edge (m)	Nest to Top Distance (m)	-0.1250203	0.17365947
Houses 1000m	Distance to Nearest Roads (m)	-0.081532	0.17214387
Distance to Terrestrial Edge (m)	Stand Diameter (cm)	-0.0818772	0.17032902
Distance to Railroad (m)	Tree Height (m)	0.08191703	0.17012033
Distance to Nearest Nest (m)	Distance to Terrestrial Edge (m)	-0.0829622	0.16471724
Distance to Brushland (m)	Nest to Top Distance (m)	-0.1285161	0.16184403
Distance to Water (m)	Distance to City Roads (m)	0.08551216	0.15207523
Houses 1000m	Distance to Railroad (m)	-0.0859423	0.15001707
Distance to Water (m)	Stand Height (m)	-0.0861143	0.1492001
Distance to Terrestrial Edge (m)	Tree DBH (cm)	-0.0870639	0.14475025
Distance to Cultivation (m)	Stand Diameter (cm)	-0.0884324	0.138516
Distance to Forest (m)	Distance to Cultivation (m)	-0.0890625	0.13571557
Distance to City Roads (m)	Tree DBH (cm)	-0.0891347	0.1353976
Distance to Grassland (m)	Stand Height (m)	0.09170619	0.12443839
Houses 1000m	Distance to Nearest Nest	-0.0923254	0.12190536

Table 17. (continued)

VARIABLE	BY VARIABLE	CORRELATION	SIGN. PROB.
	(m)		
Houses 1000m	Distance to Brushland (m)	0.09312691	0.11868591
Distance to City Roads (m)	Tree Height (m)	0.09382956	0.11591857
Houses 1000m	Landuse 1000m	0.09386681	0.11577329
Distance to Brushland (m)	Distance to Nearest Roads (m)	0.09435917	0.1138663
Distance to Nearest House (m)	Nest Height (m)	-0.1467126	0.10982082
Roads 1000m	Tree Height (m)	-0.0959203	0.10798216
Stand Diameter (cm)	Stand Height (m)	0.09633285	0.10646786
Houses 1000m	Distance to Water (m)	-0.0974297	0.10252304
Distance to Terrestrial Edge (m)	Distance to Nearest House (m)	0.09816735	0.09993602
Roads 1000m	Distance to Bog (m)	0.09950461	0.09537812
Distance to Forest (m)	Tree Height (m)	-0.1007182	0.09138638
Distance to Bog (m)	Stand Height (m)	-0.1026265	0.08538113
Distance to Water (m)	Nest to Top Distance (m)	-0.1589029	0.08300576
Houses 1000m	Distance to Nearest House (m)	-0.1066249	0.07382719
Distance to Cultivation (m)	Tree DBH (cm)	-0.1073665	0.07183076
Distance to Grassland (m)	Nest Height (m)	0.16932463	0.06448419
Distance to Brushland (m)	Distance to Cultivation (m)	0.11098837	0.06270356
Distance to City Roads (m)	Stand Diameter (cm)	-0.1121309	0.06003044
Distance to Cultivation (m)	Nest Height (m)	0.17313743	0.05861344
Distance to Cultivation (m)	Tree Height (m)	0.11303671	0.05797877
Stand Height (m)	Tree DBH (cm)	0.11408016	0.05568743
Distance to Terrestrial Edge (m)	Nest Height (m)	0.17845582	0.05116329
Landuse 1000m	Distance to Bog (m)	-0.1172472	0.04918792
Distance to Bog (m)	Distance to Cultivation (m)	-0.1180961	0.04755752
Landuse 1000m	Distance to Railroad (m)	-0.1191566	0.04558449
Distance to Nearest Nest (m)	Distance to Forest (m)	0.11978168	0.0444541
Distance to Forest (m)	Distance to City Roads (m)	-0.1209835	0.04234659
Distance to City Roads (m)	Nest Height (m)	0.1856596	0.04233643
Distance to Nearest Nest (m)	Nest Height (m)	-0.1866403	0.04123945
Distance to Water (m)	Distance to Nearest House (m)	-0.1252242	0.03556978
Distance to Terrestrial Edge (m)	Distance to Railroad (m)	0.12673766	0.03338522
Landuse 1000m	Nest Height (m)	-0.2022657	0.02672781
Distance to Bog (m)	Distance to Railroad (m)	0.13245672	0.02613122
Stand Height (m)	Nest Height (m)	0.20579384	0.02413609
Distance to Bog (m)	Distance to Brushland (m)	0.14190758	0.01710102
Landuse 1000m	Tree DBH (cm)	0.14332773	0.01601208
Distance to Nearest Roads (m)	Stand Height (m)	0.1462567	0.01395606
Distance to Railroad (m)	Distance to Nearest Roads (m)	0.14765544	0.01305875
Roads 1000m	Distance to Grassland (m)	-0.1496495	0.01186736
Stand Diameter (cm)	Tree Height (m)	0.15243073	0.01036602
Distance to Brushland (m)	Tree DBH (cm)	0.15337531	0.0098958
Tree DBH (cm)	Nest to Top Distance (m)	0.23540046	0.00964874
Landuse 1000m	Stand Diameter (cm)	0.15449953	0.00936087
Distance to Cultivation (m)	Distance to Nearest House (m)	0.16115459	0.00668838

Table 17. (continued)

VARIABLE	BY VARIABLE	CORRELATION	SIGN. PROB.
Distance to City Roads (m)	Stand Height (m)	0.16465877	0.00557553
Distance to Water (m)	Distance to Nearest Nest (m)	0.16794115	0.00468696
Distance to Cultivation (m)	Stand Height (m)	0.17092787	0.00399149
Distance to Nearest Nest (m)	Distance to Bog (m)	0.17517466	0.00316263
Roads 1000m	Distance to Terrestrial Edge (m)	-0.1773957	0.0027944
Distance to Bog (m)	Distance to City Roads (m)	-0.1832987	0.0019971
Distance to Nearest Nest (m)	Distance to Cultivation (m)	-0.1879473	0.00152201
Roads 1000m	Distance to Railroad (m)	-0.1886418	0.00146068
Roads 1000m	Distance to Nearest House (m)	-0.1995139	0.00075314
Roads 1000m	Distance to Cultivation (m)	-0.2037222	0.00057733
Landuse 1000m	Distance to Water (m)	-0.2065082	0.00048274
Houses 1000m	Distance to City Roads (m)	-0.2070257	0.00046684
Distance to Nearest House (m)	Distance to Nearest Roads (m)	0.20815823	0.00043372
Distance to Forest (m)	Stand Height (m)	-0.2082224	0.00043191
Landuse 1000m	Distance to Brushland (m)	-0.2104845	0.00037243
Distance to Water (m)	Stand Diameter (cm)	-0.2107807	0.00036523
Distance to Bog (m)	Distance to Forest (m)	0.21676324	0.00024483
Landuse 1000m	Distance to Nearest House (m)	-0.2173654	0.00023503
Distance to Forest (m)	Distance to Brushland (m)	0.22909601	0.00010367
Distance to Grassland (m)	Distance to Railroad (m)	0.23022304	0.00009561
Roads 1000m	Distance to Nearest Roads (m)	-0.2312519	0.00008877
Distance to Grassland (m)	Distance to Nearest House (m)	0.23233745	0.00008206
Roads 1000m	Landuse 1000m	0.2354633	0.00006529
Distance to Cultivation (m)	Distance to Railroad (m)	0.23563933	0.00006445
Distance to Forest (m)	Distance to Railroad (m)	0.24039598	0.00004523
Distance to City Roads (m)	Distance to Railroad (m)	0.24097938	0.00004329
Distance to Nearest Nest (m)	Stand Height (m)	-0.2414386	0.00004182
Tree Height (m)	Nest to Top Distance (m)	0.36522813	0.00004103
Distance to City Roads (m)	Distance to Nearest House (m)	0.24190956	0.00004035
Distance to Nearest Nest (m)	Tree Height (m)	-0.2549334	0.00001465
Landuse 1000m	Distance to Nearest Roads (m)	-0.2749663	0.00000276
Landuse 1000m	Distance to Grassland (m)	-0.2943794	4.81632e-7
Distance to Water (m)	Tree DBH (cm)	-0.2956963	4.25757e-7
Roads 1000m	Distance to City Roads (m)	-0.3119766	8.80406e-8
Tree DBH (cm)	Tree Height (m)	0.33302	9.92778e-9
Distance to Terrestrial Edge (m)	Distance to Grassland (m)	0.33695919	6.47562e-9
Distance to Water (m)	Tree Height (m)	-0.3525624	1.12259e-9
Landuse 1000m	Distance to City Roads (m)	-0.3617055	3.8417e-10
Distance to Terrestrial Edge (m)	Distance to Nearest Roads (m)	0.39042533	1.0537e-11
Distance to Cultivation (m)	Distance to Nearest Roads (m)	0.39272158	7.7825e-12
Distance to Terrestrial Edge (m)	Distance to Brushland (m)	0.39640851	4.7611e-12
Distance to City Roads (m)	Distance to Nearest Roads	0.40688312	1.1398e-12

Table 17. (continued)

VARIABLE	BY VARIABLE	CORRELATION	SIGN. PROB.
	(m)		
Landuse 1000m	Distance to Cultivation (m)	-0.407894	9.9025e-13
Landuse 1000m	Distance to Terrestrial Edge (m)	-0.4295097	4.3591e-14
Distance to Grassland (m)	Distance to Cultivation (m)	0.45145896	1.4437e-15
Distance to Grassland (m)	Distance to Nearest Roads (m)	0.45887322	4.3153e-16
Distance to Terrestrial Edge (m)	Distance to City Roads (m)	0.46610835	1.2906e-16
Distance to Grassland (m)	Distance to City Roads (m)	0.47233983	4.4591e-17
Stand Diameter (cm)	Tree DBH (cm)	0.47857942	1.5051e-17
Stand Height (m)	Tree Height (m)	0.48455126	5.2125e-18
Distance to Terrestrial Edge (m)	Distance to Cultivation (m)	0.49521121	7.4521e-19
Distance to Cultivation (m)	Distance to City Roads (m)	0.50379915	1.4789e-19
Tree Height (m)	Nest Height (m)	0.83226499	5.1563e-32
Houses 1000m	Roads 1000m	0.70548671	9.1495e-44

APPENDIX G. MULTI-CORRELATION SCREENING OF VARIABLES FOR PRODUCTIVITY MODELING

Table 18 presents pairwise correlation coefficients and significant correlations between each variable. Coefficients summarize the strength of linear relationship for each response variable. These data were used in screening variables for modeling productivity. Significant probabilities are arranged in descending order. Values less than 0.05 are highly correlated.

Table 18. Evaluation of variables for Productivity Modeling

VARIABLE	BY VARIABLE	CORRELATION	SIGN. PROB.
Distance to Bog (m)	Distance to Grassland (m)	0.00066479	0.99425035
Distance to Water (m)	Distance to Railroad (m)	-0.0024202	0.97906988
Stand Diameter (cm)	Nest to Top Distance (m)	-0.0028308	0.97552063
Houses 1000m	Tree DBH (cm)	0.0029053	0.97487649
Houses 1000m	Stand Diameter (cm)	0.00319911	0.97233668
Landuse 1000m	Stand Height (m)	-0.004759	0.95885759
Distance to Bog (m)	Stand Diameter (cm)	0.00476137	0.95883739
Distance to Nearest Nest (m)	Stand Height (m)	-0.0057204	0.95055639
Distance to City Roads (m)	Tree DBH (cm)	-0.0063164	0.94541251
Distance to Brushland (m)	Distance to Nearest Roads (m)	-0.0064116	0.94459036
Roads 1000m	Tree DBH (cm)	0.00654295	0.94345747
Roads 1000m	Nest Height (m)	-0.0066751	0.94231715
Roads 1000m	Tree Height (m)	0.00679383	0.94129323
Distance to Nearest Nest (m)	Distance to Nearest House (m)	0.00719471	0.93783586
Distance to Water (m)	Distance to Brushland (m)	-0.0080348	0.93059427
Distance to Railroad (m)	Distance to Nearest House (m)	0.00904447	0.92189883
Distance to Cultivation (m)	Stand Diameter (cm)	0.01068431	0.90779598
Distance to Bog (m)	Nest to Top Distance (m)	-0.0123118	0.89382763
Distance to City Roads (m)	Stand Diameter (cm)	0.0137053	0.88189328
Roads 1000m	Distance to Bog (m)	-0.014569	0.87450946
Distance to Grassland (m)	Tree DBH (cm)	0.01708529	0.85306084
Roads 1000m	Stand Diameter (cm)	-0.0186535	0.83974683
Distance to Bog (m)	Distance to Cultivation (m)	-0.0190542	0.83635181
Tree DBH (cm)	Nest Height (m)	-0.0203732	0.82519808
Stand Height (m)	Nest to Top Distance (m)	0.02186671	0.81261106
Distance to Brushland (m)	Stand Height (m)	-0.0237421	0.79687334
Stand Height (m)	Tree DBH (cm)	-0.0246381	0.78938243
Distance to Forest (m)	Tree DBH (cm)	0.02557963	0.78153195
Distance to Water (m)	Distance to Nearest House (m)	-0.0260671	0.7774761
Distance to Terrestrial Edge (m)	Stand Diameter (cm)	-0.0262091	0.77629533
Distance to Grassland (m)	Stand Diameter (cm)	0.02652957	0.77363331

Table 18. (continued)

VARIABLE	BY VARIABLE	CORRELATION	SIGN. PROB.
Distance to Railroad (m)	Stand Diameter (cm)	0.02672998	0.77196986
Stand Diameter (cm)	Stand Height (m)	-0.0286276	0.75627153
Distance to Forest (m)	Nest to Top Distance (m)	-0.0286399	0.75616998
Houses 1000m	Distance to Bog (m)	-0.0289115	0.75393124
Distance to Brushland (m)	Distance to Railroad (m)	-0.0307009	0.73923281
Distance to Terrestrial Edge (m)	Stand Height (m)	0.0313119	0.73423482
Distance to Water (m)	Distance to Cultivation (m)	0.03139749	0.73353562
Distance to Cultivation (m)	Stand Height (m)	0.0317796	0.73041669
Distance to Brushland (m)	Distance to Grassland (m)	-0.0322028	0.72696727
Houses 1000m	Landuse 1000m	0.03359121	0.71569038
Distance to Nearest Roads (m)	Tree Height (m)	-0.0344158	0.70902151
Distance to Brushland (m)	Stand Diameter (cm)	0.03472921	0.70649239
Distance to Grassland (m)	Stand Height (m)	0.03479954	0.70592532
Houses 1000m	Distance to Railroad (m)	-0.0385206	0.67615867
Distance to Railroad (m)	Tree DBH (cm)	0.03867684	0.67491956
Landuse 1000m	Distance to Railroad (m)	-0.0408882	0.65747291
Roads 1000m	Nest to Top Distance (m)	-0.0418776	0.64972535
Houses 1000m	Nest to Top Distance (m)	-0.0425151	0.64475335
Stand Diameter (cm)	Tree Height (m)	0.04256551	0.64436059
Distance to Cultivation (m)	Nest to Top Distance (m)	0.04417577	0.6318745
Distance to Nearest Nest (m)	Stand Diameter (cm)	0.0447598	0.62737112
Houses 1000m	Distance to Forest (m)	-0.0448978	0.62630893
Houses 1000m	Stand Height (m)	-0.0451411	0.62443801
Houses 1000m	Distance to Nearest Nest (m)	-0.0463847	0.61491431
Distance to Railroad (m)	Distance to Nearest Roads (m)	0.0469031	0.61096254
Distance to Cultivation (m)	Tree DBH (cm)	-0.0474963	0.60645458
Distance to Nearest House (m)	Stand Height (m)	-0.048411	0.5995326
Houses 1000m	Distance to Cultivation (m)	-0.0494461	0.5917416
Distance to Water (m)	Nest Height (m)	0.04945014	0.59171149
Distance to Nearest House (m)	Stand Diameter (cm)	-0.0505202	0.58370688
Houses 1000m	Distance to Grassland (m)	-0.0511501	0.5790176
Distance to Brushland (m)	Distance to Cultivation (m)	-0.0511913	0.57871201
Distance to Water (m)	Tree Height (m)	-0.0512027	0.578627
Distance to Forest (m)	Stand Diameter (cm)	0.05328359	0.56326828
Distance to Forest (m)	Distance to Nearest Roads (m)	-0.0534258	0.56222574
Distance to Bog (m)	Tree DBH (cm)	0.05448019	0.55452509
Roads 1000m	Stand Height (m)	0.05472116	0.55277232
Distance to Terrestrial Edge (m)	Distance to Nearest House (m)	0.05474319	0.55261221
Houses 1000m	Nest Height (m)	-0.0555856	0.54650704
Distance to Bog (m)	Distance to Terrestrial Edge (m)	-0.0578571	0.53021042
Distance to Forest (m)	Distance to Grassland (m)	-0.0582798	0.52720448
Landuse 1000m	Distance to Forest (m)	0.05977179	0.51666552
Distance to Nearest Roads (m)	Nest to Top Distance (m)	0.06007818	0.51451467
Distance to Nearest Roads (m)	Nest Height (m)	-0.0603392	0.51268569
Distance to Nearest Nest (m)	Distance to Forest (m)	-0.060488	0.51164519

Table 18. (continued)

VARIABLE	BY VARIABLE	CORRELATION	SIGN. PROB.
Distance to Water (m)	Distance to Grassland (m)	-0.061277	0.50614317
Stand Diameter (cm)	Nest Height (m)	0.06283013	0.49540366
Houses 1000m	Tree Height (m)	-0.0655807	0.47668304
Distance to City Roads (m)	Nest to Top Distance (m)	0.06632541	0.47168099
Distance to Nearest House (m)	Tree DBH (cm)	-0.0671919	0.46589718
Distance to Water (m)	Distance to Terrestrial Edge (m)	0.06724759	0.46552681
Distance to Bog (m)	Distance to Nearest House (m)	-0.0674464	0.46420557
Distance to Terrestrial Edge (m)	Distance to Brushland (m)	0.06751625	0.46374223
Distance to Forest (m)	Distance to Nearest House (m)	-0.0677242	0.46236356
Nest to Top Distance (m)	Nest Height (m)	-0.0689634	0.4541943
Distance to Water (m)	Distance to Nearest Nest (m)	-0.0701137	0.44668407
Distance to Brushland (m)	Nest Height (m)	-0.0727205	0.42992437
Houses 1000m	Distance to Nearest Roads (m)	-0.0751966	0.41434435
Roads 1000m	Distance to Water (m)	-0.0755848	0.41193238
Distance to Water (m)	Distance to Nearest Roads (m)	-0.0769349	0.40360653
Distance to Forest (m)	Distance to Cultivation (m)	-0.0777685	0.39851614
Distance to Terrestrial Edge (m)	Tree DBH (cm)	-0.0777998	0.39832604
Distance to Nearest Nest (m)	Nest to Top Distance (m)	-0.0778868	0.39779733
Landuse 1000m	Distance to Brushland (m)	-0.0819514	0.37355511
Distance to Nearest Roads (m)	Stand Height (m)	0.08275549	0.3688685
Distance to Nearest Roads (m)	Tree DBH (cm)	0.08281136	0.36854419
Distance to Nearest Nest (m)	Distance to Brushland (m)	-0.0851022	0.35539856
Distance to Nearest Roads (m)	Stand Diameter (cm)	0.08726288	0.34327159
Distance to Railroad (m)	Nest to Top Distance (m)	0.08804952	0.33892203
Distance to Nearest Nest (m)	Distance to City Roads (m)	-0.089932	0.32865579
Distance to City Roads (m)	Stand Height (m)	0.09009633	0.32776906
Distance to Nearest House (m)	Nest to Top Distance (m)	-0.0901989	0.32721658
Distance to Railroad (m)	Nest Height (m)	0.09084674	0.32373966
Distance to Bog (m)	Nest Height (m)	-0.0918641	0.31832786
Distance to Grassland (m)	Nest to Top Distance (m)	0.09382914	0.30804198
Distance to Bog (m)	Distance to Nearest Roads (m)	0.09457595	0.30419034
Distance to Brushland (m)	Distance to Nearest House (m)	-0.0947716	0.30318644
Distance to Water (m)	Distance to Forest (m)	-0.0958437	0.29772473
Distance to Cultivation (m)	Distance to Nearest House (m)	0.10012039	0.27658599
Distance to Forest (m)	Distance to Terrestrial Edge (m)	-0.1004525	0.27498759
Distance to Railroad (m)	Tree Height (m)	0.10508924	0.25332451
Houses 1000m	Distance to Terrestrial Edge (m)	0.10686055	0.24536715
Distance to Terrestrial Edge	Tree Height (m)	0.10782897	0.24109067

Table 18. (continued)

VARIABLE	BY VARIABLE	CORRELATION	SIGN. PROB.
(m)			
Landuse 1000m	Tree Height (m)	-0.1090549	0.23575175
Houses 1000m	Distance to Water (m)	-0.1107704	0.22842028
Landuse 1000m	Nest to Top Distance (m)	0.11090387	0.22785653
Distance to Bog (m)	Tree Height (m)	-0.1111681	0.22674351
Distance to City Roads (m)	Distance to Railroad (m)	0.11144269	0.22559113
Distance to Nearest Nest (m)	Distance to Nearest Roads (m)	-0.1118877	0.22373226
Distance to Brushland (m)	Tree Height (m)	-0.1119676	0.22339943
Distance to Nearest Nest (m)	Distance to Railroad (m)	-0.1128114	0.21990824
Landuse 1000m	Distance to Bog (m)	-0.1133251	0.21780156
Roads 1000m	Distance to Forest (m)	-0.1154849	0.20910176
Distance to Grassland (m)	Distance to Nearest House (m)	0.11690843	0.20350516
Distance to Forest (m)	Nest Height (m)	-0.1179483	0.19948564
Distance to Terrestrial Edge (m)	Distance to Railroad (m)	0.12076276	0.18889425
Roads 1000m	Distance to Nearest Nest (m)	0.12291706	0.18106825
Distance to Terrestrial Edge (m)	Nest to Top Distance (m)	-0.1250203	0.17365947
Distance to Water (m)	Distance to City Roads (m)	0.12621971	0.16953607
Distance to Brushland (m)	Nest to Top Distance (m)	-0.1285161	0.16184403
Distance to Grassland (m)	Distance to Railroad (m)	0.12966174	0.15810542
Distance to Bog (m)	Distance to City Roads (m)	-0.1305538	0.15523938
Distance to City Roads (m)	Tree Height (m)	0.13155051	0.15208309
Distance to Forest (m)	Tree Height (m)	-0.1315688	0.15202573
Tree DBH (cm)	Tree Height (m)	0.13168456	0.1516623
Distance to Water (m)	Tree DBH (cm)	-0.1392101	0.12941769
Houses 1000m	Distance to Nearest House (m)	-0.1417504	0.12250265
Distance to Water (m)	Distance to Bog (m)	-0.1465035	0.1103336
Distance to Nearest House (m)	Nest Height (m)	-0.1467126	0.10982082
Stand Height (m)	Tree Height (m)	0.14682774	0.10953918
Distance to Cultivation (m)	Distance to Railroad (m)	0.15523488	0.09045681
Distance to Railroad (m)	Stand Height (m)	-0.1582849	0.08422555
Distance to Water (m)	Nest to Top Distance (m)	-0.1589029	0.08300576
Roads 1000m	Distance to Railroad (m)	-0.1631126	0.07506806
Distance to Water (m)	Stand Diameter (cm)	-0.1637381	0.07394278
Distance to Bog (m)	Stand Height (m)	-0.1638151	0.07380515
Distance to Grassland (m)	Nest Height (m)	0.16932463	0.06448419
Distance to Cultivation (m)	Tree Height (m)	0.17183817	0.06056269
Landuse 1000m	Distance to Nearest Nest (m)	0.17289267	0.05897666
Distance to Nearest Nest (m)	Distance to Grassland (m)	-0.1730614	0.05872609
Distance to Cultivation (m)	Nest Height (m)	0.17313743	0.05861344
Landuse 1000m	Stand Diameter (cm)	0.17429549	0.05691969
Distance to Water (m)	Stand Height (m)	0.17690757	0.05324661
Distance to Terrestrial Edge (m)	Nest Height (m)	0.17845582	0.05116329
Distance to Brushland (m)	Tree DBH (cm)	0.17984422	0.04935282
Roads 1000m	Distance to Brushland (m)	0.18220134	0.04640077
Distance to Nearest Nest (m)	Distance to Cultivation (m)	-0.1829651	0.04547628
Distance to City Roads (m)	Nest Height (m)	0.1856596	0.04233643
Landuse 1000m	Tree DBH (cm)	0.18607906	0.04186431
Distance to Nearest Nest (m)	Nest Height (m)	-0.1866403	0.04123945

Table 18. (continued)

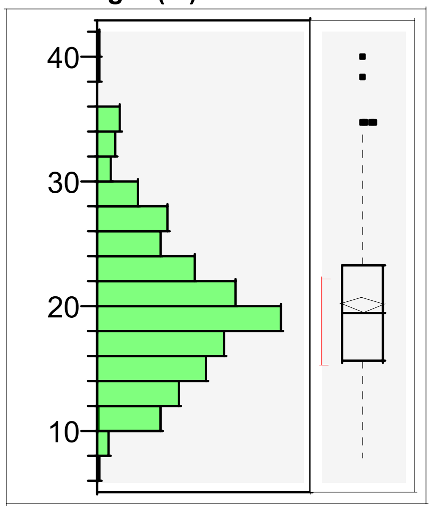
VARIABLE	BY VARIABLE	CORRELATION	SIGN. PROB.
Distance to Grassland (m)	Tree Height (m)	0.19773176	0.0304036
Distance to Nearest Nest (m)	Tree Height (m)	-0.198618	0.02965314
Roads 1000m	Distance to Grassland (m)	-0.1995912	0.02884731
Landuse 1000m	Nest Height (m)	-0.2022657	0.02672781
Stand Height (m)	Nest Height (m)	0.20579384	0.02413609
Houses 1000m	Distance to Brushland (m)	0.20835715	0.02239081
Roads 1000m	Distance to Terrestrial Edge (m)	-0.2101941	0.02120772
Distance to Brushland (m)	Distance to City Roads (m)	-0.210268	0.02116128
Distance to Nearest House (m)	Distance to Nearest Roads (m)	0.21338094	0.01928257
Distance to Nearest Nest (m)	Distance to Bog (m)	0.21499168	0.01836825
Roads 1000m	Distance to Cultivation (m)	-0.2165158	0.01753784
Landuse 1000m	Distance to Water (m)	-0.218557	0.01647675
Distance to Nearest House (m)	Tree Height (m)	-0.2218511	0.0148816
Distance to Bog (m)	Distance to Brushland (m)	0.22687136	0.01270904
Houses 1000m	Distance to City Roads (m)	-0.2303066	0.01138708
Distance to Nearest Nest (m)	Distance to Terrestrial Edge (m)	-0.2315045	0.01095531
Distance to Forest (m)	Distance to City Roads (m)	-0.2335803	0.01024102
Distance to City Roads (m)	Distance to Nearest House (m)	0.2348364	0.00982898
Roads 1000m	Distance to Nearest Roads (m)	-0.2350226	0.00976916
Tree DBH (cm)	Nest to Top Distance (m)	0.23540046	0.00964874
Distance to Nearest Nest (m)	Tree DBH (cm)	0.24195997	0.00775674
Landuse 1000m	Distance to Nearest House (m)	-0.2595127	0.00420616
Distance to Forest (m)	Stand Height (m)	-0.2608776	0.00400372
Landuse 1000m	Distance to Nearest Roads (m)	-0.2649712	0.00344791
Distance to Forest (m)	Distance to Brushland (m)	0.28458368	0.00163141
Roads 1000m	Distance to Nearest House (m)	-0.2852348	0.0015899
Distance to Terrestrial Edge (m)	Distance to City Roads (m)	0.32605144	0.00027888
Landuse 1000m	Distance to Grassland (m)	-0.3469261	0.00010365
Roads 1000m	Landuse 1000m	0.34714009	0.00010257
Tree Height (m)	Nest to Top Distance (m)	0.36522813	0.00004103
Distance to Forest (m)	Distance to Railroad (m)	0.36582574	0.00003977
Roads 1000m	Distance to City Roads (m)	-0.3662319	0.00003893
Distance to Bog (m)	Distance to Forest (m)	0.37446845	0.00002514
Stand Diameter (cm)	Tree DBH (cm)	0.37874304	0.00001994
Landuse 1000m	Distance to City Roads (m)	-0.3799085	0.00001871
Landuse 1000m	Distance to Cultivation (m)	-0.3889118	0.00001134
Distance to City Roads (m)	Distance to Nearest Roads (m)	0.4048958	0.0000045
Distance to Terrestrial Edge (m)	Distance to Grassland (m)	0.41147525	0.00000303
Distance to Bog (m)	Distance to Railroad (m)	0.43336684	7.65003e-7
Distance to Terrestrial Edge (m)	Distance to Nearest Roads (m)	0.474579	4.34958e-8
Distance to Grassland (m)	Distance to Nearest Roads (m)	0.4771449	3.59226e-8

Table 18. (continued)

VARIABLE	BY VARIABLE	CORRELATION	SIGN. PROB.
Distance to Cultivation (m)	Distance to Nearest Roads (m)	0.49375211	1.00195e-8
Distance to Terrestrial Edge (m)	Distance to Cultivation (m)	0.50759048	3.27847e-9
Distance to Grassland (m)	Distance to City Roads (m)	0.53084511	4.4661e-10
Landuse 1000m	Distance to Terrestrial Edge (m)	-0.5474971	9.7372e-11
Distance to Cultivation (m)	Distance to City Roads (m)	0.59484374	7.8415e-13
Houses 1000m	Roads 1000m	0.65605059	4.1879e-16
Distance to Grassland (m)	Distance to Cultivation (m)	0.67127979	4.8588e-17
Tree Height (m)	Nest Height (m)	0.83226499	5.1563e-32

APPENDIX H. RANGE DISTRIBUTION SCREENING OF VARIABLES FOR DISCRIMINANT ANALYSIS

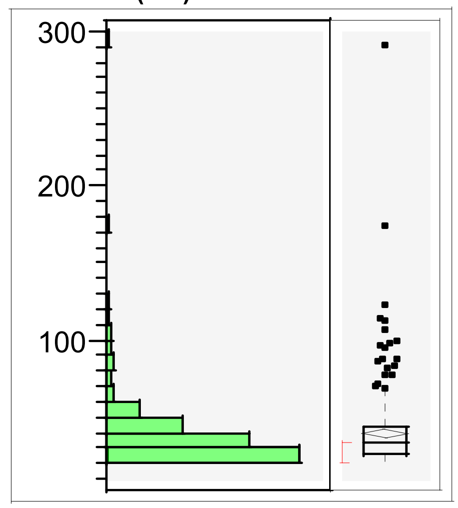
Tree Height (m)



Moments

Mean	20.103747
Std Dev	5.9830181
Std Err Mean	0.3562835
upper 95% Mean	20.805071
lower 95% Mean	19.402424
N	282

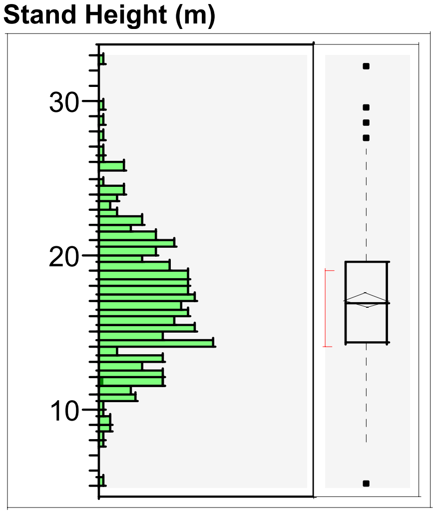
Tree DBH (cm)



Moments

Mean	39.360993
Std Dev	24.884621
Std Err Mean	1.4818576
upper 95% Mean	42.277944
lower 95% Mean	36.444042
N	282

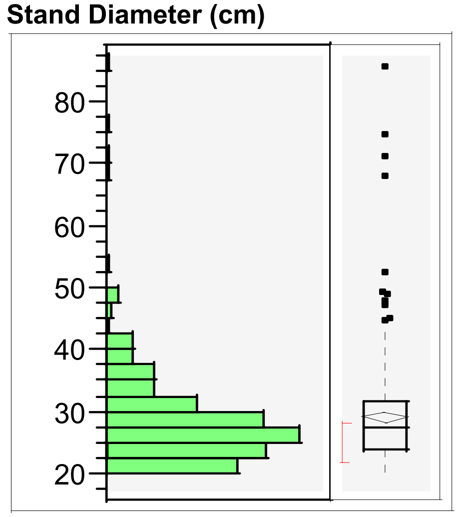
Stand Height (m)



Moments

Mean	17.069318
Std Dev	4.1179685
Std Err Mean	0.2452215
upper 95% Mean	17.552022
lower 95% Mean	16.586613
N	282

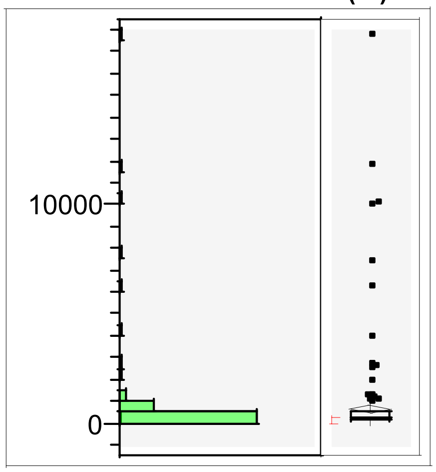
Stand Diameter (cm)



Moments

Mean	29.046908
Std Dev	8.2624525
Std Err Mean	0.4920219
upper 95% Mean	30.015424
lower 95% Mean	28.078391
N	282

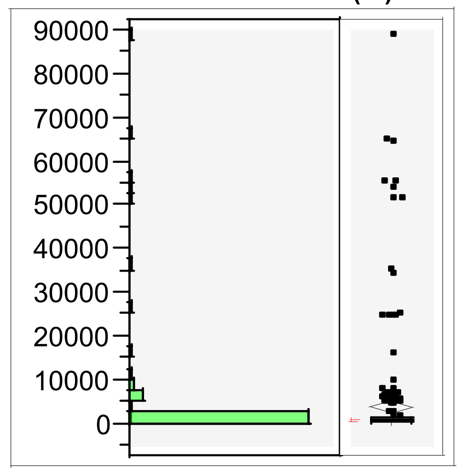
Distance to Nearest Roads (m)



Moments

Mean	605.26596
Std Dev	1656.9403
Std Err Mean	98.66936
upper 95% Mean	799.49088
lower 95% Mean	411.04104
N	282

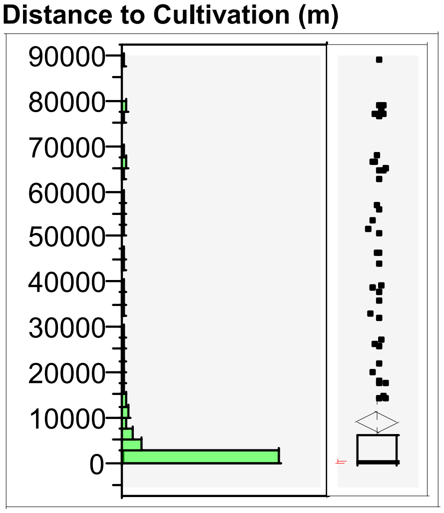
Distance to Nearest House (m)



Moments

Mean	3669.727
Std Dev	11196.513
Std Err Mean	666.74266
upper 95% Mean	4982.1713
lower 95% Mean	2357.2826
N	282

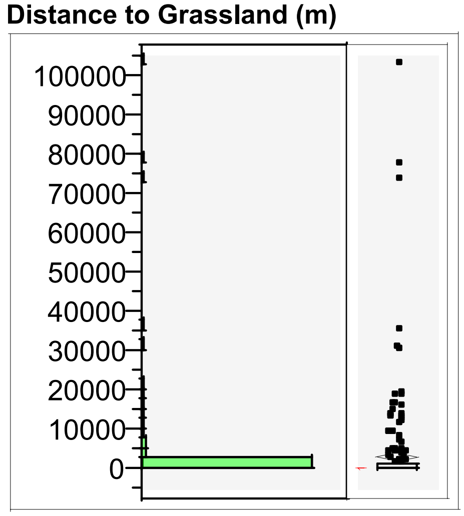
Distance to Cultivation (m)



Moments

Mean	8952.3262
Std Dev	19123.976
Std Err Mean	1138.8162
upper 95% Mean	11194.02
lower 95% Mean	6710.6325
N	282

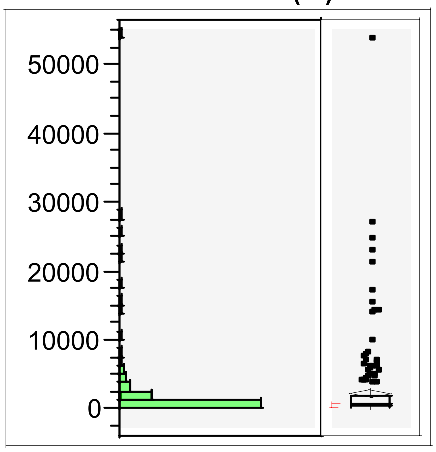
Distance to Grassland (m)



Moments

Mean	2793.5638
Std Dev	10021.132
Std Err Mean	596.74975
upper 95% Mean	3968.2312
lower 95% Mean	1618.8965
N	282

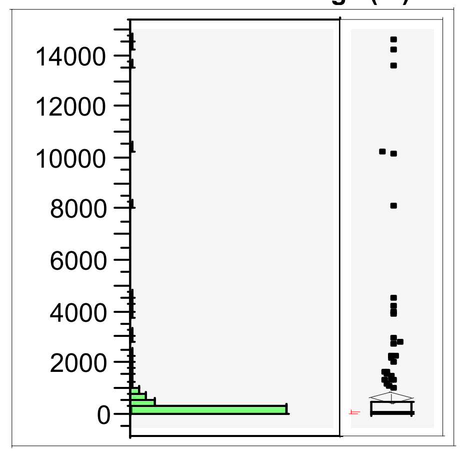
Distance to Brushland (m)



Moments

Mean	2164.523
Std Dev	4887.1576
Std Err Mean	291.026
upper 95% Mean	2737.3909
lower 95% Mean	1591.6552
N	282

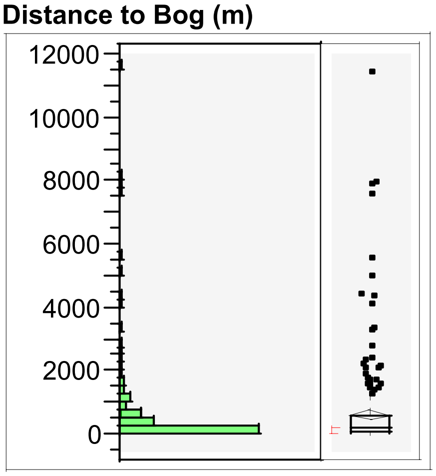
Distance to Terrestrial Edge (m)



Moments

Mean	590.80319
Std Dev	1849.0335
Std Err Mean	110.10834
upper 95% Mean	807.54508
lower 95% Mean	374.0613
N	282

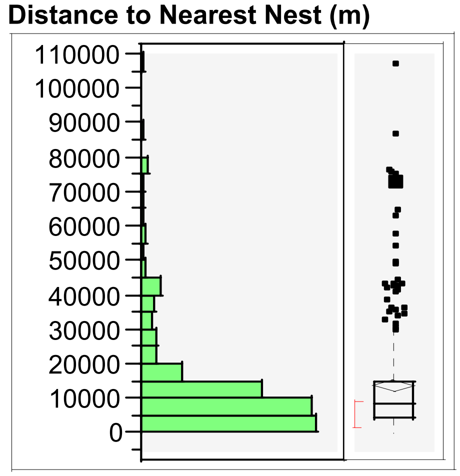
Distance to Bog (m)



Moments

Mean	602.68794
Std Dev	1295.7565
Std Err Mean	77.161175
upper 95% Mean	754.57525
lower 95% Mean	450.80064
N	282

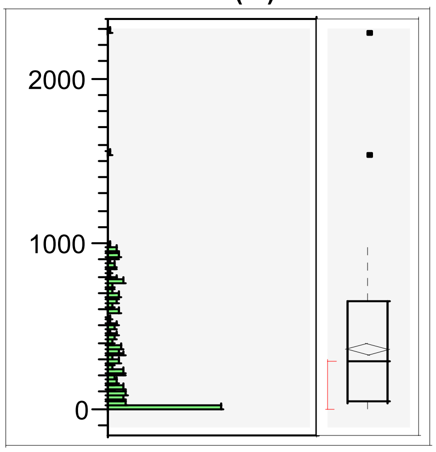
Distance to Nearest Nest (m)



Moments

Mean	13478.358
Std Dev	15867.122
Std Err Mean	944.87338
upper 95% Mean	15338.287
lower 95% Mean	11618.43
N	282

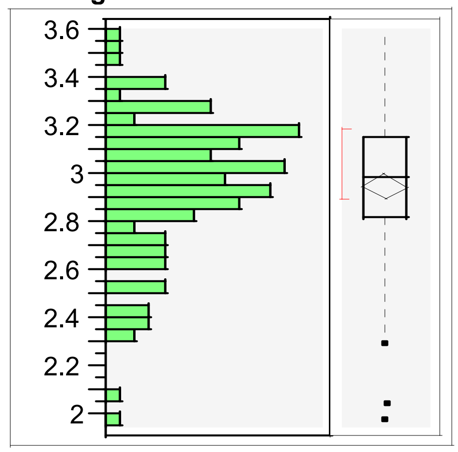
Distance to Water (m)



Moments

Mean	361.89007
Std Dev	342.49871
Std Err Mean	20.395501
upper 95% Mean	402.03743
lower 95% Mean	321.74271
N	282

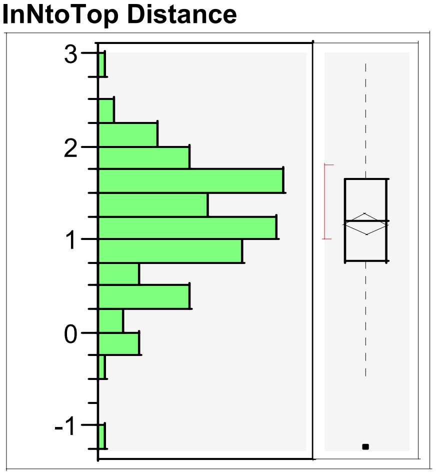
lnNHeight



Moments

Mean	2.9455912
Std Dev	0.290279
Std Err Mean	0.0264987
upper 95% Mean	2.9980613
lower 95% Mean	2.8931211
N	120

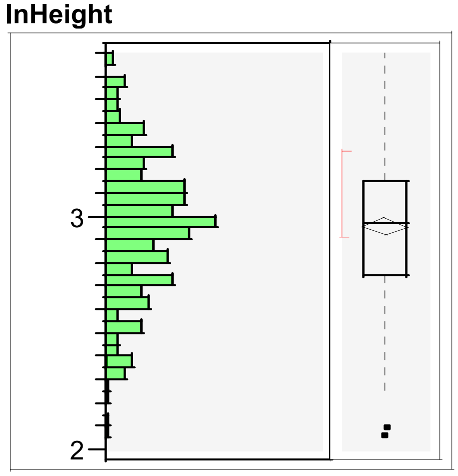
lnNtoTop Distance



Moments

Mean	1.162809
Std Dev	0.6574738
Std Err Mean	0.0600189
upper 95% Mean	1.2816523
lower 95% Mean	1.0439656
N	120

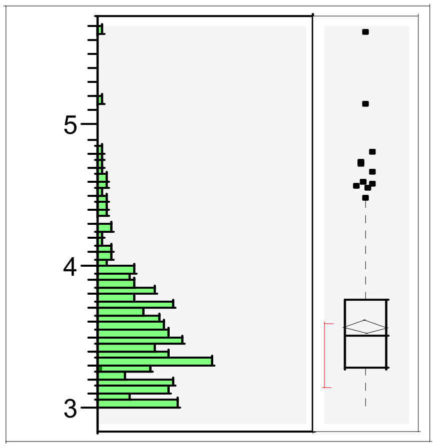
lnHeight



Moments

Mean	2.9562357
Std Dev	0.3033146
Std Err Mean	0.0180621
upper 95% Mean	2.9917899
lower 95% Mean	2.9206814
N	282

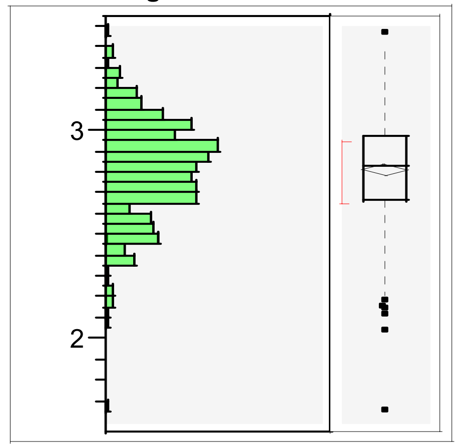
lnDBH



Moments

Mean	3.5683717
Std Dev	0.411253
Std Err Mean	0.0244898
upper 95% Mean	3.6165784
lower 95% Mean	3.520165
N	282

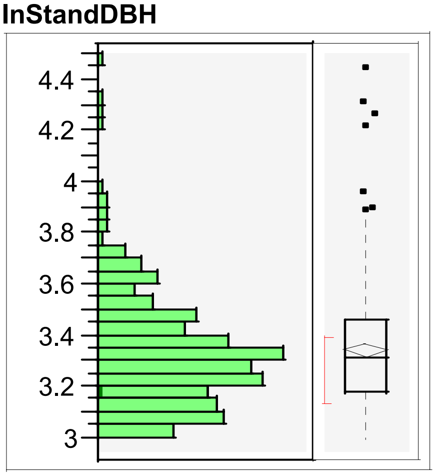
lnStandHeight



Moments

Mean	2.8070422
Std Dev	0.2516086
Std Err Mean	0.0149831
upper 95% Mean	2.8365355
lower 95% Mean	2.7775489
N	282

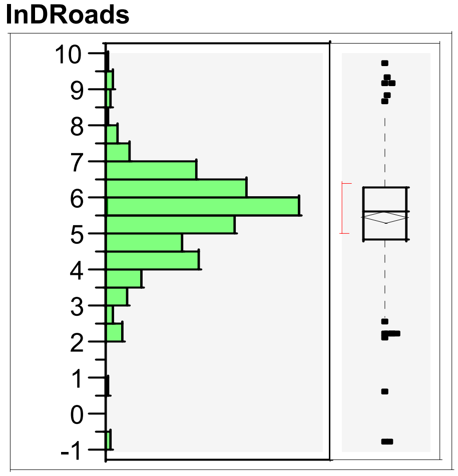
lnStandDBH



Moments

Mean	3.3391921
Std Dev	0.2299294
Std Err Mean	0.0136921
upper 95% Mean	3.3661442
lower 95% Mean	3.31224
N	282

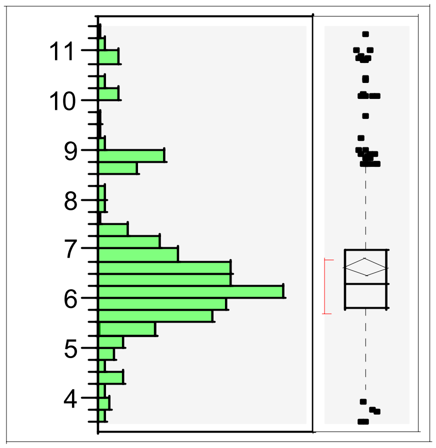
lnDRoads



Moments

Mean	5.4571842
Std Dev	1.3663616
Std Err Mean	0.0813657
upper 95% Mean	5.6173478
lower 95% Mean	5.2970206
N	282

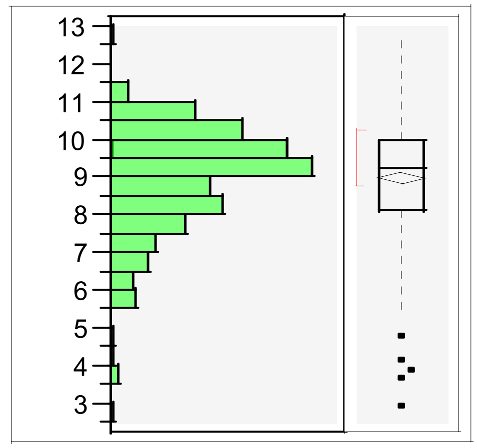
lnDHouse



Moments

Mean	6.6253605
Std Dev	1.4557696
Std Err Mean	0.0866898
upper 95% Mean	6.7960043
lower 95% Mean	6.4547166
N	282

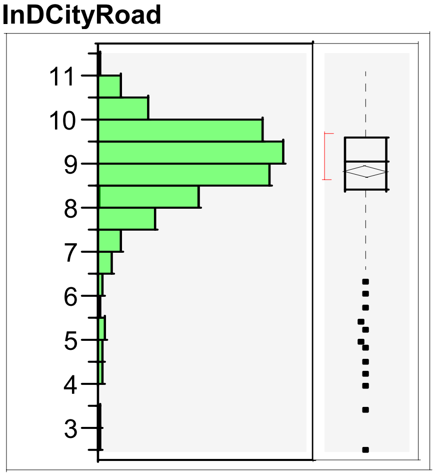
lnDRail



Moments

Mean	8.9613801
Std Dev	1.4276742
Std Err Mean	0.0850168
upper 95% Mean	9.1287307
lower 95% Mean	8.7940296
N	282

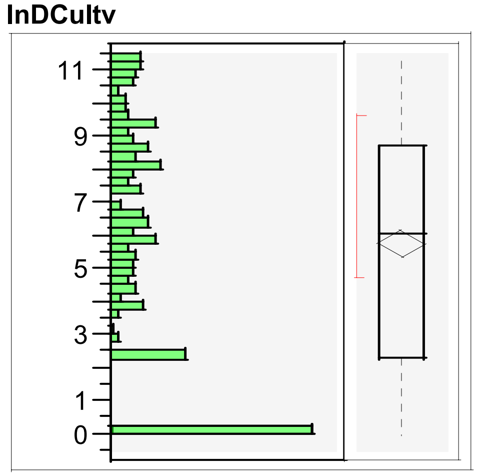
lnDCityRoad



Moments

Mean	8.8292097
Std Dev	1.1924385
Std Err Mean	0.0710087
upper 95% Mean	8.9689862
lower 95% Mean	8.6894332
N	282

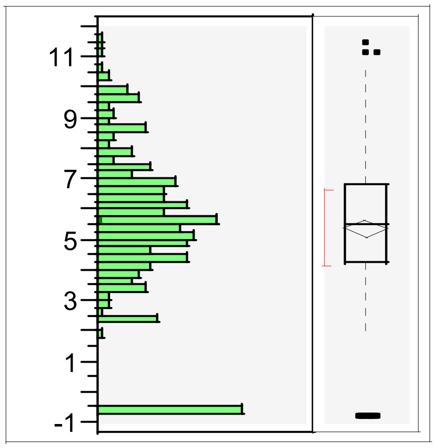
lnDCultv



Moments

Mean	5.7266527
Std Dev	3.6336186
Std Err Mean	0.2163788
upper 95% Mean	6.1525819
lower 95% Mean	5.3007235
N	282

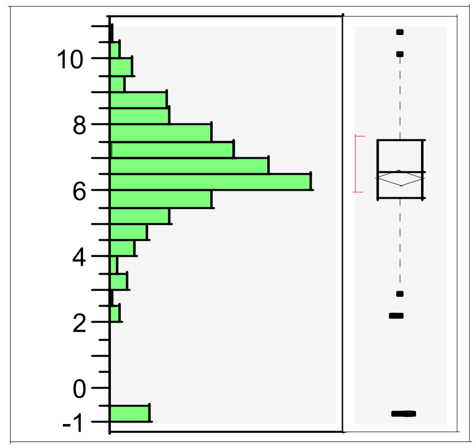
lnDGrass



Moments

Mean	5.3555778
Std Dev	2.6230645
Std Err Mean	0.1562012
upper 95% Mean	5.6630509
lower 95% Mean	5.0481048
N	282

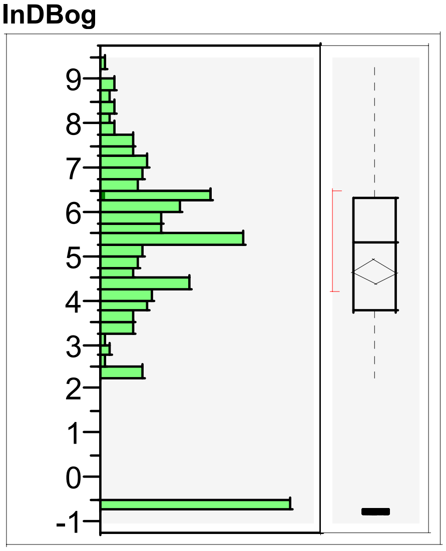
lnDBrush



Moments

Mean	6.4094786
Std Dev	2.0141247
Std Err Mean	0.1199394
upper 95% Mean	6.6455723
lower 95% Mean	6.1733848
N	282

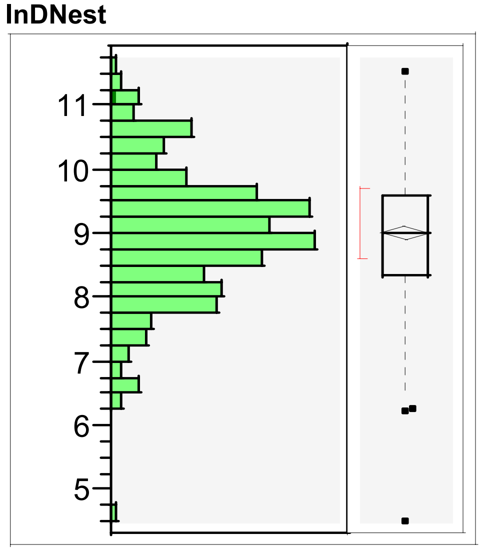
lnDBog



Moments

Mean	4.6443191
Std Dev	2.5647087
Std Err Mean	0.1527262
upper 95% Mean	4.9449517
lower 95% Mean	4.3436864
N	282

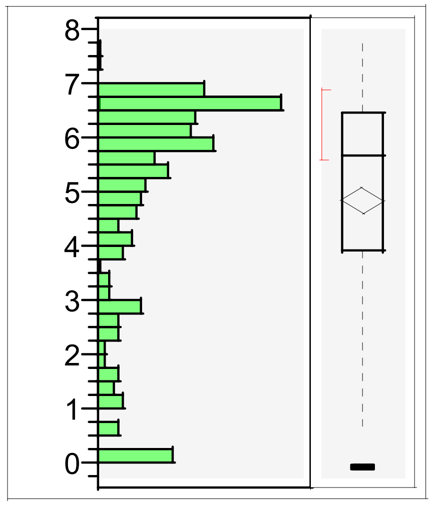
lnDNest



Moments

Mean	9.0008826
Std Dev	1.0404972
Std Err Mean	0.0619607
upper 95% Mean	9.1228487
lower 95% Mean	8.8789165
N	282

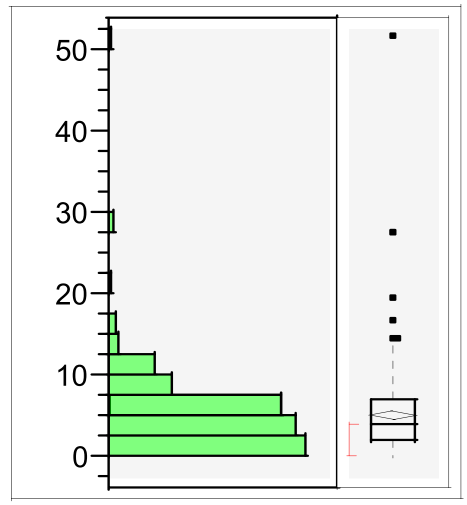
lnDWater



Moments

Mean	4.8442697
Std Dev	2.0567651
Std Err Mean	0.1224786
upper 95% Mean	5.0853617
lower 95% Mean	4.6031777
N	282

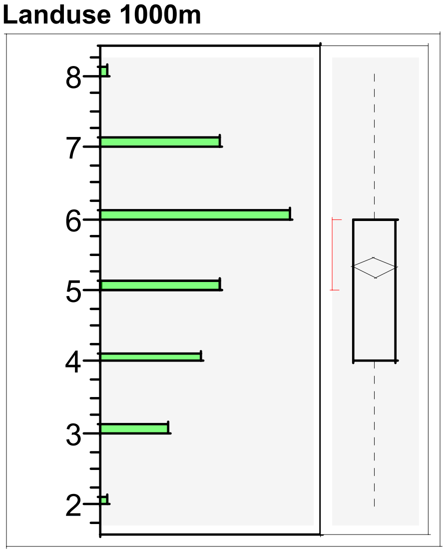
Roads 1000m



Moments

Mean	5.0567376
Std Dev	4.8614586
Std Err Mean	0.2894956
upper 95% Mean	5.626593
lower 95% Mean	4.4868822
N	282

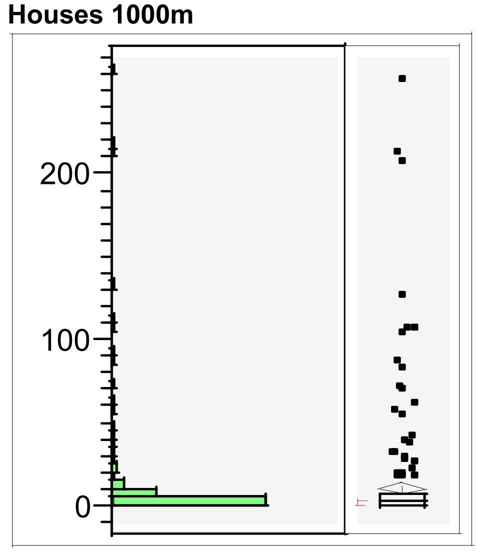
Landuse 1000m



Moments

Mean	5.3156028
Std Dev	1.3615348
Std Err Mean	0.0810782
upper 95% Mean	5.4752006
lower 95% Mean	5.1560051
N	282

Houses 1000m

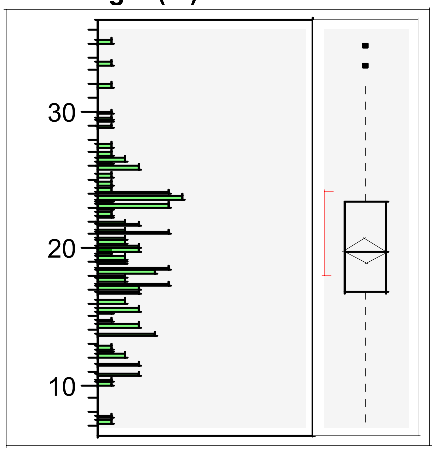


Moments

Mean	10.379433
Std Dev	29.04913
Std Err Mean	1.7298505
upper 95% Mean	13.784543
lower 95% Mean	6.974322
N	282

APPENDIX I. RANGE DISTRIBUTION SCREENING OF VARIABLES FOR PRODUCTIVITY MODELING

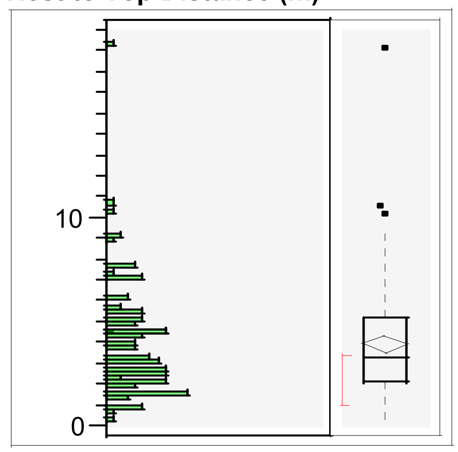
Nest Height (m)



Moments

Mean	19.777874
Std Dev	5.2878275
Std Err Mean	0.4827104
upper 95% Mean	20.733689
lower 95% Mean	18.82206
N	120

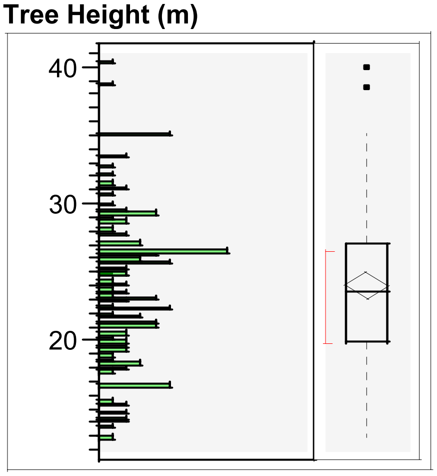
Nest to Top Distance (m)



Moments

Mean	3.8976663
Std Dev	2.5504142
Std Err Mean	0.2328199
upper 95% Mean	4.358673
lower 95% Mean	3.4366597
N	120

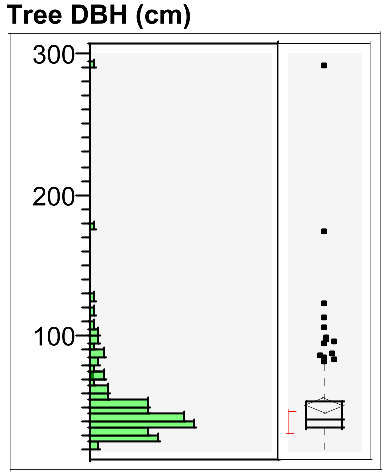
Tree Height (m)



Moments

Mean	23.994314
Std Dev	5.7090758
Std Err Mean	0.5211649
upper 95% Mean	25.026273
lower 95% Mean	22.962356
N	120

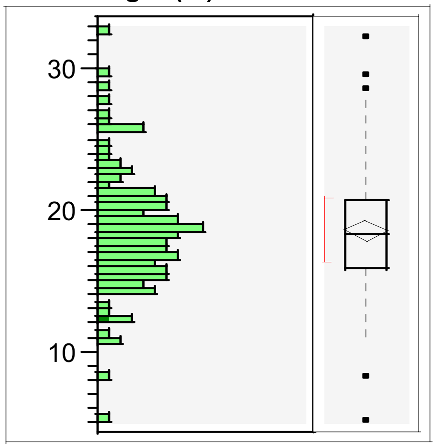
Tree DBH (cm)



Moments

Mean	51.559167
Std Dev	32.549095
Std Err Mean	2.9713123
upper 95% Mean	57.442662
lower 95% Mean	45.675672
N	120

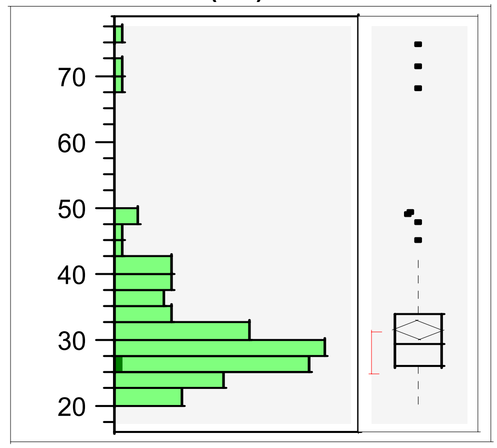
Stand Height (m)



Moments

Mean	18.548319
Std Dev	4.2348356
Std Err Mean	0.3865858
upper 95% Mean	19.313797
lower 95% Mean	17.78284
N	120

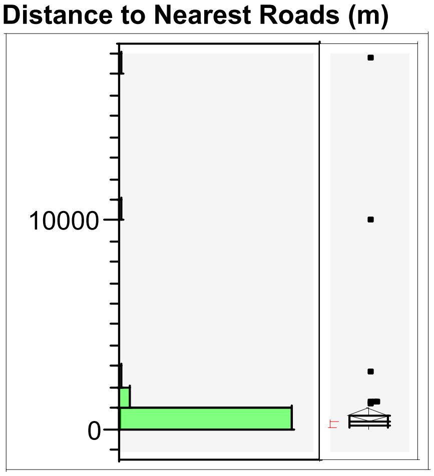
Stand Diameter (cm)



Moments

Mean	31.411807
Std Dev	9.0547656
Std Err Mean	0.8265832
upper 95% Mean	33.048524
lower 95% Mean	29.77509
N	120

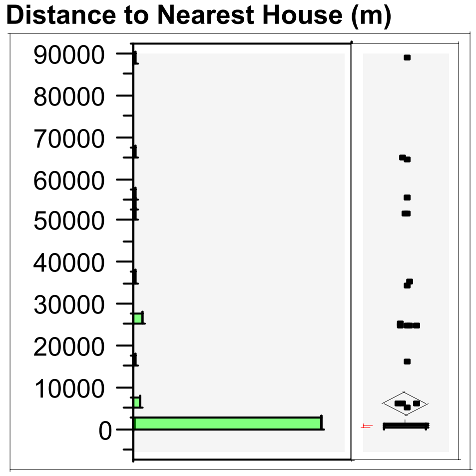
Distance to Nearest Roads (m)



Moments

Mean	668.88333
Std Dev	1864.4425
Std Err Mean	170.19953
upper 95% Mean	1005.8954
lower 95% Mean	331.87126
N	120

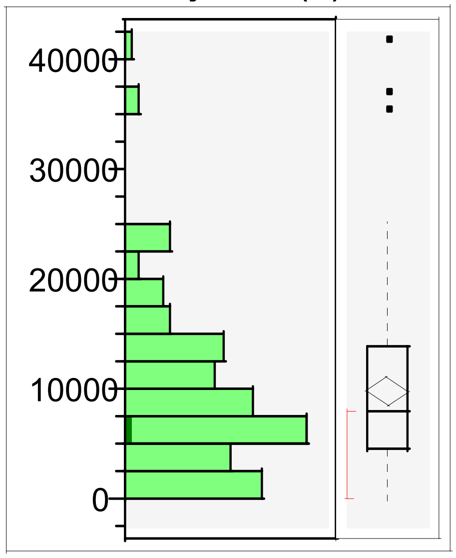
Distance to Nearest House (m)



Moments

Mean	6147.6
Std Dev	15949.327
Std Err Mean	1455.9677
upper 95% Mean	9030.5614
lower 95% Mean	3264.6386
N	120

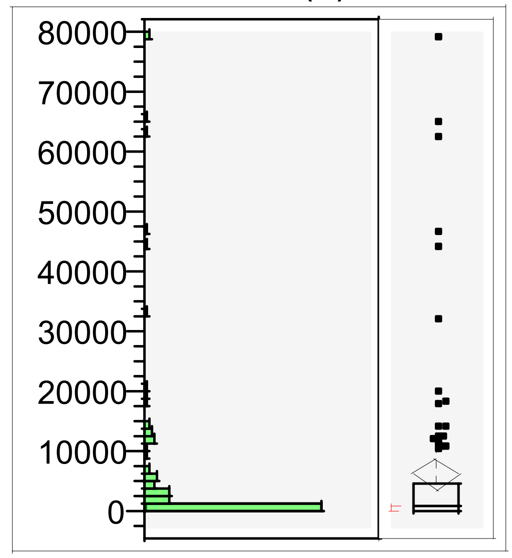
Distance to City Roads (m)



Moments

Mean	9752.025
Std Dev	7787.5412
Std Err Mean	710.902
upper 95% Mean	11159.682
lower 95% Mean	8344.368
N	120

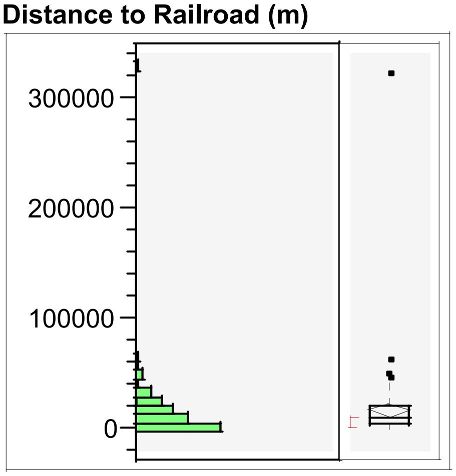
Distance to Cultivation (m)



Moments

Mean	6128.9667
Std Dev	14522.693
Std Err Mean	1325.7344
upper 95% Mean	8754.0533
lower 95% Mean	3503.8801
N	120

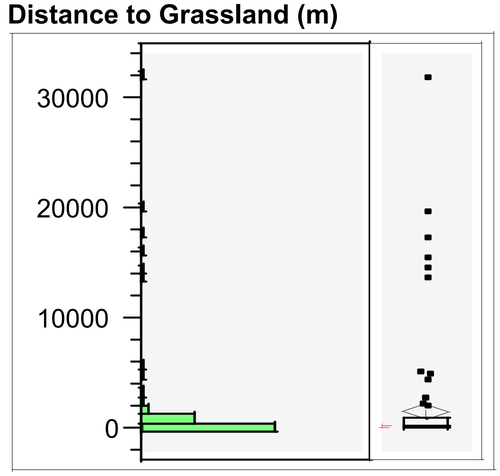
Distance to Railroad (m)



Moments

Mean	15521.458
Std Dev	31434.982
Std Err Mean	2869.6082
upper 95% Mean	21203.569
lower 95% Mean	9839.3476
N	120

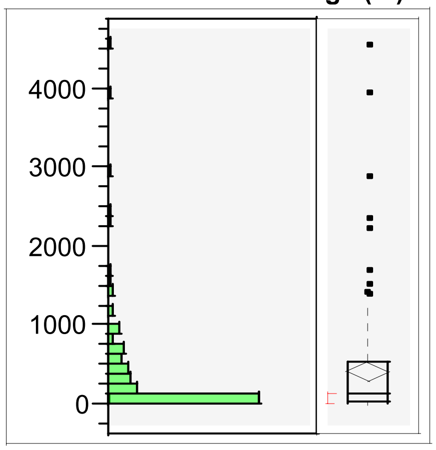
Distance to Grassland (m)



Moments

Mean	1480.4083
Std Dev	4369.0082
Std Err Mean	398.83405
upper 95% Mean	2270.1396
lower 95% Mean	690.67707
N	120

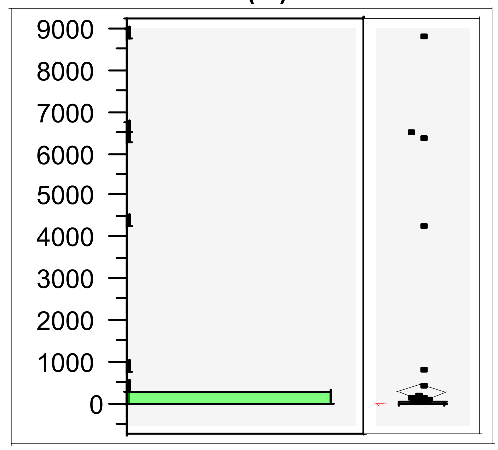
Distance to Terrestrial Edge (m)



Moments

Mean	413.675
Std Dev	723.41834
Std Err Mean	66.038757
upper 95% Mean	544.43833
lower 95% Mean	282.91167
N	120

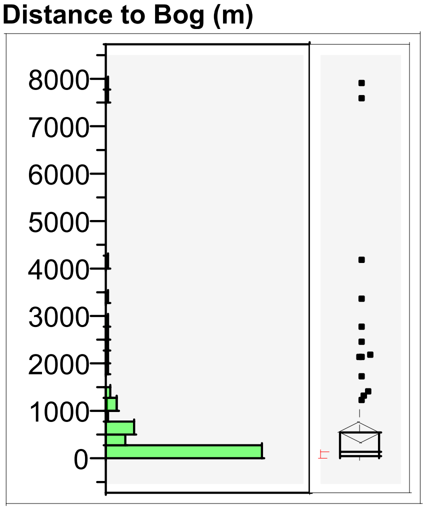
Distance to Forest (m)



Moments

Mean	254.65417
Std Dev	1215.2049
Std Err Mean	110.93252
upper 95% Mean	474.31164
lower 95% Mean	34.996693
N	120

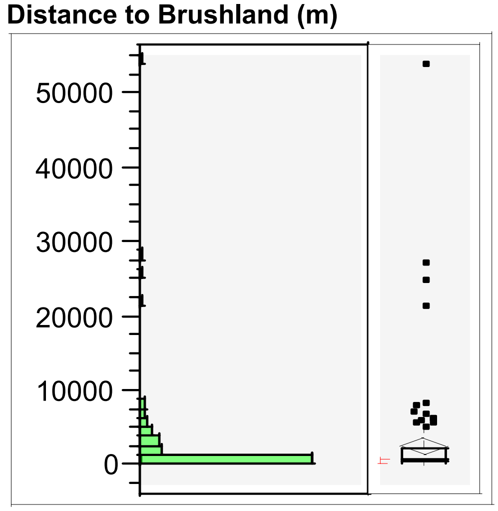
Distance to Bog (m)



Moments

Mean	547.67917
Std Dev	1189.518
Std Err Mean	108.58764
upper 95% Mean	762.69354
lower 95% Mean	332.66479
N	120

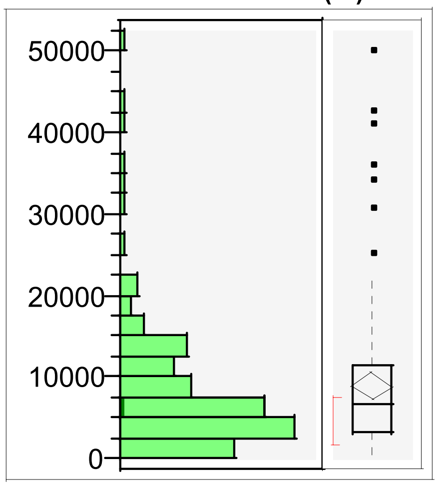
Distance to Brushland (m)



Moments

Mean	2550.6
Std Dev	6345.9534
Std Err Mean	579.30364
upper 95% Mean	3697.6791
lower 95% Mean	1403.5209
N	120

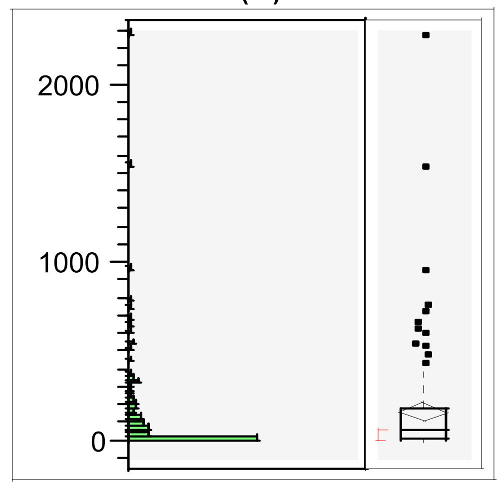
Distance to Nearest Nest (m)



Moments

Mean	8876.575
Std Dev	8914.1154
Std Err Mean	813.74368
upper 95% Mean	10487.869
lower 95% Mean	7265.2812
N	120

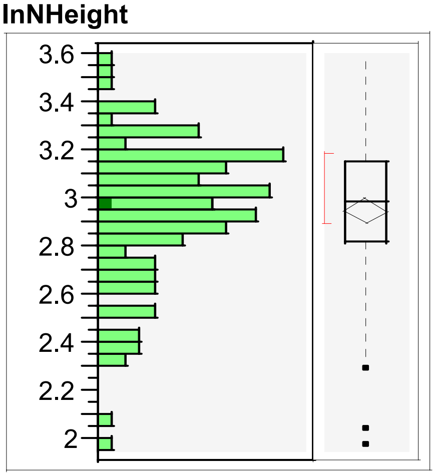
Distance to Water (m)



Moments

Mean	159.275
Std Dev	302.02919
Std Err Mean	27.571366
upper 95% Mean	213.86906
lower 95% Mean	104.68094
N	120

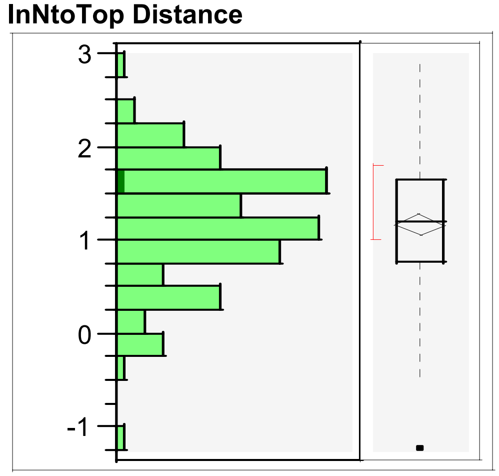
lnNHeight



Moments

Mean	2.9455912
Std Dev	0.290279
Std Err Mean	0.0264987
upper 95% Mean	2.9980613
lower 95% Mean	2.8931211
N	120

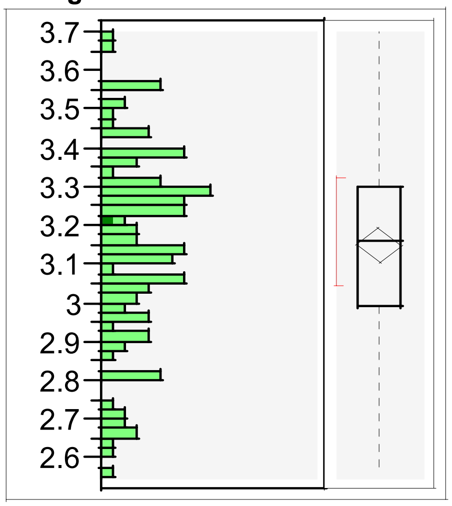
lnNtoTop Distance



Moments

Mean	1.162809
Std Dev	0.6574738
Std Err Mean	0.0600189
upper 95% Mean	1.2816523
lower 95% Mean	1.0439656
N	120

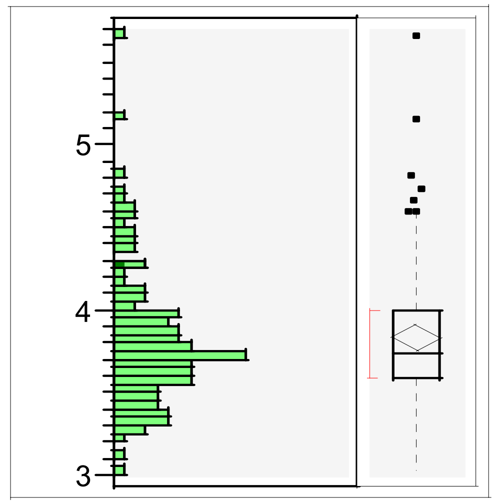
lnHeight



Moments

Mean	3.1488688
Std Dev	0.2448543
Std Err Mean	0.022352
upper 95% Mean	3.1931281
lower 95% Mean	3.1046096
N	120

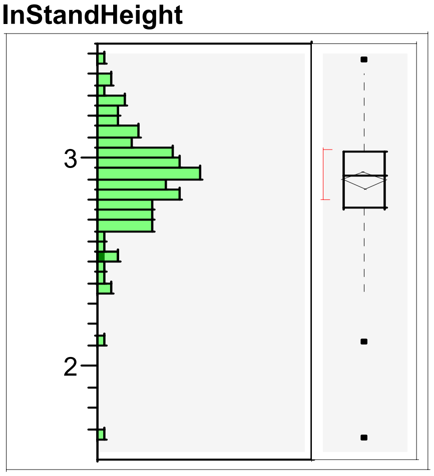
lnDBH



Moments

Mean	3.8326582
Std Dev	0.4262665
Std Err Mean	0.0389126
upper 95% Mean	3.9097091
lower 95% Mean	3.7556073
N	120

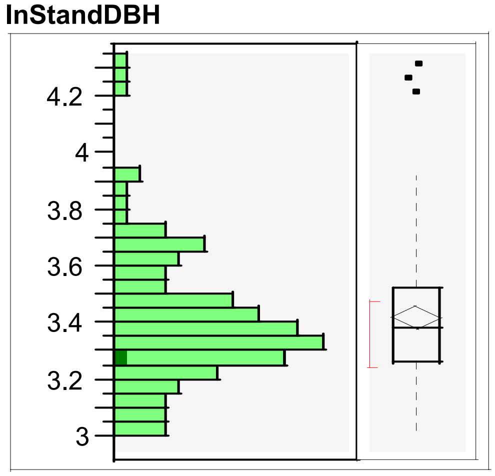
lnStandHeight



Moments

Mean	2.8924871
Std Dev	0.2462666
Std Err Mean	0.022481
upper 95% Mean	2.9370017
lower 95% Mean	2.8479726
N	120

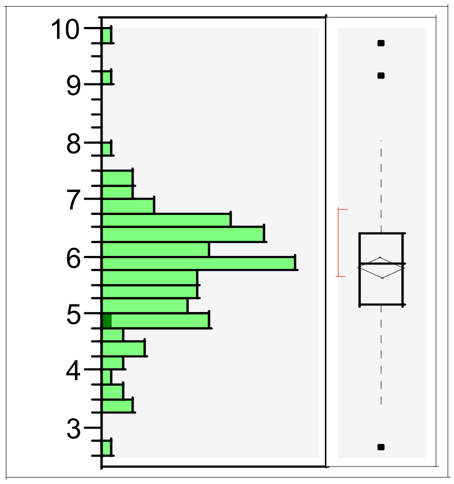
lnStandDBH



Moments

Mean	3.4153208
Std Dev	0.2407655
Std Err Mean	0.0219788
upper 95% Mean	3.458841
lower 95% Mean	3.3718006
N	120

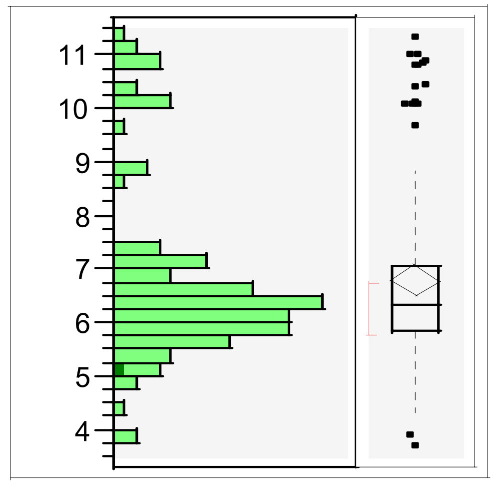
lnDRoads



Moments

Mean	5.782635
Std Dev	1.0579104
Std Err Mean	0.0965736
upper 95% Mean	5.9738603
lower 95% Mean	5.5914097
N	120

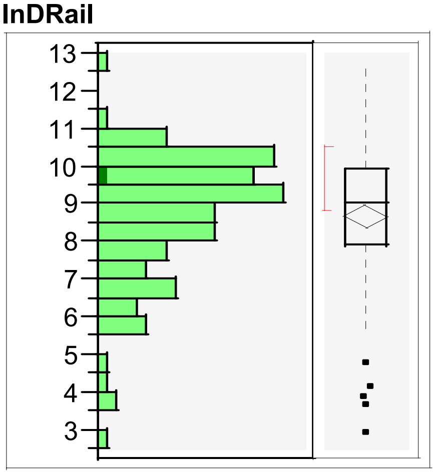
lnDHouse



Moments

Mean	6.7819221
Std Dev	1.6501398
Std Err Mean	0.1506365
upper 95% Mean	7.0801974
lower 95% Mean	6.4836469
N	120

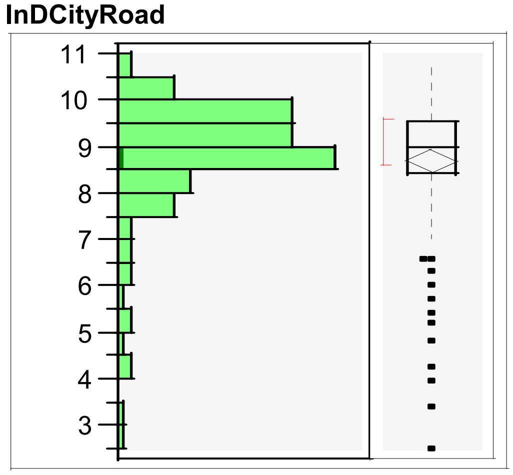
lnDRail



Moments

Mean	8.6538558
Std Dev	1.7126554
Std Err Mean	0.1563433
upper 95% Mean	8.9634312
lower 95% Mean	8.3442804
N	120

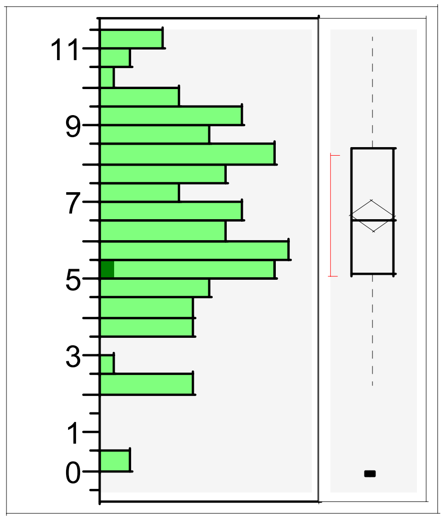
lnDCityRoad



Moments

Mean	8.6701881
Std Dev	1.4126332
Std Err Mean	0.1289552
upper 95% Mean	8.9255323
lower 95% Mean	8.414844
N	120

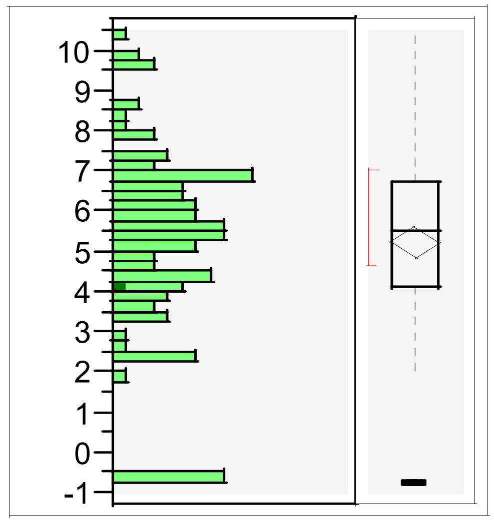
lnDCultv



Moments

Mean	6.6366913
Std Dev	2.3666509
Std Err Mean	0.2160447
upper 95% Mean	7.0644813
lower 95% Mean	6.2089012
N	120

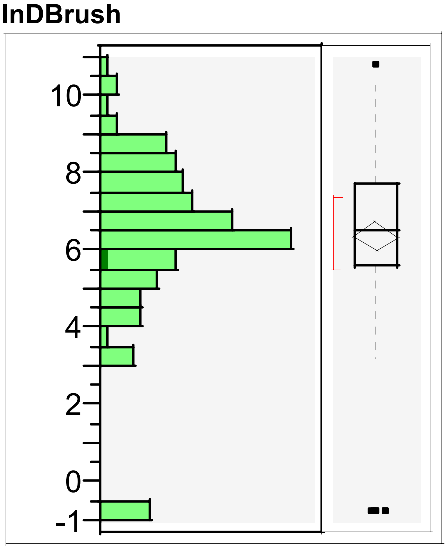
lnDGrass



Moments

Mean	5.2181792
Std Dev	2.3598521
Std Err Mean	0.215424
upper 95% Mean	5.6447403
lower 95% Mean	4.7916181
N	120

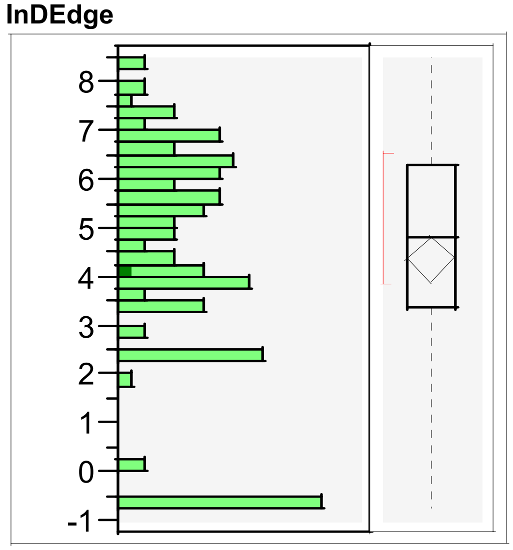
lnDBrush



Moments

Mean	6.3503903
Std Dev	2.1976921
Std Err Mean	0.2006209
upper 95% Mean	6.7476397
lower 95% Mean	5.9531408
N	120

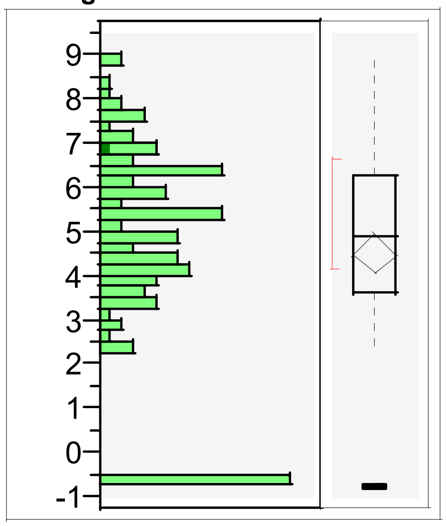
lnDEdge



Moments

Mean	4.3505765
Std Dev	2.4633822
Std Err Mean	0.224875
upper 95% Mean	4.7958514
lower 95% Mean	3.9053015
N	120

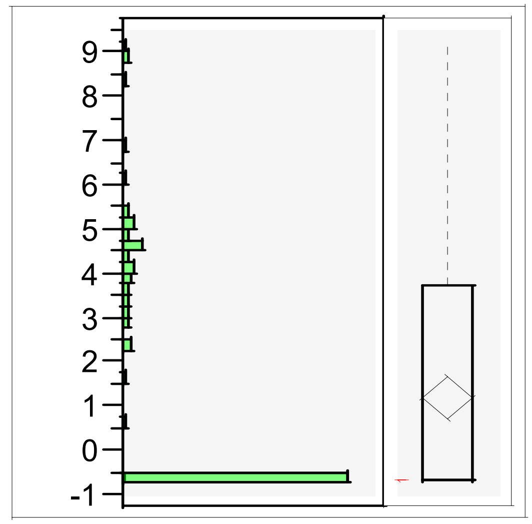
lnDBog



Moments

Mean	4.4751395
Std Dev	2.539028
Std Err Mean	0.2317805
upper 95% Mean	4.9340881
lower 95% Mean	4.016191
N	120

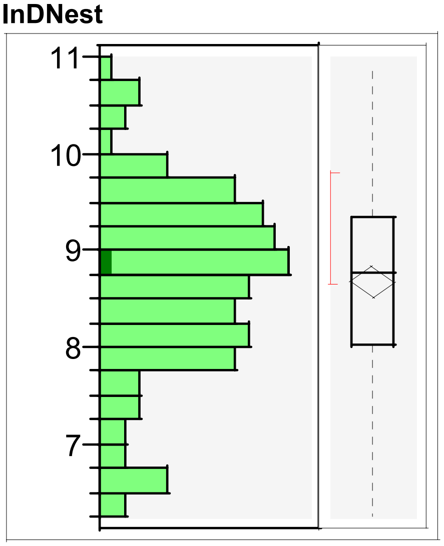
lnDForest



Moments

Mean	1.1750718
Std Dev	2.7279994
Std Err Mean	0.2490311
upper 95% Mean	1.6681783
lower 95% Mean	0.6819653
N	120

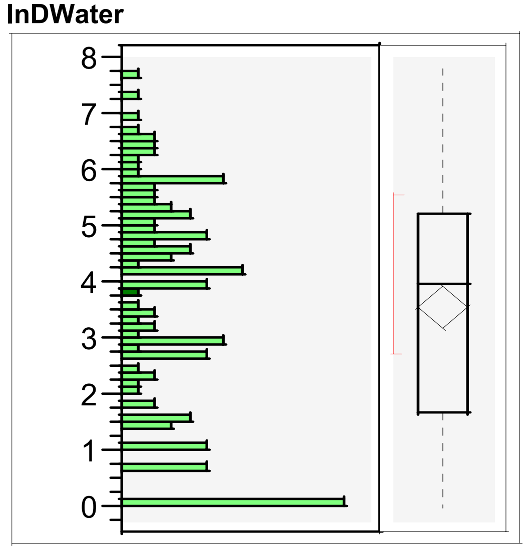
lnDNest



Moments

Mean	8.6698254
Std Dev	0.9697258
Std Err Mean	0.0885235
upper 95% Mean	8.8451107
lower 95% Mean	8.4945401
N	120

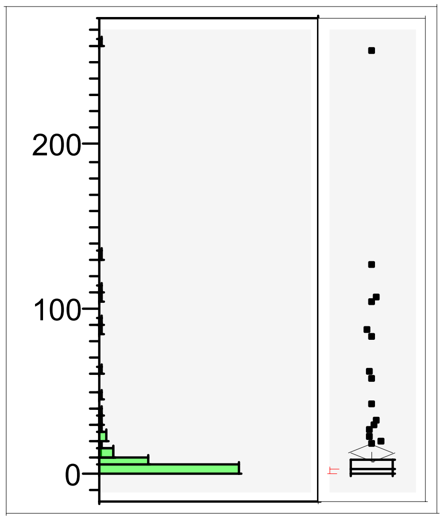
lnDWater



Moments

Mean	3.537652
Std Dev	2.0773397
Std Err Mean	0.1896343
upper 95% Mean	3.9131469
lower 95% Mean	3.1621572
N	120

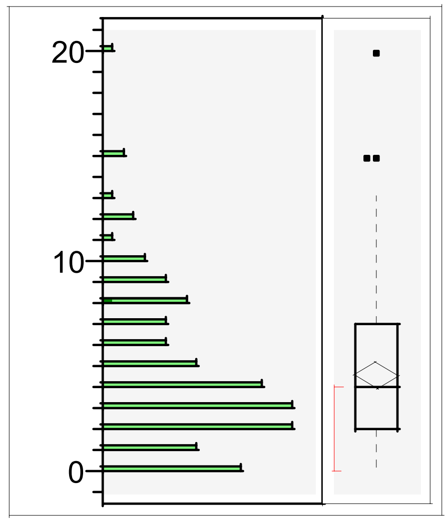
Houses 1000m



Moments

Mean	12.416667
Std Dev	32.047911
Std Err Mean	2.9255607
upper 95% Mean	18.209569
lower 95% Mean	6.6237643
N	120

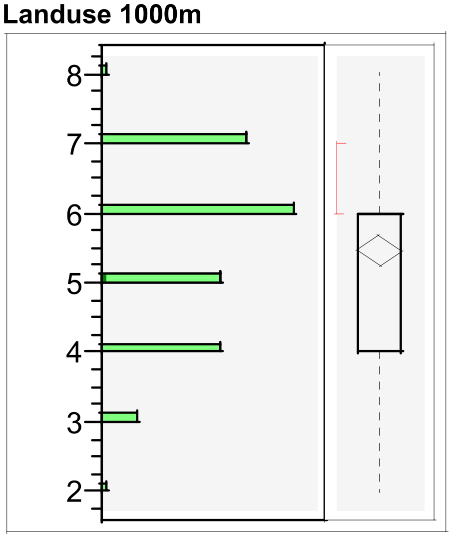
Roads 1000m



Moments

Mean	4.5833333
Std Dev	3.7429673
Std Err Mean	0.3416846
upper 95% Mean	5.259903
lower 95% Mean	3.9067637
N	120

Distributions
Landuse 1000m



Moments

Mean	5.4666667
Std Dev	1.2697736
Std Err Mean	0.1159139
upper 95% Mean	5.6961878
lower 95% Mean	5.2371455
N	120

APPENDIX J. DISTRIBUTION AND CORRELATIONS OF EACH VARIABLE MEASURED FOR DISCRIMINANT ANALYSIS

Species

Distribution: N/A

Correlations: Tightly correlated to ecoregion. Ecoregion predicts species present.

Nest Tree Height

Distribution: Normal

Correlations: Stand Diameter (0.013)
Nest to Top Distance (0.0004)
Distance to Nearest Active Nest (0.000015)
Tree Diameter (<0.0000001)
Distance to Water (<0.0000001)
Stand Height (<0.00000001)
Nest Height (<0.00000001)

Nest Tree Diameter

Distribution: Right Skewed; After Log Transformation: Near Normal

Correlations: Density of Land-use Types (0.016)
Distance to Brushland (0.0099)
Nest to Top Distance (0.0096)
Distance to Water (<0.0000001)
Tree Height (<0.00000001)
Stand Diameter (<0.00000001)

Canopy Elevation

Difficult to measure in the field, thus eliminated from list.

Stand Diameter

Distribution: Near Normal

Correlations: Tree Height (0.010)
Density of Land-use Types (0.0094)
Distance to Water (0.00037)
Tree Diameter (<0.00000001)

Stand Height

Distribution: Normal

Correlations: Nest Height (0.024)
Distance to City Roads (0.0056)

Distance to Cultivation (0.0040)
Distance to Forest (0.00043)
Distance to Nearest Active Nest (0.00004)
Tree Height (<0.0000001)

Distance to Active Nest

Distribution: Near Normal; After Log Transformation: Normal

Correlations: Distance to Forest (0.0444)
Nest Height (0.04123)
Distance to Water (0.0047)
Distance to Bog (0.0032)
Distance to Cultivation (0.0015)
Stand Height (0.000042)
Tree Height (0.000014)

Distance to Water

Distribution: Right Skewed; After Log Transformation: Near Normal

Correlations: Distance to Nearest House (0.0356)
Distance to Nearest Active Nest (0.0047)
Density of Land-use Types (0.00048)
Stand Diameter (0.00037)
Tree Diameter (<0.00000001)
Tree Height (<0.000000001)

Distance to Nearest Road

Distribution: Right Skewed; After Log Transformation: Normal

Correlations: Stand Height (0.01396)
Distance to Nearest House (0.00043)
Density of Roads (0.000089)
Density of Land-use Types (0.0000028)
Distance to Terrestrial Edge (<0.000000001)
Distance to Cultivation (<0.000000001)
Distance to Urban (<0.000000001)
Distance to Grassland (<0.00000001)

Distance to House

Distribution: Right Skewed; After Log Transformation: Near Normal

Correlations: Distance to Water (0.03556)
Distance to Cultivation (0.00669)
Density of Roads (0.00075)
Distance to Nearest Road (0.00043)
Density of Land-use Types (0.00235)

Distance to Grassland (0.000082)
Distance to Urban (0.000040)

Density of Houses

Distribution: Right Skewed

Correlations: Distance to Urban (0.000467)
Density of Roads (<0.000000001)

Distance to Urban

Distribution: Right Skewed; After Log Transformation: Normal

Correlations: Distance to Forest (0.04234)
Nest Height (0.04233)
Stand Height (0.00558)
Distance to Bog (0.001997)
Density of Houses (0.000467)
Distance to Nearest House (0.0000404)
Density of Roads ((<0.0000001)
Density of Land-use Types (<0.0000001)
Distance to Terrestrial Edge (<0.0000001)
Distance to Grassland (<0.00000001)
Distance to Cultivation (<0.00000001)

Distance to Forest

Distribution: Right Skewed; After Log Transformation: Right Skewed

Correlations: Distance to Nearest Nest (0.0445)
Distance to City Roads (0.4234)
Stand Height (0.00043)
Distance to Bog (0.0002)
Distance to Railroad (0.000045)

Distance to Grassland

Distribution: Right Skewed; After Log Transformation: Near Normal

Correlations: Density of Roads (0.01187)
Distance to Railroad (0.000096)
Distance to Nearest House (0.000082)
Density of Land-use Types (<0.00000001)
Distance to Terrestrial Edge (<0.00000001)
Distance to Cultivation (<0.00000001)
Distance to Nearest Roads (<0.00000001)
Distance to Urban Area (<0.00000001)

Distance to Bog

Distribution: Right Skewed; After Log Transformation: Near Normal

Correlations: Density of Land-use Types (0.04919)
Distance to Cultivation (0.047558)
Distance to Railroad (0.02613)
Distance to Brushland (0.01710)
Distance to Nearest Nest (0.0032)
Distance to Urban Area (0.001997)
Distance to Forest (0.00024)

Distance to Brushland

Distribution: Right Skewed; After Log Transformation: Normal

Correlations: Distance to Bog (0.01710)
Land-use Density (0.000372)
Distance to Forest (0.000104)
Distance to Terrestrial Edge (<0.00000001)

Distance to Cultivation

Distribution: Right Skewed; After Log Transformation: Near Normal

Correlations: Distance to Bog (0.047557)
Distance to Nearest House (0.006688)
Stand Height (0.00399)
Distance to Nearest Active Nest (0.001522)
Density of Roads (0.000577)
Distance to Railroad (0.00006445)
Distance to Nearest Road (<0.000000001)
Land-use Density (<0.00000001)
Distance to Grassland (<0.00000001)
Distance to Terrestrial Edge (<0.0000001)
Distance to Urban (<0.00000001)

Density of Land-use Types

Distribution: Normal

Correlations: Distance to Bog (0.049188)
Distance to Railroad (0.045584)
Nest Height (0.026728)
Tree Diameter (0.016012)
Stand Diameter (0.00936)
Distance to Water (0.000483)
Distance to Brushland (0.0003824)
Distance to Nearest House (0.0002448)
Density of Roads (0.00006529)

Distance to Nearest Road (0.0000028)
Distance to Grassland (<0.000000001)
Distance to Urban (<0.0000000001)
Distance to Cultivation (<0.000000001)
Distance to Terrestrial Edge (<0.000000001)

Distance to Terrestrial Edge

Distribution: Right Skewed; After Log Transformation: Normal

Correlations: Density of Roads (0.002794)
Distance to Grassland (<0.0000000001)
Distance to Nearest Road (<0.000000001)
Distance to Brushland (<0.0000000001)
Density of Land-use (<0.000000001)
Distance to Urban (<0.0000000001)
Distance to Cultivation (0.0000000001)

Density of Roads:

Distribution: Near Normal

Correlations: Distance to Grassland (0.011867)
Distance to Terrestrial Edge (0.00279)
Distance to Nearest House (0.000753)
Distance to Cultivation (0.0005773)
Distance to Nearest Road (0.0000888)
Density of Land-use (0.000065)
Distance to Urban (<0.000000001)
Density of Houses (<0.000000001)

APPENDIX K. DISTRIBUTION AND CORRELATIONS OF EACH VARIABLE MEASURED FOR PRODUCTIVITY MODELING

Ground to nest

Distribution: Normal

Correlations: Distance to Urban (0.042336)
Distance to Nearest Active Nest (0.0412395)
Density of Land-use (0.0257278)
Stand Height (0.0241361)
Tree Height (<0.000000001)

Nest to top

Distribution: Normal

Correlations: Tree Diameter (0.009649)
Tree Height (0.00004103)

Species

Distribution: N/A

Correlations: Tightly correlated to ecoregion. Ecoregion predicts species present.

Nest Tree Height

Distribution: Normal

Correlations: Distance to Grassland (0.0304)
Distance to Nearest Active Nest (0.02965)
Distance to Nearest House (0.01488)
Nest to Top Distance (0.00004103)
Nest Height (<0.00000001)

Nest Tree Diameter

Distribution: Right Skewed; After Log Transformation: Normal

Correlations: Distance to Brushland (0.046408)
Density of Land-use (0.04186)
Nest to Top Distance (0.009649)
Distance to Nearest Active Nest (0.007757)
Stand Diameter (0.00001994)

Canopy Elevation

Difficult to measure in the field, thus eliminated from list.

Stand Diameter

Distribution: Normal

Correlations: Tree DBH (0.00001994)

Stand Height

Distribution: Normal

Correlations: Nest Height (0.02414)
Distance to Forest (0.0016314)

Distance to Active Nest

Distribution: Near Normal

Correlations: Distance to Cultivation (0.045476)
Tree Height (0.029653)
Distance to Bog (0.018368)
Distance to Terrestrial Edge (0.010955)
Tree DBH (0.0077567)

Distance to Water

Distribution: Right Skewed; After Log Transformation: Normal

Correlations: Density of Land-use (0.016477)

Distance to Nearest Road

Distribution: Right Skewed; After Log Transformation: Normal

Correlations: Density of Roads (0.009748)
Density of Land-use (0.003448)
Distance to Urban (0.0000045)
Distance to Terrestrial Edge (<0.000000001)
Distance to Grassland (<0.000000001)
Distance to Cultivation (<0.000000001)

Distance to House

Distribution: Right Skewed; After Log Transformation: Normal

Correlations: Distance to Nearest Road (0.01928)
Tree Height (0.01488)
Distance to Urban (0.009829)
Density of Land-use (0.004206)
Density of Roads (0.001590)

Density of Houses

Distribution: Right Skewed

Correlations: Distance to Brushland (0.0224908)
Distance to Urban (0.011387)
Density of Roads (<0.00000001)

Distance to Urban

Distribution: Near Normal

Correlations: Nest Height (0.042336)
Distance to Brushland (0.02116)
Density of Houses (0.011387)
Distance to Forest (0.01024)
Distance to Terrestrial Edge (0.0002789)
Density of Roads (0.0000289)
Density of Land-use (0.0000187)
Distance to Nearest Roads (<0.00000001)
Distance to Grassland (<0.00000001)
Distance to Cultivation (<0.00000001)

Distance to Forest

Distribution: Right Skewed; After Log Transformation: Right Skewed

Correlations: Distance to Urban (0.010241)
Stand Height (0.004004)
Distance to Brushland (0.001631)

Distance to Grassland

Distribution: Right Skewed; After Log Transformation: Normal

Correlations: Tree Height (0.0304036)
Density of Roads (0.028847)
Density of Land-use (0.00010365)
Distance to Terrestrial Edge (<0.00000001)
Distance to Nearest Road (<0.00000001)
Distance to Urban (<0.00000001)
Distance to Cultivation (<0.0000000001)

Distance to Bog

Distribution: Right Skewed; After Log Transformation: Near Normal

Correlations: Distance to Nearest Active Nest (0.018368)
Distance to Brushland (0.012709)
Distance to Forest (0.00002514)
Distance to Railroad (<0.000000001)

Distance to Brushland

Distribution: Right Skewed; After Log Transformation: Normal

Correlations: Tree Diameter (0.049253)
Density of Roads (0.04641)
Density of Houses (0.02239)
Distance to Urban (0.02121)
Distance to Bog (0.01271)
Distance to Forest (0.001631)

Distance to Cultivation

Distribution: Right Skewed; After Log Transformation: Normal

Correlations: Distance to Nearest Active Nest (0.041239)
Density of Roads (0.017538)
Density of Land-use (0.0000113)
Distance to Nearest Road (<0.000000001)
Distance to Terrestrial Edge (<0.000000001)
Distance to Urban (<0.000000001)
Distance to Grassland (<0.000000001)

Density of Land-use Types

Distribution: Normal

Correlations: Tree Diameter (0.041864)
Nest Height (0.026727)
Distance to Water (0.01648)
Distance to Nearest House (0.00420616)
Distance to Nearest Road (0.0034479)
Distance to Grassland (0.0001037)
Density of Roads (0.0001026)
Distance to Urban (0.0000187)
Distance to Cultivation (0.00001134)
Distance to Terrestrial Edge (<0.000000001)

Distance to Terrestrial Edge

Distribution: Right Skewed; Near Normal

Correlations: Density of Roads (0.02121)
Distance to Nearest Active Nest (0.01096)
Distance to Urban (0.0002789)
Distance to Grassland (0.00000303)
Distance to Cultivation (<0.0000000001)
Density of Land-use (<0.000000001)

Density of Roads

Distribution: Normal

Correlations: Distance to Brushland (0.046401)
Distance to Grassland (0.028847)
Distance to Terrestrial Edge (0.02121)
Distance to Cultivation (0.01754)
Distance to Nearest Roads (0.00977)
Distance to Nearest House (0.00159)
Density of Land-use (0.000103)
Distance to Urban (0.0000389)
Density of Houses (<0.0000000001)