HABITAT SELECTION BY RED-TAILED HAWKS
(Buteo jamaicensis)
IN PRAIRIE LANDSCAPES MANAGED FOR ENHANCED WATERFOWL RECRUITMENT

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Your file Votre référence
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Pour mes parents

Rachel et Jacques Fontaine.

Pour votre amour et support sans condition.

Et pour m'avoir toujours inspiré

à faire de mon mieux.

Avec amour

et

un grand sourire.

Je vous dédie cette thèse.

The black prairie was built by the prairie plants, a hundred distinctive species of grasses, herbs, and shrubs; by the prairie fungi, insects, and bacteria; by the prairie mammals and birds, all interlocked in one humming community of co-operations and competitions, one biota. This biota, through ten thousand years of living and dying, burning and growing, preying and fleeing, freezing and thawing, built that dark and bloody ground we call prairie.

-Aldo Leopold
A Sand County Almanac

ABSTRACT

In the Canadian prairies, native grasslands have been largely replaced by an agricultural landscape with a mosaic of habitats now better described as aspen parkland. Although habitat requirements of true prairie *Buteo* species, Swainson's (*Buteo swainsoni*) and ferruginous hawks (*B. regalis*), are relatively well identified, little is known about habitat use by red-tailed hawks (*B. jamaicensis*) in this ecoregion. This study, evaluating productivity and habitat selection of red-tailed hawks breeding in aspen parkland, was conducted on Prairie Habitat Joint Venture (PHJV) assessment sites in central Saskatchewan in 1997 and 1998. Red-tailed hawk nesting densities and productivity were determined at three sites. Home ranges were mapped. Macrohabitat use and availability data were generated from digitized aerial photographs of PHJV assessment sites using a Geographic Information System. Microhabitat variables were measured in 0.04 ha plots centered on nests and random locations. Nesting densities averaging 0.40 nests/km^2 were similar to those in other aspen parkland areas but were much higher than those typical of the prairies and in most other areas of the continent. All territorial pairs attempted to breed. Densities were limited by availability of nest sites, intraspecific territoriality, and minimum spatial requirements. Nests were dispersed regularly at two sites but clumped around the best hunting habitat at the other. The number of young fledged/nest (0.95) was low compared to other studies but nest success (63.6%) was similar. Red-tailed hawks nested in areas with significantly more and larger overstory trees but with significantly fewer trees in intermediate crown classes and lower canopy cover. Selection of these nest site features suggests that red-tailed hawks choose nest sites with unobstructed flight access and good visibility. Nests were in areas with greater amounts of dense nesting cover (DNC), scrubland, and woodland and lesser amounts of cropland and human-related habitats when compared to randomly selected sites. DNC had a positive effect on productivity whereas pastures had a negative effect. Red-tailed hawks appear to choose nest sites based on habitat characteristics within a 750 m radius from nest sites, which indicates a minimum

spatial requirement of 1.77 km^2 in aspen parkland. Saskatchewan's aspen parkland provides excellent nesting habitat for red-tailed hawks. Nests were highly successful in areas managed for enhanced waterfowl recruitment. DNC and scrubland provide abundant prey, and other studies suggest that the abundant waterfowl in the surrounding wetlands form an important component of their diet.

RÉSUMÉ

Les prairies indigènes canadiennes ont été largement remplacées par un paysage agricole comprenant une mosaïque d'habitats maintenant parsemée de peuplements de peupliers. Bien que les besoins en habitat des espèces de *Buteo* propre aux prairies, la buse de Swainson (*Buteo swainsoni*) et rouilleuses (*B. regalis*), sont relativement bien identifiés, très peu d'information est disponible quant aux besoins en habitat de la buse à queue rousse (*B. regalis*) dans ce biôme. Cette étude évalue la productivité et la sélection d'habitat des buses à queue rousse nichant dans les paysages de peuplements de peupliers des prairies et a été effectuée en 1997 et 1998 sur les sites d'évaluation du "Projet Conjoint d'Habitat des Prairies" dans le centre de la Saskatchewan. Trois sites furent étudiés intensivement dans le but de déterminer la densité de couples reproducteurs et la productivité des buses à queue rousse. Le territoire de chaque couple fut cartographié. Les données d'utilisation et de disponibilité à l'échelle du macrohabitat furent produites à partir de photos aériennes numérisées à l'aide d'un système d'information géographique (SIG). Les caractéristiques de microhabitat furent mesurées à l'intérieur de parcelles d'échantillonage de 0.04 ha centrées sur les nids et sur des sites aléatoires. J'ai observé une densité moyenne de couple reproducteur de 0.40 nids/km^2. Cette densité est sensiblement identique à celles obtenues par d'autres études dans des paysages similaires mais est toutefois beaucoup plus élevée que celle typique des vraies prairies ainsi que celles observées à-travers l'aire de répartition de cette espèce. Toutes les paires ayant maintenu un territoire ont tenté de se reproduire. La densité de nidification fut limitée par la disponibilité de sites propices à la nidification, la territorialité intra-spécifique, et les besoins critiques d'espace des paires. La distribution des nids dans le paysage fut régulière pour deux des sites d'études mais fut groupée auprès des meilleurs habitats de quêtes alimentaires à l'autre site. Le nombre moyen de jeunes ayant quitté le nid fut de 0.95/nid, ce qui est bas par rapport à d'autre études et le succès de nidification fut de 63.6%, ce qui est similaire. Les sites de nidification choisis par les couples de buses à queue rousse avaient des

densités et des tailles d'arbres significativement plus élevées dans la canopé supérieure ainsi que moins d'arbres dans les classes de taille intermédiaires et où le couvert de la canopé était moins dense. Ces résultat suggèrent qu'un accès non-obstrué au nid ainsi qu'une bonne visibilité du paysage avoisinant sont importants. À l'échelle du paysage, les buses à queue rousse nichèrent dans les aires ayant un plus grand "couvert de nidification dense ou CND" (couvert végétal au sol pour la nidification de la sauvagine), de bosquets arbustifs, d'îlots forestiers ainsi qu'un plus faible couvert de cultures céréalières et d'habitats d'origine anthropogénique comparé aux sites aléatoires. Le CND eut une influence positive sur le succès de nidification tandis que les pâturages eurent une influence négative. Il est probable que les buses à queue rousse choisissent des sites de nidification en se basant sur les caractéristiques des habitats présents à l'intérieur d'un rayon de 750 m des nids, suggérant ainsi un besoin d'espace minimum de 1.77 km^2 dans les paysages de peuplements de peupliers des prairies. Ces résultats suggèrent que dans les prairies de la Saskatchewan, les peuplements de peupliers sont propices à la nidification de la buse à queue rousse. Les buses nichant dans les aires ayant un couvert aménagé pour augmenter la production de la sauvagine furent plus productives. Cela pourrait être le résultat des densités élevées de proies dans le CND et les bosquets arbustifs et par la présence de sauvagine dans les milieux humides avoisinant qui, selon d'autres études, sont une composante importante de la diète de la buse à queue rousse.

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PREFACE

This study was initiated by way of an agreement reached between Ducks Unlimited and SaskPower over the construction of a power line through the Allan Hills in southcentral Saskatchewan. Ducks Unlimited owns and leases large tracts of land in this region and manages them for wildlife conservation, specifically for enhanced waterfowl production. Ducks Unlimited was concerned with the possible detrimental effects on waterfowl production because of increased raptor predation since it has been shown that birds of prey use such structures as hunting perches and for nesting. In an effort to mitigate impacts and to cooperate with Ducks Unlimited, SaskPower offered to establish a trust in their name, interest from which would be used to finance research judged adequate by the Institute for Waterfowl and Wetland Research (IWWR), the research arm of Ducks Unlimited. This study of red-tailed hawk habitat selection is one of the first initiatives funded through the interest generated by this trust. It is part of a larger project examining the ecology of red-tailed hawks, with special interest in their feeding ecology in areas managed for enhanced waterfowl recruitment.

LITERATURE REVIEW

DISTRIBUTION and STATUS

In eastern North America, the breeding distribution of the red-tailed hawk (*Buteo jamaicensis*) extends south from the 55^{th} parallel in Quebec and Labrador. It is absent from Anticosti Island, the Magdalen Islands, and Newfoundland (Chagnon and Bombardier 1995). It is present throughout all other Canadian provinces as well as the Yukon Territory. It occurs in the southwestern corner of the Northwest Territories west of Great Bear and Great Slave Lakes. It is absent from all of Nunavut. The breeding range extends to the west through central and southern coastal Alaska, but does not include northern and western portions of Alaska. The range extends south through the entire continental United States and Central America down to Panama as well as the West Indies. Wintering and breeding ranges overlap, except that the most northern areas are vacated during winter.

The breeding range of the red-tailed hawk has greatly expanded through North America in the past century, mostly in response to habitat fragmentation. Forest clearing in the eastern and midwestern United States has allowed it to displace the red-shouldered hawk (*B. lineatus*) (Titus and Mosher 1981, Bednarz and Dinsmore 1982) as well as opened new breeding areas in boreal forests of Quebec, Labrador, and Ontario (Chagnon and Bombardier 1995). The same phenomenon has occurred in the central Canadian grasslands where agricultural expansion and invasion of aspen (*Populus spp.*) have provided nesting sites and allowed displacement of other *Buteo* species such as the Swainson's (*B. swainsoni*) and ferruginous (*B. regalis*) hawks (Houston and Bechard 1983, Murphy 1993).

There are no clear geographic trends in breeding densities. Variations within and between geographic regions are best explained by landscape composition, mainly perch and nest site availability, and food availability (Preston and Beane 1993). These factors are considered most likely to limit and regulate red-tailed hawk populations. In central Alberta, breeding population size has remained remarkably stable over a 10-year period despite high fluctuations in prey densities (Luttich et al. 1971, McInvaile and Keith 1974, Adamcik et al. 1979). Intense competition for space and territoriality rather than food availability may be limiting this population (Preston and Beane 1993).

Greatest breeding densities generally occur in regions with high availability of large, mature trees and large expanses of open hunting areas (Preston and Beane 1993). Breeding populations increased during the period 1965-1979 in nearly all regions of North America (Robbins et al. 1986). North American Christmas Bird Counts showed an increase in winter populations of 33% between the 1970's and early 1980's (Preston and Beane 1993). Populations seem to be increasing in response to replacement of large expanses of both open prairies and large forest tracts by broken open wooded parkland (Preston and Beane 1993).

BREEDING BIOLOGY

Pair Formation and Arrival on the Breeding Range

In nonmigratory populations, pairs remain together throughout the year and the pair bond is usually maintained until the death of a partner (Bent 1937, Petersen 1979). Whether this is the case with migratory birds such as the Canadian prairie nesting birds is unknown. However, red-tailed hawks show a high degree of territorial fidelity and pair members usually return to the same territory (Janes 1984b). Acquisition of a new mate can occur rapidly after the death of a member of the pair (Bent 1937, Petersen 1979). Courtship displays occur throughout the year, but are much more common in early spring and may serve to maintain the pair bond outside the breeding season (Preston and Beane 1993). Initial formation of a pair bond may occur during late winter and early spring (Preston and Beane 1993). The first breeding pairs appear in northwest North Dakota typically in early April (Murphy 1993) and at Rochester, Alberta, from 2-11 April (Luttich et al. 1971).

Nest Construction

Both adults contribute to building a new or refurbishing an old nest, but the female spends most of her time forming the nest bowl (Preston and Beane 1993). Nest construction is done mostly in the morning and lasts 4-7 days (Petersen 1979). Members of the pair are extremely wary during nest construction and nest building is often discontinued if human intruders are detected in the proximity of a nest (Bent 1937). The nest is usually constructed of deciduous sticks and twigs of 1-2 cm diameter and the nest lining is usually composed of bark strips, catkins, and fresh deciduous sprigs (Bent 1937, Petersen 1979, Schmutz et al. 1980, Preston and Beane 1993). In north central Alberta, nest construction typically begins in mid-April (Luttich et al. 1971).

Clutch Initiation, Clutch Size, and Incubation

The interval reported between nest selection and clutch initiation was three weeks for a population in Alberta (Luttich et al. 1971). Typically an egg is laid every other day and the clutch is completed 2-5 days after the first laid egg (Preston and Beane 1993). Clutch size varies between 1 and 5 eggs, but typically consists of 2-3 eggs (Henny and Wight 1972, Adamcik et al. 1979). Mean clutch size at Rochester, Alberta, from 1966 to 1975 was 2.18 (n = 191) (Adamcik et al. 1979). Incubation takes between 28 and 35 days (Bent 1937, Hardy 1939) and begins with the first laid egg (Preston and Beane 1993). If the first clutch is removed or lost, a second may be produced in another nest (Bent 1937). In Saskatchewan, however, probably because of the late initiation of the breeding season in comparison with populations breeding at more southerly latitudes and corresponding shorter breeding season, the author observed only one renesting attempt after a clutch failure (A.J. Fontaine, this study). At Rochester, Alberta, mean incubation initiation date was 1 May, but ranged from 12 April to 26 May (Luttich et al. 1971).

Hatching

Hatching is asynchronous and within a brood occurs over a period of 2-4 days (Preston and Beane 1993), but may sometimes take a little over a week (A.J. Fontaine, pers. obs.). Mean hatching dates in northwestern North Dakota (Murphy 1993) was 21 May and at Rochester, Alberta (Adamcik et al. 1979), ranged from 30 May to 10 June through the 10-year study.

Feeding of the Young

Males provide most of the food for females during both incubation and nestling stages, although females occasionally leave the nest for brief hunting bouts (Preston and Beane 1993). The female feeds the young, but both adults may deliver food to the nest. In early nestling stages food is torn into small pieces and fed to the young by the female, but later in the season food is simply deposited in the nest for nestlings to tear and eat on their own (Fitch et al. 1946). Adults may bring more food to the nest than the young can eat and early in the breeding season excess food is usually carried away within a day or two (Preston and Beane 1993). Nonetheless, carcasses are allowed to accumulate in the nest bowl in late stages of the nestling period (Fitch et al. 1946). After fledging, the parents deliver food directly to or more commonly drop it near the young (Preston and Beane 1993). However, in the first 2 weeks after fledging, parents often deliver food to the nest where the young return to feed (A.J. Fontaine, pers.obs.). Juveniles begin capturing small vertebrate prey after 6-7 weeks, but parents deliver food to the young up to 8 weeks after fledging (Petersen 1979, Johnson 1986).

Delivery rate and biomass vary between individuals and are affected by brood size, but there is no evidence to suggest that parents adjust food deliveries as chicks age (Preston and Beane 1993). It is unclear how food is distributed between parents or between parents and chicks; however, according to Fitch et al. (1946), the young are usually fed the same foods as parents eat.

FLEDGING

Young red-tailed hawks leave the nest for the first time 42 to 46 days after hatching, but usually stay very near the nest for the first few days after fledging (Fitch et al. 1946). They may remain in the immediate vicinity of the nest for up to 25 days (Johnson 1973, Petersen 1979). Sustained flight is possible 2.5 weeks after fledging (Preston and Beane 1993). In migratory populations, juveniles remain associated with parents for up to 10 weeks (Johnson 1973). From 1966 to 1969 at Rochester, Alberta, mean fledging date ranged from 11-20 July (Luttich et al. 1971).

BREEDING DENSITIES

On a North American scale, reported estimates of breeding population show no clear geographical trends (Preston and Beane 1993). However, the few estimates of breeding density of red-tailed hawks documented throughout the prairie pothole region show a definite trend. Densities are highest in prey-rich regions where the landscape is interspersed with aspen clumps suitable for nest sites and hunting perches as well as with open hunting areas. In aspen parkland, nesting densities range from 0.10 to 0.47 breeding pairs/km^2 (Adamcick et al. 1979, Houston and Bechard 1983, Rothfels and Lein 1983, Murphy 1993), whereas in more typical prairie habitat, nesting densities are much lower, from 0.004 to 0.02 breeding pairs/km^2 (Lokeomoen and Dubbert 1976, Schmutz et al. 1980, Gilmer et al. 1983).

NESTING SUCCESS and REPRODUCTIVE OUTPUT

Red-tailed hawks are long-lived birds of prey that may reach ages in the mid-teens in the wild according to a life table prepared by Luttich et al. (1971). The oldest known banded wild individual was 21.5 years (Preston and Beane 1993) and one captive female reached an age of at least 29.5 years (Palmer 1988). This longevity allows them plenty of opportunity to breed successfully; however, the lifetime reproductive output of red-tailed hawks is yet undetermined (Preston and Beane 1993).

Reproductive success is strongly affected by prey abundance, perch density and distribution, and proximity of conspecific neighbors (Adamcik et al. 1979, Schmutz et al. 1980, Preston and Beane 1993). Low food availability has been related to brood reduction and lower nestling survival (Preston and Beane 1993). Distribution and abundance of suitable perch sites influence productivity by affecting hunting efficiency directly (Janes 1984a, b). Productivity is reduced in regions of low nest site availability, which forces congeners and other raptor species to nest in close proximity (Schmutz et al. 1980, Preston and Beane 1993). Furthermore, weather has also been implicated as a very important factor in nesting success (Adamcik et al. 1979, Stinson 1980, Murphy 1993). Murphy (1993) found nesting success to be considerably lower in three drought years as well as in a year with a heavy snowstorm in the early incubation period when compared to other years. Adamcik et al.

(1979) found that 70% of annual variation in mortality of nestlings was jointly attributable to frequency of rainfall and weight of food brought to the nestlings. These two factors are probably codependent because hunting activity and success of adults were reduced by rain (Adamcik et al. 1979). Direct adverse effects of rainfall on survival of nestling red-tailed hawks were observed by Fitch et al. (1946) and Hagar (1957).

Annual productivity through the 1980's at Lostwood National Wildlife Refuge in northwestern North Dakota was erratic and low with a mean nesting success of 55.9% and a mean number of young fledged per occupied nest of 0.86 ($n = 174$) (Murphy 1993). In central North Dakota, Gilmer et al. (1983) recorded a mean nesting success of 78% and mean young fledged per occupied nests of 1.63 ($n = 54$) in the late 1970's. From 1966 to 1975, at Rochester in northcentral Alberta, Adamcick et al. (1979) recorded mean young fledged per occupied nests of 1.15 for a total of 191 nests.

SPATIAL REQUIREMENTS

Home Range

The home range of red-tailed hawks varies in relation to topography, habitat structure, food availability, human disturbance, and season (Fitch et al. 1946, Petersen 1979, Preston and Beane 1993). Home range size is generally negatively related to the level of fragmentation of forested areas (Preston and Beane 1993). Consequently, home range size is variable geographically. Craighead and Craighead (1969) reported a hunting range radius of 1.21 km for a population in Michigan; McInvaille and Keith (1974) suggested an average defended area of 3.46 km^2 assuming a circular home range for a population in central Alberta; Petersen (1979) reported an average home range size of 1.17 km^2 in Wisconsin; and in the most thorough study, Janes (1984b) reported a mean territory size of 2.33 km^2 for 33 territories in northcentral Oregon.

Fidelity to Breeding Territory

Red-tailed hawks exhibit a high degree of territory fidelity and occupancy (Janes 1984a, b), but some may be vacated for a year or more and then reused (R. K. Murphy, pers.

comm.). Janes (1984b) showed that territorial boundaries are very stable between years regardless of turnover of individuals. Other studies have also shown long-term population stability (Adamcik et al. 1979, Murphy 1993). Territories are intraspecifically exclusive and interspecifically exclusive with other *Buteos* (Fitch et al. 1946, Newton 1976, Janes 1984a,b, Preston and Beane 1993)

Nest Site

Both members of a pair participate in nest site selection, but their respective roles are unknown (Preston and Beane 1993). Several nests within a territory are revisited by the pair and often two or more nests are repaired as well as a new nest built before one nest is finally selected (Bent 1937, Janes 1984b). A nest may be used in more than one year by a pair, abandoned for a new location for one or more years, and then used again (Preston and Beane 1993). In forested regions, nests are typically located in the crown of one of the tallest trees within the woodlot (Preston and Beane 1993). The nest location usually provides an unobstructed access to the nest from above and an open view of the surrounding landscape (Preston and Beane 1993). When compared to sympatric Swainson's and ferruginous hawks, red-tailed hawks select sites which are taller, more open, and closer to water (Schmutz et al. 1980, Bechard et al. 1990).

General Habitat Use

Red-tailed hawks can be described as habitat generalists, occurring throughout most of North America in a wide range of altitudes and habitats including broken deciduous, coniferous, and tropical rain forests, desert scrubland, urban parkland, as well as prairie and montane grasslands (Preston and Beane 1993). The major requirements common to all habitats utilized are availability of scattered, elevated perch sites used for hunting, and nest sites. Hence, red-tailed hawks are absent from regions north of the tree line (Preston and Beane 1993). Elevated hunting perches are important because red-tailed hawks perform 60-80% of their hunting from perches from which they scan the surrounding area for prey (Fitch et al. 1946, Ballam 1984). Dependence on this hunting method as opposed to hunting using flight is probably associated with the relatively low length to width ratio of their wings (Janes 1985). No differences in habitat use between sexes have been reported during the breeding season (Preston and Beane 1993).

Grasslands

Compared to sympatric Swainson's and ferruginous hawks in western grasslands, red-tailed hawks are associated with areas of woodland with taller trees (Janes 1985, Murphy 1993). Within the grasslands, there also seems to be habitat segregation; ferruginous hawks appear to inhabit arid and open landscapes, red-tailed hawks inhabit open landscapes with an abundance of trees, and Swainson's occupy the interface (Schmutz et al. 1980, Murphy 1993).

THE ASPEN PARKLAND POPULATION: HISTORICAL and PRESENT

Strong evidence exists to suggest that major changes in the central grasslands raptor community have occurred in the past century. Since the late 1800's, red-tailed hawk populations have dramatically increased throughout North America. Population increases were particularly noticeable from the mid 1960`s to the late 1970`s (Robbins et al. 1986). This was due in large part to broad scale habitat fragmentation and movement into ecological zones which were previously unsuitable. This phenomenon is easily observable in the Great Plains which were unoccupied by red-tailed hawks until the 1920's (Houston and Bechard 1983). Now they are one of the most common large birds of prey. In some areas, invasion is even more recent. Red-tailed hawks only started breeding at Lostwood National Wildlife Refuge in northwest North Dakota in the 1960`s where they were totally absent even in migration until the 1950`s (Murphy 1993). In contrast, Swainson's and ferruginous hawks were common throughout the prairies in the late 1800's and early 1900's (Houston and Bechard 1983, Murphy 1993). Since then, numbers of Swainson's and ferruginous hawks have declined while red-tailed hawks have increased (Houston and Bechard 1983, 1984, Murphy 1993).

The ultimate factor responsible for changes in the raptor community of the central grasslands is the successional change in the plant community of an ecosystem that evolved under frequent intense disturbances (Weaver 1968, Heady 1975), and the corresponding impact on populations of prey species. Fire suppression by early settlers in the late 1800's and early 1900's was the most important factor allowing aspen to reach tree size and other vegetation to grow and accumulate (Sauer 1950, Bird 1971, Nelson and England 1971, Vogl 1974, Wright and Bailey 1982, Higgins 1986). Loss of periodic intense grazing through massive eradication of immense bison (*Bison bison*) herds probably also had a positive influence on plant growth (Edwards 1978, Higgins 1986). Vegetation changes involved growth and proliferation of woody vegetation such as trees and shrubs, but also an increase in height and density of herbaceous vegetation.

Although humans often view wildfires as ecological catastrophes that must be prevented, they play an important role in the ecology and maintenance of many habitats. Grasslands are fire-regenerated habitats in the same manner as lodgepole (*Pinus contorta*) and jack pine (*P. banksiana*) forests that have serotinous cones that require heat to open and release their seeds (Sauer 1950, Kricher and Morrison 1993). Frequent prairie fires kept the prairies treeless by preventing the invasion of seedlings from trees such as the trembling aspen (*Populus tremuloides*), balsam poplar (*P. balsamifera*), and Manitoba maple (*Acer negundo*), thereby allowing native grasses to remain dominant. By stopping fires, early settlers allowed the aspen parkland to gradually move southward and colonize the grasslands. In most areas of southern Saskatchewan, which were typically open prairie, the landscape is now scattered with bluffs of trembling aspen and balsam poplar (Houston and Bechard 1983).

Both Swainson's and ferruginous hawks are associated with open shortgrass prairie with lower tree abundance and smaller tree size than those more commonly selected by red-tailed hawks (Schmutz et al. 1980, Bechard 1982, Janes 1985, Murphy 1993). The increase in vegetation proliferation, height and density resulted in a decrease in prey availability for Swainson's and ferruginous hawks because of better protection afforded to prey animals by the vegetation and because of a related decrease in some key prey species such as Richardson's ground squirrel (*Spermophilus richardsonii*) (Houston 1978, Bechard 1982, Houston and Bechard 1983, Gilmer and Stewart 1984, Schmutz 1989, Murphy 1993). Furthermore, both of these raptors hunt in flight or from low perches and are not adapted morphologically nor behaviorally to hunt in tall dense cover (Wakeley 1978, Jasikoff 1982, Janes 1985). Comparatively, the red-tailed hawks' general habitat preferences and behavior towards other *Buteos* preadapted them to colonize this new habitat. The red-tailed hawk is a habitat generalist which is able to use a variety of habitats both in the breeding and nonbreeding season (Preston and Beane 1993). They especially seem to thrive in habitat mosaics composed of edges between open areas and woodland. Red-tailed hawks are well adapted to capitalize on this tall dense cover for hunting since they are a perch-and-wait predator partially dependent on availability of tall perches for hunting (Petersen 1979, Janes 1984b, 1985, 1987, Preston 1990, Preston and Beane 1993). This increase of well dispersed aspen tree clumps which grew and proliferated throughout the prairies provided ideal nesting sites and hunting perches for red-tailed hawks in an area where they were previously absent. Unfortunately they were either neutral or negative nesting habitat attributes for sympatric *Buteos* (Schmutz et al. 1980, Houston and Bechard 1983, Schmutz 1984, Janes 1985, 1987, Murphy 1993). Consequently, red-tailed hawk invasion of the prairies followed the invasion of suitable nest trees, most commonly areas where aspens reached 10 m tall or approximately 30 years of age (Houston and Bechard 1983).

However, this does not mean that tall dense herbaceous vegetation did not occur in the prairies. In fact, this type of vegetation is considered essential to other grassland breeding raptors such as the northern harrier (*Circus cyaneus*) and short-eared owl (*Asio flammeus*) both of which preferentially nest and hunt for their favorite prey, voles, in this type of cover (Birney et al. 1976, Kaufman et al. 1988, Murphy 1993). Both species were historically common and populations appear to have remained stable throughout the past century, which in addition to historical grassland descriptions, suggests that this type of vegetation was always present (Murphy 1993). Native mixed grass prairie was composed of a continuum of vegetation types ranging from burnt or heavily grazed areas to short grass prairie to tall grass prairie which were alternately favored through time depending on the type of disturbance (fire or grazing) and moisture condition (drought or rainy years) (McMillan 1959, Ryan

1990, Murphy 1993).

A secondary factor involved in changes within the raptor community relates to interspecific interactions between *Buteos* native to the grasslands and invading red-tailed hawks. Interspecific territoriality, aggression and reduced productivity under close nesting proximity are known to occur between *Buteo* species (Houston and Bechard 1983, Rothfels and Lein 1983, Littlefield et al. 1984, Janes 1987). The aggressive behavior towards other *Buteos* on habitat edges, in this case on the gradient from woodland to open prairie as well as the destruction of open grassland habitat for agricultural purposes, has allowed the red-tailed hawk to displace sympatric Swainson's and ferruginous hawks in many areas (Bock and Lepthien 1976, Houston and Bechard 1983, Murphy 1993). The red-tailed hawk has displaced eastern populations of red-shouldered hawks in the same manner, but the expansion in this case is related to deforestation (Titus and Mosher 1981, Bednarz and Dinsmore 1982). Both practices tend to create a mosaic of woodlands and open areas that are favored by red-tailed hawks.

Population changes within the prairie raptor community are important to this study because even though central grassland Swainson's and ferruginous hawks do prey on waterfowl, the importance of ducks and other wetland prey in their diet is limited when compared to the red-tailed hawk, which regularly brings waterfowl ducklings and adults to the nest as food for the young (Lokemoen and Duebbert 1976, Sherrod 1978, Adamcik et al. 1979, Schmutz et al.1980, Gilmer et al. 1983, Gilmer and Stewart 1984, Murphy 1993, Olendorff 1993). Increased conversion of short grass prairie into tall grass prairie and shrub dominated uplands resulted in a decrease of preferred hunting habitat and changes in the prey community, mainly a decrease in local abundance of their favorite prey, the Richardson's ground squirrel. As a result, they may rely more heavily on other prey species including waterfowl. Birds of prey respond both functionally and numerically to changing prey abundance (Galushin 1974, Adamcik et al. 1978, Phelan and Robertson 1978, Adamcik et al. 1979, Steenhoff and Kochert 1985, 1988, Schmutz and Hungle 1989).

INTRODUCTION

THE PRAIRIE HABITAT JOINT VENTURE

The North American Waterfowl Management Plan (NAWMP) is an agreement between Canada, the United States, and Mexico to raise waterfowl populations to the levels characteristic of the mid-1970's by increasing waterfowl production rates. It is the largest conservation initiative in North America to date and involves funding from non-government agencies, state and U.S. federal governments, and provincial and Canadian federal governments. The NAWMP steers conservation organizations to focus investments on critical habitat areas for migrating waterfowl. One of the largest and most important components of the NAWMP is the Prairie Habitat Joint Venture (PHJV) that oversees key waterfowl habitat in Alberta, Saskatchewan, and Manitoba. This area provides breeding habitat for nearly half of the continent's duck population (Stewart and Kantrud 1974, Johnsgard 1975, Bellrose 1979). The PHJV is the structure that coordinates the delivery of the NAWMP in the three Canadian prairie provinces.

Low average nesting success of dabbling ducks is thought to be the main factor limiting waterfowl production in the Canadian prairies (Klett et al. 1988, Johnson et al. 1989). Management of upland cover to improve nesting success is the primary mechanism chosen by the PHJV to increase production. PHJV habitat programs are implemented mostly within the aspen parkland biome of the three Canadian Provinces. In target areas, 5 to 20% of the total land base will be affected by the PHJV.

Conservation programs are put in place to maximize waterfowl production on small parcels of land dedicated to wildlife and generally involve purchase or lease of land and planting dense nesting cover (DNC), idling existing grass cover, and other similar cover management practices. Increasing cover available to nesting waterfowl could allow increases in local waterfowl production through increased nest density and hatching success (Kadlec and Smith 1992). Intensive farming practices have concentrated duck nests along narrow wetland edges and other limited "strips" of untilled cover where mammalian predators concentrate their foraging activities (Higgins 1977, Cowardin et al. 1983, Sugden and

Beyersbergen 1984, Klett et al. 1988, Sargeant and Raveling 1992). Establishing large blocks of cover permit waterfowl to space their nests widely and to reduce predator detection, thereby increasing the likelihood that a nest will hatch (Duebbert and Lokemoen 1976, Livezey 1981, Greenwood et al. 1987, Kadlec and Smith 1992). A recent study also showed that mammalian predators avoid entering dense cover, decreasing chances of a predator encountering a nest (Larivière and Messier 2000).

To test whether waterfowl production increases in response to PHJV upland habitat program deliveries, an 8-year Assessment Program was established in 1993, led by the research arm of Ducks Unlimited (DU), the Institute for Wetland and Waterfowl Research (IWWR). Two to five sites were studied each year. Assessment sites were randomly selected in areas targeted for implementation of the PHJV and had varying levels of treatment ranging from low (5%) to high (20%), program combinations, and landscape.

THE PROBLEM

An additional benefit of the PHJV program has been increased use of managed habitats by birds of prey (IWWR, unpubl. data). Conversely, hawks and owls may be benefiting in a manner that is counter to the NAWMP objectives since the four major raptor species implicated, i.e. red-tailed hawks, Swainson's hawks, northern harriers and great horned owls (*Bubo virginianus*), are known to include waterfowl in their diet (Adamcik et al. 1978, 1979, Schmutz et al. 1980, Gilmer et al. 1983, Barnard et al. 1987, Godfrey and Fedynich 1987, Murphy 1993, Murphy 1994, MacWhirter and Bildstein 1996, England et al. 1997, Pauzé 2002).

IWWR, DU and other proponents of the NAWMP are concerned about the impact of these 4 raptor species on nesting ducks and the information required can be broken down into two questions: 1) do they comprise a significant source of mortality for waterfowl at the duckling and/or adult stage? and 2) how do they use waterfowl habitat? Data on landscape features and waterfowl population biology are currently being analyzed by IWWR. Data on food habits of red-tailed hawks and great horned owls are being analyzed in a related study (Pauzé 2002). This study was designed to evaluate raptor spacing patterns, variation in reproductive success, and habitat selection.

While several species of raptors have been implicated in waterfowl mortality, red-tailed hawks are ideal subjects to address these objectives since strong evidence already exists to show that they are important predators of waterfowl. Murphy (1993) found that waterfowl comprised 36.7% by frequency of their diet, and Adamcik et al. (1979) found that waterfowl constituted 17% of total prey biomass over 10 years, with a peak of 36% in one year.

Habitat changes on the prairies may have caused increased predation on waterfowl by red-tailed hawks. The increase of available nesting and foraging sites from the southern expansion of the aspen parkland during the past century (Vogl 1974, Archibold and Wilson 1980), along with tree planting and power lines, may indeed constitute one of the most significant changes in the landscape influencing raptor predation on waterfowl. Red-tailed hawks are perch-dependent for foraging and nesting and have benefited from the habitat changes by expanding their range into previously unoccupied regions (Houston and Bechard 1983, Murphy 1993, Preston and Beane 1993).

Red-tailed hawks are known to use a wide variety of habitat types successfully throughout North America, but despite a large number of studies conducted across the continent (e.g., Craighead and Craighead 1969, Howell et al. 1978, Mader 1978, Petersen 1979, Titus and Mosher 1981, Bednarz and Dinsmore 1982, Janes 1984b, Bechard et al. 1990, Murphy 1993, Moorman and Chapman 1996), very few studies of their breeding ecology and habitat selection in the northern prairies and aspen parkland ecoregions have been published. One notable exception is a long-term breeding ecology and diet study conducted at Rochester, Alberta, in aspen parkland/mixed wood forest (Luttich et al. 1970, 1971, McInvaille and Keith 1974, Adamcik et al. 1979). It is important to ascertain how red-tailed hawks use the landscape to understand the effects this invasive species may have on other wildlife populations. My study is the first to examine red-tailed hawk habitat selection in the Canadian aspen parkland ecoregion.

AIM and OBJECTIVES

The overall aim of this study was to describe habitat selection by red-tailed hawks. Specific objectives of this study were:

1) To describe broad relationships between landscape characteristics and other ecological factors that affect nesting densities and distribution of red-tailed hawks in selected prairie waterfowl breeding habitat.

2) To determine nest site selection by red-tailed hawks at two scales:

a) macrohabitat scale, based on habitat features along a spatial gradient around the nest site

b) microhabitat scale, based on vegetation structure and features in the immediate vicinity of the nest.

3) To relate habitat features at both the macrohabitat and microhabitat scale to red-tailed hawk nesting success.

4) To make recommendations to wildlife managers concerning tactics to reduce raptor predation on prairie breeding waterfowl.

STUDY AREAS

GENERAL

Work was conducted in Saskatchewan, Canada, on the PHJV assessment sites from mid-April to mid-August, 1997 and 1998. Saskatchewan is located in the centre of the prairie-parkland region and supports the highest densities of waterfowl breeding pairs in continental North America (Stewart and Kantrud 1974, Johnsgard 1975, Bellrose 1979). From 1991 to 2000, 27 sites (64.75 km^2) were established in the three prairie provinces to assess the effectiveness of PHJV programs on waterfowl recruitment. Each assessment site was studied for one field season. Land on most of the assessment sites was privately owned, and agreements were made with landowners for access to their land. Other waterfowl researchers working at these sites provided insight on ecological interactions between various wildlife populations.

At the end of each field season, aerial photographs of all PHJV assessment sites were taken at a scale of 1:5000. All identifiable land cover types in all land parcels were visited, delineated on the images, and assigned a habitat classification. These were then digitized at high resolution using a Geographical Information System (GIS) to generate detailed land use maps of each site. In all, 47 different habitat classes were recognized in the digitizing process, of which 31 occurred on the assessment sites that were part of this study (Appendix A). For analysis, these were further aggregated into nine habitat classes: grassland, pasture, hay, dense nesting cover (DNC), cropland, woodland, scrubland, wetland, and other (Appendix B). These aggregations were required because using more narrowly defined land cover classes reduced the power and precision of comparisons of habitat use versus availability.

In 1997, two PHJV assessment sites were examined intensively, Willowbrook and Allan Hills West (Fig. 1). Although fieldwork was planned on both the Farrerdale and Jumping Deer Creek PHJV assessment sites in 1998, it was conducted only at the latter (Fig. 1). Densities of birds of prey at Farrerdale were too low to justify the effort and expense required to study this site intensively.

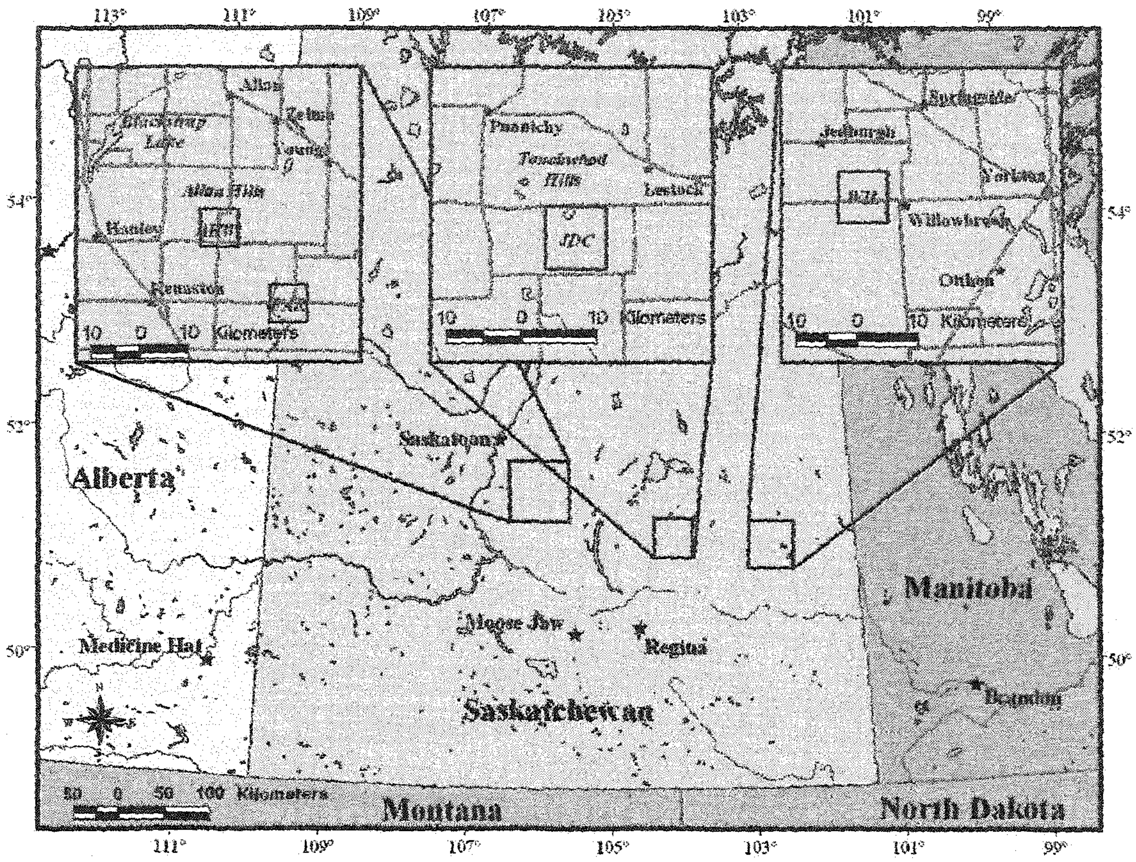

Figure 1. Location of the 1997, Willowbrook (WIL) and Allan Hills West (AHW), and 1998, Jumping Deer Creek (JDC) and Farrerdale(FAR), PHJV assessment sites, Saskatchewan.

All study areas had a lightly human-populated rural landscape dominated by agricultural land use, primarily cereal grain and oilseed farming (Appendix C). Main crops included wheat (*Triticum aestivum*), barley (*Hordeum sp.*), oats (*Avena sativa*), canola (*Brasica napus*), flax (*Linum sp.*), reed canary grass (*Phalaris arundinacae*), peas (*Lathyrus sp.*) and lentils (*Lens culinaris*). Forage production and livestock grazing were also part of the agricultural landscape. Areas not used for agricultural purposes included scattered groves of deciduous trees, wetland basins, native grassland, DNC, fence lines, and linear rights-of-way such as roads, railways, and power lines. Deciduous groves consisted mainly of trembling aspen on richer soils and a mix of balsam poplar and trembling aspen on poorer soils.

Typically, the best of these areas were being reclaimed for agricultural purposes on all study areas (see the Pushpile habitat class in Appendix C). Houston and Bechard (1983) noted a similar trend beginning in the early 1980's, which may signify a halt or decrease in aspen expansion. Other tree species such as white spruce (*Picea glauca*), Norway spruce (*P. abies*), Manitoba maple, green ash (*Fraxinus pennsylvanica*), and caragana (*Caragana arborescens*) were found around farmsteads. Understory shrubs and small trees consisted mainly of serviceberry (*Amelanchier alnifolia*), willows (*Salix spp.*), red osier dogwood (*Cornus sericea*), alder (*Alnus sp.*), hazelnut (*Corylus cornuta*), pin cherry (*Prunus pensylvanica*), chokecherry (*P. virginiana*), and hawthorn (*Crataegus sp.*). Scrub vegetation consisted mainly of snowberry (*Symphoricarpos albus*), silverberry (*Elaeagnus commutata*), wild rose (*Rosa spp.*), and gooseberry (*Ribes sp.*). Scrubland was typically found around aspen bluffs, but also grew as small, scattered patches in pasture and grassland. Dotting the landscape were numerous seasonal, semi-permanent and permanent wetlands (Stewart and Kantrud 1971, Millar 1976). Emergent, wet meadow and wetland fringe vegetation communities were primarily composed of cattail (*Typha spp.*), bulrushes (*Scirpus spp.*), whitetop grass (*Scolochloa festucacea*), sedges (*Carex spp.*), rushes (*Juncus spp.*), mannagrass (*Glyceria sp.*), slough grass (*Beckmannia syzigachne*), reedgrass (*Calamagrostis sp.*), and common reed grass (*Phragmites australis*). Willows were the dominant shrubs in low-lying areas, especially around wetland basins. Small patches of native grassland were found throughout the study areas. These included parcels that have been secured from agricultural use and allowed to grow wild; others were patches of unbroken sod within other habitat classes. DNC was composed of various mixtures of grasses and legumes, mainly brome grass (*Bromus sp.*), wheatgrass (*Agropyron spp.*), sweet clover (*Melilotus sp.*) and alfalfa (*Medicago sativa*), planted for wildlife cover and/or soil conservation.

SITE DESCRIPTIONS

A detailed table showing each site's habitat characteristics in surface area and percent coverage is provided in Appendix C.

Willowbrook

The main 1997 study area, the Willowbrook assessment site (Figs. 2 and 3), was located approximately 22 km west of Yorkton (51°13'N, 102°54'W) (Fig. 1) in the 4249 km^2 Touchwood Slope subregion of the Parkland Ecoregion (Poston et al. 1990). Its eastern boundary begins 3.2 km west of the village of Willowbrook (51°12'N, 102°47'W). The coordinates of the NW and SE corners are 51°25'N, 102°97'W and 51°18'N, 102°85'W, respectively.

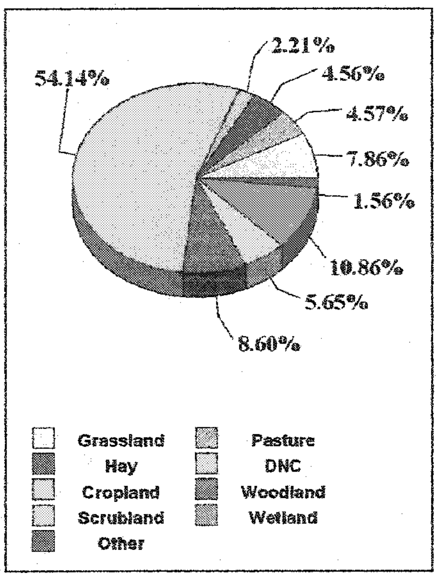

Figure 2. Land use (%) at the 1997 Willowbrook PHJV assessment site, Saskatchewan.

The area was generally flat and largely invaded by aspen parkland, forested areas and scrubland covering 8.6% and 5.6% of the landscape, respectively. The predominant land use was agricultural, croplands covering 54.1% of the area and livestock grazing pastures covering 4.6%. The Willowbrook site was considered a low treatment site with only 2.5% of the area under some form of PHJV program management, including 2.2% in DNC and 0.3% in delayed hay. Nonetheless, grassland and hayland, two habitat classes used extensively by nesting waterfowl accounted for 7.9% and 4.6% (includes delayed hay), respectively, of the land use coverage. Wetlands comprised 10.9% of the land use. Of special interest for waterfowl management was the presence of an electrified predator exclosure surrounding 10.9 ha of DNC as well as 41 waterfowl nesting structures (tunnels and baskets). The fence was not operational at the time of the study.

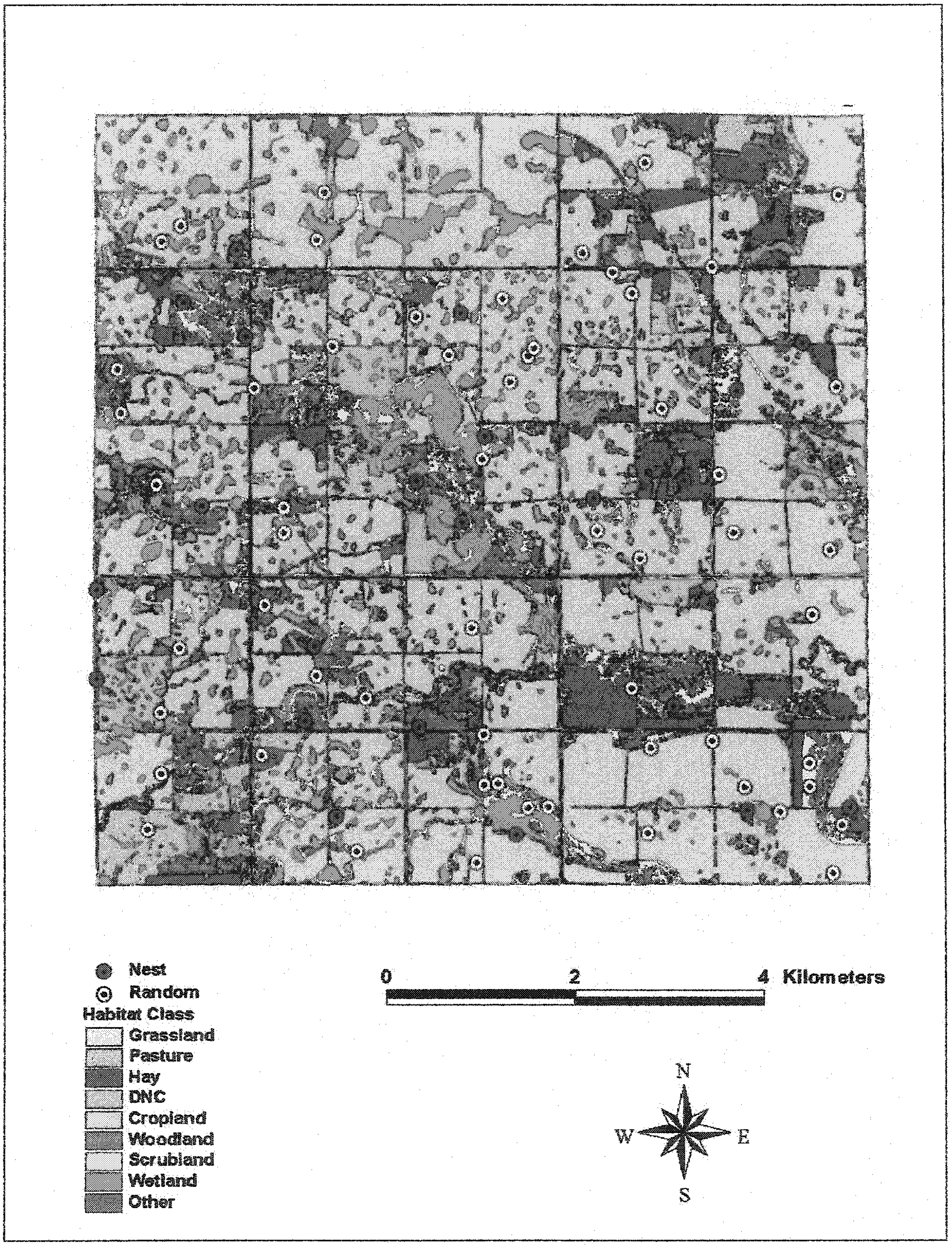

Figure 3. Land use cover map and location of red-tailed hawk nests and macrohabitat random sampling points at the 1997 Willowbrook PHJV assessment site, Saskatchewan.

Allan Hills West

The secondary study area in 1997, Allan Hills West (Figs. 4 and 5), was centered approximately 24 km east of Hanley, SK (51°39'N, 106°05'W) (Fig. 1) in the 1843 km^2 Allan Hills subregion of the Parkland Ecoregion (Poston et al. 1990). The coordinates of the NW and SE corners are 51°68'N, 106°13'W and 51°61'N, 106°02'W, respectively.

The highly rolling landscape and paucity of aspen bluffs were characteristic of the Allan Hills area. Aspens covered only 1.5% of the area and scrubland 3.3%. A dominant feature of the Allan Hills landscape was the high coverage in cereal and oilseed crops, croplands making up 51.5% of the landscape. In comparison, pastures occupied only 0.9%. A large portion of the study area was under Ducks Unlimited control and management through land leases or land ownership. It was a high treatment site with 18.9% of the area in some form of management under the PHJV program, including 17.7% in DNC and 1.2% in delayed hay. Another important waterfowl nesting area, grasslands, covered a substantial portion, 9.2%, of the study area. On the other hand, hay fields occupied only 0.1% of the site (excluding delayed hay). The Allan Hills had numerous small and deep wetlands in hilly areas, and larger shallow wetlands in flatter areas. In all, 13.6% of the site was covered with wetlands.

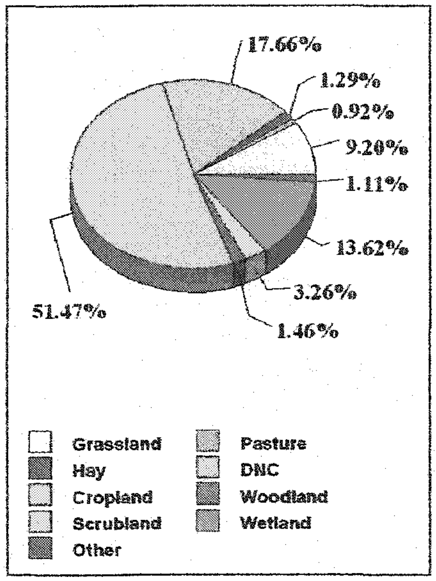

Figure 4. Land use (%) at the 1997 Allan Hills West PHJV assessment site, Saskatchewan.

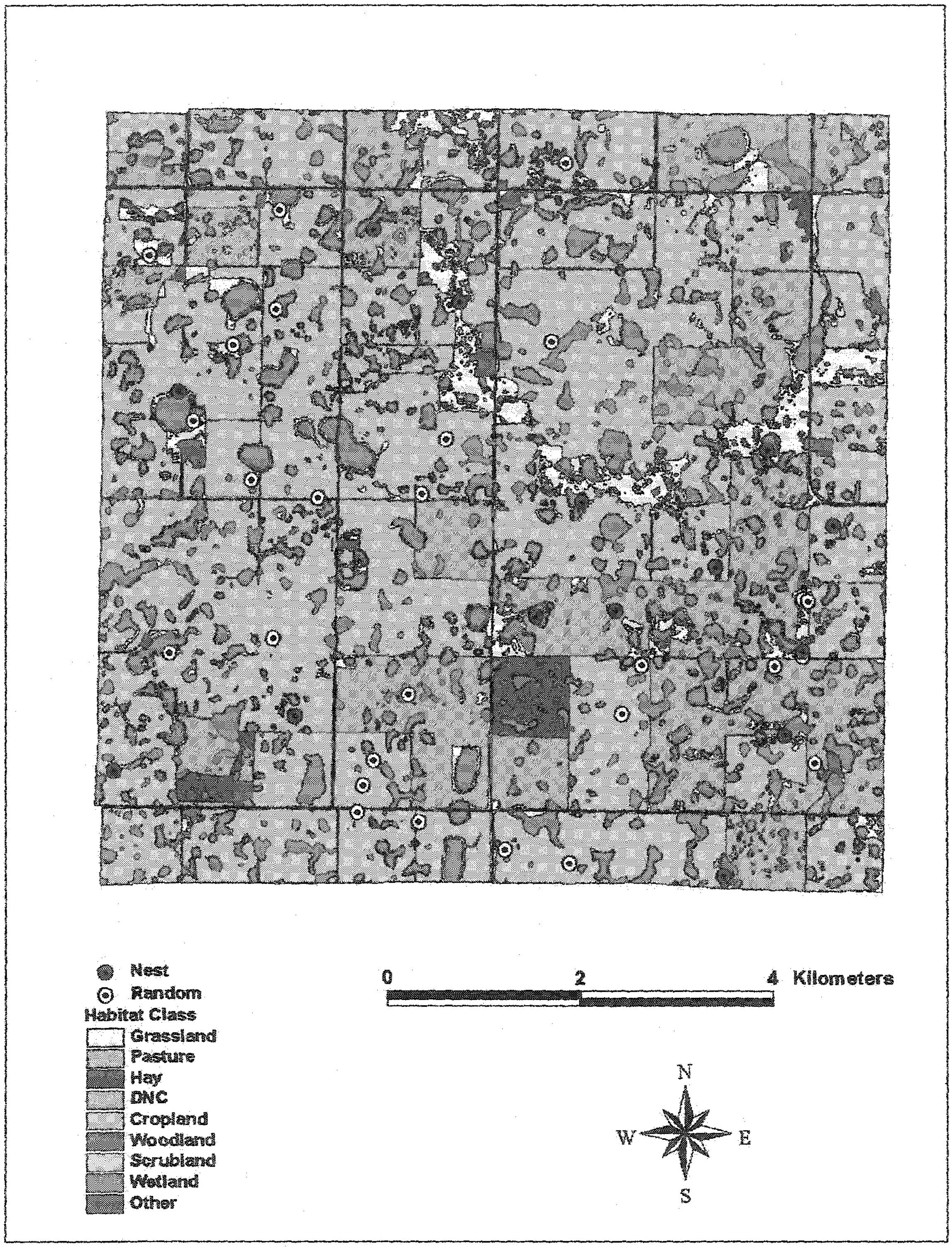

Figure 5. Land use cover map and location of red-tailed hawk nests and macrohabitat random sampling points at the 1997 Allan Hills West PHJV assessment site, Saskatchewan.

Jumping Deer Creek

In 1998, work was conducted on the Jumping Deer Creek assessment site (Figs. 6 and 7) centered approximately 16 km southwest of Lestock, (51°14'N, 104°08'W) (Fig. 1) in the 2715 km^2 Touchwood Upland subregion of the Parkland Ecoregion (Poston et al. 1990). The coordinates of the NW and SE corners are 51°27'N, 104°18'W and 51°20'N, 104°07'W, respectively.

The Touchwood Hills were characterized by a gently rolling landscape largely influenced by the southern expansion of the aspen parkland, with 12.6% comprising forested land and 9.9% scrubland. This was probably a reflection of the rocky nature of the soil. Farmers have allowed aspens and poplars to invade larger tracts of land compared to the other study areas and practice alternative land uses giving the landscape a more "balanced" habitat structure. Although the main land use on this site was agricultural, croplands occupied less than half (24.5%) the coverage than the other two study areas. Pastures replaced some of the cropland coverage characteristic of other sites, occupying 14.2%. This land use was particularly evident on the western side of the study area. Jumping Deer Creek was considered a high treatment site with 15.1% in some form of management under the PHJV including 13.9% in DNC, 0.5% in delayed hay, and 0.7% in idle hay. Waterfowl nesting ground cover was also available in other habitats, with grasslands and hay occupying 3% and 2.4% (excluding delayed and idle hay) of the area, respectively. The site also had excellent wetland availability for waterfowl brood rearing, since 17.3% of the area was covered in wetlands. Twenty-one waterfowl nesting structures were also present.

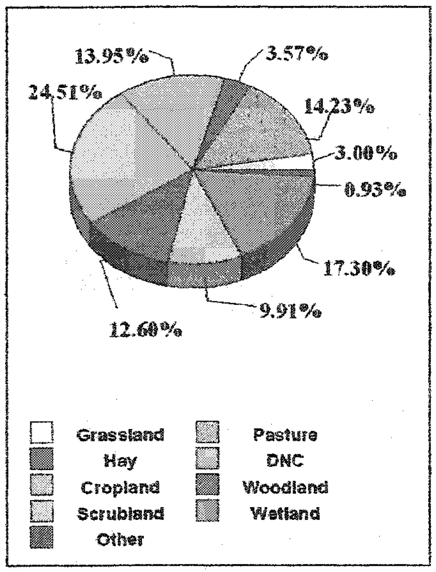

Figure 6. Land use (%) at the 1998 Jumping Deer Creek PHJV assessment site, Saskatchewan.

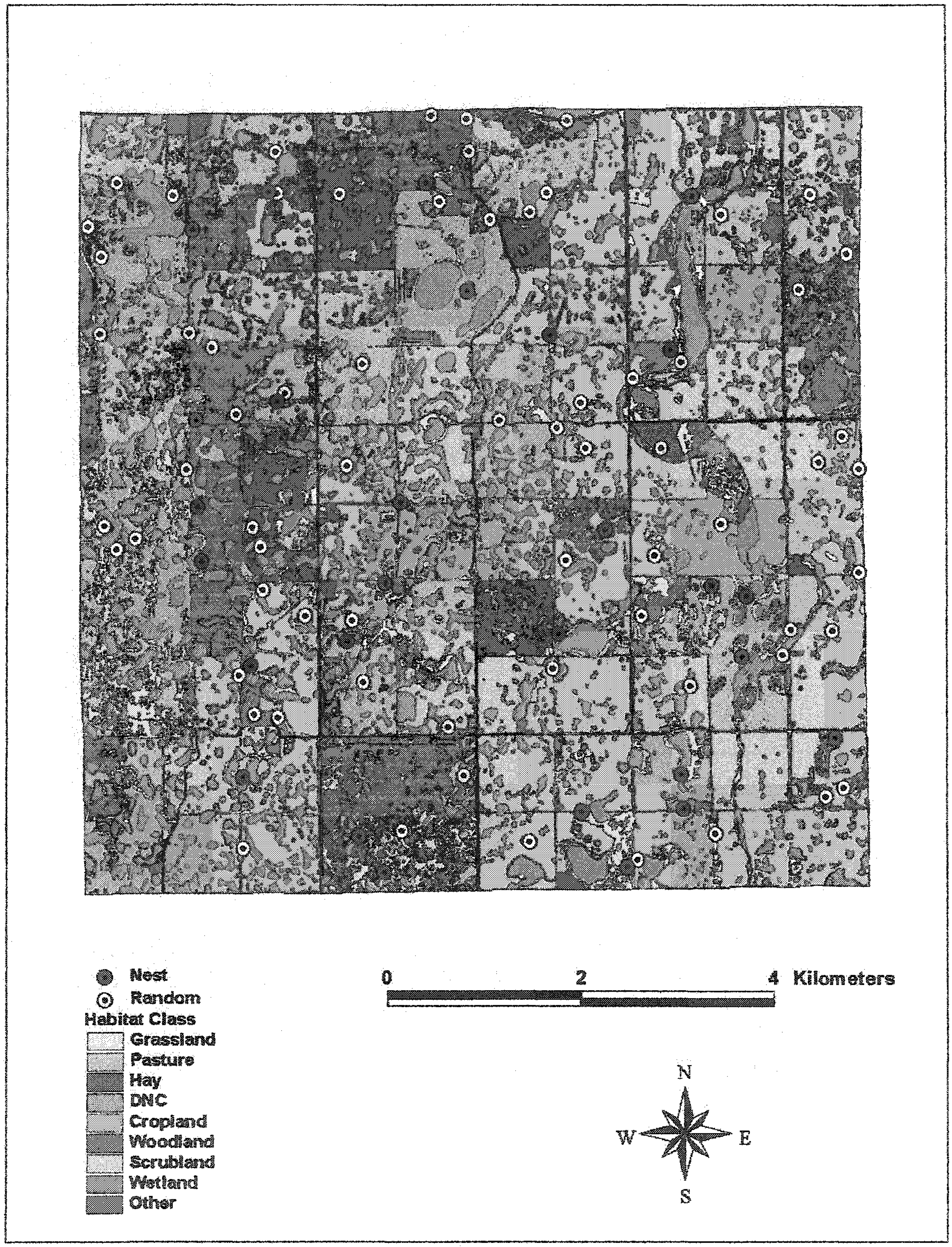

Figure 7. Land use cover map and location of red-tailed hawk nests and macrohabitat random sampling points at the 1998 Jumping Deer Creek PHJV assessment site, Saskatchewan.

MATERIALS and METHODS

NESTING DENSITIES and PRODUCTIVITY

Intensive foot and roadside surveys of all woodlots on the study areas were undertaken prior to leaf-out in April and early May to determine nesting densities of red-tailed hawks, following the protocol of Fuller and Mosher (1987). Red-tailed hawk nests are large and conspicuous and easily found prior to tree leaf development. Furthermore, adults are highly territorial early in the nesting season and call in response to most intruders approaching a nest (Andersen 1990, Preston and Beane 1993). These auditory cues can be used to help in locating nests. Collectively, these breeding characteristics allow nesting densities to be easily and accurately assessed. Initial surveys were conducted along all roads. Observers used 30x-power telescopes mounted on the windows of a vehicle to inspect nearby woodlots. All remaining bluffs were visited on foot and searched for nests. In larger woodlots, closely-spaced transects were walked to allow observation of all tree crowns and ensure that no nests were missed. All stick nests were noted on 1:5000 aerial photographs and were monitored for occupancy weekly prior to and during incubation. A nest was considered occupied if a hawk was seen sitting on it (presumably incubating), if greenery and other new materials had been added to the nest, or if a pair exhibited aggressive behavior when investigators approached. Luttich et al. (1971) verified that a clutch was incubated in all instances where these behaviors were observed. In addition to my protocols, IWWR staff recorded the location of raptor stick nests as well as casual sightings of raptors on the assessment sites in the course of their work (IWWR 1998). Thus, I am confident that all nests were found.

In most cases, nests were not inspected until the nestling period to minimize desertion. As a result, clutch size was often unknown. Initial brood size, and later the number of chicks present in active nests, were recorded from the ground using binoculars. After hatching, nest checks were conducted every four days. In cases when young were missing from a nest, ground searches were conducted in the nest vicinity in attempt to determine nestling fate. All fallen young were found dead except one. This chick was placed back into the nest, but was again found on the ground four days later, apparently killed or scavenged by a skunk (*Mephitis mephitis*). In addition, nest trees were climbed repeatedly at Jumping Deer Creek as part of another study of food habits. During these visits to nests, the number and condition of eggs and chicks were recorded. When hatching dates were uncertain, nestling age was estimated by measuring the 4^{th} primary approximately two to three weeks after hatching (Petersen and Thompson 1977, Bechard et al. 1985). Most nestling mortality occurred shortly after hatching (< 15 days post-hatch). Unless a different fate was known, nestlings were considered to have fledged if they survived 31 days (Steenhof 1987).

Procedures described by Fyfe and Olendorff (1976) were followed to minimize nest disturbance. In general, observers are more likely to have negative effects on breeding birds in the earlier stages of the breeding cycle, more specifically during the pre-laying and incubation periods. To prevent nest abandonment during these periods, observers stayed at least 300 m away from nests while conducting searches or nest status visits whenever feasible. Nest climbs were attempted only after whitewash (faeces) was seen either around the nest cup or in substantial amounts on the ground at the base of the nest tree or when young were spotted in a nest. Nests were approached along open sight lines to alert adults to the presence of the observers so that the female could fly off at her leisure instead of being startled, thus minimizing risks of eggs and young being ejected from the nest or injured. The amount of time spent at each nest was minimized, ranging from one to 30 min depending on the task. This reduced risks of exposure, predation, and missed feedings by allowing adults to return quickly to the nest. Typically, two observers were present when climbing nest trees. This procedure enhanced safety and saved time because one observer could concentrate on the climb and handling birds while the other recorded data. In the interests of both the birds and the observers, nest trees were not visited nor climbed during inclement weather (low temperature, rain, or high winds).

HOME RANGE

For most migratory red-tailed hawks in the northern Great Plains, the territory (defended area) of a pair approximates the pair's home range (larger undefended foraging area) in both size and shape (Craighead and Craighead 1969, R.K. Murphy, pers. comm.). Regions with year-round resident populations see an influx of birds from northerly breeding areas in the wintering season. These non-migratory hawks may defend territories that are smaller than the home range and home ranges usually overlap (Craighead and Craighead 1969, Preston and Beane 1993). In my study, territory and home range were considered equivalent because the Saskatchewan red-tailed hawk population is largely migratory (Preston and Beane 1993, A.J. Fontaine, pers. obs.).

Home ranges of red-tailed hawk pairs were estimated for the Willowbrook and Jumping Deer Creek assessment sites. Observations were conducted during the incubation period from locations that were near the edge of the home range or other remote observation posts to prevent disturbance. When a hawk was spotted, hawk locations were recorded systematically on aerial photographs of the study area using landmarks until the individual was lost from sight. Red-tailed hawk locations were also noted throughout the field season and used for home range estimation. Observations were excluded if a nest affiliation could not be determined. Home range assessment was facilitated by several factors. Overall, landscapes were generally open with low topographic relief and home ranges appeared relatively small. Intraspecific territorial behavior as well as territorial aggression towards humans and other intruders in flight over a large extent of the home range was used to map home ranges. Birds were not marked so recognition of individuals was based on behavioral observations (e.g., flying from or to the nest), and when possible, specific morphological characteristics such as missing feathers or color morph, and continuous long-term observation of an individual. Red-tailed hawk territorial boundaries are very stable, even between years, and territories are intra- and interspecifically exclusive (Fitch et al. 1946, Newton 1976, Janes 1984a, Preston and Beane 1993), which further facilitated recognition of individuals.

Janes (1984b) used visual observations of 23 pairs to ascertain that 9.1 h of observation of each pair member (or 18.2 h per nesting pair) defined 95% of a territory's area. At Willowbrook, total observation per pair averaged 24.6 h. Total average observation periods per pair were slightly shorter on the Jumping Deer Creek site. Consequently, home ranges were likely accurately mapped for pairs with > 18 h of observation. Home ranges for pairs with < 18 h of observation were excluded if insufficient incidental data were collected to consider them accurately mapped.

Home ranges were digitized on the land cover maps using the Minimum Convex Polygon method (Mohr 1947, Hayne 1949). This involved joining all outer location points to construct a polygon composed of convex faces. Surface area of home ranges was extracted.

As the number of new locations for a pair increases, so does the estimated home range size. This is due to a sampling effect up to the point where few new locations can be established (inflection point of the asymptote). As well, the method estimates total area utilized and not the area utilized through normal movements. To reduce this bias, outlying points influenced by external factors were excluded. External events included artificially increased prey availability when fields were hayed, and brush or hay/straw bale fires which forced small mammals to move out of protective cover and into exposed areas. These events attracted hawks from territories sometimes well away from the disturbance, and made previously unused areas appear used. One striking instance occurred at Jumping Deer Creek in mid-June when a farmer was burning the vegetation margin around all wetlands in a recently plowed quarter section. For two consecutive days, this event attracted adults from six surrounding red-tailed hawk territories, a pair of Swainson's hawks that was nesting outside the study area, and three rough-legged hawks (*B. lagopus*). Territoriality seemed abandoned.

MACROHABITAT SELECTION

The strategy used to assess habitat selection involved a comparison of habitat measurements recorded at breeding red-tailed hawk nests with measurements from random sites. Nests were plotted on assessment site maps using vector-based GIS software ArcView 3.2 (ESRI 1996). A series of concentric circular areas centered on the nest, referred to as "buffers", was constructed. These buffers started at a radius of 0.25 km and increased in increments of 0.25 km up to 1.75 km for a total of seven different buffer classes. Buffer data were cumulative so that data from the 0.25 km buffer were included in the 0.5 km buffer, that of the 0.25 and 0.5 km buffers in the 0.75 km buffer, and so forth. Since I wanted to look at effects of spatial scale, I chose a radius of 1.75 km as the largest radius because I deemed that it should extend beyond any actual home range. Sample sizes were 14, 29, and 34 nests for Allan Hills West, Willowbrook, and Jumping Deer Creek, respectively. To test for habitat selection, measurements were also taken at two random sites for each nest. These points were randomly generated using the GIS software IDRISI (Eastman 2001) and imported into ArcView. Random points were generated at the landscape level in this case because home range selection occurs at this level (second order habitat selection) as opposed to nest site selection which occurs within the home range (third order habitat selection) (Johnson 1980, Seamans and Gutiérrez 1995). For red-tailed hawk nests and random sites, and for each spatial scale, total area occupied by all habitat classes and their mean proportions were measured by extracting data using the GIS.

This technique enabled me to look at the effect of spatial scale on habitat selection. More specifically, the analysis allowed me to examine the distance up to which selection occurred for different habitat variables as well as in general. Based on this, approximate home range size was then assessed and compared to home ranges mapped at the Willowbrook and Jumping Deer Creek assessment sites. Moorman and Chapman (1996) also used concentric circles centered on nest sites and random locations to assess nest-site selection of red-shouldered and red-tailed hawks in Georgia. This technique has also been used repeatedly for habitat selection studies of spotted owls (*Strix occidentalis*) in old growth forests (e.g., Lehmkuhl and Raphael 1993, Hunter et al. 1995).

MICROHABITAT SELECTION

Red-tailed hawk nest sites were examined at a microhabitat scale at Willowbrook and Allan Hills West using a modification of methods described by James and Shugart (1970). Discrete habitat measures were made around nests and randomly selected points after fledging or nest failure. The area sampled consisted of a 400 m^2 circular quadrat (11.28 m radius – 0.04 ha). Nest quadrats were centered on the nest tree. Many nests were located at the edges of woodlots. No corrections were made if part of the quadrat fell into an open area, this opening being considered part of the plot. Except for nest tree-specific variables, measurements taken were the same at random points as at nest sites. A list and description of quantitative and qualitative variables measured within the quadrats is given in Tables 1 and 2. Qualitative variables were collected for descriptive purposes only and assessed only at nest plots. All tree heights were estimated visually to the nearest meter based on three reference height measurements taken with a Haga clinometer, i.e. nest height, nest tree height, and height of the tallest tree in the plot. Diameter at breast height (DBH) was measured with a metric DBH tape.

Table 1. Quantitative variables measured or calculated in 400m^2 quadrat around each red-tailed hawk nest and random point[a] at PHJV assessment sites, Saskatchewan, in 1997.

Variable abbreviation	Description
Variables measured/calculated for all quadrats:	
MEAN_DBH (cm)	Mean diameter at breast height (DBH) of trees with DBH $\geq$3 cm
MEAN_HEIGHT (m)	Mean height of trees with DBH $\geq$3 cm
TOTAL_BA (m^2)	Total basal area of trees with DBH $\geq$3 cm
TBA_1 (m^2)	Total basal area of trees in DBH class 1 (3 - 4.9 cm)
TBA_2 (m^2)	Total basal area of trees in DBH class 2 (5 - 9.9 cm)
TBA_3 (m^2)	Total basal area of trees in DBH class 3 (10 - 14.9 cm)
TBA_4 (m^2)	Total basal area of trees in DBH class 4 (15 - 19.9 cm)
TBA_5 (m^2)	Total basal area of trees in DBH class 5 ($\geq$20 cm)
GRCO (%)	Approximate ground cover of vascular plants smaller than 1 m
SHCO (%)	Approximate shrub cover of shrubs 1 to 5 m
CACO (%)	Approximate canopy cover of trees greater than 5 m
Variables measured at nest sites only:	
NTDBH (cm)	DBH of the nest tree
NTH (m)	Height of the nest tree
NTHTH (%)	Health of the nest tree, approximate % of tree in decay
NH (m)	Height of the nest from the ground measured at the base of the nest
NCACO (%)	Approximate nest canopy cover based on an imaginary cylinder with a radius of 1 m extending over the canopy from the base of the nest

[a] - if applicable

Table 2. Qualitative variables measured at red-tailed hawk nest sites at the 1997 PHJV assessment sites, Saskatchewan.

Variable	Description
Grazing	Presence or absence of grazing by livestock; if present, recent or old
Nest tree species	Species of the tree supporting the nest
Nest tree crown class	Crown class of the tree supporting the nest (dominant, codominant, intermediate, suppressed) (Smith 1986)
Nest condition	Condition of the nest (excellent, good, poor, fell off during in the breeding season)
Nest position	Position of the nest in the canopy (top, middle, bottom)
Nest exposure	Direction of exposure in compass degrees

Habitat availability was characterized by selecting a number of random points equal to the number of nests at each assessment site, 27 and 14 for Willowbrook and Allan Hills West, respectively. There were actually 29 nests at the Willowbrook site; however landowners declined access to two quarter sections where nests were located. Random sites were selected by laying a transparent 1 cm^2 grid over the home range of a pair on 1:5000 aerial photographs (Reese and Kadlec 1985). Every point where a grid intersection fell over a wooded area was given a number and one of these points was selected randomly. Since red-tailed hawks require mature trees as nest substrate, only random points that fell in mature wooded areas were considered. All random site quadrats were centered on the tree with a DBH > 10 cm closest to the point identified on the aerial photograph. This tree was not assumed to be equivalent to the nest tree but used only as a focal point for the quadrat. Thus, its measurements were not compared to those of the nest tree in the analyses. Where home ranges could not be determined because of nest abandonment and subsequent departure of the pair, home ranges were based on a 2 km^2 circular area (radius = 0.805 km) centered at the nest and drawn on aerial photographs. This area was chosen recognizing that others had recorded mean radii of home ranges ranging from 0.8 to 1.1 km (Craighead and Craighead 1969, Janes 1984b). Consequently, I considered that this area encompassed the home range of most red-tailed hawk pairs on the study sites. Because little overlap was found between adjacent home ranges, portions within these circular areas that were part of the home range (or circular area) of other pairs were excluded. This technique was applied to three nests at Willowbrook and to all nests at Allan Hills because home ranges were not determined on that site. The same area delineation was used at random sites. In habitat use versus availability studies, designation of habitat components available to an organism can have considerable influence on results (Johnson 1980). Random sites were chosen within the home range of each pair because it was assumed that what is available to a pair as a nest site is what is within its home range only and not in the home range of other pairs. Since territories are stable from year to year this assumption is justified (Fitch et al. 1946, Newton 1976, Janes 1984a, Preston and Beane 1993). Dykstra et al. (2000) chose random sites paired to nests in a similar fashion.

DATA ANALYSES

Some buffers from the macrohabitat selection data had portions that extended beyond the study area boundaries (Fig. 8). Since aerial photographs from outside the study area were not digitized, land uses for those portions of the buffers were unknown. The maximum area missing from a buffer was 50% for a nest on the study area boundary. Analysis of variance with Tukey's HSD multiple comparison procedures (Zar 1984) was conducted using SYSTAT (SPSS 1997) to test for statistical differences between buffers which were completely inside the study areas and those which had 1-10%, 11-20%, 21-30%, 31-40%, and >40% of their area outside the study area. Buffers from nest and random sites for all study areas were pooled for these analyses. It was determined that buffers with > 30% of their area outside the study areas were statistically different from buffers which were completely within the study areas. Therefore, for statistical analyses, usable buffers for both nests and random sites were limited to those containing ≥70% of their areas within the study areas. Since data used in final analyses were proportions of habitat classes and not area, the data did not require further adjustments.

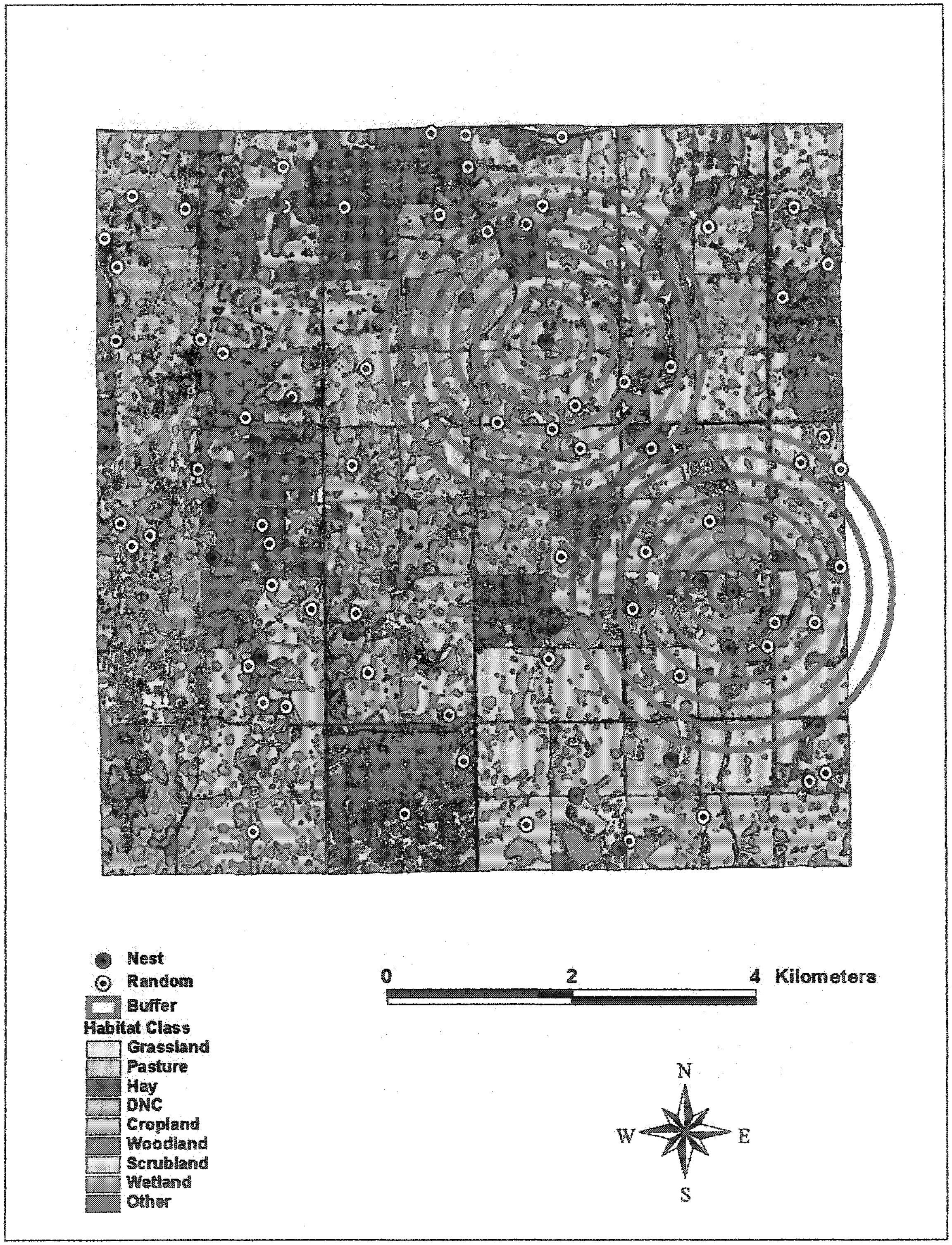

Figure 8. Land use cover map showing an example of the macrohabitat buffer sampling procedure for two red-tailed hawk nests at the 1998 Jumping Deer Creek PHJV assessment site, Saskatchewan.

Habitat selection and habitat-productivity relationships for red-tailed hawks were assessed by comparing the means of paired variables. Data on structural measures of the vegetation and habitat classes were evaluated for normality using box plots. For microhabitat and macrohabitat analysis, 10 of 16 variables and 37 of 63 variables, respectively, were not normally distributed. Therefore, nonparametric statistics were used so that non-normal and percentage data did not require transformation (Zar 1984, Sokal and Rohlf 1995). Mann-Whitney *U*-tests were used for all tests for the null hypothesis of no difference in landscape patterns or vegetation structural measurements among paired variables with the statistics package SYSTAT (SPSS 1997).

Since I aimed to describe nesting habitats of red-tailed hawks across their breeding range in the Saskatchewan aspen parkland, data from all sites were pooled. For the microhabitat analysis, some variables were found to be significantly different, however magnitudes were small and were likely not biologically meaningful (Appendix D). Habitat characteristics, both for microhabitat and macrohabitat selection, were compared between nests and random sites, between successful nests and random sites, and between unsuccessful nests and random sites. Successful nests fledged at least one young and unsuccessful nests fledged none. The effect of habitat on productivity, both for microhabitat and macrohabitat selection, was examined by pooling data for all sites and comparing successful to unsuccessful nests. Comparisons generating a P value of ≤ 0.05 were considered statistically significant.

INTERPRETATION of MACROHABITAT FIGURES

To simplify interpretation of the large number of pair-wise statistical tests, only results with P values smaller than 0.099 were presented. Complete test results and sample sizes are presented in Appendices E-H. My goal at this stage was to examine all variables that may influence selection, so I chose to include all comparisons with $P < 0.1$. Moreover, it was considered that inclusion of these test results was relevant since they permit examination of the spatial component of habitat selection with increasing distance from the nest. Results with high significance ($P < 0.05$) are presented in red, moderate significance ($0.05 > P < 0.075$) are presented in yellow, and low significance ($0.076 > P < 0.099$) in blue. Empty cells in the figures refer to random selection or selection of a cover type in proportion to its availability. Cells containing a "+" sign represent "preference" or use in greater proportion than availability and cells containing a "-"represent "avoidance" or use less than availability (Johnson 1980). For the effects of habitat on productivity analyses, the "+" sign indicates a positive effect of habitat on productivity and the "-" sign indicates a negative effect.

RESULTS

NESTING DENSITIES and DISTRIBUTION

Nesting densities at all assessment sites were high (Table 3). The highest densities were found on the Jumping Deer Creek site where 34 nests (0.53 nesting pairs/km^2) were occupied. At Willowbrook, there were 29 active nests (0.45 pair/km^2). The lowest nesting density was at Allan Hills West where 14 nests (0.22 nesting pairs/km^2) were found. For all sites combined, nesting densities were 0.40 pairs/km^2. Red-tailed hawk nesting densities increased in proportion to the amount of woodland cover on each assessment site (Fig. 9).

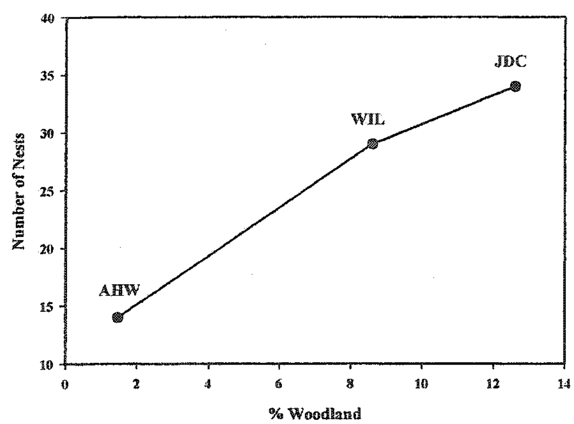

Figure 9. Number of red-tailed hawk pairs nesting on the Allan Hills West (AHW), Willowbrook (WIL), and Jumping Deer Creek (JDC) PHJV assessment sites in relation to the percentage of woodland available, Saskatchewan, 1997-98.

Table 3. Red-tailed hawk nesting densities and productivity estimates at PHJV assessment sites, Saskatchewan, in 1997-98.

Location	Nesting Densities[a] (nests/km^2)	Young Fledged[b] (young/nest)	Nest Success[c] (%)
Willowbrook, SK	0.45 (29)	0.79 (23)	65.5 (19/29)
Allan Hills, SK	0.22 (14)	1.86 (26)	85.7 (12/14)
Jumping Deer Creek, SK	0.53 (34)	0.71 (24)	52.9 (18/34)
All sites combined, SK	0.40	0.95	63.6

[a] – Numbers in brackets indicate the total number of nesting pairs on each site
[b] – Numbers in brackets indicate the total number of young fledged on each site
[c] – Numbers in brackets indicate the total number of successful nests over the total number of active nests on each site

Home ranges had a regular distribution through the landscape at Willowbrook (Fig. 10) and at Jumping Deer Creek (Fig. 11). Home ranges at Allan Hills West could not be assessed; however, nests appeared clumped around DNC and native grassland, the two areas with the highest tree availability (Fig. 5). Mean home range size was significantly larger at Willowbrook than at Jumping Deer Creek (Table 4; t=4.67, $P < 0.001$, df = 40), and there was little variation in home range size at either assessment site (Table 4).

Table 4. Home range size observed at the 1997 Willowbrook (WIL) and 1998 Jumping Deer Creek (JDC) PHJV assessment sites, Saskatchewan.

Assessment	*n*	Home Range Size (km^2)				
Site		x	SE	Minimum	Maximum	Radius[a] (m)
WIL	26	1.25	0.08	0.58	2.07	631
JDC	27	0.81	0.05	0.39	1.31	508
Pooled	53	1.02	0.05	0.39	2.07	570

[a] – Assuming a circular home range

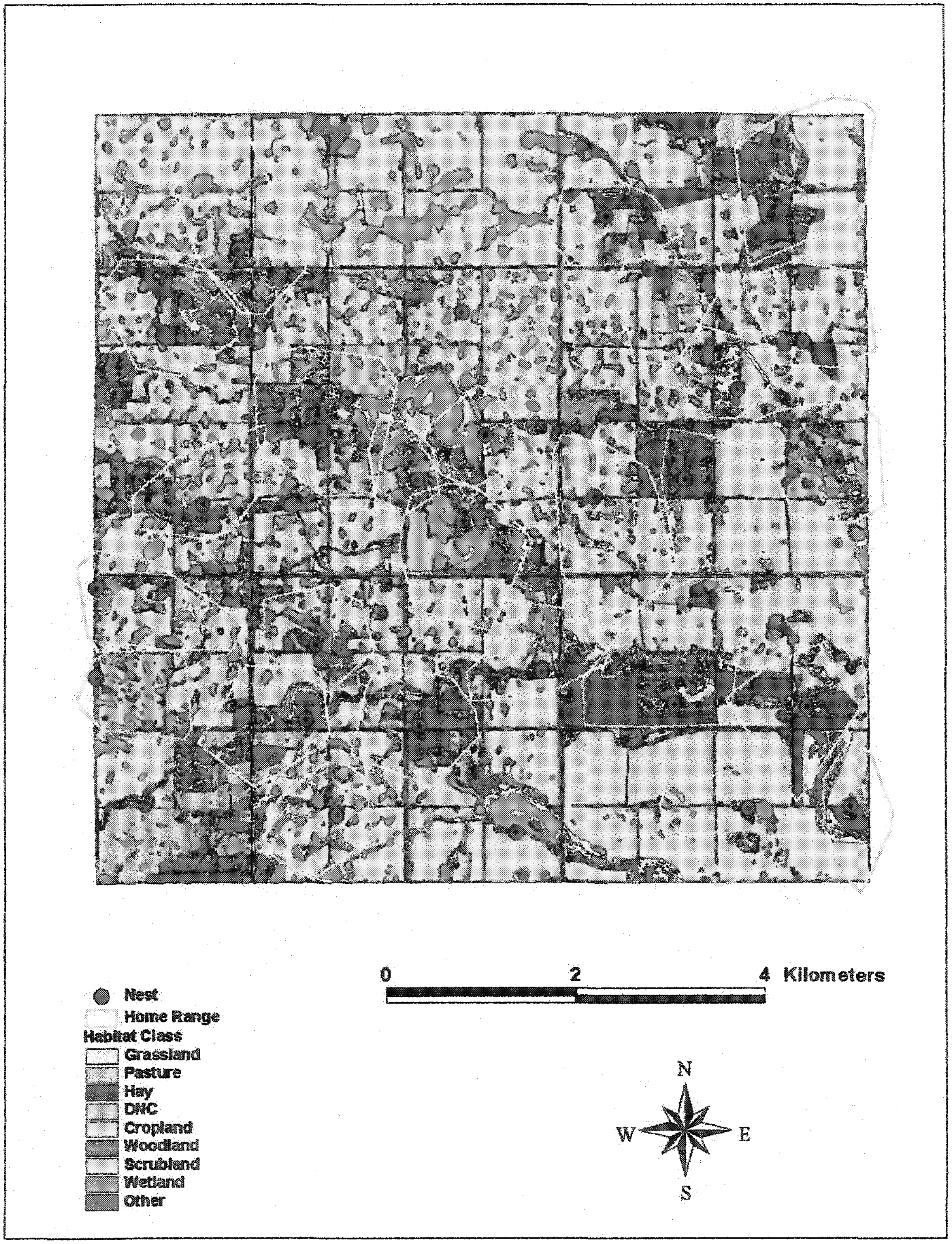

Figure 10. Land use cover map and red-tailed hawk home ranges and nest locations at the 1997 Willowbrook PHJV assessment site, Saskatchewan.

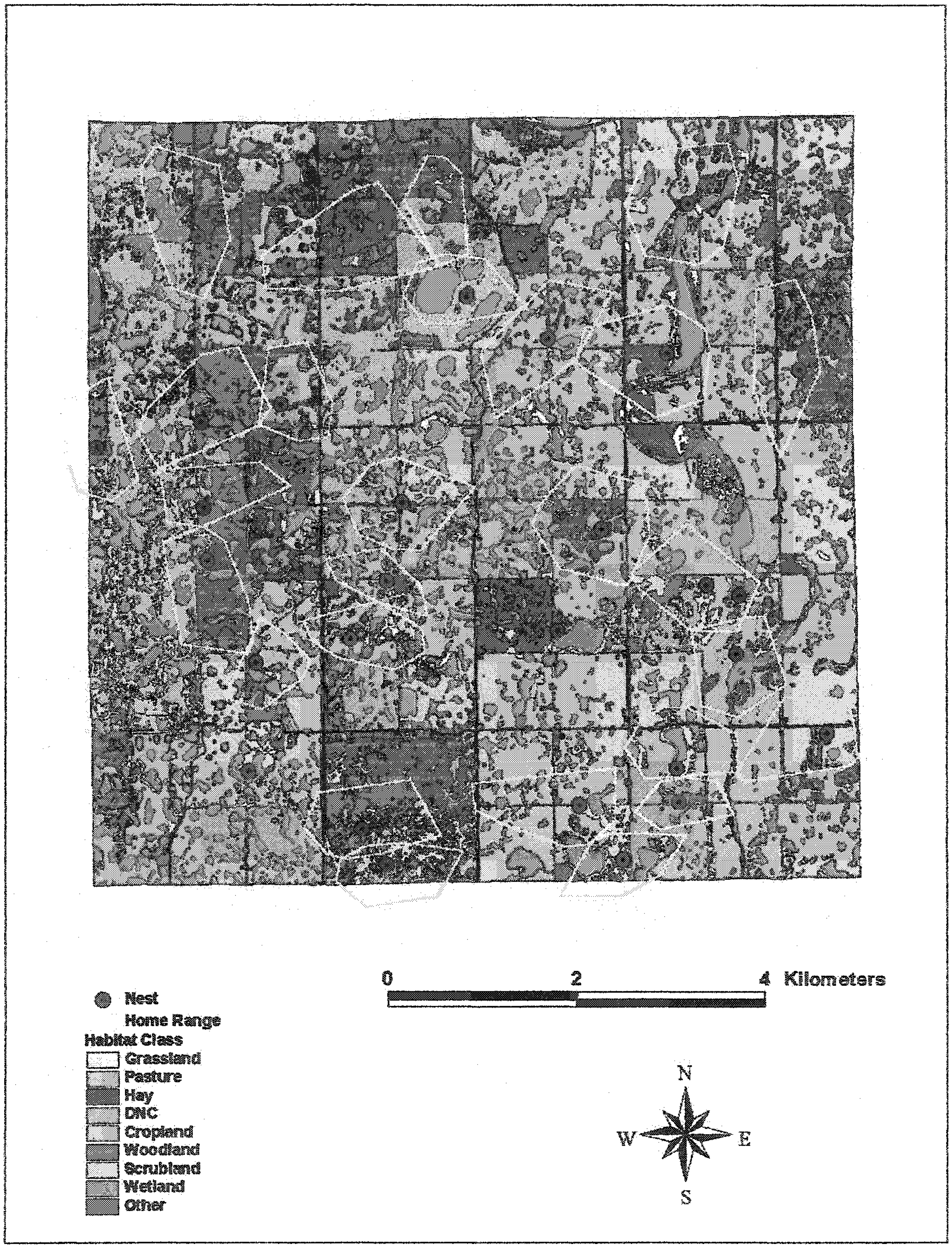

Figure 11. Land use cover map and red-tailed hawk home ranges and nest locations at the 1998 Jumping Deer Creek PHJV assessment site, Saskatchewan.

PRODUCTIVITY

General Behavior

The first red-tailed hawks appeared on the study areas in early April. Within a week of arrival, pairs selected nesting territories and reacted aggressively towards neighboring red-tailed hawks, migrant hawks, and human intruders near their nests. Sightings of non-territorial and migrating red-tailed hawks were frequent in April and the first half of May. Nesting territories were occupied by the first week of May. All territorial pairs (n = 77) selected nest sites and attempted to breed. None of the breeding red-tailed hawks were in juvenile (first-year) plumage. First-year birds were not observed on any of the study areas until after nestlings started leaving the nests. After spring migration was completed, suspected vagrant birds or floaters were not observed on any of the assessment sites except for one hawk at Willowbrook in mid-June. This hawk was easily recognizable by its dark coloration, its small size, and by its numerous missing flight feathers. A territorial pair quickly chased it out of the study area. It was spotted again a few times over the next week and then it disappeared.

Productivity

Because investigator disturbance during the nest initiation and incubation periods was minimized, accurate data on clutch size or brood size at hatching were too few to report rates of egg mortality, hatching success, or nestling survival. The total number of young fledged/site was stable across sites with 23, 26, and 24 young fledged at Willowbrook, Allan Hills West, and Jumping Deer Creek, respectively (Table 3). However, the number of young fledged per active nest at Allan Hills West, 1.86 young/nest, was more than double that at the other two sites (Table 3). Reproductive success was similar for Willowbrook and Jumping Deer Creek. Nest success varied among assessment sites (Table 3), but was highest at Allan Hills West (85.7%) and moderate at Willowbrook (65.5%). Nest success at Jumping Deer Creek was low, with nearly half the nests failing to fledge any young. For all sites combined, the mean productivity was 0.95 young fledged/active nest and mean nest success was 63.6%. Nestlings began leaving nests in mid-July, but most fledged in the last week of July.

When examined in more detail, the pattern of production per nest was quite different among sites (Table 5). Three of the failed nesting attempts at Willowbrook were attributed to a snowstorm in mid-incubation after which these nests were abandoned. Two nest failures were the result of predation, one by a flock of black-billed magpies (*Pica pica*) late in the incubation period and the other by an unknown predator soon after the single egg hatched. Two nests were abandoned when fires were set in the woodlots where nests were situated. In once case the eggs had just hatched, and the stage of the breeding cycle of the other was unknown because of land access restrictions. Two nests were abandoned in mid-incubation when livestock were let into the pastures where the nests were located. For one other nest failure, the only nestling observed was found dead below the nest. It appeared in good condition. Two other nestlings, each from a brood of two, were found dead below their nests, and both appeared to be in good condition.

Table 5. Number of red-tailed hawk nests which fledged none, one, two, and three young on PHJV assessment sites, Saskatchewan, in 1997-98.

Assessment	Number of nests which fledged *n* young			
Site	0	1	2	3
Willowbrook	10	15	4	0
Allan Hills West	2	2	6	4
Jumping Deer Creek	16	13	4	1

The cause of one nesting failure at Allan Hills was unknown, but evidence suggests that the eggs hatched. A partial eggshell was found under the nest and other fragments were found in the nest bowl. The other failed nest was abandoned in mid-incubation when livestock were let into the pasture where the nest was located. A pair of Cooper's hawk (*Accipiter cooperii*) later occupied the nest and had 4 chicks present on 20 July.

At Jumping Deer Creek, nest failures occurred primarily during the late incubation and early nestling periods. For a period of eight consecutive days, temperatures were unseasonably low, with constant rain showers and high wind speeds. Road conditions were poor enough to prevent access to the site for the entire period, so investigator effects during that period were nil. This weather event was responsible for eight nesting failures. Of these, six clutches were abandoned prior to hatching; five clutches had two eggs and one had one egg. The other two were broods of two chicks. In each case, the first nestling to die from exposure and starvation was partially consumed by the other nestling before the second nestling died. Also during this period, eight broods were reduced from two to one as a chick from each brood died from exposure and starvation. In six of these cases, the dead chick was partially consumed by its sibling and in the other two cases, the chicks disappeared from the nests. Predation accounted for five nest failures. Of these, raccoons (*Procyon lotor*) depredated two clutches based on the presence of raccoon fur in the nest and along the tree trunk. The other three entire broods (all had two nestlings) disappeared from the nests. Two brood failures with two young occurred when chicks died of exposure and starvation shortly after hatching. Because many prey items were present in each nest, adults more likely failed to provide adequate care for their nestlings. Another nest containing three eggs fell down. This nest was unusually large. Another brood was reduced from two to one when a nestling fell from the nest and was killed or scavenged by a skunk.

To my knowledge, only one pair attempted re-nesting after failure of their first attempt. The pair, which was nesting on the Jumping Deer Creek site, began construction of a second nest in a young aspen grove at a height and in a tree that appeared unsuitable. The nest was half completed and the pair stopped their effort. In two failed nesting attempts at Allan Hills, both pairs left the study area. At Willowbrook, six pairs with failed nests left the study area and four pairs maintained their territories. Of failed breeders at Jumping Deer Creek, six pairs left the study area and 10 pairs maintained their territories.

MACROHABITAT SELECTION

Comparisons of Nests and Random Sites

Red-tailed hawks selected areas with greater proportions of DNC, woodland, and scrubland in the local landscape and areas with lesser proportions of cropland and "other" land cover types than was available (Fig. 12, Appendix E). "Other" land cover types consisted of farmsteads, buildings, and roads (Appendices B and C). Spatially, habitat selection appeared strong up to 750 m from the nest and was weak reaching 1000 m as indicated by the number of comparisons with $P < 0.1$. DNC and woodland were important factors related to site selection in the nest vicinity. More nests were located in areas with high proportions of scrubland, up to a radius of 1000 m from the nest. Red-tailed hawks avoided nesting in close proximity to human-occupied and heavily cultivated areas.

Habitat	Buffer Radius (m)						
Class	**250**	**500**	**750**	**1000**	**1250**	**1500**	**1750**
DNC	+	+					
Cropland	-	-	-	-			
Woodland	+	+	+				
Scrubland	+	+	+	+	+		
Other	-						

Figure 12: Red-tailed hawk habitat selection among continuous macrohabitat variables measured within concentric buffers centered on nest and random sites for the 1997-98 PHJV assessment sites, Saskatchewan. Complete tests results and sample sizes are presented in Appendix E. Results with high significance (P < 0.05) are presented in red, moderate significance (0.05 > P < 0.075) are presented in yellow, and low significance (0.076 > P < 0.099) in blue.

Comparisons of Successful Nests and Random Sites

To further elucidate the patterns of macrohabitat nest site selection shown in Fig. 12, macrohabitat variables were measured within a series of concentric circles centered on successful red-tailed hawk nest sites and compared to similar measurements collected at random sites (a subset of the previous analysis). Preference and avoidance of land cover types for successful red-tailed hawk pairs was similar to that found when all nesting pairs were considered as would be expected because they represented most of the nests in the previous analysis (Figs. 12 and 13). Nonetheless, spatially their selection varied for some land cover types (Fig. 13). Hawks with successful nests avoided the cropland and "other" land cover types at the same level as all nests in general. However, they nested in areas that had significantly more DNC than when all nests were considered. As well, successful pairs nested in areas with more woodland and scrubland as an additional 250 m buffer presented a significant comparison compared to all nests pooled.

Habitat	Buffer Radius (m)						
Class	250	500	750	1000	1250	1500	1750
DNC	+	+	+	+	+		
Cropland	-	-	-	-			
Woodland	+	+					
Scrubland	+	+	+				
Other	-						

Figure 13: Red-tailed hawk habitat selection among continuous macrohabitat variables measured within concentric buffers centered on successful nests and random sites for the 1997-98 PHJV assessment sites, Saskatchewan. Complete tests results and sample sizes are presented in Appendix F. Results with high significance ($P < 0.05$) are presented in red, moderate significance ($0.05 > P < 0.075$) are presented in yellow, and low significance ($0.076 > P < 0.099$) in blue.

Comparisons of Unsuccessful Nests and Random Sites

In contrast to the pattern for successful nests, unsuccessful red-tailed hawks exhibited noticeably different habitat selection (Figs. 12 and 14). The distance from the nest at which macrohabitat features may have influenced nest site location was not as clear as for successful nests, but it appeared to be in the range of 750 to 1000 m. A major difference was that unsuccessful hawks used DNC and "other" cover types in proportion to availability. Furthermore, they nested relatively more often in areas with higher pasture cover at all analyzed distances from the nest; however, preference was weak for some of these buffers. Unsuccessful hawks nested in areas surrounded by more woodland and scrubland and less cropland compared to all nests.

Habitat	Buffer Radius (m)						
Class	**250**	**500**	**750**	**1000**	**1250**	**1500**	**1750**
Pasture	+	+	+	+	+	+	+
Cropland	-	-					
Woodland	+	+	+	+			
Scrubland	+	+	+	+	+		

Figure 14: Red-tailed hawk habitat selection among continuous macrohabitat variables measured within concentric buffers centered on unsuccessful nests and random sites for the 1997-98 PHJV assessment sites, Saskatchewan. Complete tests results and sample sizes are presented in Appendix G. Results with high significance (P < 0.05) are presented in red, moderate significance (0.05 > P < 0.075) are presented in yellow, and low significance (0.076 > P < 0.099) in blue.

Effects of Macrohabitat on Productivity

Effects of habitat on productivity were assessed by comparing macrohabitat variables of successful and unsuccessful nest sites. Two land cover types, DNC and pasture, produced significant effects (Fig. 15). Red-tailed hawk nests were more likely to fail when they were located in relatively large pasture areas, and were more likely to be successful when they were located near large tracts of DNC (Fig. 15). Grassland had a weak positive effect on productivity at 1750 m ($P = 0.06$), however this was likely a statistical artifact since it had no influence in closer buffer zones. Furthermore, in analyses of individual assessment sites (A.J. Fontaine, unpubl. data), no influence from the grassland cover type was found.

Habitat Class	Buffer Radius (m) 250	500	750	1000	1250	1500	1750
Grassland							+
Pasture	-	-	-	-	-	-	-
DNC	+	+	+	+	+	+	

Figure 15: Effects of habitat on red-tailed hawk productivity comparing habitat use among continuous macrohabitat variables measured within concentric buffers centered on successful and unsuccessful nests for the 1997-98 PHJV assessment sites, Saskatchewan. Complete tests results and sample sizes are presented in Appendix H. Results with high significance (P < 0.05) are presented in red, moderate significance (0.05 > P < 0.075) are presented in yellow, and low significance (0.076 > P < 0.099) in blue.

MICROHABITAT SELECTION

Description of nesting sites

Some nests had been built in previous years, and others were new. The proportion of newly built nests was unknown. Unoccupied large raptor stick nests were abundant on all assessment sites. In general, nests were constructed of aspen and poplar twigs and lined with decayed aspen bark and young leafy twigs.

Seven species of overstory trees were recorded on the study areas: trembling aspen, balsam poplar, Manitoba maple, green ash, weeping willows (*Salix babylonica*), white spruce, and Norway spruce, the latter four growing exclusively around farmsteads. Only trembling aspens and balsam poplars were used to support active red-tailed hawk nests, trembling aspens being used much more frequently (Table 6). No other structures, either natural or anthropogenic in origin, supported nests. All nest trees were in dominant and codominant crown classes (Table 6). Most nests were located in the middle of the canopy whereas top and bottom nest positions had similar number of nests (Table 6). Livestock had grazed (includes recent and old grazing events) 15% of nest quadrats (Table 6).

Table 6. Qualitative red-tailed hawk nest tree variables (n = 41[a]) observed on PHJV assessment sites, Saskatchewan, in 1997.

Nest Tree Species[b]		Nest Tree Crown Class[c]		Nest Position in Canopy			Grazing	
t.a.	b.p.	Dominant	Codominant	Top	Middle	Bottom	Yes	No
36	5	22	19	7	26	8	6	35

[a] – Because of land access restrictions, data were collected at 27 of the 29 nests available at Willowbrook.
[b] – Nest tree species were trembling aspen (t.a.) and balsam poplar (b.p.)
[c] – See Smith (1986) for crown class definitions

Means for quantitative variables describing red-tailed hawk nests are presented in Table 7. The smallest and largest nest trees, both trembling aspens, had a DBH of 12.7 cm and 38.4 cm and a height of 7 m and 20 m, respectively. The highest and lowest nests were both located in trembling aspens at 17.5 m and 3 m above ground, respectively. The lowest nest was in a small lone trembling aspen growing in a willow grove on the side of a large wetland. This nest site was different from any red-tailed hawk nest site encountered over the two years of the study. Most nest trees had a portion of their crown in decay, and ranged from healthy trees with almost no decay (0-10%) to dead trees or snags (100%).

Table 7. Characteristics ($\bar{x} \pm$ SE) of red-tailed hawk nest trees ($n = 41^{a}$) measured on PHJV assessment sites, Saskatchewan, in 1997. Refer to Table 1 for a description of mnemonics.

NTDBH		NTH		NTHTH		NH		NCACO	
$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
23.57	0.78	13.65	0.43	44.63	4.66	9.79	0.33	40.98	4.13

[a] – Because of land access restrictions, data were collected at 27 of the 29 nests available at Willowbrook

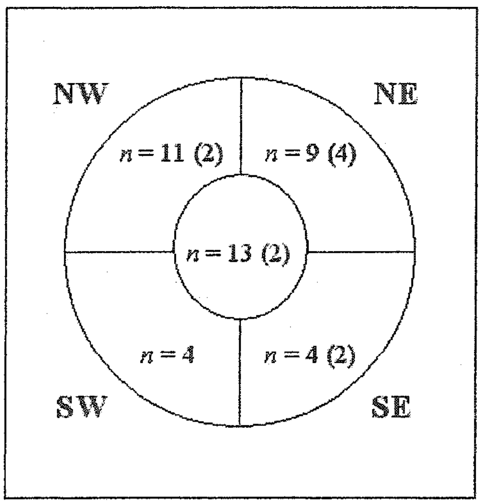

Figure 16. Nest exposure (n = 41) at red-tailed hawk nest sites at the 1997 PHJV assessment sites. Sample size is indicated for each direction (quadrant) and numbers in brackets identify the number of nests that failed.

Red-tailed hawk nesting pairs chose predominantly northwest and northeast nest exposures (Fig. 16). A large proportion of nests were completely exposed (n = 13). Exposures presented in Fig. 16 are only the main direction of exposure and quadrants were assigned to all nests that did not have a complete 360° exposure. Exposure width was often very large; excluding complete exposures (360°), the degree of exposure ranged from 50° to 330° and averaged 160°. Exposures of failed nests were distributed in low numbers across all quadrants except the southwest quadrant.

Comparisons of Nests and Random Sites

Red-tailed hawks chose nest sites selectively in the Saskatchewan aspen parkland (Table 8). They selected sites with a significantly greater mean DBH ($P = 0.021$) and class 5 total basal area ($P < 0.001$) compared to random sites. Selected nest sites had fewer trees in intermediate total basal area classes 2 ($P = 0.002$) and 3 ($P = 0.001$) as well as less canopy cover ($P = 0.022$) than random sites. Other nest microhabitat variables did not differ from random sites.

Table 8. Characteristics ($\bar{x} \pm$ SE) of microhabitat variables for red-tailed hawk nests ($n = 41$) and random sites ($n = 41$) at PHJV assessment sites, Saskatchewan, in 1997. Refer to Table 1 for a description of mnemonics.

Variables	Nest Sites		Random Sites		Test Statistic[a]	
	$\bar{x}$	SE	$\bar{x}$	SE	U	P
MEAN_DBH	10.20	0.46	9.06	0.48	592.5	0.021
MEAN_HEIGHT	7.76	0.31	7.55	0.29	770	0.513
TOTAL_BA	1.01	0.07	0.87	0.05	653	0.082
TBA_1	0.04	0.01	0.05	0.01	970.5	0.228
TBA_2	0.09	0.01	0.16	0.02	1168	0.002
TBA_3	0.15	0.02	0.25	0.03	1189	0.001
TBA_4	0.26	0.04	0.21	0.03	767	0.495
TBA_5	0.47	0.05	0.19	0.03	406	<0.001
GRCO	64.39	4.39	56.83	4.02	702	0.196
SHCO	33.90	3.04	28.78	3.34	679	0.127
CACO	33.17	2.65	45.12	3.65	1083.5	0.022

[a] - Mann-Whitney U-test, all with 1 df

Comparisons of Successful Nests and Random Sites

To further elucidate the patterns of microhabitat nest site selection shown in Table 8, successful red-tailed hawk nest sites were compared to random sites to determine if successful pairs were more selective in their choice of nests sites (a subset of the previous analysis). Overall, microhabitat characteristics of successful nests differed from random sites but in a similar pattern to all nests pooled (Table 9). The differences in shrub cover and mean DBH between successful nests and random sites were not significant, although these may be biologically meaningful ($P = 0.075$, and $P = 0.083$, respectively).

Table 9. Characteristics ($\bar{x} \pm$ SE) of microhabitat variables for successful red-tailed hawk nests ($n = 31$) and random sites ($n = 41$) at PHJV assessment sites, Saskatchewan, in 1997. Refer to Table 1 for a description of mnemonics.

Variables	Successful Nest Sites		Random Sites		Test Statistic[a]	
	$\bar{x}$	SE	$\bar{x}$	SE	U	P
MEAN_DBH	9.82	0.50	9.06	0.48	788	0.083
MEAN_HEIGHT	7.53	0.35	7.55	0.29	655	0.824
TOTAL_BA	1.02	0.08	0.87	0.05	774.5	0.114
TBA_1	0.04	0.01	0.05	0.01	563	0.41
TBA_2	0.09	0.01	0.16	0.02	400	0.007
TBA_3	0.16	0.03	0.25	0.03	405.5	0.009
TBA_4	0.26	0.05	0.21	0.03	638.5	0.973
TBA_5	0.47	0.07	0.19	0.03	935	0.001
GRCO	65.48	5.39	56.83	4.02	754	0.175
SHCO	35.48	3.40	28.78	3.34	789	0.075
CACO	31.29	2.77	45.12	3.65	419	0.013

[a] - Mann-Whitney U-test, all with 1 df

Comparisons of Unsuccessful Nests and Random Sites

Unsuccessful red-tailed hawk nest sites were also compared to random sites to determine if unsuccessful pairs were less selective in their choice of nests sites. Although the sample size was small ($n = 10$), unsuccessful nest sites were chosen nearly as selectively as all nests pooled or successful nests (Table 10). Conversely, canopy cover at unsuccessful nests was not thinner than the cover found at random sites ($P = 0.525$).

Table 10. Characteristics ($\bar{x} \pm$ SE) of microhabitat variables for unsuccessful red-tailed hawk nests ($n = 10$) and random sites ($n = 41$) at PHJV assessment sites, Saskatchewan, in 1997. Refer to Table 1 for a description of mnemonics.

Variables	Unsuccessful Nest Sites		Random Sites		Test Statistic[a]	
	$\bar{x}$	SE	$\bar{x}$	SE	U	P
MEAN_DBH	11.36	1.08	9.06	0.48	300.5	0.023
MEAN_HEIGHT	8.49	0.69	7.55	0.29	256	0.226
TOTAL_BA	0.98	0.08	0.87	0.05	253.5	0.25
TBA_1	0.03	0.01	0.05	0.01	147.5	0.172
TBA_2	0.08	0.02	0.16	0.02	113	0.029
TBA_3	0.11	0.03	0.25	0.03	86.5	0.005
TBA_4	0.29	0.03	0.21	0.03	275.5	0.094
TBA_5	0.47	0.06	0.19	0.03	340	0.001
GRCO	61.00	7.06	56.83	4.02	225	0.632
SHCO	29.00	6.74	28.78	3.34	213	0.845
CACO	39.00	6.57	45.12	3.65	178.5	0.525

[a] - Mann-Whitney U-test, all with 1 df

Effects of Microhabitat on Productivity

Successful red-tailed hawk nest sites were compared to unsuccessful nest sites to determine if assessed microhabitat variables had an effect on nesting success. No differences in microhabitat that related to productivity were found (Table 11). The only significant difference showed a greater amount of decay in successful nest trees compared to unsuccessful ones ($P = 0.008$). This difference was not reflected in canopy cover in the quadrat ($P = 0.278$) or nest canopy cover ($P = 0.678$).

Table 11. Characteristics ($\bar{x}$ ± SE) of microhabitat variables for successful ($n = 31$) and unsuccessful ($n = 10$) red-tailed hawk nests at PHJV assessment sites, Saskatchewan, in 1997. Refer to Table 1 for a description of mnemonics.

Variables	Successful Nest Sites		Unsuccessful Nest Sites		Test Statistic[a]	
	$\bar{x}$	SE	$\bar{x}$	SE	*U*	*P*
MEAN_DBH	9.82	0.50	11.36	1.08	196.5	0.208
MEAN_HEIGHT	7.53	0.35	8.49	0.69	192	0.261
TOTAL_BA	1.02	0.08	0.98	0.08	158	0.927
TBA_1	0.04	0.01	0.03	0.01	104.5	0.125
TBA_2	0.09	0.01	0.08	0.02	134	0.524
TBA_3	0.16	0.03	0.11	0.03	126.5	0.387
TBA_4	0.26	0.05	0.29	0.03	214.5	0.071
TBA_5	0.47	0.07	0.47	0.06	164	0.785
GRCO	65.48	5.39	61.00	7.06	136	0.561
SHCO	35.48	3.40	29.00	6.74	118.5	0.261
CACO	31.29	2.77	39.00	6.57	190	0.278
NTDBH	23.47	1.02	23.89	0.69	180.5	0.439
NTH	13.32	0.49	14.65	0.88	184	0.377
NTHTH	50.00	5.23	28.00	8.54	68.5	0.008
NH	9.65	0.33	10.25	0.92	148.5	0.843
NCACO	40.32	4.94	43.00	7.61	168.5	0.678

[a] - Mann-Whitney *U*-test, all with 1 df

DISCUSSION

NESTING DENSITIES AND DISTRIBUTION

Measures of nesting density in this study were higher than those found over much of the red-tailed hawk's breeding range. A portion of these differences is presumably attributable to methodological artifact since nest-searching efforts differ between studies. Nesting densities on the assessment sites were slightly higher than those found in other studies in the aspen parkland (Tables 3 and 12). Densities on Jumping Deer Creek were the highest reported anywhere for this type of habitat. Nesting densities in aspen parkland, 0.10 to 0.53 nests/km^2, were much higher than those found in typical prairie habitat, 0.004 to 0.03 nests/km^2 (Tables 3 and 12), where the paucity of trees and other nesting and perching structures make this ecoregion unsuitable breeding habitat for the red-tailed hawk (Janes 1984b, Preston 1990, Janes 1994). The red-tailed hawk breeds in relatively low densities through much of its range (Table 12). Reported nesting densities ranged widely from 0.003 active nests/km^2 in Idaho (Hansen and Flake 1995) to 0.32 active nests/km^2 in Wyoming (Craighead and Craighead 1969). The highest density of territorial pairs (not nesting pairs) reported was 0.77 pairs/km^2 in California (Fitch et al. 1946). Overall, most nesting densities fell in the range of 0.10 to 0.25 active nests/km^2 (Table 12).

Nesting densities on the Allan Hills West assessment site and those reported by Murphy (1993) in northwest North Dakota were very similar (Tables 3 and 12). The habitat composition of both landscapes is intermediate between those typically found in the parkland and prairie ecoregions, with small islands of aspen-poplar growing on sheltered hillsides and around wetlands as opposed to large aspen/poplar groves in aspen parkland and isolated planted trees in prairie landscapes (Murphy 1993).

Nesting densities on the assessment sites were likely limited by the availability of nesting sites, namely woodland cover. Red-tailed hawk nesting densities increased in relation to the amount of woodland coverage on each site. However, the sample was small (3 sites) and it would be interesting to add more sites to determine if this was a true relationship and to assess the population asymptote resulting from territorial spacing. Presumably, nesting densities would reach a plateau as the amount of woodland cover increases and then perhaps start declining as the amount of woodland replaces hunting habitat. Schmutz et al. (1980) also showed an increase in the number of prairie *Buteos* with the number of available tree clumps.

Table 12. Summary of reported red-tailed hawk nesting densities and productivity estimates.

Location	Nesting Densities (nests/km^2)	Young Fledged (young/nest)	Nest Success (%)	Reference
Parkland Ecotone				
Yellow Creek, SK	0.38	-	-	Houston and Bechard 1983
Calgary, AB	0.42-0.47	-	-	Rothfels and Lein 1983
Rochester, AB	0.10-0.18	0.28-1.9	-	Adamcick et al. 1979
North Dakota, LNWR	0.21-0.27	0.52-1.24	34.8-84.6	Murphy 1993
North Dakota, Lucy township	0.15-0.16	1.17-1.69	75-92.3	Murphy 1993
Prairie Ecotone				
Alberta (Hanna)	0.02-0.03	-	-	Schmutz et al. 1980
North Dakota	0.009	1.63	78	Gilmer et al. 1983
South Dakota	0.004	-	-	Lokemoen and Duebbert 1976
Other Regions				
Arizona	-	1.55	81	Mader 1978
California	0.77[a]	0.9[b]	53.8	Fitch et al. 1946
California	0.31	1.64	73.6	Wiley 1975
Colorado	0.17-0.5[c]	-	-	McGovern and McNurney 1986
Georgia	0.17	0.5-1.16	50-83	Moorman et al. 1999
Idaho	0.003-0.004	0.8-1.9	37.5-100	Hansen and Flake 1995
Michigan	0.02-0.05	0.5-0.8	-	Craighead and Craighead 1969
Montana	0.09-0.11	1.38-1.70	58.6-61.9	Johnson 1975
Montana	0.06	1.50	-	Restani 1991
Montana	-	0.9	50	Seidensticker and Reynolds 1971
New York	0.12	1.1	59	Hagar 1957
New York	0.08	1.1	67.9	Minor et al. 1993
Ohio	0.16	1.29	65.8	Kirkley and Springer 1980
Oregon	-	1.47	-	Janes 1984b
Oregon	0.24	-	-	Janes 1994
Utah	0.03	-	-	Smith and Murphy 1973
Washington	0.11-0.13	0.8-1.9	50-71.4	Knight and Smith 1982
Wisconsin	0.08-0.11	0.9-1.4	50-78	Gates 1972
Wisconsin	0.11-0.13	1.1-1.8	63.6-88.9	Orians and Kuhlman 1956
Wisconsin	0.18-0.23	1.0-1.6	53-86	Petersen 1979
Wisconsin	-	1.13-1.91	75.3-92.7	Stout et al. 1998
Wyoming	0.32	1.7	-	Craighead and Craighead 1969

[a] – Approximate densities of adult pairs and not nesting pairs
[b] – Minimum estimate based on nests from which # of young fledged was known
[c] – Size of the study area with 0.5 nest/km^2 was 14 km^2

Observed mean home range size was among the lowest reported for studies across North America (Tables 4 and 13). Differences in home range estimates among studies may reflect differences in habitat quality and prey densities (Fitch et al. 1946, Preston and Beane 1993). Johnson (1975) observed that the largest home ranges were located in poorer foraging habitat (cropland) while the smallest were located in better habitat (pasture). However, as was the case for nesting densities, some of these differences can be attributed to varying methodology and data quality.

Table 13. Summary of reported red-tailed hawk breeding season home range sizes.

Location	Home Range Size (km^2)	Reference
Alberta	3.46	McInvaille and Keith 1974
California	1.30	Fitch et al 1946
Michigan	3.88 (1.3-6.22)	Craighead and Craighead 1969
Montana	2.56-4.66	Johnson 1975
Oregon	2.33	Janes 1984
Wisconsin	1.17	Petersen 1979
Wyoming	1.94 (0.78-3.86)	Craighead and Craighead 1969

Based on the home range mapping conducted at the Willowbrook and Jumping Deer Creek assessment sites, nests were distributed regularly through the landscape (Figs. 10 and 11). This was probably an indication of good habitat and suitable nest tree distribution. Others have also observed regular intraspecific nesting distributions in landscapes with good nesting site availability (Adamcick et al. 1979, Petersen 1979, McGovern and McNurney 1986). Regular distribution of nesting territories functions as a spacing mechanism and territoriality may well be limiting the number of nesting pairs on the Willowbrook and Jumping Deer Creek assessment sites (Adamcick et al. 1979, Schmutz et al. 1980). In contrast, nesting populations on the Allan Hills West site were likely limited by the availability of nesting sites and hunting cover as well as territorial spacing. In this case nest distributions were clumped around the best habitat, native grassland and DNC (Fig. 5). Nonetheless, although home ranges were not assessed, within this suitable habitat nests appeared regularly spaced, implying territorial spacing. In landscapes with poor nesting site availability, nest distributions are often clumped around the most suitable habitat such as wooded drainages in arid grasslands (Schmutz et al. 1980, Gilmer et al. 1983, Restani 1991, Hansen and Flake 1995). Spatial arrangement among birds is never random in spite of seemingly random dispersion (Petersen 1979). Newton (1976) suggested that diurnal raptor densities and distribution are in part determined by the availability of nesting sites. Intraspecific territoriality along with relative stability of total available prey usually results in optimum density of resident red-tailed hawks within the available habitat (Petersen 1979). The high nesting densities on all the assessment sites were suggestive of stable population densities having reached saturation level based on the available nesting habitat and minimum territorial spacing requirements.

Breeding densities of diurnal raptors appear to be limited based on stability in numbers and distribution over many years (Newton 1976). Invasion of aspen parkland on the prairies has been underway for over a hundred years and aspen/poplar stands greater than thirty years old are well established in most parkland areas (at which age they become large enough for use as nesting substrates by red-tailed hawks) (Houston and Bechard 1983). Given the widespread high nesting densities of red-tailed hawks in aspen parkland, the breeding populations of hawks at the study sites appear to be well established. Increases in red-tailed hawk populations in Saskatchewan became apparent in the 1950s (Houston and Bechard 1983).

PRODUCTIVITY

In this study, all resident pairs on the assessment sites made a breeding attempt. This was somewhat atypical, because often up to 16% of resident pairs maintain a territory but do not attempt to breed (Orians and Kuhlman 1956, Craighead and Craighead 1969, Johnson 1975, Adamcik et al. 1979, Petersen 1979, Kirkley and Springer 1980), and non-breeding pairs can sometimes be as high as 26% (Hagar 1957). Why birds in this study differed from most others in this respect is unknown and the reasons why some hawks fail to breed remain unclear (Preston and Beane 1993). The exceptionally high nesting densities at my study sites may indicate that hawks assess this region as high quality habitat. Perhaps the habitat configuration and food abundance signal excellent breeding conditions so that most birds attempt to breed.

The number of young fledged per nest was poor compared with populations investigated elsewhere (Tables 3 and 12). This was mostly the result of three factors: 1) high clutch/brood losses due to inclement weather, 2) predation, and 3) poor tenacity of the breeding pairs. The majority of nesting failures generally occur in the incubation or early brood stages (Luttich et al. 1971, Seidensticker and Reynolds 1971, Johnson 1975, Kirkley and Springer 1980).

Inclement weather, including high winds, was directly responsible for 12 nesting failures on the study areas. Breeding pairs responded to inclement weather by abandoning nests or reducing incubation/sheltering of young. At the Jumping Deer Creek site, this resulted in a 23% decrease in nesting success and the additional loss of eight young, one each in eight nests. Inclement weather was also responsible for a decrease in nesting success of 10% at Willowbrook when three nests were abandoned after a snowstorm. When parents provided less food or shelter, direct effects of exposure combined with sibling aggression (likely under food stress) were responsible for most deaths. Adamcick et al. (1979) found that about 70% of annual variation in mortality through the age of four weeks was jointly attributable to rain and reduced food brought to nestlings. Several times in the course of their 10-year study, entire broods were found dead, wet, and/or abandoned after heavy rains. In my study, numerous cases of clutch abandonment and sibling cannibalism were observed. Hunting activity and success were likely reduced by rain (Adamcick et al. 1979, Restani 1991), preventing males from providing sufficient food to incubating females and nestlings. At some nests under observation in a related food habits study, intense sibling aggression from the bigger nestling was directed towards the smaller one (A.J. Fontaine, pers. obs.). Stinson (1980) described a case of sibling aggression and brood reduction in Washington, apparently in response to adverse effects of weather on parental hunting success. Wind, snow, and cold rainy weather likely were responsible for red-tailed hawk nesting failures and nestling mortality in numerous studies (Fitch et al. 1946, Hagar 1957, Seidensticker and Reynolds 1971, Adamcick et al. 1979, Kirkley and Springer 1980, Stinson 1980, Murphy

1993, Hansen and Flake 1995).

Predation and clutch/brood disappearances were responsible for eight failed breeding attempts on my study areas. I found no direct evidence of great horned owl interference. However, one adult male red-tailed hawk was killed and partially consumed by a great horned owl at the Willowbrook study area. Interference by great horned owls during the nesting period has also been implicated in nest desertions and failures (Hagar 1957, Luttich et al. 1971, Seidensticker and Reynolds 1971). Reduced productivity has also been reported for prairie *Buteos* nesting in proximity to one another (< 300 m; Schmutz et al. 1980). The main predators of eggs and nestlings are corvids (Fitch et al. 1946, Seidensticker and Reynolds 1971, Fyfe and Olendorff 1976, Petersen 1979, Kirkley and Springer 1980), raccoons (Fyfe and Olendorff 1976, Kirkley and Springer 1980), and great horned owls (Fitch 1940, Hamerstrom and Hamerstrom 1951, Orians and Kuhlman 1956, Craighead and Craighead 1969, Luttich et al. 1970, 1971, Kirkley and Springer 1980). Nesting failures caused by clutch or brood disappearance are largely attributed to predators (Luttich et al. 1971).

Human activities were directly responsible for five nesting failures. The introduction of livestock to pastures near some nests promptly caused three pairs to abandon. Surprisingly, the mere presence of livestock in the vicinity of the nest appeared to intensely disturb some nesting pairs (A.J. Fontaine, pers. obs.). Although pastures were an important land cover class in the areas surrounding the nests of many pairs, no other nests were located immediately adjacent to livestock (grazing within 50 m of the nest) from nest initiation to the first half of the nestling period. Some of these areas had obviously been grazed in previous years, although few were recent. Numbers of field personnel for all ongoing studies on each site ranged from 19 to 27 people depending on the time and site and all were advised to stay away from raptor nests. As with all studies, I am aware that one cannot discount the influence of researcher disturbance on the raptor populations. Stress associated with some human disturbance may have been sufficient to increase the impact of other factors such as bad weather, increased predation, and decreased hunting time and success. Red-tailed hawks tend to abandon their nests when disturbed in the early stages of the nesting period (Bent 1937).

Fitch et al. (1946), Luttich et al. (1971), and Seidensticker and Reynolds (1971) all reported high red-tailed hawk nest abandonment rates after climbing to nests during the incubation period. Fyfe and Olendorff (1976) also reported that other prairie *Buteos* (Swainson's and ferruginous hawks) are prone to abandonment during the early nesting and incubation periods. However, I believe researcher impact to be negligible in my study based on the strict "hands off" methodology used in the early stages of the breeding cycle (nest building to hatching) (Fyfe and Olendorff 1976). Most factors related to disturbance are anthropogenic in origin: fires (Adamcick et al. 1979), land development and farming operations (Wiley 1975, Petersen 1979) and general human disturbance (Wiley 1975, Kirkley and Springer 1980) have all been blamed for nesting failures. Farming disturbances can play a major role in nest abandonment. Petersen (1979) observed that early incubation and the beginning of the spring farming operations coincided and that red-tailed hawk nests along fence lines next to cropland seemed particularly vulnerable to desertion.

Nest success varied among assessment sites. Nest success at Willowbrook and Jumping Deer Creek was similar to that reported in the literature (Tables 3 and 12), but nest success (85.7 %) at Allan Hills West was among the highest reported. The number of nests at this site was relatively low compared to the other two assessment sites. Nevertheless, even with nesting densities similar to the other sites, nest success would likely have remained high at Allan Hills West. Nesting densities were probably limited by the availability of nesting and perching sites. The Allan Hills are a very productive area and prey densities were notably higher at this site than at the other two study areas (pers. obs.).

Only one pair attempted to re-nest after a failed breeding attempt. Minor et al. (1993) observed re-nesting by red-tailed hawks on their New York study area and Petersen (1979) observed that "frustration nests" were often constructed after nesting failures. The new nest built after the failure appeared to be in unsuitable habitat as it was located within the closed canopy of a young aspen grove. The nest tree was small (DBH 6 cm, 5 m tall) and the nest was never completed. However, disturbance by investigators may have caused the pair to stop nest construction. Bent (1937) also reported re-nesting, usually in a different nest, in instances when the first clutch was lost.

Based on North American productivity and mortality data, Henny and Wight (1972) estimated that northern red-tailed hawk populations must fledge between 1.33 and 1.38 young per nesting attempt to maintain stable populations. If their estimate is correct, then production of young at the Willowbrook and Jumping Deer Creek sites was insufficient for population replacement during the years of this study. This appeared to result from the high number of nest failures during the incubation and early nestling periods. However, the number of young fledged/nest measured in several studies was much lower than those Henny and Wight considered necessary for stable populations (Table 12). Furthermore, Luttich et al. (1971) and Adamcick et al. (1979) suggested that Henny and Wight may have overestimated first-year mortality, thereby postulating a higher rate of fledging than necessary for population maintenance. This overestimated fledging requirement may be even more pronounced today since the first-year cohort in particular, and other age cohorts in general, of current raptor populations do not suffer the shooting pressure they once did until the 1970's (Kiff 1988). Therefore, having shown that nesting populations appear to be stable, I suggest that nesting populations on the study sites are self-sustainable. Nesting success and the number of young/fledged per nest should have been higher had it not been for periods of inclement weather at two study sites.

MACROHABITAT SELECTION

The territory of a red-tailed hawk must meet a variety of requirements including provision of a suitable nest site, adequate prey availability, and an adequate hunting and flight environment. These needs often require diverse habitat features within an area sufficiently small to provide easy access for the pair. Red-tailed hawk nesting pairs tend to obtain their food from the dominant land cover surrounding nests, rather than exploiting any particular type consistently. As a result, food habits of individual pairs can be predictably related to the cover types surrounding the nests (Luttich et al. 1970, McInvaille and Keith 1974). Consequently, it is important that their nests be located in or near the best hunting cover possible.

Red-tailed hawks showed a strong preference for nesting near DNC, which was particularly evident for successful nests. In contrast, hawks occupying unsuccessful nests chose this cover in proportion to its availability. In total, 33 nests were located directly in or on the edge of DNC, hay, or grassland cover types and other hawks had these cover types within 400 m of their nests. Having DNC close to the nest possibly allowed hawks to minimize foraging trips to carry prey back to the nestlings. DNC provides waterfowl with excellent nesting cover and is generally a prey-rich habitat. Duck populations were higher on sites with greater DNC coverage (D.W. Howerter, pers. comm.). Next to woodland, DNC had the highest relative abundance of microtine rodents (*Peromyscus maniculatus*, *Microtus pennsylvanicus*, and *Clethrionomys gapperi* combined; M. Pasitschniak-Arts, pers. comm.) and the second highest abundance of ground squirrels (three species combined: *S. franklinii*, *S. richardsonii*, *S. tridecemlineatus*) and pocket gophers (*Thomomys talpoides*) next to hay (Pauzé 2002). DNC is also used by many nesting songbird species (pers. obs.). Songbirds are part of red-tailed hawks diet on the assessment sites (Pauzé 2002, pers. obs.). Stout et al. (1998) suggested that red-tailed hawk populations increased in southeast Wisconsin over the past 25 years in response to increased availability of nesting habitat resulting from agricultural changes (reduced cropland) because of the Conservation Reserve Program (CRP). In the CRP, suboptimal land is seeded with wildlife cover (generally DNC), providing hawks with better hunting areas than cropland.

In general, hawk nests were placed more frequently near woodland. This was somewhat intuitive because all red-tailed hawks nested in woodlots or shelterbelts, thereby increasing the importance of woodland cover in the closest buffer zones. However, woodlots form a crucial part of the red-tailed hawks' spatial requirements; they rely heavily on trees for hunting perches. Red-tailed hawks are perch-and-wait predators poorly adapted to hunting in flight (Ballam 1984, Janes 1985). The importance of good perch availability for hunting to red-tailed hawks has been emphasized in numerous studies (Fitch et al. 1946, Schnell 1968, Janes 1984b, Bildstein 1987, Preston 1990, Janes 1994). Fence posts were also readily available, but most observed hawk hunting forays began from perches in trees. As stated earlier, woodland also had the highest relative abundance of microtine prey (M. Pasitschniak-Arts, pers. comm.) and hawks may have found the woodland edge a profitable hunting area, especially where it bordered other prey-rich habitats. Woodlots were abundant and well dispersed on the assessment sites except for Allan Hills West where they were thought to have been limiting to the red-tailed hawk population. Observed nest site selection was probably influenced by site-specific characteristics. A large contribution to successful nests came from Allan Hills West (fewer trees) and more of the contribution to unsuccessful nests came from the Willowbrook and Jumping Deer Creek sites (more trees) with corresponding effects on selection in the respective analyses. The availability of perches (i.e., trees) is good throughout the aspen parkland landscape, and it may have little influence on overall habitat selection. Hawks may be responding to habitats with high prey availability and may nest near these habitats. However, availability of woodland likely plays a substantial role in controlling nesting densities of local populations.

Both successful and unsuccessful red-tailed hawks showed a strong preference for scrubland, even at long distances away from the nest. Scrubland was typically associated with edges of other land uses, mainly grassland and woodland, the latter providing good hunting perches. Because scrubland is a mosaic of other habitats (mix of various land covers, usually native grassland with a minimum of 30 % shrub cover), it was a prey-rich habitat with variable but generally low plant cover density (pers. obs.). Combined, these habitat features likely made it a favorite hunting area for hawks. Bechard et al. (1990) found red-tailed hawks nesting in areas with high shrub and grassland cover.

There was no evidence of selection based on wetland cover. Red-tailed hawks are known to rely on wetland prey for a significant portion of their diets in some areas (Adamcick et al. 1979, Schmutz et al. 1980, Murphy 1993). Wetlands were abundant and well dispersed on all study areas, so a lack of statistical significance does not necessarily preclude their importance to nesting red-tailed hawks. Other studies have also failed to show a positive association of red-tailed hawk nests with water cover (Titus and Mosher 1981, Bednarz and Dinsmore 1982, Speiser and Bosakowski 1988). On the other hand, in their comparative study of sympatric prairie *Buteos*, Bechard et al. (1990) found that red-tailed hawks nested closest to water. Red-tailed hawk pairs nesting in wetland habitat have been known to bring more food by weight and frequency to the nestlings compared to pairs nesting in other habitats (Luttich et al. 1970). They suggest that prey may be more available or vulnerable in wetland habitat. Although differences were not significant, wetland coverage was greater within nest site buffers for all pooled nests as well as successful nests compared to random buffers. Furthermore, unsuccessful nest buffers had lower wetland coverage than random buffers and successful nest buffers. Based on this and the significant waterfowl composition in red-tailed hawk diet at the study sites (Pauzé 2002), wetlands likely formed an important habitat component of their spatial requirements.

Red-tailed hawks avoided nesting near farmsteads, buildings, and roads. Breeding pairs are likely disturbed by human activity in these areas. Furthermore, birds of prey also have a history of persecution by humans and although the negative mind-set towards raptors has changed through public environmental education efforts, it still persists (Henny and Wight 1972, Kiff 1988, Moorman et al. 1999). One northern harrier, one red-tailed hawk, and two great horned owls were found shot in my study. Other random events of wildlife shooting were also noted on one study area. Hawks may have avoided nesting near these areas to minimize disturbance and harassment, which is especially important in the incubation period when nests are most susceptible to abandonment (Bent 1937, Fitch et al. 1946, Luttich et al. 1971, Seidensticker and Reynolds 1971). Conversely, Speiser and Bosakowski (1988) found that nest sites were not significantly farther from human habitation than random sites. However, their study was conducted in fragmented hardwood forests in New York and New Jersey, USA, an area undoubtedly more populated than our study sites.

Red-tailed hawks clearly avoided nesting in areas with higher proportions of cropland than what was available in the landscape. Even unsuccessful pairs, which may have been less experienced, avoided this land cover type up to 500 m from the nest. Bechard et al. (1990) observed that most red-tailed hawks nested in areas devoid of cropland under wheat cultivation although, as was true in this study, some did nest in areas with variable cropland coverage (Appendix E). Intensive agricultural practices such as plowing and fallowing effectively eliminate most prey (Janes 1984b, Pauzé 2002). Bare patches of ground and plowed fields are avoided because plowed fields contain significantly fewer rodents than other land cover types (Schnell 1968, Bildstein 1987, Preston 1990, Pauzé 2002). Bednarz and Dinsmore (1982) did not observe red-tailed hawks foraging in cropland and consequently, did not even consider this cover as a potential hunting habitat. In contrast, others have found that cultivated fields supporting large numbers of prey were not hunted until crop harvest reduced the density of plant canopy, thereby enhancing prey accessibility (Bechard 1982, Preston 1990). Most studies finding preference or increased use of cropland over other habitats were conducted in winter when crops had been harvested and hawks were hunting the stubble fields (Schnell 1968, Petersen 1979, Bildstein 1987, Preston 1990). Use of croplands by rodents is likely much higher after harvest when strips of straw and other debris are left on the ground providing some protective cover and ample waste grain. Through the course of this work and other field studies, abundant signs of rodent presence were noticed after harvest, especially late in the fall or right after snowmelt before fields were plowed. Hawks likely respond to this by making greater use of this land cover type during these periods.

Unsuccessful red-tailed hawk nests occurred in areas with more pasture, a pattern found for all buffer sizes, although statistical significance varied. Pasture also had a significant negative association with nesting success. The relative abundance of ground squirrels and pocket gophers found in pastures was similar to those in native grasslands, but was lower than that found in DNC and hay (Pauzé 2002). Pastures are the preferred habitat of Richardson's ground squirrels, which are among the main prey of prairie *Buteos* (Adamcik et al. 1979, Schmutz et al. 1980). However, pastures do not offer appropriate habitat requirements for other species such as microtine rodents and songbirds (i.e. poor cover) and consequently, their abundance was much lower in pasture than in DNC, hay, and native grasslands (Pauzé 2002, pers. obs.). Therefore, red-tailed hawks likely nested near pastures because they also offer good hunting habitat, but only when other better habitat (e.g., DNC) was unavailable. Livestock disturbance was directly responsible for three cases of nest abandonment and I suggest that disturbance by livestock may have had an indirect effect by increasing the likelihood of nest abandonment from other factors such as poor weather. Pastures were a dominant land use around red-tailed hawk nests in many studies examined (McInvaille and Keith 1974, Johnson 1975, Schmutz et al. 1980, Bednarz and Dinsmore

1982, Gilmer et al. 1983, Moorman and Chapman 1996). However, Bildstein (1987) observed that red-tailed hawks avoided hunting in grazed pastures while they preferred hunting in cropland stubble. In many of these studies, red-tailed hawk nesting pairs may have been making the best of their situation by using pastures since they were the best open hunting areas available. Nesting densities in these studies were also much lower than those found in this study, which may indicate lower habitat quality.

My study is the first to examine red-tailed hawk habitat selection in the aspen parkland. Contrary to my findings, Moorman and Chapman (1996) found the effects of plot scale to be minimal and settled on a 1 km^2 circular area (564 m radius) for all of their analyses. In this study, strength of selection decreased gradually with increasing scale, enabling me to gauge the spatial requirements of nesting pairs in aspen parkland. Nest site selection was strong based on macrohabitat features up to 750 m from nest sites, suggesting minimum spatial requirements of 1.77 km^2/nesting pair. In the home range analysis at Willowbrook and Jumping Deer Creek, home range radii of 631 and 508 m, respectively, were found. These figures are similar to those resulting from the macrohabitat analysis, and given the low densities at Allan Hills West, home ranges were likely larger at that site. Given the study area size of 64.75 km^2, nesting densities were at or close to carrying capacity based on the available nesting habitat and prey base (at Jumping Deer Creek 34 nesting pairs X 1.77 km^2 occupies 60.2 km^2). McInvaille and Keith (1974) found that proportions of cover types within 1.2 km from the nests were almost identical to the availability of these covers. Considering that they conducted their study in similar habitat in Alberta and based on my results, I suggest that their radius was too large. In this study, significant preference and avoidance of some land cover types up to 1000 m away from the nest were found. However, very rarely did it extend up to 1250 m where most land cover types were being selected in proportion to their availability.

MICROHABITAT SELECTION

Consistent with previous studies, red-tailed hawk nests were built in some of the largest and tallest overstory trees available, although mean nest height (9.79 ± 0.33 m) was much lower than in other studies (12.5 to 19.2 m) (Orians and Kuhlman 1956, Dunstan and Harrell 1973, Titus and Mosher 1981, Gilmer et al. 1983, Speiser and Bosakowski 1988, Hansen and Flake 1995). In mixed wood forests, tree species diversity and tree height are much greater than those found on my study sites. Nonetheless, my results are comparable to those of Schmutz et al. (1980) in southern Alberta, where mean nest height was slightly above 8 m. The only tree species available away from farmsteads were trembling aspens, balsam poplars and some sporadic Manitoba maples. These trees do not grow as tall and as large as other tree species from the east and west coast. In Saskatchewan parkland habitat, balsam poplars are usually much taller than trembling aspen. However, they offer few good quality nest sites because they tend to grow straight and tall with very few crotches and their branches are weak and flexible. Most nests were found in trembling aspen because they offered the most suitable canopy for support. The lowest red-tailed hawk nest height recorded was 3 m above the ground at Allan Hills as compared to the lowest (5.3 m) reported in North Dakota (Gilmer et al. 1983). This nest was unusual in that it was located in a small lone trembling aspen growing in a willow grove at the side of a large wetland. There appeared to be more suitable nesting sites nearby. No other nests were found below 7 m nor in a similar location.

Red-tailed hawks selected nest sites in locations with a greater number of trees in the dominant and co-dominant crown classes and with lower canopy cover and lower number of trees in intermediate crown classes. Nest heights averaged 71.7% of nest tree height (Table 7), similar to values reported in other studies (Bohm 1978, Titus and Mosher 1981, Speiser and Bosakowski 1988). By placing their nests high in trees, in areas with fewer trees in intermediate crown classes, and in areas with low canopy cover, red-tailed hawks ensure that access to the nest is unobstructed. Numerous studies have noted the importance of unobstructed access and a commanding view of the surrounding area (Orians and Kuhlman 1956, Mader 1978, Petersen 1979, Titus and Mosher 1981, Bednarz and Dinsmore 1982, Speiser and Bosakowski 1988, Bechard et al. 1990, Moorman and Chapman 1996, Stout et al. 1998). Santana et al. (1986) suggested five reasons why red-tailed hawks should nest in highest available sites: 1) unobstructed access to the nest, 2) wide view to detect predators at a distance, 3) wide view to detect territorial intruders, 4) nest highly visible to other hawks which can serve as a territorial marker, and 5) nest can be monitored from a distance while hunting in the territory. These factors could favor selection of the highest and most exposed nest sites possible; however, negative selection pressures caused by higher visibility to nest predators and higher exposure to the elements may offset some of these benefits (Mosher and White 1976, Bednarz and Dinsmore 1982, Speiser and Bosakowski 1988). Accordingly, in my study most nests were located in the middle of the canopy of open canopy trees, usually in primary or secondary crotches. Few nests were located at the bottom of the canopy, likely because of difficulty of access. Few nests were located in the very top of the canopy because of inappropriate branch and crown structure. As a result, most nests received some protection from crown foliage, yet remained highly visible and accessible.

Most nests on the study areas were located at the edge (within 20 m) of woodlots. Given the small size of most woodlots and the habitat structure, very few opportunities existed for red-tailed hawk pairs to build a nest in continuous canopy cover. Several other studies have also found red-tailed hawk nest sites to be associated with open areas at the edges of woodlots, in openings in continuous canopy, or in shelterbelts and isolated trees along fence lines while few nests are located in closed canopy woodlots (Orians and Kuhlman 1956, Hagar 1957, Gates 1972, Bohm 1978, Speiser and Bosakowski 1988, Moorman and Chapman 1996). Nesting along habitat edges also favors easy access.

Nest exposure ranged from 50° to 330° and averaged 160°, implying that most nests had open and easy access. Red-tailed hawks nesting on the study areas chose predominantly northwest and northeast exposures as well as fully exposed sites (Fig. 16). Microclimate surrounding the nest is believed to be important for nest site selection by red-tailed hawks. Other researchers have found northerly and easterly exposures to be significantly predominant at nest sites (Titus and Mosher 1981, Speiser and Bosakowski 1988, Stout et al. 1988, Bechard et al. 1990). Most showed a preference for northwest and northeast exposures, but one also showed a preference for southeast exposures. Northerly exposure is thought to maximize insulation to the nest on cold mornings and minimize heat stress in the afternoon, thereby buffering temperature extremes (Mosher and White 1976). Bednarz and Dinsmore

(1982) and Speiser and Bosakowski (1988) found that southwest exposures were avoided. This exposure quadrant as well as the southeast quadrant were least used in my study (Fig. 16).

There were no differences in the microhabitat variables of successful and unsuccessful nests, but there were differences between nest sites and random locations. This implies that all pairs were selective. Intuitively, one would assume that some less experienced pairs are less selective, but this did not show from the analyses. The small sample size for unsuccessful nests may have masked this effect. Moorman and Chapman (1996) found that successful red-tailed hawk nests were in significantly shorter trees than unsuccessful nests, however this was not observed in my study. Nest tree health was the only variable found to differ significantly between successful and unsuccessful nests ($P = 0.008$). Successful nests had a greater proportion of their crown in decay (Table 11), which translates into a more open canopy. Conversely, there were no significant differences for nest and quadrat canopy cover between successful and unsuccessful nesting pairs. Nest failures were caused by fire, livestock, predation, and inclement weather, factors either not related or weakly related to tree health.

Red-tailed hawks selectively chose nest sites in areas with larger and taller trees, with lower canopy cover, and lower number of trees in intermediate crown classes. Considering these findings, I suggest that given suitable surrounding habitat, the prevailing factor in red-tailed hawk nest site selection is accessibility to the nest. Even though red-tailed hawks are habitat generalists compared to Swainson's and ferruginous hawks, they have a substantial constraint related to their specific nest site requirements. For their nests, they require tall elevated places, preferably well branched, open canopy trees, and when trees are not available they rely on other elevated structures such as power lines or cliffs (Seidensticker and Reynolds 1971, Mader 1978, Petersen 1979, Bechard et al. 1990, Stout et al. 1998). They also require an abundance of perches from which to hunt because their low aspect ratio makes them poorly adapted for hunting in flight (Fitch et al. 1946, Ballam 1984, Janes 1984b, 1985, 1994). Swainson's and ferruginous hawks also nest high in tall trees when they are available, but they usually nest lower than red-tailed hawks. They also nest in shrubs and on the ground which red-tailed hawks rarely do (Rolfe 1896, Smith and Murphy 1973, Lokemoen and Duebbert 1976, Schmutz et al. 1980, Bechard et al. 1990, Restani 1991, Hansen and Flake 1995). Schmutz et al. (1980) suggested that for sympatric *Buteos* nesting in southern Alberta, species differences in the selection of nest sites probably reflects the typical habitat of each, red-tailed hawks occupying parkland, ferruginous hawks the open plains, and Swainson's hawks occupying both the parkland and prairie ecoregions. These three species are now more widely sympatric in the northern Great Plains and other areas than they were historically. These changes have arisen from important modifications to the grasslands resulting from intensive agriculture, tree planting, and reduced prairie fires providing a highly modified landscape now occupied by the three species (Schmutz et al. 1980, Houston and Bechard 1983, 1984, Hansen and Flake 1995).

CONCLUSION

GENERAL CONCLUSIONS

This study showed that red-tailed hawks breeding in the aspen parkland of central Canada were selective in their use of nest sites within the aspen stands but also in the placement of their nests within the landscape. A combination of nest site availability, territorial behavior, and minimum spatial requirements likely limited nesting densities. Mean territory size was 1.02 km^2 based on home range analyses, and approximately 1.77 km^2 based on the macrohabitat use analyses. Both values are smaller than most territory sizes reported in the literature and nesting densities were much higher than those reported elsewhere.

The amount of natural macrohabitat cover around red-tailed hawks nests was an important component of their nesting habitat. They nested in portions of the landscape with greater cover of DNC (dense nesting cover), scrubland, and woodland, which are all potentially prey-rich land covers. Such habitat provides this perch-and-wait predator with plenty of well-distributed hunting perches. Hawks nested in areas with less cropland cover, likely because these areas have low prey abundance during the breeding season. Use of this cover is probably much higher in the fall and winter when waste grain and harvest debris attract rodents and other prey. They also avoided nesting in proximity to areas frequently disturbed by humans.

Consistent with studies elsewhere in North America, in this study preferred microhabitat features favored unobstructed access to the nest and a commanding view of the surrounding landscape. However, exposure during periods of unseasonable weather may offset some of these benefits in some years.

This is the only detailed study of red-tailed hawk habitat selection in the aspen parkland of central Canada. Future work should involve expanding the analysis to include data from all other PHJV assessment sites across the three prairie provinces as well as developing habitat selection models for all large raptors on those sites to better understand interactions between these species. In addition, such analyses would permit comparisons of raptor populations between sites and the landscape features that affect them.

LIMITATIONS of the STUDY

Because of study methodology, main limitations involved the lack of marked birds and corresponding uncertainty over home range estimation, as well as a lack of information on timing of nesting, exact clutch initiation date, clutch size, hatching success, and causes of nest failures. However, an end benefit was decreased frequency of human disturbance at critical periods (nest building to hatching) in the breeding cycle of red-tailed hawks, which likely minimized researcher effects on nesting success. In initial study development, it was judged more important to have one accurate productivity figure, nesting success, to relate to habitats surrounding nests than many figures possibly influenced by researcher effects.

Nesting densities on the study sites were high when compared to densities reported in other North American studies (Tables 3 and 12). It is possible that nesting densities were artificially high because of the attractiveness of DNC. This would render the macrohabitat selection results applicable mostly to landscapes that are managed for enhanced waterfowl recruitment. However, Willowbrook had very low land use in DNC (2.3%), and nesting densities, next to Jumping Deer Creek, were still the second highest found in aspen parkland. Rothfels and Lein (1983) found similar densities near Calgary, Alberta. Overall, nesting densities are high throughout much of the aspen parkland (Tables 3 and 12). Results found in this study are likely applicable throughout this ecoregion. The only noteworthy difference is in the proportion of managed cover throughout the aspen parkland, which is variable but on average resembles that found at Willowbrook (i.e. between two and five percent).

MANAGEMENT IMPLICATIONS

Birds of prey and other predators play an important role in the normal functioning of ecosystems. Raptors also contribute aesthetic value to our environment, which has been widely viewed and used by Ducks Unlimited as a benefit of their conservation efforts. However, red-tailed hawks are not native to the central grasslands and conservation efforts aimed at increasing local populations of native wildlife species should take this into consideration.

An objective of this study was to develop management tools for resource managers to reduce predation by red-tailed hawks on prairie breeding waterfowl. Direct methods of management were not considered for three reasons: 1) birds of prey are protected through federal, state, and provincial laws; 2) they are highly controversial and public opinion as well as that of many wildlife managers is set against such practices; and most importantly, 3) such methods are not long-term solutions to a problem. It was apparent from the start of the project that management tools would require indirect methods of control. Such methods include habitat manipulations aimed at reducing encounters between waterfowl and hawks. Hence, one of the first steps when developing a management plan for the local waterfowl resource in the aspen parkland should be to examine the ecology of breeding red-tailed hawks (and other predators) in that area.

Should management options be required to control local red-tailed hawk populations, five possible but not equally feasible management strategies include: 1) removal of aspen groves, 2) acquisition of land or leases in areas with a paucity of trees, 3) proper dense nesting cover establishment, 4) creation of disturbance near the nests in the early portion of the breeding cycle to decrease nesting success, and 5) take no specific steps to "manage" red-tailed hawks.

Reversing the course of the aspen parkland invasion of prairie habitats is impossible. In addition, given the predominantly agricultural land use of the prairie provinces, it is not advisable because of soil conservation issues. However, in areas managed for enhanced waterfowl production as well as conservation of other wildlife species native to the grasslands, and based on information found in this study, it appears that management of these sites might be better served by removing (burning) aspen groves with trees > 10 m in height. Soil and wildlife conservation may be achieved through the seeding of appropriate cover. Additionally, this would effectively eliminate all perches and nesting sites, a habitat requirement of red-tailed hawks, and nearly eliminate all chances of duck-hawk encounters during the breeding season in these locations.

Ultimately, the purchase and management of land parcels as well as seeding to produce DNC, are done at high costs to increase the production of waterfowl, a group of gamebirds. Each duck "produced" on these lands is achieved at a set financial cost. Some losses of waterfowl to red-tailed hawks may be economically acceptable when balanced against the cost of removing aspen bluffs. Consequently, future land leases and purchases should be made in areas with few tall trees, and other nesting and perching structures. The best way to minimize losses of waterfowl to red-tailed hawk predation is to minimize encounters between these species.

Some quarter sections seeded with DNC were certainly suboptimal in performance. On these land parcels, soils were highly compacted and seemed so poor that the cover grew sparsely and did not afford much protection. In such parcels, rodent abundance was low and likely responsible for DNC having less abundant rodent prey than hayland. Abundance values should have been similar in these habitats since they are effectively the same cover (Pauzé 2002, Fontaine and Pauzé, unpubl. data, M. Pasitschniak-Arts, pers. comm.). Red-tailed hawks were shown to favor nesting near DNC and it had positive effects on their productivity. Emphasis should be placed on ensuring proper cover establishment on managed land to protect nesting female ducks.

Of all factors that had a negative influence on red-tailed hawk productivity, weather was certainly the dominant force. However, one factor showed some potential use as a management tool to reduce red-tailed hawk productivity. In three cases where livestock were introduced near red-tailed hawk nests during the incubation period, prompt nest abandonment was observed. Observations of nesting pairs also revealed that some pairs reacted unfavorably to livestock and were particularly concerned by their presence near nests. It may be possible to control red-tailed hawks in managed areas by fencing woodlots and using them as pastures, particularly through May and early June when red-tailed hawks are incubating and are most susceptible to nest abandonment. Pastures were also shown to have a negative influence on productivity. The sample size was small, but I believe this approach merits further investigation. However, the trade-off involving pasture land use is that in most cases, grazing also has a detrimental effect on waterfowl production.

In most areas, it is likely that management of local populations is not required when considering the economic feasibility of these practices balanced against loss of waterfowl production. It is also possible that any land use changes that reduce abundance of red-tailed hawks could increase abundance of other predators, which could also be effective duck predators. Based on a related study (Pauzé 2002), other diet studies (see Preston and Beane 1993, and Pauzé 2002 for review), and from personal observation, most red-tailed hawk pairs are generalists in their prey selection. However, some pairs are waterfowl specialists (Pauzé 2002, A.J. Fontaine, pers. obs.) and the diet of red-tailed hawk pairs nesting in or near managed waterfowl cover should be assessed. Evidence of high waterfowl predation is easily found around the base of nest trees of specialist pairs. In such cases, provided that the proper permits are obtained, targeted disturbance to cause nest abandonment (frequent visits to nest sites or ideally, direct management practices targeting the nests) should be considered as an economical alternative.

I did not observe red-tailed hawks using the utility line in the Allan Hills area in 1997 or 1999, either as hunting perches or as nesting sites (an assessment site in the Allan Hills was also studied in 1999; results are presented elsewhere), although the use of such structures by red-tailed hawks has been well documented (Schnell 1968, Gilmer and Wiehe 1977, Bechard et al. 1990, Knight and Kawashima 1993, Stout et al. 1998). The high availability of more suitable hunting and nesting substrates probably renders these sites less desirable. If trees were removed from the local landscape to limit availability of nest sites and perches, then power lines may become important to breeding red-tailed hawks.

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APPENDICES

Appendix A: Habitat codes, classes, and descriptions for the 1997-98 Saskatchewan PHJV assessment site habitat cover maps.

Habitat Code	Habitat Class	Description
0	Unclassified	Areas that were not given attributes during the digitizing process.
10	Grassland	Areas vegetated with mixtures of grasses, forbs and short woody shrubs (<30%). Livestock has not grazed these areas.
11	Grassland – Native idle	Idle native grasses and short shrubs (<30%). These areas have probably not been tilled.
12	Grassland – Pasture hayed	Tame grass is used as pasture in the first part of the breeding season. Cattle are removed so vegetation can grow and be hayed at end of summer.
13	Grassland – Pasture	Tame and/or native grassland areas having livestock grazing for majority of breeding season.
20	Hayland	Areas that have been plowed and seeded to grasses and/or legumes and hayed annually for forage production.
21	Hayland – Delayed hay	Haylands having their first cut delayed until a certain date to benefit waterfowl nesting.
23	Hayland – Idle	Haylands used previous years, but not in current breeding season.
30	Planted Cover – DNC	Mixtures of grasses and legumes planted for wildlife cover or soil conservation.
31	Planted Cover – Fenced DNC	Areas of DNC surrounded by an electrified predator exclosure fence.
40	Cropland	Areas that are tilled and planted to grain or row crops.
41	Cropland – Fallow	Cropland areas not planted during the current breeding season. Weed control maintained by periodic plowing during the growing season. Does not include firebreaks and DNC.
43	Cropland – Chemical fallow	Fallow cropland area using chemicals to control weeds. No plowing occurs during the majority of the breeding season.
47	Cropland – Idle	Fallow cropland. No weed control.
50	Woodland	Areas with woody plants (trees or tall shrubs 6m or greater in height) having an areal cover of 30% or greater. Include areas where cattle are present.
60	Scrubland	Area of shrubs 0.5 - 6m tall having an areal cover greater than or equal to 30%.
70	Wetland	Areas of emergent wetland vegetation.
71	Wetland – Open water	Areas of water without emergent vegetation.
72	Wetland – Tilled	Wetland areas in croplands plowed by farm equipment causing poor growth of wetland vegetation.
73	Wetland – Waterway	A manmade drainage ditch comprised of wetland vegetation.
80	Other – Unknown	Areas that cannot be identified as a habitat code.
81	Other – Pushpile	Areas having debris (usually trees) pushed into piles. Include beaver lodges.

Appendix A – continued

Habitat Code	Habitat Class	Description
82	Other – Rockpile	Areas having rocks set in a pile.
83	Other – Building	Any building not on a farmstead. Include silos and completely abandoned farms.
84	Other – Bales	Areas where exposed hay bales are stored.
85	Other – Bare soil/gravel pit, etc	Areas of exposed soil, mud or gravel lacking vegetation. Include: gravel pits, fire breaks in DNC and mud bottoms in dried wetlands. Do NOT include areas of pasture worn down by cattle such as trails or feed troughs.
87	Other – Cemetery, mowed grass	Mowed grass, mowed sports fields.
90	Farmstead	Include farmsteads not used as homes if the other buildings on the site are still in use.
91	Farmstead – Trees	Trees within the farmstead area.
92	Farmstead – Shrubs	Shrubs within the farmstead area.
99	Roads	Linear right of ways used by vehicles and farm equipment.

Appendix B. Reclassification of the habitat classes for the 1997-98 Saskatchewan PHJV assessment site habitat cover maps.

New Habitat Code	New Habitat Class	Original Habitat Code	Original Habitat Class
10	Grassland	10	Grassland
		11	Grassland - Native Idle
12	Pasture	12	Grassland - Pasture hayed
		13	Grassland - Pasture
20	Hay	20	Hayland
		21	Hayland - Delayed Hay
		23	Hayland - Idle
30	DNC	30	Planted Cover - DNC
		31	Planted Cover - Fenced DNC
40	Cropland	40	Cropland
		41	Cropland - Fallow
		43	Cropland - Chem Fallow
		47	Cropland - Idle
		72	Wetland - Tilled
50	Woodland	50	Woodland
60	Scrubland	60	Scrubland
70	Wetland	70	Wetland
		71	Wetland - Open Water
		73	Wetland - Waterway
80	Other	0	Unclassified
		80	Other - Unknown
		81	Other - Pushpile
		82	Other - Rockpile
		83	Other - Building
		84	Other - Bales
		85	Other - Bare Soil/Gravel Pit, etc
		87	Other - Cemetery, Mowed Grass
		90	Farmstead
		91	Farmstead - Trees
		92	Farmstead - Shrubs
		99	Roads

Appendix C: Surface area (ha) and percent coverage (%) of all habitat classes recognized in the IWWR digitizing process of the 1997-98 Saskatchewan PHJV assessment sites (Allan Hills West [AHW], Jumping Deer Creek [JDC], Willowbrook [WIL]).

Habitat Code	Habitat Class	Area (ha)			Area (%)		
		AHW	JDC	WIL	AHW	JDC	WIL
0	Unclassified	6.60	4.12	7.18	0.10	0.06	0.11
10	Grassland	329.52	182.64	481.68	5.02	2.78	7.20
11	Grassland - Native Idle	274.44	14.07	44.21	4.18	0.21	0.66
12	Grassland - Pasture hayed	0	8.62	0	0.00	0.13	0.00
13	Grassland - Pasture	60.29	924.93	305.58	0.92	14.10	4.57
20	Hayland	8.55	157.09	282.92	0.13	2.39	4.23
21	Hayland - Delayed Hay	76.27	30.81	16.95	1.16	0.47	0.25
23	Hayland - Idle	0.00	46.10	5.03	0.00	0.70	0.08
30	Planted Cover - DNC	1158.64	915.38	133.99	17.66	13.95	2.00
31	Planted Cover - Fenced DNC	0	0	13.92	0.00	0.00	0.21
40	Cropland	2571.75	1054.58	3029.49	39.19	16.08	45.29
41	Cropland - Fallow	724.32	543.11	462.69	11.04	8.28	6.92
43	Cropland - Chem Fallow	65.95	0	54.74	1.01	0.00	0.82
47	Cropland - Idle	0	0	47.54	0.00	0.00	0.71
50	Woodland	95.94	826.51	575.34	1.46	12.60	8.60
60	Scrubland	213.75	650.04	377.81	3.26	9.91	5.65
70	Wetland	457.26	765.30	434.82	6.97	11.67	6.50
71	Wetland - Open Water	435.90	369.41	291.33	6.64	5.63	4.35
72	Wetland - Tilled	15.23	10.35	27.27	0.23	0.16	0.41
73	Wetland - Waterway	0.57	0.34	0.22	0.01	0.01	0.00
80	Other - Unknown	0	0	0.03	0.00	0.00	0.00
81	Other - Pushpile	0.13	1.94	3.09	0.00	0.03	0.05
82	Other - Rockpile	0.28	0.01	0.02	0.00	0.00	0.00
83	Other - Building	0.34	0.33	0.33	0.01	0.01	0.00
84	Other - Bales	0.04	0.95	0.35	0.00	0.01	0.01
85	Other - Bare Soil/Gravel Pit, etc	0.50	10.22	9.39	0.01	0.16	0.14
87	Other - Cemetery, Mowed Grass	0.22	0	0	0.00	0.00	0.00
90	Farmstead	29.57	23.88	52.25	0.45	0.36	0.78
91	Farmstead - Trees	5.45	7.01	10.52	0.08	0.11	0.16
92	Farmstead - Shrubs	3.11	1.61	6.15	0.05	0.02	0.09
99	Roads	26.90	10.88	14.98	0.41	0.17	0.22
	Total	6561.51	6560.21	6689.82	100.00	100.00	100.00

Appendix D. Characteristics ($\bar{x}$ ± SE) of microhabitat variables for Willowbrook ($n = 27^a$) and Allan Hills West (n = 14) PHJV assessment sites at red-tailed hawk nests and random sites, Saskatchewan, 1997. Refer to Table 1 for a description of mnemonics.

Variable	Willowbrook		Allan Hills West		Test Statistics[b]	
	$\bar{x}$	SE	$\bar{x}$	SE	U	P
Nest						
MEAN_DBH	10.58	0.58	9.47	0.75	147.5	0.254
MEAN_HEIGHT	8.26	0.33	6.80	0.60	92	0.008
TOTAL_BA	0.90	0.06	1.22	0.14	292	0.005
TBA_1	0.04	0.01	0.05	0.01	244.5	0.127
TBA_2	0.07	0.01	0.12	0.02	282	0.011
TBA_3	0.11	0.03	0.21	0.03	303	0.002
TBA_4	0.21	0.03	0.36	0.09	231.5	0.243
TBA_5	0.47	0.07	0.47	0.07	207	0.621
GRCO	65.19	5.16	62.86	8.41	187.5	0.967
SHCO	37.78	3.93	26.43	4.14	129	0.095
CACO	30.74	3.06	37.86	4.94	246	0.11
NTDBH	23.86	0.94	23.00	1.46	175.5	0.71
NTH	14.59	0.47	11.82	0.68	87.5	0.005
NTHTH	37.04	4.68	59.29	9.29	254	0.071
NH	10.32	0.36	8.79	0.62	112	0.033
NCACO	42.22	4.93	38.57	7.69	167.5	0.549
Random						
MEAN_DBH	9.80	0.65	7.65	0.45	103	0.018
MEAN_HEIGHT	8.24	0.35	6.23	0.29	54	<0.001
TOTAL_BA	0.85	0.05	0.91	0.12	179.5	0.794
TBA_1	0.04	0.01	0.07	0.01	270.5	0.025
TBA_2	0.14	0.02	0.20	0.03	264.5	0.038
TBA_3	0.25	0.03	0.26	0.05	192	0.934
TBA_4	0.21	0.03	0.22	0.05	182	0.847
TBA_5	0.22	0.05	0.14	0.05	148.5	0.259
GRCO	55.56	5.63	59.29	4.74	206.5	0.628
SHCO	35.56	4.48	15.71	1.73	89	0.005
CACO	43.33	4.37	48.57	6.70	213	0.505

[a] – Because of land access restrictions, data were collected at 27 of the 29 nests available at Willowbrook.
[b] – Mann-Whitney U-test, all with 1 df

Appendix E. Characteristics ($\bar{x}$ ± SE) of macrohabitat variables measured within concentric circles centered on red-tailed hawk nests and random sites at the 1997-98 PHJV assessment sites, Saskatchewan.

Variable[a]	Nests			Random Sites			Test Statistic	
	n	$\bar{x}$	SE	n	$\bar{x}$	SE	U	P
B025-10	75	7.315	0.986	151	6.113	0.621	5114	0.235
B025-12	75	7.789	1.605	151	8.515	1.432	5583	0.846
B025-20	75	4.28	1.352	151	3.267	0.828	5615	0.883
B025-30	75	11.871	2.434	151	7.495	1.49	4965	0.048
B025-40	75	23.321	3.052	151	41.181	2.749	7374.5	<0.001
B025-50	75	18.865	1.856	151	10.243	1.046	3574.5	<0.001
B025-60	75	11.683	1.056	151	7.297	0.591	3770	<0.001
B025-70	75	14.52	1.054	151	14.078	0.803	5421	0.602
B025-80	75	0.356	0.116	151	1.812	0.397	6623	0.03
B050-10	71	7.103	0.813	146	5.882	0.383	4824.5	0.409
B050-12	71	7.443	1.453	146	8.665	1.311	5248.5	0.873
B050-20	71	4.221	1.11	146	3.041	0.582	4819	0.334
B050-30	71	13.026	2.296	146	7.98	1.362	4440	0.045
B050-40	71	28.221	2.942	146	42.583	2.341	6589.5	0.001
B050-50	71	14.068	1.492	146	9.768	0.885	3943.5	0.004
B050-60	71	10.452	0.849	146	7.019	0.5	3409	<0.001
B050-70	71	14.629	0.845	146	13.836	0.56	4899	0.513
B050-80	71	0.838	0.195	146	1.225	0.164	5815.5	0.145
B075-10	67	6.49	0.617	141	5.917	0.322	4602	0.765
B075-12	67	7.526	1.373	141	8.153	1.157	4616.5	0.787
B075-20	67	4.25	0.831	141	3.582	0.497	4522	0.6
B075-30	67	12.555	2.009	141	8.782	1.247	4146.5	0.13
B075-40	67	33.664	2.673	141	42.37	2.058	5749	0.011
B075-50	67	11.853	1.236	141	9.473	0.777	3947.5	0.056
B075-60	67	8.711	0.589	141	6.893	0.426	3523	0.003
B075-70	67	13.876	0.689	141	13.649	0.478	4627.5	0.813
B075-80	67	1.075	0.166	141	1.181	0.106	5194.5	0.246
B100-10	65	6.27	0.508	133	6.018	0.294	4252.5	0.853
B100-12	65	7.427	1.24	133	7.741	1.018	4091.5	0.537
B100-20	65	4.352	0.72	133	3.828	0.452	4057	0.476
B100-30	65	12.258	1.834	133	9.55	1.148	3903	0.258
B100-40	65	36.019	2.593	133	41.903	1.925	5047.5	0.056
B100-50	65	10.523	1.063	133	9.338	0.701	3952	0.328
B100-60	65	7.979	0.514	133	6.71	0.375	3425	0.018
B100-70	65	14.14	0.666	133	13.716	0.436	4134	0.619
B100-80	65	1.032	0.101	133	1.196	0.081	4734.5	0.277
B125-10	64	6.302	0.47	123	6.033	0.283	3823.5	0.749
B125-12	64	7.65	1.179	123	7.308	0.91	3672.5	0.45
B125-20	64	4.365	0.634	123	3.997	0.415	3829.5	0.76
B125-30	64	12.24	1.631	123	10.413	1.136	3587	0.316
B125-40	64	36.481	2.473	123	41.213	1.874	4476	0.124
B125-50	64	9.765	0.913	123	9.165	0.642	3718	0.535
B125-60	64	7.638	0.471	123	6.71	0.338	3324.5	0.082
B125-70	64	14.461	0.635	123	13.909	0.434	3709.5	0.519
B125-80	64	1.099	0.088	123	1.252	0.072	4381	0.205

Appendix E - continued

Variable[a]	Nests			Random Sites			Test Statistic	
	n	$\bar{x}$	SE	n	$\bar{x}$	SE	U	P
B150-10	64	6.42	0.448	117	5.97	0.275	3460	0.399
B150-12	64	7.912	1.176	117	7.192	0.843	3510.5	0.487
B150-20	64	4.145	0.532	117	3.849	0.359	3660	0.803
B150-30	64	11.835	1.463	117	10.866	1.104	3524	0.513
B150-40	64	37.107	2.402	117	40.907	1.84	4199.5	0.176
B150-50	64	9.501	0.801	117	9.074	0.598	3551	0.567
B150-60	64	7.483	0.432	117	6.767	0.325	3244.5	0.138
B150-70	64	14.488	0.593	117	14.175	0.408	3653	0.787
B150-80	64	1.109	0.083	117	1.199	0.064	4038.5	0.382
B175-10	62	6.164	0.427	107	5.912	0.28	3140	0.564
B175-12	62	8.287	1.215	107	7.155	0.82	3098.5	0.475
B175-20	62	3.957	0.457	107	3.959	0.33	3368	0.868
B175-30	62	11.474	1.38	107	11.102	1.08	3180.5	0.656
B175-40	62	37.405	2.393	107	40.52	1.878	3645	0.285
B175-50	62	9.601	0.76	107	8.977	0.581	3086.5	0.452
B175-60	62	7.473	0.411	107	6.814	0.332	2868	0.143
B175-70	62	14.53	0.54	107	14.419	0.409	3281.5	0.908
B175-80	62	1.111	0.079	107	1.143	0.052	3504.5	0.541

[a] – Buffer size on the left of the dash (-) and habitat class code on the right (e.g., B025-10 is buffer of 0.25 km radius for grassland).

Appendix F. Characteristics ($\bar{x} \pm$ SE) of macrohabitat variables measured within concentric circles centered on successful red-tailed hawk nests and random sites at the 1997-98 PHJV assessment sites, Saskatchewan.

Variable[a]	Successful Nests			Random Sites			Test Statistic	
	n	$\bar{x}$	SE	n	$\bar{x}$	SE	U	P
B025-10	48	7.929	1.341	151	6.113	0.621	4165	0.119
B025-12	48	4.348	1.591	151	8.515	1.432	3207	0.165
B025-20	48	3.987	1.567	151	3.267	0.828	3548	0.75
B025-30	48	15.91	3.368	151	7.495	1.49	4393	0.004
B025-40	48	23.781	3.906	151	41.181	2.749	2565.5	0.002
B025-50	48	17.423	2.354	151	10.243	1.046	4695	0.002
B025-60	48	11.951	1.365	151	7.297	0.591	4864	<0.001
B025-70	48	14.499	1.405	151	14.078	0.803	3726.5	0.768
B025-80	48	0.171	0.051	151	1.812	0.397	2799.5	0.013
B050-10	46	7.711	1.074	146	5.882	0.383	3785.5	0.193
B050-12	46	5.189	1.586	146	8.665	1.311	2885	0.124
B050-20	46	3.592	1.182	146	3.041	0.582	3637	0.329
B050-30	46	16.625	3.031	146	7.98	1.362	4174	0.004
B050-40	46	28.013	3.586	146	42.583	2.341	2427	0.005
B050-50	46	13.094	1.842	146	9.768	0.885	3961.5	0.066
B050-60	46	10.007	0.933	146	7.019	0.5	4447.5	0.001
B050-70	46	15.131	1.121	146	13.836	0.56	3668	0.346
B050-80	46	0.638	0.151	146	1.225	0.164	2869.5	0.137
B075-10	43	6.81	0.774	141	5.917	0.322	3278	0.42
B075-12	43	5.666	1.6	141	8.153	1.157	2737	0.321
B075-20	43	3.844	0.9	141	3.582	0.497	3218	0.521
B075-30	43	16.306	2.718	141	8.782	1.247	3732	0.05
B075-40	43	32.989	3.221	141	42.37	2.058	2306	0.018
B075-50	43	10.748	1.493	141	9.473	0.777	3328.5	0.331
B075-60	43	8.156	0.681	141	6.893	0.426	3637	0.048
B075-70	43	14.522	0.926	141	13.649	0.478	3296	0.387
B075-80	43	0.96	0.187	141	1.181	0.106	2612.5	0.171
B100-10	43	6.491	0.602	133	6.018	0.294	3039	0.537
B100-12	43	5.652	1.387	133	7.741	1.018	2660.5	0.486
B100-20	43	4.117	0.765	133	3.828	0.452	3111	0.379
B100-30	43	15.657	2.484	133	9.55	1.148	3406	0.055
B100-40	43	35.717	2.993	133	41.903	1.925	2322.5	0.064
B100-50	43	9.265	1.138	133	9.338	0.701	2904	0.878
B100-60	43	7.411	0.56	133	6.71	0.375	3293.5	0.135
B100-70	43	14.692	0.904	133	13.716	0.436	3185	0.262
B100-80	43	0.999	0.121	133	1.196	0.081	2524.5	0.249
B125-10	43	6.555	0.554	123	6.033	0.283	2871	0.404
B125-12	43	6.073	1.287	123	7.308	0.91	2568	0.776
B125-20	43	4.162	0.64	123	3.997	0.415	2773.5	0.633
B125-30	43	14.919	2.221	123	10.413	1.136	3109	0.084
B125-40	43	36.543	2.788	123	41.213	1.874	2244	0.14
B125-50	43	8.714	0.929	123	9.165	0.642	2657	0.963
B125-60	43	7.238	0.519	123	6.71	0.338	2946.5	0.266
B125-70	43	14.758	0.856	123	13.909	0.434	2925.5	0.3
B125-80	43	1.038	0.099	123	1.252	0.072	2254.5	0.151

Appendix F - continued

Variable[a]	Successful Nests			Random Sites			Test Statistic	
	n	$\bar{x}$	SE	n	$\bar{x}$	SE	U	P
B150-10	43	6.797	0.535	117	5.97	0.275	2888	0.152
B150-12	43	6.126	1.203	117	7.192	0.843	2389	0.625
B150-20	43	4.021	0.558	117	3.849	0.359	2617.5	0.694
B150-30	43	14.01	1.998	117	10.866	1.104	2851	0.195
B150-40	43	37.227	2.655	117	40.907	1.84	2163.5	0.175
B150-50	43	8.748	0.845	117	9.074	0.598	2550	0.894
B150-60	43	7.268	0.494	117	6.767	0.325	2801	0.272
B150-70	43	14.688	0.797	117	14.175	0.408	2664	0.568
B150-80	43	1.116	0.101	117	1.199	0.064	2357.5	0.543
B175-10	42	6.616	0.511	107	5.912	0.28	2585	0.154
B175-12	42	6.346	1.197	107	7.155	0.82	2111.5	0.567
B175-20	42	3.949	0.492	107	3.959	0.33	2267	0.933
B175-30	42	13.154	1.883	107	11.102	1.08	2480.5	0.324
B175-40	42	38.134	2.659	107	40.52	1.878	2037	0.376
B175-50	42	8.93	0.821	107	8.977	0.581	2317	0.768
B175-60	42	7.293	0.494	107	6.814	0.332	2503	0.28
B175-70	42	14.458	0.733	107	14.419	0.409	2269	0.924
B175-80	42	1.12	0.094	107	1.143	0.052	2184.5	0.792

[a] – Buffer size on the left of the dash (-) and habitat class code on the right (e.g., B025-10 is buffer of 0.25 km radius for grassland).

Appendix G. Characteristics ($\bar{x} \pm$ SE) of macrohabitat variables measured within concentric circles centered on unsuccessful red-tailed hawk nests and random sites at the 1997-98 PHJV assessment sites, Saskatchewan.

Variable[a]	Unsuccessful Nests			Random Sites			Test Statistic	
	n	$\bar{x}$	SE	n	$\bar{x}$	SE	U	P
B025-10	27	6.223	1.356	151	6.113	0.621	2046	0.976
B025-12	27	13.906	3.158	151	8.515	1.432	2535	0.025
B025-20	27	4.801	2.556	151	3.267	0.828	2162	0.48
B025-30	27	4.692	2.702	151	7.495	1.49	1967	0.683
B025-40	27	22.503	4.955	151	41.181	2.749	1385	0.008
B025-50	27	21.428	3.008	151	10.243	1.046	3055.5	<0.001
B025-60	27	11.205	1.675	151	7.297	0.591	2691	0.008
B025-70	27	14.556	1.562	151	14.078	0.803	2177.5	0.573
B025-80	27	0.686	0.303	151	1.812	0.397	1902.5	0.568
B050-10	25	5.984	1.191	146	5.882	0.383	1756	0.763
B050-12	25	11.592	2.777	146	8.665	1.311	2232.5	0.063
B050-20	25	5.38	2.302	146	3.041	0.582	1910	0.663
B050-30	25	6.402	3.026	146	7.98	1.362	1752	0.697
B050-40	25	28.602	5.227	146	42.583	2.341	1349.5	0.037
B050-50	25	15.86	2.556	146	9.768	0.885	2461	0.005
B050-60	25	11.27	1.708	146	7.019	0.5	2509.5	0.003
B050-70	25	13.706	1.237	146	13.836	0.56	1799	0.909
B050-80	25	1.205	0.478	146	1.225	0.164	1681	0.529
B075-10	24	5.918	1.033	141	5.917	0.322	1567	0.563
B075-12	24	10.86	2.447	141	8.153	1.157	2093.5	0.058
B075-20	24	4.978	1.688	141	3.582	0.497	1707	0.941
B075-30	24	5.835	2.259	141	8.782	1.247	1568.5	0.538
B075-40	24	34.872	4.816	141	42.37	2.058	1392	0.165
B075-50	24	13.833	2.164	141	9.473	0.777	2171	0.027
B075-60	24	9.705	1.094	141	6.893	0.426	2287	0.006
B075-70	24	12.718	0.952	141	13.649	0.478	1523.5	0.436
B075-80	24	1.282	0.323	141	1.181	0.106	1640	0.81
B100-10	22	5.839	0.946	133	6.018	0.294	1353.5	0.574
B100-12	22	10.894	2.338	133	7.741	1.018	1893	0.026
B100-20	22	4.812	1.539	133	3.828	0.452	1477	0.942
B100-30	22	5.615	1.723	133	9.55	1.148	1336	0.505
B100-40	22	36.61	5.049	133	41.903	1.925	1275	0.335
B100-50	22	12.984	2.163	133	9.338	0.701	1789	0.095
B100-60	22	9.09	1.032	133	6.71	0.375	1926	0.018
B100-70	22	13.061	0.846	133	13.716	0.436	1326	0.482
B100-80	22	1.095	0.188	133	1.196	0.081	1386	0.693
B125-10	21	5.783	0.885	123	6.033	0.283	1177.5	0.519
B125-12	21	10.877	2.331	123	7.308	0.91	1631.5	0.053
B125-20	21	4.781	1.445	123	3.997	0.415	0.898	0.898
B125-30	21	6.754	1.446	123	10.413	1.136	0.509	0.509
B125-40	21	36.354	5.027	123	41.213	1.874	0.43	0.43
B125-50	21	11.917	1.986	123	9.165	0.642	0.245	0.245
B125-60	21	8.456	0.96	123	6.71	0.338	0.08	0.08
B125-70	21	13.855	0.832	123	13.909	0.434	0.758	0.758
B125-80	21	1.224	0.174	123	1.252	0.072	1236.5	0.756

Appendix G - continued

Variable[a]	Unsuccessful Nests			Random Sites			Test Statistic	
	n	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*U*	*P*
B150-10	21	5.646	0.805	117	5.97	0.275	1140	0.6
B150-12	21	11.569	2.462	117	7.192	0.843	1588.5	0.032
B150-20	21	4.4	1.173	117	3.849	0.359	1210.5	0.915
B150-30	21	7.384	1.374	117	10.866	1.104	1113	0.492
B150-40	21	36.862	5.006	117	40.907	1.84	1125	0.54
B150-50	21	11.043	1.706	117	9.074	0.598	1387	0.347
B150-60	21	7.923	0.853	117	6.767	0.325	1442.5	0.205
B150-70	21	14.078	0.793	117	14.175	0.408	1171	0.733
B150-80	21	1.095	0.147	117	1.199	0.064	1092	0.418
B175-10	20	5.214	0.749	107	5.912	0.28	909	0.287
B175-12	20	12.363	2.629	107	7.155	0.82	1424	0.019
B175-20	20	3.973	0.99	107	3.959	0.33	999	0.638
B175-30	20	7.946	1.386	107	11.102	1.08	973	0.521
B175-40	20	35.873	4.979	107	40.52	1.878	952	0.435
B175-50	20	11.009	1.597	107	8.977	0.581	1230.5	0.288
B175-60	20	7.85	0.753	107	6.814	0.332	1263	0.201
B175-70	20	14.681	0.686	107	14.419	0.409	1083	0.931
B175-80	20	1.09	0.15	107	1.143	0.052	945	0.408

[a] – Buffer size on the left of the dash (-) and habitat class code on the right (e.g., B025-10 is buffer of 0.25 km radius for grassland).

Appendix H. Characteristic ($\bar{x} \pm$ SE) of macrohabitat variables measured within concentric circles centered on successful and unsuccessful red-tailed hawk nests at the 1997-98 PHJV assessment sites, Saskatchewan.

Variable[a]	Successful Nests			Unsuccessful Nests			Test Statistic	
	n	$\bar{x}$	SE	n	$\bar{x}$	SE	U	P
B025-10	27	6.223	1.356	48	7.929	1.341	569	0.382
B025-12	27	13.906	3.158	48	4.348	1.591	887	0.003
B025-20	27	4.801	2.556	48	3.987	1.567	699	0.42
B025-30	27	4.692	2.702	48	15.91	3.368	481	0.028
B025-40	27	22.503	4.955	48	23.781	3.906	626	0.804
B025-50	27	21.428	3.008	48	17.423	2.354	785	0.13
B025-60	27	11.205	1.675	48	11.951	1.365	629	0.834
B025-70	27	14.556	1.562	48	14.499	1.405	682	0.707
B025-80	27	0.686	0.303	48	0.171	0.051	760	0.185
B050-10	25	5.984	1.191	46	7.711	1.074	488	0.295
B050-12	25	11.592	2.777	46	5.189	1.586	785	0.007
B050-20	25	5.38	2.302	46	3.592	1.182	551	0.748
B050-30	25	6.402	3.026	46	16.625	3.031	410	0.028
B050-40	25	28.602	5.227	46	28.013	3.586	577	0.981
B050-50	25	15.86	2.556	46	13.094	1.842	673	0.238
B050-60	25	11.27	1.708	46	10.007	0.933	594	0.819
B050-70	25	13.706	1.237	46	15.131	1.121	511	0.441
B050-80	25	1.205	0.478	46	0.638	0.151	612.5	0.652
B075-10	24	5.918	1.033	43	6.81	0.774	545	0.418
B075-12	24	10.86	2.447	43	5.666	1.6	691	0.019
B075-20	24	4.978	1.688	43	3.844	0.9	485.5	0.676
B075-30	24	5.835	2.259	43	16.306	2.718	354	0.027
B075-40	24	34.872	4.816	43	32.989	3.221	547	0.685
B075-50	24	13.833	2.164	43	10.748	1.493	609	0.224
B075-60	24	9.705	1.094	43	8.156	0.681	595	0.302
B075-70	24	12.718	0.952	43	14.522	0.926	427	0.244
B075-80	24	1.282	0.323	43	0.96	0.187	572.5	0.46
B100-10	22	5.839	0.946	43	6.491	0.602	422	0.48
B100-12	22	10.894	2.338	43	5.652	1.387	654	0.012
B100-20	22	4.812	1.539	43	4.117	0.765	431	0.556
B100-30	22	5.615	1.723	43	15.657	2.484	335.5	0.053
B100-40	22	36.61	5.049	43	35.717	2.993	493	0.782
B100-50	22	12.984	2.163	43	9.265	1.138	563	0.212
B100-60	22	9.09	1.032	43	7.411	0.56	567	0.193
B100-70	22	13.061	0.846	43	14.692	0.904	379	0.193
B100-80	22	1.095	0.188	43	0.999	0.121	511	0.598
B125-10	21	5.783	0.885	43	6.555	0.554	389	0.372
B125-12	21	10.877	2.331	43	6.073	1.287	590	0.047
B125-20	21	4.781	1.445	43	4.162	0.64	419.5	0.645
B125-30	21	6.754	1.446	43	14.919	2.221	319	0.057
B125-40	21	36.354	5.027	43	36.543	2.788	471	0.78
B125-50	21	11.917	1.986	43	8.714	0.929	524	0.3
B125-60	21	8.456	0.96	43	7.238	0.519	525	0.293
B125-70	21	13.855	0.832	43	14.758	0.856	383	0.327
B125-80	21	1.224	0.174	43	1.038	0.099	487	0.612

Appendix H - continued

Variable[a]	Successful Nests			Unsuccessful Nests			Test Statistic	
	n	$\bar{x}$	SE	n	$\bar{x}$	SE	U	P
B150-10	21	5.646	0.805	43	6.797	0.535	355	0.168
B150-12	21	11.569	2.462	43	6.126	1.203	605	0.028
B150-20	21	4.4	1.173	43	4.021	0.558	432.5	0.785
B150-30	21	7.384	1.374	43	14.01	1.998	332	0.087
B150-40	21	36.862	5.006	43	37.227	2.655	480	0.684
B150-50	21	11.043	1.706	43	8.748	0.845	510	0.403
B150-60	21	7.923	0.853	43	7.268	0.494	493	0.553
B150-70	21	14.078	0.793	43	14.688	0.797	407	0.525
B150-80	21	1.095	0.147	43	1.116	0.101	420	0.652
B175-10	20	5.214	0.749	42	6.616	0.511	295	0.06
B175-12	20	12.363	2.629	42	6.346	1.197	581.5	0.015
B175-20	20	3.973	0.99	42	3.949	0.492	384.5	0.592
B175-30	20	7.946	1.386	42	13.154	1.883	335	0.2
B175-40	20	35.873	4.979	42	38.134	2.659	407	0.845
B175-50	20	11.009	1.597	42	8.93	0.821	487	0.313
B175-60	20	7.85	0.753	42	7.293	0.494	464	0.508
B175-70	20	14.681	0.686	42	14.458	0.733	419	0.988
B175-80	20	1.09	0.15	42	1.12	0.094	379.5	0.542

[a] – Buffer size on the left of the dash (-) and habitat class code on the right (e.g., B025-10 is buffer of 0.25 km radius for grassland).