THE DEVELOPMENT OF A HABITAT SUITABILITY INDEX MODEL FOR BURROWING OWLS IN SOUTHWESTERN MANITOBA AND SOUTHEASTERN SASKATCHEWAN

By

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A Thesis submitted to the Faculty of Graduate Studies
in partial fulfillment of the requirements for the degree of

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Abstract

Recent efforts aimed at sustaining burrowing owl (*Athene cunicularia*) populations in Manitoba have been unsuccessful, and the species is now verging upon extirpation from the province. Degradation of suitable habitat may be a major contributor to the decline of the burrowing owl population, although specific causes remain unknown. An HSI model was developed for use in determining the suitability of burrowing owl nesting habitat in southwestern Manitoba and southeastern Saskatchewan. Model parameters were obtained using a modified Delphi technique to solicit expert opinion as population sizes from which to sample were insufficient and quantitative, geographically specific habitat requirements of the species were absent from published literature. Burrowing owl experts from southwestern Manitoba and southeastern Saskatchewan identified 19 habitat components required by burrowing owls, 9 of which were determined to be critical in the identification of burrowing owl habitat suitability and were identified as model parameters. An interactive, adaptive learning approach was used in model development, iteratively refining the model until acceptable levels of accuracy and robustness were achieved. The resulting HSI model was verified using an interactive computer program then validated using known optimal burrowing owl habitat in Saskatchewan and historic burrowing owl breeding sites in Manitoba. Application of the burrowing owl HSI model on Manitoba's historic burrowing owl breeding sites determined that habitat suitability is slightly sub-optimal relative to burrowing owl habitat available in southeastern Saskatchewan due to a presence of tall vegetation at nest burrows. The suitability of burrowing owl breeding habitat in southwestern Manitoba could therefore be improved if

grassland management efforts were directed toward limiting vegetation height proximal to the nest burrow.

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Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Preamble

This study addresses the conservation of the burrowing owl (*Athene cunicularia*) in Manitoba. Although there appears to be an abundance of habitat suitable to the species in Manitoba (De Smet 1997), the population is in decline (Wedgwood 1978, Ratcliff 1986, Haug 1991, De Smet 1997). A habitat suitability index model that incorporates the specific habitat needs of the burrowing owl will indicate if sufficient habitat remains in Manitoba to sustain a viable population. The information and results obtained from this study will benefit future management plans directed toward the burrowing owl and other grassland bird species within southwestern Manitoba.

1.2 Background

The western subspecies of the burrowing owl is a non-migratory species in the southern United States, but becomes migratory in the northern portion of its range that extends into southwestern Canada (Johnsgard 1988) (Figure 1). Within Canada the burrowing owl is a summer resident, breeding in the southern interior of British Columbia as well as the southern regions of Alberta, Saskatchewan and Manitoba (Wedgwood 1978, Wellicome and Haug 1995) (Figure 1). The species has been a long-time resident of Manitoba, with records indicating its presence dating back to the 1890's (Atkinson 1899, Seton 1908). In 1992, the burrowing owl was designated as an endangered species under the Manitoba

Figure 1. Distribution of burrowing owls in North America indicating breeding (hatched), residential (cross-hatched), and wintering (stippled) ranges of the species as well as recent retractions of the Canadian range (dashed lines) (after Johnsgard 1988).

Endangered Species Act (MR 81/92 of *The Endangered Species Act*) and in 1995, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated the burrowing owl as endangered within Canada (Wellicome and Haug 1995).

There are many factors believed to contribute to the decline of burrowing owl populations, including habitat loss, pesticide use, vehicle induced mortality, burrowing mammal control practices and reduced productivity (Wedgwood 1978, Haug et al. 1993, Wellicome and Haug 1995, Hjertaas 1997, James and Espie 1997). Of particular concern is the apparent, long-term reduction in the quality and availability of grassland habitat across the burrowing owl range that is essential to the survival of the species (Wedgwood 1978, Haug 1985, Temple 1986, Haug and Oliphant 1990, Warnock 1996). Since burrowing owls require different habitats for nesting and foraging (Zarn 1974, Wedgwood 1978, Haug 1985, Haug and Oliphant 1990), the availability and proximity of both nesting and foraging habitat is critical to species survival (Haug 1985, Haug and Oliphant 1990). This, combined with increases in habitat fragmentation attributable to changing agricultural practices (Wellicome and Haug 1995, Warnock 1996), is believed to have further reduced the availability of otherwise potentially suitable grassland habitats throughout the species' range (Wellicome and Haug 1995).

While the preservation of grassland habitat is essential to the long-term sustainability of grassland bird populations, habitat improvement alone may not be sufficient to stabilize declining numbers of burrowing owls. It has been suggested that despite there being limited burrowing owl habitat in Saskatchewan, that the habitat is not saturated by the species and is capable of supporting many more burrowing owls than what are present

(Wedgwood 1976). Similarly in southwestern Manitoba, many pastures traditionally utilized by burrowing owls appear to have remained unchanged over time, yet are no longer used by the species (K. De Smet pers. com.). Preliminary assessments conducted on grassland areas typically used by breeding burrowing owls indicate that there are more than 700 pastures present in southwestern Manitoba that remain suitable for burrowing owl nesting purposes (De Smet 1992). However, De Smet (1997) does not comment on what criteria were used to make this initial assessment of nesting habitat suitability and to date, a quantitative assessment of the quality of these pastures has not been conducted (De Smet 1997).

The limited presence of breeding burrowing owls in Manitoba has lead the provincial government to classify the province's burrowing owl population as endangered (MR 81/92 of *The Endangered Species Act*). Recent absences of burrowing owls from lands traditionally used by the species suggest that subtle alterations to the landscape and its associated habitat such as increased fragmentation (Warnock 1996); changes in vegetation composition (Konrad and Gilmer 1984, Haug et al 1993), density (Green and Anthony 1989) or height (Green and Anthony 1989, Plumpton and Lutz 1993); or minute environmental changes (Wedgwood 1976) may have occurred. Although researchers have not been able to accurately measure such changes, it is possible that habitat modifications may in fact be deterring burrowing owls from nesting in those areas. Despite De Smet's estimate that Manitoba has over 700 suitable burrowing owl nesting pastures (De Smet 1997), no burrowing owls were found nesting in the province in 2000 (De Smet pers. com.). This discrepancy indicates the need for a greater understanding of the specific habitat requirements of burrowing owls as related to the conditions available for the species in southwestern Manitoba.

A better appreciation of impacts and how they influence flora and fauna through space and time can be obtained through wildlife modeling (Morrison et al. 1998). Models can assume a wide variety of types and complexities. Of these, habitat suitability index models are frequently used to evaluate habitat quality for wildlife species (O'Neil et al. 1988). A habitat suitability index (HSI) is used to quantitatively assess the ability of a site to meet the requirements of a specific species. This is accomplished by comparing the optimum habitat conditions of a species with the habitat features available within a defined region. To date, there has not been a habitat suitability index model developed for the burrowing owl.

The habitat suitability index modeling program, developed as part of the Habitat Evaluation Procedures (HEP) by the U.S. Fish and Wildlife Service (1981), conceptually has the form of:

$$\text{HSI} = \frac{\text{Habitat Condition in Study Area}}{\text{Optimal Habitat Condition}} \qquad [1]$$

HSI models are constructed using information about the species and its habitat requirements. Site-specific habitat requirements of the species are usually obtained from relevant literature or a detailed field examination of species-habitat relationships.

Alternatively, expert opinion may be used when the former fail to provide sufficient information.

By developing an HSI model for the burrowing owl, insight into the suitability of grassland habitat currently available to the burrowing owl population in Manitoba will be gained. In addition, information provided by the HSI model will assist in the design of future management plans for the species.

1.3 Issue Statement

Manitoba Conservation is concerned with the future of Manitoba's burrowing owl population. Despite what appears to be an abundance of habitat conducive to the breeding requirements of the species, the population trends of the burrowing owl in southwestern Manitoba is one of decline, now verging upon extirpation. To date, management of burrowing owl habitat (i.e. provision of artificial burrows) has not altered declining population trends. Other approaches such as the provision of key habitat components may need to be considered if Manitoba's burrowing owl population is to be preserved.

1.4 Objectives

The primary purpose of this study was to provide a mechanism to determine whether grassland habitat in southwestern Manitoba is capable of providing the habitat conditions required for burrowing owl survival. Specific objectives were to:

1. identify the breeding and foraging habitat requirements of burrowing owls;

2. determine and express mathematically the interrelationships of burrowing owl breeding and foraging habitat requirements; and
3. provide recommendations for the management of burrowing owl habitat in Manitoba.

1.5 Scope

The population trend of burrowing owls in Manitoba has been one of decline and is now verging upon extirpation. Burrowing owl populations in southeastern Saskatchewan are also in decline, however the population is considerably greater in Saskatchewan than in Manitoba. Although the range of the Canadian burrowing owl population includes Manitoba, Saskatchewan, Alberta and British Columbia (Figure 1), the landscape and accompanying habitats vary from province to province. Grassland habitats of southwestern Manitoba are most similar to those of southeastern Saskatchewan.

An absence of sufficient burrowing owls in Manitoba resulted in an inability to determine the geographically specific habitat requirements of the species. This problem was compounded by a lack of published literature on burrowing owl habitat use in Manitoba. The opinion of burrowing owl experts from Manitoba and Saskatchewan was therefore solicited to determine the habitat requirements of burrowing owls in southwestern Manitoba. Information specific to southeastern Saskatchewan was also used in model development, as habitat composition of the region is similar to that of southwestern Manitoba.

1.6 Study Approach

A literature review was conducted by searching literature on burrowing owls, their habitats and habitat suitability index models. In addition, Delphi and nominal group techniques for the purpose of accessing and collecting expert opinions were also reviewed. A modified Delphi technique workshop was held in Regina, Saskatchewan in 1997 to acquire the data necessary to develop a habitat suitability index model specific to burrowing owls in Manitoba and Saskatchewan. Field investigations were conducted in both southwestern Manitoba during the summer of 1997 and in Moose Jaw, Saskatchewan during the early fall of 1998.

Chapter 2

Breeding Burrowing Owl Literature Review

2.1 Introduction to the Burrowing Owl

2.1.1 Distribution of the Species and its Subspecies

The burrowing owl is typically associated with grasslands, low-growth shrubs and deserts throughout the Western Hemisphere (Clark 1997). The species is distributed from the interior of southern British Columbia and the prairies of southern Alberta, Saskatchewan and Manitoba, through the mid-western, western and southern United States, extending as far east as central Texas and central Mexico (Johnsgard 1988, Voous 1989, Ginn 1992, Haug et al. 1993, Clark 1997). The burrowing owl is a resident species in Florida, the West Indies (Bahamas and Hispaniola), and Clarion Island (Johnsgard 1988, Voous 1989). The species is also discontinuous in South America from Columbia to southern Argentina and Chile, south to northern Tierra del Fuego (Johnsgard 1988, Voous 1989, Ginn 1992, Haug et al. 1993) (Figure 2).

There are 21 geographic races of the burrowing owl (Table 1). Of these 21 races, only the western burrowing owl (*Athene cunicularia hypugaea*), the Florida burrowing owl (*A. c. floridana*), *A. c. troglodytes*, and *A. c. rostrata* nest in North and Central America (Johnsgard 1988, Clark 1997). The western burrowing owl breeds in mainland North America exclusive of Florida and central Mexico. The range of the Florida burrowing

Figure 2. North, Central and South American distribution of the burrowing owl (*Athene cunicularia*) (Ginn 1992).

Table 1. Geographic races of *Athene cunicularia* delineated by subspecies name, location and extinction status (after Clark 1997).

Subspecies	Location	Extinct (y/n)
cunicularia	Chile from Tarapaco to Coutin; southern Bolivia; Paraguay; Uruguay; southern Brazil; Argentina south to Tierra del Fuego.	yes – in Tierra del Fuego
grallaria	Dry interior of Brazil	no
hypugaea	Southern British Columbia east to central Manitoba, south along the eastern edge of the Great Plains, and south to western Panama. Winter as far south as Central America	no
floridana	Prairies of central and southern Florida; Bahaman Islands	no
guadeloupensis	Formerly occurred either on the Island of Guadeloupe or Marie Galante in the Lesser Antilles.	yes
amaura	Antigua; Nevis and St. Kitts	yes
troglodytes	Island of Hispaniola; Beata and Gonave Islands	no
rostrata	Clarion Island	no
nanodes	Chacaluta in extreme north Chile along the coast and lower-lying valleys north to Trujillo, Peru.	no
brachyptera	Margarita Island and parts of mainland Venezuela	no
tolimae	Western Columbia	no
juninensis	in the Andes from northwestern Argentina through southwestern Bolivia to central Peru	no
punensis	Semiarid valleys of northern Peru to the lowlands of western Ecuador	no
arubensis	Aruba Island off northern coast of Venezuela	no
intermedia	Coast of Peru from south of Payta to Pacasmayo	no
minor	Savannas of the upper Rio Branco, Brazil and probably adjacent parts of British Guiana and Surinam	no
carrikeri	Eastern Andes of Columbia	no
pichinchae	Western Ecuador north to Quito	no
boliviana	Arid habitats in tropical Bolivia and northern Argentina	no
apurensis	Northcentral Venezuela	no
partridgei	Northwestern Argentina	no

owl is restricted to Florida and the Bahaman Islands, whereas the distribution of *A. c. troglodytes* is limited to the Island of Hispaniola as well as Beata and Gonave Island. *A. c. rostrata* is found only on Clarion Island (Johnsgard 1988, Clark 1997).

2.1.2 Taxonomy of the burrowing owl

The burrowing owl has been variously placed in both *Athene* and the monotypic genus *Speotyto*. Phenotypic and karyotypic evidence have lead to numerous revisions in the taxonomy of the species (Haug et al. 1993, Clark 1997). Most recently, DNA-DNA hybridization prompted The American Ornithologists' Union to change the genus of the burrowing owl from *Speotyto* to *Athene* (American Ornithologists' Union 1997).

Although the genus of the burrowing owl continues to be reassessed and revised by the scientific community, anatomical and behavioral similarities between species have lead to the determination that the closest relative to the burrowing owl is the little owl (*Athene noctua*) (Voous 1989). The distribution of the little owl is restricted to Europe, Asia and the extreme north of Africa (Voous 1989, Ginn 1992), although Voous (1989) speculates that in North America, the burrowing owl's nearest living relative is the elf owl (*Micrathene whitneyi*).

2.1.3 Basic biology of the species

The distribution of the western burrowing owl (*Athene cunicularia hypugaea*) is restricted to North America. The species breeds from the southern interior of British Columbia, southern Alberta, southern Saskatchewan and extreme southwestern Manitoba southward to eastern Washington, central Oregon and California, east to western

Minnesota, northwestern Iowa, eastern Nebraska, central Kansas, Oklahoma, eastern Texas and Louisiana and south to central Mexico (Johnsgard 1988). The burrowing owl is a migratory species in the northern parts of the Great Basin and Great Plains and is a resident species in the southern parts of its breeding range (Figure 1) (Johnsgard 1988, Haug et al. 1993).

Band recoveries provide the majority of information regarding the specific migration routes, migration times and wintering areas of the burrowing owl. It should be noted, however, that this information is limited as only 27 bands have been recovered from 1927 to 1990 inclusive (James 1992, Haug et al. 1993). Despite such low return rates, information provided by band returns suggests that burrowing owls banded in the west (British Columbia, Washington, Oregon and California) migrate south along the coast and, in one case, into Mexico (Haug et al. 1993). Owls banded in Alberta, Saskatchewan, Manitoba, North Dakota, Montana and Idaho show a southern migration through Nebraska and Kansas into Oklahoma, Texas, Missouri (Haug et al. 1993), and possibly into Mexico (Hjertaas 1997). Owls banded in the central United States have been recovered in Arkansas, Oklahoma, Texas and Mexico while owls banded in the southern plains were found in the same states in which they were banded. James (1992) suggests that if the principles of "leap-frog" migration hold for the burrowing owl, Canadian burrowing owls may also be wintering in Central America.

The majority of burrowing owls breeding in Canada are believed to migrate north during March and April and south in September and October (Haug et al. 1993). In Saskatchewan, migration into breeding areas peaks around April 21, with the earliest arrival occurring on April 12 and the latest arrival of the species occurring on May 8 (Wedgwood 1976). It is assumed that the arrival of burrowing owls in Manitoba occurs at the same time as that in Saskatchewan, however this information is not provided in published literature. Observations of the species upon arrival suggest that burrowing owls either pair quickly following their arrival on breeding grounds or that the species pair prior to their arrival upon breeding grounds (Wedgwood 1976, Haug et al. 1993).

The burrowing owl is the only owl in North America that nests in underground burrows (Bezener and De Smet 2000). Burrowing owls typically nest on level, open, shortgrass plains or agricultural lands often associated with burrowing mammals (Johnsgard 1988, Haug et al. 1993). Nests are distributed either singly or in loose colonies (Haug et al. 1993, Bezener and De Smet 2000), with the burrowing owl nesting in underground burrows previously excavated by ground squirrels, badgers or other burrowing mammals (Zarn 1974). Western burrowing owls can excavate holes where burrowing mammals are absent (Thomsen 1971), but rarely do so (Haug et al. 1993). As a result, the burrowing owl is largely dependent upon burrowing mammals for the provision of suitable habitat (Johnsgard 1988, Haug et al. 1993). Preferred nesting areas are those with a high density of burrows available, possibly to provide extra escape burrows for young owls prior to independence as well as protection for adults from predators and inclement weather (Gleason 1978, Plumpton 1992). Burrows used by burrowing owls are often reused the following year (Haug et al. 1993), but are not necessarily used by the same individuals (Zarn 1974).

In central Saskatchewan, egg laying occurs from mid to late May (Wedgwood 1976, Haug et al. 1993). Burrowing owls typically lay one clutch of eggs per year, however renesting may occur if initial nesting attempts fail (Wedgwood 1976). Clutch sizes vary from five to eleven white eggs, with an average of seven to nine eggs laid per nest (Zarn 1974, Bezener and De Smet 2000). The female incubates eggs for approximately 28-30 days (Zarn 1974, Wedgwood 1976, Johnsgard 1988, Olenick 1990). Young first appear above ground 10-14 days after hatching (Wedgwood 1976, Haug et al. 1993) and begin to fly at four weeks of age (Zarn 1974, Haug et al. 1993). Fledging is mostly complete by mid-August (Wedgwood 1976). Although some immature young disperse completely from the nest site, most stay within the vicinity of their natal nest burrow, dispersing to satellite burrows of their own for the remainder of the breeding season (Wedgwood 1976). By mid-September most young have left the nest area, some adults have migrated south and the occasional male has also migrated (Wedgwood 1976). Fall migration of burrowing owls from Canadian prairie breeding grounds occurs from early September to late October (Wedgwood 1976, Haug et al. 1993).

Burrowing owls are opportunistic feeders, foraging primarily upon arthropods, small mammals and birds (Haug et al. 1993). During the summer, burrowing owls in Saskatchewan forage in rights-of-way and uncultivated fields (Haug et al. 1993). Hunting activities occur throughout the 24-hour period (Thomsen 1971, Marti 1974), with invertebrate prey often taken during daylight and small mammal prey taken more often after dark (Marti 1974, Plumpton 1992).

2.2 Distribution and Population Dynamics of the Burrowing Owl in Prairie Canada

The first documented report of a burrowing owl sighting in Manitoba occurred in 1897 (Seton 1908). The latent nature of this report, combined with an absence of other documented observations of the species in Manitoba and Saskatchewan, suggests that the presence of burrowing owls in the eastern Canadian prairies was rare throughout much of the 1800's (Wedgwood 1976, Ratcliff 1986, Haug et al. 1993). In 1899, Atkinson (1899) noted that the number of burrowing owls in Manitoba was increasing and by the early to mid-1900's, the number of burrowing owls breeding throughout Canada had also increased (Wedgwood 1976, Haug et al. 1993). Few researchers, however, comment on what may have been the principle reason for this increase in the burrowing owl population in the eastern Canadian prairies. Reports of increasing burrowing owl populations in Minnesota from 1881 to 1924 (Grant 1965), then later in Manitoba from 1899 (Atkinson 1899) to 1931 (Cartwright 1931) and southeastern Saskatchewan in the 1920's (Mitchell 1924), suggest that the burrowing owl may have expanded its range northward into the eastern Canadian prairies following human settlement as the intensity of pasturing increased in the region (Wedgwood 1976).

The number of burrowing owls in the eastern Canadian prairies never increased to the point where the species was considered common in prairie Canada (Wedgwood 1976, Wedgwood 1978). Instead, population growth became limited (Wedgwood 1976) and was followed by a long-term decline that has continued to this day (Wedgwood 1976, Haug et al. 1993, Wellicome and Haug 1995). The specific reason(s) for this decline remain(s) unknown (Wedgwood 1976), although causes are believed to be complex and interrelated (Hjertaas 1997). Researchers have identified the loss, degradation and fragmentation of breeding habitat; vehicle induced mortality; exposure to pesticides and rodenticides as well as reduced productivity of the species as factors potentially contributing to the decline of the burrowing owl population (Wedgwood 1978, Haug et al. 1993, Wellicome and Haug 1995, James and Espie 1997, Hjertaas 1997). It is also possible that Canadian burrowing owl populations experience adverse conditions on migration routes and wintering areas that further contribute to the decline of the species (Haug et al. 1993, Hjertaas 1997).

This reduction in burrowing owl populations has contributed to a concurrent and corresponding contraction of the species range in Canada (Wedgwood 1978, Haug et al. 1993, Wellicome and Haug 1995, Hjertaas 1997). Although, burrowing owl distribution has receded throughout much of Canada, contraction has been most severe on the northern and eastern peripheries of its range (Wellicome and Haug 1995, Hjertaas 1997). Today, burrowing owl populations that historically extended from Manitoba to British Columbia (Wedgwood 1978, Haug et al. 1993) are almost completely confined to the southern regions of Alberta and Saskatchewan (Holroyd & Wellicome 1997) (Figure 3).

The first comprehensive estimation of burrowing owl populations in Manitoba did not occur until 1978, when 110 pairs were estimated to be nesting in the province (Wedgwood 1978). Since that time, the species population has been precipitously reduced. Although there is a gap in data detailing provincial burrowing owl population dynamics between 1978 and 1982, it would appear that the population of burrowing owls

1986). Manitoba's breeding burrowing owl population decreased even further to 35 nesting pairs in 1984 (Ratcliff 1986) and continued to decline into 1987 (Haug 1991). During this time, both search efforts and the knowledge of where to look for owls increased within Manitoba (De Smet pers. com.), therefore implying that in reality, the population decline was much more drastic than that indicated by survey data (De Smet pers. com.). These decreasing densities of Manitoba's burrowing owl population in the early 1980's corresponded to a simultaneous range contraction of approximately 200km toward the southwestern corner of the province (Haug 1991).

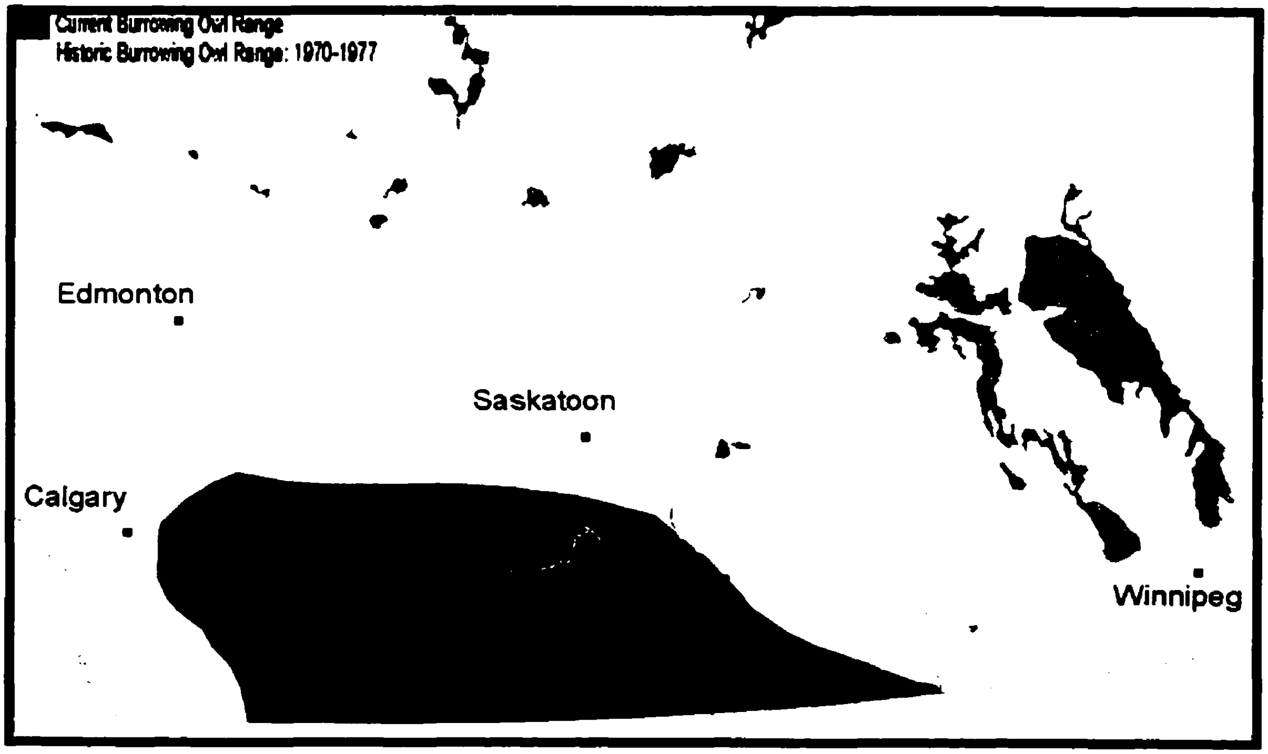

Figure 3. Contraction of the burrowing owl breeding range in prairie Canada from 1970 to 2000 (Wellicome pers. com.).

Although survey efforts were irregular from 1988 to 1996, records indicate that the number of burrowing owl nesting pairs in Manitoba steadily declined at an average rate of 25% annually from 1982 to 1996 (De Smet 1997). Adverse weather conditions during incubation periods in 1983 and 1993 resulted in the most drastic reductions of the province's breeding burrowing owl population, as pair success was substantially reduced and the number of breeding pairs returning the following year declined by 41% and 65% respectively (Ratcliff 1986, De Smet 1997). In 1998, only one burrowing owl was found nesting in the province, while three breeding pairs were documented in 1999 (De Smet pers com.). No burrowing owls were located in Manitoba in 2000 (De Smet pers. com.).

It has been suggested that because the Canadian prairie provinces are located along the northern periphery of the species' range, local populations may be especially sensitive to minute environmental changes (Wedgwood 1976). It is therefore possible that sensitivities to environmental fluctuations may be further increased since Manitoba is located along both the northern and eastern extremes of the range. A withdrawal of burrowing owl populations from the eastern Canadian prairies, rather than a population decline, may therefore account for the reduction in the number of burrowing owls in nesting areas located along the range periphery (Wedgwood 1976).

2.3 Burrowing Owl Habitat Requirements

Studies examining burrowing owl habitat selection indicate that the species does not select nest sites at random with respect to the features of their habitat (Zarn 1974, Rich 1984, Green and Anthony 1989, James et al. 1991, Warnock 1996). Throughout the North American range of the burrowing owl, habitat use is generally associated with dry, treeless, well-drained prairie grasslands, having flat to gently sloping topography, a high density of burrows and short vegetation (Coulombe 1971, Butts 1973, Zarn 1974, Wedgwood 1976, Konrad and Gilmer 1984, Plumpton 1992, Haug et al. 1993, Wellicome and Haug 1995).

Further examination of the species' habitat requirements indicate that habitat selection and hence the habitat characteristics required by burrowing owls are geographically dependent (Wellicome and Haug 1995). Although the basic attributes of nesting habitat for the western burrowing owl have been identified, the quantitative, geographically specific requirements of the species are not readily known. Little research has focused on the specific nesting and foraging habitat requirements of the burrowing owl in Canada. Of the research that has been conducted, none has occurred in Manitoba.

2.3.1 Nesting Habitat

Burrowing owls in central Saskatchewan have been found to have a mean home range size of $2.41 km^2$ (Haug 1985). Haug (1985) defined home range as the area used by burrowing owls for foraging, roosting, nesting and the raising of young. Within this area, the majority of activities typically associated with nesting (i.e. nesting, roosting, loafing, rearing of young) occurred within 50m of the nest burrow (Haug 1985), while the majority of foraging activities were found to occur at distances greater than 50m from the nest (Haug 1985, Haug and Oliphant 1990).

2.3.1.1 Burrows

Burrows are the only place in which burrowing owls will nest and roost (Coulombe 1971, Zarn 1974, Wedgwood 1976, Wellicome and Haug 1995). Therefore, an adequate presence of burrowing mammal holes and mounds is critical to burrowing owl habitat suitability (Zarn 1974, Wedgwood 1976, Haug et al. 1993). High densities of burrows are believed to further improve the suitability of nesting habitat by providing shelter areas for the species and protection from predators (Zarn 1974, Wedgwood 1976) as well as both roosting areas (King 1996) and escape burrows for young during the early post-fledging period (Zarn 1974, Haug et al. 1993). Haug (1985) found that there was an average of 6 burrows within a 30m radius of burrowing owl nests in Saskatchewan. However, studies conducted into the selection of nest sites containing higher burrow densities relative to other potential nesting areas in Colorado were inconclusive (Plumpton and Lutz 1993).

Burrows used by burrowing owls are excavated by ground squirrels (*Spermophilus* spp.) or prairie dogs (*Cynomys* spp.), badgers (*Taxidea taxus*) and occasionally fox (*Vulpes* spp.) (Zarn 1974, Wedgwood 1976, Haug 1985, Haug et al. 1993, Wellicome and Haug 1995). Where burrowing mammals are absent, the burrowing owl has been found to dig its own burrows, but rarely does so (Zarn 1974, Haug et al. 1993). Burrow sites are located in lacustrine, solonetzic, saline and alluvial soils having few rocks (Harris and Lamont 1985, Wellicome and Haug 1995) although lacustrine soils appear to be preferred (Harris and Lamont 1985). Burrow entrances are typically located in, rather than beside, mounds created from burrow excavation (Wedgwood 1976). Burrow selection does not appear to be influenced by aspect (Coulombe 1971, Butts 1973, Martin 1973, Zarn 1974, Rich 1986, Plumpton 1992, Plumpton and Lutz 1993). However, King (1996) found burrow entrances of burrowing owls in Idaho to be significantly oriented in a southeasterly direction although it is not clear whether burrows in this sample were representative of the environmental situation. Dimensions of the burrow entrance also vary depending upon the species that excavated the initial burrow. As a result, it is believed that the nest burrows selected by burrowing owls do not exhibit a consistent and explicit set of definable characteristics (Haug 1985).

Burrows used by burrowing owls are often re-used in subsequent breeding seasons (Martin 1973, Zarn 1974, Wedgwood 1976, Green and Anthony 1989, Haug et al. 1993, Plumpton and Lutz 1993), although it does not appear that burrow re-use is restricted to the original nesting pair (Zarn 1974). Studies indicate that sites are typically occupied for one to three years, experience a period of non-use, then are again used by the species, conforming to a 6 year use cycle (Rich 1984). It is hypothesized that nesting sites that have been used in consecutive years represent the best nesting habitat present within the habitat available to the species (Plumpton and Lutz 1993).

Changes in agricultural practices, nest depredation, flooding and other such events can destroy, alter or temporarily obscure burrowing owl nest burrows to such a degree that burrow re-use is not always possible. Despite this, research into burrowing owl site fidelity has shown that the species returns to the same breeding territory over consecutive years (Green and Anthony 1989, Haug et al 1993), often returning to burrows located between 50m (Green and Anthony 1989) and 230m (Millsap and Bear 1997) of previously occupied burrows. Fledged young exhibit similar site fidelity, returning to nest in areas proximal to their natal breeding areas (Haug et al. 1993, Millsap and Bear 1997).

In Manitoba, returning young nested between 2.4km and 26.4km from their natal nest areas, while owls in Alberta moved 0.3km to 30km from natal sites the following year with males dispersing shorter distances than females (Haug et al. 1993). It is hypothesized that differences in the dispersal distances of male and female burrowing owls may be due to innate behaviors directed toward the facilitation of genetic interchange by lessening the probability of inbreeding within the population.

In addition to the nest burrow, the species utilizes several satellite burrows in proximity to the nest (Wedgwood 1976, Plumpton and Lutz 1993) for perching, observation and protection from predators (Butts 1973, Zarn 1974, Wedgwood 1976, Konrad and Gilmer 1984). As nestlings grow, they often disperse into burrows nearby the natal burrow (Martin 1973, Konrad and Gilmer 1984, Plumpton and Lutz 1993), indicating that breeding pairs may be selecting nest sites based upon the qualities of adjacent burrows as well as those of the nest burrow itself (Plumpton and Lutz 1993). Martin (1973) noted that occupied nest burrows tended to be located an average of 25m from other vacant burrows.

The location of burrowing owl nests in close proximity to cattle operations may function to improve owl survivorship and thus habitat suitability. Nests and tunnel entrances of nest burrows are often lined with cattle dung (Martin 1973, Zarn 1974, Konrad and Gilmer 1984). Although studies regarding the exact purpose of this nest lining material are inconclusive, it is believed that cattle dung is used by burrowing owls to mask nest odors and limit predator detectability (Martin 1973, Green and Anthony 1989).

2.3.1.2 Vegetation

Burrows used by burrowing owls for nesting purposes are located in vegetation that is kept short or sparse by soil, climatic conditions, grazing, haying, mowing or burning (Wedgwood 1976, Wellicome and Haug 1995). The maintenance of short vegetation heights around the nest is important to nesting burrowing owls (Coulombe 1971) as it aids owls in early detection of potential predators at the nest site (Byrkjedal 1987) by increasing horizontal visibility from the burrow (Konrad and Gilmer 1984).

The specific vegetation attributes of habitats preferred by burrowing owls vary regionally throughout the breeding range of the species, although more general vegetation attributes appear to remain constant. Studies conducted in South Dakota, Colorado and Oregon have found that burrowing owls select nest sites having greater amounts of bare ground and less grass coverage relative to other potential nesting areas (Rich 1984, MacCracken et al. 1985, Green and Anthony 1989, Plumpton and Lutz 1993). An absence of dense grass cover was also found to be common to all burrowing owl nest sites in habitats examined in Oregon (Green and Anthony 1989). Research in Colorado indicates that neither the percent of grass nor the percent of forbs comprising vegetation cover contribute to the nest site selection process (Plumpton and Lutz 1993).

Studies regarding the specific vegetation species mix preferred by breeding burrowing owls in the eastern prairies are conflicting and inconclusive. Haug et al. (1993) note that within the migratory range of the species, burrowing owls nest in short-grass prairie, while Konrad and Gilmer (1984) indicate that the preferred breeding habitat of burrowing owls in North Dakota is heavily grazed, mixed-grass prairie. Although both types of grassland appear to provide burrowing owls with suitable nesting habitat, it is unclear which is preferred by the species.

With the land-use practices presently employed across the prairies, areas grazed by livestock provide the majority of burrowing owl nesting habitat in Canada (Wedgwood 1976, Wedgwood 1978, Wellicome and Haug 1995). A study conducted in Saskatchewan found that 83% of nesting attempts in rural areas were made in pastures, while the remainder of observed nesting attempts took place in stubble, croplands, roadsides and haylands (Wellicome and Haug 1995). Burrowing owls have also been found to nest in urban areas, although nesting attempts are usually confined to areas where grasses are kept short by mowing (Wellicome and Haug 1995).

Although Wellicome and Haug (1995) indicate that vegetation type does not appear to affect habitat selection as long as the vegetation cover is kept short, Wedgwood (1978) found that 82% of nesting attempts in pastures occur in areas comprised of native grass species. Wedgwood (1976) and Konrad and Gilmer (1984) have also documented results similar to those of Wedgwood (1978). Conversely, Haug (1985) found 60% of burrowing owl nests were located in pastures of tame grass species, while only 33% of nests occurred on native pasturelands. To date, no studies are known to have examined the detailed vegetation species cover composition requirements of nesting burrowing owls in the eastern Canadian prairies. In Oregon, burrowing owl nesting attempts are restricted to snakeweed, cheatgrass and bitterbrush habitats (Green and Anthony 1989). Even though these habitats are absent from the eastern Canadian prairies, the physiognomic factors of the vegetation preferred by burrowing owls on the eastern Canadian prairies appear to remain the same.

Regardless of geographic location, burrowing owls exhibit an affinity for habitats having short vegetation throughout the duration of the breeding season (Zarn 1974, Wedgwood 1976, Wedgwood 1978, Rich 1984, Rich 1986, Green and Anthony 1989, Wellicome and Haug 1995). Vegetation is typically maintained at minimal heights by cattle grazing or cropping from resident ground squirrel populations inhabiting burrowing owl nesting habitat (Wedgwood 1976, Rich 1984, Green and Anthony 1989). In Colorado and Oregon, the mean effective height of vegetation on habitats selected by nesting burrowing owls ranged between 4.7cm and 9.8cm (Green and Anthony 1989, Plumpton and Lutz 1993). Green and Anthony (1989) noted a strong preference of burrowing owls to nest in habitats where vegetation was maintained at heights less than 5cm, although the species also nested in taller vegetation when elevated perches were available.

2.3.1.3 Perches

Elevated perches are believed to be important to both predator and prey detection by burrowing owls in habitat with vegetation of moderate height (Green and Anthony 1989), but may also aid owls in thermoregulation (Coulombe 1971). Although Green and Anthony (1989) found that burrowing owls only used perches when surrounding vegetation was greater than 5cm in height, Plumpton and Lutz (1993) found that perches were used when vegetation was an average height of 8cm. Despite this apparent need for perches in areas where vegetation exceeds a threshold height, research indicates that nest burrows generally have perches located at greater distances from the burrow entrance than that exhibited by other potential burrows in the same habitat (Plumpton and Lutz 1993). Plumpton and Lutz (1993) do not specify the distance from the nest at which perches are preferred, however Wedgwood (1976) notes that males were commonly seen on sentinel perches located a maximum of 100 yards (91m) from the nest burrow. Although burrowing owls in Idaho used three or four perches at each nest site, the perch closest to the nest was used most often and was located an average 18.9 ± 2.8m away from the nest burrow (King 1996). Burrowing owls in Colorado and Oregon have also been found to select nest sites with higher perches (averaging 85.9cm) and lower mean shrub volumes relative to that available at other potential burrowing owl nesting areas (Green and Anthony 1989, Plumpton and Lutz 1993). Perches used by burrowing owls in Idaho were, on average, 0.56m higher than the surrounding vegetation (King 1996).

2.3.1.4 Internest Distance

In areas where burrowing owl populations are high, the species is often found to nest in loose colonies (Wedgwood 1978, Haug et al. 1993, Johnson 1997). Throughout much of the burrowing owl breeding range, distances between active nest burrows have been found to range between 900m (Gleason 1978) and <14m (Ross 1974), with the latter occurring only in concentrated colonial nesting situations.

In Saskatchewan, few incidents of colonial nesting burrowing owls have been reported (Wedgwood 1976). Where multiple nests have been found in the same pasture in Saskatchewan, nests were located between 200 and 400 yards (183 – 366m) from one another (Wedgwood 1976). In Manitoba, there have also been a few reports of multiple active burrowing owl nests appearing concurrently on the same pasture, however internest distances were never determined (De Smet pers. com.).

In areas where colonial nesting does not occur, research indicates that the nearest neighbor distance between active nests is important to the nest success of the species. In Oregon, a minimum internest distance of 110m was determined to be critical to the continued use of a nest throughout the breeding season as nests located less than 110m from one another were abandoned midway through the nesting cycle (Green and Anthony 1989). Although some desertions may have been due to adult mortality, Green and Anthony (1989) hypothesize that adjacent nesting pairs located less than 110m apart may have deserted their nests as a result of the regional climate and its effects on prey availability. As prey populations fluctuate throughout the breeding season, adjacent nesting pairs may have competed for the same food sources and may have become stressed by the demands of large brood sizes such that one of the two nests were abandoned (Green and Anthony 1989). When nests were located closer than 60m from one another, Green and Anthony (1989) observed that both nests were abandoned, further supporting the hypothesis that competition for food resources intensifies as the distance between burrowing owl nests decreases. Distances between active burrowing owl nest burrows in New Mexico have also been found to average 166m (Martin 1973) and 176m in Florida (Millsap and Bear 1997). The mean distance between occupied nest sites within a prairie dog town in Colorado was found to be 100.9m (Plumpton and Lutz 1993). However, burrowing owls have been found to nest at distances closer than 110m of other active burrowing owl nests in Oklahoma (Butts 1973). There is no information regarding the internest distances of burrowing owls breeding in Manitoba.

2.3.2 Forage

Foraging habits and pellet analysis of burrowing owls indicate that the species is an opportunistic forager, consuming prey items that require the least energy for the species to capture. Composition of the burrowing owl diet is further varied throughout the duration of its breeding season as the species consumes prey types that are most readily available given the season (Zarn 1974, Gleason and Johnson 1985). The burrowing owl's diet consists mostly of insects and small mammals (Zarn 1974, Konrad and Gilmer 1984, Green and Anthony 1989), with a dependence upon rodent prey, particularly voles, in early spring and late fall when invertebrate prey availability is limited (Butts 1973, Rich 1986, Green and Anthony 1989). An increase in concealing cover for rodents and a corresponding seasonal increase in the availability of arthropods such as grasshoppers and beetles have been attributed to this shift in dietary consumption (Green and Anthony 1989). Despite seasonal alterations in prey species, the majority of the biomass consumed by burrowing owls throughout the breeding season is provided by individual small mammal captures (Gleason and Craig 1979, Green 1983, Gleason and Johnson 1985, Thompson and Anderson 1988, Green and Anthony 1989).

Little information is available on the foraging habitat used by burrowing owls to secure such prey types (Wellicome and Haug 1995). A study conducted in Saskatchewan on 6 radio-tagged males found that the minimum foraging home-range size of burrowing owls averaged $2.41 km^2$, wherein the maximum distance burrowing owls traveled from the nest to forage averaged 1.73km (Haug and Oliphant 1990). Peak foraging activity and maximum distances traveled occur at night, while diurnal foraging is confined to the area surrounding the nest burrow (Gleason 1978, Haug and Oliphant 1990) and therein, usually to pastured lands (Wellicome and Haug 1995). Central place foraging theory predicts that the foraging distances a predator will travel are reduced when the size of prey hunted is decreased (Orians and Pearson 1979). As the availability of small mammal populations becomes limited with increasing vegetation densities throughout the summer, insect populations increase and the diet of burrowing owls shift. This subsequent change in the prey base of burrowing owls from small mammals to arthropods appears to alter the distance at which burrowing owls forage since foraging efforts become concentrated closer to the nest burrow (Haug 1985, Green and Anthony 1989). As a result, small mammals are primarily captured at distances further from the nest (Haug 1985, Green and Anthony 1989, Haug and Oliphant 1990, Plumpton 1992) with captures occurring as far as 600m from the nest burrow in Oregon (Green and Anthony 1989) and 1.73km in Saskatchewan (Haug 1985). In contrast, the majority of insect captures typically occur within 250m of the nest (Haug and Oliphant 1990).

When foraging at distances greater than 50m from the nest burrow, grass/forb habitat types including road rights-of-way, haylands, ungrazed pasture and uncultivated areas are preferred by burrowing owls in Saskatchewan (Haug 1985, Haug and Oliphant 1990). Croplands and grazed pastures are generally avoided in relation to their occurrence within the species' home range (Haug 1985, Haug and Oliphant 1990). Radio-tagged males in Saskatchewan were found to forage over uncultivated areas and roadside habitats more often than expected by chance (Haug and Oliphant 1990). These uncultivated areas and roadside habitats frequented by foraging burrowing owls typically exhibited dense, permanent vegetation cover that was greater than 30cm in height (Haug and Oliphant 1990). Crop and pasture habitat types were generally avoided during such foraging events whereas fallow lands were used in proportion to availability (Haug and Oliphant 1990). Small mammal trapping in similar habitats indicated that uncultivated and roadside habitats possess high densities of deer mice (*Peromyscus maniculatis*) and meadow voles (*Microtus pennsylvanicus*) (Wellicome pers. com.) and therefore that burrowing owls concentrate foraging activities in habitats having a high abundance of small mammal prey (Wellicome and Haug 1995).

An increased level of suitability is believed to be afforded to nesting sites situated closer to foraging habitats than those located at greater distances from foraging areas. Owls that nested near irrigated cropland in Idaho were found to prey more heavily upon voles and produce significantly more young than those nesting further away from the same habitat (Gleason 1978). A similar propensity for cropland was also found to occur in Oklahoma where owl populations were denser and rodent densities were greater in areas located adjacent to cereal crops when compared to those that were adjacent to other habitat types (Butts 1973). Diet analysis conducted in Idaho also revealed a positive correlation between the amount of land under cultivation and the number of voles in owl pellets (Rich 1986). As a result, prey density and availability are assumed to be major proximate factors influencing nest site and habitat selection by burrowing owls.

Although cultivated fields support large populations of small mammal prey, excessively tall (>60cm) (Wellicome and Haug 1995) or dense vegetation occurring later in the breeding season may render small mammal prey species unavailable to the burrowing owl (Zarn 1974), presumably by hindering burrowing owl access to prey species. However, vegetation in haylands is frequently harvested throughout the burrowing owl breeding season. Variation in cutting dates of haylands is common and haylands are often found in different stages of growth thus making rodent populations available to burrowing owls throughout the summer (Rich 1986). As a result, haylands may be important to the suitability of burrowing owl forage habitat and its availability and may therefore be important in the identification of burrowing owl nest site suitability.

Even though researchers have determined the vegetation attributes commonly associated with small mammal foraging efforts by burrowing owls, the amount of optimal foraging habitat breeding burrowing owls require to survive and be reproductively successful remains unknown. Wellicome and Haug (1995) suggest that "enough" permanent cover and tall vegetation (30-60cm) within the foraging home range is required to supply a sufficient amount of small mammals and other prey, yet the exact amount of forage habitat required has not yet been explored.

2.4 Habitat Loss, Degradation and Fragmentation

Information regarding the land uses associated with farming and ranching in Canada is collected every five years by agricultural census. Despite the limited detail of information collected, census data provides insight into the potential nesting habitat available to burrowing owls through its tallies of "improved" and "unimproved" pasture categories (Wellicome and Haug 1995). Such data indicate that over the past quarter century, pasture habitat within the Canadian range of the burrowing owl has declined (Wellicome and Haug 1995). From 1966 to 1991, the amount of total farm area allocated as pasture within the burrowing owl range decreased by approximately 6% in Saskatchewan and 8% in Manitoba (Wellicome and Haug 1995). This was paired with concurrent increases of similar magnitudes in cultivated land, such that of the pastures existing in 1966, approximately 19% were converted to crop in Saskatchewan while 31% was converted to cropland in Manitoba by 1991 (Wellicome and Haug 1995). If one assumes that the total area of potential burrowing owl breeding habitat before the turn of the century is equal to the present total amount of pasture plus cultivated land reported by agricultural census, the amount of pasture remaining today constitutes approximately 26% of the original habitat within the burrowing owl's range in Saskatchewan and only 19% in Manitoba (Wellicome and Haug 1995). Inventories conducted on much of the 1978 burrowing owl range in Saskatchewan indicate that only 14% of the remaining native vegetation was situated on land systems that owls select for nesting and of that, only 2% was located on the most highly preferred lacustrine soil (Wellicome and Haug 1995).

The rate at which foraging habitat is disappearing from the Canadian range of the species has not been formally quantified (Wellicome and Haug 1995). Nonetheless, the number of uncultivated areas possessing tall vegetation and an abundance of burrowing owl prey species (Wellicome 1994) are believed to have declined with the advent of modern farming practices (Wellicome and Haug 1995).

In addition to habitat destruction, subtle modifications of a species' habitat can also function to lower the quality of a site relative to the species habitat requirements and thus reduce the carrying capacity of an area (Wellicome and Haug 1995). It is believed that habitat degradation, as a result of habitat modification, may have rendered many areas in the Canadian prairies unsuitable for the breeding of burrowing owls (Wellicome and Haug 1995).

The preference of burrowing owls toward habitats having short or sparse vegetation proximal to the nest burrow (Coulombe 1971, Green and Anthony 1989, James et al. 1991, Wellicome and Haug 1995) renders the maintenance of cropped vegetation heights imperative to the preservation of burrowing owl nesting habitat attributes. Should a cessation of grazing in pastures occur, the habitat becomes less attractive to owls (Wellicome and Haug 1995) and limits the suitability of available nesting habitat. Research in Saskatchewan indicates that grazing has ceased on 7% of the lands inhabited by burrowing owls over a three-year period (Dundas 1993). Similar data are not currently available for southwestern Manitoba, but it has been suggested that grazing practices in Manitoba have remained somewhat stable over the past 5 years, although the intensity of grazing pressure on pastures appears to fluctuate with summer levels of precipitation (De Smet pers. com.). As the level of summer precipitation decreases, the intensity of grazing pressure is believed to increase (De Smet pers. com).

Changes in land-use practices associated with agriculture have also contributed to the decline in breeding burrowing owl habitat in Canada (Wellicome and Haug 1995). Fire suppression and the planting of trees for shelter belts have lead to an increase in the number of trees on the prairie landscape and therein have allowed populations of some burrowing owl avian predators to increase (Schmutz et al. 1980). Great horned owls (*Bubo virginianus*), Swainson's hawks (*Buteo swainsonii*) and red-tailed hawks (*Buteo jamaicensis*) are more abundant today than on the previously treeless prairie plains (Wellicome and Haug 1995).

In addition to the effects that agricultural land-use practices have had on the populations of both burrowing owl avian predators and burrowing mammals, agricultural land-use practices have also functioned to transform small mammal communities on the Canadian prairies (Wellicome and Haug 1995). Research on meadow vole (*Microtus pennsylvanicus*) and prairie vole populations (*Microtus ochrogaster*) in Alberta shows that the species are almost exclusively associated to areas of permanent vegetative cover (Wellicome pers. com.). However, the conversion of permanent vegetative cover to croplands (van Kooten and Schmitz 1992), is believed to have lead to the decline of such vole populations and thus, a reduction in burrowing owl prey sources (Wellicome and Haug 1995).

Furthermore, the increasing fragmentation of grassland habitats as a result of increased agricultural land use threatens grassland bird populations through the outright loss of habitat, a reduction in the size of habitat patches, increased edge habitat and increased isolation (Wellicome and Haug 1995). Since raptor home-range size is correlated with the density of their prey, raptors require larger home ranges when foraging habitat is fragmented into small patches (Redpath 1995). Haug (1985) found that the home range sizes of six male burrowing owls was significantly correlated with the proportion of cultivated land located within their home ranges, thus suggesting that fragmentation resulting from cultivation near burrowing owl nest burrows increases foraging distances and therefore time spent away from the nest. Increases in the amount of edge habitat within burrowing owl home ranges has also been found to increase nest predation (Wellicome and Haug 1995, Warnock 1996).

In many parts of the burrowing owl's Canadian range, isolation as a result of fragmentation is substantial (Wellicome and Haug 1995). Isolation affects wildlife populations by interrupting the normal flow of individuals between habitat patches such that the probability that individuals will successfully disperse into an area is lessened as the distance from one nest site to another is increased (Verner 1992, Warnock 1996). In Saskatchewan, research indicates that burrowing owls tend to select nesting pastures that are closer to other occupied pastures (Warnock 1996). As distances between suitable habitat patches increase, owls are more likely to attempt to nest in inter-patch habitats of poorer quality where their chances of survival are less than if nesting were to occur in suitable habitat (Warnock 1996).

It is possible that a minimum proportion of suitable habitat distributed throughout a region is necessary for the persistence of burrowing owl populations (Wellicome and Haug 1995, Fahrig 1997). In the absence of continued habitat loss or degradation, populations may also decline should the rate of local extinctions exceed the rate of recolonization (Lande 1987). If habitat loss in the past has created a level of habitat fragmentation that impedes the normal inter-colony movement of burrowing owls, extirpation could potentially exceed recolonization if stochastic events such as predation or inclement weather were to temporarily empty colonies (Temple 1986, Wellicome and Haug 1995). Since burrowing owl nesting pastures tend to remain occupied if they are closer to other occupied pastures, immigration and emigration are assumed to play a role in the persistence of colonies. Therefore, it is possible that owl populations could potentially decline in habitats that have not been modified as a result of poor reproduction or colony failure at distant sites (Wellicome and Haug 1995).

Chapter 3

Determining the Habitat Requirements of the Burrowing Owl in Eastern Prairie Canada Using Expert Opinion

3.1 Introduction

Although the more general habitat requirements of breeding burrowing owls have been well documented (Zarn 1974, Wedgwood 1976, Wedgwood 1978, Konrad and Gilmer 1984, Plumpton 1992, Haug et al 1993, Wellicome and Haug 1995), quantitative descriptions of burrowing owl habitat preferences in the eastern Canadian prairies are lacking from published literature. In the absence of such information, development of a habitat suitability index model for burrowing owls is substantially compromised as both the species' habitat suitability criteria and the habitat suitability index curves upon which the model depend are unavailable.

Habitat suitability index curves are one method of presenting a species' habitat suitability criteria and are necessary components of equation based habitat suitability index models (Crance 1987). Habitat suitability criteria or suitability index curves may be formulated using source data collected at locations where the species of concern has been observed, at locations frequently preferred by the species or may be based upon professional judgement using little or no empirical data (Bovee 1986). Either of the first two of these methods of data collection are preferable when formulating habitat suitability criteria and suitability index curves (Crance 1987). However, such information is rarely available and intensive field sampling required to obtain the desired data often cannot be undertaken given prevailing time and financial constraints (Schuster et al. 1985, Crance 1987) or insufficient population sizes from which to sample (Ratti and Garton 1996). Conversely, information gathered using procedures that emphasize speed and simplicity to satisfy the data requirements of such mathematical models often lack the scientific credibility necessary to defend results (Schuster et al. 1985). In such circumstances, an alternative approach is the development and interim use of both habitat suitability criteria and suitability index curves based upon expert opinion (Crance 1987).

There are numerous methods used to solicit expert opinion. However, research indicates that both the quality and quantity of information disseminated differ with each approach. Interactive group discussions conventionally used to amass expert opinion are typically known to succumb to the influence of a few individuals due to status, personality and other forces (Delbecq et al. 1975, Schuster et al. 1985). Unbiased approaches such as the Delphi Method and the Nominal Group Technique (NGT) are alternative methods of gathering expert opinion and are frequently employed by habitat suitability studies to effectively combine the knowledge and opinions of a group of experts (Schuster et al. 1985, Crance 1987, Mollohan et al. 1995, Terrell et al. 1995). Both the Delphi Method and NGT produce timely and credible information by systematically exploiting the opinions, ideas, experiences and knowledge of individuals without requiring on-site field measurements (Dalkey 1969, Delbecq et al. 1975, Schuster et al 1985, Crance 1987). Although each approach is fundamentally similar in the quantity and quality of information gathered, the two methodologies employ slightly different group processes by which to collect the desired data (Delbecq et al. 1975). Information available in published literature suggests that of the two methodologies, the Delphi Method is the approach most often employed for the purpose of developing expert-opinion based habitat suitability criteria and suitability index curves.

3.1.1 Delphi Method

The Delphi Method was developed in 1953 by the RAND Corporation (Dalkey and Helmer 1963) as a systematic tool for harnessing group knowledge (Dalkey 1969). The concept guiding the development of this information collection methodology was based upon the premise that opinions of experts are justifiable inputs in decision-making when absolute answers are unknown (Fusfeld and Foster 1971, Crance 1987). This innovative approach to data collection was first used by the U.S. Air Force for the purpose of obtaining greater consensus among experts in the absence of face-to-face discussion when addressing urgent defence problems (Zuboy 1981, Uhl 1983, Schuster et al. 1985). The Delphi Method was subsequently accepted and applied for corporate planning (Delbecq et al. 1975) and in the fields of renewable resources management, health care (Zuboy 1981), and education (Uhl 1983). More recently, the Delphi Method has been used to amass expert opinion with regards to habitat suitability assessment (Schuster et al. 1985, Holthausen et al. 1994, Mollohan et al. 1995) and develop suitability index curves (Crance 1987, Mollohan 1995).

Since expert-opinion-based data gathered through interactive discussions have been found to be biased and of limited accuracy (Dalkey 1969, Delbecq et al. 1975), the primary objective of the Delphi method is to obtain an unbiased convergence of opinion from a group of experts in the absence of face-to-face interaction (Delbecq et al. 1975, Uhl 1983, Schuster et al. 1985). A secondary objective of the Delphi Method is to amass more information than would otherwise be provided if only one individual was consulted (Dalkey 1969, Fusfeld and Foster 1971. Crance 1987). These objectives are often achieved by systematically soliciting and collating judgements on a topic using a series of sequential questionnaires interspersed with summarized information and feedback of opinions from earlier responses (Dalkey 1969, Delbecq et al. 1975, Uhl 1983).

The principle feature unique to the Delphi Method is that participants typically remain anonymous during the Delphi information gathering exercise (Dalkey 1969, Delbecq et al. 1975, Coughlan and Armour 1992). In doing so, participants provide information using written responses though the use of a series of questionnaires employed to clarify areas of agreement and disagreement (Dalkey 1969, Delbecq et al. 1975). Anonymity and isolation resulting from this approach function to alleviate conformity pressures (Delbecq et al. 1975) and therein promote group consensus (Schuster et al. 1985). Further improvements in consensus are produced by the iterative process where participants assess the issue at hand, justify their assessment and are given an opportunity to reassess their earlier position in light of information provided by other participants (Schuster et al. 1985).

As a result, it is believed that the Delphi Method has the ability to provide "quality information over a wide range of topics important to natural resources managers" (Schuster et al. 1985). Additional benefits resulting from this approach include the advantage of obtaining quality judgements from geographically removed experts who would otherwise be excluded from more traditional interactive decision-making events (Dalkey 1969, Delbecq et al. 1975).

3.1.1.1 Delphi Method Data Collection Procedure

Due to the wide ranging topics and complexities of information which the Delphi Method can be used to acquire, there is not one specific, dictated process for data collection that exists and is followed when using this methodology. Instead, the exact form assumed by the Delphi approach for information dissemination is influenced by time, available resources and associated costs (Delbecq et al. 1975, Crance 1987). Information regarding the decision-making process leading to the derivation of a protocol by which to apply the Delphi Method is absent from published literature.

Even though the specific process guiding the application of the Delphi Method differs with each study, the more fundamental procedures employed when applying this methodology remain somewhat constant. Typically, the Delphi Method is a series of questionnaires and feedback iterations (Dalkey 1969, Delbecq et al. 1975, Uhl 1983, Schuster et al. 1985) with each subsequent questionnaire building upon responses to the preceding questionnaire until a consensus is reached (Dalkey 1969, Delbecq et al. 1975, Crance 1987) (Figure 4). The number of iterations used by the Delphi Method is open-ended, but may be specified on the basis of a pre-determined level of consensus (Schuster et al. 1985).

The number of participants required to effectively employ the Delphi Method has not been determined (Crance 1987). Sample sizes are generally selected based upon the number of respondents required to constitute a representative pooling of the judgements for each target group and therein are flexible (Delbecq et al. 1975). For the purpose of gathering habitat suitability information, Crance (1987) indicates that participants should represent a diversity of knowledge regarding habitat use by the species of interest, although priority should be given to experts who are knowledgeable about habitat suitability of the species.

Once individuals have been selected to serve as experts in the data acquisition effort, the Delphi method is initiated with the development of a broad question or series of questions

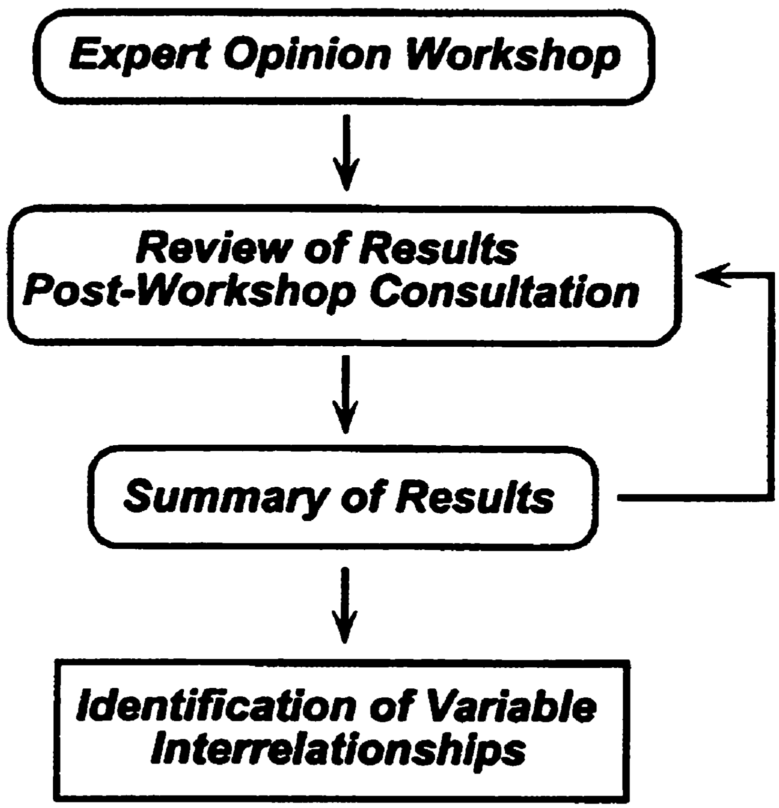

Figure 4. Typical procedure followed when using the Delphi Method for data acquisition.

for which the answer is the desired product of the data acquisition exercise (Delbecq et al. 1975, Coughlan and Armour 1992). Questions are incorporated into a questionnaire and participants are sent the first in the series of questionnaire iterations. Participants are requested to independently generate their ideas when responding to the questionnaire (Dalkey 1969, Delbecq et al. 1975), rank items to establish the preliminary priorities of habitat suitability criteria (Delbecq et al. 1975) and return questionnaires upon completion (Dalkey 1969, Delbecq et al. 1975, Crance 1987).

Completed questionnaires are analyzed and a summary of participant responses is used to develop a feedback report that is distributed with the second questionnaire (Dalkey 1969, Delbecq et al. 1975, Zuboy 1981, Uhl 1983, Crance 1987). There is not a standard format by which to provide participants with feedback (Schuster et al. 1985). Instead, Schuster et al. (1985) indicate that each feedback report must be tailored to the situation at hand.

When Delphi data acquisition efforts are directed toward the identification of habitat suitability criteria and SI curves, feedback reports typically include preliminary SI curves for each variable identified by participants as being important (Schuster et al. 1985, Crance 1987). Participant responses are summarized such that the medians of estimates provided by participants for each variable are used as coordinates in the generation of preliminary SI curves (Zuboy 1981, Crance 1987, Bovee 1992). However, preliminary SI curves resulting from the first round of questionnaire iterations may also be derived using both the lowest and highest estimates provided by participants for each variable (Zuboy 1981, Crance 1987, Bovee 1992). It is recommended that participants' comments pertinent to the curves also be included in the summary, although slight revisions or omissions may be required to preserve participant anonymity (Crance 1987). In addition, the feedback report highlights areas of participant agreement and disagreement and definitions are further clarified as required (Crance 1987, Coughlan and Armour 1992).

The questionnaire for the second round of iterations addresses the preliminary SI curves provided in the first feedback report (Crance 1987). Participants are encouraged to re-evaluate earlier responses in light of the summarized information and respond to the questionnaire by indicating agreement or disagreement with each preliminary SI curve (Dalkey 1969, Delbecq et al. 1975, Schuster et al. 1985, Crance 1987). Should an expert disagree with a preliminary SI curve, they are requested to provide their own version of the curve as well as its graphic coordinates, and provide comments, references and logic to support their version (Delbecq et al. 1975, Crance 1987). If a participant agrees with a preliminary SI curve, they are requested to provide additional comments to support this position (Delbecq et al. 1975, Crance 1987). In addition, participants are asked to independently vote on priority ideas included in the second questionnaire and once again return questionnaires upon completion (Dalkey 1969, Delbecq et al. 1975, Uhl 1983, Crance 1987). Responses to the second questionnaire are then assessed and summarized (Dalkey 1969, Delbecq et al. 1975, Uhl 1983, Crance 1987).

The Delphi data acquisition exercise is terminated when either a consensus or an acceptable level of agreement has been reached among participants (Dalkey 1969, Delbecq et al. 1975, Uhl 1983, Schuster et al. 1985, Crance 1987). However, Bovee (1992) indicates that the stability of the distribution of responses over successive rounds may be a more significant measure for a stopping criterion when applying the Delphi

Method, than the degree of convergence achieved. In the event that a suitable level of agreement is not reached upon completion of the second questionnaire or stability is not achieved, it is recommended that subsequent iterations be conducted (Dalkey 1969, Crance 1987, Bovee 1992).

3.1.1.2 Shortcomings of the Delphi Method

Although the Delphi Method is capable of providing quality expert-based information regardless of the topic, this approach to data acquisition does have its drawbacks. Since data are collected from participants in absentia, others are not present to stimulate and maintain participant motivation. As a result, both the quality of responses provided and the success of the exercise are heavily influenced by the interest, motivation, and commitment of participants (Delbecq et al, 1975, Coughlan and Armour 1992) as well as the quality of participants' written communication skills (Coughlan and Armour 1992).

Participant isolation combined with the anonymity required by the Delphi Method also creates interpretation difficulties among respondents as verbal clarification is not possible (Delbecq et al. 1975). Group priorities are determined simply by pooling and adding the votes of respondents such that conflicting or incompatible ideas are not addressed in feedback reports (Delbecq et al. 1975). Hence, conflicts are never discussed nor resolved and the accuracy of data may be compromised (Delbecq et al. 1975).

Finally, the calendar time required to obtain judgements from participants and complete multiple iterations is considerably longer than that required by NGT (Delbecq et al. 1975, Coughlan and Armour 1992). Although the time commitment required by participants is small in relation to NGT (Delbecq et al. 1975), the time necessary to formulate feedback reports, develop questionnaires and receive completed questionnaires may be lengthy.

3.2 Objectives of Data Acquisition

Since burrowing owls require distinctly different habitat types for nesting and foraging, data acquisition was designed to establish the needs of the species for each of these habitat types. Specific objectives of data collection were:

1. to determine the specific habitat requirements of burrowing owls breeding in southwestern Manitoba and southeastern Saskatchewan;
2. to identify which of the habitat requirements are critical to burrowing owl survival in southwestern Manitoba and southeastern Saskatchewan; and
3. to rank and assign weights to the critical habitat requirements of the species for use in the development of a habitat suitability index model.

3.3 Methods

In order to develop a Habitat Suitability Index model for burrowing owls in southwestern Manitoba and southeastern Saskatchewan, the habitat requirements of the species had to be identified. However, small burrowing owl populations in southwestern Manitoba and southeastern Saskatchewan were incapable of providing sample sizes large enough for the collection of empirical habitat suitability criteria. Furthermore, limited information specific to the species' quantitative breeding habitat requirements in the eastern Canadian prairies exists in published literature. Due to the absence of data collected from field studies and literature sources, it was determined that the collective judgement of species experts to effectively identify burrowing owl habitat suitability criteria and thus, the quantifiable habitat requirements of the species was the appropriate methodology to employ.

The opinions of burrowing owl experts from southwestern Manitoba and southeastern Saskatchewan were therefore solicited to provide the information required for the development of an HSI model for burrowing owls in the eastern Canadian prairies. In light of the amount of time required to conduct traditional Delphi Method data acquisition as well as the time constraints associated with expert availability, a variation of the Delphi Method was selected for the purpose of this study. The Delphi Method was modified from the original approach documented by Dalkey (1969) through the addition of a one-day, interactive workshop followed by a series of questionnaire iterations.

3.3.1 Workshop Process

To establish the nesting and foraging habitat needs of burrowing owls breeding in southwestern Manitoba and southeastern Saskatchewan, an HSI information dissemination workshop was held with burrowing owl experts familiar with the species' breeding ecology in the eastern Canadian prairies. Burrowing owi experts were selected to participate in the Delphi Method following participant selection procedures discussed by Crance (1987) and Coughlan and Armour (1992). Two or three individuals considered to be species experts in the area of concern were identified. One expert was called and interviewed during which time both the objectives of the proposed exercise and the need for SI curves were discussed and a general explanation of the Delphi Method was provided. The expert was asked if he/she would consider serving as an expert for the proposed Delphi exercise and whom they would consider to be highly knowledgeable in the area of habitat suitability for the species. The process was repeated until no new names of burrowing owl experts were suggested. Priority was given to those experts whose expertise focused in the geographic area of concern.

In total, eight people participated in the modified Delphi data acquisition exercise (Table 2). Data were collected using a one-day workshop divided into three distinct information gathering sessions. Sessions One and Two addressed the identification of burrowing owl nesting and foraging habitat requirements respectively. Habitat requirements identified during Sessions One and Two were used as the basis for the identification of critical habitat requirements for the species upon completion of Session Two. Session Three assigned priority to variables identified in sessions one and two by specifying the importance of each of the variables to the burrowing owl nest site selection process.

Table 2. Participants of the Burrowing Owl Habitat Suitability Index Workshop, their professional affiliations and the roles they played during the workshop.

Participant	Professional Affiliation	Role in Workshop
Tanys Uhmann	University of Manitoba, Natural Resources Institute	Workshop organizer and chairperson
Herb Goulden	Manitoba Habitat Heritage Corporation	Workshop facilitator
Dr. Richard Baydack	University of Manitoba, Natural Resources Institute	Workshop secretary and assistant facilitator
Troy Wellicome	University of Alberta, Department of Zoology	Saskatchewan burrowing owl expert
Dr. Paul James	Saskatchewan Environment and Resources Management	Saskatchewan burrowing owl expert
Kort Clayton	University of Saskatchewan, Department of Zoology	Saskatchewan burrowing owl expert
Dale Hjertaas	Saskatchewan Environment and Resources Management	Saskatchewan burrowing owl expert
Ken De Smet	Manitoba Department of Conservation, Wildlife Branch	Manitoba burrowing owl expert

A literature review of burrowing owl habitat requirements and habitat modeling approaches provided the foundation for questions guiding the information generation phase of the workshop. During this phase, participants were asked to describe the habitat characteristics of land commonly inhabited by breeding burrowing owls in southwestern Manitoba and southeastern Saskatchewan. Participants were requested to provide information by drawing upon personal research, previously reviewed literature or supposition while considering their ideas in relation to the geographic location of concern. Habitat characteristics identified during this process were limited to those typically found on lands producing large numbers of successful burrowing owl broods.

The latter half of the workshop focused upon information synthesis. Using the habitat components identified during the information generation phase of the workshop, participants identified the habitat requirements most critical to burrowing owl survival. In an effort to alleviate biases, participants used secret ballots to individually identify ten habitat requirements they believed were most critical to burrowing owls in Manitoba and Saskatchewan. Votes were tabulated and recorded on a flip chart. Participants collectively discussed the results of the vote and altered the list as required to achieve a consensus. Upon identification of the critical habitat requirements of the species, participants were provided the opportunity, in Session Three, to develop suitability indices (SIs) for each of the critical habitat requirements. Individually and as a group, participants also described how SIs could be considered to collectively produce an estimate of habitat suitability. Throughout the process, collaborative problem solving emphasizing group ownership, and a continued focus on the objectives of the workshop were employed.

Following the identification of burrowing owl critical habitat requirements and the development of SI curves, weights were assigned to describe the interrelationships functioning between each of the critical habitat components. The weighting process was conducted using secret ballots wherein participants individually weighted the relationship of each variable in relation to all other remaining variables. A maximum of 10 points was available to be assigned to each variable. The greater the number of points assigned, the greater the importance of the variable in determining habitat suitability. Results were tabulated, recorded on a flip chart, and displayed for the purpose of discussion and consensus building. Participants collectively reviewed the results and made changes where necessary to more accurately reflect group opinions.

3.3.2 Delphi Component

Detailed results of the workshop were summarized and forwarded to workshop participants. Participants were asked to provide clarification where necessary and indicate agreement or disagreement with workshop results. In the event that participants no longer agreed with the results of the workshop, experts were instructed to provide reasons for their discontent and present alternative suggestions. Upon completion, participants were requested to return their comments and revisions to the workshop chairperson.

Efforts to maintain consensus among workshop participants were pursued. All comments and suggestions received from the first feedback report were summarized and a second feedback report was prepared and forwarded to workshop participants for their comment and approval. Consultation with burrowing owl experts ceased following receipt of participant responses to the second feedback report.

To address divergent opinions regarding habitat suitability and the critical habitat requirements of breeding burrowing owl populations, it was assumed that responses to the second feedback report addressed all participant comments and were therefore most important to the description of burrowing owl habitat suitability. Information provided in responses to the second feedback report was pooled and analyzed. Suitability indices were modified to reflect the mean of empirical measurements suggested by participants corresponding to each level of suitability until the entire range of habitat suitability was determined. SI curves generated at the workshop were further modified in accordance to the revised habitat suitability index values resulting from participant comments to feedback reports. Additional information provided by participant responses to questionnaire iterations was summarized and incorporated into a final summary of the results of the Delphi data collection exercise.

3.4 Results and Discussion

Five burrowing owl experts with experience researching the species' breeding habitat characteristics in southwestern Manitoba and southeastern Saskatchewan participated in the Delphi HSI data acquisition workshop (Table 2). During Sessions One and Two, participants identified a total of 19 habitat components required by burrowing owls in southwestern Manitoba and southeastern Saskatchewan. Of those components identified, 10 were determined to be critical in the identification of burrowing owl habitat suitability (Table 3). Nine of the critical habitat components were specific to the habitat proximate to nest burrows while the remaining habitat component addressed habitat fragmentation at a considerably larger landscape scale than that considered by the other nine critical habitat components.

Table 3. Habitat suitability components required by breeding burrowing owls in southwestern Manitoba and southeastern Saskatchewan and the critical habitat requirements of the species.

Habitat Suitability Components	Critical Habitat Requirements
Burrow type	Burrow availability
Forage habitat type	Availability of forage
Topography	Vegetation cover at nest
Openness of nest site	Proximity of forage
Pasture size	Fragmentation
Burrow size	Soil
Slope of burrow entrance	Openness of nest site
Height of vegetation cover at the nest	Topography
Soil type	Size of nest pasture
Burrow density	Perch
Proximity of forage	
Fragmentation	
Semi-elevated perches	
Soil stoniness	
Type of vegetation at the nest	
Prey accessibility	
Prey density	
Abundance of prey habitat	
Burrowing mammal density	

Post-workshop questionnaires addressing results of the Delphi HSI data acquisition workshop resulted in responses from 4 out of 5 participants. Participant responses lead to the modification of the critical habitat components originally identified by the workshop. SI values and their associated SI curves as well as the ranks and weights of variables were also modified in response to post-workshop consultations with participants. As a result, subsequent modifications to some habitat components occurred while others remained virtually unchanged.

3.4.1 Identification of the Critical Habitat Requirements of Breeding Burrowing Owls

3.4.1.1 Nest Burrows

Three habitat components were identified as being potentially important in the classification of suitable burrowing owl nest burrows.

Burrow Availability

Workshop participants determined that an abundance of Richardson's ground squirrels and their associated burrows was beneficial to burrowing owls as the probability of burrowing owl depredation is reduced in response to the availability of alternate prey. Burrowing owl experts also indicated that a minimum burrow density of 2 holes/ha was required for the species to use an area for nesting purposes. Habitat suitability was therefore determined to be dependent upon the suitability index described below (Table 4).

Table 4. Workshop generated burrowing owl burrow density suitability index.

Holes/ha	SI
2	0.1
20	0.5
50	0.9
100	1.0

Consultations with participants following the workshop resulted in a modification of the lower portion of the SI curve. Participants unanimously agreed that suitable land having an absence of burrows would not be considered for nesting by the species and a suitability index value of zero was assigned. Respondents further indicated that burrowing owls have been found to nest on lands possessing an average of 1 burrow/ha. Three respondents assigned an SI value of 0.1 to land with an average of 1burrow/ha and increased the SI value for habitat having 2 burrows/ha to 0.2. The suitability of burrow density was therefore altered (Table 5). To achieve a linear relationship, a logarithmic curve was selected to graphically represent this SI.

Table 5. Revised burrowing owl burrow density suitability index.

Burrows/ha	SI
0	0.0
1	0.1
2	0.2
20	0.5
50	0.5
100	1.0

Burrow Type

During the workshop, participants identified the types of burrows that produced the most successful burrowing owl nests and SI values were assigned to each burrow type (Table 6).

Table 6. Workshop generated burrow type suitability index for burrowing owls.

Burrow Type	SI
Last year's burrowing owl burrow	1.0
Old burrowing owl burrow	1.0
Artificial burrow	1.0
Badger burrow	0.9
Red fox burrow	0.7
Richardson's ground squirrel burrow	0.5

Participants noted that although fresh digging was believed to aid owls in identifying the location of a nest burrow, it was not critical to burrow selection. Workshop participants also concluded that burrow design and slope were generally consistent in each burrow type preferred by burrowing owls and therefore the inclusion of these factors was determined to be extraneous to the HSI model. Furthermore, since owls typically do not reject burrows that are located at inappropriate elevations, the experts concluded that burrow elevation need not be considered by the HSI.

Hole Diameter at Burrow Entrance

Participants agreed that burrowing owls nest in burrows requiring the least modification. The suitability of burrow entrance diameters was established to reflect this and is described in Table 7.

Table 7. Workshop generated suitability index of burrow entrance diameter for burrowing owls.

Diameter (cm)	SI
< 5	0.0
7.5	0.5
15	1.0

When burrow diameter was considered in relation to burrow type during post-workshop consultations, all respondents indicated that SI values determined at the workshop required revisions. As a result, burrow diameter SI values were modified to accommodate suggested changes (Table 8).

Table 8. Revised suitability index of burrow entrance diameter for burrowing owls.

Diameter (cm)	SI
<7.5	0.0
7.5	0.1
14	0.5
20	1.0
30	1.0
35	0.5
>40	0.0

3.4.1.2 Vegetation at Nest Site

Participants assumed that burrowing owls select nest sites based upon the habitat cues present when the species explores an area for suitable nesting conditions. Cues provided by vegetation at potential nest sites were believed to function highly in the habitat selection process. As burrowing owls typically select nest sites upon return from wintering grounds, workshop participants determined that the HSI model should consider only those characteristics specific to the vegetative condition present in late March or early April. Vegetation characteristics identified as potential cues in the habitat selection process included both vegetation height and density at the nest, land use type and the number of trees present within the nesting area.

Vegetation Height

Burrowing owls prefer to nest in grazed pastures, areas possessing regularly mowed or burned vegetation and other areas having short, sparse grass. Workshop participants indicated that in addition to the aforementioned habitat conditions, bare ground and short forbs provide suitable nesting habitat for the species. Participants also indicated that burrowing owls do not select nest areas based upon a presence of either native or tame grasses.

Suitable nesting conditions were determined to occur in areas where vegetation is maintained at a height of 15cm or less, although sparse vegetation may be taller and still be suitable. A vegetation height of 5cm was determined to produce optimal habitat conditions for the species regardless of vegetation density. Using this information and personal experience, workshop participants developed a suitability index for vegetation height (Table 9).

Table 9. Workshop generated burrowing owl vegetation height suitability index.

Height (cm)	SI
≤ 5	1.0
15	0.5
30	0.0

Following the workshop, three participants suggested that revisions be made to the SI curve, while the other respondent suggested that vegetation height was not an appropriate indicator of habitat suitability. Of the participants who maintained that vegetation height was important in the habitat selection process, two suggested that optimal vegetation height be extended to 10cm, while the third participant indicated that 5cm was optimal. Two of the three respondents also suggested that the suitability index approach zero at 50cm, while the third indicated that the zero point of the SI curve should be maintained at 30cm. As a result, the vegetation height suitability index was modified to reflect participant suggestions (Table 10). Where possible, the mean of suitability index values provided by respondents was used to modify the suitability index.

Table 10. Revised burrowing owl vegetation height suitability index.

Height (cm)	SI
≤ 5	1.0
10	0.8
15	0.5
30	0.1
≥50	0.0

Vegetation Density

During the workshop, vegetation density was determined to be a significant factor in the assessment of nesting habitat suitability. An inability of participants to provide qualitative vegetation densities for SI development resulted in the collective decision to substitute similar values from a Daubenmire vegetation density study conducted by Dr. Paul James, a workshop participant (James pers. com.). This study identified vegetation density characteristics typically found at occupied burrowing owl nest sites in southeastern Saskatchewan and determined optimal vegetation density was a unique combination of vegetation types and proportions (Table 11).

The aforementioned vegetation densities were required to occur collectively and in the amounts specified for a nest site to be identified as optimal habitat (SI = 1.0). Any vegetative condition that differed was determined to be less than optimal and a linear relationship was assumed.

Table 11. Vegetation density characteristics describing optimum burrowing owl habitat suitability (James pers. com.).

Vegetation Type	Daubenmire Value	Percentage of Ground Cover
Bare ground	3.656	>50%
Grass	2.942	~25%
Forbs	1.448	15%
Shrubs	1.084	10%

Post-workshop consultations provided participants with an opportunity to view the results of Dr. James's study. Problems associated with participant interpretation of Daubenmire vegetation density values combined with an inability to incorporate the Daubenmire results into the HSI model resulted in the decision to omit the Daubenmire vegetation density component from the HSI. Subsequent participant consultations revealed that 2 respondents believed vegetation density was a necessary component in the identification of habitat suitability. However, a lack of suitable alternative density measurements rendered it impossible to generate SI values for this component and thus, the incorporation of vegetation density into the HSI was not possible.

Land Use Type

Workshop participants identified the suitability of land use types commonly available to nesting burrowing owls in southwestern Manitoba and southeastern Saskatchewan and assigned corresponding SI values (Table 12).

Table 12. Workshop generated land use type suitability index for burrowing owl nesting habitat.

Land Use Type	SI
Grazed Pastureland	1.0
Mowed Lawns (cemeteries, golf courses)	0.75
Hayland	0.5
Roadsides	0.3
Cropped Land	0.1
Idle Grasslands	0.1
Cultivated Land	0.1

In post-workshop consultations participants were requested to provide vegetation heights corresponding to each land use category. Three out of four respondents indicated that land use types could not be effectively expressed by vegetation height. As a result, land use type was determined to be an inappropriate variable for use directly within the HSI model. Instead, it was suggested that land use types and their associated SI values be employed prior to HSI application for the purpose of guiding wildlife managers in the identification of lands suitable for habitat assessment.

Openness of site

The risk of burrowing owl depredation by aerial predators such as great horned owls and red tailed hawks lead to the identification of openness as a component of nest habitat suitability. Workshop participants described nest site openness as a function of the number of trees occurring within 100m of the nest burrow while trees were defined as vegetation equal to or greater than 3 meters in height. A bluff was also defined as a high density of trees covering an area of 50-100m^2. Habitat suitability was determined and a suitability index curve was developed (Table 13).

Table 13. Workshop generated openness suitability index for burrowing owls.

# Trees	SI
0 trees (open)	1.0
Isolated trees	0.3
bluff	0.1
forest	0.0

In post-workshop consultations, participants revised the suitability index of openness (Table 14).

Table 14. Revised openness suitability index for burrowing owls.

# Trees	SI
0	1.0
1-3	0.9
7	0.5
30	0.05
>40	0.0

3.4.1.3 Soil

Since research indicates that burrowing owls prefer to nest in lacustrine soils, workshop participants assigned SI values to a variety of lacustrine soil conditions. Participants also determined that soil stoniness influenced the suitability of burrowing owl nesting conditions. Suitability index values were generated to describe the suitability of both soil type (Table 15) and soil stoniness (Table 16), with the soil stoniness SI assuming a linear relationship.

Table 15. Workshop generated soil type suitability index for nesting burrowing owls.

Soil Type	SI
Clay/Loam	1.0
Sandy Loam	0.75
Sandy	0.4
Bedrock	0.0

Table 16. Workshop generated percent of soil stoniness suitability index for nesting burrowing owls.

% Stoniness	SI
0	1.0
100	0.0

In post-workshop consultations, three respondents suggested revisions to the above SIs.

Two respondents indicated that soil conditions were more relevant to the creation of burrows by burrowing mammals than they were in the nest site selection process and thus were reflected by burrow availability. As a result, it was believed that the inclusion of soil type and stoniness within the HSI model would be redundant. A third respondent indicated that although soil type and soil stoniness were equally worthy of inclusion within the HSI model, soil characteristics were of minimal importance in identification of nest habitat suitability.

Since three out of four respondents indicated that soil characteristics provided limited cues to burrowing owls in the identification of nesting habitat suitability, the soil component was determined to be extraneous to the burrowing owl HSI model.

3.4.1.4 Topography

Workshop participants described the topographic suitability of land located within a 50m radius of a nest burrow (Table 17).

Table 17. Workshop generated topography suitability index for burrowing owl nesting habitat.

Topography	SI
Cliffs	0.0
Heavy rolling, coulee edges	0.1
Flat	0.9
Slightly rolling	1.0

Subsequent correspondence with participants resulted in few revisions to these results. Two of the four respondents concurred with SI values determined during the workshop while two other respondents suggested modifications to the SI value describing flat land. The mean of the suggested revisions resulted in an SI value of 0.9 and the SI values resulting from the workshop were retained.

3.4.1.5 Semi-elevated Perches

Workshop discussions on nest site suitability addressed the importance perches play in both burrowing owl thermoregulation and predator/prey detection. The maximum height of a suitable perch was determined to be 3m and perch suitability was described (Table 18).

Table 18. Workshop generated perch substrate suitability index for nesting burrowing owls.

Perch	SI
Post or fence (<3m)	1.0
Mound or rock	0.5
No perch (flat)	0.1

During post-workshop consultations, respondents unanimously agreed that perch proximity to the nest burrow was important in the determination of nest suitability and suggested that additional perch related factors other than simply perch availability be considered for inclusion in the HSI. Respondents also collectively determined that perch height was a more appropriate indicator of perch suitability rather than perch substrate as was earlier suggested (Table 19).

Table 19. Post workshop generated perch height suitability index for nesting burrowing owls.

Perch Height (m)	SI
0.0	0.1
0.5	0.5
1.0	1.0
1.5	1.0
2.0	0.5
3.0	0.0

Three participants further suggested that perch availability be incorporated into the HSI using a two-pronged approach that addressed both perch height and perch proximity to the nest burrow. However, a consensus could not be reached in the identification of a comprehensive indicator of perch suitability and its interrelationship with nest site suitability. As a result, decisions regarding perch suitability were suspended until such time that the development of the HSI model required that a decision be made.

3.4.1.6 Size of Nesting Pasture

Participants determined that the suitability of nesting habitat was dependent upon the amount of continuous, unfragmented grassland surrounding occupied nest burrows (Table 20).

Table 20. Workshop generated nest pasture size suitability index for burrowing owls.

Habitat Area	SI
≥ 40 acres	1.00
20 acres	0.75
1 acre	0.50
0.0 acres	0.00

Three of the four participants responding to post-workshop consultations maintained agreement with the above suitability index developed during the workshop. The fourth respondent indicated that suitability should decrease when the area of nesting habitat was greater than 40 acres. However, since the majority of respondents concurred with decisions agreed upon at the workshop, the SI describing nest pasture size suitability was not modified.

3.4.1.7 Fragmentation

Workshop participants determined that the suitability of nesting habitat was influenced by the degree of fragmentation occurring within the landscape. For the purpose of this study, participants collectively defined fragmentation as the distance between an occupied nesting area and the nearest adjacent suitable nesting habitat. Distances between suitable nesting habitats were assigned suitability index values (Table 21).

Table 21. Workshop generated habitat fragmentation suitability index for nesting burrowing owls.

Distance to Nearest Nest Habitat (km)	SI
< 1	1.0
≥ 10	0.1

Of the four participants who responded to post-workshop consultations, only three provided comment on the fragmentation variable. Two participants indicated agreement with the workshop generated SI values while the other participant suggested that the SI value describing the suitability of nesting habitats separated by a distance of 10km or more be reduced from a score of 0.1 to 0.0. Two of the three respondents also suggested that an asymptotic relationship best described the fragmentation SI curve while the third respondent indicated that a linear fragmentation SI curve was more appropriate.

3.4.1.8 Internest Distance

The importance of internest distance in the determination of nest site suitability was discussed during the workshop, but was not identified as a critical habitat requirement of breeding burrowing owls. During post-workshop consultations, respondents again indicated that internest distance was an important factor in the identification of nest site suitability and unanimously agreed that internest distance should be addressed in the HSI model. Three of the four respondents indicated that a bell-shaped relationship described internest distance suitability and respondents collectively assigned values to formulate the positive slope of the SI curve as well as the point at which the optimum internest distance was reached. Respondents were unable to reach a consensus on the SI values comprising the negative portion of the internest distance SI curve.

The inability of respondents to collectively agree upon values comprising the negative portion of the SI curve resulted in the development of SI values in the absence of continued expert opinion solicitation. The suitability index was generated from the mean values provided by respondents (Table 22).

Table 22. Burrowing owl internest distance suitability index.

Internest Distance (m)	SI
≤10	0.0
25	0.1
50	0.5
100	1.0
1000	1.0

3.4.1.9 Foraging Habitat

Workshop participants concurred that prey availability is a critical requirement in the maintenance of burrowing owl populations in prairie Canada. Since mice and voles comprise the majority of food consumed by the species during the early part of the breeding season, it was determined that the HSI forage component would focus upon the mouse and vole prey sources available to burrowing owls. Workshop participants indicated that burrowing owl consumption of microtines is directly linked to the availability of prey and hence, the availability of suitable *Microtus* habitat. As a result, participants determined that the forage component of the burrowing owl HSI model would be best served by considering both the availability of suitable *Microtus* habitat and the proximity of such habitat to suitable burrowing owl nest areas.

Suitable forage habitat

To determine the suitability of forage habitat with respect to the proximity of burrowing owl nest sites to *Microtus* habitat, workshop participants identified the characteristics commonly exhibited by *Microtus* habitat by referring to past experiences in which burrowing owls had been observed hunting for and/or foraging on small mammal populations. Participants determined that small mammal foraging by burrowing owls typically occurred in croplands, alfalfa and uncropped grass habitats. The average height of vegetation in which burrowing owls successfully hunted mice and voles was determined to range from 30-50cm. Participants indicated that vegetation taller than 50cm in height was believed to impeded burrowing owl detectability of microtines and vegetation >50cm in height was allocated an SI value less than 1.0.

During post-workshop consultations three respondents proposed revisions to the aforementioned vegetation heights in an attempt to more accurately reflect the suitability of vegetation height for microtine populations. Of these three respondents, one further suggested that a multifaceted approach be used to describe the forage habitat suitability component. The suggested approach considered the influence vegetation height exerts upon both the density of *Microtus* populations and burrowing owl detectability of microtines as a means to describe the suitability of vegetation height for burrowing owl prey sources.

Subsequent consultations informed participants of the suggested revisions and asked participants to provide comments. Three respondents concurred with the suggested use of a multifaceted approach to describe forage suitability while the fourth respondent disagreed. The fourth respondent further suggested that vegetation density rather than vegetation height be used as to indicate burrowing owl forage habitat suitability. In light of the discrepancies and the inability of respondents to reach a consensus as to an appropriate method of describing forage habitat suitability for burrowing owls, the fourth respondent suggested that the forage habitat component be excluded from the HSI model and that a prey density component be included instead.

Despite general agreement among three out of four respondents, a consensus was not reached on a suitability index that appropriately described the suitability of burrowing owl forage habitat. As a result, a forage habitat SI was developed in the absence of continued expert opinion solicitation. Using the SI values provided by burrowing owl experts over the course of the workshop and post-workshop consultations, mean SI values were calculated and the suitability of burrowing owl forage habitat was described (Table 23).

Table 23. Burrowing owl forage vegetation height suitability index.

Vegetation Height (cm)	SI
0	0.0
25	0.6
30	1.0
35	1.0
40	0.8
45	0.7
≥ 65	0.0

Availability of Prey

Workshop participants determined that both the abundance of prey and burrowing owl accessibility to that prey directly influenced the availability of prey for burrowing owls. Accessibility to prey was determined to be a function of the density and height of vegetation and was illustrated mathematically as:

[2]

Availability of Prey = *f*(abundance, accessibility)
when accessibility = *f*(density of forage material, height of grass, structure of forage material)}

Given the above information, workshop participants described the suitability associated with burrowing owl prey availability by assigning SI values to the land use categories most often used by burrowing owls for food acquisition (Table 24).

Table 24. Workshop generated land use suitability index for foraging burrowing owls.

Land Use Type	SI
Wet meadow	1.0
Roadside	1.0
Idle	0.8
Lightly grazed pasture	0.6
Hayland	0.6
Cropland	0.5
Moderately grazed pasture	0.4
Fallow (including stubble and bare soil)	0.4
Heavily grazed pasture	0.2
Lawns and cemeteries	0.1

Participants maintained agreement with the above SI throughout post-workshop consultations and the SI was not modified.

Proximity of the nest site to suitable prey habitat

Workshop participants developed the forage proximity SI by drawing upon participants' own field experiences as well as research conducted by Haug (1985). The suitability associated with forage habitat proximity to burrowing owl nest sites was described by participants as having a linear relationship (Table 25).

Table 25. Workshop generated forage habitat proximity suitability index for burrowing owls.

Distance	SI
2700m	0.0
0-100m	1.0

Post-workshop consultations revealed that three participants disagreed with workshop decisions regarding the suitability of forage habitat proximity. Two of these respondents indicated that the forage habitat proximity SI failed to consider that the presence of small mammal forage habitat proximal to a nest burrow could potentially increase the presence of burrowing owl predators and therefore had the potential to reduce the level of site suitability. Since Haug (1985) found that burrowing owls primarily foraged in habitat located between 50m and 600m from the nest burrow, the two respondents suggested that the suitability of forage habitat proximity address habitat suitability at distances greater than 50m from the nest site. Both respondents indicated that forage proximity suitability should be determined based upon the percentage of suitable forage habitat located between 50m and the maximum distance at which the species will forage from the nest.

Although the two respondents suggested the same approach to assessing forage habitat proximity, the respondents were unable to concur upon the maximum distance at which forage habitat proximity should be assessed. Since Haug (1985) determined that 95% of burrowing owl foraging activity occurred within 600m from the nest burrow, one respondent suggested that the maximum distance from the nest burrow at which forage habitat should be assessed was 600m. The other respondent referred to personal experience and suggested that a distance of 1000m was more appropriate than the aforementioned 600m distance.

The third respondent who expressed a lack of agreement with decisions made during the workshop with regard to the suitability of forage habitat proximity suggested that the forage habitat component in question be omitted completely from the HSI model. Reasons for this were cited as being a response to the varied diet of burrowing owls and the limited understanding researchers have of burrowing owl foraging and burrowing owl prey responses to changes in habitat.

Despite attempts made during post-workshop consultations, a consensus was not reached among participants on a suitable approach to assessing habitat suitability with regard to forage habitat proximity. As a result, decisions regarding the specifics of the habitat component were left to the discretion of the researcher. Similarly, respondents did not agree upon a methodology to assess forage habitat suitability and the development of such an approach was conducted in the absence of continued expert opinion solicitation.

3.4.2 Identification of Variable Priority in The Nest Site Selection Process

Workshop participants assigned priorities and weights to the critical habitat components identified during the workshop (Table 26). Upon completion of the post-workshop consultations, respondents revised variable weights and priorities (Table 27).

Table 26. Priorities and weights workshop participants assigned to critical habitat components.

Variable	No. of votes	Priority	Weight
Burrow availability	9	1	10/10
Availability of forage	11	2	10/10
Vegetation cover at nest	12	3	9/10
Proximity of forage	16	4	8/10
Fragmentation	35	5	7/10
Soil	23	6	4/10
Openness of site	25	7	6/10
Topography	35	8	2/10
Size of nest pasture	36	9	4/10
Perch	40	10	1/10

Table 27. Revised critical habitat component weights and priorities.

Variable	Priority	Weight
Burrow availability	1	10/10
Availability of forage	6	9/10
Vegetation cover at nest	3	8/10
Proximity of forage	2	9/10
Fragmentation	5	7/10
Soil	-	-
Openness of site	4	8/10
Topography	9	2/10
Size of nest pasture	8	4/10
Perch	10	2/10
Internest Distance	7	5/10

Over the duration of the Delphi data acquisition exercise, the 10 critical burrowing owl habitat requirements originally identified during the workshop were altered only slightly. Participants unanimously agreed that the initial identification of soil as a critical habitat component was redundant since the influences of soil characteristics upon burrowing owl habitat suitability were inherently addressed by burrow availability. In addition, the initial decision by participants to exclude internest distance from the list of critical habitat requirements was reversed during post-workshop consultations.

Although the critical habitat requirements identified by participants remained somewhat constant throughout the Delphi data collection exercise, the priorities and weights assigned to critical habitat variables differed considerably over the course of data acquisition. Of the priorities assigned to critical habitat components, only three habitat variables maintained the original level of priority allocated during the workshop. Burrow availability, vegetation cover at the nest, and fragmentation were continually ranked by participants as having priorities of 1, 3 and 5 respectively. In contrast, four critical habitat variables received the same weights over the course of the Delphi data acquisition exercise. Burrow availability, fragmentation, nest pasture size, and topography were weighted at 10/10, 7/10, 4/10 and 2/10 respectively throughout the duration of data collection. As a result, burrow availability and fragmentation were the only critical habitat components that received the same priorities and weights throughout the entire Delphi data collection process.

Chapter 4

The Development, Verification and Validation of a Habitat Suitability Index Model for Burrowing Owls in the Eastern Canadian Prairies

"A model is not, ultimately concerned with numbers. The numbers are only the vehicle for the logic." (Starfield & Bleloch 1986)

4.1 Introduction

This chapter addresses the development, verification, and validation of HSI models. In it a literature review is provided. In addition, model development objectives are discussed, and the methods for model construction, verification and validation are detailed. The final section of Chapter 4 addresses the results of model construction, verification and validation and a discussion of these results is included. A summary of the study, its conclusions, and recommendations follow in Chapter 5.

4.2 Literature Review

Many tools have been developed for making informed decisions in the area of natural resources management. One such management tool used today is systems analysis or modeling. Defined as "formal expressions of the essential elements of a problem in either physical or mathematical terms" (Jeffers 1978), models are simplifications of the systems they depict (Schamberger & O'Neil 1986). The strength of modeling therefore lies in its ability to provide a symbolic logic that is capable of expressing complex ideas and relationships while retaining a simplicity of expression (Jeffers 1978). Since the most useful models mimic reality with sufficient precision to serve a broad spectrum of decisions and decision-makers (Jeffers 1978), modeling has become an integral component of the resource management decision-making process.

The synthesis of ecological models in particular, has enabled predictions to be made with respect to the effects of changes in resource management (Jeffers 1978) and provides a framework around which qualitative habitat information may be structured to facilitate decision-making (Schamberger & O'Neil 1986). Essentially, ecological modeling provides a mechanism for gaining a better appreciation of habitat impacts and how they influence flora and fauna through space and time (Kearns 1999).

Within the context of ecological modeling, wildlife-habitat relationship models describe relationships of habitat change (Anderson & Gutzwiller 1996). They can assume a wide variety of types and complexities and can focus on either multiple or single species (Morrison et al. 1998). Such models generally provide a framework around which qualitative habitat information can be structured for decision-making purposes by formulating both qualitative and quantitative relationships into testable hypotheses (Schamberger and O'Neil 1986). Morrison et al. (1998) discuss numerous single-species wildlife-habitat models have been developed (Table 28). Of these, habitat suitability index (HSI) models are the models most frequently selected for the purpose of evaluating habitat quality for wildlife species (O'Neil et al. 1988, Brooks 1997, Morrison et al. 1998).

HSI models are intended to quantify habitat quality (Schamberger and O'Neil 1986) by examining habitat in relation to the environmental factors deemed to most influence the presence, distribution or abundance of a wildlife species or group of species (Anderson & Gutzwiller 1996, Morrison et al. 1998). The value of such models lies in providing resource managers with a repeatable assessment procedure (Morrison et al. 1998) that is simple, can be applied in a timely manner with minimum cost and provides easily understandable outputs (Schamberger and O'Neil 1986). In doing so, HSI models allow for the comparison of environmental conditions when land use or habitat conditions are expected to change (Schamberger & O'Neil 1986, Morrison et al., 1998). The simplicity and wide-ranging applicability of HSI modeling have made these models one of the most popular approaches to modeling habitat conditions currently available (Brooks 1997, Morrison et al. 1998).

4.2.1 Habitat Suitability Index Modeling

The U.S. Fish and Wildlife Service originally developed habitat suitability index models in the 1970's in response to the U.S. National Environmental Protection Act (NEPA). NEPA sought to reverse natural resource exploitation and in doing so, established Habitat Evaluation Procedures (HEP) as a means to conduct environmental assessments for the purpose of assessing damages to the environment or losses to future generations (U.S. Fish and Wildlife Service 1980). HEP attempted to examine and assess the viability of entire ecosystems based upon the ability of habitats to meet the needs of each species within the ecosystem being examined. As a result, HEP formed the basis of HSI modeling and dictates the methods used to produce HSI models today (U.S. Fish and

Table 28. A comparison of various single species wildlife habitat models.

Model Type	Data Type	Hindcasting/ Forecasting	What Model Examines	Model Goal	Model Approach
Correlation	Empirical	Hindcasting	• Relationship between two sets of variables	• To display the degree to which species parameters are explained by environmental parameters	• Models relationships between wildlife species and environmental variables
Habitat Preference	Empirical	Hindcasting	• Selection and preference for food and habitats	• To identify adaptive advantages of particular behaviors	• Models animal behaviour to understand species-habitat relationships
Multivariate Statistical	Empirical	Hindcasting	• Patterns in data	• To identify combinations of environmental parameters that account for observed variation in distribution and abundance of a species	• Models relationships between wildlife species and environmental variables
Life History	Empirical/Theoretical	Hindcasting	• Evolution of behavioral and phenotypic traits	• To aid understanding of the ecological roles of species, species groups and the relations between body size, food needs and resource levels	• Models animal behaviour to understand species-habitat relationships
Optimal Foraging	Empirical/Theoretical	Hindcasting	• Foraging requirements in relation to the body structure of a species	• To interpret species behaviour as it relates to habitat use	• Models animal behaviour to understand species-habitat relationships
Habitat Capability	Empirical/Theoretical	Forecasting	• Species response to a combination of environmental parameters found within its habitat	• To provide an estimate of the total area within which resources for a species can be found OR rank a given area for the relative capability of supporting a species given a few key environmental factors	• Models relationships between wildlife species and environmental variables
Habitat Effectiveness	Empirical/Theoretical	Forecasting	• Species response to a combination of environmental parameters found within its habitat	• To rank resources in an area according to the degree to which maximum use or carrying capacity can be met	• Models relationships between wildlife species and environmental variables
Habitat Suitability Index	Empirical/Theoretical	Forecasting	• Species response to a combination of environmental parameters found within its habitat	• To represent, in a simple and understandable form, the major factors thought to influence the occurrence and abundance of a wildlife species	• Models relationships between wildlife species and environmental variables

Wildlife Service 1980).

As wildlife populations depend upon the habitats in which they live to provide the components necessary for their survival, habitat suitability index modeling is driven by the premise that wildlife requires habitat to exist. Should a habitat become modified or marginalized in any way, the suitability of that habitat to the wildlife that depend upon it also becomes impacted.

Habitat suitability index models are constrained to the basic habitat attributes believed to be most important to both the wildlife species and specific planning or management needs (Schamberger and O'Neil 1986). To determine habitat suitability, HSI models assess the physical and biological attributes of habitat for a particular species or group of species (Berry 1986) by correlating the species' optimum habitat condition with the habitat features available within a defined region (U.S. Fish and Wildlife Service 1981). In doing so, HSI models indicate the ability of a site to meet the requirements of a specific species or group of species.

The development of an HSI model involves prioritizing the important life requirements or life requisites of a species into its most basic components (Van Horne and Weins 1991). Life requisites are translated into a series of variables that describe suitable habitat. An HSI model is then formulated by combining these variables in such a manner as to depict optimal species-habitat suitability (U.S. Fish and Wildlife Service 1981). Each variable and the resulting HSI values are scaled using an index ranging from 0 to 1 where 0.0 represents no habitat suitability and 1.0 represents optimal suitability for the species in question (U.S. Fish and Wildlife Service 1981). The overall HSI value is assumed to depict the species' response to the habitat in question by combining values that represent the suitability of each environmental parameter required for the survival of the species in question (Morrison et al. 1998).

The U.S. Fish and Wildlife Service (1981) based the concept of HSI modeling on the assumption that a positive relationship constantly links habitat suitability and therein habitat optimality with carrying capacity. Early HSI models supported this assumption and typically used carrying capacity to define habitat optimality and thus derive suitability index values (Hobbs and Hanley 1990). In the absence of direct measures of carrying capacity, more recent habitat evaluation models have begun to rely upon both habitat use and animal abundance data as alternative methods for identifying habitat optimality (Schamberger and O'Neil 1986, Hobbs and Hanley 1990). The use of such habitat preference data in place of carrying capacity stems from the assumption that a species will select and use habitat that best satisfies its life requirements and greater species use will occur in "higher-quality" habitat (Schamberger and O'Neil 1986). For the most part this approach seems to be reasonable, however in situations where population levels are low, carrying capacity data are often unavailable and habitat use and/or animal abundance data for the area of concern may be difficult, if not impossible to obtain (Schamberger and O'Neil 1986). Despite these shortcomings, a suitable alternative to the use of either carrying capacity, habitat use or animal abundance data as an indicator of habitat optimality has not yet been documented in the literature.

4.2.2 Model Development

HSI models are developed using a multi-step process (Jeffers 1978). An HSI model is constructed through the aggregation of habitat variables (Schamberger and O'Neil 1986) and the resulting model is verified to ensure that the model behaves in a reasonable fashion (Jeffers 1978). Once model verification has been completed model validation is conducted and the model is tested to ensure that the model agrees with the behavior of the real-life system for which it was intended (Jeffers 1978).

4.2.2.1 Model Construction

To be effective, HSI models must be founded upon functions that are logical and biologically realistic; they should be applicable to a wide range of situations without requiring major modifications; and they should be simple and usable (Van Horne and Wiens 1991). Unfortunately however, the priorities of model validity, generality and usability often compete with one another and model function is challenged with the task of emphasizing one priority without sacrificing another (Van Horne and Wiens 1991). Since the correct balance between these priorities often depends upon the intended application of an HSI model, the objectives of a particular model determine which priorities are most important in model construction (Van Horne and Wiens 1991).

The U.S. Fish and Wildlife Service (1981) outlines the development of HSI model objectives. Van Horne and Wiens (1991) further suggest methods to enhance the development of model objectives that ensure proper model usage and thus, improve model predictability.

The intended application of an HSI model and its objectives must be considered when selecting variables for model development and identifying the method by which those variables will be aggregated to form the HSI (U.S. Fish and Wildlife Service 1981, Van Horne and Wiens 1991). Variables may be identified using either a species specific literature review (U.S. Fish and Wildlife Service 1981) or expert opinion (Crance 1985, Schuster et al. 1985, Crance 1987) and must meet several criteria to be considered viable for HSI model development (U.S. Fish and Wildlife Service 1981, Schamberger and O'Neil 1986). The U.S. Fish and Wildlife Service (1981) provides the only source of information relating to the identification of variable interrelationships and model construction procedures, including the development of suitability indices.

4.2.3 Model Verification

The U.S. Fish and Wildlife Service (1981) outlines a general HSI model testing procedure addressing both verification and validation methodologies under the guise of HSI model verification. Since each HSI model defines habitat in a slightly different manner, a standardized approach to HSI model testing does not exist (Schamberger and O'Neil 1986). Over time, some researchers have begun to view both verification and validation as separate entities in the testing of HSI model function and accuracy (Cole and Smith 1983, Terrell and Nickum 1984, Schroeder 1990, Thomasma et al. 1991, Bender et al. 1996), although some researchers still refer to all forms of model testing as verification (Prosser and Brooks 1998). For the purpose of this study however, model verification and validation were considered to be separate model testing procedures.

Verification is defined as the process of testing whether the general behaviour of a model is a 'reasonable' representation of the real life system that is being investigated (Jeffers 1978). The U.S. Fish and Wildlife Service (1981) applies model verification as a quality control mechanism to ensure that preliminary HSI models produce mathematically sound output (U.S. Fish and Wildlife Service 1981). In doing so, verification may also be used to further refine a model in the event that model function is determined to be flawed (U.S. Fish and Wildlife Service 1981).

A model is verified when it is applied to sample data sets that mimic various habitat conditions of differing levels of habitat optimality (U.S. Fish and Wildlife Service 1981). Inspection of model outputs reveal how well the model reflects the habitat condition for each data set and if necessary the model is recalibrated to produce reasonable predictions for each set of conditions (U.S. Fish and Wildlife Service 1981). Verification is therefore a largely subjective assessment of model success rather than an explicit test of model hypotheses and assumptions (Jeffers 1978).

4.2.4 Model Validation

Verification is described as a quantitative expression of the extent to which model output agrees with the behavior of a real life system" (Jeffers 1978). Validation is conducted by applying the HSI model using field data (U.S. Fish and Wildlife Service 1981). Field data must include both measurements of habitat variables and measures that represent habitat suitability (U.S. Fish and Wildlife Service 1981). The U.S. Fish and Wildlife Service (1981) cautions that HSI models should be tested against actual field data only after the model has been verified both theoretically by the author and analytically using sample data. Model validation using field data may lead to further refinements of the HSI model as data sampling methods may require modification (U.S. Fish and Wildlife Service 1981). Validation is considered to be complete when the observations and predictions of the model agree (Jeffers 1978).

4.3 HSI Model Objectives

The goal of this study was to develop a habitat suitability index model for burrowing owls using the critical habitat components identified by the modified Delphi Method.

Specific objectives included:

1. Develop, verify and validate a habitat suitability index model for burrowing owls breeding in southwestern Manitoba and southeastern Saskatchewan; and
2. Develop guidelines for the application of the habitat suitability index model and its use in the assessment of burrowing owl breeding habitat in southwestern Manitoba and southeastern Saskatchewan

4.4 Methods

Information obtained from the modified Delphi process was used to construct the HSI model. The modified Delphi Method identified 9 site-specific critical habitat components believed to be most important in the assessment of habitat suitability for breeding burrowing owls in southwestern Manitoba and southeastern Saskatchewan (see Chapter 3). To ensure that these variables were appropriate indicators of habitat suitability, each variable was assessed using criteria developed by the U.S. Fish and

Wildlife Service (1981) as well as Schamberger and O'Neil (1986). Empirical SI curves generated by the Delphi process (see Chapter 3) were also fitted to mathematical functions using regression analysis and statistical modeling (Jeffers 1982).

4.4.1 Model Development

Development of the HSI model began by formulating model objectives and assumptions. Variables identified by the Delphi technique (see Chapter 3) that were considered to be inappropriate to the modeling objectives were excluded from consideration. Exploratory data analysis was used to summarize interrelationships among the remaining variables and variables were identified as limiting, cumulative or compensatory factors using guidelines established by the U.S. Fish and Wildlife Service (1981).

A mathematical expression of habitat suitability was generated using guidelines established by the U.S. Fish and Wildlife Service (1981) as well as an adaptive learning process of combining habitat variables. Limiting factor variables were applied in a multiplicative fashion as it ensured that the HSI would equal zero should any of the SI values equal 0.0. The capacity of limiting factors to render either a suitability component or HSI equal to the value of the limiting factor having the lowest SI value was not included in this model. Instead, a geometric mean was selected as the best method to apply limiting factors in the burrowing owl HSI since geometric means were more sensitive to single, low SI values than arithmetic means.

Cumulative variables were incorporated into the HSI model using addition, while compensatory variables were applied to the model using either a geometric or arithmetic mean. Since arithmetic means favor high SI values and geometric means are more influenced by low SIs, the type of mean most appropriate to the situation was selected based upon the available information. Variable importance weighting identified by the modified Delphi process (see Chapter 3) was also applied to compensatory variables to express their relative importance in the identification of habitat suitability. These weights were incorporated into the HSI as outlined by the U.S. Fish and Wildlife Service (1981).

4.4.2 Model Verification

An interactive computer program was developed to verify the function, accuracy and robustness of the HSI model. Mathematical formulae describing each variable's SI curve (see Chapter 3) were included in the program to allow for the calculation of site-specific SI values. Empirical habitat measurements were entered into the program to explore the multi-variable behavior of the HSI model and to ensure that the HSI values computed reflected the suitability of burrowing owl habitat. In doing so, the model was examined and verified to ensure that it performed in the way intended and produced values representative of potential habitat situations.

Model verification was conducted by running sample data sets and analyzing model output. Single variable values were tested in relation to an otherwise optimal habitat situation and results were examined. Similarly, the entire model and its functions were tested using random SI values. In both cases, expected results were compared with actual output and the results were assessed for their accuracy in determining habitat suitability. Throughout model verification, values indicative of extreme habitat conditions were tested and model outputs were evaluated.

If the model behavior was deemed to be sub-optimal, iterative refinements were made until acceptable levels of accuracy and robustness were achieved. This was accomplished by reassessing model construction and reducing the number of variables comprising the model such that the model incorporated only the most important variables (see Chapter 3) that determine habitat suitability for the species. Model design was also examined and altered as required to improve the identification of habitat suitability for the burrowing owl. If the model was modified at any point following the initial development phase, model verification was repeated to ensure that the performance of the model remained accurate.

4.4.3 Model Validation

The HSI model was validated using field data collected from burrowing owl nest areas. A limited number of burrowing owls nesting in Manitoba resulted in an inability to assess model accuracy within the province. Instead, data collected from known optimal burrowing owl habitat (see Chapter 3) in southeastern Saskatchewan was used to ensure proper model function and confirm that the model produced high HSI values for known optimal habitat. Data collected from habitat historically utilized by burrowing owls in southwestern Manitoba was used to assess the suitability of historical habitat for future burrowing owl populations.

4.4.3.1 Study Area

Study areas selected for the purpose of validating the burrowing owl HSI model were located in Moose Jaw, Saskatchewan and around the town of Melita, Manitoba. The area located within Moose Jaw was chosen as a study site based upon it being known as optimal burrowing owl habitat, having a known presence of burrowing owls and an abundance of occupied nest sites. The second study site was selected and located in the vicinity of Melita, Manitoba (49°10'N, 101°00'W) within the mixed-grass prairie ecoregion where burrowing owl nesting areas have historically been located.

Site 1: Moose Jaw

A study conducted for the City of Moose Jaw and the Saskatchewan Department of Environment and Resource Management identified optimum nesting areas occupied by burrowing owls. A field investigation of these areas was conducted from September 28 to October 4, 1998. During this time, the study examined the track infield of the Moose Jaw Exhibition Grounds where burrowing owl populations have persisted for a number of years.

The Moose Jaw Exhibition Grounds are located on the north side of Thatcher Drive, east of Main Street (Figure 5) and consist of a series of buildings, paddocks, barns, training areas and pastures as well as a track and the City of Moose Jaw compost facility. Horses were housed and grazed on site with anywhere from 4-8 horses being grazed on the track infield at any one time (G. Duck, pers. com.). All manure and refuse straw produced on site was transported to the compost facility and combined with other compostable materials produced in and around Moose Jaw (G. Duck, pers. com.). At the time that field data was collected, the exhibition grounds marked the most northeastern edge of development of the city. Croplands were located north, east and southeast of the exhibition grounds property. Thatcher Drive separated the exhibition grounds from its southerly neighbor, the Hillcrest Golf and Country Club. Land to the west of the Exhibition Grounds was fully developed with both residential and commercial infrastructures. The study site examined by this report centered on the track infield as the primary nesting area. Undeveloped areas located within a 600m radius from the center of the track infield were assessed for their potential to be used as forage or nesting areas by burrowing owls (see Chapter 3).

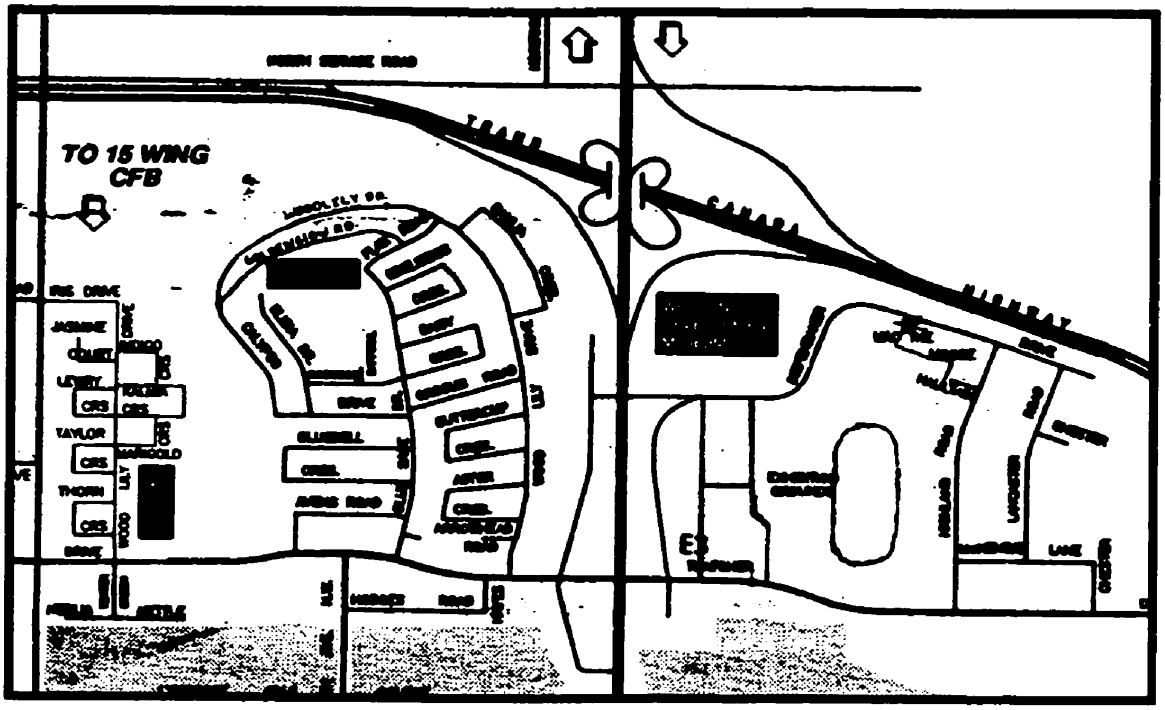

Figure 5. The Moose Jaw Exhibition Grounds burrowing owl nest sites (Moose Jaw Chamber of Commerce 1989).

Site 2: Melita Area

The proximate habitat of 13 historic nest sites used by burrowing owls between 1987 and 1997 were examined in the Melita area from June 1-5, 1998. Records of fledging success between 1987 and 1997 (De Smet pers. com.) were used to classify nest sites as historically successful (≥70% of broods fledged), marginally successful (30-50% of broods fledged), or unsuccessful (0 broods fledged). Of the 13 sites examined, six were classified as historically successful, two as marginally successful, and five as unsuccessful.

The historic burrowing owl nest sites were located within Manitoba as far north as Broomhill, as far east as Boissevain, as far south as the Canada-U.S. border and as far west as the Manitoba-Saskatchewan border (Figure 6). Little infrastructural development existed within the composite study area. Of the development that did exist, most was commercial or residential in nature and was typically confined within each of the towns' boundaries. All of the historic nest sites examined were located in present-day pastures subjected to a variety of cattle grazing intensities, including rotational grazing. Sites were interspersed among cereal and forage crops, haylands, summer fallow and other grassland habitat types.

4.4.3.2 Data Collection

Since the majority of burrowing owl activity occurs in habitats located ≤ 600m of the nest burrow (Haug and Oliphant 1990), this study addressed habitat located within a 600m radius from each nest site (see Chapter 3). Nest and forage vegetation heights, burrow availability, topography, perch availability and openness were addressed at each nest site (see Chapter 3). In addition, the distance between active nests was examined and measured whenever an active burrowing owl nest was located within 2.7km from the nest in question (see Chapter 3).

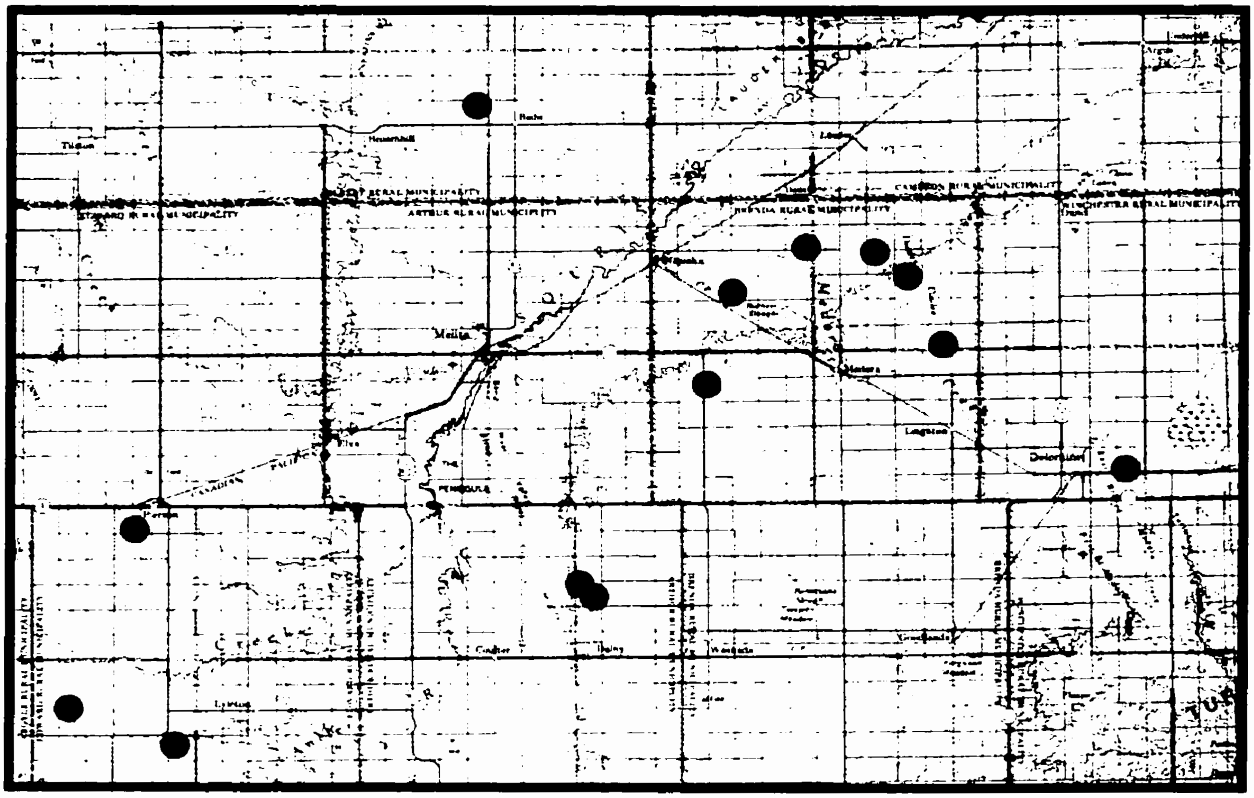

Figure 6. Locations of the 13 historic burrowing owl nest sites examined in the Melita Study Area.

Forage Vegetation Height Measurements

For the purpose of this study it was assumed that burrowing owls select foraging habitats according to the ideas expressed by the optimum foraging theory (Stephens and Krebs 1986). Assessment of burrowing owl forage habitat was therefore restricted to potential forage habitats located within 600m of the nest site that were identified as optimal for small mammal prey species (see Chapter 3). To identify potential foraging habitat, vegetation structure and composition were visually assessed by looking outward while walking a 50m radial circle centered on the nest burrow. In addition, roadside habitat within 600m of the nest was assessed. Each distinct habitat type observed within 600m of the nest was classified based upon its habitat type and assigned a suitability index value using expert-opinion data collected by the modified Delphi Method (see Chapter 3). The areal extent of each habitat class was also estimated.

Vegetation sampling of forage habitat was conducted, beginning with habitats having the highest SI value (see Chapter 3) and proceeding to habitats having lower SI values (see Chapter 3) until a total forage habitat area of 9ha or more was achieved. Within each habitat type, vegetation height was measured using a line transect sampling technique (Burnham et al. 1980). Vegetation was sampled at 10m intervals along three randomly located line transects using a meter stick with centimeter and half centimeter markings. The nearest neighbor method (Smith 1974) was used to determine which vegetation component was to be measured. Vegetation was measured to the nearest half centimeter and recorded. Mean forage vegetation height was then determined.

Vegetation Height at Nest Measurements

Nesting activity of burrowing owls is restricted to habitat located within 50m of the nest burrow (Haug 1985) (see Chapter 3). The suitability of vegetation within this area was identified by measuring vegetation height at 90° intervals along a circle having a radius of 1m extending from the burrow entrance. Vegetation height was also measured at 10m intervals along a circle having a 10m radius centered on the nest burrow. A radial distance of 10m was measured from the center of the burrow entrance using a 100m measuring tape secured at the center of the nest entrance, locked at the specified distance and used to maintain the desired distance from the nest burrow. At each 10m interval along the circumference, vegetation height was measured to within 0.5cm using a meter stick and the nearest neighbor method (Smith 1974). The mean height of vegetation at the nest site was then calculated.

Burrow Availability

Burrowing owls rely primarily upon abandoned American badger (*Taxidea taxus*) and Richardson ground squirrel (*Spermophilus richardsonii*) burrows in which to breed (Wedgwood 1978, Haug and Oliphant 1990). Results of the modified Delphi exercise indicated that burrowing owls typically nest in burrows having an entrance diameter between 8 – 35cm (see Chapter 3). To determine burrow availability at each nest site, the number of burrows (natural and artificial) within the 8 – 35cm range were counted within a 10 x 10m plot randomly located between 10 and 50m from the nest burrow.

Perch Availability, Openness, and Topography

Perch availability and habitat openness were determined at each nest site by counting the number of perches and trees located within a 50m radius of the nest (see Chapter 3). A perch was considered to be any limbless object <3m in height, whereas trees were defined as any woody vegetation ≥3m in height. In addition, site topography was visually assessed using incremental rankings from flat to moderately rolling.

4.4.4 Study Limitations

The limitations imposed upon this study stem principally from an absence of published literature specific to burrowing owl habitat requirements in the eastern Canadian prairies. Information acquired using a modified Delphi Method was employed to approximate habitat requirements of burrowing owls in a rural setting. Inherent differences between rural and urban settings make this use of information a limitation of the study.

In light of this, study design and sampling methods developed from information specific to a rural setting were not capable of a lateral shift to the urban environment in all cases. As a result, the study design and some methods of data collection were modified to better suit the Moose Jaw situation while others were dropped completely from the study because they were either impossible to obtain given the situation, or would provide information which was not applicable.

Specifically, it was determined that in Moose Jaw, measurements centering on each individual nest would not be beneficial since overlapping would occur and findings would be restated for other nests within the same loose nesting colony. Instead, the loose nesting colony present at the Moose Jaw Exhibition Grounds was assessed as though it were one nest. Measurements did not center on a specific nest, but rather used the general area of nesting to represent the nest in a broad sense. Each transect sampled was used to represent vegetation common to a different nest. Vegetation density 50m from the nest burrow was not measured since this measurement was intended to determine visibility from the nest and required that measurements be taken directly from the nest in question.

Furthermore, information obtained from burrowing owl experts, including vegetation heights and corresponding SI values, were specific to spring data collection (see Chapter 3). By comparing these values to those obtained from late spring (Melita study) or late fall data collection (Moose Jaw study), the results do not provide an accurate representation of habitat suitability, nor does the habitat portray the precise parameters owls would use to select a nest site in early spring.

4.5 Results and Discussion

Results and discussion of this study have been divided to address the separate components involved in HSI model development. Model construction addresses the results stemming from the aggregation of habitat variables to formulate a mathematical expression of burrowing owl habitat suitability and discusses the findings with respect to HSI model development for other species. Model verification examines the results of testing the burrowing owl HSI model for its mathematical tractability and robustness, then discusses these results in relation to other HSI models. Finally, model validation examines the results of burrowing owl HSI model field-testing as well as the results of model application on burrowing owl habitat in both southeastern Saskatchewan and southwestern Manitoba. Model validation also includes a discussion comparing the results of model validation with other validated HSI models and interprets the findings of the burrowing owl HSI model in Manitoba.

4.5.1 Model Development

Nine of the 10 critical habitat components identified by workshop participants were specific to the habitat proximate to nest burrows, while the tenth component addressed landscape-level habitat fragmentation. Habitat fragmentation was not utilized in model construction, since the objective of this study was to develop an HSI model for localized application. The remaining 9 critical habitat components (Table 28) were redefined as primary habitat variables for the purpose of model construction.

Assessment of the primary habitat variables revealed the interrelationships existing between each of the variables (Table 29). Burrow availability was deemed to be a limiting factor in identifying suitable nesting habitat, since nesting will not occur without a presence of available burrows and burrowing owls rarely excavate their own burrow. Burrowing owl survival is also dependent upon a presence of food and thus, the availability of suitable small mammal prey habitat. As a result, the quality and availability of burrowing owl foraging habitat were also determined to be limiting factors for the purpose of HSI model construction.

Internest distance, openness and vegetation height at the nest burrow were determined to function as compensatory factors. The identification of these interrelationships was based upon the understanding that high SI values for these variables had the capacity to offset low suitability levels of other variables.

Comparatively, topography at the nest site, areal extent of nest pasture and perch availability were identified as having a minimal influence on the suitability of burrowing owl habitat when considered independently. However collectively, these variables were determined to be important in the identification of habitat suitability and thus, in the development of a burrowing owl HSI model. Topography at the nest site, areal extent of the nest pasture and perch availability were therefore identified as being cumulative factors.

Table 29. Primary habitat variable interrelationships.

Variable Name	Variable Identifier	Interrelationship
V_1	Burrow Availability	Limiting Factor
V_2	Internest Distance	Compensatory Factor
V_3	Forage Habitat Quality	Limiting Factor
V_4	Vegetation Height at Nest	Compensatory Factor
V_5	Areal Extent of Nest Pasture	Cumulative Factor
V_6	Topography at the Nest Site	Cumulative Factor
V_7	Perch Availability	Cumulative Factor
V_8	Openness	Compensatory Factor
V_9	Forage Habitat Availability	Limiting Factor

Results indicate that this study was able to determine the interrelationships of burrowing owl breeding and foraging habitat requirements in southwestern Manitoba and southeastern Saskatchewan, using data generated by expert opinion. This finding is supported by other studies that have also successfully used expert opinion to amass species habitat data and develop HSI models for a variety of terrestrial and aquatic species. Terrell et al. (1995) used an expert opinion workshop to identify critical habitat variables, determine variable interrelationships and develop an HSI model for Atlantic salmon (*Salmo salar*). Similarly, Crance (1985) and Mollohan et al. (1995) used the Delphi technique to determine species habitat requirements and identify variable interrelationships for inland stocks of striped bass (*Morone saxatilis*) and Merriam's turkey (*Meleagris gallopavo*) respectively.

4.5.1.1 Model Construction

The burrowing owl HSI model first produced by this study incorporated all 9 habitat variables in a weighted geometric mean and used the variable weights suggested by participants of the modified Delphi exercise (see Chapter 3). When model validation was conducted, it became apparent that the resulting model was cumbersome and insensitive to changes in variable values. O'Neil et al. (1988) reported similar results and determined that HSI models comprised of fewer variables were more sensitive to changing variable values. Furthermore, simpler models using fewer variables were found to reduce the likelihood of model overfitting (Jeffers 1978) and have the additional advantage of being both mathematically tractable and more easily applied under field conditions.

To improve model function, variable interrelationships and model construction were subsequently reassessed and the model was reconstructed. HSI model reconstruction was achieved by removing the 3 variables weighted lowest by participants of the modified Delphi exercise (Table 28). The model was further revised by indirectly incorporating two additional variables into the model as stipulations guiding model application.

Specifically, the HSI model was redesigned to automatically produce an HSI value of zero under the following conditions:

1. Openness: tree or shrub encroachment within 50m of the nest site
2. Forage Availability: no forage habitat within 600m of the nest site.

Further efforts directed toward the construction and verification of the burrowing owl HSI model were focused on the 4 remaining variables (Table 29).

Results of model development indicate that this study successfully used a modified Delphi approach to develop an HSI model for burrowing owls. Crance (1985), Mollohan et al. (1995), and Terrell et al. (1995) have had similar success developing HSI models using various forms of the Delphi technique for inland stocks of striped bass, Atlantic salmon and Merriam's turkey respectively. Allen and Hoffman (1984), Finch et al. (1987), Prose (1987), Clippinger (1989), Brooks and Temple (1990), Schroeder (1990), Conway and Martin (1993), and Stanley and Trial (1995) are just a few who have also been successful in developing HSI models for a variety of terrestrial and aquatic species including prairie species such as the black-tailed prairie dog (*Cynomys ludovicianus*) and the loggerhead shrike (*Lanius ludovicianus*).

4.5.1.2 Model Application

Field protocol guidelines addressing model application and data collection methodologies were developed to accompany HSI model application and thus account for model idiosyncrasies and assumptions. Application of this burrowing owl HSI model in the absence of these protocols may compromise model accuracy such that habitat suitability levels reported by the model may be misrepresented.

Areas to Examine

The burrowing owl HSI model developed by this study was constructed using data specific to breeding burrowing owl habitat use in southwestern Manitoba and southeastern Saskatchewan. Due to the site specific nature of the data used to formulate this model, the burrowing owl HSI model is intended only for use in Manitoba and southeastern Saskatchewan. Application of this model to areas other than those intended is possible, but would require that the model be modified to better address burrowing owl habitat requirements in the area of concern.

Research shows that burrowing owls do not nest randomly on the Canadian prairie landscape (James et al. 1991, Warnock 1996). Assessments of burrowing owl habitat suitability must therefore be restricted to open, treeless areas exhibiting a presence of short or mixed grass prairie that is mowed or otherwise cropped.

The model defines a tree as any vegetation ≥3m in height. Application of the HSI model to areas having ≥30 trees within a 100m radius is not recommended as these areas possess a significant risk of burrowing owl depredation. Application of the model in areas having a singular bluff of trees ≤100m^2 and located >50m from the nest burrow is, however, permissible. Since a bluff <50m from the nest could potentially deter burrowing owls from using the nest, the habitat is considered to be unsuitable and the model should not be applied. Similarly, the presence of a bluff of trees >100m^2 or multiple bluffs

$<100m^2$ has the potential to deter burrowing owls from using a nesting area and the habitat is determined to be unsuitable.

Burrow Availability

Burrowing owls rarely excavate their own burrows and instead rely upon burrowing mammals to excavate and abandon burrows required for nesting. Although burrowing owls may modify the entry of pre-existing burrows, the diameter of a burrow suitable for use by the species ranges from 8-35cm. Assessments of burrow availability must therefore consider only those artificial and natural burrows with an entrance diameter of 8-35cm.

To determine the number of burrows available per hectare, all artificial and natural burrows with an entrance 8-35cm in diameter are counted within a randomly located 10m x 10m plot. The number of burrows within 1ha ($10{,}000m^2$ plot) is then extrapolated by multiplying the number of burrows within the 10m x 10m plot by $10{,}000m^2$ and dividing the equation by $100m^2$. The extrapolated value is then used to represent burrow availability in the HSI calculation.

Vegetation Height at Nest Burrow

Burrowing owls typically restrict nesting activities to the area extending from the nest burrow to a distance 50m from the nest. During the breeding season, females occupy the nest burrow to incubate eggs and rear young while males spend the majority of their time foraging away from the nest. To facilitate predator detection, burrowing owls prefer to nest in areas where vegetation surrounding the burrow is short or cropped. This allows for better sight lines from the burrow entrance and aids in the early identification of any impending danger.

Vegetation height at the nest burrow should be assessed by measuring the height of vegetation located within a 10m radius of the nest burrow entrance. It is recommended that a series of 10 randomly located vegetation height measurements be made at each nest site, although sampler discretion is suggested. The mean height of vegetation at the nest is calculated and used to represent the vegetation height at the nest variable in the calculation of habitat suitability.

Height of Forage Vegetation

Burrowing owls are opportunistic foragers and will forage wherever the opportunity presents itself. Although a variety of food types are consumed, small mammal populations provide the majority of food energy consumed by the species. Small mammal foraging by burrowing owls has been found to occur most often at distances ranging from 50-600m from the nest.

To limit the amount of energy expended in the search for food, it is reasonable to assume that burrowing owls forage in areas most likely to provide optimal foraging opportunities. Forage vegetation height measurements should therefore be focused on areas providing the best foraging opportunities to the species. Burrowing owl experts identified suitable forage habitat types for the species and assigned corresponding SI values to each of those habitat types (Table 30).

To identify suitable forage habitat types, it is recommended that habitat composition be visually assessed from a variety of standpoints. At a minimum, the assessment of forage habitat availability should be made by walking a 50m radial circumference around the nest, while looking outward from the nest. All areas having forage potential should be recorded and the SI value of each area determined using the forage habitat type SI table above. The area encompassed by each habitat type should also be estimated and recorded.

Table 30. Suitability index (SI) values of forage habitat types used by burrowing owls to capture small mammal prey species.

Forage Habitat Type	SI Value
Wet meadow	1.0
Road Side	1.0
Idle Grassland	0.8
Lightly Grazed Pasture	0.6
Hayland	0.6
Cropland	0.5
Moderately Grazed Pasture	0.4
Fallow Field	0.4
Heavily Grazed Pasture	0.2
Lawns and Cemeteries	0.1

A series of vegetation height measurements should be taken in each of the areas determined to be suitable for burrowing owl foraging. Vegetation sampling should begin in areas having the highest forage habitat type SI value and proceed from highest to lowest SI habitat type until the sum of the estimated areas of habitat types sampled is equal to approximately 9 ha. It is recommended that vegetation height measurements be taken along randomly located transects. A minimum of 3 transects should be sampled in each area with 10 measurements made along each transect. The vegetation heights from all areas sampled should be used to calculate an overall mean forage vegetation height. The mean height of forage vegetation is then used to represent the forage vegetation height component within the HSI calculation for the area of concern.

If time allows for a more in-depth habitat composition assessment, one may drive grid roads located within the 600m radial circumference of the nest to conduct a more comprehensive examination of the habitat composition available to burrowing owls for forging purposes. Aerial photos may also be used to identify grid roads falling within the 50m – 600m radius around the nest burrow and aid in the estimation of area encompassed by each habitat type. Identification of forage areas and vegetation sampling methodologies should proceed as indicated above.

Distance Between Active Nests

The distance between active burrowing owl nests may also influence burrowing owl habitat suitability. Although burrowing owls have been found to be colonial in more southern parts of the species range, colonial tendencies have been observed less often in the Canadian prairie regions. It is possible that the risk of diminished resources as a result of competition has functioned to deter colonial nesting on the northern periphery of the burrowing owl breeding range.

The distance between active nests becomes a factor in the calculation of habitat suitability only when another active nest is located within the home range of the nest burrow being examined. If the nest being examined is isolated from all other nesting burrowing owls, internest distance is not considered by the HSI. If however, another active burrowing owl nest is located within 2.7km of the nest burrow, the distance between active nests must be determined and used to calculate a site HSI value.

It is recommended that internest distance be estimated with the assistance of aerial photos or maps. The location of each active nest should be plotted on the map or aerial photo and the distance between the two nests should be estimated. It is possible to use any resolution of map or photo, although the higher the resolution, the more accurate nest location will be and hence the more accurate the estimated distance between active nests will be. The estimated distance between active nests should then be used to represent internest distance in the calculation of habitat suitability.

4.5.2 Model Verification

Model verification was facilitated by the creation of an interactive computer program to determine individual variable SI values and calculate a composite HSI value for a specific set of habitat parameters. Approximately 500 sets of habitat parameters were generated to explore the utility and robustness of the model. An iterative process was used to modify the model parameters until accurate model functionality was achieved. The final model incorporated the 4 most important habitat variables and their weights assigned by participants of the modified Delphi exercise. The final model took the form

$$HSI = [(S_1^{0.8})(S_2)(S_3)(S_4^{0.5})]^{1/3.3} \qquad [3]$$

Where $S_{1\text{-}4}$ are suitability values: S_1 = burrow availability

S_2 = forage vegetation height

S_3 = nest vegetation height

S_4 = internest distance

Suitability index values for the 4 variables are presented graphically in Figure 7.

During the modified Delphi exercise, participants indicated that it was possible for an area to be considered optimal burrowing owl habitat, yet not be occupied by nesting burrowing owls. However, the final model produced by this study was not mathematically capable of operating in an environment where burrowing owls were absent from the landscape. As a result, a second burrowing owl HSI model [4] was developed for use in areas where burrowing owls are not present. The second model [4] omitted internest distance from equation [3] yet maintained the remaining 3 habitat variables and their weights in the HSI as they had been in the final model

$$HSI = [(S_1^{0.8})(S_2)(S_3)]^{1/2.8} \tag{4}$$

Verification of the burrowing owl HSI model was possible. Results of model verification indicate that the burrowing owl HSI model developed by this study was robust and mathematically tractable. Verification as defined by Jeffers (1978) however, is suggested by the U.S. Fish and Wildlife Service (1981), but is not a required procedure of HSI model development. Examination of 6 randomly selected HSI models found that models developed for the greater prairie chicken (*Tympanuchus cupido*) (Prose 1985), lark bunting (*Calamospiza melanocorys*) (Finch et al. 1987) and muskrat (*Ondatra zibethicus*) (Allan and Hoffman 1984) were not verified at all to ensure proper model function. HSI models for Williamson's sapsucker (Conway and Martin 1993) and nonmigratory freshwater life stages of Atlantic salmon (Stanley and Trail 1995) were validated but not verified, while the plains sharp-tailed grouse HSI model was only partially verified (Prose 1987). No HSI models were found to verify model functionality.

4.5.3 Model Validation

Site 1: Moose Jaw

Burrowing owls have successfully nested in Moose Jaw, Saskatchewan for a number of years. The suitability of breeding habitat was assessed at the track infield of the Moose Jaw Exhibition Grounds.

Burrowing owls were actively nesting on the site when the study was conducted. Field sampling took place in late fall, therefore much of the Moose Jaw burrowing owl population had already begun the fall migration. As a result, few active nests were identified. At the time of sampling, it appeared that burrowing owls breeding on the Moose Jaw Exhibition Grounds study site had nested in a loose colony, but this hypothesis was never confirmed. None of the active burrowing owl nests identified during the study were located within 2.7km of one another. As a result, internest distance was not of consequence and [4] was used to calculate site HSI.

Eight randomly selected nest sites were sampled on the infield of the Moose Jaw Exhibition Grounds. Horses had grazed the infield throughout much of the summer and vegetation height was homogenous. Vegetation height in the infield was sampled and one mean value of vegetation height at the nest was calculated to represent all nest sites on the Exhibition Grounds infield. All nests sampled also shared the same potential foraging areas thus a single value for mean forage vegetation height was calculated. Variable SI values and a site HSI value were calculated using the interactive computer program (Appendix 1). The HSI value for the Moose Jaw study site equaled 1.0, indicating that the model successfully recognized optimal burrowing owl habitat (Table 31).

Validation of the burrowing owl HSI model using data collected from the Moose Jaw study site indicated that the model was capable of operating in a field environment and was successful in recognizing optimal burrowing owl habitat. This study is not alone in its findings. Positive correlations between model HSI predictions and measures of wildlife distributions and abundance have also been reported by Cole and Smith (1983), Cook and Irwin (1985), Verner et al. (1986), and Brennan (1991).

Table 31. Habitat conditions and corresponding SI values of the Moose Jaw Exhibition Grounds study site.

Nest	**Habitat Variables Measurements**						**Site HSI**
	Burrow Availability		Mean Forage Veg. Height		Mean Nest Veg. Height		
	# burrows/ha	SI	cm	SI	cm	SI	
1	140	1	26.1	1	4.2	1	1

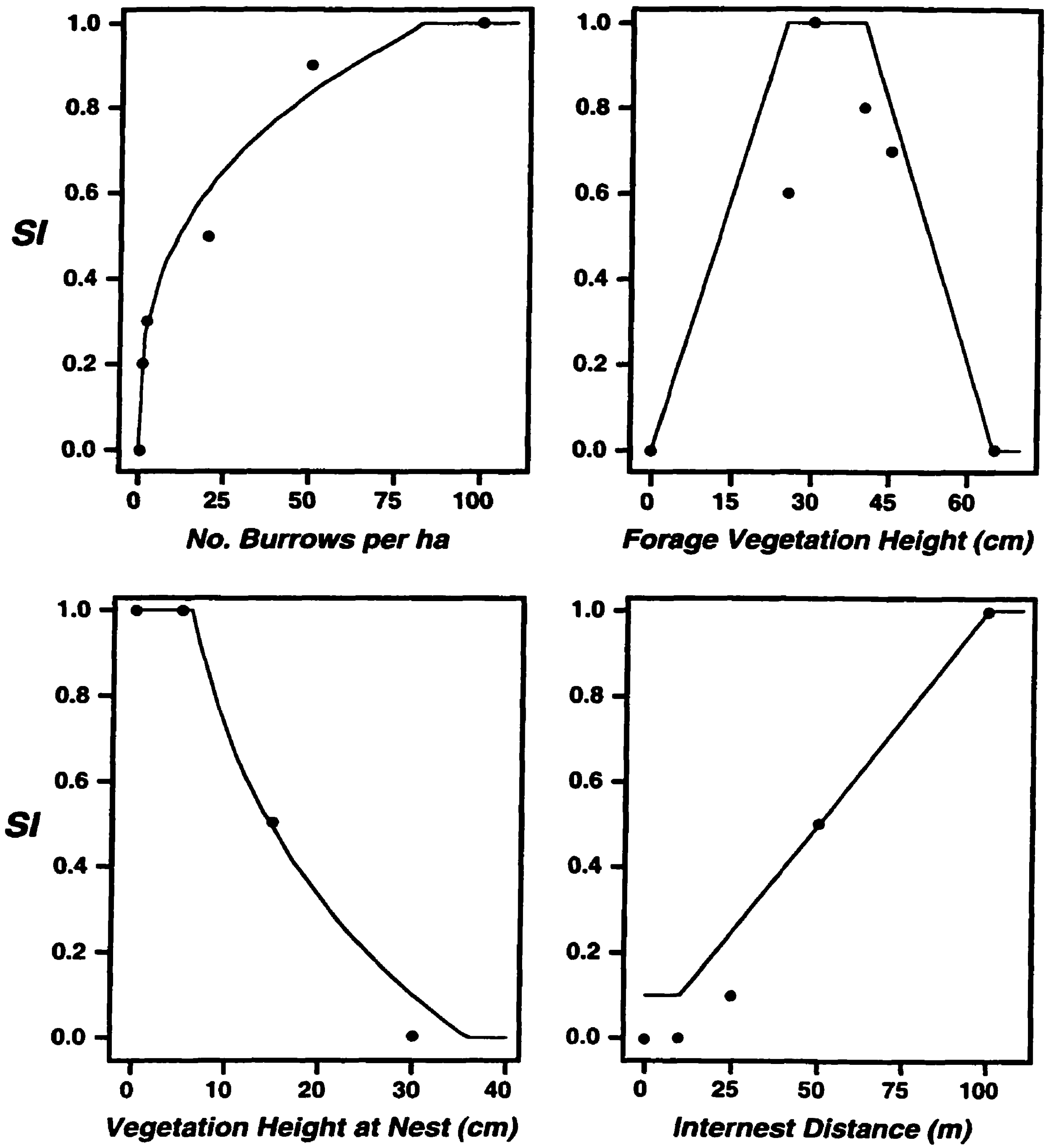

Figure 7. Suitability index curves for the four habitat variables used in the final HSI model. Fitted curves (solid lines) and variable values from the modified Delphi exercise (circles) are shown.

Site 2: Melita Area

Of the 13 historic nest sites examined in the Melita study area, 9 were artificial nest burrows and 4 were natural burrows. Three out of 4 natural burrows were classified by this study as being unsuccessful nest sites while the other remaining natural burrow occurred on a nest site classified as being moderately successful. Burrows examined by this study were selected based upon the historic success of the burrow, while the status of nests (natural/artificial) selected for sampling was random. Of the unsuccessful nests examined by this study, 75% were natural burrows while 100% of the successful nests sampled were artificial. The reasons behind this finding are unknown however De Smet (1992) reported that burrowing owls in Manitoba nested in artificial burrows more often than in natural burrows. Similar findings have not been reported elsewhere.

All historic nest sites were also located on pastures that varied in the frequency and intensity of cattle grazing. Four historic nest sites were being actively grazed during the sampling period, while 4 others appeared to have remained ungrazed for a number of years. On the remaining 5 nest sites examined, grazing had occurred in the recent past, although grazing regimes were based solely upon supposition. Discussions with landowners indicated that these pastures were being subjected to rotational grazing at the time that sampling took place.

At each nest site, forage vegetation height, burrow availability, and vegetation height at the nest were sampled. Since none of the Melita nest sites examined were occupied by burrowing owls nor were known to have burrowing owls nesting within a 2.7km radius, internest distance was not examined at any of the Melita nest sites. Individual SI values were determined for each of the three variables at each nest site sampled and HSI values were calculated for each nest site (Table 32) using [4] and the interactive computer program (Appendix 1).

Forage vegetation height SI values at all nest sites were >0.8, and in 10 of the 13 historic nest sites optimum suitability index values of 1.0 were documented. SI values for burrow availability were >0.8 for 11 of the 13 nest sites, while the remaining 2 nest sites had low SI values (<0.5) as a result of a shortage of available burrows. SI values for vegetation height at the nest showed the greatest variation, ranging from 0.19 to 1.0. Collectively, these results indicate that forage habitat quality and burrow availability were close to optimal suitability at most historic nest sites. In contrast, SI values for vegetation at the nest were low at many of the nest sites examined, particularly in ungrazed pastures.

HSI values for the 13 nest sites ranged from 0.58 to 1.0 and were significantly correlated with historical nest site success (Figure 8; $r^2 = 0.33$, $p<0.05$). Habitat suitability index values of historically unsuccessful sites ranged from 0.58 to 0.79, with the highest values occurring in pastures grazed when sampling occurred. Comparatively, HSI values for historically successful sites ranged from 0.7 to 1.0, with the lowest values occurring in nest sites that had not been grazed for some time prior to sampling. These results suggest that moderate grazing of burrowing owl breeding areas is critical to the maintenance of suitable burrowing owl breeding habitat in southwestern Manitoba.

Validation of the burrowing owl HSI model using data collected from historic burrowing owl nest sites in the Melita study area was determined to be successful. Results indicate

Table 32. Analysis of historic burrowing owl nest sites and corresponding HSI values of nest sites sampled in the Melita study area.

Nest	Nest Status		Habitat Variables Measurements						Site HSI
	Historic Success	Artificial/Natural	Burrow Availability		Mean Forage Veg. Height		Mean Nest Veg. Height		
			# burrows/h	SI	cm	SI	cm	SI	
1	successful	artificial	64	0.91	32.90	1.0	20.20	0.32	0.70
2	moderate success	artificial	8	0.44	31.84	1.0	8.82	0.79	0.70
3	successful	artificial	70	0.94	26.70	1.0	17.94	0.39	0.75
5	successful	artificial	136	1.0	20.10	0.8	9.18	0.76	0.86
6	moderate success	natural	104	1.0	20.10	0.8	12.96	0.57	0.79
8	unsuccessful	artificial	97	1.0	38.72	1.0	25.64	0.19	0.62
9	unsuccessful	artificial	5833	1.0	37.35	1.0	17.65	0.40	0.77
10	successful	artificial	101	1.0	30.29	1.0	4.57	1.00	1.00
11	successful	artificial	764	1.0	36.46	1.0	12.02	0.61	0.87
12	unsuccessful	natural	95	1.0	32.53	1.0	18.18	0.38	0.76
13	unsuccessful	natural	5	0.38	35.21	1.0	14.40	0.51	0.58
14	unsuccessful	natural	51	0.84	40.60	0.98	13.09	0.57	0.79
16	successful	artificial	92	1.0	32.75	1.0	13.55	0.31	0.84

that the burrowing owl model was capable of operating in a field environment. Validation results also indicate that HSI values calculated by the model were significant in their predictability of burrowing owl nest success. These results are further supported by Cole and Smith (1983), Cook and Irwin (1985), Verner et al. (1986), and Brennan (1991) who reported similar success in validating HSI models and finding positive correlations between model predictability and measures of wildlife distribution and abundance. By contrast, Seitz et al. (1982), Clark and Lewis (1983), Bart et al. (1984) and Robel et al. (1993) successfully validated HSI models, yet were found to be unsuccessful in developing positively correlated predictive HSI models when model validation was conducted.

Results of this study indicate that on a microhabitat level, the suitability of Manitoba's historic burrowing owl breeding habitat is slightly sub-optimal as in many cases, nest vegetation heights exceeded optimal vegetation levels. This finding contradicts that of De Smet (1992) where it was reported that >700 suitable burrowing owl nest pastures were identified in southwestern Manitoba. However, De Smet (1992) fails to indicate the method used to derive this information and thus it is impossible to comment on the discrepancy. To date, no other quantitative examinations of burrowing owl microhabitat quality have been conducted in the eastern Canadian prairies.

Validation of the burrowing owl HSI model also indicates that vegetation control practices used to maintain vegetation height at reduced levels are capable of improving sub-optimal habitat quality in cases where increased vegetation heights impede optimal habitat suitability. This finding is supported by MacCracken et al. (1985), Haug et al.

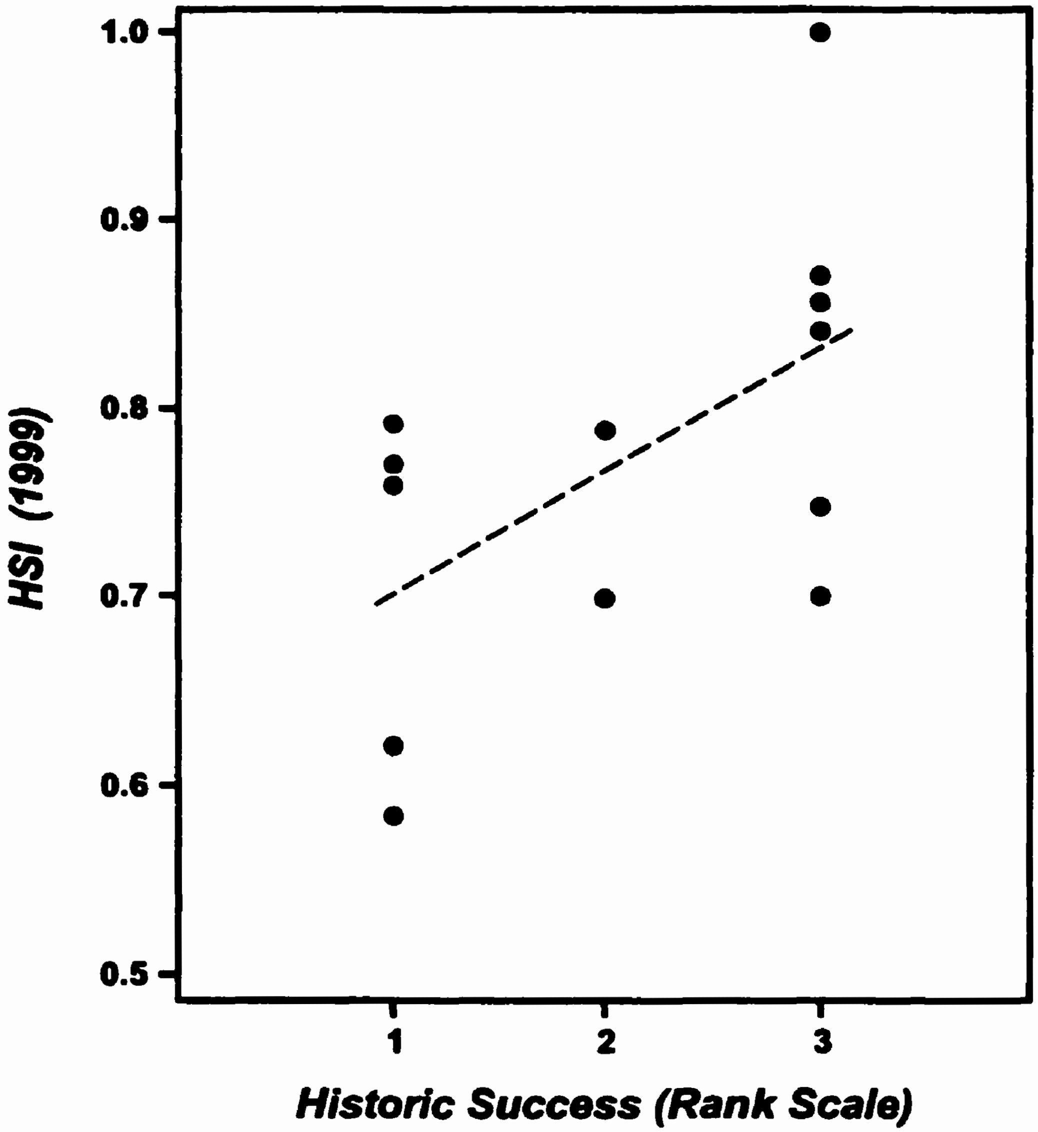

Figure 8. The relationship between historic burrowing owl brood rearing success (1987-1997) and HSI values (1999) for 13 historic burrowing owl nest sites in southwestern Manitoba. Historic success codes are: 1 = unsuccessful; 2 = moderately successful; and 3 = successful. The regression line is also shown.

(1993) and Uhmann et al. (in press) who report that land-use practices, such as grazing and mowing have suppressed vegetation growth around the nest entrance and therein have improved the suitability of burrowing owl breeding habitat.

On a micro-habitat level, results of this study indicate that the quality of burrowing owl habitat in Manitoba is slightly sub-optimal. Nonetheless it is believed that sub-optimal habitat conditions in southwestern Manitoba are not solely responsible for the decline in burrowing owl populations within the province. Instead the combined influence of multiple habitat related conditions operating on a macro-habitat level are believed to be driving declines in burrowing owl populations across the Canadian prairies. These, in concert with habitat suitability on a micro-habitat level continue to challenge management efforts directed toward the preservation of burrowing owl habitat populations.

Chapter 5

Summary, Conclusions and Recommendations

5.1 Objectives Reviewed

The primary objective of this study was to provide a mechanism to determine whether grassland habitat in southwestern Manitoba is capable of providing the habitat conditions required for burrowing owl survival. To achieve this goal, specific objectives were to:

- Identify the breeding and foraging habitat requirements of burrowing owls
- Determine and express mathematically the interrelationships of burrowing owl breeding and foraging habitat requirements
- Provide recommendations for the management of burrowing owl habitat in Manitoba

5.1.1 Identification of burrowing owl breeding and foraging habitat requirements

A modified Delphi exercise identified the breeding and foraging habitat requirements of burrowing owls in southwestern Manitoba and southeastern Saskatchewan. Burrowing owl experts identified a total of 19 habitat components required by burrowing owls, 10 of which were determined to be critical in the identification of burrowing owl habitat suitability. Nine of the 10 critical habitat components identified by expert opinion addressed the suitability of habitat proximate to nest burrows, while the tenth addressed landscape-level habitat fragmentation. As a result, the 9 critical habitat components addressing the same scale of habitat suitability were identified by this study as suitable variables for use in the development of an HSI model for burrowing owls in southwestern Manitoba and southeastern Saskatchewan.

The critical habitat components identified for use in the development of the burrowing owl HSI model were: burrow availability, vegetation cover at the nest, proximity and availability of forage habitat, openness, topography, areal extent of nest pasture, perch availability and internest distance. Critical habitat components were redefined as variables for the purpose of model construction.

5.1.2 Development of the habitat suitability index model

Habitat suitability relationships were defined and suitability index curves were developed for each of the 9 variables identified by expert opinion. Interrelationships operating between habitat variables identified by expert opinion were also determined. Burrow availability, forage habitat quality and forage habitat availability were determined to be limiting factors; internest distance, vegetation height at the nest, and openness were identified as compensatory factors; while areal extent of the nest pasture, topography at the nest and perch availability were determined to be cumulative factors.

The model initially produced by this study incorporated all 9 variables in a geometric mean using the variable weights identified using expert opinion. Preliminary verification determined that the initial model was cumbersome and insensitive to changes in variable values. Areal extent of the nest pasture, topography of the nest area and perch availability were removed from the model to improve model function while openness and forage availability were incorporated indirectly into the model as stipulations guiding model application. Subsequent model construction focused on the four remaining variables. Field protocol guidelines were developed to guide field application of the model and address model assumptions.

5.1.3 Model Verification

Model verification was undertaken by creating an interactive computer program to determine individual variable SI values and a composite HSI value for a specific set of habitat parameters. Approximately 500 sets of habitat parameters were generated to explore utility and robustness of the model. An iterative process was used to modify model parameters until a robust and mathematically tractable HSI model was achieved.

The final HSI model aggregated burrow availability, forage vegetation height, nest vegetation height and internest distance using a geometric mean. A simpler model, excluding internest distance, was developed for nest sites where burrowing owls are not present. Verification of the final HSI models indicates that model development was successful as the models are robust, mathematically tractable and responsive to changes in variable values.

5.1.4 Model Validation

Model validation found that the HSI model successfully recognizes optimal burrowing owl habitat. Application of the HSI model to historic burrowing owl nest sites in Manitoba suggested that habitat suitability was most strongly compromised by the presence of tall vegetation at the nest burrow. Moderate cattle grazing appears to be critical to the maintenance of optimal vegetation height ($\leq$ 10cm). Historic nest sites subjected to cattle grazing during habitat sampling were identified as having greater habitat suitability than ungrazed sites, thus indicting that cattle grazing may enhance the suitability of burrowing owl breeding habitat. Cessation of cattle grazing on historically successful breeding habitat resulted in degraded habitats consisting of tall and lush grasses. The HSI model developed by this study was therefore used to assess historic burrowing owl nesting pastures and identified the habitat variables that compromise habitat suitability. In doing so, the burrowing owl HSI model was found to be successful in its application as a predictive habitat assessment tool.

Historic breeding burrowing owl habitat in southwestern Manitoba was determined to be slightly sub-optimal relative to the burrowing owl habitat available in southeastern Saskatchewan. Results suggest that a presence of excessively tall vegetation proximal to nest burrows functioned to compromise the suitability of Manitoba's historic burrowing owl habitat. Results also suggest that in areas where cattle grazing was active, vegetation was maintained at suitable levels and the conditions of historic breeding burrowing owl habitat were determined to be optimal. Hence, the slightly sub-optimal habitat conditions occurring on Manitoba's historic breeding burrowing owl nest sites could be improved with the use of grassland management efforts directed toward limiting vegetation height proximal to nest burrows to ≤10cm.

5.2 Conclusions

The results suggest that a modified Delphi method is a valid method to amass expert opinion for the purpose of identifying species habitat suitability information, developing SI curves and identifying variable interrelationships when such information is absent from published literature. However, the results suggest that the modified Delphi method as applied for the purpose of this study was not as effective as anticipated in reaching a consensus among Delphi participants. The failure of burrowing owl experts to reach a consensus may have been a result of participants' inability to express their complete viewpoints in the time allotted. Results suggest that more detailed opinions may have emerged later during the mail-out portion of the modified Delphi method when experts had more time to ponder their responses. The consensus building process was therefore confounded as the incorporation of new information functioned to draw the group further away from consensus on many issues instead of solidifying consensus among the burrowing owl experts. Future application of the modified Delphi method should consider limiting the time required to conduct the Delphi process.

Results of this study also indicate that a burrowing owl HSI model for use in southwestern Manitoba and southeastern Saskatchewan was successfully developed, verified and validated. Application of the model to burrowing owl breeding grounds in southeastern Saskatchewan and southwestern Manitoba determined that the model was capable of identifying optimal burrowing owl habitat and assessing the suitability of burrowing owl nest sites. Results suggest that historic burrowing owl nesting habitat in southwestern Manitoba is slightly sub-optimal, however vegetation management at historic nest sites such as cattle grazing or mowing that maintain consistently low vegetation height around the nest burrow may be instrumental in improving habitat suitability at the local level.

The HSI model developed by this study considers only the quality of habitat proximate to the nest burrow and does not provide commentary on habitat quality across the broader landscape. Many factors influence population distribution and dynamics, however the slightly sub-optimal habitat suitability level of historic burrowing owl nest sites does not appear to be the primary factor influencing burrowing owl population levels within the province. Instead, declines in burrowing owl populations in Manitoba and throughout the Canadian burrowing owl breeding range are thought to be the result of a combination of factors all operating at levels much larger than that addressed by the burrowing owl HSI model developed by this study. Management efforts directed toward improving burrowing owl habitat suitability at the local level are only a band-aid solution to a much larger problem or suite of problems occurring across the prairie landscape.

5.3 Recommendations

This research has answered a few questions, but larger questions still remain. Why is the Manitoba burrowing owl population in decline? What other factors are at work and can they be altered so that the burrowing owl population in Manitoba can be stabilized? Or is it simply that factors beyond the confines of Manitoba dictate what happens to the province's burrowing owl population? To determine what these factors are, the following recommendations are made, primarily to Manitoba Conservation, in an effort to better direct future management efforts of burrowing owl populations in the province:

1) Further validate HSI model

- The burrowing owl HSI model should be further validated in southwestern Manitoba using data collected in late April/early May. Burrowing owls select their nest burrows when they arrive on Manitoba breeding grounds and the model was designed to reflect the nest site selection process. Time constraints required that data from historic nest sites were collected in early June rather than late April/early May. Results of model validation indicate that historically successful burrowing owl nest sites are slightly sub-optimal due to a presence of tall vegetation at the nest burrow. However the longer growing period afforded to vegetation sampled by this study may have biased the calculation of habitat suitability by unjustly decreasing nest vegetation height suitability and producing lower site HSI values than would be present if data had been collected earlier in the growing season. Further validation of the model using data collected in late April/early May would produce results more indicative of the degree of habitat suitability present in southwestern Manitoba and may determine that historically successful habitat in the province is in fact, optimal.

- Small mammal population studies should be conducted to ensure that suitability index values associated with forage quality and availability are indicative of conditions typically associated with high concentrations of small mammal populations.

- The burrowing owl HSI model should be validated using data collected from a study site where multiple active burrowing owl nests are present. Study constraints did not allow the HSI model that includes internest distance to be validated. Before the model is applied for predictive purposes, validation of the HSI model that incorporates internest distance should be conducted to ensure proper model function and model predictability.

2) Enhance working relationships between landowners and conservation agencies

- Conservation agency biologists should work more closely with landowners who have either burrowing owls nesting on their land or historic burrowing owl nest sites on their property. Previous efforts directed toward landowner education appear to have been unsuccessful as landowners seemed to be unaware that land-use practices they were employing were detrimental to burrowing owl health and the maintenance of suitable burrowing owl habitat. Effective one-on-one communication with landowners to explain burrowing owl biology and answer questions regarding sustainable land-use practices directed toward the maintenance of grassland habitat for burrowing owls is necessary.

- Efforts directed toward burrowing owl habitat management need to be expanded to include land-owner involvement. Direct land-owner involvement in burrowing owl management is central to the preservation of the species on private lands across the eastern Canadian prairies and effective working relationships between landowners and conservation agencies are paramount.

- Conservation agencies should develop grassland habitat management initiatives to protect wildlife habitat that are in the economic interests of land-owners.

3) Management of burrowing owl habitat in southwestern Manitoba

- The nesting and foraging habitat requirements of burrowing owls identified by this study should be met by managing and protecting both existing and historic burrowing owl nest sites. Suitable nesting and foraging habitat also should be identified on private and public lands then protected in an unregulatory manner through close coordination and cooperation between conservation agencies and private landowners.

- Vegetation control mechanisms such as grazing or mowing should be applied to reduce vegetation heights on historically successful burrowing owl nesting areas in Manitoba. Where grazing is applied to control vegetation growth, it is recommended that rotational grazing be employed with burrowing owl nesting habitat being grazed either in late fall or early spring. Efforts directed toward the maintenance of reduced vegetation heights on burrowing owl nesting habitat could also be applied on hydro rights-of-way to increase burrowing owl habitat availability. This may increase the overall habitat suitability for the species in Manitoba, and in that way, may serve to enhance future population levels.

- Although insufficient burrow availability was rarely observed on historic burrowing owl nest sites in Manitoba, artificial nest burrows could be added to improve habitat suitability where burrow availability is limited. This management approach would function to improve the condition of otherwise optimal grassland habitat and could be employed to improve the suitability of hydro rights-of-way for nesting burrowing owls.

- Efforts directed toward the restoration and maintenance of burrowing owl habitat in southwestern Manitoba should be increased, as should efforts directed toward reducing the degree of large-scale habitat fragmentation occurring across the prairie landscape.

- Further research into landscape level habitat fragmentation and the conditions facing burrowing owls along migration routes and on wintering grounds should be conducted to identify the factors impacting burrowing owl populations in areas other than the breeding grounds.

Results of this study indicate that grassland habitats in southwestern Manitoba are highly suited to meeting the nesting and foraging habitat requirements of the burrowing owl. Despite this, the number of burrowing owls nesting in Manitoba continues to decline and the population may soon become extirpated. Declines in burrowing owl populations across the Canadian breeding range of the species indicate that something operating on a much larger scale than the level examined by this study is at the root of burrowing owl population reductions.

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Appendix 1

Burrowing Owl HSI Computer Program

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REM PROGRAM FOR HABITAT SUITABILITY INDEX
REM TANYS UHMANN 1999
REM INPUT PARAMETERS ARE:
REM S1 = FORAGE VEGN HT, S2 = VEGN HT AT NEST,
REM S3 = NO. BURROWS PER AREA, S4= INTERNEST DISTANCE
WINDOW 1,, (0,0)-(400,400)
REM INPUT PARAMETERS
PRINT "PROGRAM NAME IS TANYS"
PRINT "IF INTERNEST DISTANCE IS AVAILABLE, TYPE 1 IF NOT TYPE 0";
INPUT Q
I=0
"CONT" I=I+1: PRINT "RUN NUMBER ";I
PRINT "--------------------------------------------------"
PRINT: PRINT "SPECIFY FORAGE VEGETATION HEIGHT (CM): ";
INPUT VH!
PRINT "SPECIFY VEGETATION HEIGHT AT NEST (CM): ";
INPUT VN!
PRINT "SPECIFY NO. BURROWS PER HECTARE: ";
INPUT NB!
IF Q=1 THEN PRINT "SPECIFY INTERNEST DISTANCE (M):";
IF Q=1 THEN INPUT ID!
REM FORAGE VEGETATION HEIGHT S1
IF VH!>65. THEN VH!=65.
S1!=1.
IF VH!<25. THEN S1!=0.04*VH!
IF VH!>40. THEN S1!=2.6-0.04*VH!
IF VH!>65. THEN S1=0.
REM VEGETATION HEIGHT AT NEST S2
IF VN!=0. THEN "SKIP"
S2!=2.006-.560*(LOG(VN!))
"SKIP" IF VN!<=6 THEN S2!=1.
IF VN!>36 THEN S2!=0.
REM NUMBER OF BURROWS S3
S3!=0.216*NB!^0.346
IF NB!>80. THEN S3!=1.
IF Q<> 1 THEN "NONEST"
REM INTERNEST DISTANCE S4
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```
S4!=1.
IF ID!> 100 THEN ID!=100
S4!=0.01*ID!
IF ID!<10. THEN S4!=0.1
"NONEST" REM COMPUTE VALUES AND PRINT THE RESULTS ONTO THE
SCREEN
SI!=(S1!*S2!^.8*S3!)
IF Q=1 THEN SI!=SI!*S4!^.5
HSI!=SI!^(1/2.8)
IF Q=1 THEN HSI=SI!^(1/3.3)
PRINT "-----------------":PRINT "HSI = ";HSI!:PRINT "-----------------"
PRINT "VEG FORAGE HT = ";VH!;"CM, S1 = ";S1!
PRINT "VEG AT NEST HT = ";VN!;"CM, S2 = ";S2!
PRINT "BURROW AVAILABILITY = ";NB!;", S3 = "; S3!
IF Q=1 PRINT "INTERNEST DIST = ";ID!;"M, S4 = ";S4!
PRINT
PRINT "TYPE 1 TO CONTINUE, 0 TO END PROGRAM"
INPUT C
IF C=1 THEN "CONT"
END
```