Habitat Fragmentation and the Burrowing Owls (*Speotyto cunicularia*) in Saskatchewan

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Abstract.—The relationship between landscape (125,664 ha circular plots) fragmentation patterns and the spatial distribution of Burrowing Owls (Speotyto cunicularia) was investigated in the heavily fragmented grasslands of Saskatchewan. Data were collected from 152 Burrowing Owl sites and 250 random sites located on 1990 LANDSAT-TM satellite images and 1:250,000 scale topographic maps. Habitat continuity, patch dimensions and isolation of sites were characterized by 15 variables. The stepwise discriminant function analyses showed that owls were not nesting randomly across the landscape. Habitat continuity and patch dimensions were more important than isolation in describing differences between owl and randomly selected sites within the core, but not in the periphery. The preferred soil type for nesting, lacustrine, was more limited in the core range which may also influence the nesting distribution of Burrowing Owls. These results suggest that Burrowing Owls chose the best remaining and not the largest pieces of habitat, near other owl sites.

Worldwide, habitat destruction is considered a major cause of wildlife extinctions (Wilson 1989). Habitat fragmentation is the process by which a large and continuous block of natural habitat is transformed into much smaller and isolated patches by human activity (Noss and Csuti 1994). However, wildlife populations may decline not only when habitats are directly eliminated, but also when natural habitats are fragmented to varying degrees. Habitat fragmentation is an important issue in modern conservation biology because the impacts on wildlife populations can be greater than what is predicted based on the area of the habitat removed alone (Robinson et al. 1992).

Due to agriculture, The Great Plains of North America is one of the most heavily modified and fragmented ecosystems in the world (Rowe 1987). These grasslands have variable, sometimes high, plant species diversity because of differences in climatic conditions, topography, soil parent material, and the frequency and intensity of disturbances such as fire (Risser 1988). However, a greater proportion of the avifauna in grasslands has been declining in the last few decades than avifauna in forest habitats (Askins 1993, Herkert 1995, Knopf 1994, Warner 1994). Modern agricultural practices, reduction of grassland habitats into smaller and more isolated patches, removal of native grazers, fire suppression, the expansion of woody vegetation, and recent increases in some predators and brood parasites are often cited as possible causes of these declines (Herkert 1994, Knick and Rotenberry 1995, Knopf 1994, Miller et al. 1994, Vickery et al. 1994, Warner 1994).

Some raptor species respond quickly to habitat degradation including fragmentation because of their high trophic positions, low densities and large area requirements (Newton 1979). In North America, studies have shown or suggested sensitivity to habitat fragmentation at a local or study site scale in Northern Spotted Owls (Strix occidentalis caurina) (e.g., Hunter 1995 et al., Lehmkuhl and Raphael 1993), Flammulated Owls, (Otus flammeolus) (Shafer

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1993), Barn Owls (Tyto alba) (Colvin 1985), Short-eared Owls (Asio flammeus) (Robinson 1991), Northern Harriers (Circus cyaneus) (Robinson 1991), Ferruginous Hawks (Buteo regalis) (Schmutz 1987) and Swainson's Hawks (Buteo swainsoni) (Schmutz 1987), and Burrowing Owls (Speotyto cunicularia) (James 1993, Warnock 1996).

The Burrowing Owl uses mammal burrows in well-drained grasslands and agricultural areas from Canada to Argentina and Chile (Haug et al. 1993). Because they are often found in farmland, the Burrowing Owl was believed to be more tolerant of cultivation than other raptors (Lepitch 1994). However, the Burrowing Owl population has declined precipitously in Canada from 2,500 pairs to about 1,000 pairs over the last decade (Wellicome and Haug 1995). Due to this trend, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) classified the Burrowing Owl as an endangered species (Wellicome and Haug 1995). A demographic model of Saskatchewan Burrowing Owls predicts extirpation within 20 years (James et al., in press).

The present extent of Burrowing Owl breeding habitat is estimated at only 27 per cent of the prairies in Saskatchewan (Wellicome and Haug 1995). It should be noted that this estimate includes land that is not suitable for Burrowing Owls (e.g., rocky soil, hilly terrain, regularly flooded lowland). As a result, cultivation of Burrowing Owl habitat has occurred more quickly (up to 3 per cent per year from 1979 to 1986) than the rate of reduction in pasture land suggests (0.8 percent per year between 1966 and 1991) (Hjertaas and Lyon 1987, Wellicome and Haug 1995). Lacustrine soils make ideal habitat for primary burrowers' and support the largest number of Burrowing Owls compared with other soil types (Wellicome and Haug 1995). However, these soils are heavily fragmented because they make choice farmland.

The purpose of this study was to examine the relationships between habitat continuity, patch dimensions, isolation, and the spatial distribution of 152 Burrowing Owl sites in Saskatchewan at a large landscape scale (125,664 ha area). Specifically, we wanted to detect any differences between randomly-selected locations and owl locations in the core and peripheral portions of the owl range, and relate the results to Burrowing Owl ecology and management.

METHODS

Data Collection and Processing

Operation Burrowing Owl (OBO) is a private land stewardship program designed to protect and enhance Burrowing Owl nesting habitat (Dundas 1996). It is the only available data set with many nesting sites from the current Burrowing Owl range in Saskatchewan (about 169,000 km^2). It contains information about the number of nesting pairs since 1987 at each OBO site. We mapped 1,144 owl breeding sites onto 1:250,000 scale topographic maps and found them on 19 1990 LANDSAT-TM satellite images. The satellite images were taken in the fall of 1990. It was assumed that those habitat patterns in 1990 were constant and representative for the whole period. Of course, this was not strictly true as habitat loss and fragmentation continued over this period. In addition, habitats in the satellite images were classified as potential owl breeding habitat (pasture/grassland) and non-owl habitats (all other cover types) based on known Burrowing Owl habitat preferences (Haug et al. 1993).

A projector called a Pro-Com 2 (Glengarry GeoScience Ltd., Ottawa) was used to magnify the images to a scale of 1:125,000, and project the images onto a table for the recording of habitat patterns. This scale was selected because it gave the best compromise between magnification and resolution. Scale is important because it influences the questions that can be addressed, procedures followed, the observations obtained, and the interpretation of the results (Andren 1994). At this scale, patch size of 4 ha and a linear distance of 200 m represents the lowest limit of resolution for accurate measurement purposes. The upper limit of resolution was 125,664 ha (20 km radius).

Plot size selection was determined by fine or coarseness of the landscape and the acquisition of statistically adequate sample sizes. To resolve these issues, the foraging plot size of 2.7 km radius (2,290 ha area) and the dispersal plot size of 20 km radius (125,664 ha area) were used in this study. The foraging plot size was based on the maximum foraging distance of Burrowing Owls in Saskatchewan

(Haug and Oliphant 1990). The dispersal plot size was based on our unpublished median year to year breeding dispersal distance of owls in Saskatchewan (James, unpubl. data).

We selected 117 OBO sites with 7 years (1987-1993) of complete data plus an additional 35 OBO sites with 6 years of data, to maximize sample sizes. If the plots of individual owl sites did overlap 50 or more percent at the 20 km radius, only one site was selected. The selection was based on the site with the maximum number of years of verified owl data. If they were the same, one site was randomly selected. This was done in an attempt to control for statistical independence of random and owl locations. Two hundred and fifty random sites of any habitat, not occupied by owls, were also selected from the satellite image and located on the 1:250,000 scale topographic maps.

An arbitrary minimum owl site density was used to classify random and OBO (owl) sites as either core or peripheral. Areas with a minimum OBO site density of 1.5 per 1,000 km^2 or greater were classified as core. The OBO density of 1.5 sites per 1,000 km^2 is equivalent to six OBO sites per quadrat (about 4,000 km^2) in figure 1. The peripheral portion of the owl range was defined by an OBO site density of less than 1.5 sites per 1,000 km^2 (fig. 1).

All habitat patterns and all OBO sites within a 20 km radius of the 152 selected OBO sites and the 250 random locations were recorded onto white sheets ("habitat sheets") at the selected scale of 1:125,000. A planimeter was used to measure areas of natural habitat patches. A digital measuring wheel was used to measure edges of natural habitat patches and distances between natural habitat patches. The shortest edge to edge distances were measured between habitat patches. Distances between owl sites were measured on the 1:250,000 scale topographic maps.

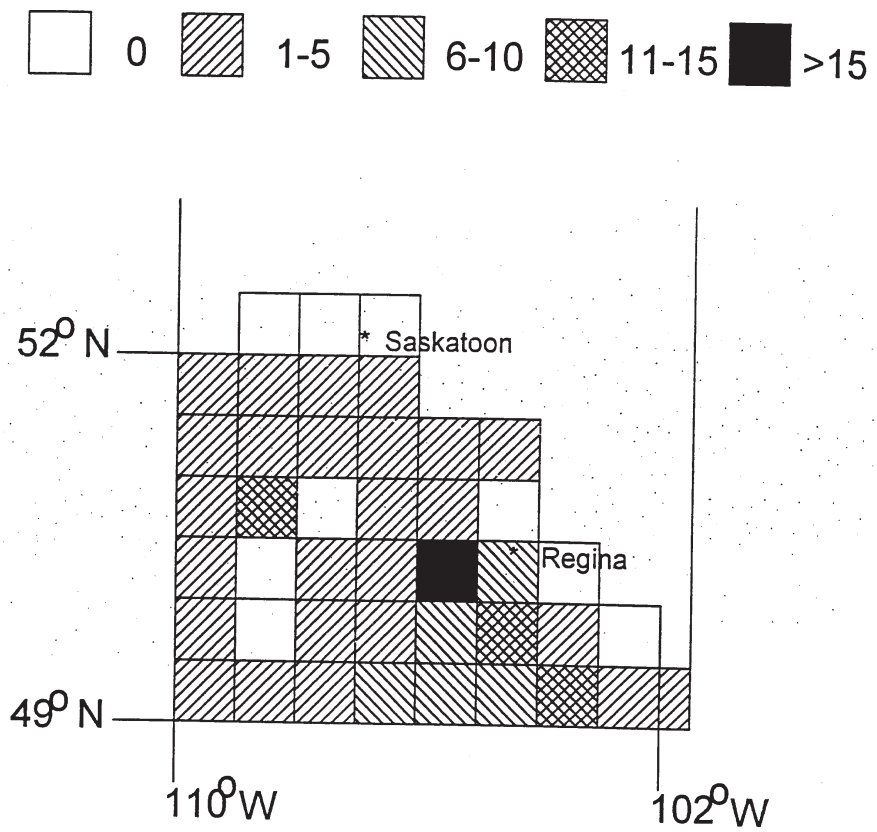

Figure 1.—Numbers and distribution of occupied sites or "colonies" as reported by Operation Burrowing Owl in Saskatchewan in 1993. Each square represents a quarter of a 1:250,000 scale map sheet. The core portion of the Saskatchewan Burrowing Owl (Speotyto cunicularia) range was delineated by squares with six or more sites in 1993 (modified from Wellicome and Haug 1995).

Previous work has shown that continuity, patch dimensions and isolation of natural habitat patches can have important effects on animal populations (see Herkert 1994, Knick and Rotenberry 1995, Vickery et al. 1994). Continuity of habitats within the two plot sizes (2,290 and 125,664 ha) for each owl and random site was measured with four variables: percent grassland (%G 20), total area to total edge ratio (A/E), number of patches (No.P.), and percent grassland to number of patches ratio (%G/No.P) (table 1). Area (AOP), perimeter or edge (EOP), and shape (AOP/EOP) of patches were measured for patches containing either a selected owl or a random site (table 1). Three common isolation measures were used in this study: distance to the nearest patch (DNP), distance to the second nearest patch (DNNP), and distance to the nearest owl site (DNO) (table 1). The number of owl sites (No. Sites) were counted within a 20 km radius of an owl or random site (table 1). The number of sites is another indicator of isolation because the number of nearby known sites should decline with increased habitat fragmentation.

Statistical Analyses

This study was correlative in nature; thus cause and effect were inferred rather than experimentally demonstrated unlike Diffendorfer et al. (1995) and Robinson et al. (1992). Four assumptions for parametric univariate and multivariate analyses were examined: randomness and independence of sites, the normality of variables (Shapiro-Wilks' W test), and the equality of variances (Levene's test). Data were log or square root transformed to normalize the data where possible (table 1). Unless indicated, all statistical procedures were run with Statistica for Windows (StatSoft Inc. 1994).

Previous work showed that core and peripheral portions of the owl range were significantly different in patterns of habitat fragmentation (Warnock 1996). Tukey's Honest Significant Difference (HSD) (a variant of ANOVA) test for unequal sample sizes was used for normalized variables. The nonparametric Mann-Whitney U-test was used for variables that could not be normalized through transformations (Sokal and Rohlf 1981). These univariate tests were used to compare owl sites and random sites. Multivariate stepwise discriminant function analysis (DFA) is commonly used to assess the effectiveness of variable sets in discriminating between groups. Two DFAs were used to find out which measured components were most correlated with the discrimination of owl and random

Table 1.—Abbreviations and units of variables used in Saskatchewan Burrowing Owl (Speotyto cunicularia) study.

Variable	Description
%G	Percent grassland. (log transformed at 20 km radius and non-transformed at 2.7 km radius.)
A/E	Total area to total edge ratio in ha/km. (log transformed at 20 km radius and non-transformed at 2.7 km radius).
No.P.	Number of patches. (log transformed at 20 km radius and non-transformed at 2.7 km radius).
%G/No.P	Percent grassland to number of patches ratio. (log transformed at 20 km radius and non-transformed at 2.7 km radius).
AOP	Area of patch containing either an owl or random location in ha. (Non-transformed).
EOP	Total edge of patch containing either an owl or random location in ha. (Non-transformed).
AOP/EOP	Area to edge ratio for owl or random patch in ha/km. (Non-transformed).
DNP	Distance to the nearest patch in km. (Square-root transformed).
DNNP	Distance to the second nearest patch in km. (Square-root transformed).
DNO	Distance to the nearest owl location in km. (Log transformed).
No. Sites	Number or nearby owl sites within 20 km radius. (Non-transformed).
N	Sample Size

A 20 km radius is based on the median breeding dispersal of owls and a 2.7 km radius is based on the maximum foraging distance of owls. Untransformable refers to an inability to obtain a normal distribution of data or a skewed distribution due to small sample sizes. Logarithmic (log) and square-root transformations were used to normalize variables where possible for analyses.

locations in the core and peripheral owl ranges in Saskatchewan. A chance corrected classification was used to remove the effects of chance on statistical significance of each DFA (Titus et al. 1984).

RESULTS AND DISCUSSION

Peripheral owl sites had much greater (P < 0.05) continuity of natural habitat within a 20 km radius (%G) than peripheral random locations (table 2). This result is consistent with the habitat fragmentation hypothesis. With this hypothesis, one can predict more habitat around nest sites of habitat fragmentation sensitive species than random locations. For example, similar results were obtained in several habitat patterns studies of the Northern Spotted Owl, a habitat fragmentation sensitive species (e.g., Hunter et al. 1995, Lehmkuhl and Raphael 1993).

In the core owl range, owl locations had much lower continuity of habitat (P < 0.05) within a 20 km radius with smaller A/E and %G/No.P ratios and larger number of patches (table 2). Patch dimensions of core owl locations were much smaller (P < 0.05) than random locations (AOP and AOP/EOP) (table 2). These results support the reported field observations of Saskatchewan Burrowing Owls nesting in small habitat patches (Haug, 1985, Houston et al. 1996). Similar results were shown for the Great Horned Owl (Bubo virginianus) (Hunter et al. 1995). If one accepts the habitat fragmentation hypothesis, larger numbers of a 'sensitive' species should be in contiguous and less isolated patches (e.g., Hanski 1994). A variety of factors could explain the distribution of core owl locations. They include habitat quality effects on habitat selection (see below) and bias in having Operation Burrowing Owl sites in a very fragmented natural landscape in the core Burrowing Owl range in Saskatchewan.

It appeared that owls prefer more fragmented but less isolated habitat in the core (table 2). This preference may be due to habitat selection at a lower scale where burrow and prey availability (related to soil type), are the primary determinants. Abundance of Burrowing Owls is probably greatest with lacustrine soils, because of higher burrow availability (Wellicome and Haug 1995). Soil types appeared to be a factor in Burrowing Owl abundance and distribution by determining the presence of ground squirrels, voles, and deer mice (Laundre and Reynolds 1993). Also, previous work showed that proportions of the major soil types did differ significantly between the core

Table 2.—Significant differences between Burrowing Owl (Speotyto cunicularia) and random sites in the core and peripheral ranges in Saskatchewan (P < 0.05).

Core range			Peripheral range		
Variable	**Owl**	**Random**	**Variable**	**Owl**	**Random**
N	57	53	N	95	197
A/E20*	56.27 ± 3.49	73.19 ± 5.26	%G20*	19.20 ± 1.33	16.19 ± 1.23
No.P20*	52.05 ± 1.98	38.24 ± 1.64	DNO*	5.75 ± 0.52	23.10 ± 1.93
%G/NoP20*	0.34 ± 0.04	0.61 ± 0.08	No.Sites#	6.02 ± 0.41	3.21 ± 0.26
No.P2.7#	2.49 ± 0.18	1.74 ± 0.13			
AOP#	2403 ± 790	8022 ± 3079			
AOP/EOP#	27.52 ± 5.87	43.21 ± 8.53			
DNP*	1.21 ± 0.12	1.88 ± 0.17			
DNNP*	2.01 ± 0.16	2.65 ± 0.12			
DNO	3.83 ± 0.57	5.31 ± 0.55			

Reported means of landscape characteristics (± 1 SE). are untransformed.
* = Tukey's Honest Significant Difference for unequal sample sizes (ANOVA).
# = Mann-Whitney U-test.
20 = 20 km radius. 2.7 = 2.7 km radius.

and the periphery ($P < 0.05$). Specifically, the core had significantly less of the primary burrowers' (ground squirrels) preferred lacustrine soil type (22.7 per cent of landscape) than the peripheral range (33.7 per cent of landscape) (Warnock 1996). Lacustrine soils make ideal burrow substrates and farmland because they are flat, have few rocks and are sandy or silty loam soils (Wellicome and Haug 1995). These results suggest that optimal Burrowing Owl habitat is more limiting and that owls could be selecting the best remaining not the largest blocks of habitat in the core range. In other words, more Burrowing Owls have been found in small uncultivated patches with lacustrine soils than any other cover type.

However, nesting in small natural patches may have additional risks. For example, Haug (1985) found that Burrowing Owl home range size increased with the percentage of cultivation. In fragmented landscapes, Burrowing Owls may forage greater distances and spend more time away from the nest, making them more vulnerable to predators, and therefore, less efficient at reproduction. Some highly fragmented owl locations used in this study had very many pairs from 1987 to 1993. Higher raptor densities in small habitat fragments have been reported before in the literature (e.g., James 1993, Loman 1991). Crowding into small patches can increase foraging interference, aggression, and conspecific predation (Saunders et al. 1991). Intraspecific competition is thought to be a major cause of nest abandonment and low productivity of dense Burrowing Owl colonies (Green and Anthony 1989). High densities of nests may attract predators while lower densities would force the predators to concentrate on their staple prey (Sugden and Beyersbergen 1986). Stochastic events such as flooding and predation are also likely to increase the probability of nest site abandonment by Burrowing Owls from small habitat fragments (Hinsley et al. 1995). These events may explain the population decline of the Burrowing Owl in Saskatchewan (Warnock 1996).

In highly fragmented areas, such as the core of the range, edges becomes important. Edge habitats predominate in fragmented landscapes. Many studies have shown that artificial nests (e.g., Burger et al. 1994) and natural nests (Johnson and Temple 1990) suffer greater predation rates when placed near edges. Owls nesting near edges would suffer greater predation because predators have been shown to search more thoroughly along pasture edges near cover (Sugden and Beyersbergen 1986). Nest predation is a major cause of nest failure and abandonment in Burrowing Owls (Green and Anthony 1989, Wellicome and Haug 1995). Burrowing Owls do not avoid pasture edges because their breeding season does start before crop seeding begins, when visibility is still good near cultivated fields, thus they may be adversely affected by edge effects (Wellicome and Haug 1995).

Peripheral owl sites were near more owl sites (No.Sites) than random locations in the periphery (table 2). Isolation was much lower ($P < 0.05$) for owl sites than for random locations in the core (DNP, DNNP, and DNO) and peripheral portions of the range (DNO) in Saskatchewan (table 2). Isolation may be less important in the core because the fragments although smaller are closer together and owl site density (although declining, Warnock 1996) was greater than in the periphery. Nesting near other owls in the periphery may be important for successful dispersal and pairing success (Faaborg et al. 1993). A reduced amount of isolation was also important for the presence of several tall-grass prairie birds (Sampson 1980), and Columbian ground squirrels (Spermophilus columbians (Ordi)) (Weddell 1991) in natural habitat patches.

Two stepwise DFAs (table 3) correctly classified more owl and random sites than predicted by chance alone in the core and periphery ($P < 0.05$) (Titus et al. 1984). The following variables (and their correlation coefficients) were important in distinguishing core owl locations and core random locations: the number of patches in a 20 km radius (0.743), isolation (DNNP (0.739), DNO (0.663)), and patch dimensions (AOP/EOP (0.648)). In the periphery, the following variables (and their correlation coefficients) were important in distinguishing owl locations from random locations: isolation (DNO (0.888)), number of patches in a 2.7 km radius (0.727), continuity of habitat (%G/No.P (2.7) (0.744), (A/E (20) (0.733)), and the patch area (AOP, (O.723)). These results suggest that Burrowing Owls were not nesting randomly across the landscape (tables 2 and 3). These results are supported by Duncan (1995) who mapped known owl sites in the last 7 to 14 years on the Canadian prairies. For example, there were well-defined concentrations of Burrowing Owl sites and large tracts in the

Table 3.—Stepwise discriminant function analyses of core and peripheral Burrowing Owl (Speotyto cunicularia) sites in Saskatchewan.

Core sites		Peripheral sites	
Group	**Correctly classified**	**Group**	**Correctly classified**
Owl (N = 57)	78.95%	Owl (N = 110)	47.74%
Random (N = 95)	77.36%	Random (N = 197)	91.33%
Total (N = 110)	78.18%	Total (N = 292)	76.71%
Z=	5.57	Z=	5.90
P=	0.0001	*P*=	0.0001

peripheral area that seemed lacking owls. It is likely that the spatial arrangement (tables 2 and 3) and the habitat quality of patches and historical and stochastic processes likely influence owl distribution, once the locational bias in the OBO database is removed (Hinsley et al. 1995).

Owl sites may be more limited in the periphery than in the core because most owl sites were 'misclassified' a posteriori by the DFA model as random sites (table 3). Habitat modification at distant sites could affect the distribution of existing Burrowing Owl sites by increasing the distance between sites and thus decreasing the probability of dispersal between owl sites. Isolation interrupts the flow of individuals between patches and lowers the probability of individuals dispersing from or into them (Fahrig and Merriam 1994). Burrowing Owls can travel the distances between patches and owl sites. However, isolation increases predation exposure, increases delays in finding another owl colony, nest burrow, or mate, and lowers the feeding efficiency. This may help to explain nesting in sub-optimal habitats such as roadsides, cropland or fallow (Wellicome and Haug 1995). In short, isolation may determine how much risk associated with dispersal, and thus the year-to-year occupancy of owl sites (Faaborg et al. 1993).

CONSERVATION IMPLICATIONS

Burrowing Owls have the capacity for rapid population recovery because of their high reproductive potential and their broad prey spectrum (Wellicome and Haug 1995). We recommend that management focus on the core portion of the Burrowing Owl range in Saskatchewan because the core contains most of the remaining owls and the population decline there is less severe (Warnock 1996). Stabilizing the core population will be critical for the long-term conservation of the species in Saskatchewan. The core will likely serve as a 'source' where reproductive output is greater than mortality. Such sources have maintained regional populations of Midwestern forest songbirds (Robinson et al. 1995). The results of this study suggest that maximizing the continuity of habitat and increasing the number of accessible patches with optimal dimensions in the core range would be a good strategy.

The conservation of the Burrowing Owl has a high level of support in Saskatchewan and many habitat patches are already protected under Operation Burrowing Owl (Wellicome and Haug 1995). However, additional patches in private and public ownership could be protected. Most of the known Burrowing Owl sites are on private land (an artifact of OBO). The provincial and federal governments hold title to most of the remaining large prairie blocks in Saskatchewan but the distribution of Burrowing Owls on these lands is poorly known (Wellicome and Haug 1995). To increase the continuity of Burrowing Owl habitat, additional private and public Burrowing Owl habitat needs to be identified and protected through close coordination and cooperation between conservation agencies and private landowners and Crown land leasees.

If the core population is stabilized, the focus could then shift to persistent peripheral owl sites. Occupancy can be enhanced by increasing habitat quality, lowering isolation between nearby owl sites and the source population, minimization of fragmentation in the maximum foraging distance and minimization of patch edges of persistent owl sites. We would hope

that these would become mini-sources within the periphery.

In conclusion, it appeared that patterns of habitat fragmentation affected the abundance and distribution of owl sites. Therefore, it is likely that habitat fragmentation on the breeding grounds has been a major contributing factor in the decline of Burrowing Owl in Saskatchewan. However, remember that the study was correlative in nature, and thus cause and effect relationships were inferred rather than proved. Demographic parameters for Burrowing Owls are only now being quantified and the understanding of the relationship between habitat fragmentation and demographic processes require more work (James et al. 1997). The conservation of the Burrowing Owl and the prairie ecosystem are intertwined. We can reduce the impacts of habitat fragmentation on Burrowing Owls and costs of their recovery by creating and protecting additional grassland habitat.

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LITERATURE CITED

Andren, H. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. Oikos. 71: 355-366.

Askins, R.A. 1993. Population trends in grassland, shrubland and forest birds in eastern North America. Current Ornithology. 11: 1-34.

Burger, L.D.; Burger, L.W., Jr.; Faaborg, J. 1994. Effects of prairie fragmentation on predation on artificial nests. Journal of Wildlife Management. 58: 249-254.

Colvin, B.A. 1985. Common Barn Owl population decline in Ohio and the relationship to agricultural practices. Journal of Field Ornithology. 56: 224-235.

Diffendorfer, J.E.; Gaine, M.S.; Holt, R.D. 1995. Habitat fragmentation and movements of three small mammals (Sigmodon, Microtus and Peromyscus). Ecology. 76: 827-839.

Duncan, J.R. 1995. Burrowing Owl nesting distribution map for the prairie provinces. Winnipeg, MB: Manitoba Department of Natural Resources.

Dundas, H. 1996. 1995 Saskatchewan Operation Burrowing Owl annual report. Regina, SK: Nature Saskatchewan.

Faaborg, J.; Brittingham, M.; Donovan, T.; Blake, J. 1993. Habitat fragmentation in the temperate zone: a perspective for managers. In: Finch, D.M.; Stangel, P.W., eds. Status and management of Neotropical migratory birds; 1992 September 21-25; Estes Park, CO. Gen. Tech. Rep. RM-229. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 331-338.

Fahrig, L.; Merriam, G. 1994. Conservation of fragmented populations. Conservation Biology. 8: 50-59.

Green, G.A.; Anthony, R.G. 1989. Nesting success and habitat relationships of Burrowing Owls in the Columbia Basin. Condor. 91: 347-351.

Hanski, I.K. 1994. Patch occupancy dynamics in fragmented landscapes. Trends in Ecology and Evolution. 9: 131-135.

Haug, E.A. 1985. Observations on the breeding ecology of Burrowing Owls in Saskatchewan. Saskatoon, SK: University of Saskatchewan. M.S. thesis.

Haug, E.A.; Millsap, B.A.; Marte, M.S.,II. 1993. Burrowing Owl (Speotyto cunicularia). In: Poole, A.; Gill, F., eds. The birds of North America. No. 61. Philadelphia, PA: The Academy of Sciences; Washington, DC: The American Ornithologists Union.

Haug, E.A.; Oliphant, L.W. 1990. Movements, activity patterns, and habitat use of Burrowing Owls in Saskatchewan. Journal of Wildlife Management. 54: 27-35.

Herkert, J.R. 1994. The effects of habitat fragmentation on midwestern grassland communities. Ecological Applications. 4: 461-474.

Herkert, J.R. 1995. Analysis of midwestern breeding bird population trends: 1966-1993. American Midland Naturalist. 134: 41-50.

Hinsley, S.A.; Bellamy, P.E.; Newton, I. 1995. Bird species turnover and stochastic extinction in woodland fragments. Ecography. 18: 41-50.

Hjertaas, D.; Lyon, W. 1987. A stratified random survey for Burrowing Owls. Saskatchewan Wildlife Branch Tech. Rep. 87-2. Regina, SK: Saskatchewan Parks and Renewable Resources.

Houston, C.S.; Hjertaas, D.G.; Scott, R.L.; James, P.C. 1996. Experience with Burrowing Owl nest-boxes in Saskatchewan with comment on decreasing range. Blue Jay. 54: 136-140.

Hunter, J.E.; Gutiérrez, R.J.; Franklin, A.B. 1995. Habitat configuration around Spotted Owl sites in northwestern California. Condor. 97: 684-693.

James, P.C. 1993. Habitat fragmentation and Burrowing Owls in Saskatchewan. In: Holroyd, G.L.; Dickson, H.L.; Regnier, M.; Smith, H.C., eds. Proceedings of the 3d prairie conservation and endangered species workshop; 1992 February; Brandon University, Brandon, MB. Natl. Hist. Occas. Pap. 19. Edmonton, AB: Provincial Museum of Alberta: 193-194.

James, P.C.; Ethier, T.J.; Toutloff, M.K. 1997. Parameters of a declining Burrowing Owl population in Saskatchewan. Journal of Raptor Research Report. 9: 34-37.

Johnson, R.G.; Temple, S.A. 1990. Nest predation and brood parasitism of tallgrass prairie birds. Journal of Wildlife Management. 54: 106-111.

Knick, S.T.; Rotenberry, J.T. 1995. Landscape characteristics of fragmented shrub-steppe habitats and breeding passerine birds. Conservation Biology. 9: 1059-1071.

Knopf, F.L. 1994. Avian assemblages on altered grasslands. Studies in Avian Biology. 15: 247-257.

Laundre, J.W.; Reynolds, T.D. 1993. Effects of soil structure on burrow characteristics of five small mammal species. Great Basin Naturalist. 53: 358-366.

Lehmkuhl, J.F.; Raphael, M.G. 1993. Habitat pattern around Northern Spotted Owl locations on the Olympic Peninsula, Washington. Journal of Wildlife Management. 57: 302-315.

Lepitch, D.J. 1994. Agricultural development and its influence on raptors in southern Idaho. Northwest Science. 68: 167-171.

Loman, J. 1991. Small mammal and raptor densities in habitat islands: area effects in a south Swedish agricultural landscape. Landscape Ecology. 5: 183-189.

Miller, B.; Ceballos, G.; Reading, R. 1994. The prairie dog and biotic diversity. Conservation Biology. 8: 677-681.

Newton, I. 1979. Population ecology of raptors. Vermillion, SD: Buteo Books.

Noss, R.F.; Csuti, B. 1994. Habitat fragmentation. In: Meffe, G.K.; Caroll, C.R., eds. Principles of conservation biology. Sunderland, MA: Sinauer Associates: 237-264.

Risser, P.G. 1988. Diversity in and among grasslands. In: Wilson, E.O.; Peter, F.M., eds. Biodiversity. Washington, DC: National Academy Press: 176-180.

Robinson, G.R.; Holt, R.D.; Gaines, M.S.; Hamburg, S.P.; Johnson, M.L.; Fitch, H.S.; Martinko, E.A. 1992. Diverse and contrasting effects of habitat fragmentation. Science. 257: 524-526.

Robinson, S.K. 1991. Effects of habitat fragmentation on midwestern raptors. In: Pendleton, B.G.; Krahe, D.L., eds. The midwest raptor management symposium and workshop. Sci. Tech. Ser. 15. Washington DC: National Wildlife Federation: 195-202.

Robinson, S.K.; Thompson, F.R., III; Donovan, T.M.; Whitehead, D.R.; Faaborg, J. 1995. Regional forest fragmentation and the nesting success of migratory birds. Science. 267: 1987-1990.

Rowe, J.S. 1987. One hundred years of land use. Blue Jay. 45: 127-139.

Sampson, F.B. 1980. Island biogeography and the conservation of prairie birds. In: Kucera, C.L., ed. Proceedings of the 7th North American prairie conference; 1980 August 4-6; Springfield, MO: Southwest Missouri State University: 293-299.

Saunders, D.A.; Hobbs, R.J.; Margules, C.R. 1991. Biological consequences of ecosystem fragmentation: a review. Conservation Biology. 5: 18-32.

Schmutz, J.K. 1987. The effects of agriculture on Ferruginous and Swainson's hawks. Journal of Range Management. 40: 438-440.

Shafer, A-L. 1993. Effects of landscape composition and fragmentation on owl species distribution of the Dixie National Forest. Utah. Logan, UT: Utah State University. M.S. thesis.

Sokal, R.; Rohf, F.J. 1981. Biometry. 2d ed. New York, NY: W.H. Freeman and Company.

StatSoft Inc. 1994. Statistica for windows. Tulsa, OK: StatSoft Inc.

Sugden, G.L.; Beyersbergen, G.W. 1986. Effect of density and concealment on American Crow predation of simulated nests. Journal of Wildlife Management. 50: 9-14.

Titus, K.; Mosher, J.A.; Williams, B.K. 1984. Chance corrected classification for use in discriminant analysis: ecological applications. American Midland Naturalist. 111: 1-7.

Vickery, P.D; Hunter, M.L., Jr.; Melvin, S.M. 1994. Effects of habitat area on the distribution of grassland birds in Maine. Conservation Biology. 8: 1087-1097.

Warner, R.E. 1994. Agricultural land use and grassland habitat in Illinois: future shock for midwestern birds? Conservation Biology. 8: 147-156.

Warnock, R.G. 1996. Spatial, temporal and turnover dynamics of Burrowing Owl (Speotyto cunicularia) distribution in the extensively fragmented grasslands of Saskatchewan. Regina, SK: University of Regina. M.S. thesis.

Weddell, B.J. 1991. Distribution and movements of Columbian ground squirrels (Spermophilus columbians (Ordi)): are habitat patches like islands? Journal of Biogeography. 18: 385-394.

Wellicome, T.I.; Haug, E.A. 1995. Updated report on the status of the Burrowing Owl (Speotyto cunicularia) in Canada.Ottawa, ON: Committee on the Status of Endangered Wildlife in Canada.

Wilson, E.O. 1989. Threats to biodiversity. Scientific American. 261(3): 108-116.