Effects of Road Type and Distance on Waterfowl Nesting Success

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Abstract

Habitat fragmentation of the Prairie Pothole Region (PPR) has resulted in decreased waterfowl nesting habitat with increased habitat edges. Few studies have examined how anthropogenic edges such as roads affect nesting waterfowl. This study followed the fate of naturally occurring waterfowl nests (n=969) in twenty-eight, 32.4 hectare (80 acre) plots of perennial cover to test the hypothesis that nest fate is influenced by its distance from road edge and by the type of road to which it is nearest. Using the logistic-exposure model (Schaffer 2004) it was found that the distance of a nest to the road edge was not significantly related to its fate (P=0.935), suggesting an absence of edge effects. The study block on which a nest was located was a significant factor determining nest fate; likely due to variability in the predator community. The type of road with nearest proximity to a nest was found to be a significant factor in determining its fate. Nests nearest paved roads had a higher daily survival rate (DSR) (0.987) and nesting success (0.634) compared to gravel roads (DSR=0.975, nesting success=0.358) and trails (DSR=0.972, nesting success=0.389). This suggests that vehicular traffic discourages predators from approaching busy roads and thus increases nesting success.

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Table of Contents

Abstract ---- ii

Acknowledgements ---- iii

Table of Contents ---- iv

List of Tables ---- v

List of Figures ---- vi

List of Appendices ---- vii

1.0 Introduction ---- 1

2.0 Methods ---- 7

2.1 Study Site Selection ---- 7

2.2 Collection of Nest Data ---- 8

2.3 Calculation of Spatial Data ---- 10

2.4 Statistical Analysis ---- 10

3.0 Results ---- 13

3.1 Nest Searches ---- 13

3.2 Logistic-Exposure Model ---- 15

4.0 Discussion ---- 19

4.1 Nest Searches and Spatial Data ---- 19

4.2 Model Results ---- 20

4.3 Management Implications ---- 26

5.0 Conclusions ---- 27

Literature Cited ---- 28

Appendix ---- 33

List of Tables

Table 1. Distribution of nests by study block and by proximity of nearest road type -- **13**

Table 2. Minimum and maximum distances (meters) of nests found by different road types ---------- **14**

Table 3. Logistic-exposure model results using distance to road, type of road, and study block as variables (α = 0.05) ---------- **15**

Table 4. Logistic-exposure model results using study block and road type as variables (α = 0.05)---------- **16**

Table 5. Logistic-exposure model results for road type adjusted to compare Paved and Trail (α = 0.05) ---------- **17**

Table 6. Daily survival rates of nests in each of the study blocks by road type with 95% confidence intervals ---------- **17**

List of Figures

Figure 1. Percent frequency of nests located at 100 meter intervals from the edges of different road types ---------- **14**

Figure 2. Daily survival rates of nests with upper and lower 95% confidence intervals for each of study blocks by road type ---------- **18**

List of Appendices

Appendix 1. General distribution of the Prairie Pothole Region (U.S. Fish & Wildlife Service)---------- **33**

Appendix 2. The four 93.3-kilometer^2 study blocks, Calio, Leeds, Crary, Courtenay and their respective locations within the counties of North Dakota, USA---------- **34**

Appendix 3. Duck pair densities of select counties in the PPR of North Dakota, USA (U.S. Fish & Wildlife Service) ---------- **35**

Appendix 4. Distribution and types of roads bordering study plots ---------- **36**

Appendix 5. Distribution of study plots and road network within each study block ---------- **37-38**

Appendix 6. Coding for the comparison of the continuous variable distance, and the categorical variables study block and road type using the maximum likelihood method in PROC GENMOD ---------- **39**

Appendix 7. Coding for the comparison of study block and road type using the PROC GENMOD procedure and determining DSR of nests by block for each road type------ **40**

1.0 Introduction

The Prairie Pothole Region (PPR) consists of 770,000 square kilometers of prairie dotted with small wetlands extending across three prairie provinces and five states (Appendix 1) (Samson *et al.* 1998). This region is important for waterfowl reproduction. Although it makes up only about 10% of all potential breeding habitat in North America, the PPR produces about 50% of all game waterfowl (Mac *et al.* 1998). The PPR however, has experienced dramatic changes in its landscape over the past century. Due to agricultural expansion and urban sprawl many wetlands have been drained and much of the native grassland has been destroyed. In some areas it is estimated that up to 99.9% of native tall-grass/mixed-grass prairie and wetlands have been destroyed (Samson *et al.* 1998). This habitat loss has created small patches of natural grassland surrounded by agricultural fields and/or urban development. This fragmentation of the PPR has resulted in major challenges for upland nesting waterfowl, including altered predator communities and habitat loss with increased edge habitats (Dijak and Thompson 2000).

Predation is an important cause of nest failure among upland nesting waterfowl (Klett *et al.* 1988; Johnson *et al.* 1989; Sargeant *et al.* 1993). Between 1966 and 1984 predation accounted for up to 85% of nest failures in the PPR across several U.S. states (Klett *et al.* 1988). The success of nests and therefore recruitment of waterfowl is strongly affected by the presence of predators and the composition of the predator community in the surrounding habitat (Johnson *et al.* 1989; Drever *et al.* 2004). Anthropogenic changes in the PPR have had major effects on the composition and

abundance of the predator community (Sargeant *et al.* 1993). Some species such as the Grey Wolf (*Canis lupus* Linnaeus) and the Swift Fox (*Vulpes velox* Say) have all but vanished from the PPR whereas species such as the American Crow (*Corvus brachyrhynchos* Brehm) and Raccoon (*Procyon lotor* Linnaeus) have increased in abundance due to habitat provided by the such features as old homesteads and treed shelter belts (Sargeant *et al.* 1993).

Today the most common nest predators in the PPR are Red Fox (*Vulpes vulpes* Desmarest), Coyote (*Canis latrans* Say), American Badger (*Taxidea taxus* Schreber), Franklin's Ground Squirrel (*Spermophilus franklinii* Sabine), Striped Skunk (*Mephitis mephitis* Linnaeus), Raccoon, and American Crow (Johnson *et al.* 1989). These predators do not exploit waterfowl nests at the same rate and the most active nest foragers have been identified as the Striped Skunk, Red Fox, and American Crow (Greenwood 1986; Johnson *et al.* 1989). However, the American Crow was never observed during this study and its effects were therefore assumed to be negligible (personal observation).

The composition and activity of the predator community are important in determining the predation pressure and nesting success of upland nesting waterfowl (Greenwood 1986; Klett *et al.* 1988; Johnson *et al.* 1989; Dijak and Thompson 2000; Phillips *et al.* 2003). In addition to the predator community, landscape characteristics also play a key role in determining nesting success. Habitat characteristics such as: nesting habitat patch size (Burger *et. al* 1994; Pasitschniak-Arts and Messier 1996; Bender *et*

al. 1998; Sovada *et al.* 2000; Phillips *et al.* 2003), nesting habitat type (Klett *et al.* 1988; Pasitschniak-Arts and Messier 1995; Pasitschniak-Arts and Messier 1996; Phillips *et al.* 2003), and the amount and type of edges (Donovan *et al.* 1997; Bergin *et al.* 2000; Dijak and Thompson 2000; Lahti 2001; Phillips *et al.* 2003) all influence nesting success. Habitat fragmentation has resulted in an alteration of the predator community (Sargeant *et al.* 1993) as well as the habitat characteristics influencing nesting success. Altered predation pressures in combination with the reduction and fragmentation of nesting habitat has resulted in two major effects on upland nesting waterfowl: patch size effects, and edge effects (Johnson 2001).

Patch size effects are more commonly known as the "ecological trap hypothesis". This is the reduction of reproductive success due to the reduction of habitat patch size causing an increase in vulnerability of density-dependent predation (Lariviere and Messier 1998; Johnson 2001). Therefore, large habitat patches may serve as refuges for nesting waterfowl by reducing density-dependent predation pressure (Crabtree *et al.* 1989; Lariviere and Messier 2000; Sovada *et al.* 2000). However, even these "refuge patches" may have areas such as edges that are more vulnerable to predation.

Higher predation rates of nests along edges of habitats are termed edge effects. Edge effects have been studied in a wide range of habitats, but the majority of studies have focused on forest ecosystems with most finding no edge effect (Lahti 2001). However, the methods used in these studies vary widely, making them difficult to compare. Another concern is a large proportion of these studies used artificial nests in

their experimental design (Lahti 2001). Artificial nests may not accurately mimic naturally occurring waterfowl nests and must thus be used with caution (Pasitschniak-Arts and Messier 1996; Guyn and Clark 1997). Due to the variation of the habitats studied and the variation in the results it is plausible to suggest that edge effects may not be ubiquitous for all habitat types. However, few studies have been performed to examine if higher probabilities of predation exist for nests located near grassland-roadway edges, a common landscape feature of the PPR.

There are approximately 62 million kilometers (38 million miles) of roads in the United States, and it has been estimated that these roads ecologically affect nearly one-fifth of the country (Forman 2000). In the PPR roads contribute to habitat fragmentation, interrupting continuous areas of habitat, reducing patch sizes, and increasing the amount of edge habitat present. Despite being such a predominant feature in the PPR few studies have been performed to examine how roads affect nesting success of upland nesting waterfowl. Among the few studies that have examined the edge effects between grasslands and roads, edge effects were absent (Mankin and Warner 1992) or weak (Pasitschniak-Arts and Messier 1995). Winter *et al.* (2000) found no edge effects with paved roads but suggested that gravel roads may have an effect, and Klett and Johnson (1982) found that nesting success increased with closer proximity to an interstate highway. In these studies roads were examined as a single type of edge in a habitat, but in the PPR roads consist of various types and traffic load. Roads in the PPR are routinely arranged in a 1.61 kilometer by 1.61 kilometer (1 mile by 1 mile) grid pattern and consist of various surfaces, including:

gravel, pavement, and dirt. The traffic noise associated with traffic volume can be an important factor affecting nest predator movements in a landscape (Forman and Alexander 1998). Depending on the type of road and traffic amount, predators may view roads as either a travel corridor -- providing them with easier travel routes -- or barriers due to high amounts of traffic (Forman and Alexander 1998).

Dense vegetation in which nests are often located has been suggested to impede the progress of predators (Schranck 1972; Crabtree *et al.* 1989). Therefore, some roads may act as travel corridors for predators by providing them with easier access routes between habitats (Bider 1968; Forman and Alexander 1998; Brock and Kelt 2004). However, due to the danger presented by traffic and the noise generated it is also possible that some roads may be avoided by predators (Klett and Johnson 1982; Pasitschniak-Arts and Messier 1995; Forman and Alexander 1998).

How predators perceive roads may result in differences in nesting success of upland nesting waterfowl in an area such as the PPR where roads are a common anthropogenic influence on the landscape. Nesting success may be lower closer to roads with low traffic due to predators using them as a travel corridor and foraging close to the edge of the road. The opposite may be true for roads with high traffic. These roads may deter predators, causing them to travel further inside nesting habitat and reducing nesting success away from the road edge.

To explore this hypothesis I focused on a prairie ecosystem in North Dakota, USA, consisting of perennial fields surrounded by agricultural land, interrupted by developed roadways. Naturally occurring nests of Mallard (*Anas platyrhynchos* Linnaeus), Northern Pintail (*Anas acuta* Linnaeus), Northern Shoveler (*Anas clypeata* Linnaeus), Blue-Winged Teal (*Anas discors* Linnaeus), Gadwall (*Anas strepera* Linnaeus), and Lesser Scaup (*Aythya affinis* Eyton) were examined to determine (1) if a nest's success was influenced by its distance from roadways and (2) if predation rates were influenced by different types of roads. Three main types of roads were examined: paved roads (high traffic amounts), gravel roads (moderate traffic amounts), and trails (low traffic amounts).

2.0 Methods

2.1 Study Site Selection

Four, 93.3 square-kilometer (36 square-mile) study blocks were chosen in the PPR of North Dakota based on duck pair density and habitat regime (Appendix 2). The study blocks required ample perennial cover (approximately 30%) and high densities of wetlands -- i.e., areas that support a minimum of 20 breeding pairs/square mile (Appendix 3). This data was obtained through the U.S. Fish and Wildlife Service's Landcover maps and Duck Pair Density maps respectively. Using a Geographic Information System (GIS), ArcGIS 9, the two map layers were overlaid and areas meeting the criteria were selected. Study blocks were then chosen based on size requirements and general location within the state. Seven, 32.4 hectare (80 acre) study plots of perennial cover were then chosen randomly in each of the four different 93.3 square-kilometer study blocks. The plots were half-quarter sections of land, approximately 400 meters by 805 meters (0.25 miles by 0.5 miles) in size, with the exception of one which was approximately 310 meters by 1035 meters (0.20 miles by 0.65 miles). These plots consisted of land enrolled in the Conservation Reserve Program or were Wetland Management Areas. The vegetation on the plots was mostly Alfalfa (*Medicago sativa* Linnaeus), Sweetclover (*Melilotus spp.*), Wheatgrasses (*Agropyron spp.*), and Smooth Brome (*Bromus inermis* Leyss). Roads bordering the plots were of various types and amounts (see Appendix 4 & 5 for details). The roads surrounding the plots were of three major types:

1) Trails, consisting of a single lane, approximately 3 meter-wide (3.5 yard-wide) dirt path with well defined tire tracks and vegetation lower than the surrounding area with ditches usually absent.

2) Gravel roads, consisting of a two lane gravel surface, approximately 5 meters (5.5 yards) wide with shallow to steep ditches on either side.

3) Paved roads, consisting of two-lane asphalt or cement highways with paved or gravel shoulders, approximately 8 meters (9 yards) wide often with wide ditches.

Overall, gravel roads consisted of 15,165 meters (16,530 yards) of edge, paved roads consisted of 3215 meters (3504 yards) of edge, and trails consisted of 2410 meters (2627 yards) of edge surrounding the plots. For plots without a bordering road the nearest roads were either gravel or trail.

The different types of roads were assumed to have traffic volumes dependent on the surface type. A trail for instance was assumed to have the least amount of traffic whereas the paved type would have the greatest.

2.2 Collection of Nest Data

At the beginning of May the plots were searched for nests using a chain drag method, slightly modified from Klett *et al.* (1986). A chain approximately 50 meters (54.5 yards) in length, without a second set of loops from the main drag line, was dragged at 5-8 kph (3-5 mph) between two All Terrain Vehicles. In order to minimize research impact nest searches were not conducted on wet, cold days to reduce vegetation

disturbances and to reduce the risks to egg health. Plots were searched from 0800-1400 hours in accordance with Gloutney *et al.* (1993) to maximize the chances of flushing the nest-attending hen. Upon flushing a hen, both observers would search the immediate vicinity on foot. Once the nest was found, the date, time, species, hen status, nest status, number of eggs, incubation stage according to Weller (1956), northing and easting coordinates, and method of flush were recorded. In addition to the coordinates, an aerial photo was also marked with the approximate location of the nest to settle any discrepancies. The nest was marked immediately outside of the nest bowl on the north side with a meter (3 foot) tall welding rod painted fluorescent orange. A marking lath painted white was then placed approximately 10 meters (11 yards) from the nest bowl on the north side and labeled with the nest number. Due to the small population of crows present in the study site, marking the nests in such an obvious manner was assumed to have little to no effect on predation rates. These nests were checked every 6-9 days and date, time, nest status, hen status, number of eggs, incubation stage, and species if necessary, were recorded. If the nest had been terminated -- i.e. hatched, depredated, or abandoned -- this result was recorded along with the possible reason for termination, whether it be due to a predator, investigator, mechanical activity, or unknown. Once a nest was terminated both the marking rod and lath were removed. Each plot was searched three times from the beginning of May to the beginning of July, at approximately two week intervals.

2.3 Calculation of Spatial Data

The nest information collected in the field was error checked to ensure that all information for each nest was complete and accurate. The information was then entered into a Microsoft Excel spreadsheet and compared to the original hardcopy of the data to ensure accurate transfer. The spreadsheet file was converted into a shape file and using ArcGIS 9 the locations of the nests were added to a map of the study area using their northing and easting coordinates. A shape file of the roads in the study area was then obtained and added to the map. However, due to some discrepancies in the layer -- i.e. roads shown as existing when they did not -- the layer was edited by comparing it to aerial photographs of the area and corrected as necessary. The layer containing the nest data and the road layer were then joined providing the distance of each nest to the nearest road. The nests were then placed into one of the three categories: paved, gravel, or trail, depending on the type of road which they were nearest. Five plots did not have a road immediately bordering one of their sides. This did not affect the procedure as the distance to the nearest road outside of the plot was calculated.

2.4 Statistical Analysis

All nests were pooled together and nest fate was designated as either successful (>1 egg hatched) or unsuccessful (depredated or abandoned due to depredation). Nests that were destroyed by mechanical means or investigators were not included.

The logistic-exposure model (Schaffer 2004) was used to evaluate the effects of numerous explanatory variables potentially related to nest survival and to estimate the daily survival rate (DSR). This is a generalized linear model that uses a binomial response distribution where nest fate between each observation interval is used as a Bernoulli trial (successful nest = 1 and an unsuccessful nest = 0). The model also uses a logistic-exposure function which incorporates the interval length between each nest visit and reduces the bias of locating nests at various stages as noted by Mayfield (1961, 1975). The advantage of using this model is that interval lengths can be greater than one day, be variable in length, and it does not require the date of termination to be known. The model also allows for the consecutive examination of numerous variables, both continuous and categorical.

Using the statistical software package SAS, the logistic-exposure model (Schaffer 2004) was first used to evaluate the effects of three variables, including: nest distance from the road edge (distance), the study block in which the nest was found (block), and the type of road that the nest was nearest (type). Using the method of maximum likelihood the model compared the continuous variable of distance, and the two categorical variables: block, which had four treatment levels (Calio, Courtenay, Crary, and Leeds); and type, which had three treatment levels (paved, gravel, and trail). The model was fitted using the PROC GENMOD procedure (see Appendix 6 for coding).

The model was run again using the same procedure but with only the two categorical variables block and type present, both with the same number of treatment levels. The

DSR and nesting success -- or probability of nest survival -- for a 35 day period (12 days for laying plus 23 days for incubation) were also estimated for the road types within each block in this model (see Appendix 7 for coding).

3.0 Results

3.1 Nest Searches

A total of 969 nests and 2417 nest visits were used in the analysis. Of the 969 nests used, 598 (61.7%) were successful and the remaining 371 (38.3%) were destroyed by predators or abandoned due to predation.

Nests were evenly spread throughout the four study blocks. Most were located along gravel roads. Few nests were found near paved roads as only two of the study blocks contained this road type (Table 1).

Table 1. Distribution of nests by study block and by proximity to nearest road type.

Study Block	**Road Type**			
	Paved	Gravel	Trail	**Total per Study Block**
Calio	43	130	44	217
Courtenay	0	192	47	239
Crary	73	125	64	262
Leeds	0	172	79	251
Total per Road Type	116	619	234	969

The proximity of nests to different road types is shown in Figure 1. Nests were clustered close to paved roads, with most (51.7%) within 100 meters (110 yards). This differed from gravel roads and trails where nests did not show the same degree of clustering.

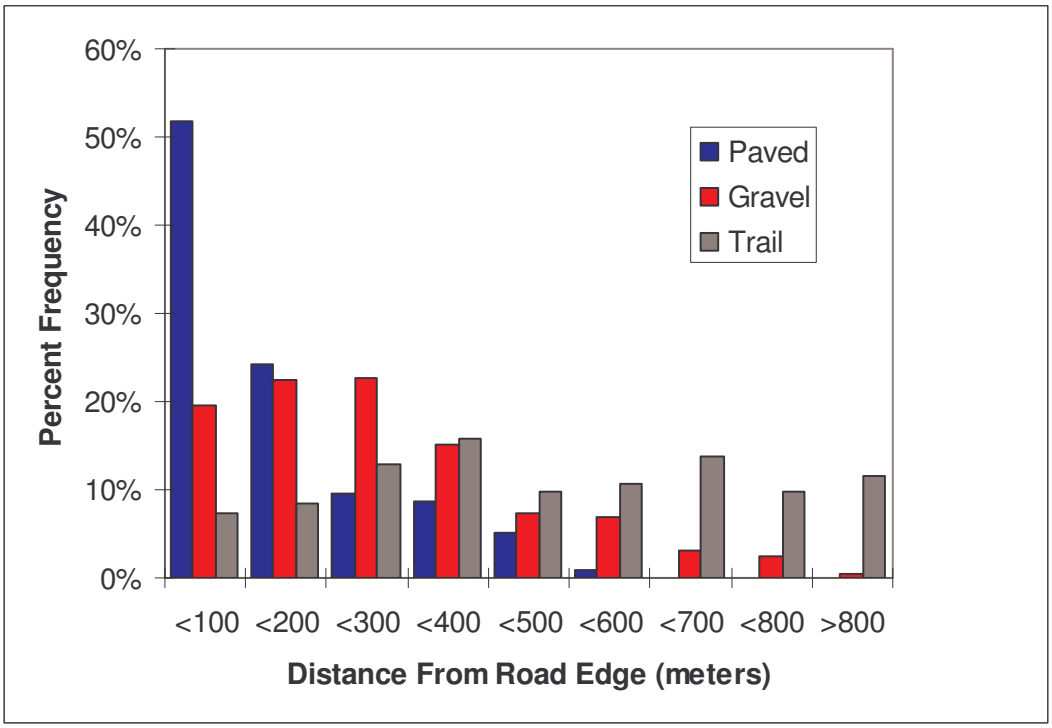

Figure 1. Percent frequency of nests located at 100 meter intervals from the edges of different road types.

The distance of nests to the nearest road ranged from 1.7 to 1382.7 meters (1.9 to 1507.1 yards) with an average of 299.5 meters (326.5 yards). The range of distances to the different roads types is presented in Table 2.

Table 2. Minimum and maximum distances (meters) of nests found by different road types.

Range	Paved	Gravel	Trail
Minimum	10.7	1.7	14.7
Maximum	529.7	953.3	1382.7

3.2 Logistic-Exposure Model

Using distance to road, type of road, and study block as independent variables, the model found that distance to road edge was not a significant factor affecting nest survival (P = 0.935). However, there was a significant effect due to the study block on which the nest was located. Two of the blocks, Courtenay and Crary, differed significantly from the Leeds block (P <0.0001), but the Calio block was not significantly different (P = 0.176) from the Leeds block (Table 3).

Road type in closest proximity to the nest was a significant factor affecting nest survival. Gravel roads and trails did not differ significantly in nest outcome (P = 0.365). However, paved roads were found to be significantly different from trails in predicting the outcome of a nest (P = 0.0016, Table 3).

Table 3. Logistic-exposure model results using distance to road, type of road, and study block as variables ($\alpha = 0.05$).

Variable	Treatment	Estimate	df	χ^2	P
Intercept	--	4.0294	1	479.15	<.0001
Distance	--	-0.0000	1	0.01	0.9348
Study Block	Calio	-0.2338	1	1.83	0.1758
	Courtenay	-0.8000	1	28.43	<0.0001
	Crary	-0.6377	1	16.05	<0.0001
	Leeds	0.0000	0	--	--
Road Type	Paved	0.7553	1	9.96	0.0016
	Gravel	0.1212	1	0.82	0.3645
	Trail	0.0000	0	--	--

Distance from a road did not have a significant effect on nesting success, and this variable was removed from the best-fit model. A model using block and type as explanatory variables yielded the following results:

The model again showed that the study block on which a nest was located was a significant predictor for nest survival. The Courtenay and Crary blocks were significantly different (P <0.0001) from the Leeds block. However, the Calio block did not differ significantly from the Leeds block (P = 0.173, Table 4).

Road type was again a significant predictor of nest survival. Gravel roads did not differ significantly from trails (P = 0.306), but paved roads did significantly differ from trails (P = 0.0006, Table 4).

Table 4. Logistic-exposure model results using study block and road type as variables ($\alpha = 0.05$).

Variable	Treatment	Estimate	df	χ^2	P
Intercept	--	4.0198	1	800.31	<.0001
Study Block	Calio	-0.2349	1	1.86	0.1725
	Courtenay	-0.7995	1	28.45	<0.0001
	Crary	-0.6385	1	16.14	<0.0001
	Leeds	0.0000	0	--	--
Road Type	Gravel	0.1256	1	1.05	0.3059
	Paved	0.7628	1	11.88	0.0006
	Trail	0.0000	0	--	--

The model was adjusted to compare gravel roads to paved roads. This comparison found that paved roads differed significantly from gravel roads (P = 0.0021, Table 5).

Table 5. Logistic-exposure model results for road type adjusted to compare Paved and Trail ($\alpha = 0.05$).

Road Type	Estimate	df	χ^2	P
Gravel	0.0000	0	--	--
Paved	0.6372	1	9.46	0.0021
Trail	-0.1256	1	1.05	0.3059

Daily survival rates and nesting success were calculated using the regression coefficients from the model with study block and road type as explanatory variables. As shown in Table 6 and Figure 2, DSR was much lower for the Courtenay and Crary blocks compared to the Calio and Leeds blocks for both gravel roads and trails. Average nesting success was similar for gravel roads and trails (0.358 and 0.389 respectively), but much lower compared to paved roads (0.634).

Table 6. Daily survival rates of nests in each of the study blocks by road type with 95% confidence intervals.

Road Type	Block	DSR	Upper 95% DSR	Lower 95% DSR	Nesting Success	Average DSR	Average Nesting Success
Paved	Calio	0.98952	0.99314	0.98402	0.69158	0.98696	0.63408
	Crary	0.98439	0.98916	0.97756	0.57657		
Gravel	Calio	0.98036	0.98472	0.97480	0.49948	0.97541	0.35799
	Courtenay	0.96597	0.97168	0.95916	0.29767		
	Crary	0.97088	0.97656	0.96388	0.35550		
	Leeds	0.98441	0.98775	0.98018	0.57697		
Trail	Calio	0.97779	0.98349	0.97019	0.45564	0.97222	0.38905
	Courtenay	0.96159	0.97007	0.95084	0.25391		
	Crary	0.96712	0.97465	0.95745	0.31027		
	Leeds	0.98236	0.98659	0.97683	0.53638		

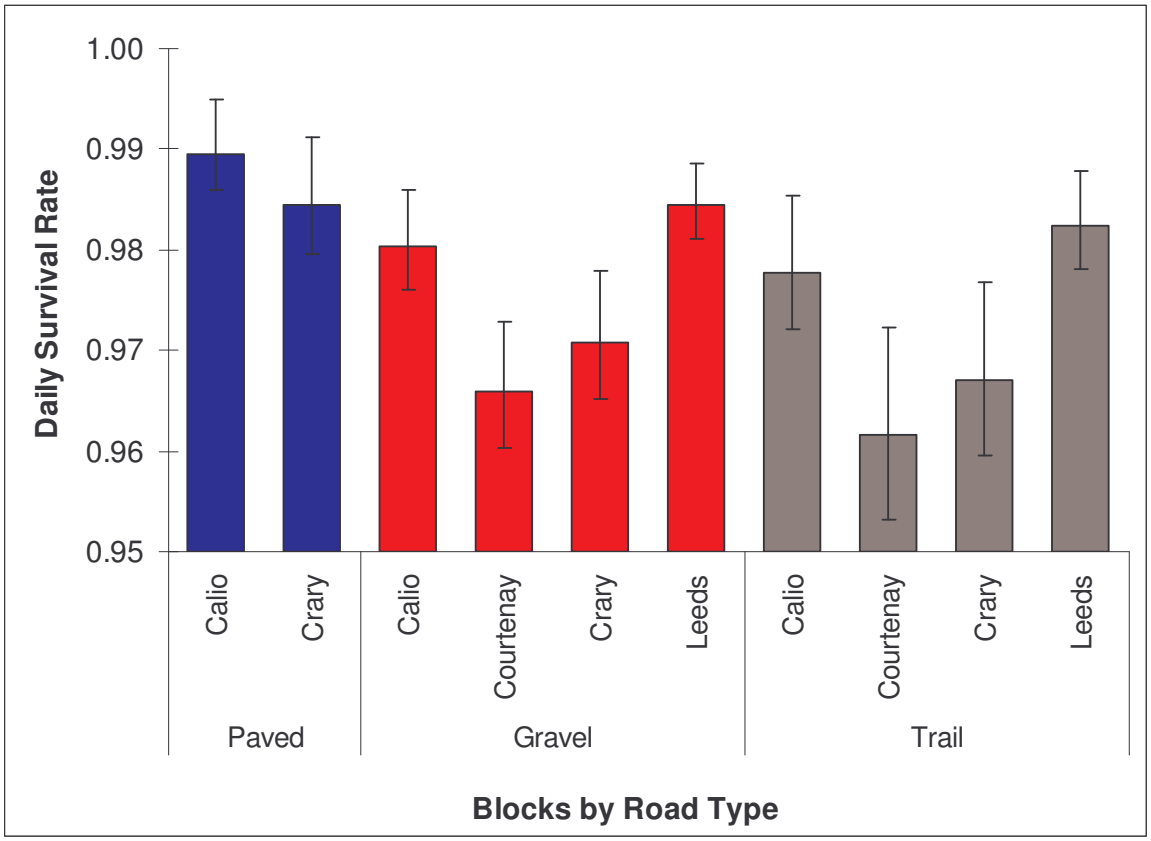

Figure 2. Daily survival rates of nests with upper and lower 95% confidence intervals for each of the study blocks by road type.

4.0 Discussion

4.1 Nest Searches and Spatial Data

Most nests were located near gravel roads, the most common road type in the study area. Nests nearest paved roads were the least common as this type of road is infrequently found in the study blocks. However, the relatively small variation between the numbers of nests found on each block suggests that the areas searched were representative of nesting habitat on a larger scale.

The frequencies of nests along gravel roads and trails possessed a greater range of distances (953.3 and 1382.7 meters [1039.1 and 1507.1 yards] respectively) than those for paved roads (529.7 meters [577.4 yards]) simply due to the fact that the five plots lacking bordering roads were in closest proximity to gravel roads or trails. Paved roads were only found bordering plots, therefore reducing the range of distance for nests to the size of the plot.

The frequencies of nests found at 100 meter intervals were relatively evenly distributed for both gravel roads and trails. However, the majority (51.7%) of nests along paved roads were very close (<100 meters) to the edge. The high frequency of nests close to paved roads compared to the others suggests that these areas are being preferentially used by nesting waterfowl or nests located at this distance have a lower probability of being depredated.

The frequency distribution of nests also highlights the need for caution when extrapolating findings from studies using artificial nests. Many studies do not take into account the micro-habitat preferences of nesting waterfowl and may therefore not accurately represent a naturally occurring system (Guyn and Clark 1997; Butler and Rotella 1998; Wilson *et al.* 1998).

4.2 Model Results

When the model included the three explanatory variables -- block, type, and distance, the distance the nest was from the road edge did not predict the survival of the nest. A simplified model using only the variables block and type yielded similar results. These results indicate that edge effects were not detected in this study. There are several possible explanations for this finding.

First, heterogeneity of natural systems is common and is often referred to as biological diversity (Landres *et al.* 1999). In a highly fragmented landscape such as the PPR many environmental factors undoubtedly vary on both a spatial and temporal scale (Jobin and Picman 2002; Stephens *et al.* 2003). The largest factor concerning environmental variation in this study would be the variation at both a local and regional scale of the predator community.

Variation in the predator community at the local scale may have contributed to the absence of edge effects. The presence of edge effects would be dependent upon the predator community, abundance, and use of the study plots (Angelstam 1986;

Sargeant *et al.* 1993; Paton 1994; Sovada *et al.* 1995; Lahti 2001; Lariviere and Messier 2001). Differences in foraging patterns, efficiency, and home ranges of predators may yield variation in predation rates among seemingly similar plots, negating any potential evidence of edge effect patterns of predation.

Second, the size of the plots may have contributed to the lack of an edge effect. Pasitschniak-Arts and Messier (1996) suggested that nests located further from edges in larger plots (200 hectares [494 acres] in the study) have a lower chance of being discovered by predators than nests located in smaller plots (50 hectares [123.5 acres] in the study). They proposed that larger plots allow nests to be far from edges causing them to be outside of most predators' search ranges and therefore increase probability for survival. Therefore, small plots such as those used in this study (32.4 hectares [80 acres]) may be extensively searched by predators reducing the chance of detecting an edge effect in predation. However, the relationship between habitat patch size and nesting success is complicated and not clearly confirmed (Clark and Nudds 1991). Nest distance to the nearest road edge was not limited to the size of the plot in this study. Numerous plots did not have a road edge bordering them and therefore distance was a continuous variable with distances ranging beyond the size of the plot. This suggests that the size of the plot was perhaps not the only factor influencing the entry of nesting habitat by predators.

The type of land surrounding the plots may have also contributed to the absence of edge effects. Landscape composition may influence predator movement and

abundance (Bergin *et al.* 2000; Dijak and Thompson 2000; Phillips *et al.* 2003). Therefore, even though roads have been suggested to be movement corridors for predators (Bider 1968; Forman and Alexander 1998; Brock and Kelt 2004) causing nests along the edges of roads to be more vulnerable to predation, this is not supported by the evidence in this study. The data suggest that predators either do not use roads as travel lanes thus not causing higher probabilities of predation for nests along edges, or predators are using roads as travel lanes but due to their foraging patterns are resulting in an equal probability of nests becoming depredated despite their distance from the edge. Roads may not be responsible for edge effects but this does not mean nests are independent from other edge effects resulting from the surrounding land type(s). For example, a plot of nesting habitat within pasture or other grassland may dilute foraging efforts and consequently reduce observed predation rates (Bergin *et al.* 2000; Phillips *et al.* 2003). However, other land types such as agriculture or wetlands, not examined in this study, may be preferentially used by predators during foraging activities (Phillips *et al.* 2003). This would again reduce the possibility of detecting edge effects along roads.

Environmental heterogeneity was also likely responsible for causing the observed differences between study blocks. In both runs of the model the block on which a nest was found was a significant predictor in determining its outcome. The differences are obvious in the DSR and nesting success of nests along gravel roads and trails in the Courtenay and Crary study blocks. The DSR and nesting success in these study blocks was much lower than that in the Calio or Leeds study blocks. Similar to the

absence of edge effects, landscape level heterogeneity of the predator community and abundances were likely responsible. Again differences in predator foraging behaviour may influence the likelihood of nests being discovered in different blocks. The predator community is affected by an array of landscape features such as the amount of habitat fragmentation, amount of different habitat types such as woodlands that may attract predators or grassland that may dilute foraging efficiency (Donovan *et al.* 1997; Bergin *et al.* 2000; Phillips *et al.* 2003).

Differences between the study blocks may have also been due to the presence of paved roads on only of two of the four study blocks. Paved roads were associated with high nesting success of waterfowl (0.634) compared to gravel roads and trails (0.358 and 0.389 respectively). Therefore, nests within the two blocks containing paved roads, Calio and Crary, would presumably have a higher nest survival. However, the results show that compared to the Leeds block, the Calio block was not significantly different ($P = 0.173$) in terms of predicting whether it was a significant factor in determining a nest's fate but the Crary block was significantly different ($P < 0.0001$). Since these blocks both contain paved roads but did not exhibit the same differences, it suggests that variability between the blocks was likely due to variations in environmental factors such as the predator community and concentrations and the extent and location of landscape features such as agriculture, wooded areas, grassland, and wetlands. Heterogeneity is not uncommon in natural systems therefore this finding was not unexpected.

Another significant factor in determining nest fate was the type of road to which it was closest. In both models gravel roads and trails did not differ significantly in their effect on nearby nests. However, paved roads did differ significantly from both gravel roads and trails. This suggests that nests nearest paved roads had a lower probability of being discovered by predators compared to those nearest gravel roads or trails. These differences are illustrated by the variation in both the DSR and nesting success between the types of roads. For gravel roads and trails the DSR averaged 0.975 and 0.972 respectively, compared to that of paved roads with an average survival rate of 0.987. The nesting success for each type of road clearly indicates that nests along paved roads had a higher probability of survival (0.634) compared to either gravel roads (0.358) or trails (0.389).

The cause of this observation is most likely due to the differences in vehicle traffic. Data regarding traffic volumes was not obtained, however it is assumed that trails experience lower traffic volume than gravel roads which experience lower traffic volume than paved roads. Traffic volume may be an important factor influencing nesting success as it has been suggested that the noise, movement, etc. generated from busy roads deters predators (Oetting and Cassel 1971; Klett and Johnson 1982; Forman and Alexander 1998). Research addressing road avoidance behaviour in the major mammalian predators of the PPR is lacking; however it has been shown that many large and small mammals have a tendency to avoid busy roads (Oxley *et al.* 1974; McLellan and Shackleton 1988; Brody and Pelton 1989).

Predators may also tend to avoid areas next to busy roads due to the reduction of potential prey in these areas. Reijnen *et al.* (1995) and Reijnen *et al.* (1996) illustrated that in both grassland and wooded areas along a busy road, 60% of the avian species studied had a lower density and Oxley *et al.* (1974) showed that small mammals such as mice are less common in these areas. Due to the lower abundances of prey in these areas the foraging costs versus the benefits received by predators may cause them to simply seek out other areas where they are likely to be more successful in foraging.

Therefore, nests located nearest paved roads appear to have a lower probability of being found by predators due to their avoidance behaviours. This does not seem to be the case with the gravel roads or trails. Nests located near these types of roads do not seem to have a lower probability of being found by predators. Due to low and infrequent traffic volumes it is unlikely that predators would attempt to avoid these areas resulting in a lowered DSR and nesting success. The relative safety of habitats near paved roads may also explain the high proportion of nests found near them. The frequency of nests close (<100 meters) to paved roads was high (51.7%) compared to gravel roads or trails (19.6% and 7.3% respectively). These results are very similar to those found by Pasitschniak-Arts *et al.* (1998) where nests were located closer to roads than predicted by a random distribution, presumably due to the safer habitat provided. Nest site fidelity is likely responsible for this observation. Safe habitat results in a higher nesting success and a greater number of birds returning to their nest site each year. Due to the safety afforded by paved road edges, more nests are successful resulting in greater numbers of birds returning to the same area year after

year. This finding suggests that distance may be a significant factor affecting nest survival along paved roads. However, due to the infrequency of paved roads in the study blocks the ability to detect this result may be diminished. Other micro-habitat preferences influencing nest site selection may also be present close to paved roads that were not measured that could influence the observed frequencies.

4.3 Management Implications

Evidence of higher nesting success along paved roads suggests that these areas may be useful for creating high production nesting areas for upland nesting waterfowl. The large traffic volumes supported by these types of roads appear to deter predators resulting in increased nest survival. Therefore, the acquisition and maintenance of nesting habitat in the PPR should consider the "benefit" of paved roads on nesting success. Oetting and Cassel (1971) previously suggested that portions of interstate highway right-of-way remain unmowed at least until mid-July when most duck nests have hatched. This could provide waterfowl with productive nesting habitat at relatively low cost with minimal effects on road traffic. Therefore, areas that are often overlooked as potential nesting habitat such as ditches, rights-of-way, and yield triangles should be considered by wildlife mangers and habitat conservation agencies. Some of the ecological damage done by the presence of roads may be mitigated by providing a relatively safe area for nesting waterfowl.

5.0 Conclusions

1. The distance of a nest from a road was not a significant predictor in determining its fate. This suggests roads are not being used by predators as travel corridors and nest fate in a fragmented environment is dependent on other variables such as the heterogeneity of the predator community on a local scale and surrounding landscape.

2. The study block in which a nest was located was a significant predictor of nest fate. This observation may due to heterogeneity of the surrounding landscape and predator community on a landscape scale.

3. Nest fate was dependent upon the type of road to which it was nearest. Paved roads had a higher DSR and nesting success than either gravel roads or trails. Presumably this is due to vehicular traffic discouraging nest predators from approaching nests along paved roads thus increasing the probabilities of a successful nest.

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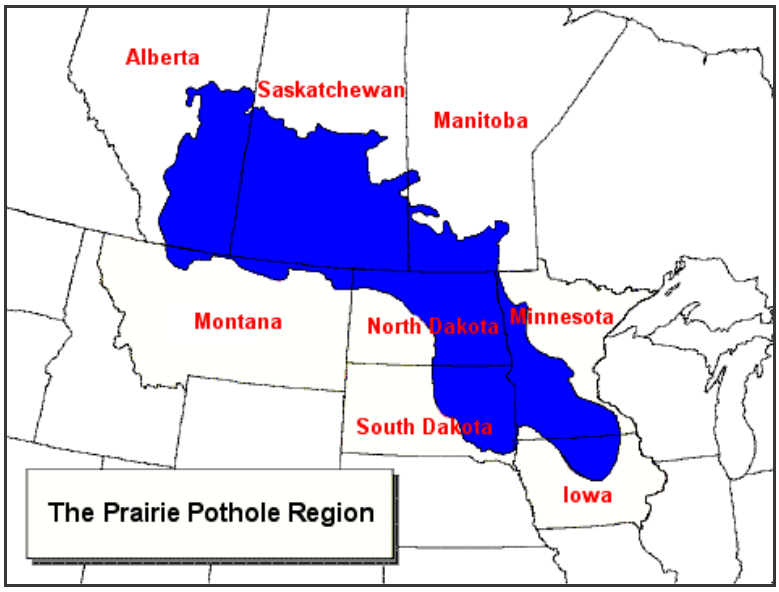
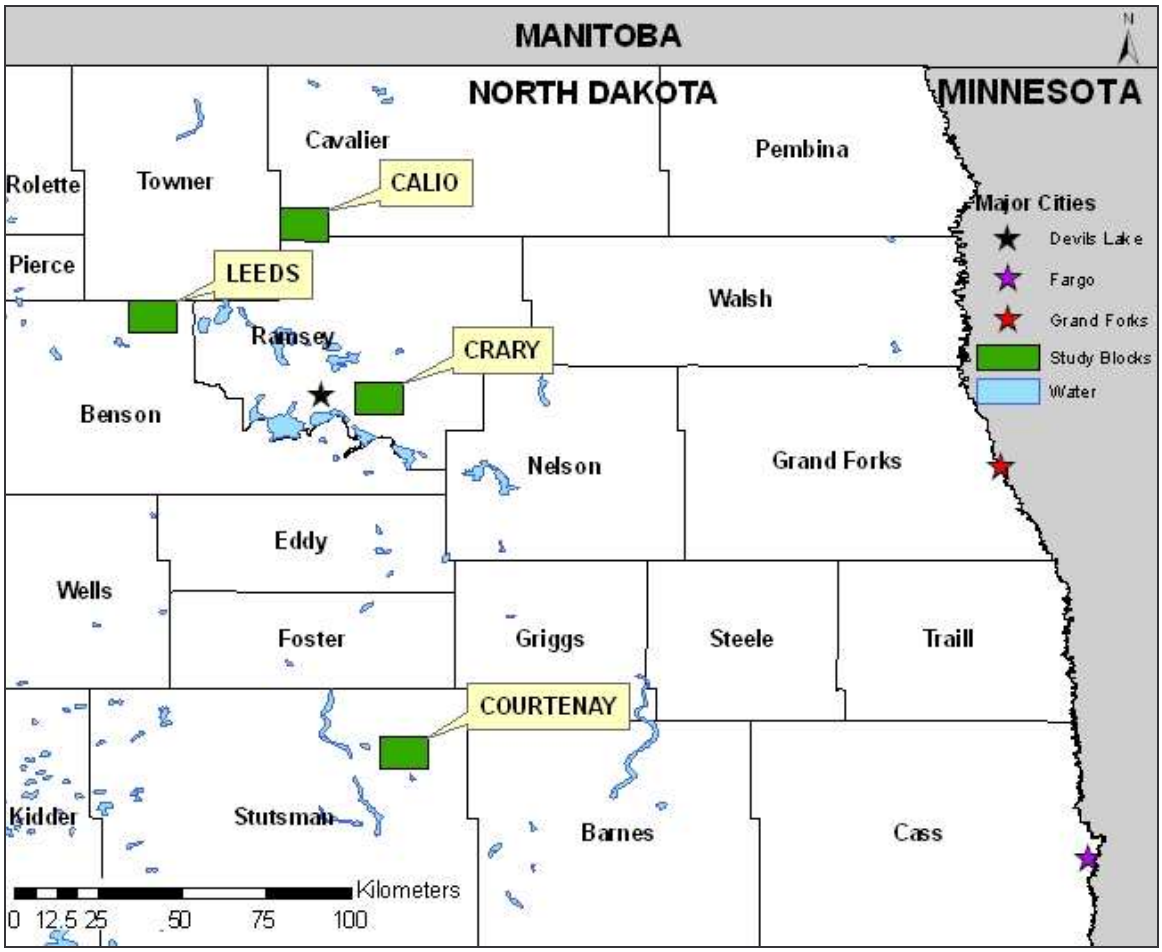
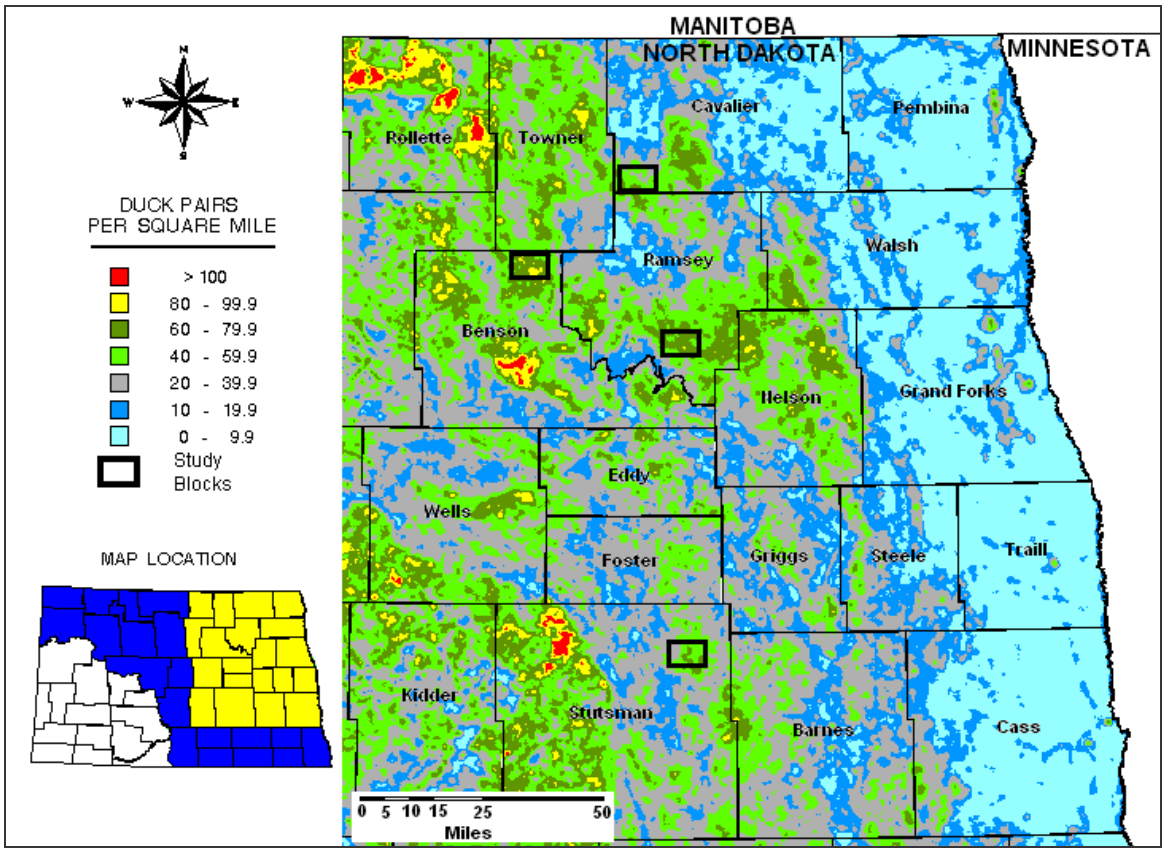
Appendix



Appendix 1. Distribution of the Prairie Pothole Region (U.S. Fish & Wildlife Service).



Appendix 2. The four 93.3-kilometer^2 study blocks, Calio, Leeds, Crary, Courtenay and their respective locations within the counties of North Dakota, USA.

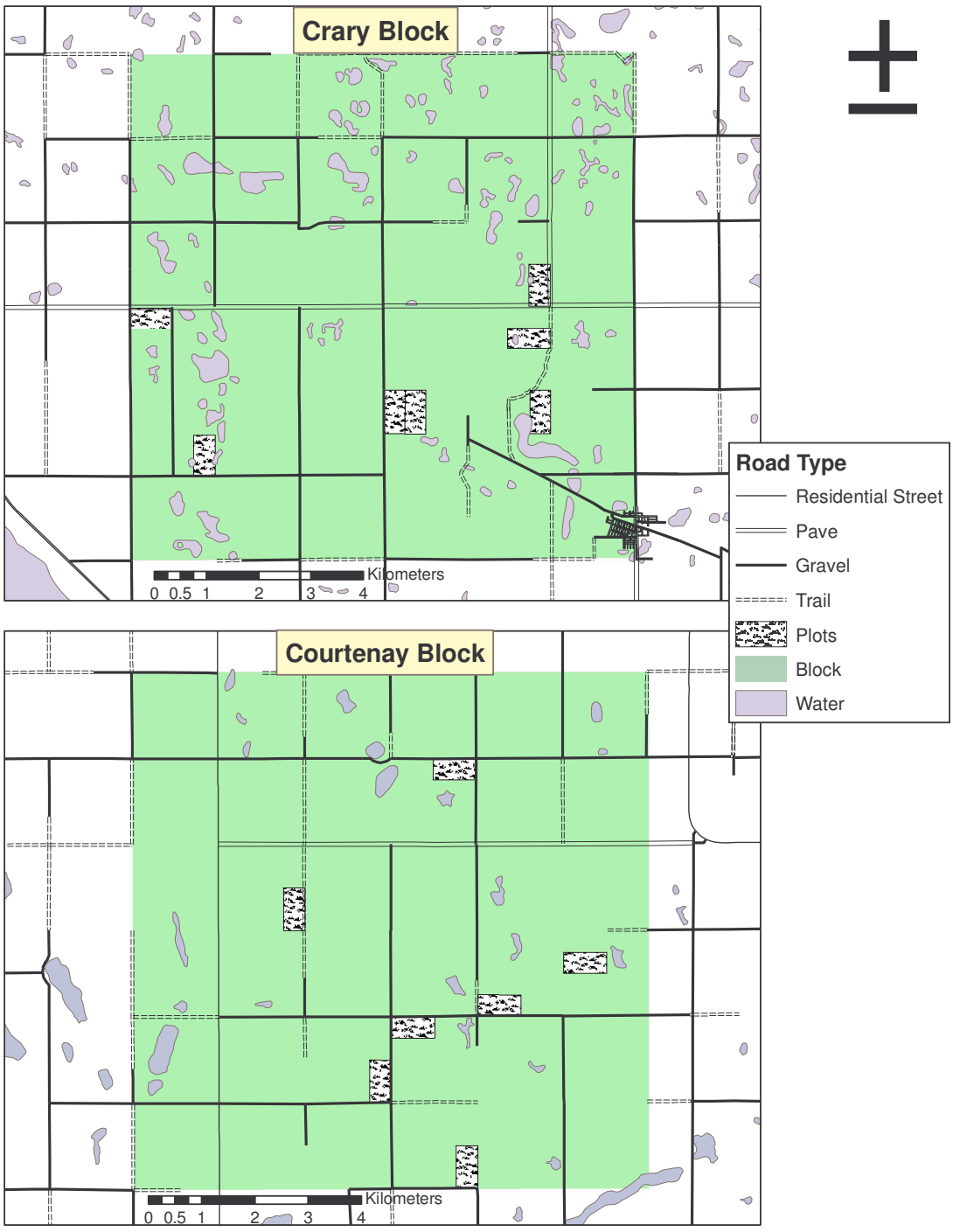


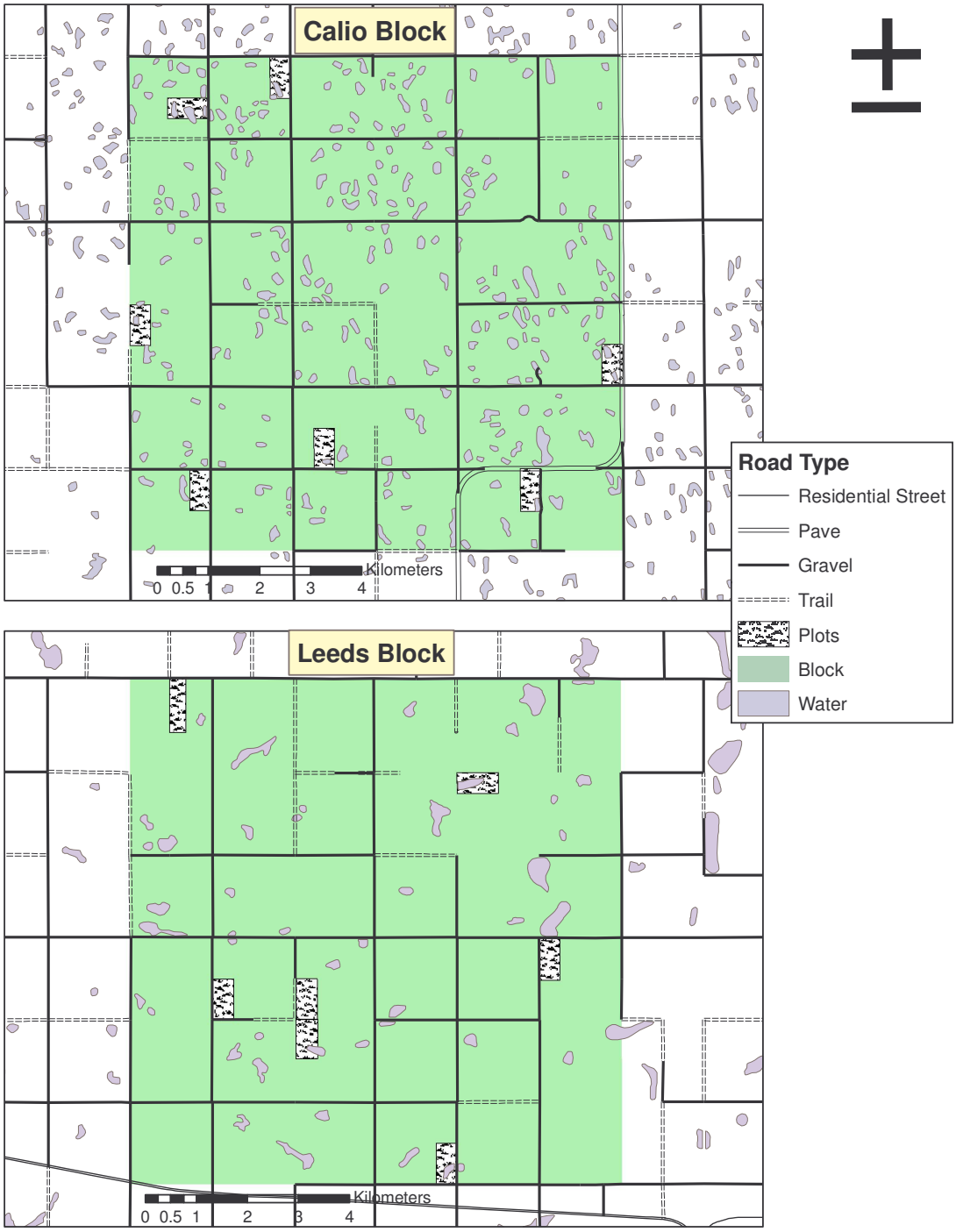
Appendix 3. Duck pair densities of select counties in the PPR of North Dakota, USA (U.S. Fish & Wildlife Service).

Number of Roads Bordering	Road Types	Number of Plots	Total
3	2 Gravel, 1 Paved	1	1
2	2 Gravel	8	11
	1 Gravel, 1 Paved	1	
	1 Gravel, 1 Trail	1	
	2 Paved	1	
1	Gravel	6	10
	Trail	4	
	Paved	0	
0	--	--	5

Appendix 4. Distribution and types of roads bordering study plots.

Note: Distance used as a continuous variable, therefore nests located on plots with no bordering roads were measured to the nearest road outside of the plot which were either gravel roads or trails.


Crary Block
Kilometers
0 0.5 1 2 3 4
Courtenay Block
Kilometers
0 0.5 1 2 3 4
Road Type
Residential Street
Pave
Gravel
Trail
Plots
Block
Water



Appendix 5. Distribution of study plots and road network within each study block.

```
PROC genmod;
class block type ;
a = 1/expose;
fwdlink link = log((_mean_**a)/(1-_mean_**a));
invlink ilink = (exp(_xbeta_)/(1+exp(_xbeta_)))**expose;
model survive/trials = block type distance / dist=binomial;
ods output modelfit=modelfit;
ods output modelinfo=modelinfo;
ods output ParameterEstimates=ParameterEstimates;
title 'logistic-exposure model';
output out = betas xbeta=bvalue stdxbeta=stdbvalue  pred=predict ;
run;
data final;
set betas;
dsr = (exp(bvalue))/(1+(exp(bvalue)));
ns = dsr**35;
run;
proc print;
run;
quit;
```

Appendix 6. Coding for the comparison of the continuous variable distance, and the categorical variables study block and road type using the maximum likelihood method in PROC GENMOD.

```
PROC genmod;
class block type ;
a = 1/expose;
fwdlink link = log((_mean_**a)/(1-_mean_**a));
invlink ilink = (exp(_xbeta_)/(1+exp(_xbeta_)))**expose;
model survive/trials = block type / dist=binomial;
ods output modelfit=modelfit;
ods output modelinfo=modelinfo;
ods output ParameterEstimates=ParameterEstimates;
title 'logistic-exposure model 2';
output out = betas xbeta=bvalue stdxbeta=stdbvalue  pred=predict ;
run;
data final;
set betas;
dsr = (exp(bvalue))/(1+(exp(bvalue)));
ns = dsr**35;
upperbvalue = bvalue + 1.96 * stdbvalue;
lowerbvalue = bvalue - 1.96 * stdbvalue;
upperdsr = (exp(upperbvalue))/(1+(exp(upperbvalue)));
lowerdsr = (exp(lowerbvalue))/(1+(exp(lowerbvalue)));
run;
proc sort data = final;
by block;
run;
data paved_prepare;
set final;
if type ne 'Paved' then delete;
run;
data paved;
set paved_prepare;
by block;
if first.block;
run;
proc print;
title2 'DSR by Block for paved roads';
run;
data gravel_prepare;
set final;
if type ne 'Gravel' then delete;
run;
data gravel;
set gravel_prepare;
by block;
if first.block;
run;
proc print;
title2 'DSR by Block for gravel roads';
run;
data Trail_prepare;
set final;
if type ne 'Trail' then delete;
run;
data Trail;
set Trail_prepare;
by block;
if first.block;
run;
proc print;
title2 'DSR by Block for trail';
run;
quit;
```

Appendix 7. Coding for the comparison of study block and road type using the PROC GENMOD procedure and determining DSR of nests by block for each road type.