EFFECTS OF CATTLE GRAZING ON UPLAND NESTING DUCK PRODUCTION IN THE ASPEN PARKLAND

by

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

In

Fish and Wildlife Management

MONTANA STATE UNIVERSITY
Bozeman, Montana

July 2004

APPROVAL

of a thesis submitted by

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ACKNOWLEDGEMENTS

I would like to begin by thanking the crew leaders and technicians whose hard work and diligence made this project possible: C. Bolli, K. Burkhart, D. Cross, B. Fletcher, S. Folk, J. Kenyon, J. Naples, R. Paul, S. Rohatyn, J. Skelton, C. Sousa, and E. Tymensen. I am also indebted to many of the staff of Ducks Unlimited Canada (DUC), who provided insight, advice, and logistical support throughout the study. J. Thompson spearheaded the study and provided constant assistance and mentoring, M. Barr, R. Hunka, and I. McFarlane assisted with logistical issues and site selection, L. Armstrong provided statistical advice, and N. Hopkins was invaluable for her GIS expertise. Many other DUC employees gave freely of their time to assist with field work. R. Stavne deserves credit for many things, but mostly for being a friend. Additionally, I would like to thank all the landowners who gave us permission to perform this study on their lands.

Sincerest thanks go to my Graduate Committee – J. Rotella, R. Garrott, and L. Irby – who guided me through this process with patience and scientific integrity.

The Institute for Wetland and Waterfowl Research and the Aspen Parkland Field Office of Ducks Unlimited Canada, and the Alberta Partners of the North American Waterfowl Management Plan provided funding and/or logistical support.

Finally, I want to thank my family and friends who never faltered in their support of my pursuit to be a wildlife biologist.

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ABSTRACT

The beef industry is growing rapidly throughout the Aspen Parkland of Canada, leading to higher stocking rates on pastures and use of previously idled areas. Conversely, increased demand for pastureland has led to conversion of cropland that may have benefited upland nesting ducks by increasing the amount of perennial cover. We undertook the current study to evaluate the relationships of nest-site selection and nesting success of upland-nesting ducks to cattle grazing in the Aspen Parkland. Nearly 4,000 ha of upland cover were searched during the study. Vegetation physiognomy was quantified at each nest and at random points within each field. Despite extensive drought, nest searches located 309 duck nests. Grazing demonstrated a strong negative effect on duck nest densities, as did declining pasture health. Our best model of nesting success indicated an interaction between nest-site vegetation and residual cover. Across most values of residual cover, nesting success was positively influenced by nest-site vegetation. However, at high values of residual cover, nest-site vegetation negatively affected nesting success. Other negative effects on nesting success included cattle presence and grassland area within a 1-km radius. Field-scale wetland area, however, demonstrated a positive relationship with nesting success. Although previous work has demonstrated higher nesting success in pastures than other habitats in the Aspen Parkland, our study is the first that we know of that investigated grazing intensity as a continuous factor along the gradient from idle to > 90 % utilization across a large number of fields (n = 97).

EFFECTS OF CATTLE GRAZING ON UPLAND NESTING DUCK PRODUCTION IN THE ASPEN PARKLAND

Introduction

The Prairie Pothole Region (PPR) supports the highest densities of breeding waterfowl in North America. Although this region covers only 10% of the available breeding habitat for waterfowl, it can account for greater than 50% of annual continental duck production (Smith et al. 1964). The PPR contains millions of hectares of shallow wetlands created during the Wisconsin glaciation approximately 12,000 years ago (Leitch 1989). These wetlands undergo a dynamic wet-dry cycle that results in one of the most productive ecosystems in North America (Murkin et al. 2000). The PPR is divided into two major zones, the larger being the grasslands, which cover the southern portion of the Prairie Provinces. The northern one-third (22 million ha) of the PPR, the Aspen Parkland, supports approximately 36% of the waterfowl that breed in the Canadian PPR (Fig. 1). This region was historically characterized by trembling aspen (*Populus tremuloides*) groves interspersed with plains rough fescue (*Festuca hallii*) grasslands. However, annual cropland or tame pasture has replaced most of the native vegetation community.

Duck production in the PPR can be severely limited by predation of females, young, and eggs (Sargeant and Raveling 1992). Predation is the dominant cause of nest loss for ducks and therefore is the primary determinant of nesting success (i.e., the probability that a nest will hatch at least one egg) in the PPR (Klett et al. 1988, Greenwood et al. 1995). Studies have demonstrated that population growth rates (λ) for upland-nesting duck species in the PPR are highly sensitive to variation in nesting success (Johnson et al. 1992, Hoekman et al. 2002). Moreover, there is evidence that nesting success in the PPR has declined over the past 70 years (Beauchamp et al. 1996).

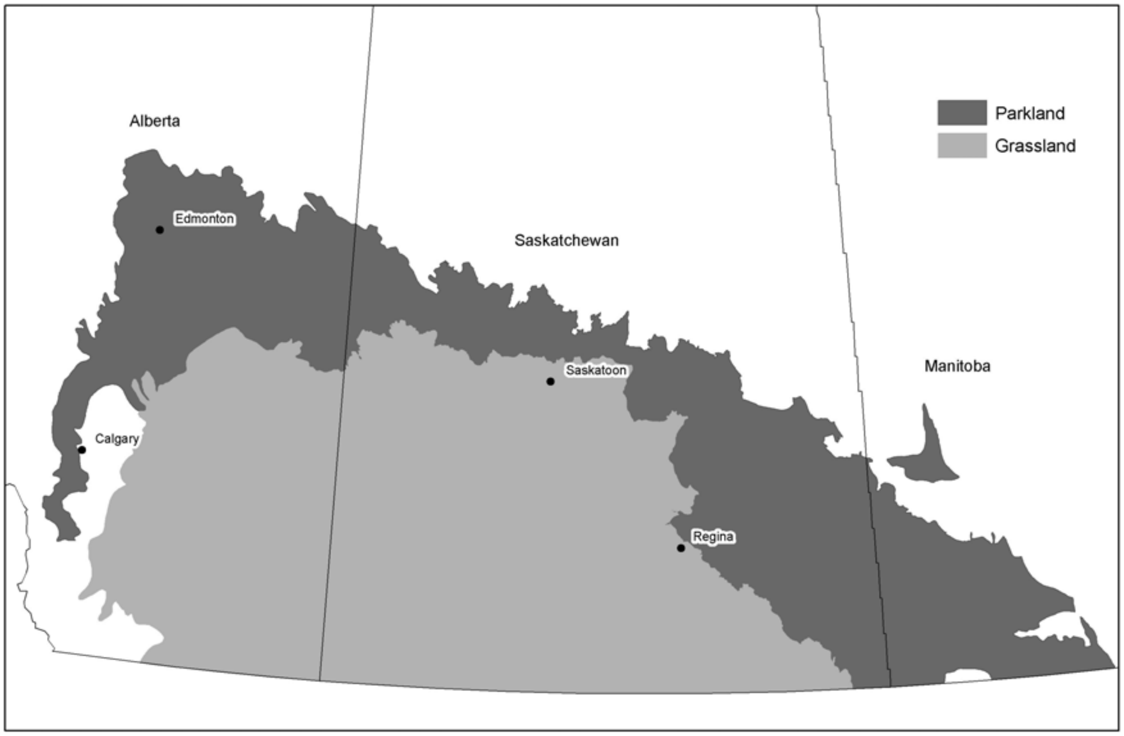


Figure 1. Map of the Canadian Prairie Pothole Region showing the Aspen Parkland (Parkland) and mixed-grass prairie (Grassland) ecoregions.

Reductions in nesting success have likely been due to declines in quantity and quality of nesting habitat and changes in the abundance and distribution of predator communities, all of which are likely related to intensification of agricultural land-use. Much of the PPR is dominated by agricultural land-use, which has led to loss and degradation of wetland and upland habitats throughout the region. Eighty percent of the Aspen Parkland has been converted to agricultural land use (Rowe 1987), and at least 40% of wetland basins have been drained or filled since settlement (Turner et al. 1987). Currently, the dominant agricultural land-use in the Aspen Parkland is production of annual crops. Another significant and increasing land-use in the Aspen Parkland is pastureland, of which there is currently 9.3 million ha (Statistics Canada 2001).

The prevalence of agricultural land-use and its effect on duck production have led to studies investigating duck production in relation to a variety of agricultural practices (Reynolds et al. 2001, Podruzny et al. 2002). The effect of cattle grazing on duck production is no exception (Kirsch 1969, Duebbert et al. 1986, Barker et al. 1990, Kruse and Bowen 1996, Ignatiuk and Duncan 2001). Much of this work has been focused in the mixed-grassland prairie, while grazing impacts in the Aspen Parkland have been largely overlooked. However, recent growth in the Canadian beef industry, which is occurring primarily in the Aspen Parkland (Statistics Canada 1996), has raised concern about the impact of grazing on vital rates of breeding ducks in this region.

Consumption and trampling of vegetation in pastures can negatively affect the attractiveness and quality of nesting habitat for ducks (Kirsch 1969). Gilbert et al. (1996) found that during the first nesting season following moderate grazing, nest densities and nesting success were 58% and 85%, respectively, of those for ungrazed areas on Monte Vista National Wildlife Refuge, Colorado. This study supports the hypothesis that increasing vegetation height and density increases nesting success, possibly by impeding predator movements and their ability to detect nests (Duebbert 1969, Schranck 1972, but see Clark and Nudds 1991). Alternatively, light or moderate levels of herbivory can increase plant productivity in some systems (Dyer et al. 1993, Milchunas and Lauenroth 1993, Frank et al. 2002), which may improve nesting cover. Several studies have documented greater nesting success in pastures than other habitats in the PPR (Barker et al. 1990, Greenwood et al. 1995), but how duck production differs among pastures along the spectrum of grazing intensities in the Aspen Parkland had not been investigated.

Growth in the Canadian beef industry has the potential to affect considerable areas of waterfowl habitat in the Aspen Parkland. There are presently 17.9 million hectares of perennial cover in the Aspen Parkland (Ducks Unlimited Canada, unpublished data). Assuming that all existing perennial cover is vulnerable to grazing, this includes at least 6.9 million hectares of area with medium to high waterfowl production capability ($\geq$ 12 Breeding Pairs/km^2) that may be impacted by a growing cattle industry (Ducks Unlimited Canada, unpublished data). Negative effects of a growing cattle industry will include grazing of perennial cover that is currently idle and higher stocking rates on existing pastureland. Conversely, growth in the cattle industry could also benefit upland nesting ducks. Conversion of cropland to pastureland to accommodate growth in the industry will result in increased perennial cover in the Aspen Parkland. Pastureland increased by more than 275,000 ha between 1991 and 2001 in the Aspen Parkland, due largely to conversion of annual cropland to pastureland (Statistics Canada 2001). Greenwood et al. (1995) found a positive relationship between the amount of perennial cover in the landscape and nesting success in the PPR, but this relationship was weaker in the Aspen Parkland than in the grasslands.

The Aspen Parkland is a highly productive region for both waterfowl and agriculture. For this reason, it is necessary for managers to have a better understanding of the effects of different land-uses on waterfowl production. Moreover, understanding variation in effects of competing land management practices within a specific category of land-use, e.g., grazing systems and levels of utilization, can lead to improved management of these systems and increased compatibility between agricultural and waterfowl production. Therefore, I undertook this study to evaluate relationships between intensity of cattle grazing and 2 different aspects of annual duck production: (1) field-specific nest abundance, and (2) field-specific nesting success. To achieve these objectives, I studied upland-nesting ducks in tame and native/naturalized pastures that varied in intensity of cattle grazing in the Aspen Parkland.

Methods

Study Area

This study was conducted on private pasturelands, provincial grazing reserves, and managed Ducks Unlimited Canada properties in the western Aspen Parkland of Alberta, which lies between 51 and 54° N latitude and 110 and 114° W longitude (Fig. 2). The region is dominated by agricultural land use with cereal grains, oil seeds, and cattle as the major products. The topography is undulating to hilly with black chernozemic soils the dominant soil type (National Wetlands Working Group 1988). Mid-continent weather extremes characterize the Parkland; temperatures vary from –40 ° C to 38 ° C, with average temperatures for January and July of –14.1° C and 17.3° C, respectively (Hare and Thomas 1979, Winter 1989). Average annual precipitation is approximately 45 cm (Winter 1989). Sixty percent of the precipitation for the region falls during the summer months, with most falling in June (Moss 1932). However, wetlands in the Aspen

Parkland are largely dependent upon spring runoff for annual recharge. Wetland densities in central Alberta average 20 basins/km^2 (Smith 1971).

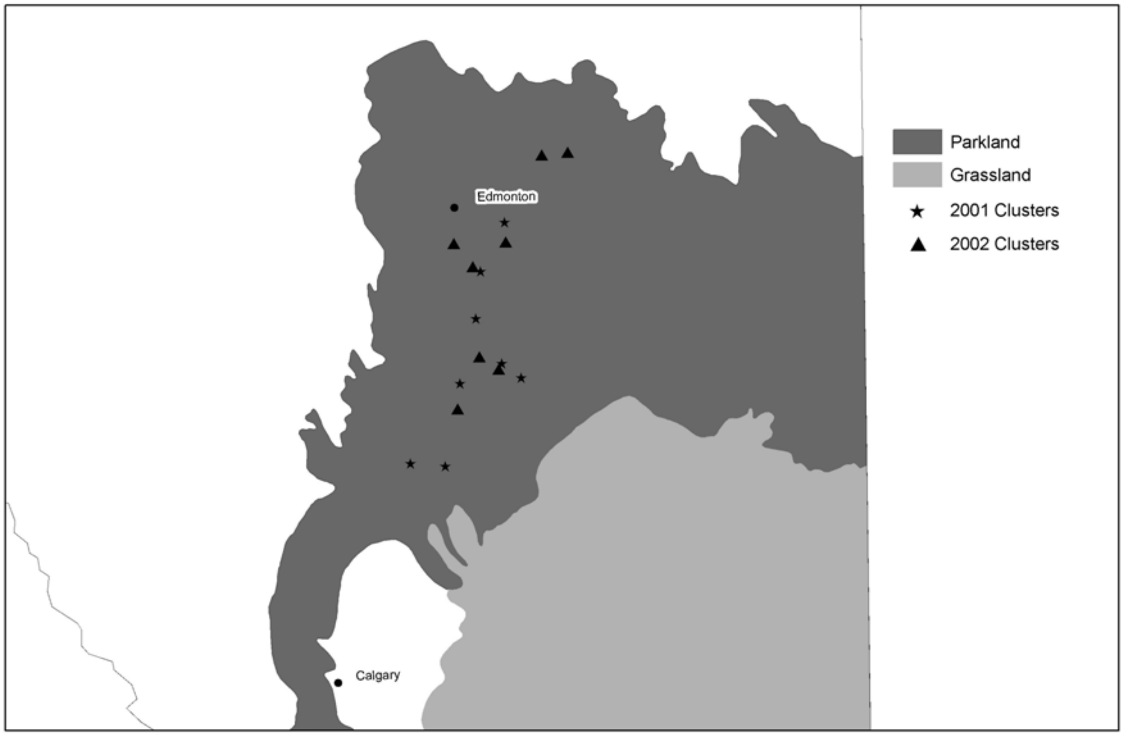


Figure 2. Location of study sites in the western Aspen Parkland of Alberta, Canada, 2001-2002. A cluster was comprised of a grouping of each of the 6 treatment types based on grazing intensity (heavy, moderate, and low/idle) and grass type (native/naturalized and tame). Fields within a cluster were selected to minimize cluster radii ($\leq$ 17.2 km) while maintaining between-field separation of $\geq$ 1.6 km.

Field Selection

Efforts were made to select fields in areas with high densities of breeding ducks to maximize the number of nests located during fieldwork, because this would increase the likelihood of detecting among-treatment differences in nest density and nesting success. Morainal areas within the western Aspen Parkland that were predicted to support $\geq$ 12 breeding duck pairs/km^2 during average wetland conditions were identified (Ducks

Unlimited Canada, unpublished data). From the moraines that met this criterion, I selected 8 clusters of fields each year. The fields in each cluster contained each of the 6 treatment levels under investigation (see below). Due to the persistent drought that occurred during the study, clusters were selected in areas with the best relative wetland conditions. Moreover, wetland density and permanency were considered when selecting fields. Fields with low wetland density and/or few basins that would contain water during drought were not selected. Fields ranged in size from 32-130 ha and were selected so that proximity to other fields was ≥ 1.6 km, while each cluster's radii, i.e., the distance from the center of each cluster to the outermost portion of the furthest fields in that cluster, was minimized (≤ 17.2 km) to help ensure that within-cluster fields experienced a similar suite of ecological regimes (e.g. predator communities, precipitation). New clusters and fields were selected for the second year of the study to increase spatial replication.

Fields were selected based on grass type (2 classes) and grazing-intensity level (3 classes). Grass types (GT) were (1) tame and (2) native/naturalized. Tame fields were typically areas planted for forage production and were dominated by tame-forage grasses (*Bromus* spp., *Phleum pratense*, *Dactylis glomerata*) and in addition frequently contained nitrogen-fixing forbs (*Medicago sativa*, *Trifolium hybridum*). Native/naturalized fields included native grasslands and naturalized tame areas that contained native shrub and forb components. Naturalized fields were dominated by introduced grasses but were structurally similar to native grasslands due to the encroachment of native shrubs and forbs such as western snowberry (*Symphoricarpos occidentalis*), willow (*Salix* spp.), and prickly rose (*Rosa acicularis*). Grazing intensity (GI) was categorized according to the estimated percent utilization of vegetation by cattle during the previous year as heavy (>66% utilization), moderate (33-65% utilization), or low/idle (<32% utilization). Categorization was approximate and done prior to data collection.

Field Characteristics

I measured or obtained field-specific characteristics considered important covariates for describing differences in upland-nesting duck production across sites. Field-scale attributes were measured directly during each field season. Within-field residual cover, vegetation height, and nesting season vegetation density changes were quantified using Robel pole measurements (Robel et al. 1970). Each field was also classified according to the amount of shrub cover present. The number, area, and permanency of all wetlands within each field were recorded during July of each year. Pasture health was assessed with a commonly used range science technique (Adams et al. 2000). Landscape-scale covariates of interest (i.e., percent perennial cover, percent grassland, percent woodland, and percent wetland) for each site were obtained from existing geographic information system databases.

Due to the qualitative nature of the preliminary categorization grazing intensity within fields, quantification of vegetation characteristics began with commencement of field data collection. Upon completion of the first nest search in each field, Robel pole and vegetation height measurements (see Nest Searching and Nest Monitoring below) were recorded at random sites. Twenty random points were established within upland habitat in each field for measurement during the first year; 30 random points were measured during the second year. Random points were used to quantify attributes of field-scale residual cover available to upland nesting ducks during the breeding season. Because the 4 Robel pole readings taken at each of the random points were not independent, a single visual obstruction measurement (VOM) was obtained by averaging the 4 readings at each random point. Within-field residual cover (RC) was estimated by averaging random-point readings for each field. The average maximum height of the vegetation (FVH) was also calculated for each field. To estimate field scale temporal change in available nesting cover for ducks, random points were revisited during the third search, and the same measurements were taken. The difference between these data was used to quantify the field trend (FTREND) in vegetation density during the breeding season. Each field was also placed into one of four categories based on the percent of searched area containing shrub cover (SA)(class 0, ≤ 5% of the searched area contained shrubs; class I, 6%-20%; class II, 21%-50%; class III, >50%).

Wetland density and permanency were considered when selecting fields to maximize the number of duck nests found. Therefore, it was necessary to quantify these covariates for each field. This was accomplished by visiting each wetland basin in July to (1) classify its permanency according to vegetation (Stewart and Kantrud 1971), and (2) delineate the wetland basin on a map created from an aerial photograph. Each wetland was later digitized and its area calculated using photo delineation and ArcView (Environmental Systems Research Institute, Redlands, California, USA) Geographic Information Systems (GIS) software. The proportion of flooded class III-V wetland basins (Stewart and Kantrud 1971) by field (PFBASIN) was estimated by dividing the number of class III-V basins containing water in July by the total number of class III-V basins in that field. Ephemeral and temporary (class I and II, respectively) wetlands were not included in this metric because those basins are normally dry by July. July wetland conditions were used because they could be consistently recorded and thus provide useful information on each season's drought levels.

To test the efficacy of a common range/pasture health assessment process to predict duck production, I assessed each field following the protocol of the Range/Pasture Health Assessment Short Form (Adams et al. 2000). This evaluation assesses rangeland health using indicators of historical grazing patterns such as plant community structure, hydrologic function and nutrient cycling, and site stability. Ten plots within each field were assessed and given a score between 0-100, with 100 being the best score attainable. Alternate random vegetation plots (see above) were chosen for health assessment during the first year, and every third random vegetation plot was assessed during the second year. Plot scores were averaged for each field for an overall score (PS) used in analysis.

In an effort to better understand the effects of landscape-scale perennial cover and several of its components (grassland, wetland, woodland) on nest survival in the Aspen Parkland, I obtained land-cover data from Agriculture and Agri-Food Canada (1995). Although these data were produced from October 1993-June 1995, they were the only data available that included all of the Canadian PPR and therefore ensured complete coverage of all fields studied. The land-cover classes were derived from 30 m resolution Landsat™ satellite imagery (Agriculture and Agri-Food Canada 1995). I used this data to estimate the percent perennial cover for each field at 4 different scales. The UTM coordinate for the center of each field was located, and concentric buffer polygons with 1, 2, 3, and 4 km radii were created using ArcView GIS software. The area of perennial land cover classes (i.e., grassland, hayland, shrubland, wetland, and woodland) within a buffer polygon was summed and then divided by the area of the polygon to give percent perennial cover. I calculated this metric for each field at each of the 4 scales represented by buffer polygons of 1 - 4-km radii, resulting in 4 perennial cover covariates for each field (PC1, PC2, PC3, and PC4, respectively). This was repeated for grassland (GL1-GL4), wetland (WEA1-WEA4), and woodland (WOA1-WOA4) land-cover classes, resulting in 16 landscape covariates.

Nest Monitoring

To obtain samples for comparing duck nest density and nesting success among treatments, grassland, shrubland, and dry wetland areas were systematically searched by 2 person crews using cable-chain drags towed by all-terrain vehicles (Klett et al. 1986). Each field was searched 3 times per summer–once during each of 3 21-day searches. Searches began on 10 May in 2001 and on 12 May in 2002 and were conducted 6 days per week from 0700 to 1400 h to coincide with times of peak nest attendance by females (Gloutney et al. 1993). Due to the distance between clusters and associated logistical constraints, search order was determined by first randomly selecting the order in which clusters were searched and then randomly selecting the order in which fields within each cluster were searched. The total area searched for each field was delineated on aerial photographs. Upland area searched for each field (SAREA) was calculated by digitizing the total area searched with ArcView GIS software and subtracting wetland area (see above).

All nests found were marked with a flagged stick placed 4 m to the north of the nest bowl. For each nest the Universal Transverse Mercator (UTM) position, habitat type (i.e., grassland, shrubland, wetland) (NHAB), and nest initiation date were recorded. Nest initiation date was estimated by field-candling eggs (Weller 1956). Nests were revisited every 6 to 10 days until fate was determined (at least one egg hatched or the nest was destroyed or abandoned). Nest revisits were performed in the afternoon to minimize risk of abandonment (Gloutney et al. 1993). On each visit nest status (active, successful, abandoned, or destroyed), interval length since last visit, and presence or absence of cattle (CP) was recorded.

Nest-Site Vegetation Monitoring

To monitor vegetation characteristics at nest sites and changes in vegetative cover over time, vegetation physiognomy was quantified using a Robel pole placed at the nest and by recording nest-site vegetation height (NVH) to the nearest 5 cm, up to a maximum of 1.5 m. These measurements were taken when nests were found during the first field season, and additionally at each subsequent visit to a nest during the second season. Robel measurements were taken at each of the 4 cardinal directions with the pole immediately north of the nest while the observer stood 4 m away and held their eye 1 m above the ground. The lowest half-decimeter block on the Robel pole that was completely obscured by vegetation was recorded. The 4 measurements were then averaged for an estimate of nest-site vegetation density (NVEG).

Data Analysis

Overall Approach. To investigate hypotheses of interest regarding each of the 2 components of duck production studied, I created and evaluated suites of *a priori* models that expressed competing ideas regarding patterns of variation in each regressed variable (Burnham and Anderson 1998). When developing model lists, I reviewed existing literature to identify factors driving duck production in the PPR and possible effects of cattle grazing on these factors (Table 1). I evaluated the strength of support that the data gave to each model by ranking models with Akaike's Information Criterion corrected for small sample sizes (AIC_c) and by calculating the normalized relative model likelihoods (ω_i) for each model (Burnham and Anderson 1998). To test for multicolliniarity among covariates used in modeling, Pearson correlation coefficients were calculated (Table 2).

Table 1. Covariates, and respective definitions, used in models to estimate the effect of cattle grazing and habitat characteristics on duck production in the Aspen Parkland of Alberta, Canada.

Covariate	Definition
CLSTR	Cluster as a random effect
CP	Presence or absence of cattle at the beginning of a nest interval
FTREND	Within-field vegetation density change between the first and third nest searches
FVH	Average field maximum vegetation height measured during the first nest search
GI	Grazing intensity (light/idle, moderate, heavy)
GL1-GL4	Proportion grassland area within a 1-, 2-, 3-, or 4-km radius, respectively, from field center
GT	Grass type (native/naturalized, tame)
JDATE	Julian date, where day 1 = the beginning of the nesting season (i.e. the initiation date of the earliest initiated nest found)
NAGE	Nest age
NHAB	Nest-site habitat classification (grassland, shrubland, wetland, woodland)
NVEG	Nest-site vegetation density
NVH	Nest-site vegetation maximum height
PC1-PC4	Proportion perennial cover within a 1-, 2-, 3-, or 4-km radius, respectively, from field center
PS	Average field pasture score
PWAREA	Proportion flooded wetland area by field
PWBASIN	Proportion flooded class III-V wetland basins by field
RC	Average field vegetation density measured during the first nest search
SA	Categories based on the proportion of nest-searched area containing shrub cover (4 classes)
SAREA	Upland area searched
SHET	Structural heterogeneity of field grassland vegetation measured during the first nest search
SITE	Site as a random effect
WEA	Proportion wetland area by field
WEA1-WEA4	Proportion wetland area within a 1-, 2-, 3-, or 4-km radius, respectively, from field center
WOA	Proportion woodland area by field
WOA1-WOA4	Proportion woodland area within a 1-, 2-, 3-, or 4-km radius, respectively, from field center
YR	Year

Table 2. Pearson correlation coefficients among covariates used to model nest density and nesting success of upland-nesting ducks in the Aspen Parkland of Alberta, Canada, 2001-2002.

	CP	FSHET	FTREND	FVH	GL1	GL2	GL3	GL4	GT	NVEG	NVH	PC1	PC2	PC3
CP	1.00	-0.17	-0.36	-0.25	0.02	-0.01	0.00	0.03	0.21	-0.06	-0.08	0.16	0.11	0.10
FSHET		1.00	0.36	0.67	0.06	0.17	0.17	0.17	-0.02	0.06	0.14	-0.11	-0.03	-0.01
FTREND			1.00	0.59	0.09	0.04	-0.03	-0.11	-0.24	0.03	0.08	-0.17	-0.06	-0.13
FVH				1.00	0.13	0.10	0.04	-0.05	-0.29	0.11	0.19	-0.15	-0.02	-0.05
GL1					1.00	0.84	0.68	0.59	0.13	0.02	-0.07	0.41	0.17	0.06
GL2						1.00	0.95	0.87	0.19	0.00	-0.07	0.28	0.31	0.29
GL3							1.00	0.96	0.20	-0.03	-0.06	0.23	0.37	0.41
GL4								1.00	0.28	-0.03	-0.07	0.28	0.39	0.44
GT									1.00	0.10	0.06	0.33	0.19	0.13
NVEG										1.00	0.49	0.00	0.01	-0.01
NVH											1.00	0.00	0.03	0.01
PC1												1.00	0.73	0.55
PC2													1.00	0.94
PC3														1.00
PC4														
PS														
RC														
SA														
WEA														
WEA1														
WEA2														
WEA3														
WEA4														
WOA														
WOA1														
WOA2														
WOA3														
WOA4														

Table 2. cont.

	PC4	PS	RC	SA	WEA	WEA1	WEA2	WEA3	WEA4	WOA	WOA1	WOA2	WOA3	WOA4
CP	0.11	-0.40	-0.26	0.18	-0.12	-0.03	-0.05	-0.01	0.06	0.11	-0.01	0.00	0.01	0.03
FSHET	-0.01	0.35	0.75	0.11	-0.11	0.10	0.22	0.20	0.14	0.08	-0.06	-0.10	-0.12	-0.13
FTREND	-0.16	0.29	0.58	-0.17	0.04	-0.17	0.04	0.01	-0.10	-0.04	-0.05	0.01	-0.02	-0.05
FVH	-0.11	0.45	0.73	-0.19	0.01	0.15	0.29	0.21	0.09	-0.09	-0.04	0.02	0.01	0.01
GL1	-0.02	0.03	0.25	0.14	0.08	0.11	-0.04	-0.09	-0.09	-0.17	-0.40	-0.36	-0.37	-0.40
GL2	0.22	0.07	0.27	0.22	0.06	0.08	0.08	0.02	-0.01	-0.10	-0.34	-0.34	-0.35	-0.37
GL3	0.38	0.07	0.21	0.24	0.07	0.13	0.16	0.09	0.05	-0.04	-0.27	-0.28	-0.30	-0.30
GL4	0.46	0.01	0.13	0.33	0.10	0.22	0.19	0.17	0.15	0.04	-0.20	-0.24	-0.26	-0.27
GT	0.14	-0.57	-0.20	0.93	-0.12	0.08	0.04	0.09	0.20	0.48	0.05	0.03	0.03	-0.02
NVEG	-0.02	-0.12	-0.01	0.18	0.07	-0.01	0.10	0.12	0.15	0.05	0.04	0.06	0.06	0.04
NVH	0.00	-0.03	0.11	0.11	-0.02	0.06	0.10	0.12	0.15	0.14	0.06	0.07	0.07	0.05
PC1	0.50	-0.20	-0.11	0.40	0.05	0.15	0.03	0.05	0.13	0.37	0.46	0.39	0.36	0.34
PC2	0.88	-0.08	-0.09	0.30	0.01	0.01	0.15	0.18	0.18	0.34	0.50	0.59	0.58	0.57
PC3	0.97	-0.02	-0.14	0.24	0.00	0.04	0.24	0.23	0.20	0.28	0.43	0.53	0.56	0.58
PC4	1.00	-0.04	-0.20	0.24	0.05	0.11	0.27	0.26	0.23	0.30	0.42	0.49	0.52	0.56
PS		1.00	0.48	-0.52	0.30	0.06	0.02	-0.08	-0.11	-0.24	0.02	-0.03	-0.05	-0.03
RC			1.00	-0.13	0.01	0.03	0.12	0.08	0.02	-0.08	-0.16	-0.19	-0.24	-0.27
SA				1.00	-0.13	0.11	0.07	0.14	0.24	0.59	0.11	0.07	0.06	0.02
WEA					1.00	0.17	-0.03	-0.12	-0.05	-0.18	0.12	0.08	0.06	0.07
WEA1						1.00	0.67	0.56	0.50	0.06	0.03	-0.06	-0.05	-0.02
WEA2							1.00	0.90	0.73	-0.03	0.16	0.19	0.22	0.24
WEA3								1.00	0.90	0.02	0.22	0.26	0.28	0.28
WEA4									1.00	0.07	0.32	0.35	0.36	0.34
WOA										1.00	0.42	0.31	0.28	0.26
WOA1											1.00	0.89	0.85	0.83
WOA2												1.00	0.98	0.95
WOA3													1.00	0.99
WOA4														1.00

Many previous grazing studies have drawn comparisons between grazed versus non-grazed areas or among specific grazing regimes (Curtin 2002). While these studies have been insightful, such comparisons may prevent accurate inference of the ecological implications of grazing across the gradient of intensities (Curtin 2002, Steury et al. 2002). Moreover, accurate estimation of the amount of vegetation removed by grazing (percent utilization) is fraught with difficulties and, therefore, not recommended for management uses (Sharp et al. 1994). I modeled response variables for nest density and nesting success as functions of continuous covariates that quantified the most direct impact of grazing, i.e., its effect on vegetation physiognomy. This type of analysis allowed inference on grazing impacts to upland-nesting waterfowl across a spectrum of grazing intensities. However, the intensive data collection required to measure these continuous covariates is generally prohibitive from the standpoint of agencies and organizations involved in landscape-scale range management activities. Therefore, I also included grazing intensity (see Site Selection above) as a categorical covariate in modeling to measure the difference in efficacy between a simple qualitative categorization and intensive quantification of grazing impacts.

Nest Density. I modeled the total number of duck nests found in upland habitats (i.e., grassland and shrubland) within a field (NESTS) as a function of habitat covariates (Table 1) using generalized linear models, a Poisson distribution of errors, and a log-link function in Proc GENMOD of SAS (SAS Institute Inc. 2001). The Poisson distribution is commonly used when analyzing discrete count data when large counts are rare events (Neter et al. 1996, Zar 1999). The log-transform of upland area searched (lSAREA) was used as an offset variable to account for differences in searched area among fields when modeling nest counts. The β coefficient for an offset variable is constrained to the value of 1, which when modeled with a log-link function, transforms the model into a model of rates (in this case, nests per hectare) (Venables and Ripley 2002). Although I wanted to test for random effects at both site and cluster scales, this was prevented by use of Proc GENMOD for this analysis.

Nest densities of upland nesting ducks depend on: (1) how ducks settle on the breeding grounds; and (2) how females select nest sites. Nest-site selection by females varies intra- and interspecifically. However, previous studies have demonstrated a positive relationship between vegetation density and nest densities (Duebbert and Lokemoen 1976, Kirsch et al. 1978, Barker et al. 1990, Kruse and Bowen 1996). Through consumption and trampling of vegetation, cattle decrease vegetation density and structure and, therefore, may decrease availability of nest sites. To model these effects, covariates that categorized or quantified field-scale vegetation density or structure (GI, FTREND, FVH, RC, SA; Table 1) were included in *a priori* models. Twelve models that included residual cover (RC, a continuous covariate) comprised the Continuous Suite of nest density models (Table 3). A separate suite of 7 models (Management Suite; Table 3) was created to investigate the amount of information lost when using a simple qualitative classification of grazing intensity by exchanging RC with the categorical covariate GI. Grazing intensity (GI) was modeled with the moderate class as a dummy variable.

Table 3. Biological hypotheses for the response of duck nest density to grazing in the Aspen Parkland of Alberta, Canada, and the resulting *a priori* models and model structures. The Continuous Suite contains a continuous variable for residual cover while the Management Suite replaces this variable with a categorical variable of grazing intensity. All models include the log of area searched (lSAREA) by field as an offset variable and the proportion of flooded wetland basins (PFBASIN) as a measure of field-specific wetland conditions.

Hypothesis	Model	Model Structure
Continuous Suite		
1. Null model	$\text{DEN}_{\text{PFBASIN}}$	$\beta_0+\beta_1(\text{PFBASIN})$
2. Year-only model	$\text{DEN}_{\text{PFBASIN+YR}}$	$\beta_0+\beta_1(\text{PFBASIN})+ \beta_2(\text{YR})$
3. Positive residual cover effect	$\text{DEN}_{\text{PFBASIN+RC}}$	$\beta_0+\beta_1(\text{PFBASIN})+\beta_2(\text{RC})$
4. Positive residual cover effect; separate intercepts for year	$\text{DEN}_{\text{PFBASIN+RC+YR}}$	$\beta_0+\beta_1(\text{PFBASIN})+\beta_2(\text{RC})+\beta_3(\text{YR})$
5. Positive residual cover and field trend effect	$\text{DEN}_{\text{PFBASIN+RC+FTREND}}$	$\beta_0+\beta_1(\text{PFBASIN})+\beta_2(\text{RC})+\beta_3(\text{FTREND})$
6. Positive residual cover and field trend effect with interaction	$\text{DEN}_{\text{PFBASIN+RC+FTREND+RC*FTREND}}$	$\beta_0+\beta_1(\text{PFBASIN})+\beta_2(\text{RC})+\beta_3(\text{FTREND})+\beta_4(\text{RC*FTREND})$
7. Positive residual cover and field vegetation height effect	$\text{DEN}_{\text{PFBASIN+RC+FVH}}$	$\beta_0+\beta_1(\text{PFBASIN})+ \beta_2(\text{RC})+\beta_3(\text{FVH})$
8. Positive residual cover effect; separate intercepts for grass type classes	$\text{DEN}_{\text{PFBASIN+RC+GT}}$	$\beta_0+\beta_1(\text{PFBASIN})+\beta_2(\text{RC})+\beta_3(\text{GT})$
9. Positive residual cover effect; separate intercepts and slopes for grass type classes	$\text{DEN}_{\text{PFBASIN+RC+GT+RC*GT}}$	$\beta_0+\beta_1(\text{PFBASIN})+\beta_2(\text{RC})+\beta_3(\text{GT})+\beta_4(\text{RC*GT})$
10. Positive residual cover effect; separate intercepts for shrub area classes	$\text{DEN}_{\text{PFBASIN+RC+SA}}$	$\beta_0+\beta_1(\text{PFBASIN})+\beta_2(\text{RC})+\beta_3(\text{SA})$
11. Positive residual cover and field trend effect, separate intercepts for grass type/year	$\text{DEN}_{\text{PFBASIN+RC+FTREND+GT+YR}}$	$\beta_0+\beta_1(\text{PFBASIN})+\beta_2(\text{RC})+\beta_3(\text{FTREND})+\beta_4(\text{GT})+ \beta_5(\text{YR})$
12. Positive pasture score effect	$\text{DEN}_{\text{PFBASIN+PS}}$	$\beta_0+\beta_1(\text{PFBASIN})+\beta_2(\text{PS})$
13. Positive residual cover and pasture score effects	$\text{DEN}_{\text{PFBASIN+RC+PS}}$	$\beta_0+\beta_1(\text{PFBASIN})+ \beta_2(\text{RC})+\beta_3(\text{PS})$
14. Positive residual cover and pasture score effects, separate intercepts for year	$\text{DEN}_{\text{PFBASIN+RC+PS+YR}}$	$\beta_0+\beta_1(\text{PFBASIN})+ \beta_2(\text{RC})+\beta_3(\text{PS})+ \beta_4(\text{YR})$
Management Suite		
1. Negative grazing intensity effect	$\text{DEN}_{\text{PFBASIN+GI}}$	$\beta_0+\beta_1(\text{PFBASIN})+\beta_3(\text{GI})$
2. Negative grazing intensity; separate intercepts for year	$\text{DEN}_{\text{PFBASIN+GI+YR}}$	$\beta_0+\beta_1(\text{PFBASIN})+\beta_2(\text{GI})+\beta_3(\text{YR})$
3. Negative grazing intensity; separate intercepts for grass type classes	$\text{DEN}_{\text{PFBASIN+GI+GT}}$	$\beta_0+\beta_1(\text{PFBASIN})+\beta_2(\text{GI})+\beta_3(\text{GT})$
4. Negative grazing intensity effect; separate intercepts and slopes for grass type classes	$\text{DEN}_{\text{PFBASIN+GI+GT+RC*GT}}$	$\beta_0+\beta_1(\text{PFBASIN})+\beta_2(\text{GI})+\beta_3(\text{GT})+\beta_4(\text{RC*GT})$
5. Negative grazing intensity effect; separate intercepts for shrub area classes	$\text{DEN}_{\text{PFBASIN+GI+SA}}$	$\beta_0+\beta_1(\text{PFBASIN})+\beta_2(\text{GI})+\beta_3(\text{SA})$
6. Negative grazing intensity and positive pasture score effects	$\text{DEN}_{\text{PFBASIN+GI+PS}}$	$\beta_0+\beta_1(\text{PFBASIN})+ \beta_2(\text{GI})+\beta_3(\text{PS})$
7. Negative grazing intensity and positive pasture score effects, separate intercepts for year	$\text{DEN}_{\text{GI+PS+YR}}$	$\beta_0+\beta_1(\text{PFBASIN})+ \beta_2(\text{GI})+\beta_3(\text{PS})+ \beta_4(\text{YR})$

Settling of breeding ducks on the landscape in the PPR is affected by multiple factors (e.g. philopatry, success of individual females the previous year). However, pair densities of breeding ducks have demonstrated a strong positive correlation with wetland conditions (Johnson and Grier 1988, Anderson et al. 1992). To control for differences in wetland conditions among fields, the proportion of flooded basins (PFBASIN) was included in each model.

Estimates of dispersion obtained during initial modeling efforts demonstrated extra-Poisson variation (i.e., overdispersion, sampling variance that is greater than theoretically expected), a common occurrence in count data (Lawless 1987). Overdispersion can be dealt with in several ways; perhaps the most convenient being utilization of the negative binomial distribution (Lawless 1987). This distribution relaxes the assumption of complete spatial randomness of organisms that is necessary when modeling with the Poisson distribution (White and Bennetts 1996). Clumped data, as could be expected with nest counts (i.e., fields with certain habitat attributes would attract more nesting ducks than fields which lack those attributes), are, therefore, typically well fit by the negative binomial distribution. All subsequent modeling of nest counts was accomplished using a negative binomial distribution. Model goodness of fit was tested with the estimated deviance, assuming a χ^2 distribution with n-k degrees of freedom, where n is the sample size and k is the number of estimated parameters (Neter et al. 1996).

Nesting Success. I was interested in modeling the response of nesting success to: (1) individual covariates specific to each nest monitored; (2) time-specific covariates such as nest age; (3) group covariates (i.e., features that were the same for multiple nests); and (4) random effects of site or cluster (Table 1). Therefore, generalized non-linear mixed models (Proc NLMIXED; SAS Institute, Inc. 2001) with a logit link were used to obtain estimates of nest daily survival rates (DSR) from the binomially distributed data. Analyzing the data with non-linear mixed models permitted testing of hypotheses using covariates measured at various scales (i.e., nest-site, field, and landscape scales) and to include both quantitative and categorical covariates in the models. Details of analysis methods were presented by Dinsmore et al. (2002), Stephens (2003), and Rotella et al. (In press). Additionally, the logit-link function constrains the estimate of DSR between 0 and 1. Proc NLMIXED allows 1 random effect (i.e., site or cluster) to be investigated at a time.

Nests abandoned, damaged or destroyed due to investigator activity, or found in woodland habitat, were not included in the analyses. Covariates used to estimate DSR were either: (1) constant across all days a nest was active (e.g. nest habitat); (2) measured during each visit and resulting values used for each day of the subsequent interval (e.g. nest-site vegetation); or (3) time-variable so that the covariate value changed across days in the interval (e.g. nest age). During the first field season, nest vegetation measurements were only taken when a nest was found (see Methods, above). Therefore, the initial nest vegetation measurement was used as a constant covariate for each nest found during the first year. Once estimates for DSR were obtained, nesting success was calculated as $(\mathrm{DSR})^n$, where n is the average number of days from initiation to hatch for upland-nesting ducks (n=35 for species used in analysis).

Non-habitat sources of variation in DSR for nests of upland nesting ducks, e.g. nest age and julian date, have recently been demonstrated (Garrettson and Rohwer 2001, Howerter 2002, Stephens 2003). I considered these sources of variation in nesting success *a priori* to be biologically important. However, due to the limited sample of nests, univariate models of nest age (NAGE) and julian date (JDATE) were analyzed to look for evidence that would warrant inclusion of one or both of these covariates in further modeling efforts. If 95% confidence intervals for the coefficient relating NAGE and/or JDATE did not include 0, the variable was considered in subsequent models. Potential annual variation in nesting success was handled in a similar manner. Additionally, I was interested *a priori* in the amount of heterogeneity in DSR that went unexplained by the covariates measured during the study. Therefore, both site (SITE) and cluster (CLSTR) were considered as potential random effects in analysis. Current techniques only allow estimation of 1 random effect at a time, so Combined Suite models (see below) were analyzed by first including SITE as a random effect and then replacing SITE with CLSTR. By comparing AIC_c values for Combined Suite models without a random effect versus those with either site or cluster as a random effect, I was able to assess the importance of these factors in explaining heterogeneity in DSR.

Three suites of models were created: 1) an *a priori* Grazing Suite; 2) an exploratory Landscape Suite; and 3) an exploratory Combined Suite (Table 4). Multiple suites of models permitted comparison of direct grazing effects to non-grazing effects at several scales. The Combined Suite was created by combining the most supported Grazing Suite models (0-4 ΔAIC_c, for nested models; Burnham and Anderson 1998) with the most supported Landscape Suite models (0-2 ΔAIC_c, for non-nested models, Burnham and Anderson 1998). Further exploratory analysis was done with Combined Suite models by eliminating non-significant covariates ($\alpha = 0.05$) from models and sequentially adding significant ones. Inference from these final exploratory models is weakened by the *a posteriori* nature of model development, relative to *a priori* models (Gilbert et al. 1996, Burnham and Anderson 1998), but still provide valuable insights to the hypotheses of interest.

Table 4. Biological hypotheses for the response of duck nesting success to habitat and non-habitat covariates in the Aspen Parkland of Alberta, Canada, and the resulting models and model structures. Hypotheses for the *a priori* Grazing Suite and exploratory Landscape Suite were made *a priori* to data analysis. I considered the Landscape Suite exploratory because every possible univariate model was included for each of the land-cover classes and scales. Grazing Suite models that contained residual cover (RC) as a covariate were also analyzed with RC in quadratic form to test for a hypothesized non-linear relationship between RC and nesting success. Combined Suite model hypotheses were made *a posteriori* based upon results obtained from analysis of this exploratory suite.

Hypothesis	Model	Model Structure
Non-habitat models		
1) Positive nest age effect	DSR_{NAGE}	$\beta_0 + \beta_1(NAGE)$
2) Positive julian date effect	DSR_{JDATE}	$\beta_0 + \beta_1(JDATE)$
Grazing Suite		
1) Null model	DSR_{Null}	β_0
2) Year only model	DSR_{YR}	$\beta_0 + \beta_1(YR)$
3) Positive nest vegetation density effect	DSR_{NVEG}	$\beta_0 + \beta_1(NVEG)$
4) Positive nest vegetation density effect, separate intercepts for grass types	$DSR_{NVEG+GT}$	$\beta_0 + \beta_1(NVEG) + \beta_2(GT)$
5) Positive nest vegetation density and height effect	$DSR_{NVEG+NVH}$	$\beta_0 + \beta_1(NVEG) + \beta_2(NVH)$
6) Interaction of nest vegetation density and residual cover	$DSR_{NVEG+RC+NVEG*RC}$	$\beta_0 + \beta_1(NVEG) + \beta_2(RC) + \beta_3(NVEG*RC)$
7) Interaction of nest vegetation density and residual cover, separate intercepts for grass types	$DSR_{NVEG+RC+NVEG*RC+GT}$	$\beta_0 + \beta_1(NVEG) + \beta_2(RC) + \beta_3(NVEG*RC) + \beta_4(GT)$
8) Positive nest vegetation density effect; separate intercepts for nest habitat types	$DSR_{NVEG+NHAB}$	$\beta_0 + \beta_1(NVEG) + \beta_2(NHAB)$
9) Interaction of nest vegetation density and residual cover, negative woodland and wetland area effect	$DSR_{NVEG+RC+NVEG*RC+WOA+WEA}$	$\beta_0 + \beta_1(NVEG) + \beta_2(RC) + \beta_3(NVEG*RC) + \beta_4(WOA) + \beta_5(WEA)$
10) Positive residual cover effect	DSR_{RC}	$\beta_0 + \beta_1(RC)$
11) Positive residual cover effect, separate intercepts for grass types	DSR_{RC+GT}	$\beta_0 + \beta_1(RC) + \beta_2(GT)$
12) Positive residual cover and pasture score effect	DSR_{RC+PS}	$\beta_0 + \beta_1(RC) + \beta_2(PS)$
13) Interaction between residual cover and field trend	$DSR_{RC+FTREND+RC*FTREND}$	$\beta_0 + \beta_1(RC) + \beta_2(FTREND) + \beta_3(RC*FTREND)$
14) Interaction between residual cover and woodland area	$DSR_{RC+WOA+RC*WOA}$	$\beta_0 + \beta_1(RC) + \beta_2(WOA) + \beta_3(RC*WOA)$
15) Interaction between residual cover and wetland area	$DSR_{RC+WEA+RC*WEA}$	$\beta_0 + \beta_1(RC) + \beta_2(WEA) + \beta_3(RC*WEA)$
16) Positive residual cover, negative woodland and wetland area effect	$DSR_{RC+WOA+WEA}$	$\beta_0 + \beta_1(RC) + \beta_2(WOA) + \beta_3(WEA)$

Table 4 cont.

Hypothesis	Model	Model Structure
17) Positive residual cover and shrub area, negative woodland and wetland area effect	$DSR_{RC+SA+WOA+WEA}$	$\beta_0 + \beta_1(RC) + \beta_2(SA) + \beta_3(WOA) + \beta_4(WEA)$
18) Nest habitat types differ	DSR_{NHAB}	$\beta_0 + \beta_1(NHAB)$
19) Negative woodland area effect	DSR_{WOA}	$\beta_0 + \beta_1(WOA)$
20) Negative wetland area effect	DSR_{WEA}	$\beta_0 + \beta_1(WEA)$
<u>Landscape Suite</u>		
1) Positive perennial cover effect – 1-km radius buffer	DSR_{PC1}	$\beta_0 + \beta_1(PC1)$
2) Positive perennial cover effect – 2-km radius buffer	DSR_{PC2}	$\beta_0 + \beta_1(PC2)$
3) Positive perennial cover effect – 3-km radius buffer	DSR_{PC3}	$\beta_0 + \beta_1(PC3)$
4) Positive perennial cover effect – 4-km radius buffer	DSR_{PC4}	$\beta_0 + \beta_1(PC4)$
5) Negative woodland area effect – 1-km radius buffer	DSR_{WOA1}	$\beta_0 + \beta_1(WOA1)$
6) Negative woodland area effect – 2-km radius buffer	DSR_{WOA2}	$\beta_0 + \beta_1(WOA2)$
7) Negative woodland area effect – 3-km radius buffer	DSR_{WOA3}	$\beta_0 + \beta_1(WOA3)$
8) Negative woodland area effect – 4-km radius buffer	DSR_{WOA4}	$\beta_0 + \beta_1(WOA4)$
9) Negative wetland area effect – 1-km radius buffer	DSR_{WEA1}	$\beta_0 + \beta_1(WEA1)$
10) Negative wetland area effect – 2-km radius buffer	DSR_{WEA2}	$\beta_0 + \beta_1(WEA2)$
11) Negative wetland area effect – 3-km radius buffer	DSR_{WEA3}	$\beta_0 + \beta_1(WEA3)$
12) Negative wetland area effect – 4-km radius buffer	DSR_{WEA4}	$\beta_0 + \beta_1(WEA4)$
13) Positive grassland area effect – 1-km radius buffer	DSR_{GL1}	$\beta_0 + \beta_1(GL1)$
14) Positive grassland area effect – 2-km radius buffer	DSR_{GL2}	$\beta_0 + \beta_1(GL2)$
15) Positive grassland area effect – 3-km radius buffer	DSR_{GL3}	$\beta_0 + \beta_1(GL3)$
16) Positive grassland area effect – 4-km radius buffer	DSR_{GL4}	$\beta_0 + \beta_1(G4)$
<u>Combined Suite</u>		
1) Positive nest vegetation density effect, negative grassland area (1-km radius buffer) effect	$DSR_{NVEG+GL1}$	$\beta_0 + \beta_1(NVEG) + \beta_2(GL1)$
2) Positive nest vegetation density effect, negative grassland area (1-km radius buffer) effect; separate intercepts for grass types	$DSR_{NVEG+ GL1+ GT}$	$\beta_0 + \beta_1(NVEG) + \beta_2(GL1) + \beta_3(GT)$
3) Positive nest vegetation density and wetland area effect, negative cattle presence and grassland area (1-km radius buffer) effect; separate intercepts for grass types	$DSR_{NVEG+WEA+CP+GL1+GT}$	$\beta_0 + \beta_1(NVEG) + \beta_2(WEA) + \beta_3(CP) + \beta_4(GL1) + \beta_5(GT)$

Table 4 cont.

Hypothesis	Model	Model Structure
4) Positive nest vegetation density effect interacting with residual cover, negative grassland area (1-km radius buffer) effect	$DSR_{NVEG+RC+NVEG*RC+GL1}$	$\beta_0 + \beta_1(NVEG) + \beta_2(RC) + \beta_3(NVEG*RC) + \beta_4(GL1)$
5) Positive nest vegetation density effect interacting with residual cover, negative grassland area (1-km radius buffer) effect; separate intercepts for grass types	$DSR_{NVEG+RC+NVEG*RC+GL1+GT}$	$\beta_0 + \beta_1(NVEG) + \beta_2(RC) + \beta_3(NVEG*RC) + \beta_4(GL1) + \beta_5(GT)$
6) Positive nest vegetation density effect interacting with residual cover, negative cattle presence and grassland area (1-km radius buffer) effect; separate intercepts for grass types	$DSR_{NVEG+RC+NVEG*RC+CP+GL1+GT}$	$\beta_0 + \beta_1(NVEG) + \beta_2(RC) + \beta_3(NVEG*RC) + \beta_4(CP) + \beta_5(GL1) + \beta_6(GT)$
7) Positive nest vegetation density effect interacting with residual cover, positive wetland area effect, negative cattle presence and grassland area (1-km radius buffer) effect; separate intercepts for grass types	$DSR_{NVEG+RC+NVEG*RC+WEA+CP+GL1+GT}$	$\beta_0 + \beta_1(NVEG) + \beta_2(RC) + \beta_3(NVEG*RC) + \beta_4(WEA) + \beta_5(CP) + \beta_6(GL1) + \beta_7(GT)$
8) Positive nest vegetation density effect interacting with residual cover, positive wetland area and woodland area effect, negative grassland area (1-km radius buffer) effect	$DSR_{NVEG+RC+NVEG*RC+WEA+WOA+GL1}$	$\beta_0 + \beta_1(NVEG) + \beta_2(RC) + \beta_3(NVEG*RC) + \beta_4(WEA) + \beta_5(WOA) + \beta_6(GL1)$
9) Positive nest vegetation density effect interacting with a quadratic form of residual cover, negative grassland area (1-km radius buffer) effect	$DSR_{NVEG+RC+NVEG*RC+RC^2+GL1}$	$\beta_0 + \beta_1(NVEG) + \beta_2(RC) + \beta_3(NVEG*RC) + \beta_4(RC*RC) + \beta_5(GL1)$
10) Positive nest vegetation density effect interacting with a quadratic form of residual cover, positive wetland area effect, negative grassland area (1-km radius buffer) effect	$DSR_{NVEG+RC+NVEG*RC+RC^2+WEA+GL1}$	$\beta_0 + \beta_1(NVEG) + \beta_2(RC) + \beta_3(NVEG*RC) + \beta_4(RC*RC) + \beta_5(WEA) + \beta_6(GL1)$
11) Positive nest vegetation density effect interacting with a quadratic form of residual cover, positive wetland area and woodland area effect, negative grassland area (1-km radius buffer) effect	$DSR_{NVEG+RC+NVEG*RC+RC^2+WEA+WOA+GL1}$	$\beta_0 + \beta_1(NVEG) + \beta_2(RC) + \beta_3(NVEG*RC) + \beta_4(RC*RC) + \beta_5(WEA) + \beta_6(WOA) + \beta_7(GL1)$
12) Positive nest vegetation density effect interacting with a quadratic form of residual cover, positive wetland area effect, negative cattle presence and grassland area (1-km radius buffer) effect	$DSR_{NVEG+RC+NVEG*RC+RC^2+WEA+CP+GL1}$	$\beta_0 + \beta_1(NVEG) + \beta_2(RC) + \beta_3(NVEG*RC) + \beta_4(RC*RC) + \beta_5(WEA) + \beta_6(CP) + \beta_7(GL1)$

Models in the Grazing Suite (Table 4) were designed to explore the relationship of nesting success to nest-site and field-scale habitat characteristics in native/naturalized and tame pastures. Earlier work addressing the response of duck nesting success to cattle grazing has been ambiguous; negative and positive responses have been demonstrated (Kirsch et al. 1978, Sedivec 1989, Barker et al. 1990, Greenwood et al. 1995, Gilbert et al. 1996, Lapointe et al. 2000). I hypothesized that a negative relationship between nest DSR and grazing would be linear, but that a positive response would be best fit by a quadratic model (i.e., moderate grazing intensity fields would have higher nest DSR than either low or heavy). Using field-scale residual cover (RC) as a proxy for grazing intensity, models containing this covariate were analyzed twice–once to test for a negative linear relationship and again with RC in quadratic form (RC*RC) to test the positive response hypothesis. Additional covariates describing nest-site and field-scale (NVEG, NVH and FVH, FTREND, respectively) vegetation density and height were included in models to further investigate potential relationships between nesting success and habitat characteristics directly affected by grazing. Pasture score (PS) was also included in several models to test the efficacy of a standardized range health assessment protocol in predicting duck production.

Field-scale habitat attributes not directly affected by grazing but which may alter predation rates were also included in *a priori* modeling. Proportion of woodland area (WOA) was hypothesized to negatively affect nesting success; increased abundance of several species known to prey upon ducks (e.g. red-tailed hawk [*Buteo jamaicensis*]) or depredate duck nests (e.g. American crow [*Corvus brachyrhynchos*]) has been attributed to aspen expansion in the Aspen Parkland (Sargeant et al. 1993). A negative effect of wetland area (WEA) on nesting success was also hypothesized due to increased foraging activity of striped skunks (*Mephitis mephitis*) and red fox (*Vulpes vulpes*) near wetland edges (Lariviére and Messier 2000, Phillips et al. 2003). Duck nesting success in shrubland habitats is generally higher than in nearby grassland habitats (Greenwood et. al 1995), possibly due to the negative effect of structural heterogeneity on foraging efficiency of nest predators (Bowman and Harris 1980). Shrub area (SA) was included in several models to test for a positive effect of increasing structural heterogeneity on nesting success. Lastly, nest habitat (NHAB) was included as a covariate; the habitat that a nest is located in has been demonstrated to be an important predictor of nesting success in the Aspen Parkland (Howerter 2003).

The exploratory Landscape Suite was created to investigate mechanisms of nest predation operating beyond the scales addressed in Grazing Suite models. Work in the mixed-grass prairies of the PPR has demonstrated a positive correlation between the amount of perennial cover at various landscape scales and nest survival (Greenwood et al. 1995, Garrettson and Rohwer 2001, Reynolds et al. 2001, Stephens 2003). Moreover, Stephens (2003) demonstrated a stronger relationship between landscape-scale covariates and nesting success than between covariates measured at nest-site and field-scales and nesting success. However, the response of nest survival to increasing amounts of landscape-scale perennial cover in the Aspen Parkland appears to be weaker than in the mixed-grass prairies (Greenwood et al.1995, Howerter 2003).

In an effort to further the understanding of the relationship between perennial cover and nesting success, I created univariate models using landscape covariates measured at several scales for perennial cover (PC1-PC4; see Field Characteristics above). Additionally, I wanted to investigate possible relationships between nesting success and the 3 primary components of perennial cover in the Aspen Parkland: grassland, wetland, and woodland habitats. I hypothesized a negative effect of field-scale woodland area and wetland area on nesting success. To further investigate these hypotheses at landscape scales, univariate models were created using covariates measuring the proportion of woodland area surrounding each field (WOA1-WOA4) and the proportion of wetland area surrounding each field (WEA1-WEA4), at the 4 landscape scales. Lastly, the proportion of grassland surrounding each field at each of the 4 scales (GL1-GL4) was included to investigate the potentially positive effect of increasing cattle numbers in the Aspen Parkland–the conversion of cropland to grassland.

Results

Over the 2 field seasons, a total of 3,290 ha of upland habitat were searched across 97 different fields. Four fields were used in both years due to difficulties in obtaining suitable replacements. Nest searches located 309 total duck nests on 62 of the fields studied; 234 nests were found in upland, 68 in wetland and 7 in woodland habitats. Blue-winged teal (*Anas discors*) nests accounted for 49% of the sample, and nests of gadwall (*A. strepera*; 16%), northern shoveler (*A. clypeata*; 15%), mallard (*A. platyrhynchos*; 11%), lesser scaup (*Aythya affinis*; 5%), green-winged teal (*Anas crecca*;

3%), cinnamon teal (*A. cyanoptera*; <1%) and redhead (*Aythya americana*; <1%) comprised the remainder.

Vegetation and Habitat Conditions of Fields

Data were collected across a broad gradient of grazing intensity and habitat conditions found in the Aspen Parkland. Field-specific residual cover (RC) ranged from <0.01 to 1.55 dm in 2001 and from 0 to 0.75 dm in 2002 (Fig. 3). Mean RC for native fields was 0.37 dm in 2001 (95% CI = 0.21–0.52) and 0.16 dm in 2002 (95% CI = 0.09–0.23). Tame field mean RC was 0.39 dm in 2001 (95% CI = 0.24–0.55) and 0.29 dm in 2002 (95% CI =0.18– 0.40). The mean proportion of wetland area by field (WEA) was 21.3% (95% CI = 18.8–23.7%) in 2001 and 22.5% (95% CI = 19.2–25.8%) in 2002, and did not differ among grazing intensity categories ($F_{2, 94} = 1.227$, $P = 0.2978$). The drought conditions experienced during the study were evident in the proportion of wetland basins containing water during July. During the 2001 field season, 561 of 2,271 (24.7%) wetlands contained water, while only 155 of 1,665 (9.3%) wetlands contained water in 2002. Of these basins, 4.8% and <1% contained flooded emergent vegetation in 2001 and 2002, respectively. Although the analysis of landscape-scale habitat composition was an *ad hoc* addition, field-specific landscape covariates (percent perennial cover, grassland, wetland, and woodland at each of the 4 scales) also exhibited a broad range of values (Appendix A).

Nest Density

When data from nests in upland habitats were analyzed, the most general model, $\mathrm{DEN}_{\mathrm{PBASIN+GI+GT+GI*GT}}$, provided a suitable fit to the data assuming that the deviance was approximately chi-square distributed ($\chi^2 = 108.89$, df = 93, $P = 0.1239$) (Neter et al. 1996). Several simpler models proved more parsimonious and provided insights regarding the hypotheses of interest. Nest density in pastures was strongly positively influenced by the amount of residual cover and health of the pasture (Fig. 4). The two most parsimonious models, $\mathrm{DEN}_{\mathrm{PBASIN+RC+PS+YR}}$ and $\mathrm{DEN}_{\mathrm{PBASIN+RC+PS}}$, received the majority of support ($\sum\omega_i = 0.778$) and had AIC_c values that were within 0.78 units of each other (Table 5). Coefficient estimates for RC and PS were positive in both models ($\mathrm{DEN}_{\mathrm{PBASIN+RC+PS+YR}}$ – estimated $\beta_{\mathrm{RC}} = 1.696$, 95% CI = 0.954–2.481, estimated $\beta_{\mathrm{PS}} = 0.018$, 95% CI = 0.004–0.033); $\mathrm{DEN}_{\mathrm{PBASIN+RC+PS}}$ – estimated $\beta_{\mathrm{RC}} = 1.468$, 95% CI = 0.764–2.220, estimated $\beta_{\mathrm{PS}} = 0.022$, 95% CI = 0.008–0.036. The estimated coefficient for year in the most parsimonious model $\mathrm{DEN}_{\mathrm{PBASIN+RC+PS+YR}}$ provided weak support for higher nest densities during the second field season (estimated $\beta_{\mathrm{YR}} = -0.460$, 95% CI = -0.062–1.000).

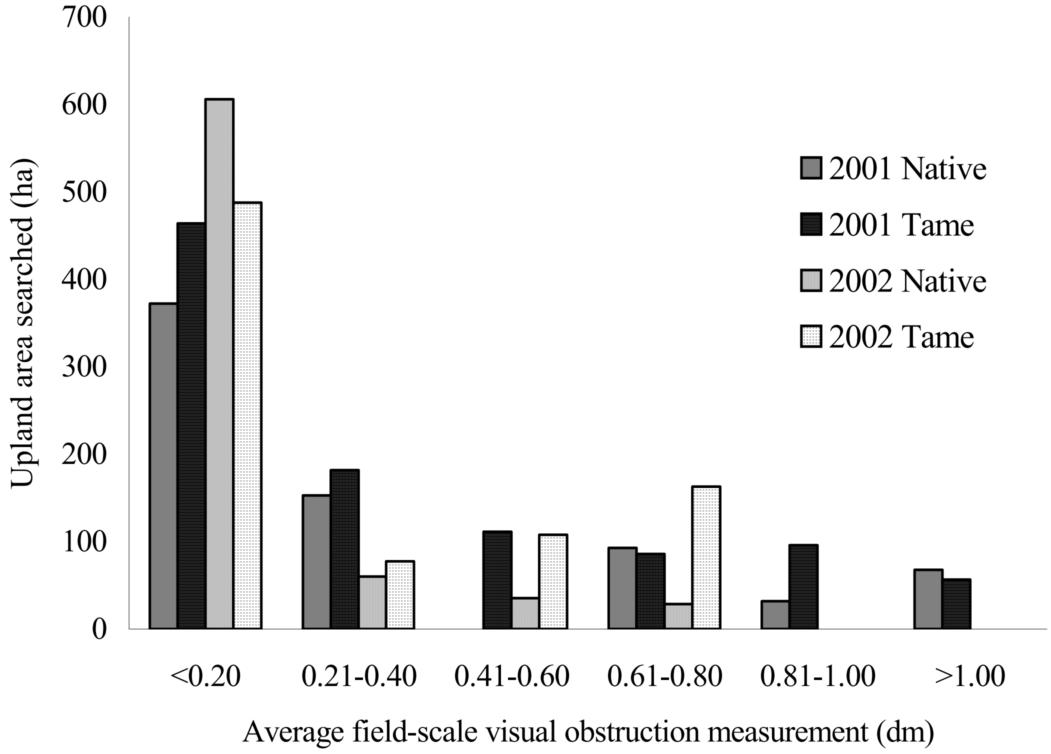
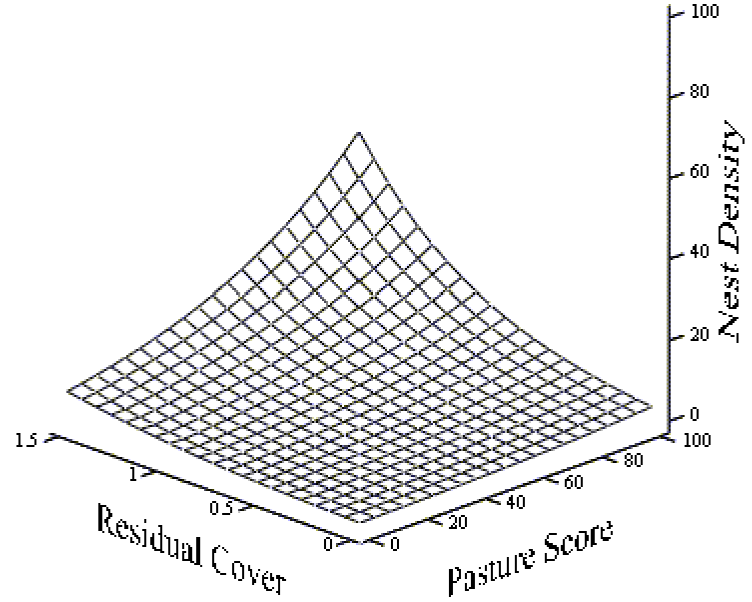


Figure 3. Upland area nest searched for each year and grass type, categorized by field-scale residual cover (RC), in the Aspen Parkland of Alberta, Canada, during May-July 2001 and 2002. Residual cover was quantified using a Robel pole (Robel et al. 1970) and averaged across 20 (2001) or 30 (2002) random plot measurements within a field immediately after the completion of the first nest search. Drought induced decline in the amount of residual cover was evident throughout this study, and was clearly indicated by the inability to locate fields with RC values >0.75 during 2002.

a) 2001



b) 2002

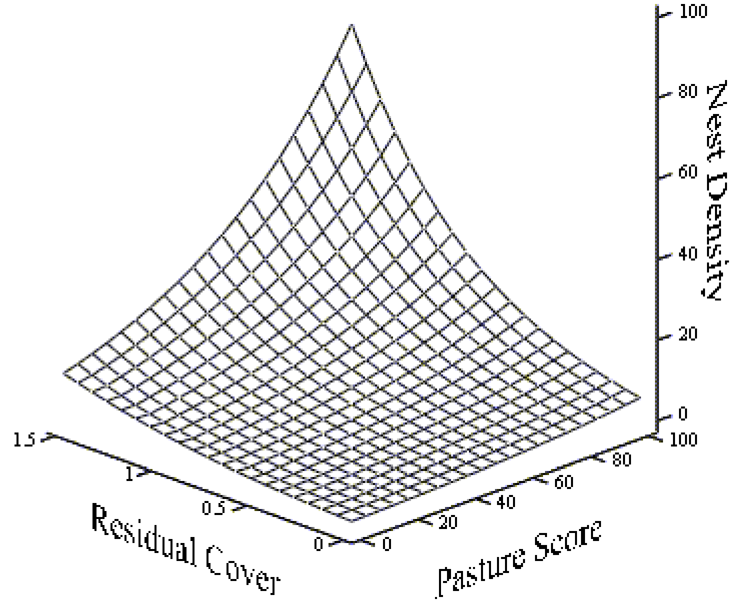


Figure 4a – 4b. Duck nest density in the Aspen Parkland of Alberta, Canada, in relation to residual cover and pasture score, during 2001 and 2002. Mean proportion of flooded wetland basins encountered during 2001-2002 (0.2547) was used for both graphs.

Table 5. Duck nest density model ranking for both *a priori* suites. All models contain a covariate to control for field-specific water conditions (proportion of flooded basins [PFBASIN]). Continuous Suite models contain field-scale residual cover (RC), a continuous quantitative covariate, as a measure of grazing intensity. Management Suite models substitute RC with grazing intensity (GI), a qualitative covariate in which fields were placed into 1 of 3 categories (low, moderate, or heavy grazing intensity). The 2 suites were created to compare the efficacy of a simple qualitative classification commonly used by managers to a more rigorous quantification of grazing intensity.

		Within suite		All models	
Model	k[a]	$\Delta\mathrm{AIC}_c$[b]	ω_i[c]	$\Delta\mathrm{AIC}_c$[d]	ω_i
Continuous Suite					
DEN$_{\mathrm{PFBASIN[e]+RC[f]+PS[g]+YR[h]}}$	5	0.000	0.465	0.000	0.464
DEN$_{\mathrm{PFBASIN+RC+PS}}$	4	0.777	0.315	0.777	0.314
DEN$_{\mathrm{PFBASIN+RC+FTREND[i]+RC*FTREND}}$	5	3.769	0.071	3.769	0.070
DEN$_{\mathrm{PFBASIN+RC+YR}}$	4	4.001	0.063	4.001	0.063
DEN$_{\mathrm{PFBASIN+RC+FTREND+GT[j]+YR}}$	6	4.631	0.046	4.631	0.046
DEN$_{\mathrm{PFBASIN+RC+SA[k]}}$	6	7.115	0.013	7.115	0.013
DEN$_{\mathrm{PFBASIN+RC}}$	3	7.516	0.011	7.516	0.011
DEN$_{\mathrm{PFBASIN+RC+FVH[l]}}$	4	9.064	<0.01	9.064	<0.01
DEN$_{\mathrm{PFBASIN+RC+GT}}$	4	9.078	<0.01	9.078	<0.01
DEN$_{\mathrm{PFBASIN+RC+FTREND}}$	4	9.337	<0.01	9.337	<0.01
DEN$_{\mathrm{PFBASIN+RC+GT+RC*GT}}$	5	10.644	<0.01	10.644	<0.01
DEN$_{\mathrm{PFBASIN+PS}}$	3	14.189	<0.01	14.189	<0.01
DEN$_{\mathrm{PFBASIN+YR}}$	3	42.925	<0.01	42.925	<0.01
DEN$_{\mathrm{PFBASIN}}$	2	43.191	<0.01	43.191	<0.01
Management Suite					
DEN$_{\mathrm{PFBASIN+GI[m]+PS}}$	5	0.000	0.706	11.467	<0.01
DEN$_{\mathrm{PFBASIN+GI+PS+YR}}$	6	2.073	0.250	13.540	<0.01
DEN$_{\mathrm{PFBASIN+GI+SA}}$	7	6.807	0.023	18.274	<0.01
DEN$_{\mathrm{PFBASIN+GI}}$	4	8.928	<0.01	20.395	<0.01
DEN$_{\mathrm{PFBASIN+GI+GT}}$	5	9.197	<0.01	20.664	<0.01
DEN$_{\mathrm{PFBASIN+GI+YR}}$	5	10.405	<0.01	21.872	<0.01
DEN$_{\mathrm{PFBASIN+GI+GT+GI*GT}}$	7	12.418	<0.01	23.885	<0.01

[a] Number of estimated parameters.

[b] The difference in AIC_c scores between the present model and the best within-suite model (Continuous Suite $\mathrm{AIC}_c = -107.099$; Management Suite $\mathrm{AIC}_c = -95.632$).

[c] Normalized relative model likelihoods.

[d] The difference in AIC_c scores between the present model and the best Continuous Suite model ($\mathrm{AIC}_c = -107.099$).

[e] Proportion of flooded basins.

[f] Average field vegetation density measured during the first nest search.

[g] Average field pasture score.

[h] Year.

[i] Within-field vegetation density change between the first and third nest searches.

[j] Grass type (native/naturalized, tame).

[k] Categories based on the proportion of nest-searched area containing shrub cover (4 classes).

[l] Average field maximum vegetation height measured during the first nest search.

[m] Grazing intensity (light/idle, moderate, heavy).

Models of the Management Suite were consistently less parsimonious than Continuous Suite models, but they largely indicated the same key features as important. The top 2 models were $\text{DEN}_{\text{PBASIN+GI+PS}}$ and $\text{DEN}_{\text{PBASIN+GI+PS+YR}}$ (Table 5) and comprised fully the 95% confidence set of models (combined $\omega_i = 0.964$). As was the case for the most parsimonious Continuous Suite models, the most parsimonious Management Suite model demonstrated a negative effect of grazing on nest density (Table 5). Relative to fields with moderate grazing, lightly grazed fields had higher nest density (estimated $\beta_L = 0.525$, 95% CI = 0.003–1.044), while fields with heavy grazing tended to have lower nest density, although the 95% confidence interval included zero for this class (estimated $\beta_H = -0.343$, 95% CI = -0.976–0.289). The effect of pasture score was also similar between the Continuous- and Management Suite models. The coefficient estimate for pasture score was positive for model $\text{DEN}_{\text{PBASIN+GI+PS}}$ (estimated $\beta_{PS} = 0.026$, 95% CI = 0.011–0.042), indicating greater nest densities with increasing pasture health.

Nesting Success

Of the 309 nests found, 270 nests were suitable for analysis and yielded data for 633 nest re-visit intervals that were used for modeling DSR. Currently, techniques for assessing goodness of fit for nest survival models are lacking (Dinsmore et al. 2002). Therefore, I was unable to evaluate the fit of the global model. The global model did, however, consider diverse covariates. I did not find strong support for a relationship between DSR and either nest age or julian date (estimated $\beta_{NAGE} = 0.001$, 95% CI = -0.015–0.018; estimated $\beta_{JDATE} = 0.005$, 95% CI =-0.004–0.014). Thus, further modeling

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of DSR did not include these effects. Similarly, inclusion of site or cluster as a random effect did not improve model ranking for Combined Suite models.

Daily survival rate (DSR) of duck nests was positively influenced by increasing density of vegetation at the nest site (Table 6). Within the Grazing Suite, 6 models were within 2 AIC_c units of the best model, $DSR_{NVEG+RC+NVEG*RC}$ (Table 6). All of these models contained nest-site vegetation density (NVEG), and 5 of the 7 included an interaction between NVEG and residual cover (RC; Table 6). The most parsimonious model indicated that across most values of RC, nest survival was positively influenced by NVEG. However, at high values of RC, NVEG negatively affected nest survival (Fig. 5). Although precisely estimated (i.e., 95% confidence intervals did not include zero), the negative response of nest survival to NVEG at high levels of RC was driven by relatively few observations (Fig. 5). The hypothesized positive effect of moderate grazing (i.e., a negative quadratic relationship) on nesting success was not supported by the 2 models that were within 0.5 AIC_c units of the most parsimonious model (Table 6). Each model contained a positive quadratic RC term, indicating that nesting success was greater at both higher and lower levels of grazing intensity. Models that included RC were generally poorly supported ($\Delta AIC_c > 4$), excluding those that had RC in quadratic form or interacting with NVEG (Table 6).

Table 6. Duck nest daily survival rate (DSR) model ranking for the *a priori* Grazing Suite. Within-suite ranking is based on the best Grazing Suite model; the ranking of Grazing Suite models relative to the best model from the Combined Suite is also provided.

Model	k^{a}	Within suite		All models	
		ΔAIC_c^{b}	ω_i^{c}	ΔAIC_c^{d}	ω_i
$DSR_{NVEG^{e}+RC^{f}+NVEG*RC}$	4	0.000	0.143	14.185	<0.01
DSR_{NVEG}	2	0.242	0.126	14.427	<0.01
$DSR_{NVEG+RC+NVEG*RC+RC^{2}+WOA^{g}+WEA^{h}}$	7	0.316	0.122	14.501	<0.01
$DSR_{NVEG+RC+NVEG*RC+RC^{2}}$	5	0.453	0.114	14.638	<0.01
$DSR_{NVEG+RC+NVEG*RC+WOA+WEA}$	6	0.473	0.113	14.658	<0.01
$DSR_{NVEG+GT^{i}}$	3	1.052	0.084	15.237	<0.01
$DSR_{NVEG+RC+NVEG*RC+GT}$	5	1.245	0.077	15.430	<0.01
$DSR_{NVEG+RC+NVEG*RC+RC^{2}+GT}$	6	2.027	0.052	16.212	<0.01
$DSR_{NVEG+NVH^{j}}$	3	2.241	0.047	16.426	<0.01
$DSR_{NVEG+NHAB^{k}}$	4	3.255	0.028	17.440	<0.01
DSR_{NHAB}	3	4.722	0.013	18.907	<0.01
DSR_{WOA}	2	4.841	0.013	19.026	<0.01
$DSR_{Null^{l}}$	1	5.262	0.010	19.447	<0.01
DSR_{WEA}	2	5.336	0.010	19.521	<0.01
$DSR_{YR^{m}}$	3	5.921	<0.01	20.106	<0.01
$DSR_{RC+WOA+WEA}$	4	5.983	<0.01	20.168	<0.01
$DSR_{RC+RC^{2}+WOA+WEA}$	5	6.478	<0.01	20.663	<0.01
$DSR_{RC+FTREND^{n}+RC*FTREND}$	4	6.687	<0.01	20.872	<0.01
DSR_{RC}	2	7.266	<0.01	21.451	<0.01
DSR_{RC+GT}	3	7.385	<0.01	21.570	<0.01
$DSR_{RC+RC^{2}}$	3	8.380	<0.01	22.565	<0.01
$DSR_{RC+RC^{2}+FTREND+RC*FTREND}$	5	8.625	<0.01	22.810	<0.01
DSR_{RC*WOA}	4	8.856	<0.01	23.041	<0.01
$DSR_{RC+SA^{o}+WOA+WEA}$	7	8.867	<0.01	23.052	<0.01
$DSR_{RC+RC^{2}+GT}$	4	8.910	<0.01	23.095	<0.01
DSR_{RC*WEA}	4	9.027	<0.01	23.212	<0.01
$DSR_{RC+PS^{p}}$	3	9.144	<0.01	23.329	<0.01
$DSR_{RC+RC^{2}+WEA+RC*WEA}$	5	9.409	<0.01	23.594	<0.01
$DSR_{RC+RC^{2}+SA+WOA+WEA}$	8	9.717	<0.01	23.902	<0.01
$DSR_{RC+RC^{2}*WOA}$	5	10.337	<0.01	24.522	<0.01
$DSR_{RC+RC^{2}+PS}$	4	10.400	<0.01	24.585	<0.01

[a] Number of estimated parameters.

[b] The difference in AIC_c scores between the present model and the best Grazing Suite model ($AIC_c = 765.371$).

[c] Normalized relative model likelihoods.

[d] The difference in AIC_c scores between the present model and the best Combined Suite model ($AIC_c = 751.186$).

[e] Nest-site vegetation density.

[f] Average field vegetation density during the first nest search.

[g] Proportion woodland area by field.

[h] Proportion wetland area by field.

[i] Grass type (native/naturalized, tame).

[j] Nest-site vegetation maximum height.

[k] Nest-site habitat classification (grassland or shrubland).

[l] Intercept-only model

[m] Year

[n] Within-field vegetation density change between the first and third nest searches.

[o] Categories based on the proportion of nest-searched area containing shrub cover (4 classes).

[p] Average field pasture score.

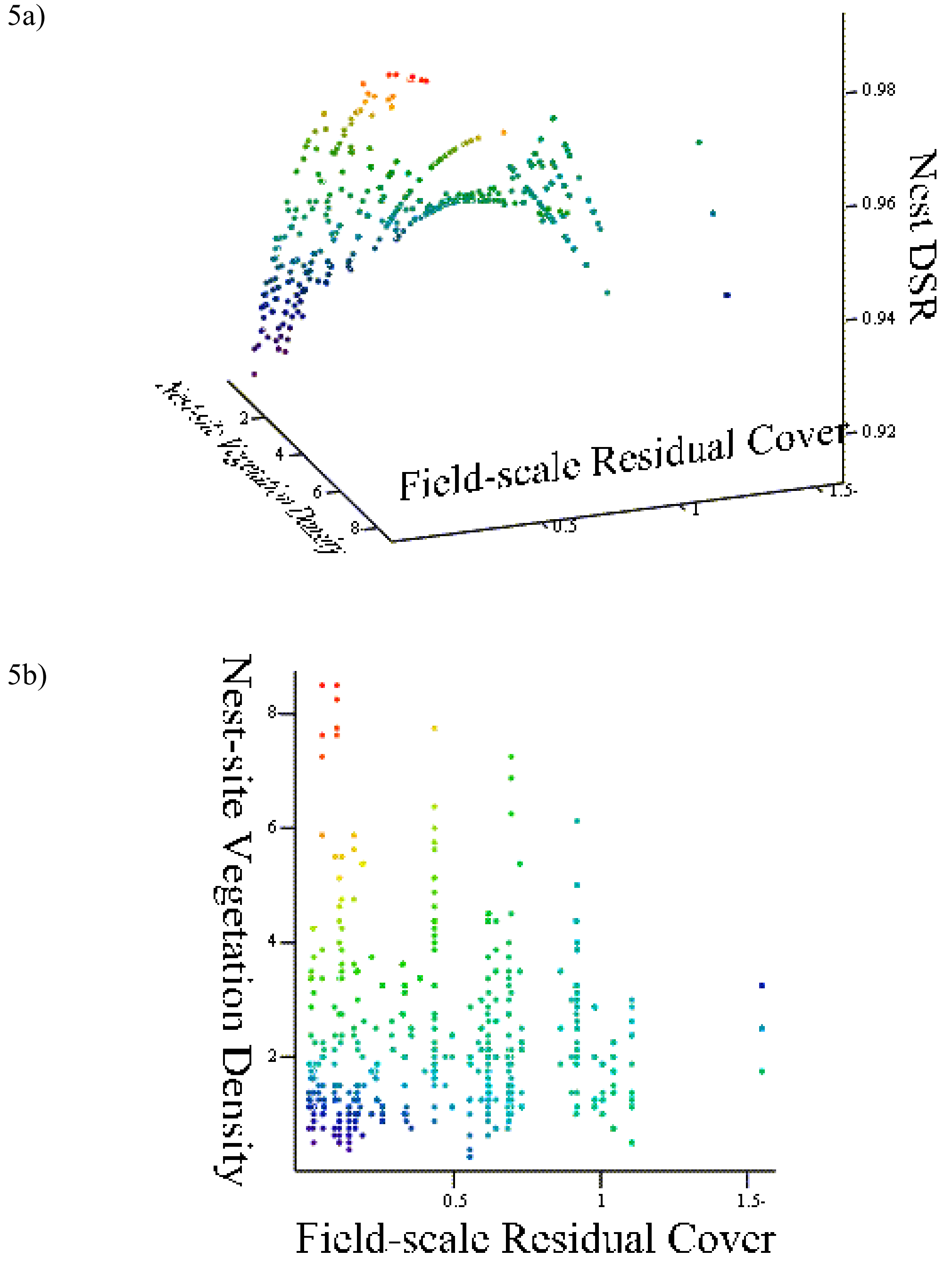


Figure 5a – 5b. 5a) Daily survival rate (DSR) of duck nests in the Aspen Parkland of Alberta, Canada, in relation to nest-site vegetation density (NVEG) and field-scale residual cover (RC) based on the most parsimonious Grazing Suite model, $DSR_{NVEG+RC+NVEG*RC}$. 5b) Nest-site vegetation density and RC readings from nests used to estimate DSR. Colors represent DSR for each combination of NVEG and RC, following fig. 5a.

In the Landscape Suite, a model containing grassland area at the 1-km radius (GL1) was the most parsimonious (Table 7) and indicated a negative relationship between the amount of grassland within a 1-km radius of a field and DSR (estimated β = -1.157, 95% CI = -1.893 – -0.420). Landscape models provided little support that woodland area influenced DSR of duck nests ($\Delta\text{AIC}_c \geq 3.762$; Table 7). Interestingly, there was even less support that landscape level measures of perennial cover influenced DSR of nests ($\Delta\text{AIC}_c \geq 4.898$; Table 7).

Table 7. Duck nest daily survival rate (DSR) model ranking for the exploratory Landscape Suite. Within-suite ranking is based on the best Landscape Suite model; the ranking of Landscape Suite models relative to the best model from the Combined Suite is also provided.

		Within suite		All models	
Model	*k*[a]	ΔAIC_c[b]	Weight (ω_i)[c]	ΔAIC_c[d]	Weight (ω_i)
DSR_{GL1}[e]	2	0.000	0.536	12.154	<0.01
DSR_{WOA1}[f]	2	3.762	0.082	15.916	<0.01
DSR_{WOA4}[g]	2	3.935	0.075	16.089	<0.01
DSR_{WOA3}[h]	2	4.023	0.072	16.177	<0.01
DSR_{WOA2}[i]	2	4.120	0.068	16.274	<0.01
DSR_{PC4}[j]	2	4.898	0.046	17.052	<0.01
DSR_{PC3}[k]	2	5.940	0.027	18.094	<0.01
DSR_{PC2}[l]	2	6.235	0.024	18.389	<0.01
DSR_{GL2}[m]	2	6.549	0.020	18.703	<0.01
DSR_{WEA1}[n]	2	7.434	0.013	19.588	<0.01
DSR_{GL3}[o]	2	8.312	<0.01	20.466	<0.01
DSR_{WEA3}[p]	2	8.843	<0.01	20.997	<0.01
DSR_{GL4}[q]	2	8.899	<0.01	21.053	<0.01
DSR_{PC1}[r]	2	9.134	<0.01	21.288	<0.01
DSR_{WEA4}[s]	2	9.169	<0.01	21.323	<0.01
DSR_{WEA2}[t]	2	9.303	<0.01	21.457	<0.01

[a] Number of estimated parameters.

[b] The difference in AIC_c scores between the present model and the best Landscape Suite model (AIC_c = 763.340).

[c] Normalized relative model likelihoods.

[d] The difference in AIC_c scores between the present model and the best Combined Suite model (AIC_c = 751.186).

[e, m, o, q] Proportion grassland area within a 1, 2, 3, or 4-km radius from a field's center, respectively.

[f, i, h, g] Proportion woodland area within a 1, 2, 3, or 4-km radius from a field's center, respectively.

[r, l, k, j] Proportion perennial cover within a 1, 2, 3, or 4-km radius from a field's center.

[n, t, p, s] Proportion wetland area within a 1, 2, 3, or 4-km radius from a field's center.

All Combined Suite models were better than the best model in either the Grazing Suite (Δ AIC$_c$ = 7.809) or the Landscape Suite (Δ AIC$_c$ = 5.808). Four models in the Combined Suite received strong support (ΔAIC$_c$ < 2; Table 8). The best model (Table 8) indicated that duck nest DSR was positively related to nest-site vegetation density (estimated β_{NVEG} = 0.358, 95% CI = 0.132–0.584) and field-scale wetland area (estimated β_{WEA} = 1.672, 95% CI = −0.135–3.479) but negatively related to grassland area within a 1-km radius (estimated β_{GL1} = -1.314, 95% CI = -2.081– -0.547) and cattle presence (estimated β_{CP} = -0.562, 95% CI = -1.000– -0.124) (Table 9). There was a negative interaction between NVEG and RC (estimated $\beta_{NVEG*RC}$ = -0.456, 95% CI = -0.827– -0.086; Fig. 6), similar to the most parsimonious Grazing Suite model (see above). Moreover, the quadratic form of RC indicated that nesting success reached a minimum at moderate levels of residual cover in a field and improved as residual cover either increased or decreased (estimated β = 1.390, 95% CI = 0.148–2.632; Fig. 6).

Table 8. Duck nest daily survival rate (DSR) model ranking for the exploratory Combined Suite. The least parsimonious Combined Suite model was better than the best model in the Grazing Suite (Δ AIC$_c$ = 7.809) and the Landscape Suite (Δ AIC$_c$ = 5.808). Combined Suite modeling provided little support for site or cluster-specific effects on DSR of duck nests.

Model	k^{a}	$\Delta AIC_c{}^{b}$	Weight (ω_i)
$DSR_{NVEG^{d}+RC^{e}+NVEG*RC+RC^{2}+WEA^{f}+CP^{g}+GL1^{h}}$	8	0.000	0.327
$DSR_{NVEG+WEA+CP+GL1+GT^{i}}$	6	1.050	0.191
$DSR_{NVEG+RC+NVEG*RC+WEA+CP+GL1+GT}$	8	1.292	0.169
$DSR_{NVEG+RC+NVEG*RC+CP+GL1+GT}$	7	1.560	0.148
$DSR_{NVEG+RC+NVEG*RC+RC^{2}+WEA+GL1}$	7	3.949	0.045
$DSR_{NVEG+RC+NVEG*RC+RC^{2}+WEA+WOA^{j}+GL1}$	8	5.184	0.024
$DSR_{NVEG+RC+NVEG*RC+GL1+GT}$	6	5.305	0.023
$DSR_{NVEG+RC+NVEG*RC+GL1}$	5	5.506	0.021
$DSR_{NVEG+RC+NVEG*RC+RC^{2}+GL1}$	6	5.687	0.019
$DSR_{NVEG+RC+NVEG*RC+WEA+WOA+GL1}$	7	6.199	0.015
$DSR_{NVEG+GL1+GT}$	4	6.376	0.013
$DSR_{NVEG+GL1}$	3	6.763	0.011

[a] Number of estimated parameters.

[b] The difference in AIC$_c$ scores between the present model and the best model (AIC$_c$ = 751.186).

[c] Normalized relative model likelihoods.

[d] Nest-site vegetation density.

[e] Average field vegetation density measured during the first nest search.

[f] Proportion wetland area by field.

[g] Presence or absence of cattle at the beginning of a nest interval.

[h] Proportion grassland area within a 1-km radius from a field's center.

[i] Grass type (native/naturalized, tame).

[j] Proportion woodland area by field.

Table 9. Coefficient estimates, standard errors (SE), and 95% confidence intervals (CI) for the most parsimonious nesting success model for upland-nesting ducks in the Aspen Parkland of Alberta, Canada, 2001-2002.

			95% CI	
Model Parameter	Estimated β	SE (Estimated β)	LCI	UCI
Intercept	2.604	0.352	1.913	3.294
NVEG[a]	0.358	0.115	0.132	0.584
RC[b]	-0.672	0.812	-2.267	0.924
NVEG*RC	-0.456	0.189	-0.827	-0.086
RC^{2}	1.390	0.633	0.148	2.632
WEA[c]	1.672	0.920	-0.135	3.479
CP[d]	-0.562	0.223	-1.000	-0.124
GL1[e]	-1.314	0.391	-2.081	-0.547

[a] Nest-site vegetation density.

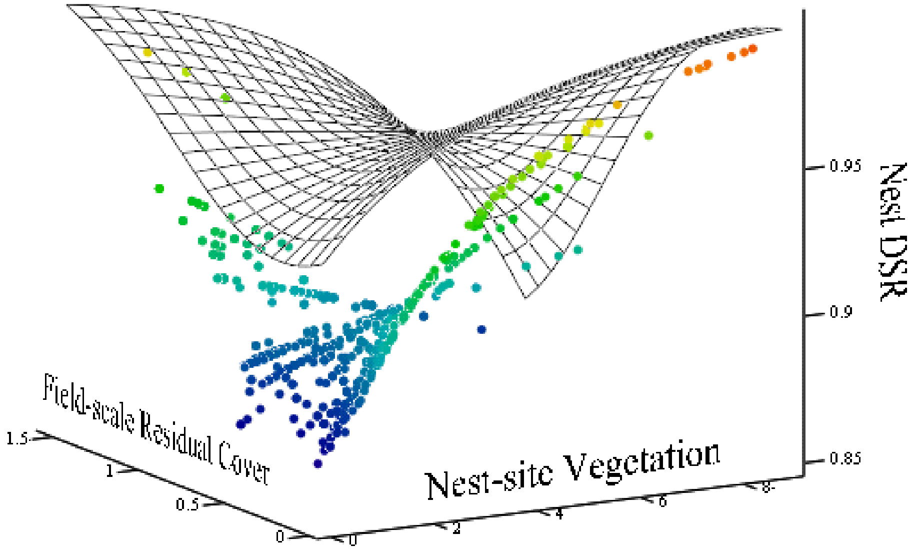
[b] Average field vegetation density measured during the first nest search.

[c] Proportion wetland area by field.

[d] Presence or absence of cattle at the beginning of a nest interval.

[e] Proportion grassland area within a 1-km radius from a field's center.

6a) CP = 0, 1st quartile GL1 (0.1974)



6b) CP = 1, 1st quartile GL1 (0.1974)

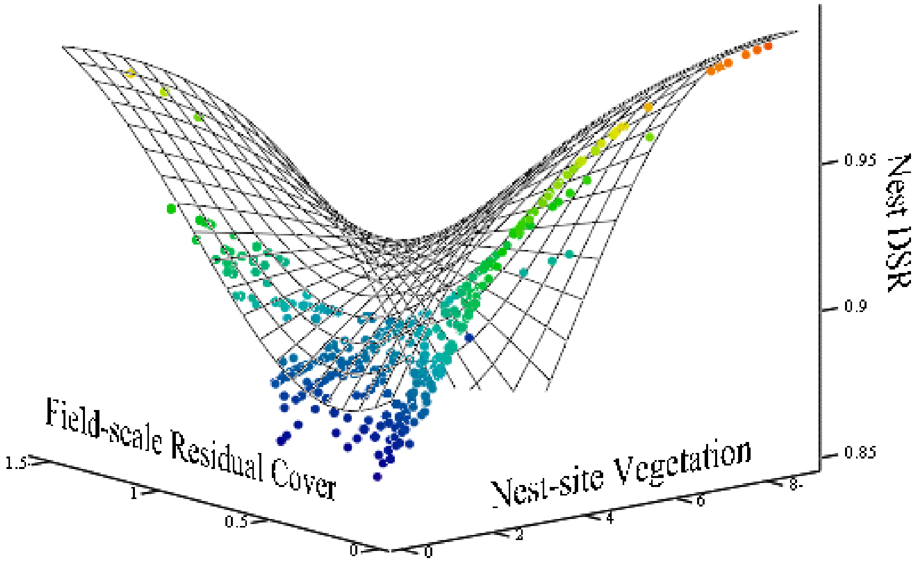
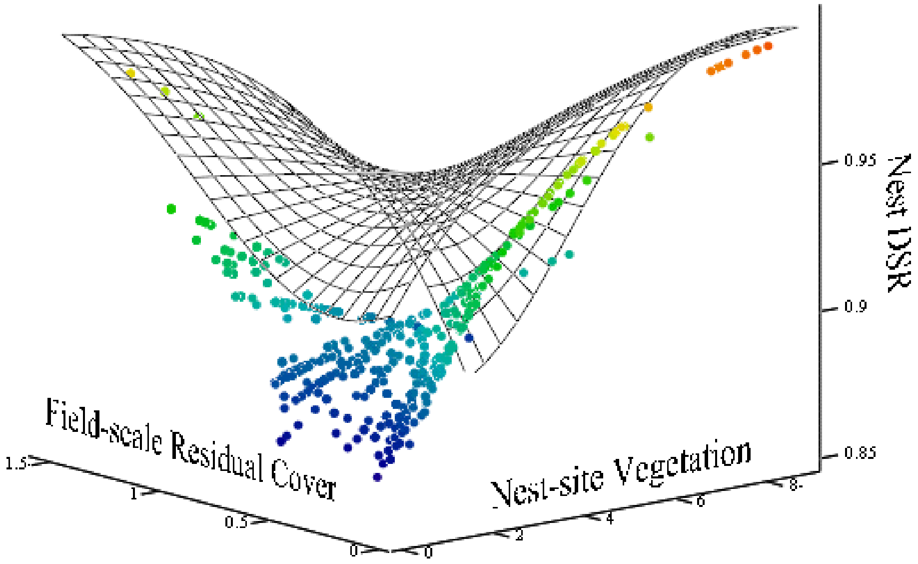
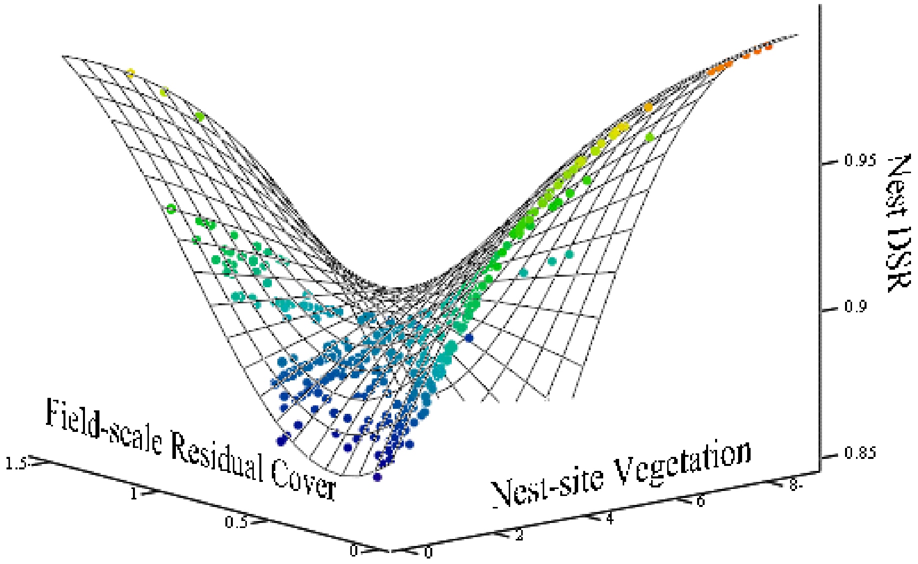


Figure 6a – 6f. Predicted (plane) and observed (points) duck nest daily survival rate (DSR) in the Aspen Parkland of Alberta, Canada, in relation to nest-site vegetation density (NVEG) and field-scale residual cover (RC) based on the most parsimonious model, $DSR_{NVEG+RC+NVEG*RC+RC^2+WEA+CP+GL1}$. To demonstrate the negative relationship between grassland area and DSR, the 1st quartile (6a – b), mean (6c – d), and 3rd quartile (6e – f) values of the proportion of grassland area within a 1-km radius of a field (GL1) are graphed. Figures 6a, 6c, and 6e demonstrate nesting success when cattle are not present (CP = 0) for each respective GL1 value; figures 6b, 6d, and 6f demonstrate nesting success when cattle are present (CP = 1). The mean value for the proportion of wetland area (WEA = 0.2155) encountered during 2001-2002 is used in each figure.

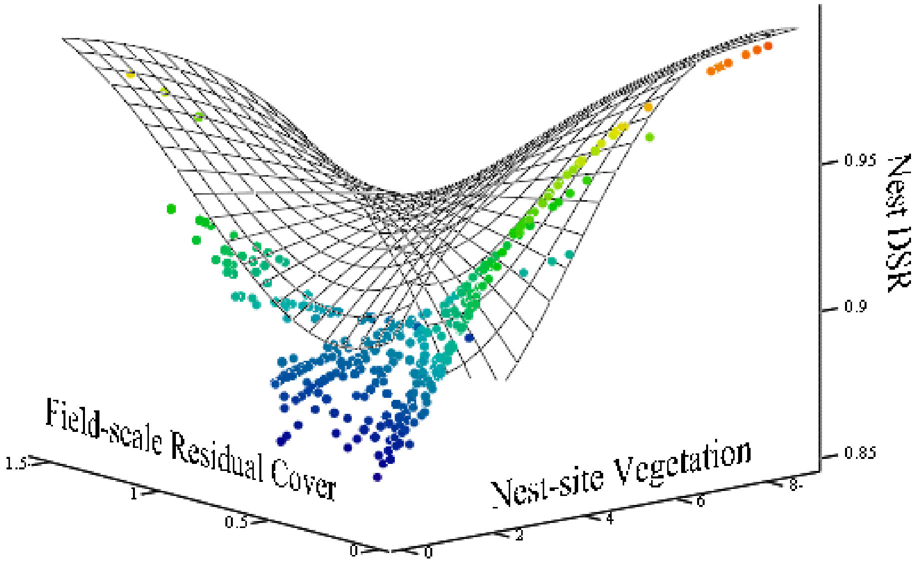
6c) CP = 0, mean GL1 (0.3538)



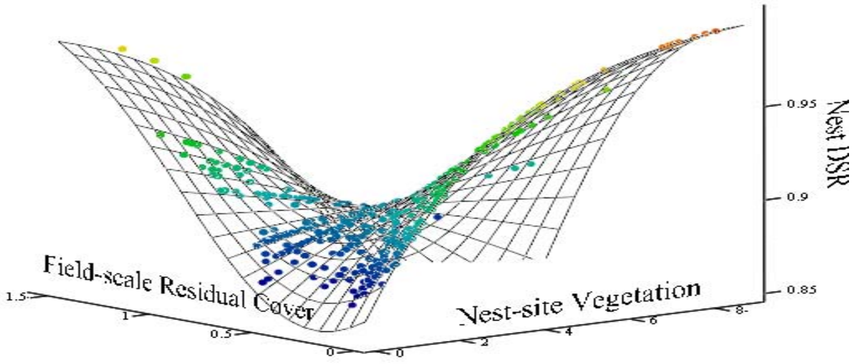
6d) CP = 1, mean GL1 (0.3538)



6e) CP = 0, 3rd quartile GL1 (0.4447)



6f) CP = 1, 3rd quartile GL1 (0.4447)



(NV , RC , DSR) , (realNV , realRC , realDSR)

Discussion

The results demonstrated complex relationships between cattle grazing in the Aspen Parkland and the 2 components of upland-nesting duck production studied. I found a strong negative relationship between duck nest density and cattle grazing, which is consistent with earlier work in the grasslands of the PPR that demonstrated a positive response of duck nest density to vegetation density (Miller 1971, Kirsch et al. 1978, Klett et al. 1988). My results also indicated a complex, nonlinear relationship among nesting success, grazing intensity, and nest-site vegetation. Nests with low levels of nest-site vegetation, i.e., poorly concealed nests, were more likely to survive in fields with high residual cover. Conversely, survival of nests with moderate to high levels of nest-site vegetation was improved by grazing-caused reductions in field-scale residual cover. Other studies in the PPR have found improved nesting success in grazed versus ungrazed treatments (Kaiser 1976, Barker et al. 1990), or in pastures relative to other habitat types (Greenwood et al. 1995). However, this study is the first to investigate grazing intensity as a continuous factor along the gradient from idle to > 90 % utilization across a large number of fields (n = 97). This allowed me to more fully describe the pattern of duck nesting success relative to grazing intensity.

The results suggest that grazing has both immediate and longer-term effects on duck nest densities. The immediate effect is evident in the negative relationship found between nest density and field-scale height and density of vegetation. Cattle reduce vegetation height and density in pastures through consumption and trampling (Lapointe et al. 2000, Fondell and Ball 2004), which lowers the number of suitable nest sites.

Kruse and Bowen (1996) demonstrated that upland-nesting ducks preferred nest-sites with vegetation VOM ≥ 0.5 dm, however, average VOM was lower than this for most fields searched during this study.

Pasture health, which relates historical grazing management and ecological function (see Methods above), was an important covariate suggesting that grazing management can have long-term consequences for duck nest density. Fields that scored high for pasture health generally had more duck nests than lower scoring fields. The negative effects of long-term overgrazing are many (Holechek et al. 1998) and frequently lead to conditions that result in reduced pasture health. Perhaps the most important negative effect of long-term overgrazing that can lead to reduced duck nest densities is decreased biodiversity of plant communities (Kirby et al. 1992). The loss of shrub and forb species, rather than plant biodiversity per se, would likely lead to reduced nest densities. For example, Duebbert et al. (1986) found that while western snowberry (*Symphoricarpos occidentalis*) and Woods rose (*Rosa woodsii*) comprised only 2% of the available cover, 42% and 35% of mallard and gadwall nests, respectively, were located within patches of these shrub species. Alternatively, the relationship between pasture health and nest density may be because long-term grazing management is indicative of current management, i.e., fields that were in poor health due to long-term overgrazing were more likely to be overgrazed during this study and therefore have fewer nests.

In contrast to results for nest density, nesting success was not greatest in lightly grazed and idled fields. Rather, nesting success increased with grazing intensity for nests with moderate to high levels of nest-site vegetation, and decreased with grazing intensity for nests with low levels of nest-site vegetation. The complex relationship among nest-site vegetation, residual cover, and nesting success found during this study may explain the ambiguous results of previous work investigating the response of duck nesting success to grazing intensity (Kaiser 1976, Kirsch et al. 1978, Sedivec 1989, Barker et al. 1990, Greenwood et al. 1995, Gilbert et al. 1996).

The lack of a positive relationship between nest density and nesting success may be explained by density-dependent nest depredation. For example, Lariviére and Messier (1998), using simulated duck nests, found a density-dependent response of predators to high densities of simulated duck nests (>10 nests/ha). These nest densities were considerably greater than nest densities observed during this study, even in idled and lightly grazed fields. However, if predators respond to combined densities of prey items, i.e., small mammals and nests, the effect of grazing on predator foraging behavior, and resultant nesting success, may be evident even at relatively low levels of nest density. Density, biomass, and species diversity of grassland small mammal communities tend to decrease in response to grazing-induced changes in vegetative cover (Birney et al 1976, Grant et al. 1982). Reduced densities of small mammals and duck nests in grazed areas would likely result in lower foraging efficiency for predators, and, therefore, lead to greater avoidance of grazed areas by predators.

This hypothesis would not be supported by the alternative prey hypothesis (Clark et al. 1996). Simply stated, this hypothesis predicts greater nesting success in areas with abundant alternate prey items, assuming no numerical response by predators. Unfortunately, grazing impacts on predator foraging behavior in the PPR have not been studied, precluding definitive explanation of the nesting success results. Research directed at understanding the relationship among predators, ground-nesting birds, and small mammals in grazed areas of the PPR is needed to better define the mechanisms behind increased nesting success in moderately grazed areas.

At the nest-site scale, the relationship between nesting success and vegetation density was dependent upon the amount of vegetation in the surrounding field. Nesting success of upland-nesting ducks in the PPR is generally believed to be positively related to nest-site vegetation density (Duebbert 1969, Shranck 1972, Sedivec 1989). My results corroborate these findings for fields with low to moderate levels of residual cover, but in fields with high levels of residual cover (i.e., lightly grazed or idled fields) nesting success was negatively related to nest-site vegetation density. This interaction may be the result of a threshold effect of increasing nest-site vegetation. In fields with little residual cover, increasing nest-site vegetation density would provide duck nests greater concealment from predators, especially avian predators (Smith 1971, Sugden and Beyersbergen 1987), reducing the likelihood of nest depredation. This positive effect would likely decline as field-scale vegetation density increased and approached that of a nest-site. Additionally, because of the increased nest depredation rates in densely vegetated fields, where nest-site vegetation would also be expected to be at its greatest, a negative relationship between nesting success and nest-site vegetation density may result.

The presence of cattle in a field reduced the probability that a nest in that field would be successful. I hypothesized that cattle presence would not have a strong relationship with nesting success, given historic grazing by native ungulates in the ecosystem. Plains bison (*Bison bison bison*) occurred throughout the Aspen Parkland prior to European settlement (Bird 1930, Campbell et al. 1994, Olson 1994). Additionally, there is evidence that nest survival is higher in pastures relative to other habitats in the PPR (Sedivec 1989, Greenwood et al. 1995). Although trampling of nests by cattle can negatively affect nesting success (Koerth et al. 1983, Jensen et al. 1990), I found little direct evidence during the study to support this (only 3 nests were classified as having been destroyed by trampling).

I believe that the negative relationship between cattle presence and nesting success may be explained by: 1) the strong positive relationship between nest-site vegetation density and nesting success; and 2) drought conditions. Precipitation is a strong determinant of above-ground net primary production (ANPP) in the northern mixed-grass prairies (Biondini et al. 1998). Although ANPP was not quantified during this study, the negative effect of drought on ANPP was pronounced. Due to this, I believe that grazing resulted in greater reduction of vegetation density in fields and at nest-sites than would be expected during years of normal precipitation (i.e., grazing effects on nesting ducks were exacerbated by drought). Grazing induced declines in vegetation density, exacerbated by the drought, and a positive relationship between nest-site vegetation density and nesting success may have led to the negative relationship between nesting success and cattle presence.

I hypothesized that a potential positive effect of increasing cattle numbers in the Aspen Parkland would be conversion of cropland to grassland. Increasing area of grassland would result in: 1) larger patches of grassland habitat; and 2) a higher proportion of perennial cover at a landscape scale, both of which are positively correlated with duck nesting success in the PPR (Greenwood et al. 1995, Pasitschniak-Arts and Messier 1995, Reynolds et al. 2001, Howerter 2003, Stephens 2003). Contrary to current theory, my results indicated that nesting success decreased as grassland area increased within a 1-km radius from a field's center. Howerter (2003) found that nest survival was positively related to grassland patch size in the Aspen Parkland, but that nest survival in large patches of grassland declined sharply during the nesting season. He postulated that seasonal changes in predator foraging behavior caused the declines in nesting success in large grassland patches (Howerter 2003). However, if a seasonal shift in predator foraging behavior occurred during this study, I was unable to detect it. Increasing grassland area could negatively affect nesting success if larger, intact grasslands supported increasingly diverse predator communities. If grassland fragments function as "islands" of endemic habitat within a landscape matrix dominated by cropland, the species-area relationship of island biogeography (MacArthur and Wilson 1967) would predict a non-linear (i.e., sigmoidal) increase in the number of predator species present as grassland area increased. This would result in large grassland areas having a disproportionately high number of predators, and a disproportionately greater individual prey risk (Case 2000), relative to smaller grasslands. An empirical example of this would be the preference of coyotes for large grassland areas (Sargeant et al. 1993, Greenwood et al. 1995).

I found weak evidence of a positive relationship between field-scale wetland area and nesting success. This is in contrast to recent studies that reported nesting success to be: 1) positively related to the distance to the nearest wetland; and 2) negatively related to wetland density (Howerter 2003, Stephens 2003). However, Devries et al. (2003) found that female mallard survival during the breeding season was positively correlated with percent wetland habitat in the western Aspen Parkland. Greater wetland area may distribute over a larger area the: 1) activity of predators that spend a disproportionate amount of time foraging in wetland habitats, e.g. striped skunks (Lariviére and Messier 2000); and 2) nests of duck species that show a proclivity to nest near wetlands, resulting in greater nest survival. Alternatively, areas with a higher proportion of wetland habitat may be indicative of less fragmented habitat, i.e., less cropland and the wetland losses typically associated with this land-use and more perennial cover. Greenwood et al. (1995) and Stephens (2003) have shown that nesting success is positively related to perennial cover in the PPR. However, I did not find a positive correlation between nesting success and perennial cover in this study.

When viewed together, the nest density and nesting success results suggest that most females did not choose to nest in the safest places. This seeming contradiction could be the result of several scenarios. If individuals are prevented from occupying, or are unable to recognize, an optimal habitat, patterns of habitat use may not represent the optimal choice for a species (Clark and Shutler 1999). Lower nesting success in fields with greater nest densities could also be the result of a density-dependent response by predators (Clark and Nudds 1991, Lariviére and Messier 1998). Alternatively, given that nesting success is but one of several components of reproductive success, it is possible that other vital rates (e.g. female survival during the breeding season) may be higher in lightly grazed areas and therefore offset lower nesting success. For instance, survival of nesting females may be greater in areas with greater vegetation density, i.e., areas with lower levels of grazing. Greater field-scale vegetation density would provide nesting females with increased aerial coverage and, therefore, lower the probability of being detected by raptors such as red-tailed hawks and great horned owls (*Bubo virginianus*), abundant and important predators on nesting females (Murphy 1993, Sargeant et al. 1993). Additionally, even if greater field-scale vegetation density does not reduce the probability of a nest being detected by mammalian predators, it may impede their ability to capture a nesting female. Higher female survival in lightly grazed fields could, therefore, offset putative increases in reproductive success in moderately grazed areas.

Management Implications

My results indicate that nesting success increases with increasing grazing intensity at most levels of nest-site vegetation. Conversely, fewer ducks select moderately or heavily grazed fields relative to idled areas or fields grazed at lighter intensities. However, the difference in nesting success between idled and lightly grazed fields versus fields grazed at higher intensities was not sufficient to compensate for reduced nest densities. Duck production was greatest in lightly grazed/idled fields and declined with increasing grazing intensity (Table 10).

Table 10. Estimated duck production (hatched nests per 100 ha) for upland-nesting ducks in the Aspen Parkland of Alberta, Canada, 2001-2002, by grazing intensity and cattle presence. Mean values by grazing intensity of field residual cover (RC) and pasture score (PS), and overall proportion of flooded basins (PFBASINS; 0.2547) were used to estimate duck nest density using the second most parsimonious nest density model, $\mathrm{DEN}_{\mathrm{PFBASIN+RC+PS}}$. This model differed from the most parsimonious model only in lacking a year effect. Nesting success was estimated using the most parsimonious nesting success model, $\mathrm{DSR}_{\mathrm{NVEG+RC+NVEG*RC+RC^2+WEA+CP+GL1}}$. The following covariate values were used in this model: mean RC by grazing intensity, overall mean proportion of wetland area by field (WEA; 0.2155), grassland area within a 1-km radius of a field (GL1; 0.3538), and nest-site vegetation density (NVEG; 2.23).

	Grazing Intensity	Mean RC	Mean PS	Estimated Nest Density	Estimated Nesting Success (%)	Estimated Duck Production
Cattle Not Present	Low/Idle	0.75	73	31	2	0.61
	Moderate	0.18	59	2	4	0.09
	Heavy	0.04	45	<1	7	0.05
Cattle Present	Low/Idle	0.75	73	31	10	3.11
	Moderate	0.18	59	2	16	0.35
	Heavy	0.04	45	<1	22	0.15

Unfortunately, high grazing intensities are common in the Aspen Parkland. Greater levels and more consistent precipitation in the Aspen Parkland, relative to the more arid and drought prone mixed-grass prairies, generally permits producers to graze at higher utilization rates with fewer perceived negative consequences (Holecheck et al 1999). Also, mixed farming (i.e., annual crops and beef production) is more common in the Aspen Parkland than the mixed-grass prairies, with income from cattle production typically second to annual crops (Statistics Canada 2001). This results in less impetus for investing time in rangeland management relative to annual crop operations. These factors lead to an “industry standard” grazing level that results in high utilization rates in pasturelands. However, persistent heavy grazing leads to lower forage production due to: 1) soil compaction; 2) low litter levels; 3) reduced root biomass; 4) less moisture infiltration into the soil; and 5) increased soil temperatures (Holecheck et al. 1998).

VanPoollen and Lacey (1979), in a review of the literature on grazing systems and stocking rate in the Great Plains and the western USA, found that plant production increases on average 35% when stocking rate is reduced from heavy to moderate. Moderate stocking rates also result in higher net financial returns, relative to heavy stocking, on native pastures (Holechek et al. 1999).

Working with cattle producers to increase awareness of the economic benefits of moderate grazing levels versus the more typical heavy grazing levels could result in improved nesting habitat across significant areas of the Aspen Parkland. Currently, there are 9.3 million ha of pastureland in the Aspen Parkland, and this amount is increasing (Statistics Canada 2001). This study suggests that although nesting success may be lower, reducing grazing intensity levels will provide nesting habitat that is both more attractive and more productive for upland-nesting ducks.

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APPENDIX A

FIELD CHARACTERISTICS

Field locations, characteristics, and covariate values used to investigate the effect of cattle grazing on duck production in the Aspen Parkland of Alberta, Canada, 2001 and 2002. Covariate abbreviations and definitions can be found in Table 1.

Site	Year	Cluster	Legal Land Location	GT	GI	BP[a]	NESTS	SAREA
Ames	2002	BAE	NE9-42-20-W4	N	H	19.8	1	38.0
Andrews, DUC	2001	RDL	NE14-42-21-W4	T	L	30.4	6	18.5
Andrews, DUC	2002	BAE	NE14-42-21-W4	T	L	30.4	1	18.5
Annie, DUC	2002	MUN	SW26-52-17-W4	N	L	0.0	0	20.2
B & E Lease	2001	PLW	NW16-35-25-W4	T	L	83.4	18	47.8
Barritt LUEP	2002	ALX	NE2/SW11-40-22-W4	T	M	26.1	0	66.0
Basilian	2002	MUN	SW/SE9-53-16W4	T	M	11.1	1	36.6
Beck, DUC	2001	BLK	NE15-47-21-W4	N	L	48.2	9	28.3
Beck, DUC	2002	BL2	NE15-47-21-W4	N	L	76.5	8	28.3
Behnke	2002	BL2	NW33-46-22-W4	T	M	46.3	1	13.1
Berger	2002	BL2	SE8/NE5-47-22-W4	T	H	44.5	1	34.4
Bergman	2002	ALX	NW5-40-22-W4	T	H	137.0	0	34.7
Best	2002	ROV	SW13-49-23-W4	T	M	16.7	0	28.8
Bilan	2002	BVN	NE17-53-19-W4	T	H	35.1	0	35.1
Blaikie, DUC	2001	PLE	NW35-36-24-W4	N	L	19.8	8	24.9
Bluesky, DUC	2001	BLK	NE29-46-21-W4	N	M	49.8	6	42.6
Bluesky, DUC	2002	BL2	NE29-46-21-W4	N	M	82.8	4	42.6
Boote	2001	PLW	NE29-36-25-W4	N	M	0.0	2	13.5
Bosma	2001	LAP	SW12-40-20-W4	T	M	13.7	0	52.7
Boyden, DUC	2001	PLE	SE11-36-23-W4	T	L	4.6	3	38.2
Brimacombe 26	2002	SL2	NW26-41-22-W4	T	H	28.6	0	54.7
Brimacombe 34	2002	BAE	NW34-41-21-W4	T	H	36.5	2	49.5
Brosinsky	2001	CAS	SE2-42-20-W4	N	H	65.0	0	20.0
Brownlee	2001	MLK	SW7-51-19-W4	T	M	12.2	2	31.1
Caine, DUC	2002	BAE	NE6-41-19-W4	T	M	16.7	4	29.6
Cha	2001	BLK	SE35-46-21-W4	T	H	30.4	2	42.4
Churchill, DUC	2001	MLK	SE12-49-21-W4	T	M	27.0	1	24.0
Cole/Reimer	2001	RDL	SE30-45-22-W4	N	H	13.5	0	52.5
Collins Crown	2001	PLE	SE29-35-23-W4	N	M	67.4	2	24.0
Cossey	2002	BVN	NE27-53-18-W4	N	H	13.7	0	50.1
Crown	2002	ALX	NW/NE11-39-23-W4	N	M	50.6	1	29.9
Dahl	2001	PLE	NE18-36-23-W4	T	H	13.7	0	33.4
Dawson	2001	RDL	NW/NE16-43-21-W4	T	M	24.2	2	40.5
Dochstader, DUC	2002	MUN	NE7-53-16-W4	T	L	49.9	3	28.0
Fankhanel	2001	CAS	NE/SE29-42-20-W4	T	H	16.5	0	29.3
Felt	2002	SL2	SE5-42-22-W4	N	H	28.9	7	30.4
Ferguson	2001	SLK	NW20-41-23-W4	T	H	43.5	0	50.7
Firmaniuk, DUC	2002	MUN	NE33-54-17-W4	N	L	2.8	0	15.1
Frere Farms	2001	PLE	NW3-36-23-W4	N	H	27.4	0	51.0
Gallaugher, DUC	2002	BL2	NE19-48-21-W4	T	M	6.1	3	24.8
Gloria Lease	2001	PLW	NW35-35-25-W4	N	L	16.7	3	20.7
Hagstrom, DUC	2002	ROV	SW31-47-22-W4	T	L	33.5	8	24.1
Hawthorne, DUC	2001	SLK	NW24-38-24-W4	T	L	24.3	4	27.7

Appendix A cont.

Site	Year	Cluster	Legal Land Location	GT	GI	BP	NESTS	SAREA
Hawthorne, DUC	2002	ALX	NW24-38-24-W4	T	L	22.4	1	27.7
Hewko, DUC	2002	BVN	NW3-53-17-W4	T	L	0.0	0	23.6
Hillson/Krause	2001	BLK	NE21/NW22-46-22-W4	N	H	24.7	2	30.7
Hofstra	2002	ROV	NW11-48-23-W4	N	M	19.5	2	30.6
Hutterite SE	2001	RDL	SE9-46-22-W4	N	M	6.1	3	37.6
Jenson	2001	SLK	SW18-41-22-W4	N	M	12.2	0	46.2
Johnson SW	2002	BL2	SW11-46-23-W4	N	H	4.6	0	47.1
Johnson, DUC	2002	BL2	SE29-46-22-W4	T	L	70.9	16	20.5
Klassen/Hutterite	2001	RDL	NE15-44-22-W4	N	L	16.4	1	11.4
Krause 24	2001	BLK	NE24-46-22-W4	T	H	37.7	1	24.5
Krause 31	2001	PLW	NE31-35-25-W4	N	H	25.4	0	34.6
Lakeview LUEP	2001	MLK	NE7-49-20-W4	T	M	18.9	2	11.1
Lawson, DUC	2001	LAP	SE23-40-20-W4	N	L	42.0	4	30.3
Lazari	2002	ML2	SE35-48-20-W4	N	L	6.1	1	14.5
Lyseng, DUC	2001	MLK	SW24-48-21-W4	T	L	31.9	5	19.6
MacNaughton	2001	LAP	NW/NE11-40-19-W4	N	M	19.0	1	56.0
Matson	2002	ML2	NW25-48-21-W4	T	H	39.5	3	25.2
Mayowski	2002	BVN	NW36-53-19-W4	T	M	10.6	0	51.8
McKinney	2002	ROV	NE17-48-23-W4	N	H	22.1	0	30.8
Meadahl	2001	MLK	NE35-49-20-W4	T	L	41.1	1	28.0
Montgomery	2001	LAP	NW21-42-19-W4	T	H	47.7	0	29.5
Moseson	2001	RDL	SW27-44-22-W4	T	H	33.2	5	23.7
Moulton	2002	ALX	NE11-40-23-W4	N	L	0.0	1	38.9
Mulloy, DUC	2002	ML2	SE13-49-21-W4	T	L	6.1	1	28.4
Neufeld	2002	BL2	SW7-48-22-W4	N	H	68.9	1	18.3
Nixon, DUC	2001	CAS	NE15-41-19-W4	T	L	16.7	9	42.2
Ohman	2001	BLK	SE5-47-22-W4	T	L	33.0	3	36.7
Paillard	2002	BVN	NW5-54-18-W4	N	L	3.0	1	30.0
Peters	2001	LAP	SW5-40-19-W4	T	L	24.3	0	45.6
Perry, DUC	2002	BAE	SW8-42-20-W4	T	M	31.7	0	25.4
Pipke	2002	SL2	NE23-42-22-W4	N	M	28.1	1	27.2
Plaister	2001	SLK	SE14-41-23-W4	N	L	13.6	2	18.9
Pyramid Farms	2002	ALX	NE/SE32-39-23-W4	N	H	4.4	1	66.4
Ripley	2001	SLK	NW3-40-22-W4	N	H	30.2	1	15.0
Robinson Ranch	2001	PLW	NW35-36-26-W4	T	H	48.2	3	31.4
Salmon 01	2001	CAS	NE/SE24-41-20-W4	N	L	21.8	3	43.7
Salmon 02	2002	BAE	SW30-41-19-W4	N	L	18.9	0	20.7
Sargent	2001	SLK	SW/NW26-40-23-W4	T	M	23.5	0	37.8
Schoff	2001	CAS	NW17-42-20-W4	N	L	40.7	4	31.8
Shute	2002	ML2	NW5-48-19-W4	N	M	4.6	0	26.8
Siemans, DUC 01	2001	RDL	NW28-42-21-W4	T	L	23.5	4	11.3
Siemans, DUC 02	2002	SL2	SW33-42-21-W4	T	M	27.2	2	48.8
Spruyt	2001	MLK	SW30-49-19-W4	T	M	3.0	0	22.6
Stauffer, DUC	2002	SL2	NE/NW4-43-21-W4	T	L	20.3	12	39.9
Stavne	2001	MLK	NW26-49-21-W4	T	H	19.8	0	40.2

Appendix A cont.

Site	Year	Cluster	Legal Land Location	GT	GI	BP	NESTS	SAREA
Steele	2001	PLW	NW/NE14-37-26-W4	T	M	15.0	1	83.4
Stollery	2001	MLK	SW19-49-20-W4	N	H	48.2	0	34.1
Thompson, DUC	2001	CAS	SE34-41-22-W4	T	M	51.0	5	28.2
Vanguard, DUC	2002	ML2	NW23-48-21-W4	T	M	54.5	4	36.8
Walker	2002	ML2	SW8-49-20-W4	N	H	40.8	0	27.4
Walstrom	2001	LAP	SE34-40-19-W4	N	H	4.6	0	29.0
Wik, DUC	2001	PLE	SE32-35-24-W4	T	M	35.3	5	43.0
Willy, DUC	2002	BAE	SE31-40-21-W4	N	H	14.9	1	24.7
Wood	2002	BAE	SW1-42-20-W4	N	M	59.7	2	12.8
Zeleny, C	2002	MUN	SE24-53-17-W4	N	H	3.0	0	12.6
Zeleny, W	2002	MUN	SE23-53-17-W4	T	H	3.0	0	37.5
Ziegler	2002	BVN	NE/SE15-53-18-W4	N	M	37.6	1	72.4

Appendix A cont.

Site	Year	PFBASIN	RC	FVH	SHET	SA	FTREND	PSCORE
Ames	2002	0.25	0.11	3.60	0.31	3	0.16	46.70
Andrews, DUC	2001	0.38	1.04	4.78	0.23	0	1.71	88.00
Andrews, DUC	2002	0.24	0.58	5.47	0.22	0	0.30	94.40
Annie, DUC	2002	0.05	0.45	4.33	0.23	2	0.23	78.60
B & E Lease	2001	0.48	0.92	5.73	0.28	0	1.68	68.60
Barritt LUEP	2002	0.17	0.14	3.38	0.17	0	0.28	78.20
Basilian	2002	0.05	0.19	2.66	0.25	0	0.05	84.00
Beck, DUC	2001	0.59	0.62	2.93	0.29	2	0.47	71.00
Beck, DUC	2002	0.12	0.70	4.23	0.27	2	0.31	63.30
Behnke	2002	0.29	0.11	2.00	0.20	0	0.01	79.17
Berger	2002	0.21	0.03	1.40	0.08	0	0.21	59.40
Bergman	2002	0.14	0.00	1.88	0.00	0	0.00	58.50
Best	2002	0.05	0.00	1.53	0.00	0	0.03	55.80
Bilan	2002	0.06	0.03	1.00	0.08	0	0.00	51.70
Blaikie, DUC	2001	0.50	1.11	5.10	0.55	3	1.00	76.20
Bluesky, DUC	2001	0.47	1.01	4.75	0.53	2	-0.55	47.60
Bluesky, DUC	2002	0.11	0.14	2.22	0.20	2	0.30	55.40
Boote	2001	0.40	0.61	3.38	0.33	3	1.03	56.50
Bosma	2001	0.31	0.08	1.35	0.17	0	0.08	27.40
Boyden, DUC	2001	0.04	1.55	6.05	0.59	0	2.03	72.10
Brimacombe 26	2002	0.30	0.18	2.28	0.21	0	-0.08	71.80
Brimacombe 34	2002	0.07	0.00	1.38	0.02	0	0.00	55.20
Brosinsky	2001	0.60	0.02	1.38	0.06	1	0.03	31.60
Brownlee	2001	0.21	0.24	3.45	0.31	0	0.23	53.33
Caine, DUC	2002	0.14	0.17	4.52	0.16	0	0.18	93.40
Cha	2001	0.38	0.09	1.00	0.22	0	0.47	48.60
Churchill, DUC	2001	0.18	0.71	3.65	0.54	0	0.19	61.80
Cole/Reimer	2001	0.18	0.11	1.45	0.18	1	0.13	34.90
Collins Crown	2001	0.32	0.17	3.23	0.25	3	0.43	46.00
Cossey	2002	0.09	0.00	1.12	0.00	1	0.00	22.20
Crown	2002	0.23	0.23	5.15	0.30	3	0.89	63.10
Dahl	2001	0.17	0.01	0.73	0.03	0	0.06	24.80
Dawson	2001	0.24	0.49	4.88	0.35	0	1.13	61.17
Dochstader, DUC	2002	0.16	0.68	4.62	0.30	0	0.30	94.80
Fankhanel	2001	0.41	0.01	1.45	0.03	0	0.39	51.70
Felt	2002	0.24	0.02	1.07	0.07	2	0.09	39.10
Ferguson	2001	0.25	0.08	0.83	0.21	0	0.51	45.70
Firmaniuk, DUC	2002	0.00	0.47	3.17	0.24	1	0.18	74.50
Frere Farms	2001	0.31	0.08	2.43	0.14	2	0.48	34.30
Gallaugher, DUC	2002	0.08	0.55	3.57	0.35	0	0.23	89.70
Gloria Lease	2001	0.14	0.86	4.25	0.55	3	1.48	70.50
Hagstrom, DUC	2002	0.06	0.62	4.95	0.26	0	0.35	85.30
Hawthorne, DUC	2001	0.18	0.56	4.85	0.37	0	1.59	80.00

Appendix A cont.

Site	Year	PFBASIN	RC	FVH	SHET	SA	FTREND	PSCORE
Hawthorne, DUC	2002	0.18	0.47	5.98	0.23	0	0.28	99.50
Hewko, DUC	2002	0.00	0.75	5.63	0.23	0	0.24	100.00
Hillson/Krause	2001	0.73	0.02	1.37	0.06	1	0.13	34.60
Hofstra	2002	0.07	0.16	2.13	0.19	2	0.39	56.70
Hutterite SE	2001	0.28	0.17	3.00	0.18	2	0.98	56.71
Jenson	2001	0.20	0.24	2.93	0.36	2	0.24	47.70
Johnson SW	2002	0.17	0.12	2.45	0.19	2	0.26	53.50
Johnson, DUC	2002	0.39	0.69	4.10	0.30	0	0.46	85.40
Klassen/Hutterite	2001	0.54	0.92	7.00	0.50	2	1.38	61.33
Krause 24	2001	0.36	0.02	2.05	0.06	0	0.27	45.70
Krause 31	2001	0.07	0.14	2.53	0.28	3	0.38	40.60
Lakeview LUEP	2001	0.53	0.29	2.96	0.31	0	0.76	60.17
Lawson, DUC	2001	0.45	0.73	4.78	0.58	3	0.55	68.40
Lazari	2002	0.38	0.09	1.98	0.19	2	-0.01	21.50
Lyseng, DUC	2001	0.19	0.73	4.00	0.37	0	0.61	84.7
MacNaughton	2001	0.27	0.38	4.13	0.40	3	0.69	55.40
Matson	2002	0.15	0.11	1.90	0.17	0	0.03	66.00
Mayowski	2002	0.07	0.18	3.07	0.23	0	-0.02	69.10
McKinney	2002	0.06	0.03	1.93	0.12	2	0.15	46.40
Meadahl	2001	0.34	0.36	3.19	0.31	0	0.15	46.00
Montgomery	2001	0.22	0.02	2.10	0.06	0	-0.01	29.00
Moseson	2001	0.47	0.05	2.00	0.11	0	0.32	62.71
Moulton	2002	0.09	0.12	4.23	0.17	3	0.41	48.00
Mulloy, DUC	2002	0.03	0.29	3.22	0.23	0	1.12	95.00
Neufeld	2002	0.13	0.12	1.98	0.21	3	0.35	52.00
Nixon, DUC	2001	0.46	0.64	6.35	0.37	0	1.29	83.00
Ohman	2001	0.45	0.90	2.73	0.40	0	2.18	73.70
Paillard	2002	0.23	0.34	3.67	0.26	1	-0.07	75.40
Peters	2001	0.31	0.06	2.50	0.12	0	0.61	67.50
Perry, DUC	2002	0.33	0.02	2.55	0.07	0	0.04	71.00
Pipke	2002	0.60	0.16	3.12	0.19	0	0.09	56.10
Plaister	2001	0.22	0.33	3.83	0.31	3	0.34	43.54
Pyramid Farms	2002	0.08	0.04	3.30	0.08	3	0.18	28.40
Ripley	2001	0.56	0.01	2.21	0.04	1	0.06	59.00
Robinson Ranch	2001	0.57	0.06	2.15	0.13	0	0.92	60.83
Salmon 01	2001	0.69	0.19	4.65	0.27	3	0.53	42.70
Salmon 02	2002	0.00	0.13	7.38	0.17	1	0.01	56.30
Sargent	2001	0.22	0.13	2.25	0.24	0	0.16	52.30
Schoff	2001	0.52	0.26	4.47	0.29	0	1.54	68.70
Shute	2002	0.07	0.10	2.02	0.18	2	0.18	29.30
Siemans, DUC 01	2001	0.32	0.98	7.00	0.39	0	1.39	63.00
Siemans, DUC 02	2002	0.27	0.35	4.22	0.28	0	-0.01	74.80
Spruyt	2001	0.15	0.11	1.98	0.16	0	0.25	56.22
Stauffer, DUC	2002	0.24	0.62	4.82	0.40	0	0.55	69.80
Stavne	2001	0.09	0.11	1.65	0.22	0	0.26	40.60

Appendix A cont.

Site	Year	PFBASIN	RC	FVH	SHET	SA	FTREND	PSCORE
Steele	2001	0.49	0.22	2.95	0.23	0	0.48	46.69
Stollery	2001	0.83	0.03	0.98	0.09	3	0.11	34.30
Thompson, DUC	2001	0.17	0.33	3.28	0.31	0	1.31	80.30
Vanguard, DUC	2002	0.07	0.43	4.18	0.34	0	0.13	79.70
Walker	2002	0.18	0.06	1.47	0.16	1	0.03	25.40
Walstrom	2001	0.23	0.07	2.74	0.12	3	0.27	48.30
Wik, DUC	2001	0.25	0.59	3.83	0.42	0	0.41	75.10
Willy, DUC	2002	0.07	0.10	2.90	0.21	3	0.13	42.00
Wood	2002	0.33	0.05	3.55	0.17	3	0.16	56.83
Zeleny, C	2002	0.06	0.01	1.98	0.05	1	0.02	52.40
Zeleny, W	2002	0.04	0.01	2.45	0.04	0	0.02	25.60
Ziegler	2002	0.14	0.09	2.32	0.14	2	0.09	39.00

Appendix A cont.

Site	Year	PC1	PC2	PC3	PC4	GL1	GL2	GL3	GL4
Ames	2002	0.95	0.83	0.82	0.78	0.39	0.38	0.32	0.31
Andrews, DUC	2001	0.87	0.93	0.89	0.81	0.37	0.34	0.32	0.30
Andrews, DUC	2002	0.87	0.93	0.89	0.81	0.37	0.34	0.32	0.30
Annie, DUC	2002	0.25	0.21	0.24	0.26	0.21	0.18	0.18	0.19
B & E Lease	2001	0.68	0.52	0.42	0.37	0.62	0.39	0.28	0.22
Barritt LUEP	2002	0.82	0.88	0.87	0.82	0.24	0.24	0.28	0.28
Basilian	2002	0.42	0.38	0.39	0.37	0.13	0.26	0.29	0.27
Beck, DUC	2001	0.87	0.66	0.58	0.58	0.41	0.38	0.37	0.37
Beck, DUC	2002	0.87	0.66	0.58	0.58	0.41	0.38	0.37	0.37
Behnke	2002	0.76	0.63	0.64	0.59	0.34	0.30	0.29	0.28
Berger	2002	0.62	0.47	0.47	0.53	0.31	0.17	0.21	0.24
Bergman	2002	0.76	0.62	0.71	0.74	0.14	0.18	0.21	0.25
Best	2002	0.98	0.90	0.88	0.85	0.31	0.32	0.32	0.29
Bilan	2002	0.77	0.74	0.79	0.80	0.37	0.30	0.34	0.33
Blaikie, DUC	2001	0.98	0.87	0.83	0.78	0.70	0.67	0.60	0.56
Bluesky, DUC	2001	0.72	0.54	0.49	0.48	0.50	0.33	0.26	0.26
Bluesky, DUC	2002	0.72	0.54	0.49	0.48	0.50	0.33	0.26	0.26
Boote	2001	0.84	0.87	0.90	0.90	0.43	0.38	0.32	0.34
Bosma	2001	0.79	0.83	0.77	0.72	0.61	0.44	0.40	0.39
Boyden, DUC	2001	0.52	0.58	0.62	0.63	0.36	0.39	0.41	0.40
Brimacombe 26	2002	0.39	0.51	0.53	0.58	0.07	0.13	0.15	0.17
Brimacombe 34	2002	0.84	0.72	0.75	0.74	0.47	0.42	0.38	0.36
Brosinsky	2001	0.89	0.89	0.86	0.82	0.44	0.36	0.37	0.34
Brownlee	2001	0.99	0.91	0.88	0.82	0.40	0.26	0.22	0.19
Caine, DUC	2002	0.91	0.93	0.87	0.83	0.35	0.32	0.30	0.30
Cha	2001	0.66	0.57	0.47	0.48	0.25	0.25	0.23	0.22
Churchill, DUC	2001	0.83	0.85	0.84	0.84	0.18	0.21	0.23	0.24
Cole/Reimer	2001	0.86	0.73	0.61	0.54	0.44	0.30	0.25	0.23
Collins Crown	2001	0.82	0.82	0.81	0.81	0.46	0.52	0.53	0.53
Cossey	2002	0.97	0.85	0.79	0.79	0.81	0.75	0.70	0.70
Crown	2002	0.98	0.76	0.69	0.68	0.31	0.24	0.24	0.24
Dahl	2001	0.89	0.85	0.73	0.71	0.67	0.53	0.44	0.43
Dawson	2001	0.72	0.65	0.50	0.56	0.31	0.27	0.22	0.26
Dochstader, DUC	2002	0.63	0.41	0.36	0.31	0.43	0.29	0.23	0.20
Fankhanel	2001	0.78	0.72	0.66	0.63	0.16	0.20	0.25	0.26
Felt	2002	0.92	0.74	0.66	0.65	0.04	0.06	0.07	0.08
Ferguson	2001	0.89	0.59	0.51	0.55	0.01	0.09	0.07	0.14
Firmaniuk, DUC	2002	0.46	0.25	0.26	0.28	0.30	0.15	0.18	0.19
Frere Farms	2001	0.96	0.84	0.78	0.74	0.64	0.55	0.53	0.50
Gallaugher, DUC	2002	0.34	0.33	0.43	0.45	0.16	0.16	0.19	0.23
Gloria Lease	2001	0.75	0.63	0.54	0.54	0.55	0.43	0.37	0.34
Hagstrom, DUC	2002	0.92	0.65	0.60	0.58	0.80	0.44	0.36	0.34
Hawthorne, DUC	2001	0.50	0.61	0.65	0.66	0.32	0.34	0.35	0.32

Appendix A cont.

Site	Year	PC1	PC2	PC3	PC4	GL1	GL2	GL3	GL4
Hawthorne, DUC	2002	0.50	0.61	0.65	0.66	0.32	0.34	0.35	0.32
Hewko, DUC	2002	0.39	0.41	0.30	0.29	0.18	0.23	0.19	0.19
Hillson/Krause	2001	0.95	0.79	0.77	0.75	0.59	0.41	0.39	0.38
Hofstra	2002	0.88	0.83	0.78	0.80	0.78	0.49	0.42	0.45
Hutterite SE	2001	0.83	0.71	0.69	0.70	0.33	0.27	0.25	0.28
Jenson	2001	0.92	0.86	0.81	0.73	0.16	0.19	0.18	0.19
Johnson SW	2002	0.43	0.44	0.37	0.39	0.14	0.16	0.14	0.13
Johnson, DUC	2002	0.68	0.75	0.78	0.71	0.45	0.44	0.43	0.33
Klassen/Hutterite	2001	0.63	0.67	0.60	0.51	0.23	0.19	0.19	0.17
Krause 24	2001	0.59	0.66	0.71	0.68	0.31	0.39	0.41	0.36
Krause 31	2001	0.79	0.66	0.62	0.57	0.70	0.42	0.38	0.38
Lakeview LUEP	2001	0.92	0.84	0.85	0.81	0.13	0.21	0.20	0.20
Lawson, DUC	2001	0.99	0.87	0.82	0.78	0.36	0.27	0.31	0.33
Lazari	2002	0.66	0.57	0.59	0.55	0.38	0.39	0.39	0.37
Lyseng, DUC	2001	0.67	0.65	0.67	0.69	0.35	0.29	0.29	0.30
MacNaughton	2001	0.78	0.50	0.51	0.52	0.33	0.30	0.28	0.23
Matson	2002	0.87	0.76	0.73	0.71	0.29	0.30	0.27	0.26
Mayowski	2002	0.69	0.59	0.57	0.61	0.52	0.36	0.31	0.30
McKinney	2002	0.92	0.84	0.84	0.80	0.52	0.32	0.31	0.33
Meadahl	2001	0.99	0.93	0.93	0.90	0.22	0.19	0.16	0.16
Montgomery	2001	0.72	0.65	0.64	0.65	0.37	0.32	0.35	0.39
Moseson	2001	0.64	0.50	0.46	0.42	0.34	0.23	0.18	0.15
Moulton	2002	0.97	0.90	0.88	0.79	0.30	0.37	0.33	0.28
Mulloy, DUC	2002	0.91	0.89	0.86	0.81	0.29	0.22	0.20	0.20
Neufeld	2002	0.71	0.75	0.73	0.73	0.55	0.51	0.49	0.50
Nixon, DUC	2001	0.86	0.77	0.68	0.63	0.45	0.36	0.32	0.29
Ohman	2001	0.43	0.48	0.49	0.55	0.08	0.15	0.19	0.23
Paillard	2002	0.51	0.51	0.56	0.58	0.47	0.42	0.47	0.50
Perry, DUC	2002	0.93	0.85	0.82	0.79	0.41	0.39	0.34	0.33
Peters	2001	0.75	0.71	0.67	0.62	0.37	0.34	0.34	0.36
Pipke	2002	0.67	0.70	0.66	0.62	0.44	0.44	0.37	0.30
Plaister	2001	0.77	0.77	0.73	0.70	0.06	0.08	0.09	0.14
Pyramid Farms	2002	0.95	0.88	0.83	0.73	0.13	0.19	0.23	0.24
Ripley	2001								
Robinson Ranch	2001	0.62	0.62	0.68	0.70	0.43	0.45	0.48	0.47
Salmon 01	2001	0.88	0.81	0.86	0.83	0.37	0.31	0.35	0.33
Salmon 02	2002								
Sargent	2001	0.93	0.80	0.76	0.75	0.08	0.12	0.17	0.23
Schoff	2001	0.60	0.69	0.75	0.79	0.21	0.28	0.28	0.28
Shute	2002	0.65	0.62	0.64	0.61	0.33	0.37	0.43	0.44
Siemans, DUC 01	2001	0.47	0.59	0.62	0.63	0.12	0.24	0.27	0.28
Siemans, DUC 02	2002	0.47	0.59	0.62	0.63	0.12	0.24	0.27	0.28
Spruyt	2001	0.73	0.71	0.66	0.66	0.19	0.11	0.13	0.16
Stauffer, DUC	2002	0.72	0.64	0.64	0.63	0.29	0.28	0.27	0.27
Stavne	2001	1.00	0.93	0.88	0.85	0.15	0.13	0.15	0.14

Appendix A cont.

Site	Year	PC1	PC2	PC3	PC4	GL1	GL2	GL3	GL4
Steele	2001	1.00	0.94	0.91	0.87	0.76	0.56	0.50	0.45
Stollery	2001	0.93	0.71	0.72	0.79	0.18	0.16	0.17	0.15
Thompson, DUC	2001	0.70	0.63	0.57	0.59	0.13	0.10	0.11	0.13
Vanguard, DUC	2002	0.70	0.64	0.65	0.68	0.19	0.25	0.25	0.27
Walker	2002	0.91	0.79	0.78	0.79	0.17	0.20	0.22	0.21
Walstrom	2001	0.48	0.54	0.63	0.70	0.25	0.24	0.26	0.29
Wik, DUC	2001	0.35	0.63	0.65	0.59	0.20	0.47	0.48	0.43
Willy, DUC	2002	0.47	0.57	0.56	0.52	0.37	0.34	0.29	0.24
Wood	2002	0.86	0.84	0.82	0.80	0.40	0.36	0.34	0.34
Zeleny, C	2002	0.40	0.41	0.39	0.36	0.31	0.33	0.28	0.24
Zeleny, W	2002	0.66	0.43	0.35	0.33	0.60	0.32	0.26	0.24
Ziegler	2002	0.98	0.88	0.88	0.87	0.93	0.77	0.80	0.78

Appendix A cont.

Site	Year	WOA	WOA1	WOA2	WOA3	WOA4	WEA	WEA1	WEA2	WEA3	WEA4
Ames	2002	0.18	0.34	0.31	0.36	0.33	0.22	0.13	0.15	0.16	0.17
Andrews, DUC	2001	0.12	0.47	0.47	0.41	0.35	0.34	0.09	0.12	0.14	0.16
Andrews, DUC	2002	0.12	0.47	0.47	0.41	0.35	0.34	0.09	0.12	0.14	0.16
Annie, DUC	2002	0.04	0.04	0.03	0.03	0.03	0.29	0.15	0.13	0.12	0.11
B & E Lease	2001	0.03	0.06	0.05	0.04	0.04	0.27	0.07	0.07	0.05	0.05
Barritt LUEP	2002	0.05	0.26	0.23	0.26	0.25	0.29	0.14	0.09	0.09	0.09
Basilian	2002	0.04	0.10	0.06	0.07	0.07	0.16	0.07	0.06	0.08	0.09
Beck, DUC	2001	0.22	0.32	0.17	0.13	0.11	0.31	0.17	0.10	0.09	0.12
Beck, DUC	2002	0.22	0.32	0.17	0.13	0.11	0.31	0.17	0.10	0.09	0.12
Behnke	2002	0.04	0.00	0.02	0.04	0.06	0.16	0.08	0.06	0.08	0.12
Berger	2002	0.05	0.01	0.04	0.02	0.03	0.17	0.08	0.04	0.04	0.06
Bergman	2002	0.04	0.13	0.17	0.19	0.20	0.35	0.09	0.21	0.26	0.18
Best	2002	0.03	0.19	0.27	0.19	0.16	0.09	0.09	0.14	0.12	0.09
Bilan	2002	0.18	0.19	0.24	0.25	0.30	0.29	0.27	0.12	0.10	0.12
Blaikie, DUC	2001	0.19	0.12	0.09	0.08	0.07	0.18	0.14	0.12	0.10	0.10
Bluesky, DUC	2001	0.12	0.11	0.11	0.11	0.11	0.21	0.13	0.08	0.10	0.15
Bluesky, DUC	2002	0.12	0.11	0.11	0.11	0.11	0.21	0.13	0.08	0.10	0.15
Boote	2001	0.33	0.23	0.25	0.25	0.22	0.16	0.27	0.17	0.12	0.10
Bosma	2001	0.01	0.04	0.15	0.19	0.20	0.18	0.20	0.19	0.20	0.21
Boyden, DUC	2001	0.13	0.06	0.06	0.04	0.04	0.12	0.12	0.26	0.26	0.18
Brimacombe 26	2002	0.13	0.23	0.19	0.18	0.18	0.27	0.08	0.06	0.05	0.05
Brimacombe 34	2002	0.04	0.26	0.18	0.19	0.20	0.17	0.07	0.14	0.15	0.16
Brosinsky	2001	0.08	0.29	0.42	0.40	0.37	0.40	0.20	0.17	0.19	0.20
Brownlee	2001	0.14	0.58	0.54	0.51	0.48	0.27	0.06	0.06	0.05	0.06
Caine, DUC	2002	0.32	0.46	0.47	0.42	0.40	0.22	0.14	0.14	0.15	0.17
Cha	2001	0.01	0.08	0.13	0.10	0.10	0.18	0.06	0.09	0.09	0.08
Churchill, DUC	2001	0.01	0.36	0.40	0.40	0.40	0.15	0.08	0.09	0.09	0.09
Cole/Reimer	2001	0.03	0.28	0.29	0.27	0.22	0.18	0.08	0.07	0.08	0.07
Collins Crown	2001	0.29	0.24	0.16	0.12	0.10	0.28	0.16	0.10	0.11	0.09
Cossey	2002	0.02	0.16	0.09	0.06	0.05	0.22	0.23	0.15	0.13	0.11
Crown	2002	0.54	0.61	0.29	0.22	0.24	0.19	0.07	0.08	0.05	0.05
Dahl	2001	0.03	0.06	0.07	0.07	0.07	0.17	0.12	0.08	0.06	0.06
Dawson	2001	0.01	0.22	0.16	0.14	0.15	0.26	0.15	0.11	0.19	0.17
Dochstader, DUC	2002	0.01	0.17	0.10	0.09	0.07	0.44	0.20	0.13	0.10	0.10
DUSW	2002	0.44	0.45	0.34	0.32	0.30	0.15	0.12	0.19	0.16	0.15
Fankhanel	2001	0.01	0.33	0.29	0.25	0.22	0.17	0.10	0.12	0.12	0.12
Felt	2002	0.34	0.20	0.18	0.16	0.16	0.16	0.11	0.05	0.05	0.04
Ferguson	2001	0.06	0.10	0.07	0.08	0.10	0.16	0.07	0.04	0.03	0.04
Firmaniuk, DUC	2002	0.10	0.04	0.03	0.04	0.05	0.60	0.26	0.13	0.10	0.08
Frere Farms	2001	0.23	0.06	0.06	0.06	0.05	0.36	0.13	0.10	0.12	0.16
Gallaugher, DUC	2002	0.04	0.00	0.00	0.01	0.01	0.12	0.12	0.06	0.10	0.10
Gloria Lease	2001	0.54	0.16	0.11	0.08	0.07	0.12	0.09	0.07	0.06	0.07
Hagstrom, DUC	2002	0.05	0.00	0.00	0.01	0.03	0.27	0.39	0.18	0.14	0.12
Hawthorne, DUC	2001	0.27	0.02	0.03	0.04	0.06	0.30	0.08	0.04	0.03	0.04

Appendix A cont.

Site	Year	WOA	WOA1	WOA2	WOA3	WOA4	WEA	WEA1	WEA2	WEA3	WEA4
Hawthorne, DUC	2002	0.27	0.02	0.03	0.04	0.06	0.30	0.08	0.04	0.03	0.04
Hewko, DUC	2002	0.04	0.05	0.05	0.04	0.04	0.20	0.11	0.12	0.11	0.10
Hillson/Krause	2001	0.01	0.21	0.25	0.21	0.17	0.10	0.05	0.06	0.06	0.06
Hofstra	2002	0.08	0.04	0.15	0.14	0.10	0.17	0.03	0.04	0.03	0.04
Hutterite SE	2001	0.20	0.28	0.22	0.25	0.27	0.21	0.07	0.05	0.05	0.05
Jenson	2001	0.16	0.11	0.12	0.11	0.11	0.16	0.16	0.19	0.16	0.16
Johnson SW	2002	0.01	0.05	0.07	0.06	0.09	0.11	0.07	0.05	0.04	0.03
Johnson, DUC	2002	0.03	0.14	0.13	0.13	0.14	0.23	0.07	0.08	0.06	0.05
Klassen/Hutterite	2001	0.14	0.22	0.35	0.30	0.23	0.21	0.11	0.13	0.13	0.12
Krause 24	2001	0.02	0.14	0.10	0.15	0.15	0.14	0.11	0.06	0.07	0.10
Krause 31	2001	0.35	0.05	0.11	0.10	0.08	0.12	0.06	0.06	0.06	0.06
Lakeview LUEP	2001	0.18	0.55	0.49	0.50	0.44	0.15	0.10	0.09	0.08	0.12
Lawson, DUC	2001	0.39	0.56	0.51	0.38	0.32	0.20	0.19	0.18	0.18	0.21
Lazari	2002	0.31	0.09	0.07	0.09	0.09	0.08	0.04	0.05	0.06	0.07
Lyseng, DUC	2001	0.19	0.18	0.17	0.20	0.19	0.43	0.15	0.12	0.09	0.08
MacNaughton	2001	0.43	0.44	0.18	0.18	0.18	0.15	0.21	0.18	0.16	0.14
Matson	2002	0.24	0.49	0.34	0.28	0.25	0.19	0.13	0.11	0.12	0.11
Mayowski	2002	0.00	0.03	0.10	0.08	0.14	0.15	0.08	0.05	0.04	0.05
McKinney	2002	0.10	0.05	0.15	0.18	0.17	0.19	0.03	0.06	0.06	0.06
Meadahl	2001	0.32	0.69	0.63	0.61	0.57	0.18	0.10	0.10	0.13	0.11
Montgomery	2001	0.02	0.21	0.17	0.16	0.16	0.20	0.14	0.11	0.11	0.10
Moseson	2001	0.12	0.16	0.22	0.23	0.19	0.15	0.08	0.11	0.08	0.08
Moulton	2002	0.41	0.46	0.34	0.31	0.27	0.03	0.04	0.21	0.21	0.16
Mulloy, DUC	2002	0.33	0.54	0.45	0.44	0.41	0.14	0.06	0.07	0.11	0.17
Neufeld	2002	0.12	0.04	0.04	0.02	0.02	0.45	0.19	0.14	0.12	0.11
Nixon, DUC	2001	0.09	0.39	0.33	0.29	0.25	0.26	0.14	0.11	0.09	0.10
Ohman	2001	0.08	0.08	0.04	0.02	0.05	0.17	0.05	0.04	0.04	0.08
Paillard	2002	0.23	0.04	0.03	0.06	0.05	0.13	0.02	0.03	0.04	0.04
Peters	2001	0.06	0.19	0.18	0.16	0.12	0.23	0.21	0.22	0.20	0.18
Pipke	2002	0.00	0.03	0.07	0.09	0.11	0.20	0.14	0.20	0.11	0.09
Plaister	2001	0.25	0.10	0.11	0.13	0.12	0.13	0.07	0.07	0.10	0.11
Pyramid Farms	2002	0.42	0.56	0.43	0.36	0.32	0.06	0.06	0.05	0.05	0.05
Ripley	2001	0.02									
Robinson Ranch	2001	0.11	0.09	0.05	0.05	0.05	0.40	0.16	0.08	0.07	0.08
Salmon 01	2001	0.17	0.34	0.37	0.35	0.34	0.30	0.30	0.26	0.21	0.19
Salmon 02	2002	0.09									
Sargent	2001	0.16	0.02	0.08	0.15	0.15	0.08	0.03	0.02	0.03	0.05
Schoff	2001	0.09	0.26	0.32	0.34	0.33	0.27	0.16	0.20	0.17	0.15
Shute	2002	0.12	0.27	0.16	0.15	0.12	0.11	0.09	0.08	0.14	0.16
Siemans, DUC 01	2001	0.25	0.22	0.19	0.17	0.18	0.19	0.23	0.16	0.12	0.11
Siemans, DUC 02	2002	0.16	0.22	0.19	0.17	0.18	0.19	0.23	0.16	0.12	0.11
Spruyt	2001	0.28	0.18	0.24	0.23	0.26	0.10	0.03	0.04	0.05	0.05
Stauffer, DUC	2002	0.03	0.27	0.16	0.16	0.17	0.13	0.22	0.19	0.18	0.15
Stavne	2001	0.18	0.51	0.64	0.57	0.53	0.22	0.04	0.13	0.15	0.18

Appendix A cont.

Site	Year	WOA	WOA1	WOA2	WOA3	WOA4	WEA	WEA1	WEA2	WEA3	WEA4
Steele	2001	0.10	0.04	0.08	0.10	0.10	0.13	0.04	0.08	0.08	0.08
Stollery	2001	0.22	0.53	0.40	0.43	0.49	0.19	0.10	0.29	0.29	0.24
Thompson, DUC	2001	0.07	0.36	0.25	0.20	0.19	0.36	0.10	0.07	0.05	0.05
Vanguard, DUC	2002	0.05	0.26	0.19	0.18	0.19	0.38	0.12	0.11	0.09	0.09
Walker	2002	0.26	0.53	0.45	0.39	0.42	0.24	0.09	0.08	0.07	0.09
Walstrom	2001	0.39	0.21	0.24	0.31	0.32	0.11	0.17	0.19	0.19	0.17
Wik, DUC	2001	0.02	0.09	0.11	0.10	0.09	0.14	0.10	0.09	0.09	0.09
Willy, DUC	2002	0.06	0.09	0.11	0.12	0.10	0.13	0.09	0.10	0.14	0.21
Wood	2002	0.32	0.40	0.38	0.40	0.37	0.37	0.22	0.17	0.19	0.19
Zeleny, C	2002	0.00	0.08	0.07	0.07	0.06	0.24	0.15	0.13	0.12	0.11
Zeleny, W	2002	0.06	0.03	0.04	0.06	0.06	0.35	0.16	0.16	0.13	0.12
Ziegler	2002	0.00	0.04	0.09	0.07	0.08	0.44	0.21	0.16	0.15	0.15

[a] Estimated duck breeding pair density (pr/km^2).