ARCTIC
VOL. 61, NO. 2 (JUNE 2008) P. 190–198

Effects of Seismic Lines on the Abundance of Breeding Birds in the Kendall Island Bird Sanctuary, Northwest Territories, Canada

AMBER R. ASHENHURST[1] and SUSAN J. HANNON[1,2]

(*Received 14 May 2007; accepted in revised form 5 September 2007*)

ABSTRACT. Current plans to increase oil and gas exploration and extraction in the Canadian Arctic include development in the Kendall Island Bird Sanctuary, Northwest Territories. Various studies have shown impacts of seismic lines on vegetation, but the effects on bird abundance in the Arctic are poorly known. We evaluated the impact of new (0.5–1.5 years old) and old (10–35 years old) visible seismic lines within the sanctuary on the abundance of breeding passerines (savannah sparrow, *Passerculus sandwichensis*; Lapland longspur, *Calcarius lapponicus*; common redpoll, *Carduelis flammea*; American tree sparrow, *Spizella arborea*; and red-necked phalarope, *Phalaropus lobatus*) in upland tundra, low-centre polygon, and sedge/willow habitats. Along new seismic lines, effects on abundance were not statistically significant for most groups of birds, although the trend in most habitats was for more birds on reference transects than on seismic lines. Significant impacts were found for passerines grouped in upland tundra and for savannah sparrow in sedge/willow. The latter effect (possibly due to standing water along the line) was not significant the following year. Along old seismic lines, abundance of passerines was lower than on reference transects in upland tundra and low-centre polygon habitat, except for Lapland longspurs in upland tundra. Lines created 10–30 years ago have persistent vegetative changes and this appears to have reduced bird abundance. Although we did not plot individual territories, birds were seen crossing the seismic lines and sometimes perched on them, suggesting that they were not avoiding the lines altogether. Instead, these birds may have increased territory size to compensate for vegetative changes along the lines.

Key words: Arctic birds, seismic exploration, seismic lines, Kendall Island Bird Sanctuary, oil and gas development

RÉSUMÉ. Les plans actuels visant l'intensification des travaux d'exploration et d'extraction pétrolière et gazière dans l'Arctique canadien visent la mise en valeur du refuge d'oiseaux de l'île Kendall, dans les Territoires du Nord-Ouest. Même si diverses études ont permis de démontrer les effets des profils sismiques sur la végétation, les effets de ces profils sur l'abondance d'oiseaux dans l'Arctique sont méconnus. Au sein du refuge, nous avons évalué l'incidence des nouveaux (de 0,5 à 1,5 an) et anciens (de 10 à 35 ans) profils sismiques visibles sur l'abondance des passériformes nicheurs (bruant des prés, *Passerculus sandwichensis*; bruant lapon, *Calcarius lapponicus*; sizerin flammé, *Carduelis flammea*; bruant hudsonien, *Spizella arborea* et phalarope à bec large, *Phalaropus lobatus*) dans la toundra supérieure, le polygone à centre concave et les habitats de laiche et de saule. Le long des nouveaux profils sismiques, les effets enregistrés sur l'abondance n'étaient pas statistiquement importants pour la plupart des groupes d'oiseaux, bien que dans la plupart des habitats, la tendance se traduit par la présence d'un plus grand nombre d'oiseaux dans les transects de référence que dans les profils sismiques. Les effets étaient importants dans le cas des passériformes regroupés dans la toundra supérieure ainsi que dans le cas du bruant des prés évoluant dans l'habitat de laiche et de saule. Ce dernier effet (qui pourrait être attribuable à l'eau stagnante le long du profil) n'était pas considérable l'année suivante. Le long des anciens profils sismiques, les passériformes se trouvaient en moins grande abondance que dans l'habitat du transect de référence de la toundra supérieure et du polygone à centre concave, sauf dans le cas du bruant lapon de la toundra supérieure. Les profils dont l'existence remonte à 10 à 30 ans sont caractérisés par des changements durables du point de vue de la végétation, et cela semble avoir eu pour effet de diminuer l'abondance d'oiseaux. Même si nous n'avons pas tracé de territoires individuels, nous avons aperçu des oiseaux en train de traverser les profils sismiques, où ils se perchaient même parfois, ce qui laisse entrevoir qu'ils n'évitaient pas les profils. Au lieu, il se peut que ces oiseaux disposent d'un territoire plus grand, ce qui compenserait pour les changements végétatifs dénotés le long des profils.

Mots clés : oiseaux arctiques, exploration sismique, profils sismiques, refuge d'oiseaux de l'île Kendall, mise en valeur pétrolière et gazière

Traduit pour la revue *Arctic* par Nicole Giguère.

[1] Department of Biological Sciences, University of Alberta, Edmonton, Alberta T6G 2E9, Canada
[2] Corresponding author: sue.hannon@ualberta.ca

INTRODUCTION

The Arctic has high faunal species richness (Chernov, 1995), provides critical breeding habitat for many species of migratory birds (Alexander et al., 1988; Chernov, 1995), and recovers slowly from anthropogenic disturbances (Babb and Bliss, 1974; Reynolds and Tenhunen, 1996). Human activities, including petroleum development, are increasing in the Arctic (Walker et al., 1987; Walker and Walker, 1991; Truett et al., 1994; Truett, 2000; Forbes et al., 2001) and may detrimentally affect bird populations (e.g., Barry, 1976; Barry and Spencer, 1976; Troy and Carpenter, 1990). Some developments (e.g., drill pads, airstrips, camps) result in permanent removal of habitat, and other activities, such as seismic exploration, may cause soil compaction and alteration of vegetation, leaving linear features on the landscape (Felix and Raynolds, 1989).

Creation of seismic lines to explore for hydrocarbons began in the Canadian Arctic during the summer of 1965. During the late 1960s, seismic exploration was moved to winter in an attempt to decrease damage to tundra plant communities (Bliss and Wein, 1972). However, studies performed five years (Felix et al., 1992), eight years (Emers et al., 1995), and 20–30 years (Kemper and Macdonald, in press) after winter seismic exploration found that changes in vegetation structure and composition had persisted. Removal of vegetation or alteration of plant communities could affect the distribution and abundance of breeding birds. In addition, if habitat is dissected or fragmented by high densities of seismic lines, populations of bird species that avoid the lines may decline (Bayne et al., 2005). Although the effects of fragmentation by seismic lines have not been studied in the Arctic, densities of ground-nesting birds have been found to decrease with increasing fragmentation in other open habitats such as grasslands (Winter and Faaborg, 1999) and marshes (Benoit and Askins, 2002).

The Kendall Island Bird Sanctuary was established by an Order in Council of the Canadian federal government in 1961 to ensure long-term protection of colonies of breeding lesser snow geese (*Chen caerulescens caerulescens*) on some of the outer islands of the Mackenzie River Delta, Northwest Territories (CWS, 1992). The sanctuary also protects key nesting and staging habitats for 84 other bird species, which include waterfowl, waterbirds, shorebirds, ptarmigan, raptors, and passerines (CWS, 1992). Discoveries of large natural gas fields under the sanctuary have raised concerns about the effects of hydrocarbon development on sensitive tundra ecosystems and the bird populations they support (Dickson, 1992). In this study, we sampled seismic lines, both new (0.5–1.5 years old, created in 2001 and 2002) and old (> 10 years old, created on or before 1992), to determine their short- and long-term effects on bird abundance. The lines were created by a series of vehicles—a survey vehicle, an energy source vehicle, a receiver vehicle, and sometimes a vehicle to house workers—driving in single file along a fixed bearing, producing a linear strip about 6 m wide. On older lines, a blade was used to clear snow, which may have damaged some vegetation; however, this practice was abandoned on newer lines. We assessed whether seismic lines affected breeding birds in three habitat types by comparing bird abundance and distribution along transects centred on seismic lines and along paired reference transects in the same habitat.

A seismic line could affect birds in four ways. (1) Birds could select for habitat on the seismic line. In this case, birds would be more abundant on seismic lines, and their distance from the centre of the line should be shorter than on reference transects. (2) Birds could avoid habitat on the seismic line. Bird abundance would then be lower on seismic lines than on reference transects, and bird distance from the centre of the transect would be higher on seismic than on reference lines. In this case, birds would not have territories that spanned the seismic line. (3) Birds could enlarge their territories to compensate for reduced habitat suitability on the seismic line. Bird abundance would be lower on the seismic transect, distance from the centre of the seismic line transect would be higher on seismic than on reference transects, and bird territories would span the line. (4) Birds could be unaffected by the seismic line. Distance from the centre of the line and abundance would not differ between seismic and reference transects.

METHODS

Study Area

Field research took place in 2002 and 2003 within and adjacent to the 623 km^2 Kendall Island Bird Sanctuary, Northwest Territories (69˚15′ N and 135˚00′ W). Habitat types were described by Jaques (1991) and Gratto-Trevor (1994, 1996) using a classified 1986 LANDSAT Thematic Mapper (TM) image. We sampled three habitats: low-centre polygon, wet sedge/willow, and upland tundra. Low-centre polygon habitat is wetland with a patterned ground structure. The interior of the polygon is wet and dominated by sedges (*Carex* spp.), and its ridges are moist and covered with willows and sedges. Wet sedge/willow (hereafter called sedge/willow) habitat is also wetland, with vegetation similar to low-centre polygon vegetation, but without the patterned ground. It has short to medium willow cover, and wetness varies from moist and muddy to very wet (~50 cm water). Upland tundra habitat is dry, with dwarf shrubs, forbs, and sedge tussocks.

Seismic Line Footprint

Using ArcMap™ GIS, we determined the areas of the land and water in the sanctuary. We created polygon GIS layers for low-centre polygon and upland tundra. Sedge/willow habitat was not uniquely distinguishable from the

TABLE 1. Area, percent of total land area, and length (km) of seismic lines for each terrestrial habitat studied in the Kendall Island Bird Sanctuary, Northwest Territories.

Habitat	Area (km^2)	% of Total Land Area	New Lines (km)	Old Lines (km)	Total km of Visible Lines[1]	km Visible Lines/km^2
Upland tundra	49.3	15%	7.0	121.0	125	2.5
Low-centre polygon	71.6	21%	29.7	319.4	298.3	4.2
Other[2]	214.3	64%	65.5	450.3	440.7	2.1
Total	335.2	100%	102.2	890.7	992.9	2.58

[1] We calculated total km of visible lines using correction factors from Kemper and MacDonald (in press), who used aerial surveys to determine what proportion of the lines in the National Energy Board database was actually visible on the ground.

[2] Other = sedge/willow, dense willow, mudflats, emergents, and polygonal upland tundra combined, as these habitats could not be reliably distinguished from the image.

LANDSAT TM image or an IKONOS image taken in August 2002, and thus we could not create a layer for it. We created a line layer for all old seismic lines using the National Energy Board GIS layer of old seismic lines and superimposed these on the IKONOS image. This step provided the length (km) of old seismic lines on land in each habitat type (Table 1). New lines were created as a layer in ArcMap. These new lines were clearly visible on the IKONOS image and were checked against the map produced by the company that created the seismic lines.

The sanctuary has a total of 993 km of seismic lines, 891 km of old lines created in winter between 1967 and 1992 and 102 km of new lines created during the winters of 2001 and 2002 (Table 1). Density of seismic lines over the land area of the sanctuary is 3 km of lines/km^2, of which 2.58 km/km^2 are visible (Kemper and Macdonald, in press). Density is higher in low-centre polygon habitat than in upland tundra (Table 1). Using a 6 m line width, we calculated an anthropogenic footprint from seismic lines over the entire sanctuary (all habitats) of 1.54%. The seismic footprint is 1.5% within upland tundra and 2.5% within low-centre polygon habitat.

Choice of Sampling Locations

We chose habitats to sample using either the LANDSAT TM or the IKONOS image, and then checked them in the field to verify habitat classification. All new seismic lines on our GIS maps could be located in the field; however, many old lines were not accurately plotted on the map (e.g., 0–~100 m displaced) and hence we had to be able to see them in order to sample them. Thus, we sampled only seismic lines that were visible from the air or the ground and sampled all the lines that we could, provided that they were in the appropriate habitat and had sufficient adjacent similar habitat to fit in a reference transect (see below).

Bird Sampling

We sampled birds on paired transects (a treatment transect centred on the seismic line and a reference belt transect), each 100 m wide (50 m on either side of the centre line) and usually over 500 m long (range 230–750 m). Hanowski et al. (1990) suggested transect lengths of 250 m for sampling moderately common species and 500 m for sampling uncommon species. The reference transect was in the same habitat type and placed parallel to the seismic transect, either to the left or to the right. The direction was chosen randomly, except in cases where there was insufficient habitat in one of the directions. In 2002, the edges of the seismic and reference transects were 50 m apart. Since habitats were open, we could determine whether the same bird flew between reference and seismic transects. Although such flights were rarely observed in 2002, in 2003 we decided to increase the distance apart of transect edges to 100 m to ensure independence between the reference and seismic transects. Although we do not know how large territories were for species in our study area, in other northern areas average territory radii vary from about 30 m to 120 m, e.g., 60 m for savannah sparrow (Wheelwright and Rising, 1993), 74–121 m for Lapland longspur (Hussell and Montgomerie, 2002), and 30–110 m for tree sparrow (Naugler, 1993). Thus, a bird with a territory centred off the midline of the transect, or between the two transects, should be counted on only one transect. Sets of seismic and reference transects were separated by 300 m to ensure independence.

We sampled birds on transects from early June through to the end of the breeding season, after young birds had fledged (early July). Treatment and reference transect pairs were sampled simultaneously to control for potential temporal differences in weather and to avoid double counting of birds. Sampling was not done during heavy rain, fog, snow or strong winds, defined as greater than 4 (20–29 km/hour) on the Beaufort scale. During the survey, observers walked at approximately 1 km/hour and recorded bird species, sex, perpendicular distance (m) from the centre of the transect, and distance from the starting point. Birds flying above were not recorded. Measuring distances for every bird was very time-consuming, so in 2003 we estimated the distance perpendicular to the line for savannah sparrows (the most common bird) and measured it for the rest of the birds. Observers alternated between treatment and control transects to prevent possible observer bias. In 2002, there were four observers, two per transect (one trained in bird identification, one to assist in measuring). In 2003 there were two observers, one per transect (both trained in bird identification). We counted only birds seen within the 50 m strip on either side of the transect line. Single males or females (i.e., not associated with another bird) were counted as one bird, and pairs were counted as one record, so our counts are an estimate of the number of pairs along the transect. If another seismic line crossed the reference or seismic transect, we omitted birds seen within 50 m of that line from the total for the transect.

Over the two summers, we sampled 81 seismic transects totaling 60.5 km (46 transects on new lines in upland tundra, low-centre polygon, and sedge/willow in 2002, and 35 transects on old lines in upland tundra and low-centre polygon in 2003), along with their paired reference transects. All transects were sampled once, except that in 2003 we resampled six new lines in sedge/willow to determine whether effects noted in 2002 had persisted. Total distance (km) surveyed per habitat is found in Table 3. In 2003, we did not have time to sample old lines in the sedge/willow habitat, as we wished to get a large sample size in upland tundra and low-centre polygon habitats. We focused on these two because visual impacts were still apparent in these habitats.

Data Analysis

We analyzed abundance data for reference and seismic transects using a generalized linear mixed-effects model in S-Plus 7.0, with habitat and treatment as fixed effects and transect as a random effect (since reference and seismic transects were paired). We used Poisson-distributed errors if dispersion parameters were close to one; otherwise, we used a quasi-likelihood function (link = log; variance = mu). We analyzed old and new lines separately, as line age was confounded with year. The dependant variable was abundance of each species with sufficient data. For both seismic and reference transects, we compared the distance of individuals of each species from the centre line, using a general linear model in SPSS 15.0, with habitat type and treatment as factors. Species were not analyzed for habitats where they were rarely found.

For all statistical tests, we considered that differences were significant if $p < 0.1$. We used this conservative value of p because sample sizes for some species were small and variation was high, and we wanted to avoid making a type II error (accepting the null hypothesis when it is actually false). This precaution was necessary considering that conservation and management decisions in a federal bird sanctuary might be based, in part, on these results. Conservative p values are often used in conservation and impact assessment research (e.g., Schmiegelow et al., 1997; Irons et al., 2000).

RESULTS

Thirty-one species were observed on transect lines during the surveys. Savannah sparrows and Lapland longspurs were the most common species. Shorebirds were sparsely distributed, with whimbrel (*Numenius phaeopus*) and red-necked phalarope the most common in this group. Measurements on reference transects indicate that birds were more abundant in 2003 than in 2002 (8.92/km in 2003 vs. 7.04 birds/km in 2002). Because of the low abundance in the area of most bird species, we restricted our analyses to the more common passerines (savannah sparrow, Lapland longspur, common redpoll, American tree sparrow) and the red-necked phalarope. We also created a group called "passerines" that included all passerines except savannah sparrows, which were the most common. We did not analyze data for whimbrel because their territories are very large (Dickson et al., 1989) relative to the disturbance of a single line.

Abundance on New Lines

In 2002, abundance of savannah sparrows was highest in sedge/willow, followed by upland tundra, and was lowest in low-centre polygon (Tables 2, 3). A treatment effect was evident only in sedge/willow habitat, where savannah sparrows were more abundant on reference lines than on new seismic lines. A similar trend appeared in 2003 for the six resampled lines, but it was not significant, probably because of the small sample size (Tables 2, 3). Lapland longspurs were abundant enough for analysis only in upland tundra and low-centre polygon habitats, and we found no habitat or treatment effect on this species (Table 2). All passerines combined (excluding savannah sparrow) had higher abundance in upland tundra, and they were more abundant on reference lines than on seismic lines in upland tundra only (Tables 2, 3). Red-necked phalaropes were abundant enough to analyze only in sedge/willow in 2002, and their abundance did not differ significantly between seismic and reference lines (Table 2). Overall, in 7 of 10 comparisons, birds were more abundant on reference transects than on seismic lines, although this difference was statistically significant for only two comparisons (Table 3).

Abundance on Old Lines

Old lines were sampled only in 2003 and only in upland tundra and low-centre polygon habitats. Savannah sparrows, Lapland longspurs, and passerines (excluding savannah sparrow) were more abundant in upland tundra than in low-centre polygon habitat. All three species groups were more abundant on reference transects than on seismic lines in low-centre polygon habitat. Savannah sparrow and passerines also had higher abundances on reference transects in upland tundra (Tables 2, 3). Common redpoll had similar abundance in upland tundra and low-centre polygon habitats, and tree sparrows were found only in upland tundra. Both showed higher abundances on reference transects than on old seismic lines (Tables 2, 3). Thus, except for the Lapland longspurs in upland tundra,

TABLE 2. Statistics from generalized linear mixed-effect models that compare abundance of species by habitat type (upland tundra, low-centre polygon, or sedge meadow) and treatment (seismic line or reference transect). Items in bold were statistically significant at $p < 0.10$.

Species/group	Habitat or Treatment Effects	Beta	SE	df	*p*-value
New lines:					
Savannah sparrow	**habitat**	**-0.96**	**0.56**	**43**	**0.09**
	treatment	0.15	0.33	43	0.65
	habXtrt	**-0.88**	**0.47**	**43**	**0.07**
Savannah sparrow 2003[1]	treatment	-0.34	0.27	6	0.25
Lapland longspur[2]	habitat	-0.10	0.23	29	0.66
	treatment	-0.11	0.17	29	0.52
	habXtrt	0.11	0.17	29	0.52
Passerines	**habitat**	**-0.79**	**0.21**	**43**	**0.0005**
	treatment	**-0.23**	**0.14**	**43**	**0.08**
	habXtrt	-0.05	0.17	43	0.56
Red-necked phalarope[1]	treatment	-0.46	0.31	14	0.16
Old lines[2]:					
Savannah sparrow	**habitat**	**-0.38**	**0.13**	**33**	**0.006**
	treatment	**-0.25**	**0.09**	**33**	**0.01**
	habXtrt	-0.03	0.09	33	0.73
Lapland longspur	**habitat**	**-1.20**	**0.37**	**33**	**0.002**
	treatment	**-0.41**	**0.16**	**33**	**0.013**
	habXtrt	**-0.34**	**0.16**	**33**	**0.04**
Common redpoll	habitat	-0.48	0.35	33	0.17
	treatment	-0.84	0.29	33	0.006
	habXtrt	-0.35	0.29	33	0.22
Tree sparrow[3]	**treatment**	**-0.30**	**0.12**	**20**	**0.02**
Passerines	**habitat**	**-1.08**	**0.23**	**33**	**0.0001**
	treatment	**-0.59**	**0.19**	**33**	**0.005**
	habXtrt	**-0.35**	**0.19**	**33**	**0.08**

[1] Sedge meadow only.
[2] Upland tundra and low-centre polygon only.
[3] Upland tundra only.

abundance of all species was negatively affected by the old seismic lines. In the habitats sampled in 2003, red-necked phalaropes were not abundant enough to analyze.

Distance from the Centre of the Line

The locations with respect to the transect midline of species for which we had sufficient sample sizes did not differ between seismic and reference lines for new or old lines (Table 4). The range of individual distances from the centre of the seismic lines encompassed the width of the line itself (3 m on either side of the centre), as some birds were observed perching on the line. Although we did not plot individual territories, birds were seen crossing the seismic lines, suggesting that their territories spanned the lines.

DISCUSSION

We postulated that birds could be affected by the seismic line in four ways. They could select for habitat on the seismic line, avoid it, enlarge their territories to compensate for reduced habitat suitability on the seismic line, or remain unaffected. We found that no species selected for habitat on old or new seismic lines. Most species or groups appeared to be unaffected by the new lines, with two exceptions. Savannah sparrow abundance was lower on new sedge/willow lines in 2002, and passerines (excluding savannah sparrow) were less abundant on new lines than on reference transects in upland tundra, but not in other habitats. On old seismic lines, in both upland tundra and low-centre polygon habitats, bird abundance was consistently lower than on reference lines, suggesting that birds were either avoiding the old lines or enlarging their territories to encompass more suitable habitats (see below).

New Lines

According to Kemper (2005), who worked in the same study area, alteration to plant structure by new seismic activity was most obvious in upland tundra compared to other habitat types. He found a large decrease in vascular plant cover, more dead shrubs, shorter shrubs, more bare ground, and reduced species richness and diversity of vascular plants. These changes did not appear to affect savannah sparrows or Lapland longspurs; however, passerines as a group (excluding savannah sparrows) had lower abundance on the new seismic lines. Impact of seismic activity on plants was lowest in low-centre polygon habitat (Kemper, 2005) and consistent with this pattern, we found no significant differences in bird abundance between treatment and reference lines in this habitat. However, sample sizes were small because seismic lines were scarce and bird abundance low in that habitat.

TABLE 3. Average number of birds/transect (SE) for reference (R) and seismic (S) transects in three habitats in 2002 and 2003. Items in bold were statistically significant at $p < 0.10$ (see Table 2).

Species	New Lines								Old Lines			
Habitat/year (No. of transects; km surveyed)	Upland tundra 2002 (17; 8.25)		Low-centre polygon 2002 (14; 6.43)		Sedge/willow 2002 (15; 5.98)		Sedge/willow 2003 (6; 4.48)		Upland tundra 2003 (21; 24.4)		Low-centre polygon 2003 (14; 10.98)	
	R	S	R	S	R	S	R	S	R	S	R	S
Savannah sparrow	1.06 (0.23)	1.24 (0.26)	0.43 (0.29)	0.43 (0.23)	**2.07 (0.53)**	**1.00 (0.29)**	1.71 (0.77)	0.86 (0.40)	**4.29 (0.55)**	**2.76 (0.59)**	**2.14 (0.64)**	**1.21 (0.46)**
Lapland longspur	0.82 (0.26)	0.53 (0.21)	0.57 (0.29)	0.57 (0.25)					2.57 (0.63)	2.24 (0.52)	**0.64 (0.36)**	**0.14 (0.10)**
Common redpoll									**1.00 (0.31)**	**0.38 (0.16)**	**0.79 (0.35)**	**0.07 (0.07)**
Tree sparrow									**2.29 (0.25)**	**1.24 (0.48)**		
Passerines	**2.18 (0.39)**	**1.35 (0.31)**	0.93 (0.40)	0.71 (0.27)	0.53 (0.27)	0.27 (0.12)			**6.38 (0.92)**	**3.9 (0.93)**	**1.43 (0.57)**	**0.21 (0.11)**
Red-necked phalarope					0.67 (0.39)	0.27 (0.15)						

TABLE 4. Distance (m) of birds from the centre of the transect line on new or old seismic lines and reference transects[1] (n = number of birds; UT = upland tundra, LCP = low-centre polygon, SW = sedge/willow). Categories with very low sample sizes were omitted.

Habitat type	Age/year	Species	Seismic lines			Reference lines		
			Mean	Range	n	Mean	Range	n
UT	New 2002	savannah sparrow	20.3	0–50	19	16.4	0–43	20
		Lapland longspur	32.8	12–50	11	26.1	4–50	14
		tree sparrow	24.0	3–46	9	23.2	1–43	15
	Old 2003	savannah sparrow	20.9	0–50	65	20.5	0–50	103
		Lapland longspur	23.2	0–50	54	24.2	0–50	73
		common redpoll	16.9	2–32	8	21.3	3–50	21
		tree sparrow	22.5	0–50	29	26.7	0–50	53
LCP	Old 2003	savannah sparrow	23.9	0–50	20	18.7	0–50	37
SW	New 2002	savannah sparrow	19.7	0–48	20	20.2	0–49	37

[1] Model statistics from ANOVA with treatment and habitat as factors: savannah sparrow ($F_{7,313} = 1.22$, $p = 0.30$); Lapland longspur ($F_{3,148} = 0.72$, $p = 0.39$); tree sparrow ($F_{3,102} = 0.49$, $p = 0.68$); common redpoll ($F_{1,27} = 0.62$, $p = 0.44$).

Abundance of savannah sparrows was lower on new lines in sedge/willow than on reference lines in 2002. The following year, the trend again was for more sparrows on reference transects than on seismic lines; however, the abundance of sparrows was lower on both reference and seismic lines, and the difference was not significant. New seismic lines in this habitat have lower total vascular plant cover, shrubs, sedges, and horsetails (*Equisetum* spp.), as well as an increase in water, which are probably due to soil compaction by vehicles (Felix and Raynolds, 1989; Kemper, 2005). Many of these lines had standing water on them during the 2002 breeding season, making them unsuitable for nesting.

Old Lines

Old seismic lines appeared to have a much larger impact than new lines on bird abundance. All of the species analyzed showed lower abundance on old seismic lines compared to reference transects in either upland tundra or low-centre polygon habitat, or both. Reduction in bird abundance along old seismic lines is probably related to changes in vegetation. Working in our study area, Kemper (2005) measured soil characteristics and vegetation composition and structure along seismic lines 18 to 33 years old and adjacent reference areas. In upland tundra, seismic lines had more bare ground and deciduous shrubs (especially *Betula glandulosa*, *Alnus crispa*, and *Salix* spp.) and less moss and lichen than reference areas. These differences in vegetation structure made old seismic lines easy to see from the air (Kemper, 2005). In similar habitat in Alaska, Felix and Raynolds (1989) found that tussocks and shrubs were shorter and more damaged on seismic lines. The larger amount of bare ground and greater density of deciduous shrubs on old lines may have made these habitats less suitable for species that nest on the ground or in more open grassy or hummocky areas, such as the savannah sparrow (Wheelwright and Rising, 1993) and tree sparrow (Naugler, 1993).

In low-centre polygon habitat, all of the passerine species we tested had lower abundance along old seismic lines. Unfortunately, Kemper (2005) did not measure vegetation on old lines in low-centre polygon habitat. However, old seismic lines in sedge-dominated habitats, such as low-centre polygon, have denser vegetation cover than reference habitat (Emers et al., 1995). This density is due to the compression of sedges by seismic equipment, which results in a nutrient flush and subsequent increase in plant productivity (Chapin and Shaver, 1981; Emers et al., 1995). Birds may avoid dense vegetation for nesting and foraging, as it may be more difficult for them to detect predators. In addition, Kevan et al. (1995) noted a decrease in arthropod abundance on tundra where tracked vehicles had passed, suggesting that food supply could be reduced on these old lines.

The distances of birds from the line centre did not differ significantly between reference transects and old seismic lines. This result was inconsistent with our prediction if birds were avoiding lines or enlarging their territories to compensate for reduced habitat suitability along the line. Since birds were often seen crossing the lines and since some were observed perched on the line, it does not appear that they are avoiding the seismic lines altogether. We suggest that birds may have enlarged their territories in areas where seismic lines passed through. For a bird with a territorial radius of 30–110 m, a 6 m wide swath of seismic line would encompass between 3.5% and 13% of the territory, assuming a round territory with the line passing through the middle.

Do Seismic Lines Affect Bird Abundance?

The Canadian Wildlife Service defines a "natural state" as that combination of flora and fauna at a particular site that is similar to that which existed prior to oil and gas industrial activities (CWS, 2004). A "long-term impact" is the alteration, disruption, removal, covering, or degradation of wildlife habitat that is not restored to its natural state, through natural processes or human assistance, within three years. A "temporary impact" is defined as the alteration, disruption, removal, covering or degradation of wildlife habitat that may be restored to its natural state through natural processes or human assistance within three years. In combination, our results and those of Kemper (2005) indicate that old lines have a long-term impact. New lines have affected vegetation structure and composition, but these changes have not had statistically significant measurable effects on bird abundance in the short term. Old lines may have more of an impact because they were created using different techniques than new lines, or it is possible that alterations to vegetation communities take a long time to develop. Since the trajectory of vegetation change and recovery on these disturbed sites is unknown, longer-term studies are required to monitor bird abundance and recovery in vegetation communities on new lines.

As of 2003, visible seismic lines covered 1.54% of the land area in the sanctuary: 1.5% of upland tundra and 2.5% of low-centre polygon. The majority of these were old lines (Table 1), which, as we have demonstrated, caused a decrease in bird abundance. While this study focused on impacts of seismic lines, other alterations of habitat have occurred and are proposed to occur in the sanctuary as part of oil and gas development, such as the creation of drill pads, landing strips, pipelines, and additional seismic lines. Thus managers should carefully consider the cumulative effects of oil and gas development, particularly in low-centre polygon habitat, which already has the highest proportion of disturbance and is important habitat for shorebirds (Gratto-Trevor, 1996).

Caveats and Future Research

Seismic lines that were sampled had to be visible to ensure that the sampling transect was on a seismic line. There may be some seismic lines in the sanctuary that have recovered and are no longer visible. We corrected for this possibility in our calculation of the footprint using visibility factors developed by Kemper and MacDonald (in press). However, there may be additional seismic lines in the sanctuary that were not on the maps we had, and thus our calculation of the seismic footprint may be an underestimate.

Although we found an impact of old lines on bird abundance, we did not demonstrate that this affected the total population of birds in the sanctuary. An extrapolation of the effects on the lines we sampled to the population of birds in the sanctuary would have to assume that the habitat is saturated with birds and that reductions in birds along seismic lines would not be compensated for in areas of the sanctuary that were not affected by seismic activity. Since so little work has been done on population dynamics of Arctic birds, we cannot address this caveat.

Abundances for most of the species that we used in the analysis were low and spatially variable. Hence, our power to detect statistical differences was often low, and we may have underestimated the impact of seismic lines on bird abundance, particularly for new lines. We do note, however, that the overall pattern in most of our comparisons was for birds to be more abundant on reference transects than on seismic lines, suggesting that further work with larger samples sizes, perhaps outside the sanctuary, should be done. Furthermore, a number of species, in particular shorebirds, were not abundant enough for statistical analysis. A larger sample size may aid in assessing how other species react to seismic lines.

ACKNOWLEDGEMENTS

The Canadian Wildlife Service, Wildlife Habitat Canada, the Anadarko Petroleum Corporation, and the Canadian Association of

Petroleum Producers provided funding for this project. Additional funding came from a Northern Scientific Training Project grant, a Circumpolar/Boreal Alberta Research Grant, a Natural Sciences and Engineering Research Council of Canada Industrial Scholarship, and a Walter H. Johns Graduate Fellowship, all awarded to Amber Ashenhurst. The Polar Continental Shelf Project provided logistical support. Assistance in the field was provided by D. Klein, R. Reeves, and T. Kemper. We thank P. Latour, C. Machtans, E. MacDonald, P. McLoughlin, and C. Paszkowski for input on study design or manuscript preparation.

REFERENCES

ALEXANDER, S.A., BARRY, T.W., DICKSON, D.L., PRUS, H.D., and SMYTH, K.E. 1988. Key areas for birds in coastal regions of the Canadian Beaufort Sea. Edmonton, Alberta: Canadian Wildlife Service.

BABB, T.A., and BLISS, L.C. 1974. Effects of physical disturbance of Arctic vegetation in the Queen Elizabeth Islands. Journal of Applied Ecology 11:549–562.

BARRY S.J. 1976. Birdlife response to oil well drilling, during operations and five years later. Edmonton, Alberta: Hyperborean Services.

BARRY, T.W., and SPENCER, R. 1976. Wildlife response to oil drilling. Edmonton, Alberta: Canadian Wildlife Service.

BAYNE, E.M., VAN WILENBURG, S.L., BOUTIN, S., and HOBSON, K.A. 2005. Modeling and field-testing of ovenbird (*Seiurus aurocapillus*) responses to boreal forest dissection by energy sector development at multiple spatial scales. Landscape Ecology 20:203–216.

BENOIT, L.K., and ASKINS, R.A. 2002. Relationship between habitat area and the distribution of tidal marsh birds. Wilson Bulletin 114:314–323.

BLISS, L.C., and WEIN, R.W. 1972. Plant community response to disturbances in the western Canadian Arctic. Canadian Journal of Botany 50:1097–1109.

CWS (CANADIAN WILDLIFE SERVICE). 1992. Management of migratory bird sanctuaries in the Inuvialuit Settlement Region, Anderson River Delta Sanctuary, Banks Island Bird Sanctuary No.1, Banks Island Bird Sanctuary No. 2, Cape Parry Bird Sanctuary, Kendall Island Bird Sanctuary. Yellowknife, Northwest Territories: Environment Canada.

———. 2004. A management agreement for the Kendall Island Migratory Bird Sanctuary. Yellowknife, Northwest Territories: Environment Canada.

CHAPIN, F.S., and SHAVER, G.R. 1981. Changes in soil properties and vegetation following disturbances of Alaskan Arctic tundra. Journal of Applied Ecology 18:605–617.

CHERNOV, Y.I. 1995. Diversity of the Arctic terrestrial fauna. In: Chapin, F.S., III, and Körner, C., eds. Arctic and alpine diversity. Berlin: Springer-Verlag. 81–96.

DICKSON, D.L. 1992. The red-throated loon as an indicator of environmental quality. Edmonton, Alberta: Canadian Wildlife Service, Environment Canada.

DICKSON, H.L., JAQUES, D., BARRY, S., TELFER, E.S., and SMITH, A.R. 1989. Identification of nesting and staging shorebirds areas in the Mackenzie River Delta and Richards Island area, Northwest Territories, using LANDSAT thematic mapper imagery, 1985–1987. NOGAP project C7.3. Edmonton, Alberta: Canadian Wildlife Service.

EMERS, M., JORGENSON, J.C., and REYNOLDS, M.K. 1995. Response of Arctic tundra plant communities to winter vehicle disturbance. Canadian Journal of Botany 73:906–917.

FELIX, N.A., and RAYNOLDS, M.K. 1989. The effects of winter seismic trails on tundra vegetation in northeastern Alaska, U.S.A. Arctic and Alpine Research 21:188–202.

FELIX, N.A., RAYNOLDS, M.K., JORGENSON, J.C., and DUBOIS, K.E. 1992. Resistance and resilience of tundra plant communities to disturbance by winter seismic vehicles. Arctic and Alpine Research 24:69–77.

FORBES, B.C., EBERSOLE, J.J., and STRANDBERG, B. 2001. Anthropogenic disturbance and patch dynamics in circumpolar Arctic ecosystems. Conservation Biology 15:954–969.

GRATTO-TREVOR, C.L. 1994. Use of Landsat TM imagery in determining important shorebird habitat in the outer Mackenzie Delta, NWT (NOGAP subproject C.24). Saskatoon, Saskatchewan: Canadian Wildlife Service, Environment Canada.

———. 1996. Use of Landsat TM imagery in determining important shorebird habitat in the outer Mackenzie Delta, Northwest Territories. Arctic 49(1):11–22.

HANOWSKI, J.M., NIEMI, G.J., and BLAKE, J.G. 1990. Statistical perspectives and experimental design when counting birds on line transects. Condor 92:326–335.

HUSSELL, D.J.T., and MONTGOMERIE, R. 2002. Lapland longspur. In: Poole, A., and Gill, F., eds. The birds of North America, No. 656. Philadelphia, Pennsylvania: Academy of Natural Sciences and Washington, D.C.: American Ornithologists' Union. http://bna.birds.cornell.edu/BNA/.

IRONS, D.B., KENDALL, S.J., ERICKSON, W.P., McDONALD, L.L., and LANCE, B.K. 2000. Nine years after the Exxon Valdez oil spill: Effects on marine bird populations in Prince William Sound, Alaska. Condor 102:723–737.

JAQUES, D. 1991. LANDSAT Thematic Mapper Imagery for mapping vegetation of the outer Mackenzie Delta, Northwest Territories, Canada. Unpubl. report prepared by Ecosat Geobotanical Surveys, Inc., North Vancouver, British Columbia. Available from the Canadian Wildlife Service, 4999 –98 Avenue, Edmonton, Alberta T6B 2X3.

KEMPER, J.T. 2005. Effects of winter seismic exploration on plant communities of the Kendall Island Migratory Bird Sanctuary, NWT, Canada. PhD dissertation, University of Alberta, Edmonton, Alberta.

KEMPER, J.T., and MacDONALD, S.E. In press. Directional change in low-arctic upland and tundra plant communities 20–30 years following seismic exploration. Journal of Vegetation Science.

KEVAN, P.G., FORBES, B.C., KEVAN, S.M., and BEHAN-PELLETIER, V. 1995. Vehicle tracks in High Arctic tundra: Their effects on the soil, vegetation, and soil arthropods. Journal of Applied Ecology 32:655–667.

NAUGLER, C.T. 1993. American tree sparrow. In: Poole, A., and Gill, F., eds. The birds of North America, No. 37. Philadelphia, Pennsylvania: Academy of Natural Sciences and Washington, D.C.: American Ornithologists' Union. http://bna.birds.cornell.edu/BNA/.

REYNOLDS, J.F., and TENHUNEN, J.D. 1996. Ecosystem response, resistance, resilience and recovery in Arctic landscapes: Introduction. In: Reynolds, J.F., and Tenhunen, J.D., eds. Landscape function and disturbance in Arctic tundra. Berlin: Springer-Verlag. 3–18.

SCHMIEGELOW, F.K.A., MACHTANS, C.S., and HANNON, S.J. 1997. Are boreal birds resilient to fragmentation? An experimental study of short-term community responses. Ecology 78:1914–1932.

TROY, D.M., and CARPENTER, T.A. 1990. The fate of birds displaced by the Prudhoe Bay oil field: The distribution of nesting birds before and after P-pad construction. Report to BP Exploration (Alaska) by Troy Ecological Research Associates, 2322 E 16 Avenue, Anchorage, Alaska 99508-2905.

TRUETT, J.C. 2000. Introduction. In: Truett, J.C., and Johnson, S.R., eds. The natural history of an Arctic oilfield. San Diego, California: Academic Press. 3–13.

TRUETT, J.C., SENNER, R.G.B., KERTELL, K., RODRIGUES, R., and POLLARD, R.H. 1994. Wildlife responses to small-scale disturbances in Arctic tundra. Wildlife Society Bulletin 22:317–324.

WALKER, D.A., and WALKER, M.D. 1991. History and pattern of disturbance in Alaskan Arctic terrestrial ecosystems: A hierarchical approach to analyzing landscape change. Journal of Applied Ecology 28:244–276.

WALKER, D.A., WEBBER, P.J., BINNIAN, E.F., EVERETT, K.R., LEDERER, N.D., NORDSTRAND, E.A., and WALKER, M.D. 1987. Cumulative impacts of oil fields on northern Alaskan landscapes. Science 238:757–761.

WHEELWRIGHT, N.T., and RISING, J.D. 1993. Savannah sparrow. In: Poole, A., and Gill, F., eds. The birds of North America, No. 45. Philadelphia, Pennsylvania: Academy of Natural Sciences and Washington, D.C.: American Ornithologists' Union. http://bna.birds.cornell.edu/BNA/.

WINTER, M., and FAABORG, J. 1999. Patterns of area sensitivity in grassland-nesting birds. Conservation Biology 13: 1424–1436.