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J. Todd Kemper

For:

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444-7th Ave S.W.
Calgary, Alberta
T2P 0X8

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Executive Summary

Plant communities on seismic lines were surveyed and compared to those of adjacent undisturbed sites. Two periods of seismic exploration were examined: 2000-2001 (recent operations) and 1970-1986 (historic operations).

Recent seismic lines differed from undisturbed tundra in that vascular plant cover was significantly reduced on seismic lines in all community types sampled. In upland vegetation types depth to permafrost was greater on seismic lines than at undisturbed sites. Plant community composition on seismic lines in upland tundra was also different than in undisturbed communities. Overall, impacts were greatest in upland vegetation types, where they appeared to be larger than those documented elsewhere in the literature. In lowland communities on the other hand, the only considerable effects were decreases in total plant cover along seismic lines. Recent seismic operations in lowland vegetation types did not appear to lead to changes in thaw depth or plant community composition, at least in the short term.

Historic seismic lines (those from 1970-1986) were sampled only in upland tundra communities. Plant communities along these seismic lines differed from adjacent undisturbed sites in that they generally had greater total cover of vascular plants, denser cover of deciduous shrubs, and lower cover of lichens. The denser growth of deciduous shrubs on historic seismic lines in upland terrain indicates altered productivity (increased biomass) at these sites.

Results obtained from historic seismic lines should not be used to estimate the recovery of upland vegetation subjected to current seismic operations. Because of operational differences between historic and modern seismic programs these results are more useful for assessing the potential for tundra vegetation to recover from varying levels of disturbance over time than they are for predicting the structure of future plant communities.

The management implications of these findings depend on decisions that reflect conservation and management priorities. If the goal of management in the region is to limit human-caused changes in vegetation structure there are implications for both recent and older seismic programs. If management priorities are to preserve landscape function and prevent change to wildlife communities or wildlife behavior, the ramifications are somewhat less clear. The focus of planning and conservation efforts related to seismic operations should be directed toward consideration of the longer-term accumulation of impacts, and subsequent cumulative effects.

The following recommendations are based on this research, as well as a review of available literature. They are intended to provide for a continued reduction in impacts from future seismic operations, and to assist further development of guidelines, technologies, and techniques that aim to minimize disturbance to tundra vegetation.

These recommendations are:

1. Create a public, shared, database containing the precise locations and details of seismic operations in the ISR that could be used for cumulative effects monitoring, as well as to guide future research and planning.

2. Increase the minimum allowable snow depth required prior to authorization of off road vehicle travel from 20 to 25cm.

3. Limit the number of vehicles traversing seismic lines to the absolute minimum number required to carry out geophysical surveys safely and effectively.

4. Incorporate available technologies, designed to reduce impacts to tundra, into all future seismic programs. Variation between programs in the types of implements used in this aim could form the basis of future comparative studies.

5. Implement research and monitoring programs, specifically designed to better determine the mechanisms by which seismic operations impact tundra terrain; in so doing, develop operational or technological tools that can further reduce winter seismic impacts.

Résumé

Les communautés végétales établies le long des lignes sismiques ont été étudiées et comparées à celles de sites non perturbés adjacents. Deux périodes de prospection sismique ont été examinées : la période 2000-2001 (programmes récents) et la période 1970-1986 (anciens programmes).

Dans le cas des lignes sismiques récentes, les zones de toundra perturbées différaient des zones non perturbées en cela que le couvert de plantes vasculaires était considérablement réduit le long des lignes sismiques pour tous les types de communautés échantillonnés. Dans la toundra des hautes terres, le pergélisol survenait à une plus grande profondeur le long des lignes sismiques que dans les sites non perturbés. De plus, la composition des communautés végétales le long des lignes sismiques présentait des différences par rapport aux communautés non perturbées. Dans l'ensemble, les travaux de prospection sismique ont eu le plus d'impact sur la végétation des hautes terres, et cet impact semble être plus marqué que celui qui est relevé dans d'autres études. Par ailleurs, dans les communautés des basses terres, les seuls effets notables consistaient en une diminution du couvert végétal total le long des lignes sismiques. Les travaux sismiques récents menés dans des zones de basses terres ne semblaient pas avoir entraîné de changements quant à la profondeur de dégel ou à la composition des communautés végétales, du moins à court terme.

Les lignes sismiques des anciens programmes (période de 1970-1986) n'ont été échantillonnées que dans les zones de toundra des hautes terres. Les communautés végétales situées le long des anciennes lignes sismiques présentaient plusieurs différences par rapport à celles de sites non perturbés adjacents. D'une manière générale, les sites perturbés présentaient un plus grand couvert total de plantes vasculaires, un couvert plus dense d'arbustes à feuilles caduques et un couvert réduit de lichens. La densité supérieure des arbustes à feuilles caduques le long des lignes sismiques plus anciennes est une indication que la productivité des sites en question a été modifiée. Cependant, on se gardera d'utiliser les constatations concernant les lignes sismiques anciennes pour estimer le rétablissement des communautés végétales dans les zones de hautes terres touchées par les travaux sismiques actuels. En effet, en raison des différences d'ordre opérationnel entre les programmes de prospection sismique modernes et les anciens programmes, ces résultats sont plus utiles pour évaluer le potentiel de rétablissement de la végétation de la toundra perturbée au cours des périodes en question, plutôt que pour prédire la structure des communautés végétales futures.

Sur le plan de la gestion, les conclusions qui précèdent comportent des conséquences différentes selon les priorités de conservation et de gestion qui sous-tendent les décisions de gestion. Si l'objectif de gestion dans la région consiste à limiter les changements causés par l'activité humaine à la structure de la végétation, cela a des conséquences autant pour les programmes sismiques récents que pour les plus anciens. Si les priorités de gestion consistent à préserver la fonction du paysage et à prévenir la modification des communautés animales ou du comportement de la faune, les solutions sont moins évidentes. Les efforts de planification et de conservation associés aux études sismiques

devraient s'intéresser à l'accumulation à long terme des incidences de la prospection sismique, et aux effets cumulatifs qui en résultent.

Les recommandations qui suivent visent à promouvoir une réduction continue de l'incidence des travaux sismiques futurs et à guider l'élaboration de lignes directrices, de technologies et de techniques qui contribueront à réduire au minimum la perturbation de la végétation des toundras.

1. Créer une base de données publique partagée répertoriant les emplacements précis et les détails des études sismiques effectuées dans la région désignée des Inuvialuit, qui pourra être utilisée pour suivre les effets cumulatifs et pour guider les futurs travaux de recherche et de planification.

2. Accroître la profondeur de neige minimale requise pour autoriser le passage de véhicules hors route, en la faisant passer de 20 cm à 25 cm.

3. Limiter le nombre de véhicules circulant sur les lignes sismiques à celui qui est strictement nécessaire pour mener les relevés géophysiques de manière efficace et en toute sécurité.

4. Incorporer les technologies connues, conçues pour réduire l'impact sur la toundra, dans tous les futurs programmes de prospection sismique. Les différences entre les types d'instruments utilisés à cette fin dans les divers programmes pourraient être l'objet d'études futures.

5. Exécuter des programmes de recherche et de suivi conçus expressément pour cerner les mécanismes par lesquels les travaux de prospection sismique influent sur le terrain de la toundra et, ce faisant, mettre au point des outils technologiques et opérationnels qui réduiront encore davantage les effets des études sismiques réalisées pendant l'hiver.

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Disclaimer

This report summarizes some of the key findings of a graduate research project conducted in 2002-2003. Some of the details of this research, including the delineation of plant communities, statistical treatments, full findings, and detailed discussions are beyond the scope of this report and are not included here. These are available in the full copy of the M.Sc. thesis (Kemper 2005). The author does not assume responsibility for the implementation of recommendations made herein.

1. Introduction

1.1 Seismic Exploration in the Western Arctic

Oil and gas exploration has been conducted in the Alaskan arctic since 1944, and in the Mackenzie Delta area since 1965. Early seismic programs borrowed techniques and equipment from similar programs in the south and were conducted primarily during the summer thaw period. By nature, seismic programs involve the passage of tracked and/or wheeled vehicles over tundra terrain, followed by transmission of energy (from vibration or dynamite) into the ground. Early (summer) seismic programs in Alaska, and on the Tuktoyaktuk peninsula, caused extensive damage to vegetation and permafrost that remain visible today (NRC 2003; and Hernandez 1973, respectively). In the early 1970s the exploration period was shifted to winter months, when snow cover and frozen ground provide a level of protection for tundra plant communities (Bliss and Wein 1972; Webber and Ives 1978). By preventing vehicle travel during the summer thaw period, much of the impact that was previously seen was avoided in later programs.

1.2 Impacts of Seismic Operations

Since the shift to winter seismic operations there has been a widely held belief that seismic impacts to tundra terrain are negligible, or primarily aesthetic in nature (e.g. Walker *et al* 1987) with little ecological implication. A suite of investigations that tracked the effects of a single exploration program in the Arctic National Wildlife Refuge from 1984 to present, however, have cast some doubt on this assertion. Collectively, these studies (Felix and Raynolds 1989a; Raynolds and Felix 1989; Felix *et al* 1992; Emers *et al* 1995; Emers and Jorgenson 1997) suggested that the effects of winter seismic exploration on tundra vegetation are highly variable, but are generally of greater magnitude, and longer lasting, than was previously considered.

Although individually small, the accumulation of seismic lines across the landscape, both spatially and temporally, could potentially affect a substantial area of tundra. The focus of environmental research into oil and gas activities in the arctic is now largely related to concern for these types of cumulative effects (Walker 1996). By their nature, seismic programs present several potential sources of disturbance to tundra ecosystems, including:

- linear disturbances caused by off-road vehicle travel,
- point disturbances where energy charges are transmitted into the ground,
- disturbances from camp and equipment staging areas, and
- accidental fuel or greywater spills

Of these, the disturbances caused by off-road vehicle travel cover the largest extent of ground and are the most visible evidence of seismic operations. The focus of this report is limited to these linear disturbances. The reader should bear in mind, however, that other types of impacts might occur due to seismic operations.

2. Research Objectives

The purpose of this research was to identify and describe the statistically significant effects of winter seismic programs on the vegetation of the outer Mackenzie Delta area. The scope of this study was limited to two dimensional (2D) seismic programs and by design did not include any three dimensional programs, which may have different effects than 2D operations because of fewer passes of vehicles per line (In 3D seismic operations source and receiver lines are perpendicular to one another, whereas in 2D seismic source and receiver lines are shared).

Because scientific research regarding oil and gas exploration impacts in the western arctic has followed cycles of exploration activity, the most recent scientific accounts of seismic impacts are twenty to thirty years dated and do not necessarily reflect current practices. Modern winter seismic programs differ from those conducted in previous waves of exploration (1970s – 1980s) in several ways including: the types of vehicles used, the primary energy source used (vibration vs. dynamite), the operational procedures (clearing trails vs. 'walking down' vegetation), and the nature of camps (fixed vs. mobile). In general there has been a trend towards increasing environmental scrutiny, and continued development of tools and techniques designed to minimize impacts. Contemporary seismic operations, therefore, are sufficiently different to warrant a re-investigation of their short-term (<3 years) effects. Further, because a subset of seismic lines in this region was studied during the previous wave of exploration (e.g. Bliss and Wein 1972; Hernandez 1973) the longer-term impacts of earlier exploration activity in this region can be assessed, and tentatively compared to observations made in the initial years following more recent disturbance.

Information regarding the effects of modern seismic exploration activities is required to properly understand and mitigate any adverse impacts associated with these activities. The objective of this research, therefore, was to provide information on the short-term effects of current winter seismic exploration practices on tundra vegetation, as well as the longer-term impacts associated with earlier exploration practices.

3. Study Area

3.1 Physiographic Setting

The study area for this project was centered on the Kendall Island Bird Sanctuary (KIBS) and spanned portions of both the outer Mackenzie Delta and Richards Island, from approximately 69°00' to 69°24'N latitude and 135°35' to 134°05'W longitude (Fig. 1). The study area is bordered by the Beaufort Sea to the north and lies entirely within Canada's Southern Arctic ecozone (Wiken 1986). Although small, the study area is geologically diverse and includes portions of the Mackenzie Delta and Tuktoyaktuk Coastlands physiographic divisions of the Arctic Coastal Plain (Rampton 1988). In total the study area comprises three distinct geological settings: the active Mackenzie Delta, the Big Lake Delta Plain, and the Tununuk Low Hills. The Tununuk Low Hills are upland areas situated on Pleistocene deposits, characterized by rolling hills and a relatively high abundance of periglacial features – thaw lakes, drained lakes, pingos, and patterned ground. The Mackenzie Delta and Big Lake Delta Plain are low-lying, alluvial areas dominated by wetlands with limited topography and relatively saturated soils. The Big Lake Delta Plain differs somewhat from the active Mackenzie Delta in that it is an area of Pleistocene deposits that have since been eroded by a north-eastwardly extension of the modern Mackenzie River. It is composed of thinner sediments than those of the true Mackenzie Delta (Rampton 1988), and also has a greater ground ice volume (expressed as patterned ground) than the true delta (Mackay 1963).

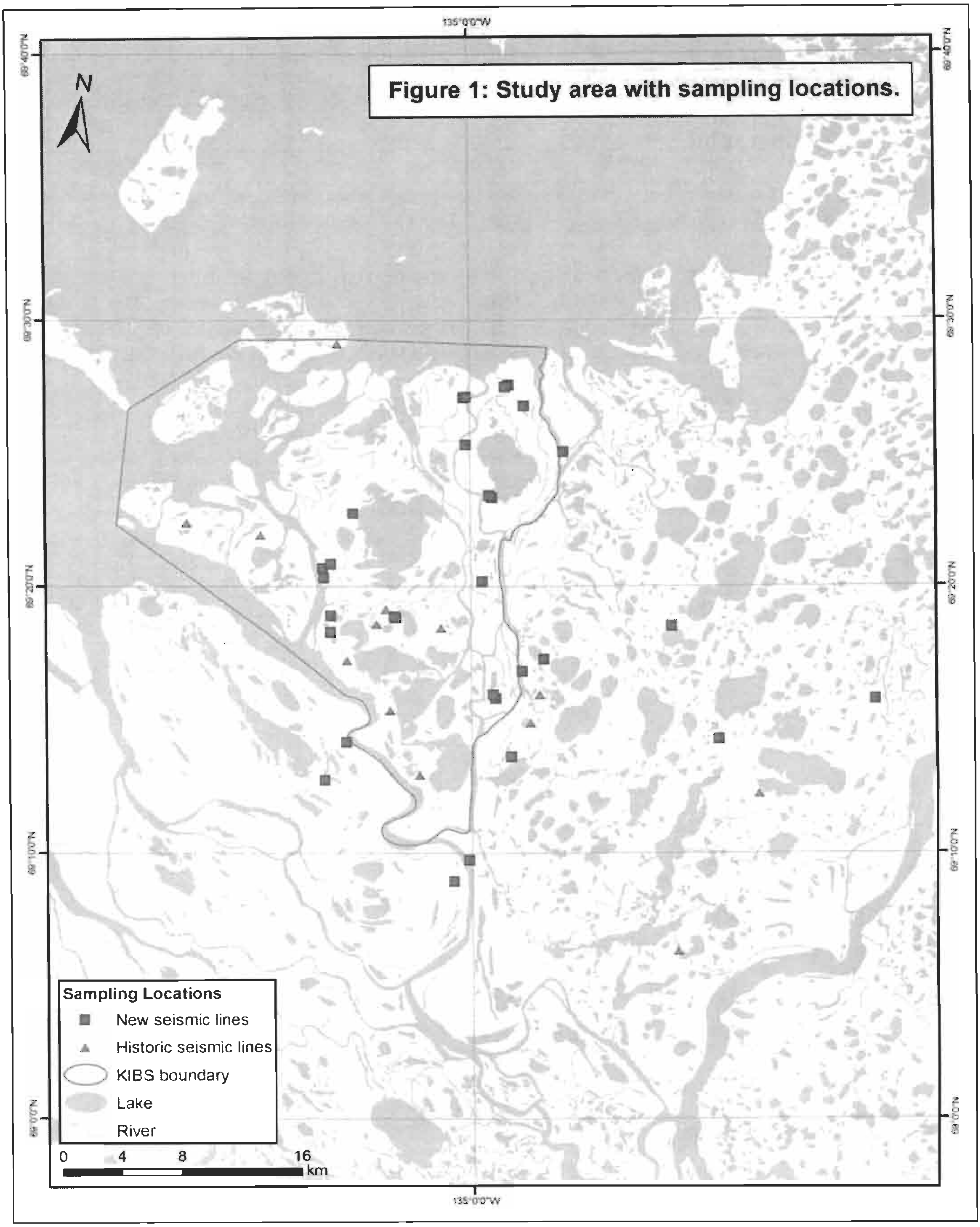
Figure 1: Study area with sampling locations.

3.2 Permafrost

The study area lies within the zone of continuous permafrost. All terrestrial plant communities are underlain by permafrost with the possible exception of some riparian communities potentially occurring over taliks that have formed beneath lakes and river channels and extend beyond the shoreline. Permafrost depth is greatest on Richards Island and lowest in the Mackenzie Delta where the warming influence of surface water pervades. The Tununuk Low Hills have extensive ground ice (Rampton 1988), as is evidenced by thermokarst lakes, pingos, and patterned ground. Ground ice is also common in the Big Lake Delta Plain, where it is expressed as lowland polygon fen complexes.

The presence, extent, and volume of ground ice are important determinants of disturbance response (Lawson 1986; Walker and Walker 1991). Disturbances that cause sufficient thawing of ground ice can cause unintended slope failure or thermokarst initiation, processes which are essentially irreversible.

3.3 Plant Communities

Plant communities of the study area are typical of low-arctic conditions. The study area lies just north of the latitudinal treeline, and represents the two warmest bioclimatic zones (Zone D and E) of the arctic regions (CAVM Team 2003). The latitudinal climatic gradient, however, is steep, particularly towards the coast where the cooling influence of the Beaufort Sea is prevalent. Dwarf shrubs, heaths, and a variety of forbs dominate the plant communities of upland areas, while lowland areas are dominated by hydrophilic graminoid and willow species. Four distinct plant community types were identified in the study area:

- **Low Shrub – Heath (LSH)**, an upland community type of somewhat cooler microclimates than the MSH, often with high cover of willows, typified by white avens *(Dryas integrifolia)*, and blueberries (*Vaccinium uliginosum*). Maximum shrub height is less than in the Medium Shrub – Heath (typically <1m)
- **Medium Shrub – Heath (MSH)**, an upland community type of warmer microclimates typified by green alder (*Alnus crispa*), dwarf birch (*Betula glandulosa*), *Ledum decumbens*, and mountain cranberry (*Vaccinium vitis-idaea*)
- **Tall Shrub – Herb (TSH)**, a wetland/riparian community type, primarily of riparian areas, typified by an often tall (>1.5m) canopy of willows (*Salix lanata* ssp *richardsonii* and *Salix alaxensis*) with horsetails (*Equisetum* ssp.) and water sedge (*Carex aquatilis*) dominating the herbaceous layer
- **Wet Graminoid (WG)**, a wetland/riparian community type dominated by narrow leaved cotton-grass (*Eriophorum angustifolium*) and water sedge (*Carex aquatilis*); a variety of grasses (*Dupontia fisherii*, *Arctophila fulva*) and willows (*Salix arctica*, *Salix arctophila*) also occur commonly in this vegetation type.

These plant community types (also referred to herein as vegetation types) follow the classification found in Kemper (2005), and are partially adapted from those of Corns (1974).

4. Methods

Differences in vegetation characteristics between seismic lines and undisturbed communities were quantified through statistical comparisons between observations made on seismic lines and in adjacent, undisturbed, plant communities. Sampling took place during the active growing season (~July 1 – August 10) in 2002 and 2003. Observations were made at 28 sites (178 quadrats) on seismic lines from 2000-2001 (recent seismic), and 13 sites (68 quadrats) on seismic lines from 1970-1986 (historic seismic). Following an initial examination of data collected in 2002 a decision was made to limit sampling on older seismic lines in 2003 to upland terrain only. This decision stemmed from; 1) operational costs that precluded the possibility of attaining adequate sample sizes within both groups with the available funds, and 2) observations made in the field during 2002, along with an initial evaluation of the data, suggesting that a greater proportion of seismic lines were visible in upland than in lowland habitats.

Sites were initially chosen in a stratified random design to represent an approximately equal representation of seismic programs and habitat types. Sites selection was also limited to seismic lines that could be visibly detected from the air; this encompassed 100% of seismic lines from 2000-2001. It was, however, a potential source of bias for seismic lines from the historic period. In order to minimize such bias a great deal of effort was undertaken to survey seismic lines that were scarcely discernable, even from the air. This often involved ground crews marking seismic lines on the ground while communicating with a hovering helicopter that could identify the margins of a seismic line from altitude. In addition, aerial surveys were performed in July and August 2003 to determine the proportion of all historic seismic lines that were visible to some degree on the landscape, and thus the potential for bias to have been introduced due to the necessity of sampling known (i.e., visible) disturbances. These surveys indicated that more than 90% of randomly chosen seismic line segments in upland terrain (selected from an NEB database) could be located from the air when searched for (Kemper, unpublished data). Because these were visible to a degree that allowed their location to be delineated well enough to be sampled, it was concluded that any bias inherent in the methods used should not have affected the outcome of the analyses.

At each site a number of quadrat pairs (one quadrat each for seismic line and undisturbed tundra) were used to describe the vegetation. Within each quadrat all vascular plant species were identified and the percent cover of each was estimated using a set of precision guidelines and reference cards. Simultaneously, the depth of thaw (active layer depth at time of sampling) was measured using a steel probe. Soil organic layer depth was measured by carefully cutting a soil profile so as not to compress the organic layer, and subsequently measuring the depth to the organic-mineral horizon (if present) or permafrost (if the organic layer penetrated to this depth) with a clear plastic ruler.

The percent cover estimates and species enumerations made in each quadrat were used to calculate the total cover of living vascular plants by species, as well as mosses and lichens; and were used to determine species diversity of vascular plants, and community composition.

Statistical tests of significance were performed separately for each plant community type. For recent seismic lines, however, the two upland community types (Medium Shrub – Heath and Low Shrub – Heath) were analyzed together because of a low sample size in the LSH community. Complete details of statistical analyses are beyond the scope of this report[1], however the general procedures used included:

- Mixed Linear Models
  - to test for statistical differences in univariate variables (cover, richness, diversity, thaw depth, organic layer depth) between seismic lines and undisturbed tundra.
- Wilcoxon Signed Rank tests
  - used where univariate data did not fit the assumptions of Mixed Linear Models
- Ordinations and Multi-Response Permutation Procedures
  - used to test for differences in (multivariate) species composition between seismic lines and undisturbed tundra
- Indicator Species Analysis
  - to test for individual species responses (positive or negative associations) to seismic lines.

For all univariate variables the statistical tests were designed to test the difference in each variable between seismic lines and undisturbed communities, and returned: the mean (or for Wilcoxon Signed rank test, median) difference; the 95% confidence limits encompassing this difference; and the associated critical values for the test of significance. The multivariate tests were chosen for their ability to accurately handle datasets with quantitative ecological data (relative abundance) and relatively small sample sizes.

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[1] Full details of statistical analyses and data screening procedures are available in Kemper (2005) and in peer-reviewed publications currently in preparation.

5. Results – Recent Seismic Operations

The most prominent effect of two to three year old seismic operations in all the community types studied was a decrease in living plant cover and increase in the amount of exposed mineral soil or scoured organic soil. This effect was most pronounced in the upland (Medium Shrub – Heath and Low Shrub – Heath) community types, with the Tall Shrub – Herb and Wet Graminoid types experiencing less direct loss of plant cover; the effect, however, was significant in all communities (Table 1). Depth to permafrost (thaw depth) was greater on seismic lines than in undisturbed tundra for two of the three community types, with the largest thaw increase occurring in the upland (MSH and LSH) communities (Table 1).

Moss cover was lower on seismic lines than in undisturbed tundra for the upland community types, but was not statistically different from undisturbed tundra on seismic lines in the other community types. Lichens, which were present only in upland communities, were significantly less abundant on seismic lines than in undisturbed communities. The decline in lichen cover from an average of 11.64% in undisturbed communities to 6.68% along seismic lines represents a loss of nearly half of the total lichen abundance on these disturbances.

Table 1. Difference in vegetation characteristics between recent (2-3 yrs post-disturbance) seismic lines and undisturbed terrain in upland (MSH/LSH) and wetland/riparian (TSH and WG) vegetation types.

Community Type	Variable	Difference (seismic – control)	95% CL	Statistical Significance (P-value)*
MSH/ LSH	Vascular plant cover	-59.50 %	±13.8	***<0.0001***
	Moss cover	-17.10 %	±12.68	***0.0145***
	Lichen cover	-4.95 %	±3.03	***0.0173***
	Species Richness	-1.88	±1.04	***0.0021***
	Organic layer depth	+3.24mm	±18.96	NS
	Thaw depth	+6.61cm	±3.43	***<0.0001***
TSH	Vascular plant cover	-26.89 %	±12.71	***0.0002***
	Moss cover	-2.37 %	±12.88	NS
	Lichen cover	-	-	-
	Species Richness	+0.21	±0.76	NS
	Organic layer depth	-13.17mm	±38.75	NS
	Thaw depth	+3.03cm	±11.44	NS
WG	Vascular plant cover	-18.36	±6.75	***<0.0001***
	Moss cover	-4.02	±10.63	NS
	Lichen cover	-	-	-
	Species Richness	-0.25	±0.65	NS
	Organic layer depth	-4.38mm	±25.83	NS
	Thaw depth	+2.37cm	±2.22	***0.0440***

* *results are statistically significant at a P value of 0.05 or smaller; NS = not significant.*

The amount of exposed soil on seismic lines varied between community types, and was greatest in the upland communities (where there was the highest reduction in plant cover) and least in the wet graminoid and riparian communities (Fig. 1).

Plant community composition, a measure that includes both which (vascular) species are present at a site as well as the relative abundance of each, was found to be statistically different from undisturbed tundra on seismic lines in the upland (Medium Shrub – Heath and Low Shrub – Heath) communities. This indicates that some species in these communities are disproportionately affected by seismic activity. No species were found to be positively associated with recent seismic lines. The short-term change in composition was therefore driven by species that were adversely affected by recent seismic operations.

No changes in species composition were detected in the riparian Tall Shrub – Herb, or the Wet Graminoid communities.

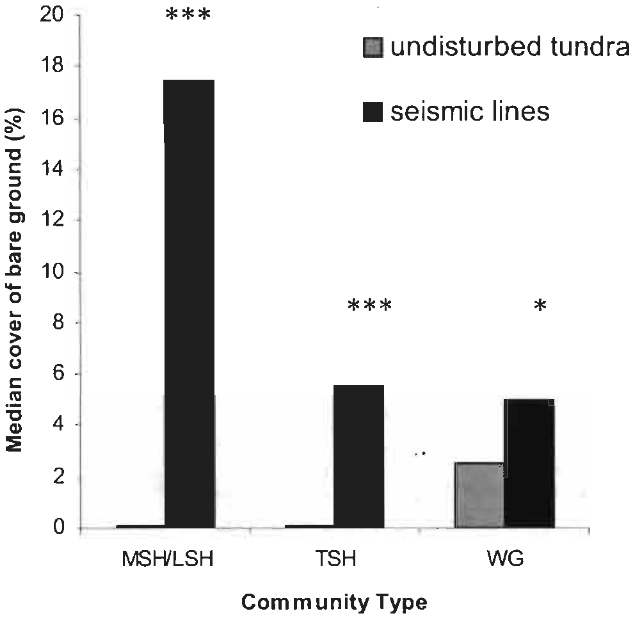

Fig. 2 Median cover of bare ground (exposed soil) on seismic lines and in undisturbed tundra for all plant community types studied. *significant at $p<0.05$, *** significant at $p<0.001$

6. Results – Historic Seismic Operations (1970-1986)

Historic seismic lines exhibit a visible signature that is often difficult to discern at ground level but readily apparent from the air. The most prominent difference between historic seismic lines and undisturbed tundra was a trend towards greater total vascular plant cover on seismic lines than at adjacent undisturbed sites (Table 2). This result was most pronounced in the Medium Shrub – Heath community type (MSH) where vascular plant cover on seismic lines was 16.5% greater on average than in undisturbed tundra, and as much as 36.14% greater (95% confidence limit). In the Low Shrub – Heath community type vascular plant cover on seismic lines averaged 11.83% greater than in undisturbed communities and was as much as 21.64% greater (95% confidence limit). At most sites, this effect appeared to be driven by denser shrub cover. Deciduous shrub cover was denser on seismic lines than in adjacent undisturbed communities (Fig. 3). The trend towards denser plant cover on historic seismic lines indicates that these sites have higher productivity than undisturbed tundra. Similar conditions have been reported on vehicle trails elsewhere in the low arctic (Forbes *et al* 2001).

Historic seismic lines in both upland community types had a lower abundance of lichens than did undisturbed communities (Table 2). Whether this is due to the slow growth rates (and hence slow recovery from disturbance) of tundra lichens, or to shading effects from the denser cover of deciduous shrubs on seismic lines cannot be determined. It seems likely that both factors might play a role.

In the Low Shrub – Heath (LSH) vegetation type, mosses were less abundant on seismic lines than in adjacent tundra. There was also a slight trend in this community type towards increased cover of grasses on seismic lines (which played a role in the visibility of seismic lines from the air, depending on light conditions and seasonality), although this was not statistically significant.

Table 2. Difference in vegetation characteristics between historic (18-33 yrs post disturbance) seismic lines and undisturbed tundra in upland plant community types.

Community Type	Variable	Difference (seismic - control)	95% CL	Statistical Significance* (P-value)
MSH	Vascular Plant Cover	+ 16.53 %	± 19.61	***0.0909***
	Moss Cover	-0.5%	+10.5, -24.0	NS
	Lichen Cover	-8.0%	+2.0, -3.0	***0.0052***
	Vascular Richness	+ 0.25	± 1.38	NS
	Organic Layer Depth	- 8.31 mm	± 24.02	NS
	Thaw Depth	- 1.58 cm	± 2.49	NS
LSH	Vascular Plant Cover	+11.83 %	± 9.81	***0.0196***
	Moss Cover	-17.44%	±17.20	***0.0463***
	Lichen Cover	-6.0%	+3.0, -1.0	***0.0369***
	Vascular Richness	- 0.7026	± 3.016	NS
	Organic Layer Depth	+12.49 mm	± 21.31	NS
	Thaw Depth	- 1.06 cm	± 2.36	NS

**results are statistically significant at P-value of 0.05 or smaller; P-values of 0.05 – 0.10 are considered marginally significant; NS = not significant.*

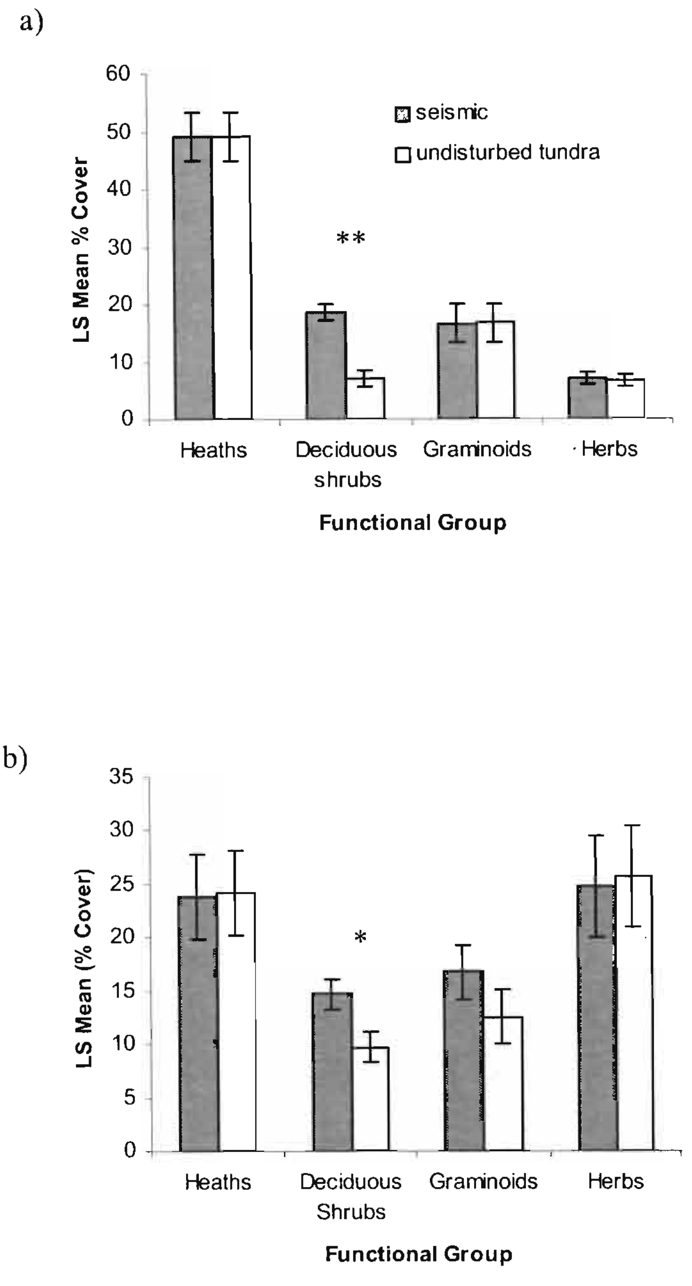

Figure 3. Least-square mean vascular plant cover (±1SE), grouped by functional type, on historic seismic lines and in undisturbed tundra for two upland vegetation types – Medium Shrub – Heath (a), and Low Shrub – Heath (b). *significant at $p<0.05$, **significant at $p<0.01$

7. Implications for Land Management

In addition to their essential contribution to biodiversity, tundra plant communities perform several important ecological functions. They serve as habitat for ungulates, waterfowl, and mammals, they insulate permafrost (Walker et al 2003), and they are net carbon sinks (Bliss and Matveyeva 1992). In considering the ecological implications of the effects noted above, all of these factors must be considered relevant. It is, however, the role of management authorities to make decisions regarding what is, and is not, acceptable or important, and to set management priorities that reflect these decisions. Because wildlife populations and wildlife habitat have been identified as a primary management focus in both the Inuvialuit Final Agreement and in Community Conservation Plans (KAVIK-AXYS 2002), the following discussion is directed primarily to this concern, with the above noted caveats.

Different vegetation types support different communities of small mammals and birds and also have different value as forage and cover for these as well as larger mammals. Given this, the fact that the different vegetation types in this study clearly differed in their resistance to winter seismic would seem to suggest that there is potential for some wildlife species to be disproportionately affected.

7.1 Management Implications in Upland Habitats

Impacts from recent (2 – 3 yr old) seismic operations were clearly greatest in the upland plant community types (Medium Shrub – Heath and Low Shrub – Heath). The degree of impact in upland vegetation types was variable, but was generally higher than that reported elsewhere in the literature[2]. The results obtained from historic seismic lines (18 to 33 yrs post disturbance) in upland communities also indicate that there is the potential for persistent (decades long) effects of vehicle operations in these communities. Despite the fact that soils and permafrost conditions on historic seismic lines were not readily different from undisturbed tundra there remained changes to productivity and vegetation structure.

Together these observations imply that wildlife species that are dependant upon upland plant communities experience some level of habitat *loss* from contemporary seismic programs in the short term, and the potential for habitat *alteration* in the longer term. Whether or not these effects are perceived by wildlife is beyond the scope of this study, and is currently an unresolved issue (Latour, pers. com.). There is at least some evidence, however, to suggest that bird species may compensate for habitat loss/alteration following seismic programs by increasing territory size when a seismic line is present (Ashenhurst 2004). It is also possible that changes in plant community composition (or structure) would affect some wildlife populations negatively, but others positively. In such a scenario changes in wildlife species composition become increasingly likely as the

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[2] To my knowledge, all other reports of winter seismic impacts have come from programs where dynamite was the primary energy source, whereas vibroseis was used in most of the programs studied here. Raynolds and Felix (1989) did report that vibroseis vehicles appeared to dig more deeply into terrain than did lighter drill units, but this effect was not tested due to sample size limitations.

cumulative spatial extent of altered vegetation increases on the landscape with the creation of additional disturbances. Management concerns should be not with respect to vegetation change on a single seismic line, or even a single seismic program, but rather with the potential for effects to accumulate through space and time as additional seismic (and other exploratory) disturbances are added to the landscape.

7.2 Management Implications in Wetland/Riparian Habitats

The reduction in vascular plant cover on recent seismic lines in the Tall Shrub – Herb community type is also potentially of interest to land managers as it dramatically increases the visibility of seismic lines through these communities. In addition to direct habitat loss for wildlife species dependent on riparian willow vegetation types, this also suggests the possibility that bird species might avoid these disturbances because of their obvious visible signature. Because of the slow growth rates of arctic shrubs (Billings and Mooney 1968) it will likely be several years (perhaps decades) before shrubs along seismic lines regain their original height. Thus, the potential for effects to accumulate in these communities is also relatively high.

The smallest difference in vascular plant cover between recent seismic lines and undisturbed vegetation occurred in the Wet Graminoid vegetation type. If changes in vegetation cover are a suitable proxy for habitat loss then it would appear that impacts to wildlife would be least in these areas. There was a statistically significant increase in thaw depth along recent seismic lines in the Wet Graminoid communities. However, the magnitude of the change was relatively small (+2.37cm on average) and would likely not have any direct consequences for plant growth. The potential for effects to manifest later during secondary succession should not be dismissed; delayed nutrient flushes (resulting from warmer soils, plant materials being pressed into contact with soil decomposers, and changes in hydrology) are commonly reported from vehicle trails in arctic regions (Rickard and Brown 1974; Abele et al 1984). Felix *et al* (1992) reported that changes in plant community structure and composition on seismic lines in moist sedge tundra continued to *increase* 4-5 years post disturbance.

8. Recommended Practices

This study describes the generalized response of tundra vegetation to winter seismic exploration. The study included seismic lines from multiple exploration programs, each of which was potentially unique with respect to factors important in determining disturbance intensity, including: types of vehicles used (tracked vs. wheeled, weight, ground pressure), energy source used (dynamite vs. vibration), number of vehicles used, climatic conditions at time of line travel (ground hardness, depth of frozen ground), and snow characteristics (depth, moisture content, crust condition). Given the influence of these variables, and the fact that they could not be controlled for in this study, it is difficult to distill the data gathered here into techniques or technologies that could mitigate the impacts of current and future seismic programs. The following recommendations, therefore, are developed both from the results of this study and from a review of pertinent literature.

An evolving and adaptive management policy, in combination with ongoing data collection and monitoring should be adopted; in this manner best management practices can evolve in concert with growing knowledge and changes in seismic exploration practices.

8.1 Creation of a Spatial Database of Disturbances

A publicly accessible database compiling information on the date, location, and spatial extent of seismic lines could be used track the total amount of all seismic disturbances in each of the physiographic regions of the ISR. This could be accomplished by collecting spatial data, together with project operational information (vehicle types, camp locations etc.), and compiling these line locations into a regularly maintained database[3]. Seismic lines would be added to the database as new programs are undertaken, and removed from the 'disturbance tally' of the database once a pre-determined set of recovery criteria are met, as determined by periodic monitoring.. Revegetation monitoring is required because the period within which tundra plant communities will fully recover from winter seismic operations is currently not well understood, and would likely vary among vegetation types and physiographic regions. In addition, it is not clear to what degree a return to pre-disturbance plant communities should be expected, given variability in the degree of disturbance, and the influence of a changing climate. Recent estimates, based on the collective results of the Alaskan ANWAR studies would suggest that ~8-10 years might be sufficient for the recovery of sites that were not irreversibly damaged (NRC 2003).

In addition to seismic programs (2D and 3D), the database could be augmented to include the locations and spatial extent of ice roads, temporary drilling pads, sumps, and camp locations. In this manner both the location and total area of exploration disturbances in the ISR could be tracked, and could be used by various stakeholders to direct monitoring

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[3] No suggestion is made regarding which parties would be responsible for creating and maintaining such a database, but it is assumed that some level of government (local, territorial, federal) would be the most likely candidate.

programs and evaluate the potential for cumulative effects in subsequent management decisions.

8.2 Increased Snow Depth Requirements

Minimum snow-depth requirements have been used to protect tundra terrain from vehicle travel in a number of jurisdictions, each with its own requirements. However, these measurements have often been used only to determine when the 'season' for tundra travel is opened, and have been made at pre-determined, fixed, locations unassociated with any particular planned program (Bader and Guimond 2005). As such, they provide little guarantee of *in-situ* protection because local topography, vegetation characteristics, and wind patterns modify the actual depth and hardness of the snow pack at any given location. An important component of this recommendation, therefore, is that exploration programs proceed only when *on-site* measurements within the intended exploration area indicate that adequate snow cover is present to protect vegetation and permafrost. Although what constitutes "adequate" snow cover is not fully understood, a modestly conservative measure for protecting tundra plant communities, such as the 25 cm proposed by Felix and Raynolds (1989b), could be adopted. Current guidelines in the ISR range from a requirement for 25 cm of snow over "flat and level terrain" currently attached to exploration permits for the Kendall Island Bird Sanctuary[4], to 15 cm or 20 cm requirements typically attached to approvals elsewhere in the ISR. Clearly, a simplified regulatory framework that encompassed both Inuvialuit private lands and Crown lands could simplify the planning of seismic programs and simultaneously help mitigate their effects. It is possible that a different set of snow-depth requirements might apply to 3D seismic programs, since these typically involve fewer vehicle passes. However, since there a lack of published information on the relative impacts of 3D vs. 2D seismic in tundra biomes, this should be approached with caution and based on empirical data.

8.3 Limiting Vehicle Passes

The effects of multiple vehicle passes on disturbance intensity are well understood (Rickard and Brown 1974). By limiting the number of vehicles traversing seismic trails to the absolute minimum number required, unnecessary damage to vegetation and soils can be avoided. This should be considered as an effective tool for minimizing impacts in particularly sensitive areas. Using fixed camps, and using helicopters to move crews and portable equipment on and off site wherever possible may be a potential avenue for limiting vehicle travel. There are multiple means of achieving this, in practice. Careful consideration by proponents at the project planning stage could voluntarily limit unnecessary disturbance. Alternatively, approval conditions that place an upper limit on the number of vehicle passes per trail could be applied by the local authorities responsible for approving project descriptions (e.g., Environmental Impact Screening Committee). 3-

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[4] This permit requirement was implemented by the Canadian Wildlife Service in 2004 and has, to date, only been applied to one seismic program. Previously no specific snow-depth requirements above and beyond those used elsewhere in the ISR have been in place for the Kendall Island Bird Sanctuary (Latour, pers. com.)

dimensional seismic operations, which already involve fewer vehicle passes than 2D operations may have fewer options in this regard.

8.4 Technological Implements

Technologies designed specifically to reduce impacts of off-road vehicle travel on tundra have existed for a number of decades and continue to be developed. Examples of these are ‘mushroom shoes’ attached to bulldozer blades to prevent cutting of hummocks, low ground pressure tires (e.g., Rolligon), and air bladder tires (e.g., CATCO). While further studies are required to determine the relative efficacy of these implements, their use should be encouraged in all seismic operations.

Permitting multiple seismic programs, each with a unique combination of technologies, vehicles, terrain, and snow conditions, could form the experimental foundation upon which more detailed studies could be conducted. Through such studies more effective regulatory guidelines and best management practices can be developed, with the ultimate goal of limiting disturbance from seismic operations to an absolute minimum.

8.5 Recommended Studies

The suggested practices above are designed to dovetail together with an adaptive management program and ongoing investigations. Continued monitoring is absolutely necessary if informed management decisions are to be made to minimize cumulative effects. In order to develop effective and economically feasible best management practices, ongoing research into the mechanisms of disturbance and influence of ameliorating factors is warranted. The National Research Council of the United States has identified protective snow depth thresholds as one research need (NRC 2003). The results of the present study suggest that a more detailed comparison of effects from seismic programs using vibroseis vs. those using dynamite should also be considered.

The call for such a strategy is not new: Rickard and Brown (1974) suggested the need for a series of permanent study sites to experimentally test and monitor the long-term effects of vehicles on different types of tundra vegetation. Such a scientific program, where exploration proceeds in concert with both on-site (real time), *and* post hoc measurements is required to inform a management regime that is acceptable to all stakeholders and preserves the natural functioning and diversity of arctic ecosystems. The following observations would be required to carry out such a program:

- The type and weight of each vehicle traversing seismic lines, and the number of passes of each
- The snow depth, snow moisture content, and depth of frozen ground at the time of passage
- The precise location and type of energy discharge (dynamite, vibration)
- The operational and technological tools used to minimize disturbance (e.g. walking down vegetation, wide turn radius’, use of mushroom shoes)

Subsequent, and long-term investigations of the vegetation dynamics, permafrost, soil nutrient conditions, and herbivory, will be necessary at these sites to accurately assess the nature and mechanism of seismic impacts, and to predict the long-term effects associated with future oil and gas exploration activities in tundra biomes. Alongside this experimental research program, simpler ongoing revegetation monitoring programs should occur at other sites throughout the ISR to build a better understanding of how plant communities will ultimately recover from contemporary seismic programs, and how long this recovery will require in various vegetation types.

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