U. S. Department of the Interior
Bureau of Land Management

Alaska Open File Report 112
BLM/AK/ST-07/011+6700+020
June 2007

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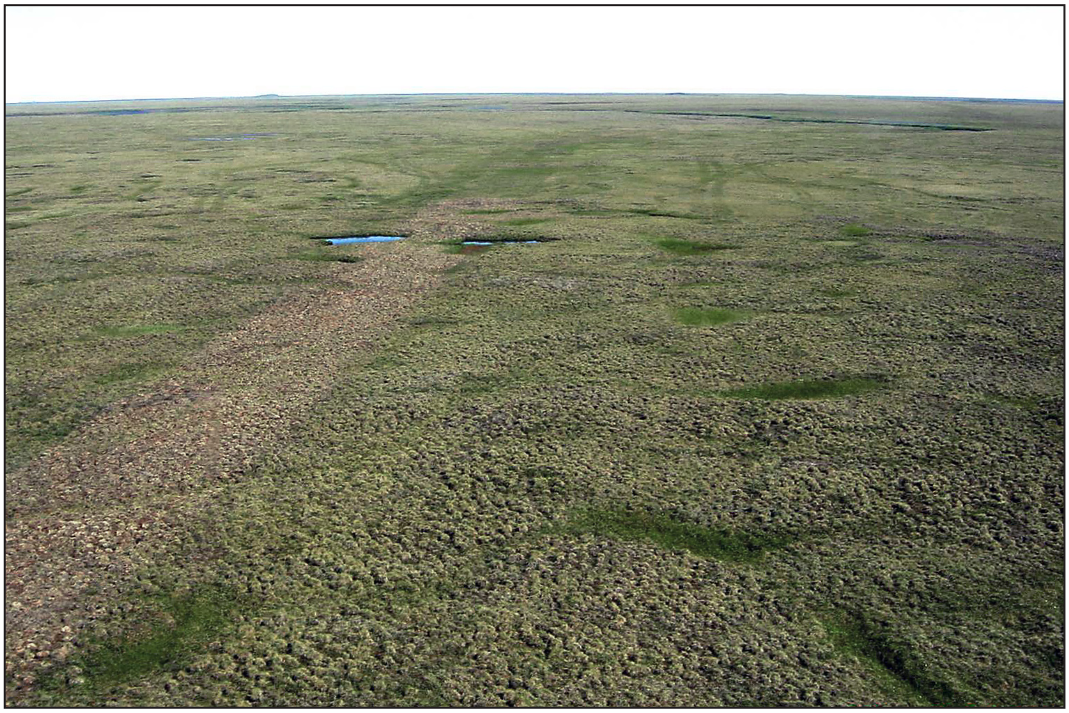
Offsetting versus Overlapping Ice Road Routes from Year to Year: Impacts to Tundra Vegetation

Dave Yokel, Darek Huebner, Randy Meyers, Debbie Nigro and Jay Ver Hoef



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Cover Photo

Ice road path on low shrub tussock tundra vegetation near the Ublutuoch River in the National Petroleum Reserve - Alaska. Photo by Scott Guyer.

Authors

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Abstract

In the Record of Decision for the Northeast National Petroleum Reserve – Alaska Integrated Activity Plan (1998), the Bureau of Land Management stipulated that the location of ice roads be offset from year to year. The rationale for this requirement was based on the assumption that it is environmentally preferable to spread the impact over a greater area of tundra because in that way the tundra vegetation will recover more quickly, i.e., a less severe impact over a greater area is preferable to a more severe impact over a smaller area. This study was intended to test a part of that assumption: additive impacts occur to tundra vegetation with subsequent years of ice road construction.

We established transects across ice road paths with four plots per transect: control (outside the road boundaries) and three treatments (2001 road only, overlap area of 2001 and 2002 roads, and 2002 road only). In each of three summers (2002–2004), we measured depth of thaw, proportion of tussocks damaged, and percent ground cover by eight vegetation cover types to see if greater impacts occurred in the overlap-road plots than in the single-year road plots.

No statistically significant differences in depth of thaw were found among control and treatment plots or between single-year plots and overlap plots. The only significant result among the thaw data was a "year effect": the thaw depths for all treatments became deeper with each successive year.

The data for proportion of tussocks damaged showed significant overall differences among the control and treatments, due mostly to the marked difference between the control by itself and the three road treatments combined. More importantly, the overlap treatment displayed a marginally greater level of damage than the two single-year treatments. However, a significant year effect due to a decrease in damaged tussocks from one year to the next suggested the resilience of tussocks to some types of damage.

The percent of ground cover by eight vegetation cover types showed no significant difference between the overlap-road plots and the single-year road plots when data from three years were combined, but did display a significant additive effect in the overlap-road plots for one year (2003) when the three years were analyzed separately.

Data from this three-year study provided only minimal evidence of additive impacts from building ice roads over the same path in two subsequent years. Given the observed recovery of the tundra during the three years of study, it is doubtful that any significant environmental benefit would be gained by requiring that all ice roads be completely offset from paths of previous years. A more appropriate mitigation would be to require that ice road routes follow the wetter habitats to the greatest extent possible without significantly increasing their length.

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Introduction

Studies of impacts to vegetation from seismic exploration in the Arctic National Wildlife Refuge (ANWR) in 1984 and 1985 suggested that greater damage occurred to tundra where camp-train and seismic vehicle trails overlapped than where either occurred alone (Jorgenson et al., 1996). Greater damage also occurred where multiple vehicles moved along a single, narrow trail rather than along dispersed trails (Jorgenson, 2000). Beginning in at least the mid-1980s, the Bureau of Land Management (BLM) stipulated for seismic operations in the National Petroleum Reserve – Alaska (NPR-A) that "care shall be taken to ensure that when multiple trips over the same trails are taken, that vehicles will not utilize exactly the same tracks... " (Meares, Don; pers. comm.). In the Record of Decision for the Northeast NPR-A Integrated Activity Plan / Environmental Impact Statement (1998), the BLM revised that stipulation somewhat to require that vehicles avoid using the same trails for multiple trips. Transferring that same logic from seismic exploration to ice road construction, it was also stipulated that the location of ice roads be offset from year to year.

The rationale for this logic is not presented in these BLM documents, but is presumably based on the following assumption; it is environmentally preferable to spread the impact over a greater area of tundra because in that way the tundra vegetation will recover more quickly, i.e., a less severe impact over a greater area is preferable to a more severe impact over a smaller area. This has been verified for seismic camp trains in the Arctic National Wildlife Refuge, where the bulldozers pulling heavy trailers on skids can result in ruts in the tundra (Jorgenson, 2000). Resultant depression of the tundra mat may cause wetter soils and a conversion to more hydrophilic vegetation that persists for at least 14 years and possibly much longer.

From the 1940s until the late 1960s, overland travel in the NPR-A and other parts of northern Alaska was often accomplished simply by bulldozing trails across the tundra in both winter and summer (Lawson et al., 1978; Lawson, 1982). Ice roads were recognized to cause less damage to tundra, and they have been used on Alaska's North Slope and the adjacent Yukon and Northwest Territories since the early 1970s (Adam and Hernandez, 1977; Fisher, 1978; Lawson, 1979, 1986; Walker et al., 1987), although gravel pads and roads were still commonly used for oil exploration activities during this period. In the 1990s, exploratory drilling activities moved almost exclusively to the use of ice roads and pads (Hazen, 1997), yet relatively few studies have addressed their impacts (Jorgenson, 1999; Guyer and Keating, 2005; Pullman et al., 2005).

Of those studies that have looked at impacts from ice roads, none has tested the above assumption inherent to the rationale for requiring ice roads to be offset from one year to the next. This study was intended to test part of that assumption; additive impacts occur to tundra vegetation with subsequent years of ice road construction. It was not envisioned that three years of study would be long enough to determine if any additive impact would result in a longer recovery period.

Study Area and Methods

Following the 1998 Record of Decision, the first exploratory drilling in the NE NPR-A occurred in 2000 in an area west of the village of Nuiqsut, Alaska, and east of Judy Creek. Additional drilling occurred in each of the following two years, and all of it was supported by ice roads. This study began in the summer of 2002, using paths of ice roads constructed and used in the periods of January through April, 2001 and 2002. Study sites ranged from 8 to 30 km west of Nuiqsut.

The study design required areas of partial overlap between the roads of the two years. In this way, a transect placed across the roads could provide a control (outside the road boundaries) and three treatments: 2001 road only, overlap area of 2001 and 2002 roads, and 2002 road only. Since the lessees were required to offset the roads from year to year, there were very limited opportunities to establish transects with a segment of overlap. Opportunities arose when the roads were too close together, and thus overlapping, or when the 2002 road crossed at an oblique angle from one side of the 2001 road to the other.

Our previous summertime observations of seismic trails and ice road paths, along with those of others (Felix and Raynolds, 1989), indicated that the wetter the vegetation type, the less the impacts during winter travel. This is due to the protection provided by the solidly frozen ground, or even ice above the soil substrate. Flooded and wet tundra types typically display little to no impact from winter travel, precluding the possibility of additive impacts from multiple seasons of use. For this reason, we confined this study to moist tundra types. Between the two restrictions of road layout and moist vegetation types, very limited possibilities existed for establishing transects for study sites. We found only five suitable sites, four of which were tussock (*Eriophorum vaginatum*) tundra with relatively few shrubs and one of drier *E. vaginatum* tussocks dominated by dwarf shrubs.

We established transects at 90° to the ice road paths and marked control/treatment boundaries with wooden stakes. Because those boundaries were more easily observed from the air, we double-checked our initial stake placement from a helicopter, noted corrections, and then reset the stakes accordingly after landing again. Subsequent photographs taken from the air confirmed the correct placement of the stakes. Nonetheless, we collected no data within 0.5 m of any control or treatment boundary to reduce the possibility of assigning data incorrectly to control/treatment type.

We collected three types of data on the control and each of three treatments at each of the five study sites: depth of thawed soil, proportion of tussocks damaged and percent ground cover by eight vegetation/cover types. Data collection occurred within the periods of August 8–9, 2002; July 28–August 2, 2003; and July 30–August 6, 2004. We measured thaw depth and tussock damage within 1 m of, and on the same side of, the transect line in each of the three years. We collected vegetation cover data within 2 m on either side of the transect line.

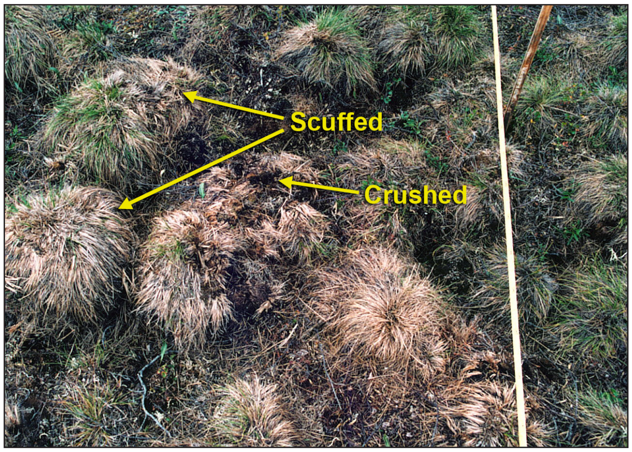

Figure 1. Examples of scuffed and crushed *Eriophorum vaginatum* tussocks.

Figure 2. Examples of healthy, undamaged *Eriophorum vaginatum* tussocks, displaying a substantial component of standing dead sedge blades.

We measured thaw depth to the nearest cm by pressing a pointed steel probe into the ground until encountering hard, frozen soil. To maintain consistency within the highly variable microtopography of tussock tundra, we only took measurements between tussocks and not on them. We took 10 measurements within the control and each of three ice road treatments during each of the three years.

We categorized tussocks in one of two classes: undamaged or damaged, with the latter including both scuffed and crushed tussocks (Figure 1). All tussocks within a rectangle made of the transect line, a parallel line 1 m away and lines 0.5 m from either end of the treatment zone were included in the sample. Tussocks bisected by the rectangle boundaries were included if on the left or trailing edges, and excluded if on the right or leading edges.

We categorized ground cover into eight classes: bare ground, litter, live moss or lichen, dead moss or lichen, live graminoid (sedges and grasses), dead (but standing) graminoid, live shrub/forb or dead shrub/forb. Healthy, undamaged tussocks (Figure 2), as well as other undamaged sedges and grasses, included a substantial component of standing dead biomass from previous years. Litter consisted of dead biomass that had become detached from a plant of any of the classes, whether naturally or by the physical action of ice road construction and use. We used the same eight cover classes in each of the three years, but our method of estimation from the first year differed in the following two years. In 2002 we made ocular estimates from a 0.25 m^2 quadrat randomly placed within the treatment. Pre-sampling (off-site) suggested that the variation within a treatment could be adequately sampled using this small a frame, but after completion of our first field season we decided to come prepared in the following year to use a more precise and accurate technique (and a more time-consuming one, hence the greater number of days involved). In the following two years, we sampled the ground cover using a pin frame. Within each treatment, we sampled a 2 x 4 m grid of 200 points with 20 cm even spacing using a starting point randomly located along the length of the transect line and within 20 cm of the line. We dropped sharpened pins through the frame and recorded the first cover class struck by the pin. Thus the data represent the “canopy” cover for each treatment.

We went one step further in 2004 and recorded each pin "hit" to genus, or when possible species, in addition to one of the eight cover classes. We were rarely able to identify mosses to genus, and most often classified them by growth form (cushion or feather). Similarly, we identified crustose lichens by growth form only, but identified foliose and fruticose lichens to genus or species. A complete list of growth forms and species appears in Appendix A.

We analyzed depth of thaw data using analysis of variance (ANOVA) tested against the F (three- or four-way comparisons) or Student's t (two-way comparisons) distributions. We used a logistic regression model to analyze the proportion of tussocks categorized as damaged in 2002. The most parsimonious model was selected by using likelihood ratio tests against the chi-square ($\square^2$) distribution. Pooling 2002 data with those from 2003 and 2004 in later years, and adding a "year effect," altered the covariance structure and required the use of a different test. Thereafter we analyzed damage to tussocks with a simultaneous Wald test, which is compared against the F or Student's t distributions. We analyzed the cover data, with eight cover types as variables, using principal components analysis of covariance matrices. Plot scores (also known as factor scores) were computed for each plot for each principal component, and these plot scores were analyzed using ANOVA tested against the F or Student's t distributions. We loosely used an alpha level of 0.05 as a threshold for statistical significance. By "loosely," we mean that results were not ignored if alpha was slightly greater than 0.05, but that they provided us less confidence.

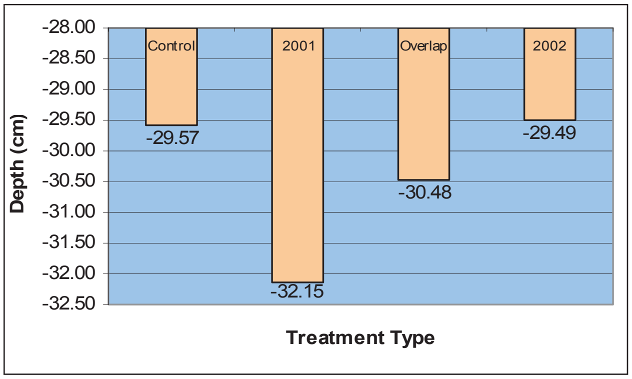

Figure 3. Mean depth of thaw for pooled data from 2002–2004. Note the Y-axis does not begin at zero, giving an impression of greater difference among treatments than really exists.

Results

Depth of Thaw

No statistically significant differences in depth of thaw were found among control and treatment plots for pooled data from 2002–2004 ($F = 0.84$, $p = 0.50$; Figure 3). It follows, then, that the test of most interest to the study's purpose, whether or not the two-year road overlap treatment had significantly deeper thaw than the 2001 and 2002 single-road treatments, was also not significant ($t = 0.21$, $p = 0.84$). In fact, the sample data suggest less thaw in the overlap than in the 2001 treatment. The only significant result among the pooled data was the year effect ($F = 101.76$, $p < 0.0001$; Figure 4), i.e., the thaw depths for all

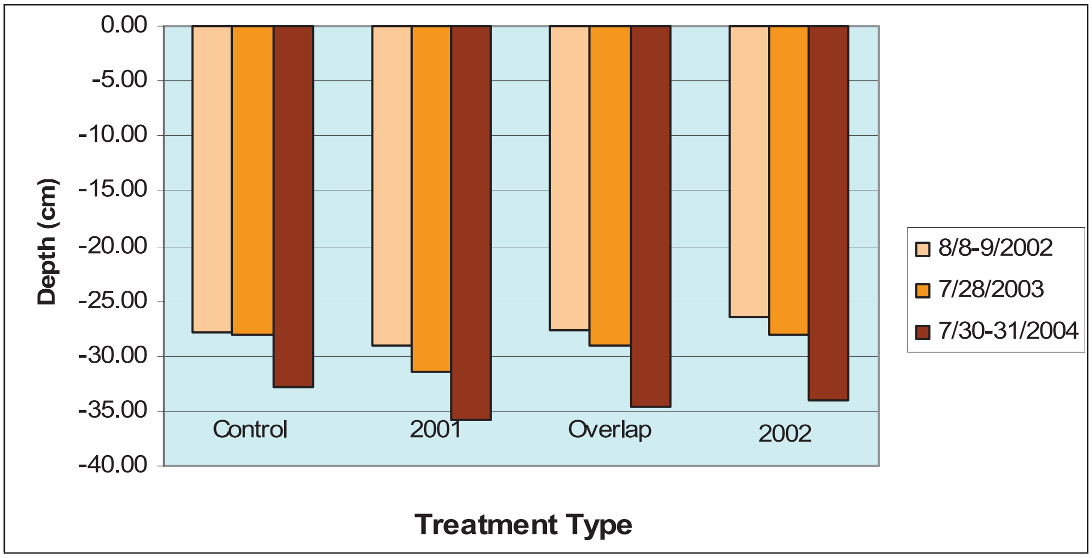

Figure 4. Effect of year on thaw depth within each of four treatments.

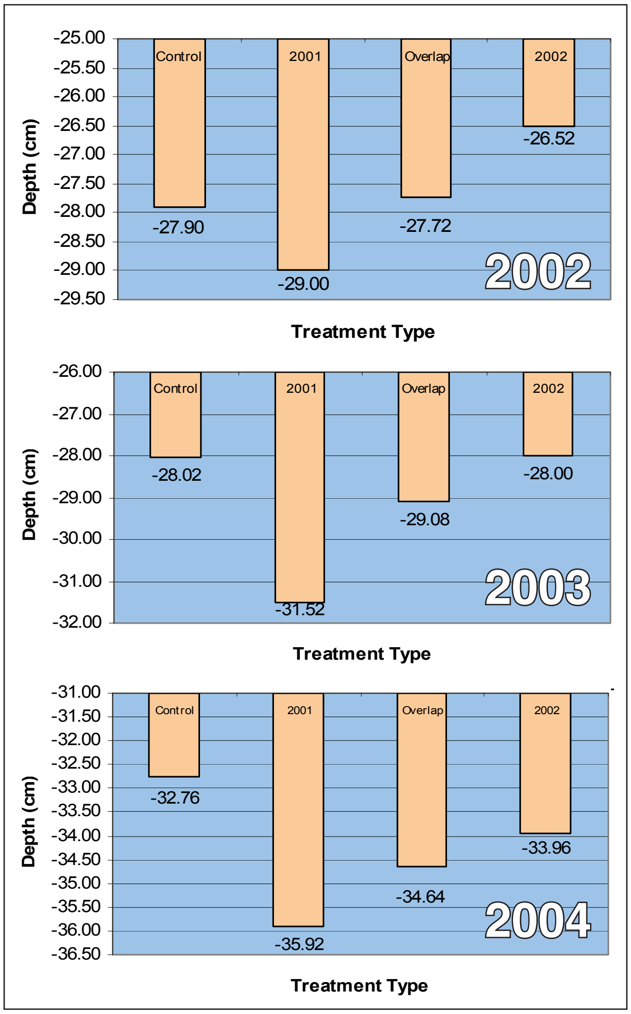

Figure 5. Mean depth of thaw in each of three years.

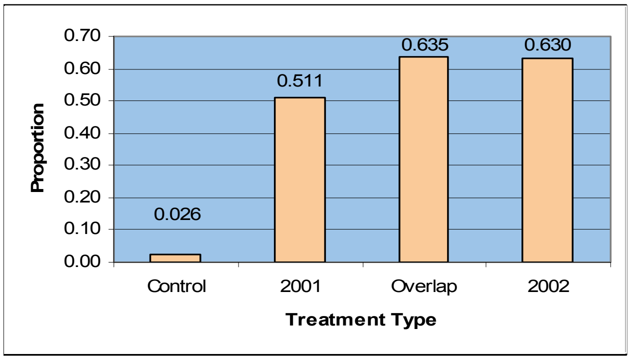

Figure 6. Proportion of tussocks that were damaged, by treatment type, for pooled data from 2002–2004.

treatments combined differed significantly among the three years in which data were collected. These differences were also significant between pairs of data collection years (2002 vs. 2003: $t = 2.79$, $p = 0.008$; 2003 vs. 2004: $t = 10.65$, $p < 0.0001$), and displayed an increase in depth of thaw (~5–7 cm) over two years.

No significant differences among control and treatments were found when the data were analyzed separately by year. Nonetheless, the same trends were evident among years (Figure 5).

Damage to Tussocks

The pooled data from 2002–2004 for proportion of tussocks damaged showed significant overall differences among the control and treatments ($F = 68.2$, $p < 0.0001$; Figure 6). Most of this is due to the marked difference between the control by itself and the three road treatments combined (<3% damaged vs. >50% damaged; $t = 13.7$, $p < 0.0001$). In contrast to the data for depth of thaw, the 2001 road treatment (51% damaged) displayed less impact than the 2002 road treatment (63% damaged; $t = 3.93$, $p = 0.0003$). Most important to the purpose of the study is the comparison between the two single-year treatments combined and the overlap treatment, which was marginally significant ($t = 1.88$, $p = 0.07$). These combined data for the three years also showed a significant year effect ($F = 44.4$, $p < 0.0001$; Figure 7) due to a significant decrease in damaged tussocks from one year to the next (2002 vs. 2003: $t = 6.06$, $p < 0.0001$; 2003 vs. 2004: $t = 3.22$, $p = 0.002$).

Despite the year effect, the same general trends were evident when the data for each sampling year were analyzed separately (Figure 8). The difference between the 2001 and 2002 single-road treatments was significant in two of three years (2002: $\square^2 = 8.96$, $p = 0.003$; 2003: $t = 0.87$, $p = 0.40$; 2004: $t = 2.36$, $p = 0.04$), with the 2001 treatment displaying less damage. The 2001 treatment also displayed significantly less damage than the overlap treatment in the same two out of three years (2002: $\square^2 = 7.11$, $p = 0.008$; 2003: $t = 1.30$, $p = 0.22$; 2004: $t = 2.20$, $p = 0.05$). In two of three data collection years, the trends for the difference between the overlap treatment and the two single-road treatments combined fit the expected pattern for an additive impact in the overlap treatment, but none of the three years showed a significant difference (2002: $\square^2 = 2.08$, $p = 0.15$; 2003: $t = 1.01$, $p = 0.33$; 2004: $t = 1.36$, $p = 0.20$).

Ground Cover

The first principal component ($PC1_{pooled}$) for the pooled cover data (2002–2004) explained 46% of the variance in the data. The live graminoid class loaded strongly positive on $PC1_{pooled}$, and dominated the characteristics of that component (Figure 9). Dead (standing) graminoids, litter and live shrubs/forbs were weakly positive and dead moss/lichen loaded weakly negative. There was significant difference among the mean plot scores for the control and three treatments for $\mathrm{PC1}_{\mathrm{pooled}}$, but only marginally so (Figure 10; $F = 2.73$, $p = 0.05$). The control was significantly more positive than the three treatments combined ($t = 2.39$, $p = 0.02$), but no other comparisons were statistically significant, including the one of most interest, the two single-road treatments versus the overlap treatment ($t = 0.38$, $p = 0.71$).

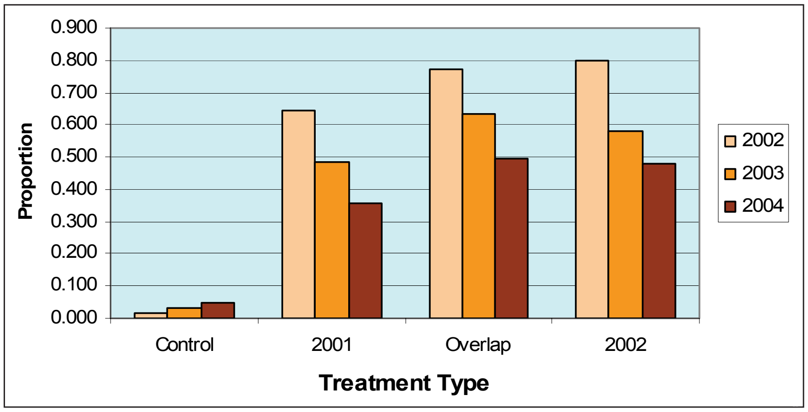

Figure 7. Effect of year on proportion of tussocks damaged within each treatment.

Most notable among these pooled data was a highly significant year effect ($F = 140.03$, $p < 0.0001$). It was expected that, because the coverage estimation technique changed between 2002 and 2003, the data collected in 2002 ($\mathrm{PC1}_{\mathrm{pooled}}$ mean = –17.56) might be dissimilar from the following two years (2003 $\mathrm{PC1}_{\mathrm{pooled}}$ mean = –15.72; 2004 $\mathrm{PC1}_{\mathrm{pooled}}$ mean = 33.27). However, there was no difference between 2002 and 2003 ($t = 0.53$, $p = 0.60$) and the major change causing the year effect occurred between 2003 and 2004; the $\mathrm{PC1}_{\mathrm{pooled}}$ mean plot score in 2004 was significantly different from the previous two years (2002 vs. 2004: $t = 14.75$, $p < 0.0001$; 2003 vs. 2004: $t = 14.22$, $p < 0.0001$).

Because of the strong year effect, it is worthwhile to look at the analyses for data collected in each year separately. The first principal component ($\mathrm{PC1}_{02}$) for the 2002 cover data explained 44% of the variance in the data. The live graminoid, live shrub/forb and live moss/lichen classes all loaded strongly negative on $\mathrm{PC1}_{02}$, whereas the dead moss/lichen and litter classes both loaded strongly positive (Figure 11). Dead graminoids were weakly negative and bare ground and dead shrubs/forbs were weakly positive. There was significant difference among the mean plot scores for the control and three treatments for $\mathrm{PC1}_{02}$ (Figure 12; $F = 8.36$, $p = 0.003$), and the control was significantly more negative than the three treatments combined ($t = 4.35$, $p = 0.0009$). The comparison of the two single-road treatments versus the overlap treatment showed the expected trend, but was not significant ($t = 1.41$, $p = 0.18$). There was, however, a marginally significant difference between the 2001 single-road treatment and the other two (2001 vs. overlap: $t = 2.24$, $p = 0.04$; 2001 vs. 2002: $t = 2.04$, $p = 0.06$). There was no difference between the mean plot scores of the overlap and 2002 single-road treatments ($t = 0.20$, $p = 0.84$).

The first principal component ($\mathrm{PC1}_{03}$) for the 2003 cover data explained 49% of the variance in the data. The live shrub/forb and dead graminoid classes loaded strongly negative on $\mathrm{PC1}_{03}$, whereas the litter, dead shrub/forb and dead moss/lichen classes loaded

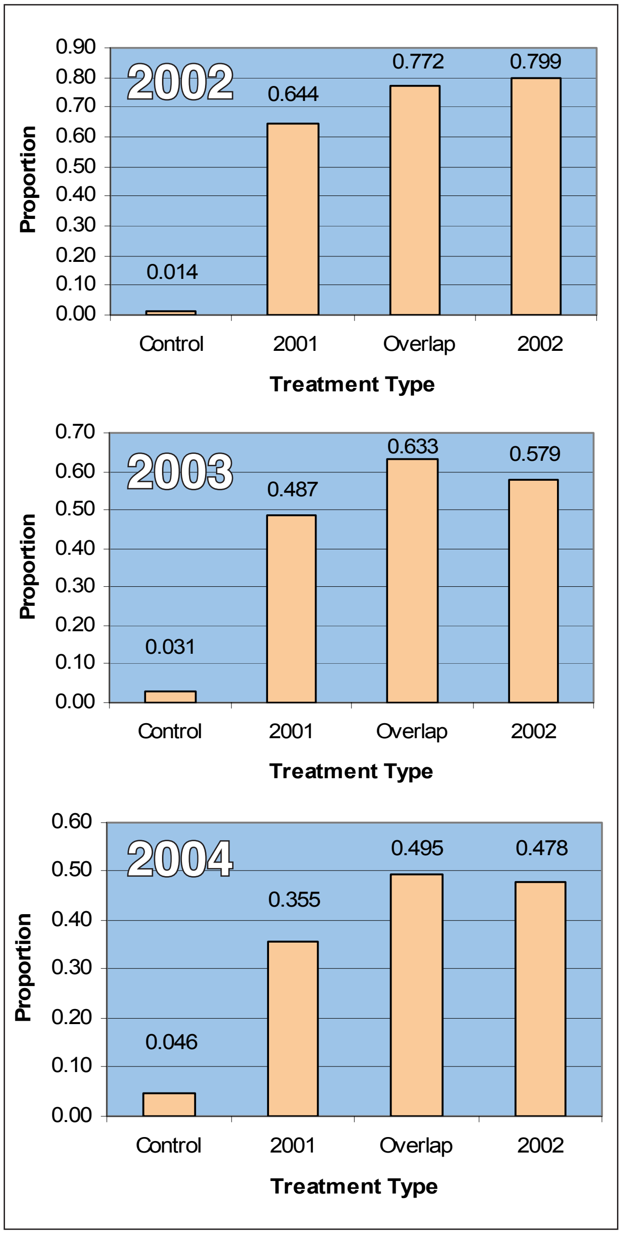

Figure 8. Proportion of tussocks damaged in each of three years.

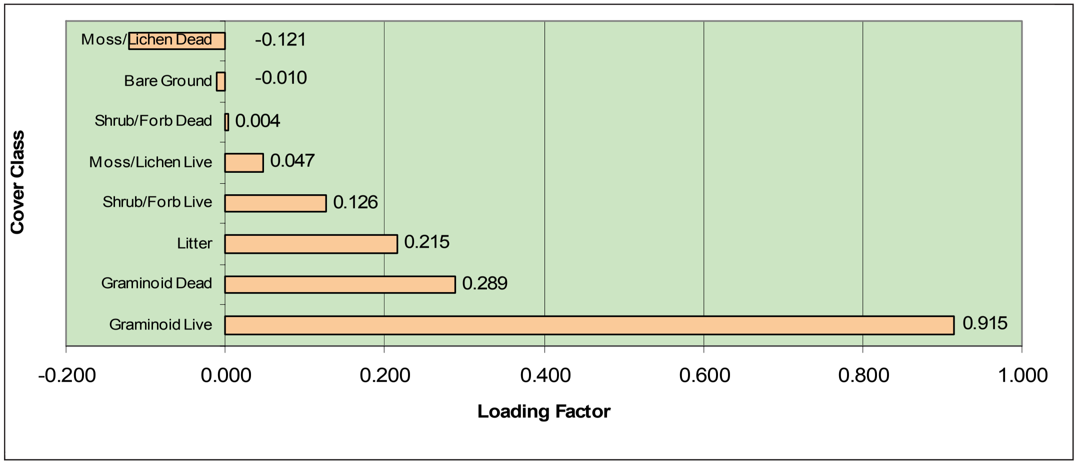

Figure 9. Cover category loadings on the first principal component for pooled data from 2002–2004.

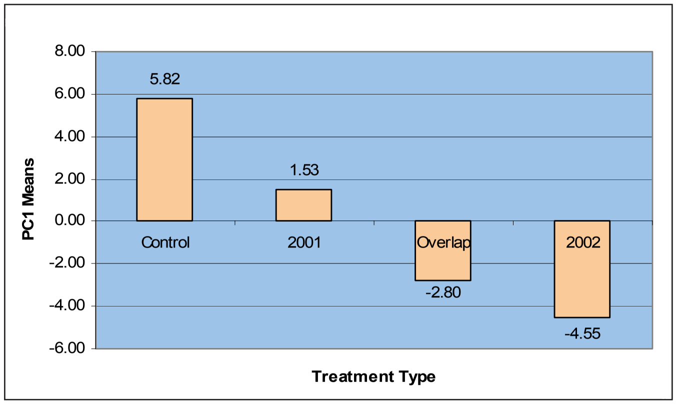

Figure 10. Means of the first principal component for the control and three treatments for pooled data from 2002–2004.

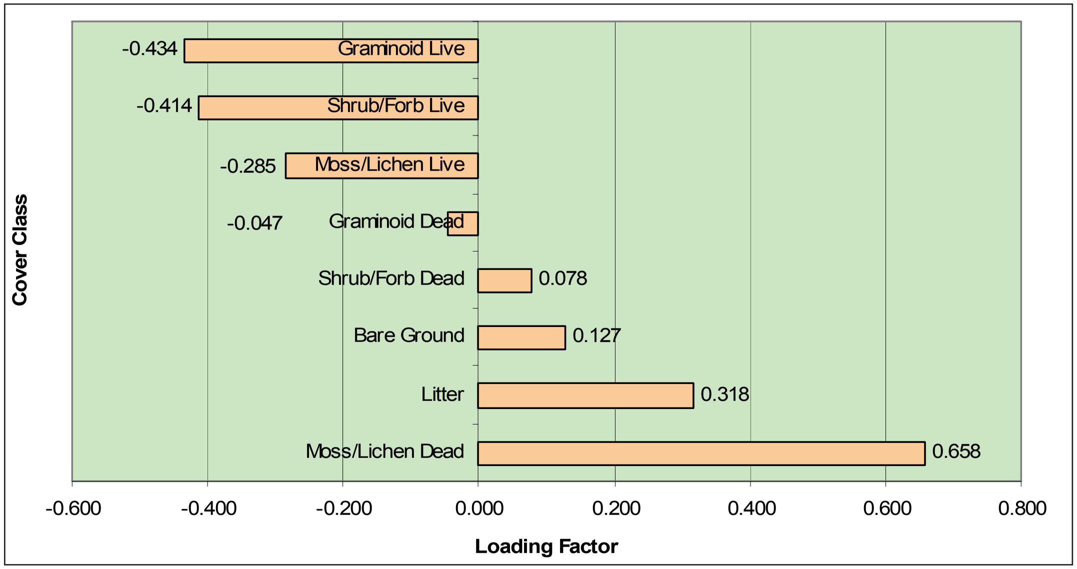

Figure 11. Cover category loadings on the first principal component for data from 2002.

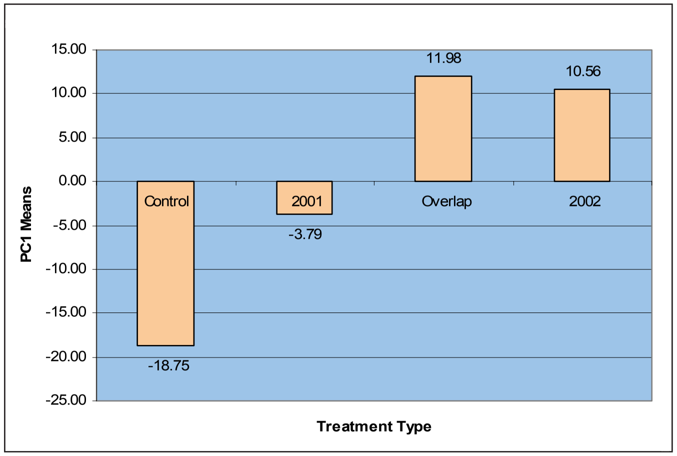

Figure 12. Means of the first principal component for the control and three treatments for data from 2002.

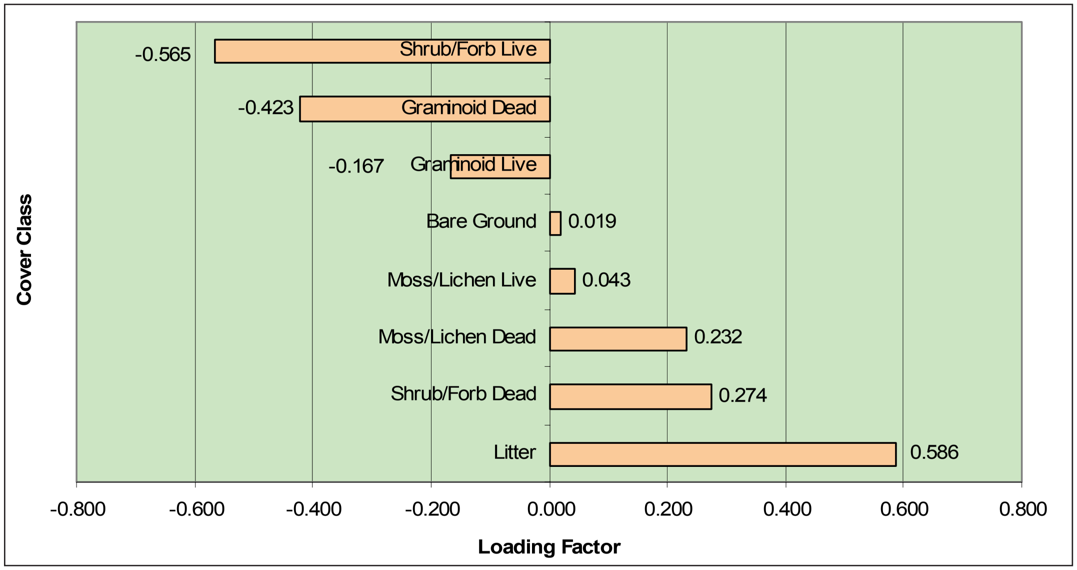

Figure 13. Cover category loadings on the first principal component for data from 2003.

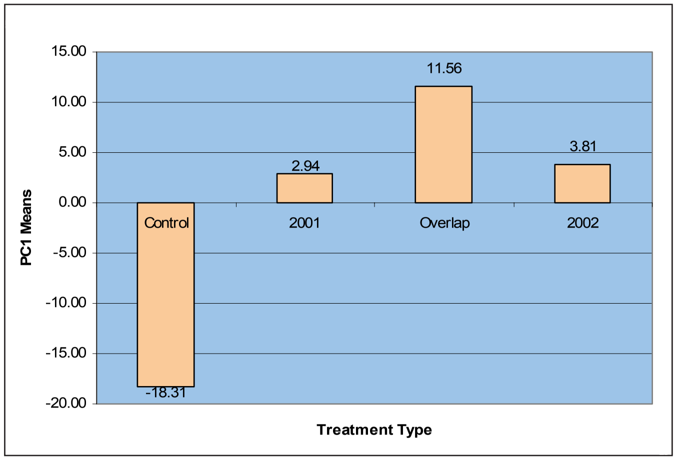

Figure 14. Means of the first principal component for the control and three treatments for data from 2003.

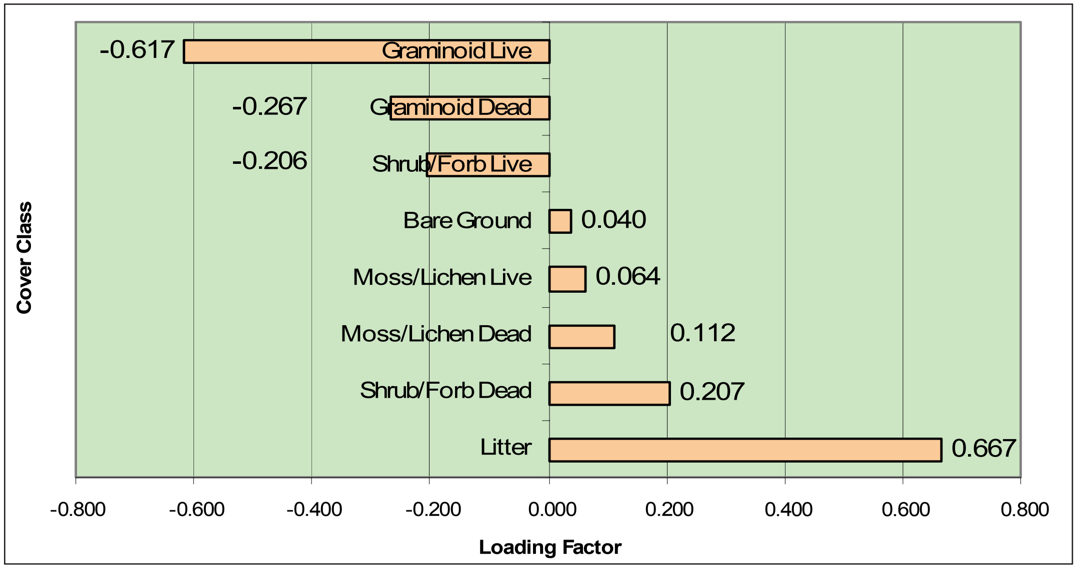

Figure 15. Cover category loadings on the first principal component for data from 2004.

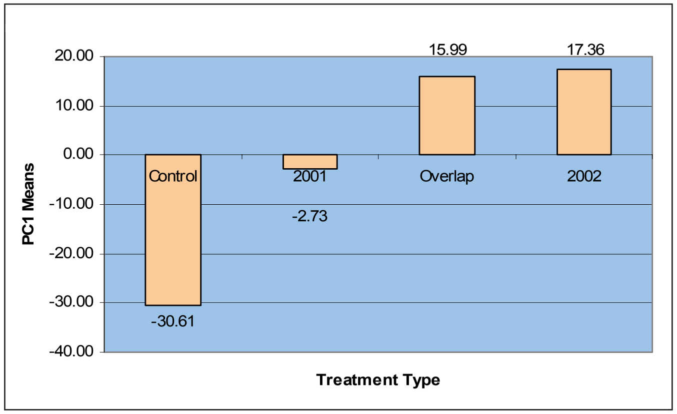

Figure 16. Means of the first principal component for the control and three treatments for data from 2004.

strongly positive (Figure 13). Live graminoids were weakly negative and live moss/lichen and bare ground were positive but so weakly as to be insignificant to $PC1_{03}$. There was significant difference among the mean plot scores for the control and three treatments for $PC1_{03}$ (Figure 14; $F = 29.91$, $p < 0.0001$), and the control was significantly more negative than the three treatments combined ($t = 9.03$, $p < 0.0001$). The comparison of the two single-road treatments versus the overlap treatment not only showed the expected trend, but this time it was statistically significant ($t = 2.86$, $p = 0.01$). Both of the single-road treatments were significantly different from the overlap treatment (2001 vs. overlap: $t = 2.61$, $p = 0.02$; 2002 vs. overlap: $t = 2.34$, $p = 0.04$). There was no difference between the means of the two single-road treatments ($t = 0.26$, $p = 0.80$).

The first principal component ($PC1_{04}$) for the 2004 cover data explained 57% of the variance in the data, which was the highest level among the three years of data. The live graminoid class loaded strongly negative on $PC1_{04}$, whereas the litter class again loaded strongly positive (Figure 15). Dead graminoid and live shrub/forb were moderately negative, dead shrub/forb was moderately positive, and dead moss/lichen, live moss/lichen, and bare ground were progressively more weakly positive on $PC1_{04}$. There was significant difference among the mean plot scores for the control and three treatments for $PC1_{04}$ (Figure 16; $F = 10.31$, $p = 0.001$), and the control was significantly more negative than the three treatments combined ($t = 5.07$, $p = 0.0003$). The comparison of the two single-road treatments versus the overlap treatment was not significant ($t = 1.02$, $p = 0.33$). The 2001 single-road treatment was marginally different from the overlap treatment ($t = 1.90$, $p = 0.08$) and the 2002 single-road treatment ($t= 2.04$, $p = 0.06$). There was no difference between the means of the 2002 single-road and overlap treatments ($t = 0.14$, $p = 0.89$).

Recording the ground cover pin “hits” to species rather than one of the eight cover classes resulted in 86 variables instead of eight. Two of the 86, litter and bare ground, were identical to the litter and bare ground classes of the prior method involving eight total classes. Many of the other 84 classes, however, occurred rarely among the 4,000 data points from four treatments across five study transects. With their consequently low covariances, the loadings of many of these (64 of 86) on the first principal component ($PC1_{sp}$) for data by species ranged between -0.01 and 0.01 (Figure 17). Litter loaded strongly positive while *E. vaginatum* (tussock sedge) live and dead (#42 and #46, respectively, in Figure 21) loaded strongly negative. *E. vaginatum* was by far the most frequently occurring species among the sedges and grasses. Cushion mosses were the most common moss type, and loadings for both live (#3) and dead (#7) cushion mosses were, relative to other moss classes, significantly positive. Live shrubs tended to load negatively, and dead shrubs tended to load positively. However, both live and dead forbs tended to load positively. Not surprisingly, the means for the control and three treatments for $PC1_{sp}$ (Figure 18) displayed nearly the same pattern as did those for $PC1_{04}$. There was significant difference among the control and three treatments ($F = 10.04$, $p = 0.001$), and the control was significantly more negative than the three treatments combined ($t = 5.00$, $p = 0.0003$). Although the trend for $PC1_{sp}$ better fit the hypothesis of an additive effect in the overlap treatment than did $PC1_{04}$, the comparison of the two single-road treatments versus the overlap treatment was still not significant ($t = 1.59$, $p = 0.14$). The 2001 single-road treatment was more negative than the overlap treatment ($t = 2.19$, $p = 0.05$), but not significantly more so than the 2002 single-road treatment ($t = 1.62$, $p = 0.13$). There was no difference between the means of the 2002 single-road and overlap treatments ($t = 0.57$, $p = 0.58$).

The second principal component ($PC2_{pooled}$) for the pooled cover data (2002–2004) explained 26% of the variance in the data. The litter class loaded strongly positive on $PC2_{pooled}$, dead shrub/forb and dead moss/lichen were weakly positive, and bare ground and live moss lichen were positive but relatively insignificant (Figure 19). Live shrub/forb was moderately negative and the live and dead graminoid classes were even less strongly negative. There was significant difference among the means for the control and three treatments for $PC2_{pooled}$ (Figure 20; $F = 21.57$, $p < 0.0001$), and the control was significantly more negative than the three treatments combined ($t = 7.68$, $p < 0.0001$). The expected relationship among the two single-road treatments and the overlap was apparent, but not statistically significant ($t = 1.82$, $p = 0.09$). The 2001 single-road treatment was significantly different from the overlap treatment ($t = 2.34$, $p = 0.04$), but neither of the other two paired comparisons of treatments were.

There was also a significant year effect for $PC2_{pooled}$ ($F = 7.62$, $p = 0.002$). As for $PC1_{pooled}$, this was due to a difference between the data from 2004 and those of the other two years (2002 vs. 2004: $t = 3.78$, $p = 0.0005$; 2003 vs. 2004: $t = 2.74$, $p = 0.009$). There was no difference between 2002 and 2003 ($t = 1.03$, $p = 0.31$).

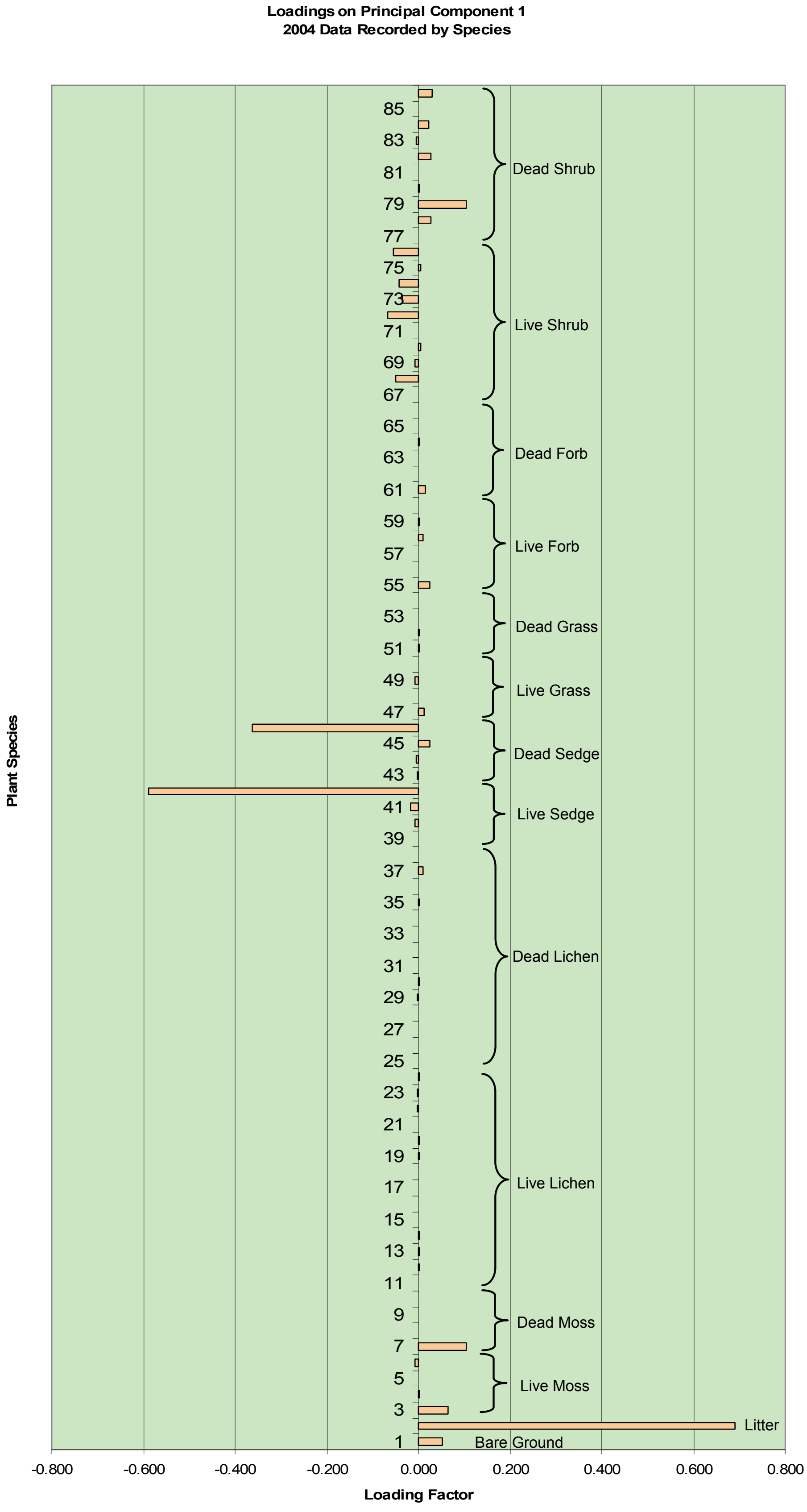

Figure 17. Cover type loadings on the first principal component for data by species in 2004. See Appendix A for key to plant species identifying numbers.

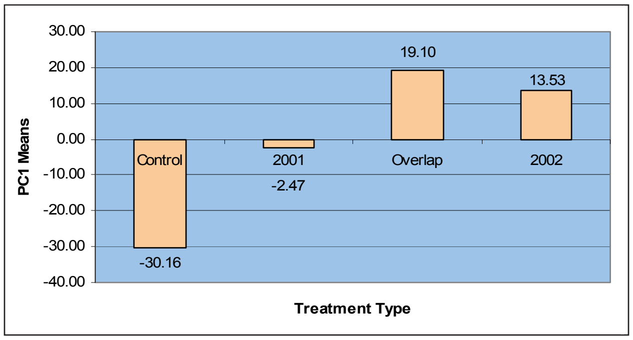

Figure 18. Means of the first principal component for the control and three treatments for data by species in 2004.

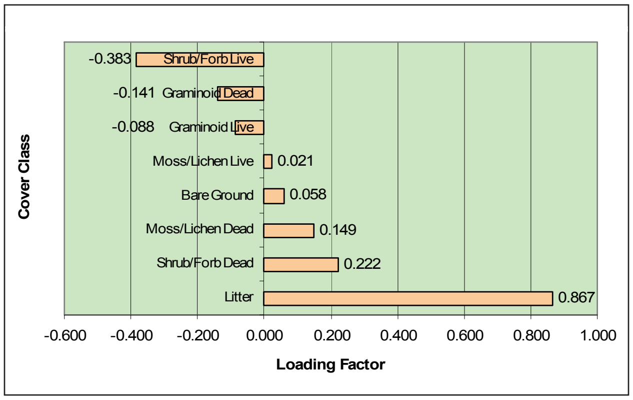

Figure 19. Cover category loadings on the second principal component for pooled data from 2002–2004.

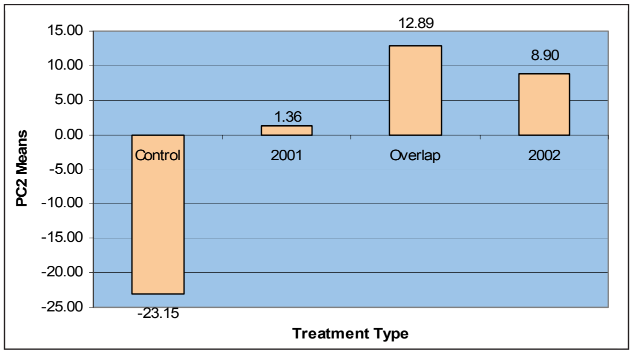

Figure 20. Means of the second principal component for the control and three treatments for pooled data from 2002–2004.

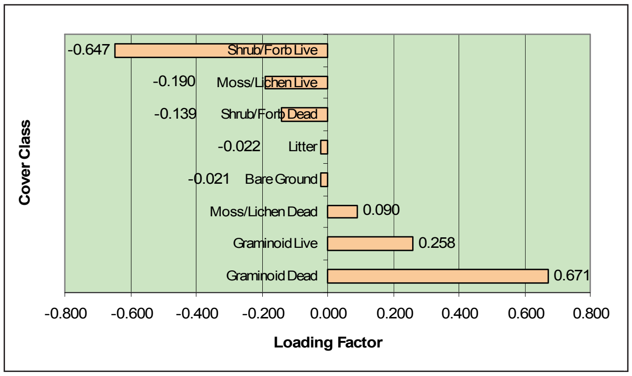

Figure 21. Cover category loadings on the second principal component for data from 2003.

Despite the year effect, it is of little value to look at PC2 for data collected in each year separately. PC2 accounted for 24% to 33% of the variance in the three individual, yearly data sets. This is a significant proportion of the overall variance, but unfortunately it is difficult to interpret what characteristics of ground cover are represented by PC2 for any of these analyses (see “Discussion” section). For example, the live shrub/forb class loads significantly negative on $PC2_{03}$ for the 2003 data, but live and dead (still standing) graminoid classes both load positively (Figure 21). Having these different indicators of healthy tundra vegetation on opposite ends of the spectrum is not readily explainable, i.e., the variance explained by $PC2_{03}$ is not likely an effect of the treatments. For this reason, no further analyses of PC2 data are presented.

Discussion

Depth of Thaw

Studies conducted in the ANWR following seismic exploration in 1984 and 1985 showed that the depth of thaw was significantly greater in seismic trails than in control plots in the initial summer following disturbance, and that thaw depths increased between the initial summer and 1988 (Felix et al., 1992). Differences between controls and trails were up to 12 cm, and usually in the range of 7–12 cm. Depth of thaw was positively correlated with disturbance level. Although thaw depth was significantly greater in trails than in controls for all study sites combined, about 25% of the study sites had no significant difference, and six highly disturbed sites showed depth of thaw shallower than their controls in 1991 (Emers et al., 1995). In the latter sites, dead sedge leaves may have increased insulation of the ground. Sample sizes were larger for these ANWR studies than for this study.

In the path of an ice road built in the NPR-A in 1978, thaw depths were greater than on nearby control plots during the first summer following construction (Lawson, 1979) and ranged from imperceptible to 4–6 cm on some slopes while being 4–20 cm in poorly drained areas. Pullman et al. (2005) found significantly greater thaw depths (2–5 cm) in ice road plots versus controls in the first summer following road construction, but no significant differences in the second summer. Observations of ice roads in Canada (Everett, K.R., unpublished data, in Walker et al., 1987) suggest that thaw depths return to pre-impact depths within a few years.

There are several possible hypotheses for why depth of thaw may differ between ice road plots and controls. During spring thaw, the ice road may remain on the tundra for a week or more after the surrounding snow has melted. This would result in greater depth of thaw in control plots, but the opposite was found in both of the above ice road studies. Perhaps any effect of delayed melt is present for only a brief time in early summer.

Alternatively, compressed or dead vegetation in the path of a previous winter's ice road may provide less insulation from summer air temperatures or less shading from the sun than undisturbed vegetation, leading to greater depth of thaw on disturbed plots. Color changes in the tundra surface caused by vegetation death, delayed vegetation green-up, or exposure of soil could change solar input to the ground. Depending on whether color changes to a darker or lighter cast compared to surrounding tundra, this may lead to a greater or lesser depth of thaw. Our observations (Figure 22) were that vegetation in the path of a previous winter's ice road has a light brown cast compared to the surrounding tundra in the first summer following ice road construction, but a dark gray cast in following summers.

Regardless, our study failed to demonstrate any additive impacts from two years of ice road construction in the overlap treatment, or any other significant relationship among control and treatments. Since the same trend among treatments is apparent in each of the three years, it is possible that a larger sample size could result in statistically significant differences. However, the range of difference among control and treatments in any one year is only 2.5–3.5 cm. Pullman et al. (2005) argued that since inter-annual variation in thaw depths (8–13 cm) was greater than within-year/between-treatment differences (2–5 cm), the latter were probably not ecologically relevant.

Also, even if our observed differences are real, the trend among the three ice road construction treatments (depth in 2001 > overlap > 2002) does not reflect an additive effect of two years of road in the overlap. If real, it may reflect some difference in construction methods or technique between the two years, with greater impacts resulting from the 2001 road (but see "Damage to Tussocks" results and discussion). We do not know, however, if there were any differences in construction technique. Alternatively, if depth of thaw increases with time in disturbed areas (Felix et al., 1992), the 2001 treatment has had an extra year of thawing. However, that would not explain the shallower depth of thaw in

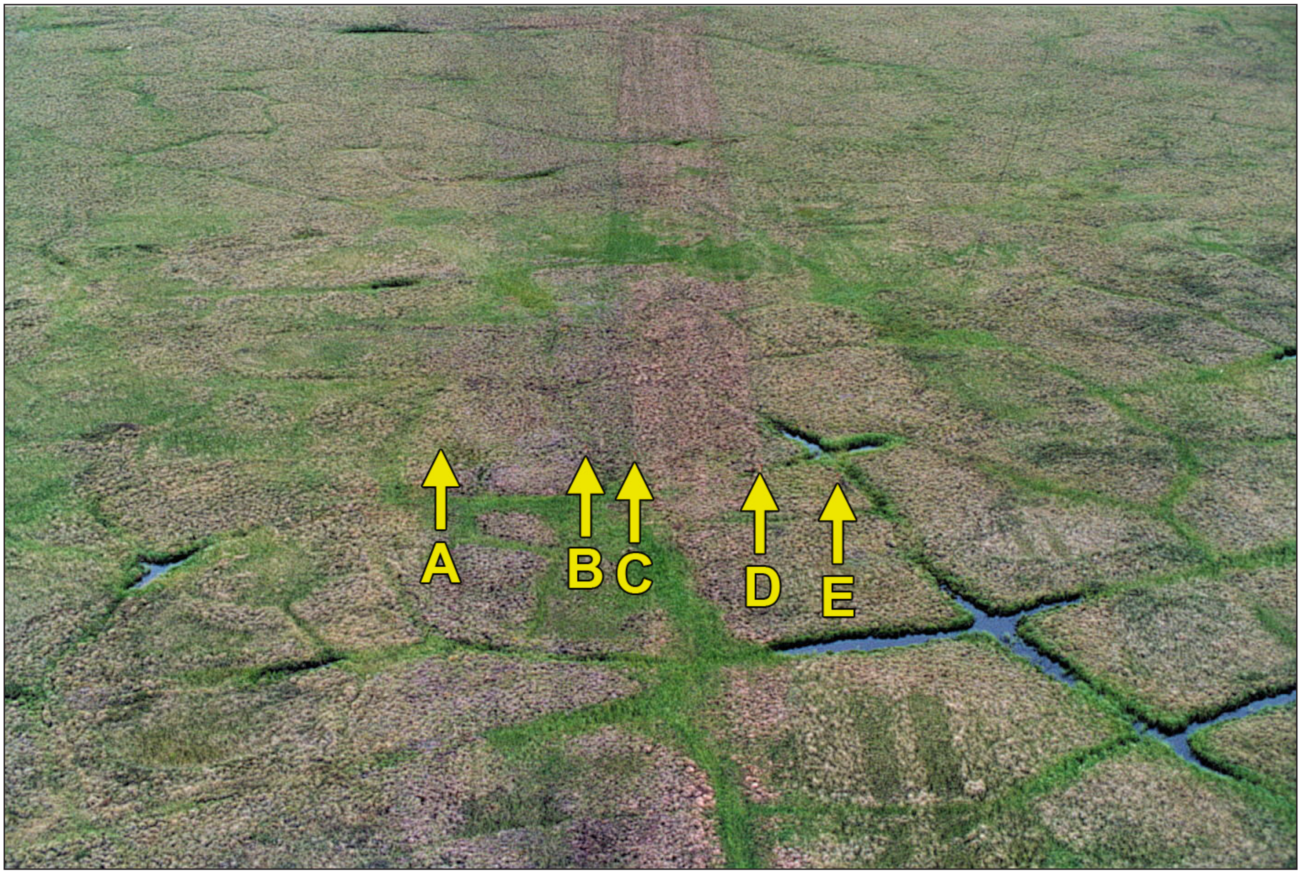

Figure 22. Aerial photo of one of the tussock tundra study sites (TT-18), taken August 8, 2002. Arrows point to wooden stakes marking the treatment boundaries. (A-B: 2001; B-C: overlap; C-D: 2002; D-E: control)

the overlap treatment. Perhaps the lighter color of the ice road path in the first summer following construction (Figure 22), before the dead vegetation weathers and darkens, increases the albedo and temporarily counteracts any effect of the disturbance. This might explain the trend observed in 2002, but fails to explain the continuation of that trend in following years when there is no apparent difference in color among treatments (Figure 23).

There was a significant overall increase in depth of thaw (5–7 cm) during the study period (2002–2004; Figure 4). This is twice the difference observed, though not statistically significant, for comparisons among treatments within years (Figure 5). This cannot be explained by the time of data collection during each summer. Data were collected more than one week later in 2002 than in the other two years, allowing more time for the ground to thaw before measurement, yet 2002 displayed the shallowest thaw of the three years. This could be explained by increased depth with time (Felix et al., 1992; but see Walker et al., 1987, above) or a change in weather over the three years, i.e., an increasingly greater accumulation of heating degree days. The latter is consistent with the overall pattern of warming observed in the Alaska Arctic over the last few decades. Perhaps both factors are at work here, since increased depth of thaw also occurred in the control, but less so than in any of the treatments.

Damage to Tussocks

The large difference between the control and the three ice road treatments in terms of damaged tussocks was not only expected, but known from observations of previous ice roads by us and others. Lawson (1979) referred to tussocks as being compressed, torn, or ripped, and Walker et al. (1987) referred to tussocks from the same study as being abraded or crushed. Similar damage was observed in two studies implemented simultaneously to this one (Guyer and Keating, 2005; Pullman et al., 2005). Indeed, that is why areas with tussocks, as opposed to wet or flooded tundra, were important to this study. Tussocks are predisposed to damage because they represent microrelief on the tundra susceptible to flattening (Walker and Webber, 1980). Noel and Pollard (1996) similarly recognized strangmoor ridges as another form of higher microtopography that can be affected by ice construction through scraping and compression.

As for the data on depth of thaw in this study, our measure of tussock damage failed to demonstrate an

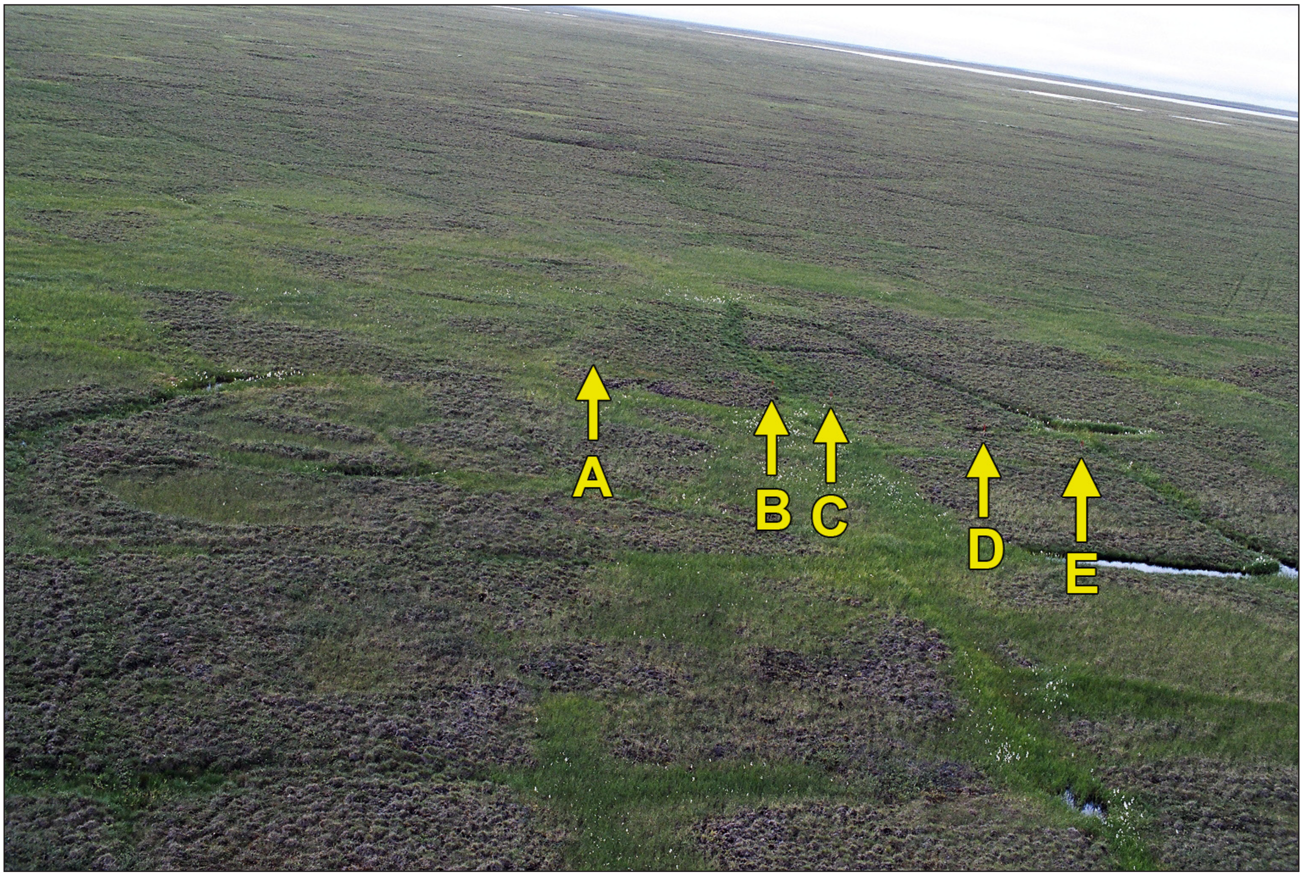

Figure 23. Aerial photo of TT-18 taken August 2, 2004. Arrows as in Figure 22.

additive impact in the area with two years of road construction versus those areas with only one year. This comparison was marginally significant when the data for all three years were pooled, but this is largely due to the much lower level of damage in the 2001 treatment versus the overlap or the 2002 treatments. The same contrast was apparent for the tests of each year analyzed separately, but none of these even approached the level of significance.

The analysis of tussocks had another aspect in common with the analysis of depth of thaw data in that there was a significant change from year to year. The most likely explanation in this case, however, has little if anything to do with differences in weather. The reduced level of damage to tussocks measured from one year to the next is best explained by recovery of the tussocks. The same trend was apparent in each of the treatments but not in the control, which implies it was a phenomenon occurring in the impacted areas only, and not widely across the tundra. Although crushed tussocks remained crushed over this short a period, scuffed tussocks often moved out of the "damaged" category due to new growth. Walker et al. (1987) noted that tussocks damaged by an ice road built and used in 1978 were recovering when they returned three years later in 1981. However, there remained areas of numerous dead tussocks comprised mostly of those that had been severely crushed or broken. These observations were similar to ours. In 2002, Guyer and Keating (2005) looked at the same 1978 ice road route and reported the ice road trace "was difficult to locate because of its faint to non-existent signature on the ground after 24 years of vegetation recovery."

The observed, but not statistically significant, trend for greater damage in the overlap treatment as compared to the two single-year road treatments may also be due to recovery over time more so than to additive impacts in the overlap treatment. In 2002, the measured damage was actually slightly greater in the 2002 than the overlap treatment, and both were significantly greater than the 2001 treatment. In this case, only the 2001 treatment had had more than a partial growing season to recover between impact and measurement. In 2004, the 2001 treatment again showed significantly less damage than the other two. By this time it had benefited from recovery during 3+ growing seasons as opposed to only 2+ growing seasons for the other two. In none of the three years were the differences between the overlap and 2002 treatments significant. Thus recovery time is a more efficient explanation of any differences, perceived or real, among the three treatments than is additive impact in the overlap treatment.

The results of the depth of thaw measurements suggested that the 2001 road construction had a greater impact on the tundra than did the 2002 construction. This was not corroborated by the tussock damage data, which displayed the opposite trend. Even if recovery time has a strong effect on observed tussock damage, it seems unlikely that it could not only mask but reverse any greater impact of construction in the winter of 2001. The best explanation for the greater depth of thaw in the 2001 treatment may remain sampling error, i.e., random chance, although increasing depth of thaw with time cannot be ruled out as a potential factor.

Ground Cover

Since the dead graminoid class primarily represents standing dead biomass of undisturbed sedges and grasses (Figure 2), it makes intuitive sense that it would load on $PC1_{pooled}$ in association with the live graminoid, live shrub/forb, and perhaps the live moss/lichen classes, and that this group would contrast with an alternative group consisting of the dead moss/lichen, bare ground, and dead shrub/forb classes (Figure 9). However, it does not make sense that the litter class would load in association with the "less disturbed" classes. Litter certainly occurs in undisturbed tundra, but it is more obvious in disturbed areas, where the canopy of graminoids and shrub/forbs has been reduced and the litter can more readily be seen from above (Pullman, 2005). The same is true for the bare ground and dead moss/lichen classes, and to a lesser extent, even the live moss/lichen class.

Principal components analysis of the cover data from all three years pooled does not support the hypothesis that additive impacts occur from building an ice road over the top of the path from the previous year's road. It is reassuring to see that the control is influenced more heavily by the "less disturbed" classes than are any of the three treatments (Figure 10) for $PC1_{pooled}$, but nonetheless, additive impacts are not demonstrated by an appropriate trend among treatments. Such a trend would have the overlap treatment as most divergent from the control, with the two single-road treatments at some intermediate level. Not too much can be made of the apparent differences among treatments, however, since none of those comparisons are statistically significant.

Because the very strong year effect for $PC1_{pooled}$ may be masking some differences among treatments within a year, we also examined the data on a year-by-year basis. The eight cover classes load onto $PC1_{02}$ (Figure 11) in the associations intuitively expected (above), to include litter among the "more disturbed" grouping.

Furthermore, the apparent trend among the control and three treatments (Figure 12) also matches the relationship expected given the hypothesis of additive impacts in the overlap treatment, but this trend is not significant. Again, the analysis fails to reject a hypothesis of no additive impact in the overlap treatment. It is possible that in fact there is no such effect, or that our sample size of five study sites has insufficient power to detect that effect from among the other variance, or "noise," in the data.

There is one indication that comes out of the 2002 cover data with a higher degree of certainty. The single-road treatment from 2001 displays less indication of disturbance than does either the 2002 treatment or the overlap. This could be due to either a difference in construction techniques between the two years, or an extra growing season for recovery by the 2001 treatment, or some combination of both. A difference in construction techniques is somewhat questionable, given the contradiction seen between the depth of thaw data and the tussock damage data, but the depth of thaw difference was not significant and the tussock damage data agree with the relationship seen here in the cover data. Both explanations still have some merit.

In the cover data from 2003, when the data were collected using a more rigorous technique (i.e., the pin frame rather than ocular estimation), the eight cover classes again load in the expected associations (Figure 13). The live moss/lichen loads very weakly with the "more disturbed" classes, but as explained above, that likely results from the removal of some of the canopy layer. The means of the $PC1_{03}$ data display a picture-perfect trend in support of the hypothesis for additive impacts in the overlap treatment, and this time the overlap shows significantly more disturbance than the two single-road treatments. The mean for the 2001 treatment shows slightly less disturbance than does the 2002 treatment, as was the case for the data collected in the previous year, but the difference does not approach any level of significance. It may be that no real difference exists among the two, or that another year of recovery for the younger (2002) treatment allowed it to "catch up" with the 2001 treatment (but see 2004 discussion below).

The same general associations seen for 2002 and 2003 appear again in how the cover data load on $PC1_{04}$ (Figure 15). But as for the 2002 data, the means of $PC1_{04}$ for the control and three treatments do not support the hypothesis for additive impacts in the overlap treatment because the overlap and 2002 single-road treatments show similar levels of disturbance. Both show significantly more disturbance than the 2001 single-road treatment, raising again the question as to whether the extra season post-disturbance has allowed the 2001 treatment substantial time for additional recovery.

Recording ground cover to genus or species does not provide any significant benefit in testing the hypothesis for additive impacts in the overlap treatment. The expected trend among control and treatments is apparent, but not statistically significant. However, this extra effort not only pays off in terms of distinctions within the eight cover classes, as seen in the dominance of *E. vaginatum* and cushion mosses, but especially in separating shrubs from forbs. After doing so, the live forbs load positively, reflecting an association with disturbed areas, and the means of $PC1_{sp}$ better fit the hypothesis of additive effects than do the means of $PC1_{04}$. This fits our observations of forbs colonizing areas where shrubs had been killed, and to a lesser extent, areas of damaged tussocks. Ebersole (1985) also described forbs as colonizers following disturbance.

Earlier studies of ice road impacts are not only few in number but also provide little quantitative detail of changes in ground cover. Walker et al. (1987) did note that an especially apparent impact was the alteration or destruction of the inter-tussock plant community. This is also apparent when comparing Figures 1 and 2. In contrast to the earlier studies, Pullman et al. (2005) provided quantitative data on nine cover classes that are subsets of ours: bare ground, litter, moss, lichen, sedge, grass, evergreen shrub, deciduous shrub, and forbs. Rather than comparing road overlap areas to single-year road paths, they compared two single-year paths constructed at different times during the same winter. In the summer immediately following construction, they found inconsistent differences between the two treatments. However, when comparing the two treatments to their controls, they observed within tussock tundra treatment plots significant increases in cover of bare ground and litter; significant decreases of moss, sedge, evergreen shrub and forbs; and a marginally significant decrease in deciduous shrub. Guyer and Keating (2005) described damage to grasses, shrubs, forbs and bryophytes, and especially to tussock sedges. The results of these two studies are generally comparable to ours.

To summarize the discussion of PC1, its mean plot scores in each of the three years of data collection indicate it has served as a good indicator of the relative level of disturbance among the control and three treatments. In each of the three years, the mean plot scores for PC1 reflect a far greater level of disturbance in the three treatments than in the control. PC1 also displays in all three years less disturbance in the 2001 treatment than in the overlap or 2002 treatments, suggesting some recovery from disturbance, although those differences are not consistently significant. But in only one of those three years (2003) does the pattern among treatments support the hypothesis for additive impacts in the overlap treatment.

PC2$_{\text{pooled}}$ appears to tell the same general story as PC1. Its cover class loadings again show the now familiar associations reflecting a relative scale of disturbance (Figure 19), and the control again scores on the "undisturbed" side of the scale, whereas the three treatments fall on the "disturbed" side (Figure 20). The expected trend appears in support of additive impacts in the overlap treatment, but without convincing statistics, and once again the 2001 treatment displays less disturbance than do the other two. There is also a significant year effect as for PC1, but this time things quickly fall apart when trying to interpret the PC2 loadings for any of the individual years of data collection. The relatively neat associations of cover classes into "disturbed" versus "undisturbed" groupings are not apparent (e.g., Figure 21). In the absence of any obvious interpretation of PC2, the most efficient explanation is that it reflects noise in the data.

Is there any additive impact associated with a second year of ice road construction? In the summer immediately following construction of the second ice road, the overlap area could be visibly distinguished from the two single-road areas (Figure 22). So there is an effect of overlap, but recovery of some of the vegetation occurs rapidly, making the ice road paths difficult to see in photography after two (Figure 23) or three (Figure 24) years. Crushed tussocks are still crushed, though they may have some new growth, but scuffed tussocks may have significant new growth. As observed on seismic trails (Felix and Raynolds, 1989), dwarf shrubs are affected greatly by ice road construction and may show little recovery in two years, but forbs may colonize that space (see above), returning the tundra to a perception of health. Any additive effects of building one ice road over the top of the previous road's path may be obscured in just a few years by recovery of the tundra.

Recovery in the short term has been demonstrated by other studies. Although their work occurred in the

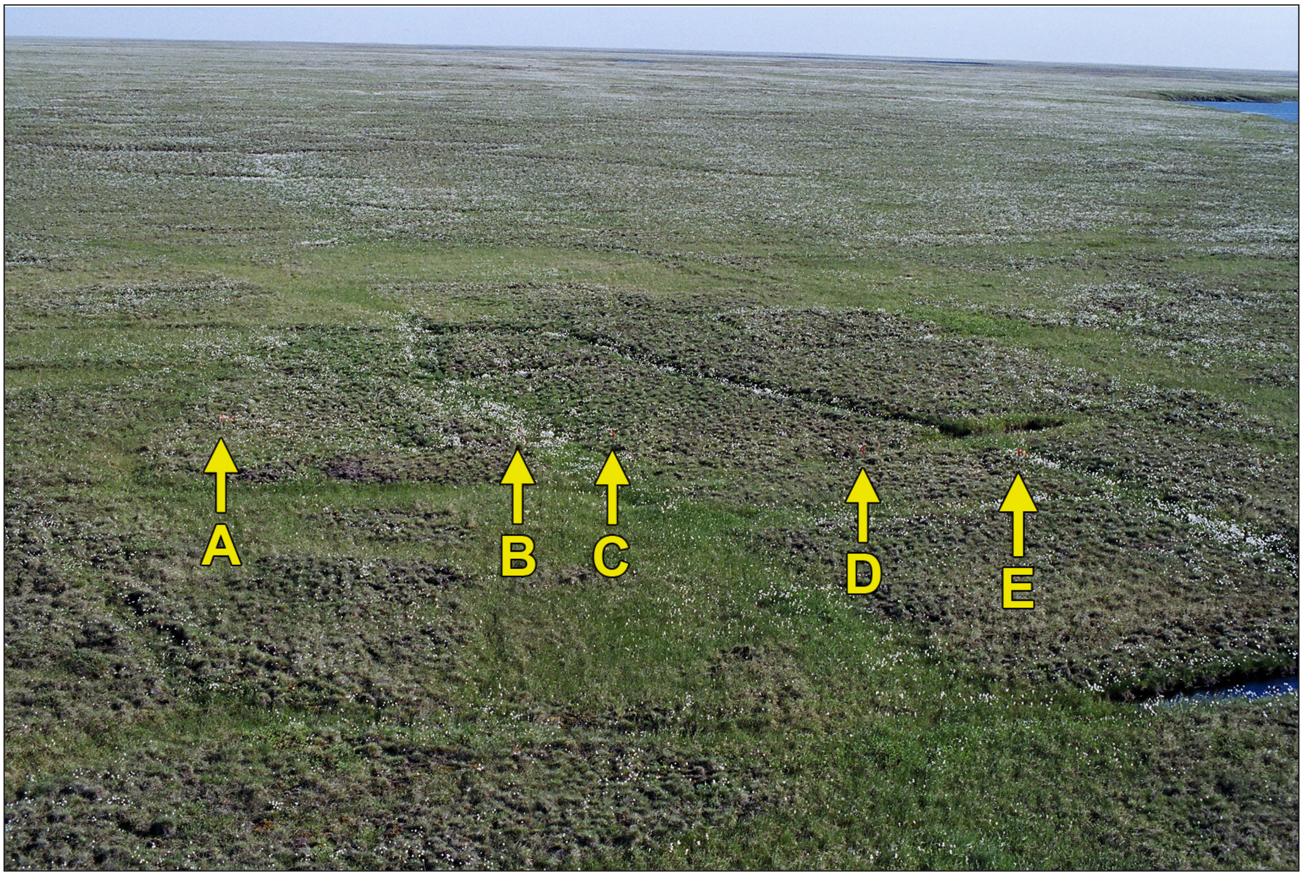

Figure 24. Aerial photo of TT-18 taken July 28, 2005. Arrows as in Figure 22. This photo was taken under better light conditions than the one in Figure 23. It also differs from both of the prior photos in that more "cotton-grass" flowers (*Eriophorum* spp.) were evident across the landscape.

boreal forest region of the Northwest Territories rather than on arctic tundra, Adam and Hernandez (1977) reported that live-plant cover increased from 11% to 16% in the summer immediately following disturbance to 31% to 44% in the following summer. Evidently the road construction technique used at that place and time, which included using a bulldozer to clear the land of trees before constructing the road, caused greater overall impacts than modern construction techniques on treeless arctic tundra. A better comparison to our study, conducted at roughly the same time and only 50 km to the east (Pullman et al. 2005), noted a 48% to 63% reduction in total live-plant cover in the ice road path compared to reference plots during the summer immediately after construction. In the following summer, total live-plant cover in ice road plots was only 23% to 43% less than in reference plots. By the time of our final data collection (2004), when the photograph in Figure 23 was taken, our study plots had had 1–2 additional years to recover than did those in the two studies above.

Conclusions and Management Implications

There are at least three important questions this study was not designed to answer either completely or at all. The first is whether it is better following two or more years of ice road construction to have less area with more severe impacts or more area with less severe impacts. Had we found strong evidence of additive impacts in the overlap treatment, we would have confirmed the validity of the question but still would not have known the answer. Instead, we found minimal evidence of "more severe" impacts, almost making the question moot. In addition, since there are no consistent differences between the overlap treatment and the 2002 single-road treatment, each of which received its last or only disturbance, respectively, in 2002, the results suggest they are recovering at similar rates.

All of this seems to make the case that ice roads may overlap from one year to the next with no significant additional impact to tundra vegetation other than retarding recovery by another year. It is important to remember, though, that these results do not prove there are no effects of overlap; all we can say for sure is that we failed to find any such effects. It would be prudent to keep this question in mind, observe these and additional ice road paths over the ensuing years as exploration and development expand in the NPR-A, and note any anecdotal evidence that suggests a reason to return to this question. It may also be of value to return to these plots again in a few years and see if depth of thaw has continued to increase, or whether the treatments have become similar to the control, as suggested by Walker et al. (1987).

The second unanswered question, and the ultimate one in terms of environmental consequences, is whether it makes any difference to the ecology of an area to have less tundra experiencing more severe impacts or more tundra with less severe impacts. Since this study was not designed to address this question at all, the response here is only speculation, but the answer is likely to be scale-dependent. If there are any additive effects of overlapping ice roads, despite our inability to measure them, there may be a consequence to populations of organisms whose range approximates the width of the ice road. These may include some invertebrates, but might be limited to non-animal organisms such as fungi or bacteria. Given the small proportion of the local or regional area that is affected by ice road construction, and the apparent rate of recovery to a level that can provide some cover and support some herbivory, it seems unlikely that overlapping versus offsetting ice roads would have any consequence to vertebrate wildlife. So at the scale at which the BLM seeks to manage the NPR-A, there is likely no difference to ecological communities.

The third question relates to impacts of overlapping ice road paths for three or more years. There is potential for this to occur if the requirement for offsetting paths from year to year is removed. The same ice road route could be used for many consecutive years during exploration and subsequent field development. Not only would this delay recovery, but perhaps it could make recovery occur at a slower rate once ice road use ends. Our anecdotal observations of the Alpine field ice road (east of the NPR-A), which was used in several consecutive years, do not suggest this is a concern, but no rigorous test of this possibility has been conducted.

Data from this three-year study provide, at best, minimal evidence of additive impacts from building ice roads over the same path in two subsequent years. Increased depth of ground thaw may be a result of ice road construction, but these data show no additive effects at all. Yet this is the measure that may be most important to tundra vegetation in the long term. Deeper thaw can lead to changes in soil moisture that may translate into a change in plant species composition. The proportion of tussocks that were damaged do provide weak evidence of an additive effect, but only when the data for all three years are pooled. An additive effect is displayed by the ground cover data, but only in one of three years. It is conceivable that increasing the sample size of this study (beyond five transects) could lead to more convincing statistics in one direction or the other, but that would not be possible without an effort to purposely build overlapping roads. It is not likely that increasing the number of years of data collection in the short term would provide more conclusive evidence of an additive effect in overlap areas because of the ongoing recovery of the vegetation during the years of data collection. However, if depth of thaw increases in the long term, it may be measurable and cause a significant change in ground cover. If so, it would likely show an effect of ice road construction in general, but not an additive effect of overlapping ice roads. Most importantly, given the fairly rapid recovery of the tundra, it is doubtful that any significant environmental benefit will be gained by requiring that all ice roads be completely offset from paths of previous years. A more appropriate mitigation would be to require that ice road routes follow the wetter habitats to the greatest extent possible without significantly increasing their length.

Literature Cited

Adam, K.M. and H. Hernandez. 1977. Snow and ice roads: ability to support traffic and effects on vegetation. Arctic 30:13–27.

BLM (Bureau of Land Management). 1998. Northeast National Petroluem Reserve – Alaska: Integrated Activity Plan / Environmental Impact Statement. Record of Decision. U.S. Department of the Interior, Bureau of Land Management, Anchorage, AK.

Ebersole, J.J. 1985. Vegetation disturbance and recovery at the Oumalik oil well, arctic coastal plain, Alaska. Ph.D. dissertation. University of Colorado, Boulder. 408 pp.

Emers, M., J.C. Jorgenson and M.K. Raynolds. 1995. Response of arctic plant communities to winter vehicle disturbance. Can. J. Bot. 73:905–919.

Felix, N.A. and M.K. Raynolds. 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., M.K. Raynolds, J.C. Jorgenson and K.E. DuBois. 1992. Resistance and resilience of tundra plant communities to disturbance by winter seismic vehicles. Arctic and Alpine Research. 24:69–77.

Fisher, E.N. 1978. Ice aggregate road construction. Pp. 176–189 in M.N. Evans, ed., Proceedings of the symposium: surface protection through prevention of damage (surface management); focus: the Arctic Slope. Bureau of Land Management, U.S. Dept. of the Interior, Anchorage, AK. BLM/AK/PROC/78/01. vi + 296 pp.

Guyer, S. and B. Keating. 2005. The impacts of ice roads and ice pads on tundra ecosystems, National Petroleum Reserve – Alaska. BLM-Alaska Open File Report 98, BLM/AK/ST-05/012+3130+971. Anchorage, AK. viii + 56 pp.

Hazen, B. 1997. Use of ice roads and ice pads for Alaskan arctic oil exploration projects. Pp. 1-11 to 1-13 in NPR-A symposium proceedings: science, traditional knowledge, and the resources of the Northeast Planning Area of the National Petroleum Reserve - Alaska. OCS Study MMS 97-0013. Minerals Management Service, Anchorage, AK.

Jorgenson, J.C. 2000. Long-term monitoring of recovery of trails from winter seismic exploration. Arctic Research 14:32–33.

Jorgenson, J.C., B.E. Reitz and M.K. Raynolds. 1996. Tundra disturbance and recovery nine years after winter seismic exploration in northern Alaska. Unpubl. Report. U.S. Fish and Wildlife Service, Fairbanks, AK.

Jorgenson, M.T. 1999. Assessment of tundra damage along the ice road to the Meltwater South exploratory well site. Unpubl. rept. prepared for ARCO Alaska, Inc., Anchorage, AK, by ABR, Inc., Fairbanks, AK. 11 pp.

Lawson, D.E. 1979. Tundra disturbances and recovery following exploratory drilling, National Petroleum Reserve – Alaska; summaries of CRREL field investigations – 1977 and 1978. Unpubl. CRREL Report. U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, NH. 13 pp.

Lawson, D.E. 1982. Long-term modifications of perennially frozen sediment and terrain at East Oumalik, northen Alaska. CRREL Report 82-36. U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH. vii + 33 pp.

Lawson, D.E. 1986. Response of permafrost terrain to disturbance: a synthesis of observations from northern Alaska, U.S.A. Arctic and Alpine Research 18:1–17.

Lawson, D.E., J. Brown, K.R. Everett, A.W. Johnson, V. Komarkova, B.M. Murray, D.F. Murray and P.J. Webber. 1978. Tundra disturbances and recovery following the 1949 exploratory drilling, Fish Creek, Alaska. CRREL Report 78–28. U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH. x + 81 pp.

Noel, L.E. and R.H. Pollard. 1996. Yukon Gold ice pad tundra vegetation assessment: 1993 through 1995. Unpublished final report. LGL Alaska Research Associates, Inc., Anchorage, AK. 73 pp.

Pullman, E.R., M.T. Jorgenson, T.C. Cater, W.A. Davis and J.E. Roth. 2005. Assessment of ecological effects of the 2002–2003 ice road demonstration project, 2004. Final report prepared for ConocoPhillips Alaska, Inc., Anchorage, AK, by ABR, Inc., Fairbanks, AK. v+34 pp.

Walker, D.A., D. Cate, J. Brown and C. Racine. 1987. Disturbance and recovery of arctic Alaskan tundra terrain; a review of recent investigations. CRREL Report 87-11. U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, NH. v+63 pp.

Walker, D.A. and P.J. Webber. 1980. Vegetation. pp. 24–34 in D.A. Walker, K.R. Everett, P.J. Webber and J. Brown (eds.). Geobotanical atlas of the Prudhoe Bay region, Alaska. CRREL Report 80-14. U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, NH. 69 pp.

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Appendix A.

List of species and growth forms included among the ground cover data from 2004, and the identification number for each as seen in Figure 17.

Species Name or Growth Form	I.D. No. Live	I.D. No. Dead
Bare Ground	n/a	1
Litter	n/a	2
Mosses		
Cushion mosses (>50% *Aulacomnium turgidum*? Next most common: *Ceratodon purpureus*?)		
cushion moss	3	7
Polytrichum spp.	5	9
Feather mosses	4	8
Sphagnum spp.	6	10
Lichens		
lichen (dead; not discernible)	21	35
Crustose lichens	14	28
Foliose lichens		
Peltigera apthosa	22	36
Peltigera scabrosa	23	37
Fruticose lichens		
Alectoria ochroleuca	11	25
Cetraria cucullata	12	26
Cetraria islandica	13	27
Cladina rangiferina	16	30
Cladina spp.	15	29
Cladonia spp.	17	31
Cladonia squamulosa	18	32
Dactylina arctica	19	33
Evernia perfragilis	20	34
Thamnolia spp.	24	38
Monocots		
Sedges (Cyperaceae)		
Carex aquatilis	39	43
Carex bigelowii	40	44
Eriophorum angustifolium	41	45
Eriophorum vaginatum	42	46
Grasses (Poaceae)		
Arctagrostis latifolia	47	51

Species Name or Growth Form	I.D. No. Live	I.D. No. Dead
Dicots		
Forbs		
Pedicularis capitata	56	62
Polygonum bistorta	55	61
Pyrola grandiflora	57	63
Saussurea angustifolia	58	64
Senecio atropurpureus	59	65
Stellaria laeta	60	66
Shrubs		
Arctostaphylos rubra	67	77
Betula nana	68	78
Cassiope tetragona	69	79
Dryas integrifolia	70	80
Empetrum nigrum	71	81
Ledum palustre ssp. *decumbens*	72	82
Rubus chamaemorus	73	83
Salix planifolia ssp. *pulchra*	74	84
Salix rotundifolia	75	85
Vaccinium vitis-idaea	76	86