

**MEASURING CHANGES IN TUNDRA CANOPY STRUCTURE  
FOLLOWING WINTER OFF-ROAD TRAVEL ACTIVITIES IN  
ARCTIC ALASKA:  
A Comparative Study of Traditional and  
Digital Image Sampling Methodologies**

**By**

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## TABLE OF CONTENTS

List of Figures .....	ii
List of Tables .....	ii
Acknowledgements .....	iii
Introduction .....	1
Objectives .....	3
Justification .....	4
Background .....	6
Methods .....	7
Point Sampling .....	8
Image Sampling .....	10
Results .....	15
Point Data .....	17
Image Data .....	18
Discussion .....	20
Conclusion .....	22
Literature Cited .....	24

## **LIST OF FIGURES**

1.1	Photo illustration of ‘greening’ effect following winter travel.....	5
2.1	General study area reference map.....	8
3.1	Photo illustration of point sampling technique.....	10
4.1	Photo illustration of through canopy perspective.....	12
4.2a	Photo illustration of cropped image plot dimensions.....	14
4.2b	Photo illustration of image plot following removal of background material.....	14
4.2c	Photo illustration of 2 class k-means classification algorithm.....	14
4.2d	photo illustration of green band extraction classification.....	14
5.1	Box plot distributions of point sampled data; total canopy cover.....	17
5.2	Box plot distributions of point sampled data; minus standing dead components.....	18
6.1	Box plot distributions of image data; total canopy cover.....	19
6.2	Box plot distributions of image data; minus standing dead components.....	20

## **LIST OF TABLES**

1.1	Basic statistics for point and image data; estimates of total canopy.....	16
1.2	Basic statistics for point and image data; estimates of standing dead material.....	16

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## **Introduction:**

Seismic surveys in Alaska's Arctic provide a valuable component to industry's continued exploration for energy resources. Surveying is conducted using both wheeled and tracked vehicles. The impacts of using these vehicles for off-road travel may range from essentially zero impact to complete removal of the surface organic mat and vegetative material. In an effort to reduce the level of environmental impact, state and federal laws currently restrict the timing of seismic operations. Surveying is permitted only during winter months when the ground has reached a minimum freezing depth of 12 inches with at least 6 inches of snow cover.

Improvements in subsurface mapping technology have greatly altered the manner in which seismic operations are conducted. The quality of collected data has been improved while the severity of surface disturbance has decreased in recent years (Jorgenson et al., 2003). Most notable has been the development of 3-D mapping techniques; carried out using vehicles equipped with large vibrating plates. Vibrosies vehicles provide an alternative to drilling and blasting techniques used in the past to collect subsurface resonance data. Vehicles have also been re-fitted for travel by removing cleats, using rubber tracks and low pressure tires. Improvements such as these have served to reduce surface damage to the tundra.

While the overall severity of disturbance has been reduced by regulatory actions and improved technologies, the extent of potential ground cover disturbance has increased (Jorgenson et al., 2003). In the past, 2-D surveys were used in field data collection. Typically the spacing of tracks in 2-D operations was on the order of approximately 2 km between survey lines. 3-D mapping, more widely used today, has a much closer spacing between survey lines, typically on the order of a few hundred meters between tracks. This higher density increases the total potential coverage area of surface impacts.

The degree to which terrain is impacted varies greatly depending on several variables including: vegetation type, micro-relief, soil moisture at freezing, snow cover, type of vehicle and number of passes over a given area. Vegetation most susceptible to damage has shown to be evergreen shrubs, followed by willows, tussock tundra and lichen (Felix and Raynolds, 1989). Generally as soil moisture decreases and/or micro-relief increases, so does the degree of disturbance. Areas of higher relative elevation such as tussocks or polygon rims have less snow cover. These areas are at a higher risk for disturbances such as crushing or breaking of tussocks and shearing of the organic surface mat. Effects of this nature have a longer recovery time and potential for compounded disturbances related to changes in albedo, thermokarsting, and active layer thaw depth (Brown, 1976).

Wet sedge meadows are typically the least affected by winter travel due to the high soil moisture content and relatively flat terrain. Crushing of standing dead from the plant canopy is the dominant form of initial impact in meadow communities. Less standing dead in the canopy results in strips of apparently greener vegetation in contrast to the surrounding landscape (Figure 1.1). While ecological damage is limited in wet sedge meadows, the visibility of trails is often more prominent than in other vegetation types, and may be objectionable for aesthetic reasons (Brown, 1976; Abele et al., 1984). Uniformity of terrain provides for a continuity of disturbance throughout meadow communities. Disturbances in other vegetation types such as tussock tundra is less regular, while more severe in nature, disturbances are often at a lower frequency and discontinuous across the landscape.



Figure 1.1: Initial 'greening' effect from winter season off-road activity.

### **Objectives:**

The purpose of this study was to document the initial change in vegetative canopy cover following winter seismic exploration on the North Slope of Alaska. The study conducted herein focuses solely on the impact to wet sedge meadow vegetation.

The overarching goal of this study is to contribute some level of ecological understanding with regards to the impacts associated with winter travel.

Objectives specific to the methodologies conducted herein include:

1. To document initial change in canopy structure of wet sedge meadow communities following disturbance through the use of traditional point sampling methods.
2. Extract canopy structure measurements through the analysis of digital images.

3. Assess the quality of canopy measurements produced from digital images with reference to those of point sampling.

Documenting the initial level of impact is an important first step in addressing concerns over off-road activities. In order to better understand the degree to which tundra systems are influenced by winter travel, continued monitoring of disturbed sites would help provide agency personnel with valuable information to more effectively regulate standards involved in the permitting of travel activities. Industry would also benefit from continued monitoring efforts; being provided with valuable insight to improve methods of travel and limit the extent or level of environmental impact.

Change detection and monitoring studies of this nature would ideally consist of several years of repeat sampling. Time constraints in this instance limited data collection to a single field season. The study design, however, was laid out in fashion to be consistent with a longer term, multiple year research project. Additional ancillary data were collected at each site location to support a broader research base and more thoroughly document site history conditions. Not all of the field data were utilized or reported in this paper.

**Justification:**

Several state and federal agencies are responsible for regulating industry operations on the North Slope. Any activity with the potential to disturb environmental conditions must be documented as to the degree and type of potential impact. Agency personnel issue permits for industry activity based on review of these impact statements. The development of North Slope



energy resources greatly accelerated the amount of environmental research pertaining to arctic ecosystems (Gilders and Cronin, 2000). Industry relies on this research to improve operating procedures and minimize environmental impacts. Regulatory agencies also require extensive environmental databases to effectively manage industry activities.

Since early exportation activities began in Alaska in the 1940's, off-road travel has remained as one of the most prevalent forms of surface disturbance in Polar Regions (Forbes, 1998). Because of its widespread use, winter travel is a concern for many local residents, agency, and environmental groups (Jorengson et al. 2003).

The network of 'green' trails (Figure 1.1) from off-road travel indicates a potential for long-term impacts to the tundra. Several studies have been conducted in order to document the effects of winter travel (Brown, 1976; Felix and Raynolds, 1989; Forbes, 1998; Jorgenson, 2003). In regions dominated by permafrost, temperature is the deterministic variable responsible for regulating vegetative production (Truett, 2000). The reduction of tundra canopy biomass following off-road travel may alter the thermal energy balance of local environments (Forbes, 1998). Changes in thermal conditions may lead to compounded long-term modifications of local site conditions, including; increased soil nutrient availability, depletion of organic carbon and soil nitrogen reserves, changes in pH, and subsidence of soil ice masses resulting in fluvial erosion (Forbes, 1997). Species composition and even entire community types may experience a shift as a result of these changes.

Intensive long-term monitoring programs to correlate initial disturbance levels with compounded environmental effects have not been widespread. The majority of our knowledge regarding long-term impacts has come from a single U.S. Fish and Wildlife study of 2-D seismic

exploration conducted in the Arctic National Wildlife Refuge during the winters of 1984 – 1986 (Emers and Jorgenson, 1997).

### **Background:**

The North Slope of Alaska comprises a vast expanse (over 200,000 square kilometers) of inimitable landscapes. Despite the relatively inaccessible extent of roadless terrain and harsh climatic conditions, this patch of arctic tundra has been the focal point of a great deal of environmental research; perhaps more intensely studied than any other arctic region (Truett, 2000).

Intensive ecological studies relating to disturbance began on the North Slope with the discovery of the Prudhoe Bay oil field in 1968. Prior to development of Prudhoe Bay, relatively few research studies regarding ecological processes of arctic tundra ecosystems had been conducted in Alaska (McKendrick, 2000). Major environmental initiatives prior to the 1970's included research conducted by the U.S. Naval Arctic Research Laboratory (NARL) at Point Barrow in 1947, and the Atomic Energy Commission (AEC) at Cape Thompson in 1958. The research conducted by NARL and the AEC provided valuable groundwork describing general plant, animal, soil, and climate conditions in the region (Brown, 1987).

The earliest significant anthropogenic disturbance activities on the North Slope began in the 1940's with the U.S. Navy's oil exploration west of the Colville River delta in what would later become the National Petroleum Reserve – Alaska (NPRA). Much of the early work done in Alaska's Arctic was carried out with little regard for environmental consequences (McKendrick, 2000). Disturbance regimes included the construction of gravel drilling pads and airstrips, burying vegetation with drilling muds and wastes, driving tracked vehicles over the tundra and

constructing peat roads to move equipment during winter months. Exploration continued with varying intensity through the 1970's. Still today, exploration of Alaska's Arctic continues, though the technology and methods used have evolved over time to alter the degree and manner of environmental disturbance.

## **Methods:**

Seismic surveys were conducted during the winter of 2002-03 in the greater Prudhoe Bay region (Figure 2.1). Site selection was based on accessibility from the existing road network. A total of 18 locations consisting of an in-track and reference plot were identified for study. All sampling sites were located in the same vegetation class of wet to moist sedge polygonal tundra to minimize variability. Each location consisted of a 0.25m<sup>2</sup> square plot frame. Frames were placed both within an identifiable track line and in the adjacent undisturbed tundra.

Two different sampling methods were used to extract measures of canopy structure: a traditional method of point-frame sampling and an exploratory method using digital imagery classification procedures. Illustrations of the two procedures are provided in Figures 3.1 and 4.1.

Using images to extract canopy measurements has several potential benefits over traditional methods. Less time consuming than traditional point sampling, a greater number of field samples can be obtained for analysis. Additionally, many tundra disturbances are in remote locations requiring the use of helicopter support to conduct field studies. As helicopter support is relatively expensive, there would be a definite cost benefit by reducing the amount of time required for field sampling. Images would also provide a hard copy of field conditions available for re-sampling or additional analysis following the initial collection.

Each method of data collection was analyzed independently to test for significant differences between the disturbed and undisturbed site locations. The methods were also compared against one another to assess the quality of image collection and analysis procedures. All statistical analyses were carried out using SYSTAT 8.0.

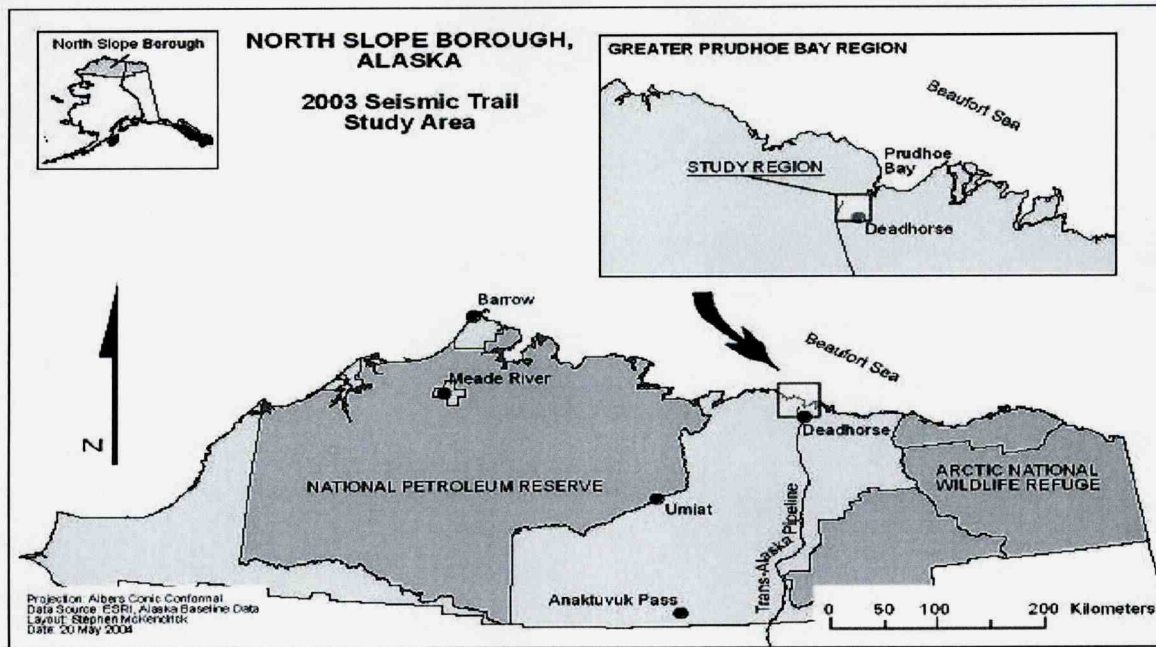


Figure 2.1: Reference map of the Greater Prudhoe Bay region and general area of study.

## POINT SAMPLING

Point sampling, in varying forms, has been extensively used in the ecological sciences to collect vegetative cover data (Coulloudon et al., 1999). As point sampling is widely accepted as a suitable means of measuring frequency and cover variables, the point intercept data were used in a secondary capacity to gauge the quality of information extracted from image analysis procedures.

Plot dimension is an important criteria when field sampling vegetation variables. In practice, using quadrats to estimate cover is not recommended. More commonly, transects or walking points are used to measure cover variables. When quadrats are used, however, rectangular plots are usually preferred over square or circular ones to better capture structural variability (Coulloudon et al., 1999). Wet sedge community canopy structure typically has little variability over small areas; therefore using a square plot was equally suited for point collection as a rectangular plot would have been.

A quarter-meter fitted point frame was placed inside each study plot. Sharpened 1/8 inch welding rods were used to vertically read 30 points at a 3x3 inch sampling interval within each plot. Figure 3.1 illustrates the point frame sampling technique. Vascular plant species were recorded for all live vegetation intercepts. Other point readings were noted as class values such as standing dead, moss, litter, bare ground etc. Each point reading counted the first intercept with any aerial canopy vegetation followed by a surface reading of ground cover material and, lastly, the nearest living plant species was recorded to identify composition values. Complete plot species were also collected at each site. While ground cover and composition data provide useful reference information, of primary interest to this study were the canopy intercept readings.

The type of vegetation was consistent between all study plots, allowing the 18 site locations to be grouped for further statistical analysis. All aerial intercept points were recorded according to species. Intercepts were later generalized to be identified as either live or dead material. Point readings were used to calculate canopy percentages for each plot.

Paired t-tests were applied to the percent canopy values to test for significant differences between the reference and in-track plots. Two t-tests were applied to the data. The first test compared total vegetation percentages between track and control sites. In an effort to isolate the

contribution of standing dead materials, all standing dead point readings were then removed from both the track and control cover values. A second t-test was performed to look for any significant difference between the track and reference plots following the removal of standing dead. Limiting the analysis to only live materials emphasizes that initial surface impacts do not immediately influence live canopy vegetation, and that the green trail effect is primarily a visual product of less dead, brown material in the canopy.



Figure 3.1: Example illustration of point frame sampling technique.

## DIGITAL IMAGE SAMPLING

Digital images were acquired before point readings to minimize any additional trampling of the vegetation. Images were captured from an absolute ground level, through canopy perspective (Figure 4.1). Digital pictures were taken using a Canon EOS 10D digital SLR camera equipped with a 19mm to 35mm wide angle lens. A gray vinyl backdrop was staked perpendicularly behind the plot to delineate the rear extent of the plot frame. A tarp was laid on

the ground in front of the plot to eliminate foreground vegetation from the images. Plan and oblique view images were also captured to provide additional archival data.

The method used for collecting digital data was adapted from a procedure used by J. Mckendrick (2003) in an earlier study to measure canopy changes following ice road construction in NPRA.

Several inconsistencies were evident among the plot canopy images. A series of steps were taken in order to standardize the image data as much as possible. A uniform cropping size was first necessary to provide consistent canopy percentage estimations among images.

Cropping height was selected relative to shortest average canopy height measured among plots. The shortest canopy height among all study plots was 6cm. Setting a crop height of 5cm from the top of the rear PVC plot frame border effectively provided a uniform image height. This further served to maximize stem density by limiting the field of view to the lower portion of the canopy. Additionally, this helped to eliminate some degree of variability present from senescing vegetative material. Dominated primarily by sedges, which senesce downward from the leaf tips, limiting the field of view to the lower portions of the canopy eliminated some degree of the current season's dead material from the images that would interfere with later classification procedures. Image width was cropped at a length of 50cm, equal to the rear plot frame border (Figure 4.2a).



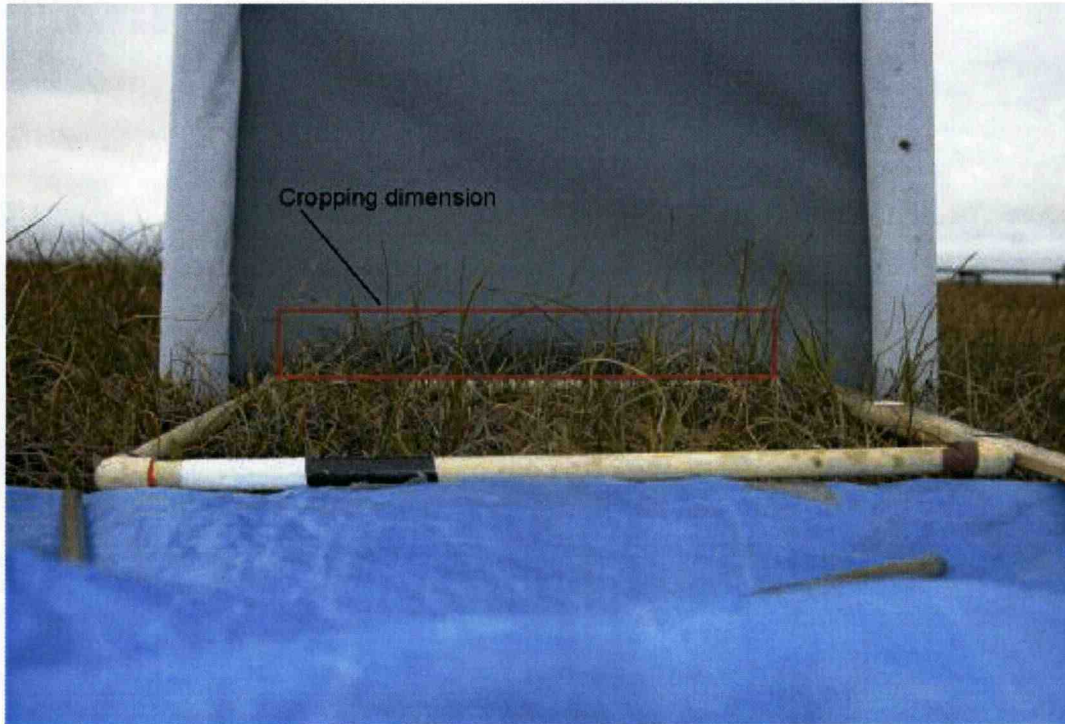


Figure 4.1: Example of canopy perspective with illustration of cropping dimensions.

Variations in lighting conditions and shadowing effects would also complicate later image classifications. Adobe Photoshop was used to pre-process the images. Brightness and contrast enhancements helped to remove shadowing and delineate between green vegetation and dead material. To aid in classification, a variety of tools were used to select and replace the gray background material with a higher contrasting red color. A combination of Photoshop's magic wand, polygon, and color range selection tools isolated background material for removal (Figure 4.2b).

Classification procedures were carried out using VegMeasure software; a proprietary program developed and provided for use by the Oregon State University's Department of Rangeland Resources. Two different classifications were used. First, a k-means 2-class unsupervised classification algorithm was applied to provide total canopy percentage values



relative to the background material. This was followed by a green band selection algorithm to separate live and dead canopy materials.

The k-means algorithm uses a chain clustering method based on a scatter plot of pixel values to identify class delineations. Random pixels within an image are first selected. The Euclidian distance between all pixel values and those of the initial random selection are then measured. This distance is relative to a threshold value in which the pixels are either grouped into the same class, or separated into different classes. As pixels are grouped, the mean value of a pixel cluster will migrate in spectral space. A series of iterations is run to monitor the migration of mean class values. An additional class threshold distance is applied to combine or maintain distinctions between class groupings of pixels. This is based on the distance a cluster's mean value (Jensen, 1996).

Different software packages provide different levels of user control over k-means algorithm variables. The user may have control over threshold value, number of iterations, or the number of classes to be identified. The VegMeasure software allows the user to define the number of iterations and the number of classes to be determined. The condition of these images, displaying two highly contrasting colors of essentially green and red, provides a favorable framework for the k-means classification. Under these circumstances, k-means is well suited to perform the relatively simple 2-class identification that was required (Figure 4.2c).

The k-means classifications did not, however, prove sensitive enough to distinguish between living and dead material within the canopy. In order to select standing dead material, a second algorithm was employed. A green band selection tool was used to further process the images. VegMeasure's green band algorithm selects out pixels with green saturation values greater than either a user defined, or an interactively calibrated threshold. As there appeared to

be significant variability between images (lighting, depth of field, focus etc.), individual threshold values were manually assigned to each image using visual quality control for best results. Adjusting towards a negative saturation threshold value, pixels with very little green saturation, i.e. dead vegetation, were identified within the images (Figure 4.2d).

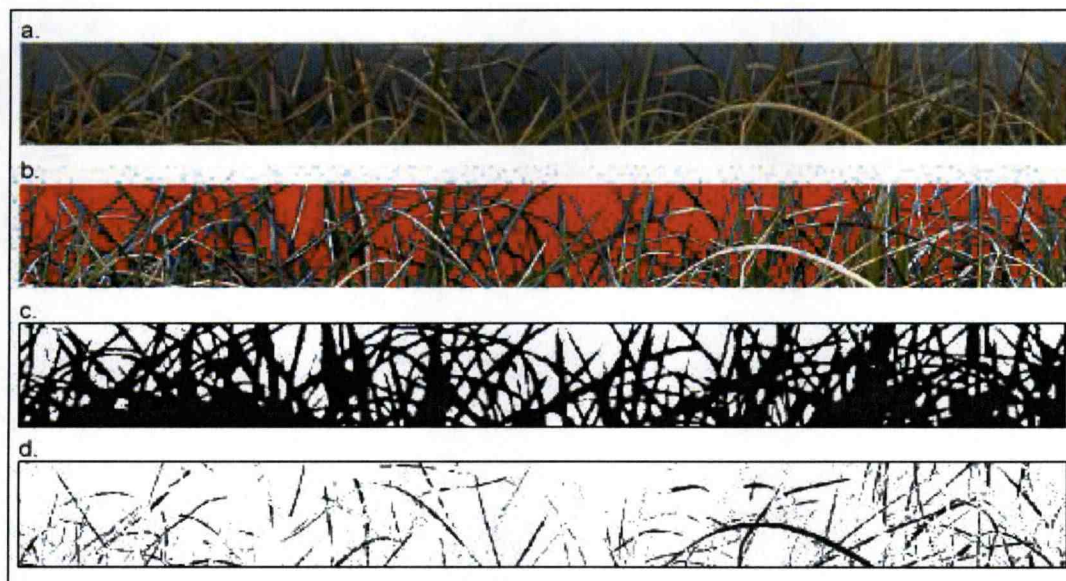


Figure 4.2: a) Image cropping results. b) Image following contrast enhancement and removal of background material. c) k-means 2 class algorithm for estimates of total vegetation cover. d) Green band selection algorithm used to isolate standing dead material.

Paired t-tests were used to identify any significant difference between the in-track and undisturbed study plots. Two series of statistical analysis were applied to the image data. The first t-test compared total canopy percentages between the track and reference plots. The second analysis was performed after removing canopy percent values associated with standing dead from the total percent cover. The second analysis was carried out to detect if the primary

difference (if any) between track and undisturbed sites was due to the crushing of standing dead material following winter disturbances.

## **Results:**

Statistical analysis provided dissimilar results between the manually sampled point data and the digitally processed images. Table 1.1 displays the basic statistics for the total canopy percentages as measured by both the point and image data collection methods. Table 1.2 shows the value of standing dead materials as measured by both methods.

Statistical results from the point sampling provided evidence that initial impacts following off-road travel include a significant reduction in the amount the amount of standing dead in the canopy. Removal of this material is responsible for the increased visibility of tracks during the summer months. The loss of standing biomass also has the potential to alter the thermal equilibrium, upsetting community stability and prolonging evidence of off-road activity.

Image analysis provided only suggestive evidence of a difference between in-track and control plot vegetation. Further testing was unable to attribute any of the slight difference between canopy values to the loss of standing dead materials.

A comparison between the image data and point sampled measurements of total canopy showed no statistical difference between the two estimations (p-value of 0.604; 95% confidence interval from -9.15 to 15.49). In-track canopy values, however, did show a significant difference between the two methods (p-value of 0.009, 95% confidence interval from 3.80 to 25.22). Comparison of standing dead canopy values also provided convincing evidence of a difference between the two methods of measurement (p-value of 0.009, 95% confidence interval from 3.81

to 25.20). Statistical evaluation of the image data in reference to the manually sampled readings provides no convincing evidence that the image sampling and/or analysis processes used herein are suitable for estimations of plant canopy variables.

<b>Treatment</b>	<b>Mean of total cover (%)</b>	<b>Standard Deviation</b>	<b>Min</b>	<b>Max</b>	<b>Range</b>
<b>Point Data</b>					
In-Track	29.07	13.95	10	56.67	46.67
Control	53.52	15.1	23.33	83.33	60
<b>Image Data</b>					
In-Track	43.58	17.44	8.37	76.47	69.1
Control	56.69	20.71	13.37	81.95	68.58

Table 1.1: Basic statistics for point and image data; total canopy measures.

<b>Treatment</b>	<b>Mean of standing dead values (%)</b>	<b>Standard Deviation</b>	<b>Min</b>	<b>Max</b>	<b>Range</b>
<b>Point Data</b>					
In-Track	7.96	10.92	0.00	46.67	46.67
Control	30.00	8.86	16.67	46.67	30.00
<b>Image Data</b>					
In-Track	1.65	1.24	0.34	4.56	4.22
Control	4.80	2.39	0.90	8.67	7.78

Table 1.2: Basic statistics for point and image data; estimated measures of standing dead canopy materials.

## POINT DATA ANALYSIS

Figure 5.1 displays the distribution of point data collected from the control and in-track site locations. The difference in means between the total canopy percentages of the control and track sites is 24.45%. Convincing evidence from the t-tests suggest a significant difference between mean canopy values of the control and in-track vegetation (p-value of 0.000, 95% confidence interval from 14.60 to 34.29).

Removing standing dead from the canopy totals significantly influences the distribution of data (Figure 5.2). Eliminating this component from the total values, a marked convergence between the distributions is noted. The in-track mean remains relatively constant; the mean value is reduced by roughly 8%. The control mean is much more sensitive to the standing dead constituent. Canopy values are reduced by approximately 30% through the loss of dead material. Statistical analysis shows no significant difference between the track and control mean values after dead material has been removed from the dataset (p-value of 0.546, 95% confidence interval from -5.62 to 10.43).

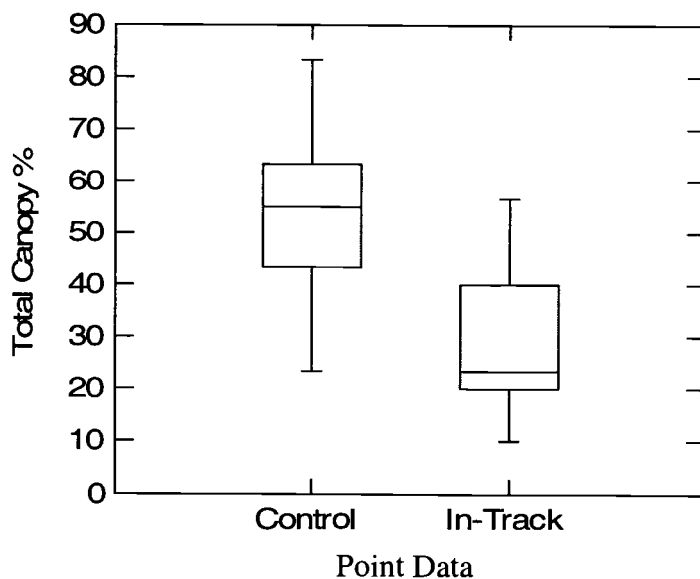


Figure 5.1: Distribution of total canopy percentages for point collected data.

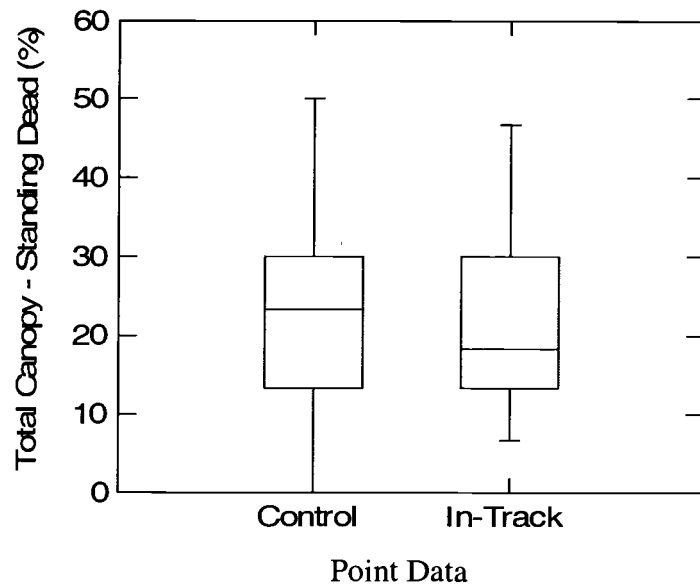


Figure 5.2: Distribution of point data following removal of standing dead components from canopy values

## IMAGE ANALYSIS

Data distributions for the image analysis results are provided in Figure 6.1. The t-test performed on total canopy percentages yields only suggestive evidence that a significant difference exists between the control and in-track canopy estimations (p-value of 0.048, 95% confidence interval from 0.124 to 26.10).

Removing standing dead components from the canopy has a much less dramatic effect on the image distributions than those of the point data. Figure 6.2 illustrates the image data distributions following removal of standing dead from the dataset. The in-track mean is reduced by only 1.65%. The control mean, which was subject to significant impact in the point readings, is reduced in the image data by only 4.8% with the loss of dead material. This slight change in values does, however, influence statistical results. Statistical analysis provides inconclusive

evidence of a significant difference between the control and in-track mean values (p-value of 0.107, 95% confidence interval from -2.8 to 22.19).

The p-value migrates from 0.048 to 0.107 after dead material is removed. While neither of these values provides ultimately convincing evidence of a significant difference, the trend of p-value migration is worth noting, as the distributions do show slight signs of convergence minus the presence of standing dead.

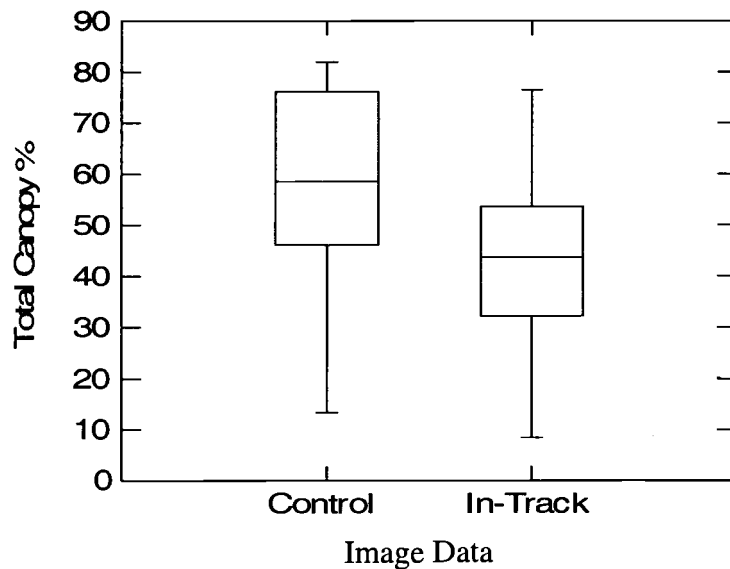


Figure 6.1: Distribution of total canopy percentages from digitally processes images.

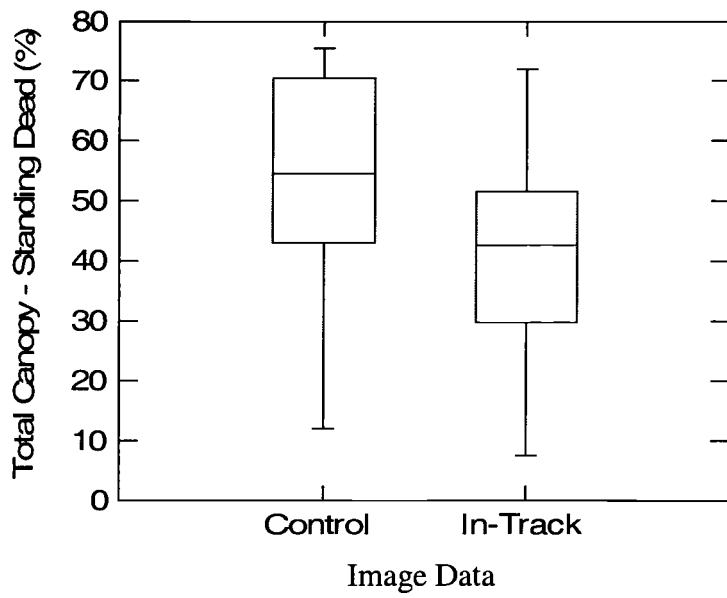


Figure 6.2: Distribution of image data following removal of standing dead from total canopy values.

### Discussion:

There was no significant difference in total canopy measures of control sites between the two methods. However, estimations of standing dead as well as in-track vegetation totals were not consistent between methods. Being able to measure one variable (total control cover) though not others (standing dead, in-track totals) through image processing, subjects the entire image database to speculation. Several factors may be at work serving to limit the effectiveness of the digitally collected data.

Of primary concern during field collection was the effect of seasonality on the vegetation. Field sites were sampled during mid-August. Sampling corresponded with the beginning of the fall season, marking the early stages of senescence for many forb and graminoid growth forms.



The current season's dying or dead material is fairly easy to distinguish during point sampling. Computer classification algorithms do not have the ability to make similar distinctions during processing. Individual leaves in the early stages of senescence would be split between classes of live and dead material. While this undoubtedly introduces error into the image data, the comparatively low quantities of standing dead measured from the images does not support this as a major source of error.

A rectangular, as opposed to square, quadrat would help eliminate errors associated with focus and depth of field. Reducing the required depth of field focal length by using a rectangular plot would produce sharper image quality. Edge blurring from focal distortions introduces error into the classification, as well as complicating the removal of background material during pre-processing. Background material becomes exceedingly difficult to isolate from leaf edges when vegetation becomes blurred. Remnant patches of background material lead to inflated quantities of vegetation and misclassification of components. Image distortion near leaf edges and areas of dense vegetation, especially in leaf axils, often result in having some quantity of background material left behind.

Using a backdrop of greater contrast during field collection may reduce some of this error. This would eliminate the need to replace the background color during pre-processing, propagating less error throughout the analysis. Variations in lighting conditions, however, would still produce shadow effects regardless of backdrop color and require some degree of processing prior to classification. Extending the backdrop to wrap around the sides of the plot and using flash photography may help to standardize lighting conditions, reducing the level of image manipulation required before classification. Achieving a suitable level of standardization among

images may also allow the use of batch processing techniques, significantly reducing the amount of time required in image processing.

Image dimensions are at an additional disadvantage in that they are only 2-dimensional. Without a third dimension of depth the quality of data from the images is severely restricted. Significant quantities of vegetation may be hidden behind foreground material. Shooting a longer rectangular plot would help reduce the level of error associated with this loss of dimension.

Implementing some of these changes may provide a more suitable means of estimating canopy cover. The recommendations for improved image collection would be fairly easy to implement and should not significantly influence the time or cost associated with image collection. The materials and software used in this analysis minimized cost by utilizing materials that are relatively easy to obtain, user friendly, and familiar to most researchers.

## **Conclusion:**

Summarizing the results with respect to the goals put forth earlier, point data analysis provides evidence that there is a significant reduction of standing dead canopy materials following winter travel; on average, approximately 20 percent of standing material is removed from the canopy. The vast majority of this material is standing dead from previous growing seasons. The resulting greening effect is, for the most part, transitory in nature (Brown, 1976). Duration of these 'green' trails should be closely correlated with site productivity. Continued monitoring would help establish a rate of recovery or any additional changes in environmental conditions.

Image analysis did not provide a suitable measure of canopy structure in reference to the point sampling, but the images still serve as a value resource. Minor modifications to the techniques employed here may afford more accurate estimations of canopy. Regardless, digital pictures from field locations continue to provide important documentation of site conditions. Having a visual record is particularly important in change detection and monitoring studies to show trends or change in condition over time. Photographs are especially valuable to non-specialists who may not be experienced in interpreting numerical data (Hart and Laycock, 1996).

The base-line data provided in this analysis contribute some degree of environmental information to an ever-growing database concerning arctic ecosystems. Results from this study are, however, limited without the benefit of continued monitoring of site locations. Documentation of environmental impacts is important. Understanding response characteristics and ecological processes following disturbance is an equally valuable asset for land managers. Expanding the scope of this study to include different community types would also help to more thoroughly address concerns regarding the expanse of seismic surveying conducted on the North Slope. Documenting impact and recovery of different tundra types provides valuable assistance in the continued development of best management practices for agency regulation and industry operations on Alaska's North Slope.

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