Chapter 1 – Introduction
An Arctic Initiation

1.1 Introduction

Arctic environments are often erroneously assumed to be barren, unproductive lands, with minimal vegetation cover. Upon greater investigation, it may be seen that these unique environments are fascinatingly complex, maintaining intricate ecosystems and plant community/environment relationships (Laidler and Treitz, 2001). It is difficult to describe a "typical" arctic vegetation, other than one that is low in stature, without trees, and occurring in the Arctic (Shaver and Chapin, 1991). The tundra zone consists of a series of vegetation belts, where succeeding belts experience decreasing diversity with increasing latitude (Young, 1994; Murray, 1997) maintaining progressively lower stature and simpler structure (Longton, 1997). Originating from a Lappish word, likely derived from Finnish *tunturi* (i.e., "treeless heights"), the word tundra reflects the mosaic of compact, wind-sculptured, plant communities usually less than one metre in height that are found within arctic tundra (Stonehouse, 1989). Despite arctic plant growth being constrained spatially, temporally, climatically, and nutritionally, there remains considerable diversity in plant growth pattern, both within and among vegetation types (Shaver and Kummerow, 1992). These characteristics provide a number of challenges, and opportunities, in attempts to determine the current state of tundra ecosystems in arctic Canada, as well as the circumpolar North.

Tundra vegetation covers approximately six million square kilometers of the Earth's surface, and is thus an important consideration in the context of global climate change (Hope *et. al.*, 1993). Arctic vegetation maintains its characteristic low stature, hardiness, resistance to cold, and many other adaptive traits, as a response to, among other things, climate. Climatic elements that most concern living systems around the world include:

ground temperature, air temperature, wind, humidity, precipitation (Stonehouse, 1989), and absorbed photosynthetically active radiation (APAR) (Baret and Guyot, 1991). Global climate change threatens to alter the climatic systems that have dominated arctic latitudes for centuries. Tundra environments are thought to be particularly sensitive and responsive to changes in climate yet it remains unclear as to how these environments will respond (Vierling *et. al.*, 1997; McMichael *et. al.*, 1999; Muller *et. al.*, 1999; Walker, 2000). Predicted rises in arctic mean annual temperatures are significantly greater than predicted global mean annual warming maintaining the potential to greatly affect permafrost – the dominant control over tundra ecosystem processes (Hope *et. al.*, 1995; Vierling *et. al.*, 1997). These forecasted changes may cause a release of previously sequestered carbon to the atmosphere, potentially shifting the global carbon budget because of the vast spatial extent of tundra environments (Vierling *et. al.*, 1997).

Alterations in arctic tundra ecosystem functioning are likely to be expressed through shifts in vegetation phenology and species composition, whereby remote sensing may provide a viable means for estimating and monitoring these large-scale, rapid shifts (Hope *et al.*, 1993; Vierling *et. al.*, 1997). Due to the remoteness and climatic challenges of the Arctic, small-scale vegetation studies may be ideal, but are not always feasible (Stow *et al.*, 1993a; Shippert *et al.*, 1995; Jacobsen and Hansen, 1999), nor necessarily useful in extrapolating to broader expanses of land (Dungan, 1995; Hope *et al.*, 1995; Lobo *et al.*, 1998; Ostendorf and Reynolds 1998; Davidson and Csillag, 2001). Remote sensing techniques maintain the potential to characterize surface variables that control carbon fluxes over landscapes (i.e., 100m^2 to 100km^2) or regions (i.e., >100km^2) (Hope *et. al.*, 1995). This capability is especially important in arctic environments where it is difficult to move across tundra landscapes on foot or vehicle, and the remoteness of study sites often limits the opportunity for field campaigns as a function of accessibility, financial cost, and weather conditions (Stow *et. al.*, 1993a; Shippert *et. al.*, 1995; Lévesque, 1996; Jacobsen and Hansen, 1999).

1.2 Rationale

Information regarding the reflectance properties of tundra vegetation communities, and related biophysical components (e.g., leaf area index or biomass) is limited, but the prospect of making large area biophysical estimates using spectral radiance or reflectance characteristics collected from satellites is attractive for regional ecosystem studies (Hope *et. al.*, 1993; Stow *et. al.*, 1993b). The lack of detailed baseline information on tundra vegetation community composition, biomass, health, and distribution at local scales (Bliss and Matveyeva, 1992) suggests that increased attention to these phenomena in Nunavut, and other arctic regions, may be valuable contributions to future ecological modeling and monitoring practices. Canadian tundra vegetation research foci have been placed primarily on the High Arctic (e.g., Wein and Rencz, 1976; Lévesque, 1996; Henry, 1998). One study by Tarnocai and Netterville (1976) mentions Boothia Peninsula, but only reports results from the Pelly Bay study site. The most extensive publications integrating remote sensing and tundra vegetation characterization focus on the North Slope of Alaska (e.g., various publications by Walker, Stow, Hope, and Shippert, among others), sparking the idea to expand investigations into the Canadian Mid-Arctic (i.e., prostrate dwarf-shrub subzone).

Arctic tundra landscapes are characterized by multiple scales of spatial heterogeneity (McFadden *et. al.*, 1998). Scale is also an inherent consideration when selecting remote sensing systems for ecological investigations. Microscale surface irregularities and disturbance produce a fine-grained patchwork of arctic plant distribution (Murray, 1997) that has proven difficult to estimate, much less quantify, without high resolution remote sensing data (Jacobsen and Hansen, 1999). For these reasons, IKONOS high spatial, multispectral resolution data were incorporated into biophysical remote sensing research of Boothia Peninsula to provide comparisons to the more conventional Landsat data. This work also responds to the reported need for expanding the geographical extent, and detail, of maps displaying biomass and vegetation community distribution/composition in polar regions (Walker, 1995; Walker, 2000). If tundra biophysical characteristics may be accurately estimated from remote sensing data, it provides a valuable starting point from which ecologists/botanists may evaluate soil properties, parent-material and soil moisture factors (Walker, 2000). The catalyst to understanding biophysical trends from remote sensing data is the investigation of relationships between spectral vegetation indices (VIs), how they vary across landscapes, and how these fluctuations are related to vegetation composition, biomass, and ecological site factors (Stow *et. al.*, 1993b; Walker *et. al.*, 1995). The advantages of such data are the non-destructive nature of reflectance measurements, and their recording of the actual, rather than potential, state of ecological variables, including local perturbations (Shippert *et. al.*, 1995). Furthermore, the utility of soil-adjusted VIs is thought to be an important component to investigate in arctic environments, whereby soil reflectance and moisture properties may drastically impact the conventional use of the normalized difference vegetation index (NDVI) (Huete, 1988; Qi *et. al.*, 1994).

1.3 Objectives

It is thought that biophysical remote sensing on Boothia Peninsula will follow similar trends to those established in Alaska, USA, but with lower productivity values resulting from the geographic location (i.e., harsher climate). It is hypothesized that VIs are directly related to above-ground biomass, percent vegetation cover, and surface moisture status, and can be modeled linearly over a larger study area. Soil-adjusted VIs are thought to improve linear biophysical correlations because of their accommodation for soil reflectance and moisture properties. It is also anticipated that IKONOS data will improve the characterization of tundra vegetation communities, compared to Landsat 7 ETM+ data, through the process of unsupervised classification. To investigate these pre-conceived notions, the objectives of this study are to:

1. characterize tundra vegetation species and community composition for twelve study plots on Boothia Peninsula, Nunavut, by establishing relative species richness and percent cover dominance trends (i.e., for both species and plant functional groupings) across a variety of environments;

2. harvest and evaluate above-ground tundra plant biomass to determine plot-level biomass amounts for functional type groupings, within the same select vegetation communities, for later investigations into the correspondence of biomass to species dominance and moisture regimes;

3. investigate the influence of remote sensing data spatial resolution on plot spectral separability, and unsupervised classification results;

4. evaluate the proficiency of four vegetation indices (i.e., NDVI, SAVI (L=0.5 and L=1), and MSAVI) for distinguishing tundra vegetation communities, employing surface spectro-radiometer, IKONOS, and Landsat 7 ETM+ data;

5. evaluate the relationship of surface and satellite VIs, using linear regression analysis to determine relationships between spectral response and study plot biophysical parameters such as biomass, and percent cover; and

6. employ regression analysis to model biophysical parameters over the larger study area as a preliminary visualization technique.

1.4 Terminology

1.4.1 Arctic delineation

Stonehouse (1989) points out that polar regions are usually poorly represented in atlases, and this is mainly due to the difficulty in determining fixed boundaries to define the circumpolar region. Since the criteria used to define vegetation characteristics result in zonation delineation, and hence artificial boundary formation, Walker's (2000) division of arctic boundaries is adopted for this thesis, as his work is most closely related to current research objectives (Appendix 1).

1.4.2 Plant species identification

When identifying tundra vegetation species in attempts to describe particular community composition, various botanical families and genera will be referenced to depict dominant vegetation types. Within these genera, one, several, or many species may also be present, depending on their tolerance and requirements for soil, drainage, climate, etc., and the particular local environmental conditions (Young, 1994). Because of the analyst's lack of experience with the botany/ecology of arctic environments, descriptions focus primarily on the family or genus level, as opposed to particular species and their minimal differentiating characteristics. For further details corresponding to this depth of knowledge Burt's *Barrenland Beauties* (1991), Pielou's *A Field Guide to Arctic Plants* (1994), and various works by A. E. Porsild should be consulted.

1.4.3 Scalar considerations

Wiens (1989, 385) states that: "The very foundation of geography is scaling. In the atmospheric and earth sciences, the physical processes that determine local and global patterns are clearly linked…and their importance is acknowledged in hierarchies of scale that guide research and define subdisciplines within these sciences." Plant ecologists have long recognized the impact of sampling scale on their descriptions of dispersion/distribution of species, yet field experiments tend to focus on field plots approximately 1m^2 in diameter (Wiens, 1989). Remote sensing observations are playing an increasing role in the study of landscapes and regions (Jelinski and Wu, 1996), expanding localized results to broader ecological extents while also initiating debates as to appropriate scales of observation.

Remote sensing spatial resolution may be considered analogous to the scale of research observations, as it is fundamentally related to the size of the surface area from which measurements comprising digital image properties are derived (Woodcock and Strahler, 1987). Employing three different remote sensing spatial scales (i.e., spectro-radiometer, IKONOS, and Landsat 7 ETM+) alleviates some of the constraints of spatial scale on the phenomena of investigation; however, including multi-resolution data influences the scale at which ground measurements are made (i.e., must correspond to the coarsest remote sensing scale in order to be informative for all data types). Because scale inherently affects the characterization of tundra biophysical properties, it is important to keep the following components of remote sensing data in mind:

1) the local variance in images is related to the relationship between the size of the objects in the scene and the spatial resolution of the sensor;
2) the spatial resolutions of high local variance change as a function of environment; and
3) multiple scales of variation in an environment will produce multiple ranges of spatial resolution with high local variance. (Woodcock and Strahler, 1987, 329).

The notion of scale offers a framework for ordering nature that may help reveal generalities from a mass of particulars (Hoekstra *et. al.*, 1991), but it is acknowledged that the selected research scale remains an arbitrary decision based on experience, data availability, and practicality. Furthermore, scale is inherently an artificial limitation imposed on natural systems, where scalar impacts on the results of tundra biophysical characterization are difficult to eliminate. The current multi-scale approach is therefore attractive and deemed useful in arctic environments where vegetation properties/distribution are highly influenced by hierarchical data aggregation.

1.5 Thesis Outline

Chapter 2 reviews the key literature involved in biophysical remote sensing of arctic environments, serving as a guide for the methods employed and directions taken in the study on Boothia Peninsula. Moreover, previous studies allow for relative comparisons from which to evaluate the accuracy and utility of, or flaws in, the adopted research approach. Chapter 3 provides a description of the study area and outlines the methods employed for all study plot investigations: i) field sampling scheme development; ii) quadrat sampling procedures; iii) radiometric sampling; iv) conversion of surface data to plot estimates; v) image rectification; vi) image analysis; and vii) statistical analysis. Chapters 4 and 5 present results and discussion organized according to the two major research themes: i) field sampling; and ii) remote sensing. Results and discussion correspond with the order and topics presented in Chapter 3. The combined results and discussion chapters are thought to enhance the comprehension of results, as well as minimize redundancy and repetition. Discussions are summarized to comprise overarching themes in Chapter 6, reiterating conclusions into a concise synthesis. Concluding statements are supplemented by several recommendations with which future research may be improved. Finally, suggestions to facilitate the expansion of the scope of research are presented to ensure applicability within the broader ecological, political, and social dynamic.