

## Chapter 6 – Conclusions and Recommendations

### *An Arctic Introspective*

#### 6.1 Conclusions

Ordered according to sequence of objectives, the following conclusions may be drawn from results presented in this study:

1. Vegetation communities within the Boothia Peninsula study area demonstrate relatively little variability in trends of species dominance. *Dryas integrifolia* is the dominant species found on both dry and moist sites, where rock cover is also quite prevalent. Wetter sites follow trends towards graminoid dominance by *Eriophorum spp.* and *Carex spp.* with bryophyte cover also prolific underlying the graminoid layer. Plant species richness does not factor into species plot dominance, as forbs contribute substantially to richness measures but minimally to overall vegetation cover. Conservative species richness estimates range from 14 on the most barren ridge-top study plot (i.e., P12) to 23 on moist (i.e., P2) to wet (i.e., P8) plots. These measures likely underestimate actual species richness due to analyst limitations during *in situ* species identification. When species are grouped into plant functional types, %cover trends show that three plots are predominantly non-vegetated (i.e., P6, P7, P12), five plots are dominated by shrub cover (i.e., P1, P2, P4, P9, P11), and graminoids dominate two plots (i.e., P3, P10), while P5 (i.e., mainly shrubs and mosses) and P8 (i.e., almost equal amounts of graminoids, mosses, and non-vegetated cover) demonstrate co-/multiple dominance. Vegetation cover characteristics follow microtopographic gradients which influence soil moisture, nutrient availability, snow cover, exposure, and microclimate differences that define habitats broadly as dwarf-shrub heath or moist to wet sedge meadows. A variety of *in situ* plot differentiations

are also made based on vegetation distribution patterns such as sorted/non-sorted stripes (i.e., P7, P11), sorted/non-sorted circles (i.e., P6), fell fields (i.e., P2, P4), and localized representations of polar desert (i.e., P12), moist sedge meadow (i.e., P1, P8, P10), water-track communities (i.e., P9), and snowbed communities (i.e., P2, P3, P5).

2. Due to difficulties encountered in the field, above-ground biomass collection was limited to vascular plant biomass. Dry weights are relatively consistent with trends in other arctic environments, where the moist study plot (i.e., P2) maintained the highest biomass ( $514 \text{ g/m}^2$ ) and the lowest biomass (i.e.  $<150\text{g/m}^2$ ) was recorded for the wettest and driest plots (i.e., P10 and P12), respectively. Biomass results tend to reflect relative %cover of plant functional groups; however, when comparing plots with similar amounts of graminoid and shrub cover, biomass is consistently lower for graminoids due to their increased below-ground allocation of biomass and decreased fibre density. The relative moisture term collected within each biomass quadrat resulted in one of the most beneficial variables throughout analysis of results. Scaled from 1 to 10, this qualitative moisture estimate provided valuable insight throughout investigations whereby moisture influences on %cover, biomass, and spectral reflectance were clearly demonstrated.
3. Plot spectral separability proved superior when employing Landsat data, as its higher waveband capacity seems to enhance spectral distinction among cover types that appear similar through the visible and near-infrared wavelengths. The issue of spectral resolution also factors into unsupervised classification analyses; however, as the maximum number of classes allowable is increased, IKONOS proves more useful in delineating tundra vegetation components because of its superior 4m spatial resolution

(compared to 30m for Landsat). IKONOS data can detect microsite variations within plots, and along linear and convoluted topographic features such as watertracks and snowbed vegetation communities.

4. The spectral vegetation indices NDVI, SAVI, and MSAVI were calculated using surface spectro-radiometer, IKONOS, and Landsat 7 ETM+ data. Graphic representation showed common trends of decreased values for soil-adjusted VIs. Statistical comparisons were unexpected in that ANOVA results showed soil-adjusted VIs to be significantly different from NDVI only when analyzing surface VIs, across a range of cover types. Segregating the data into moist and dry plots revealed additional patterns. Observed VIs were identical for dry environments, but soil-adjusted VIs were significantly lower than NDVI for all sensors when analyzing moist plots. Soil-adjusted VIs were concluded to be functionally equivalent for all sensors in the current tundra environment using supplementary independent sample t-tests. This reality led to using only NDVI and SAVI for remaining analysis. Furthermore, no significant difference can be reported when investigating the difference of means for NDVI or SAVI, across a range of environments, using multiple sensors. However, significant differences are found between all but Landsat and surface VIs, within moist plots, when segregating study plots. In other words, spectral vegetation index characterization (using red and near-infrared image bands) of tundra vegetation communities does not seem influenced by spatial resolution, while the utility of soil-adjusted VIs is limited over a range of environments.
5. Linear regression analyses showed strong, significant relationships between VIs and %cover values (i.e.  $R^2 > 0.7$ ,  $p < 0.01$ ). Poor results were determined for vascular plant

biomass (i.e.,  $R^2 < 0.1$ ). The missing bryophyte biomass values are thought to be a major cause for these disappointing results. Linear relationships were highest between IKONOS VIs and %cover, followed by Landsat and surface VIs. SAVI did not provide improved linear relations between biophysical variables and remote sensing data, suggesting that soil-adjusted VIs are of limited use in arctic environments as the low stature and canopy density may impart too much soil reflectance to improve NDVI results.

6. Since IKONOS data provided relatively successful linear correlations between NDVI and %cover, the high spatial resolution was deemed the most appropriate when attempting to extrapolate plot-specific results across the entire study area. While image representation of %cover distribution is conservative due to a small sample size, results showing the delineation of environmental gradients experienced during the field campaign are encouraging. Despite not being able to include moisture estimates in regression analysis, strong Spearman's rank correlations are determined between VIs and moisture, where data type again seems of minimal influence. Weaker correlations between %cover and moisture suggest that VIs may be important intermediary variables with which to characterize tundra community types. These results establish preliminary estimates from which future, more exhaustive studies, can build upon to improve the accuracy of spatial and spectral representation of tundra biophysical parameters on Boothia Peninsula, and throughout the Canadian Arctic.

## 6.2 Recommendations

The following are suggested as means of improving current study results:

1. Collecting bryophyte biomass cannot be done using reference squares. Improving harvesting techniques to include the entire moss mat, with appropriate soil line

- delineation, is likely the missing link for developing linear relations between above-ground biomass and VIs. Furthermore, expanding photographic cover and biomass estimates described by Wein and Rencz (1976), to eliminate or minimize destructive biomass harvests, would increase field sampling efficiency while also decreasing environmental impact legacies of scientific field campaigns.
2. Following Spjelkavik's (1995) suggestion to include botanists/field ecologists in field campaigns and satellite interpretation would enhance the representation of species richness and dominance measures, as well as the characterization of vegetation communities.
  3. Expanding sample size through more exhaustive field campaigns may characterize biophysical variables more extensively and accurately, but these efforts cannot come at the expense of shrinking within-plot replicates. To accomplish this expansion, future research would require: i) more collaborative researchers (i.e., more people in the field performing a variety of sampling regimes); or ii) multi-year research projects with a longer-term vision (which creates new problems of accounting for seasonal variations). Compromises are inherently necessary since the growing season and transportation factors are so limiting to arctic field studies.
  4. Establishing quantitative moisture estimates that may be incorporated into regression analysis may provide an informative additional dimension to biophysical analysis.
  5. Developing reliable means of converting IKONOS multispectral data to reflectance values would enhance the interpretation and meaning of IKONOS VIs. In turn, this would increase confidence in the ability of IKONOS to delineate vegetation communities both spectrally and spatially.
  6. Establishing reliable methods of calculating atmospheric effects at the time of remote sensing data acquisition could improve the representation of VIs by correcting for atmospheric effects that influence digital brightness values (Stow *et. al.*, 1993b; Shippert *et. al.*, 1995; Jacobsen and Hansen, 1999) and may lead to stronger correlations between biophysical parameters and VIs (Turner *et. al.*, 1999).
  7. More research incorporating the utility of soil-adjusted VIs in arctic environments is warranted to determine the accuracy of current conclusions regarding their functional equivalence for estimating tundra biophysical properties.

### **6.3 Future Directions for Arctic Research**

Global warming is expected to be most pronounced at high latitudes (Edlund, 1991; Shaver *et. al.*, 1992; Chapin *et. al.*, 1995); therefore, estimating the sensitivity of tundra environments to potential variations in precipitation and temperature is one of the most prominent research foci in recent and ongoing arctic research. Time series satellite data has

the potential to play a large role in the monitoring of predicted vegetation changes, and hopefully, distinguishing natural variation from industrial human impacts that threaten arctic ecosystems (Spjelkavik, 1995). The need for increased baseline studies is pressing, because natural and human impacts may soon become inseparable, and potential global climate changes are currently unpredictable (Bliss and Matveyeva, 1992). Much important research has been conducted to determine the degree to which tundra vegetation stores/releases carbon dioxide (Oberbauer and Dawson, 1992; Shaver *et. al.*, 1992; Chapin *et. al.*, 1995; Oechel *et. al.*, 1997) but there remains little consensus on the short- or long-term biosphere impacts of these relations. If these shifts are translated into variations in vegetation cover and species composition (as indicated by McFadden *et. al.*, 1998) then the utility of biophysical remote sensing becomes apparent in its ability to characterize large, remote expanses of arctic tundra (Nemani and Running, 1995). Because there are inherent risks involved in using simplified, aggregated models to represent vegetation and ecosystem processes at the scale of a landscape (Ostendorf and Reynolds, 1998), remote sensing can never replace detailed ecological studies, but it may be the link for extrapolating these results to estimate broader implications of locally modified phenomena. Increased collaboration across previously independent research disciplines may provide the most efficient means of tackling the complexity of issues in need of investigation (Chapin *et. al.*, 1992a).

Northern Canada is the dominant national areal component and is important for a variety of political, environmental, economic, and social reasons (Dey and Richards, 1981). Despite the fact that it is unlikely to become home for millions of people (Dey and Richards, 1981), the Arctic is the cherished home of approximately 50 000 Inuit Canadians. Many of these permanent residents still rely heavily on local biological resources and would be greatly affected by changes in their surroundings resulting from climate changes (Chapin *et. al.*,

1992b); therefore, for its permanent residents, as well as the entire country, it is necessary to understand the current and potential state of the environment in arctic Canada. Chapin *et. al.* (1992b, 450) warn that "...the sensitivity of arctic ecosystems to human activities associated with resource extraction and exploitation will undoubtedly change with changes in vegetation and the thermal balance of the tundra. Thus climatic change could strongly alter the interactions between human populations and their arctic environments." It is for these reasons that the final recommendation is to pave new research directions that adequately account for human/environment interactions, including both scientific and social scientific methods, to most accurately represent the ecological realities with which Inuit must live on a daily basis. These new initiatives become increasingly warranted as Nunavut legislates community approval, and some degree of local participation, in all research projects conducted within the new territory. Jacobs (1991, 6) presents an interesting perspective on the evolving challenges for arctic scientific research:

Though the scientist may instinctively focus on the relationships of [environmental] problems to the people and the ecosystem of which they are a part, it requires exceptional skill in communication and some understanding of the culture to convince skeptical, pragmatic people who do not share our sometimes unquestioning faith in the inherent usefulness of scientific inquiry. Hope of winning the tolerance if not the enthusiastic support of northerners for the practice of science in the North rests ultimately on the relevance of the research to their situation, demonstrated through communication and education, and on their effective participation in the process.

Because of these changing realities it is foreseeable, and strongly recommended, that new research disciplines are created to bridge the gaps between scientific, social scientific, and local, expertise. This attempt is believed to maximize the contribution of all valid insights, while characterizing tundra environments in a fashion applicable within the broader Canadian and global context.