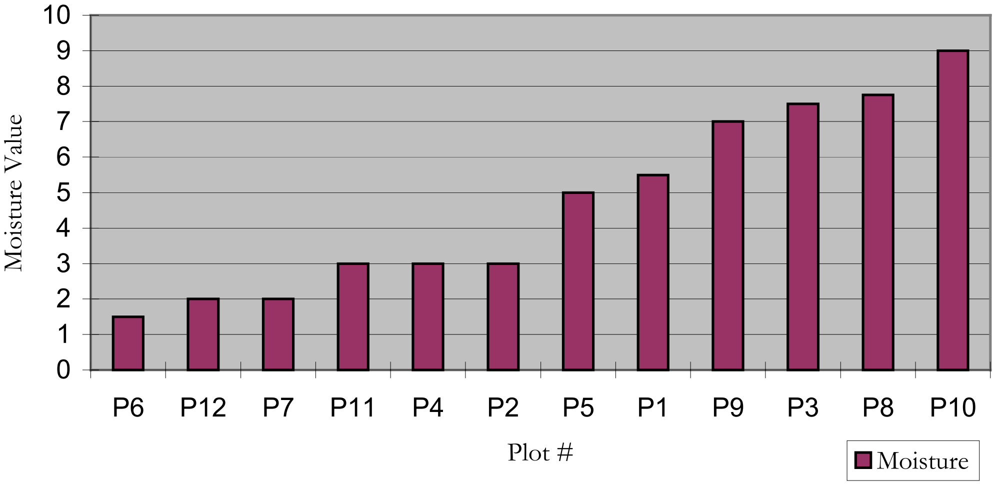
# Chapter 4 – Results and Discussion
## *Plot species, percent cover, biomass, and moisture*

### 4.1 Moisture

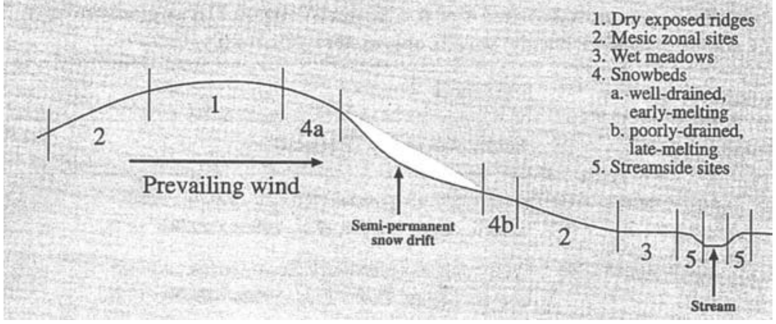
A relative moisture term was recorded for each biomass quadrat within each of the twelve plots (Section 3.2.5). The median of this moisture value is taken as an indication of the relative plot moisture status. Figure 4.1 shows the increasing moisture trend for each plot, demonstrating the variety of environments sampled. Plots follow quite closely to an idealized mesotopographic moisture gradient (Figure 4.2) where each plot can be characterized generally according to one of the five major habitat types (Table 4.1). For these reasons, all following graphic depictions of plot species richness, species dominance, %cover, and biomass results will be arranged according to the plot moisture status highlighted in Figure 4.1. Results of the relative moisture estimates show P6 to be the driest site (< 2), while P10 is the wettest community (> 8).

Figure 4.1 - Relative plot moisture



In the majority of arctic locations, the environmental factor most closely correlated with vegetation type is soil moisture (Oberbauer and Dawson, 1992). In areas of high elevation, water is a limiting factor and an important determinant of vegetation structure, productivity, and composition; in lower areas these aspects may not be directly controlled by soil moisture, but rather by factors correlated with, or affected by, soil moisture (i.e., nutrient availability, thaw depth, soil aeration, redox potential, and pH) (Oberbauer and Dawson, 1992). Microscale moisture gradients (e.g., troughs to high centre polygons, across 2 to 3m from wet meadows to beach ridges, and frost boils/stone stripes) have great influence on the pattern and distribution of vegetation throughout tundra plant communities. This within-plot variability is prominently demonstrated in P6, P5, P8, and P9, whereby small variations in moisture – and likely frost action – impact where vegetation is prolific and where non-vegetated surfaces are exposed (Figure 4.3). Mesoscale soil moisture has an inverse relationship with slope and elevation, whereby fell field ridgetops are the driest environments, increasing downhill to riparian zones in valleys that demonstrate the wettest habitats (e.g., P9 overview, Figure 4.4) (Oberbauer and Dawson, 1992). These trends echo Walker's (2000) depiction of a mesotopographic gradient (Figure 4.3), along which the twelve study plots may be placed (Table 4.1). A variety of physiological factors also play

Figure 4.2 – Idealized mesotopographic gradient



Source: Walker, 2000, 29

Table 4.1 – Approximate habitat types*

| Plot | Habitat |
|---|---|
| P1 | 3 |
| P2 | 2 |
| P3 | 3 |
| P4 | 2 |
| P5 | 4b |
| P6 | 4a |
| P7 | 4a |
| P8 | 3 |
| P9 | 5 |
| P10 | 3 |
| P11 | 4a |
| P12 | 1 |

*Habitat codes based on Figure 4.2

into the water relations of arctic vascular plants, and readers are referred to Oberbauer and Dawson (1992) for a detailed review.

## 4.2 Within-plot Species Richness and Dominance

Forbs are a determining factor in species richness (Figure 4.5, Appendix 30), contributing between 35% (P3) and 52% (P8 and P5) to the measure of plot species richness. *Saxifraga oppositfolia* is most prominent on dry and mesic plots, while a variety of *Pedicularis spp.* may be found on moist to wet sites. The most common shrub species include *Dryas integrifolia* and prostrate *Salix spp.*, whilst the most familiar graminoid species include *Eriophorum spp.*, and *Carex spp.*. Bryophytes are limited to one main group, simply labeled moss (MO – likely *Sphagnum spp.*), because of the difficulty in determining subspecies in the field. For similar reasons, lichen species are also described in general terms (Appendix 23). Plot species richness cannot be taken as a measure of cover dominance because the sole measure of species presence in a given quadrat does not ensure correlation to areal coverage (Appendix 31). In fact, the selected plot community types demonstrate only a few dominant species,

Figure 4.3 – Microsite variability

P6: non-sorted stripe and circle formations with vegetation prolific in-between exposed, raised surfaces

P5: exposed dark and light soils create microsite variability

P8: sparse graminoid canopies allow for underlying soils and organics to show through

P9: high centre polygons vary greatly in vegetation composition from centres to troughs

Figure 4.4 – P9 Overview showing mesoscale moisture gradient

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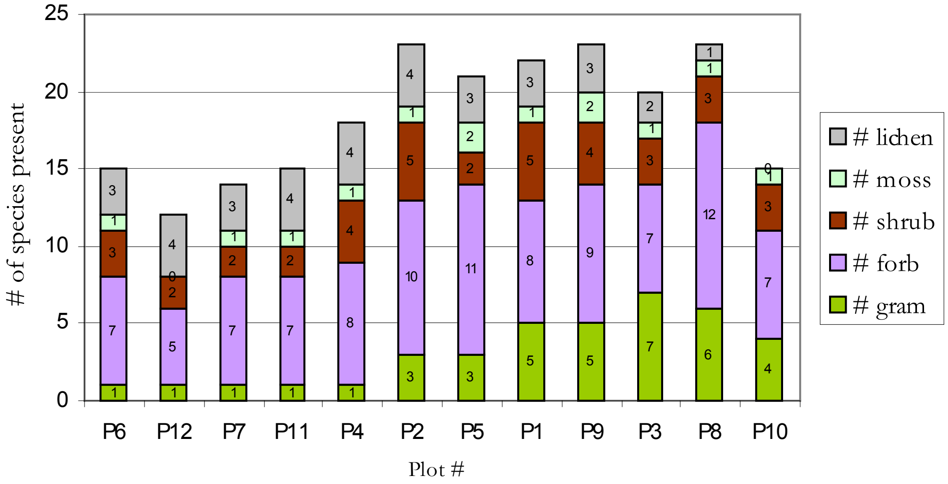
regardless of total species present. Dominant plant species do, however, correspond to high frequencies within quadrats as may be expected according to Brown (1984) (Figure 4.6). On drier, elevated sites *Dryas integrigolia* is dominant, while rock or exposed soil may be even more prominent. Wetter sites show *Eriophorum spp.* (usually *Eriophorum angustifolium*) as dominant, while *Carex aquatilis* and moss may also play important roles. Soil exposure on these sites is limited, but where present it is of a dark organic nature.

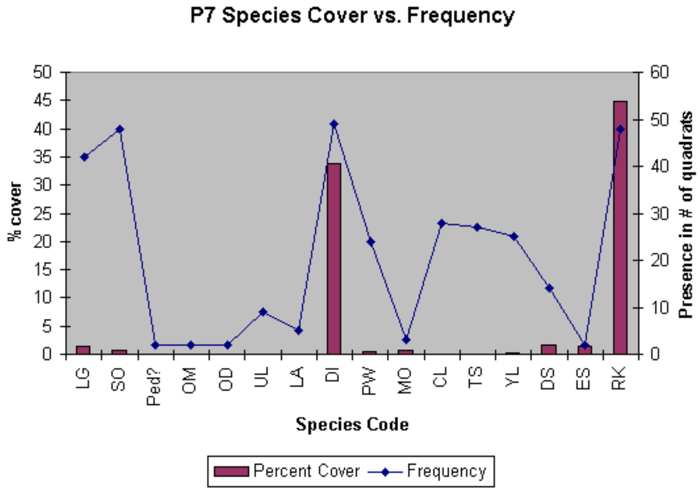
Figure 4.5 - Plot species richness



Exploratory regression analysis between vegetated species %cover (including the variety of non-vegetated cover types) and frequency of appearance in quadrats shows a weak linear relationship in most plots for P2, P4, P7, P9, P12 (i.e., $R^2<0.5$), while somewhat stronger relationships are demonstrated in P1, P3, P5, P6, P8, P10, P11 (i.e., $R^2>0.5$)

(Appendix 32). These poor results are a function of the high frequency of *Saxifraga oppositfolia*, *Carex bigelowii*, and prostrate *Salix spp.*, associated with their minimal contribution to overall vegetation cover, which prevents the formation of meaningful intrinsically linear trends. Study plot P7 is an excellent example of how species dominance cannot be determined from species frequency – *Saxifraga oppositfolia, Carex bigelowii,* and lichens are frequently found within random quadrats, yet they occupy very little of the total %cover of quadrats and hence of the overall study plot (Figure 4.6). *Dryas integrifolia* and rock cover types are, however, found frequently and combine to characterize 70% of total plot cover (Figure 4.6). Appendix 32 highlights that no frequency/cover relationships would be found if dominant species were excluded from calculations (i.e., dominant cover types are important influential outliers, essentially determining the cover/frequency relationship). Acknowledging these trends, it is reiterated that plot %cover estimates are grouped into plant functional types reflecting all vegetation cover; however, functional type %cover tends to be determined by one to three dominant species.

Figure 4.6 – Species cover and frequency example



To understand what controls species richness and dominance patterns in arctic environments, "it is necessary to appreciate the environment in which the plants grow, the physical constraints to growth, reproduction, and dispersal, and what the physical conditions mean to spatial organization of habitats, the plant cover, breeding systems, and populations structure." (Murray, 1997, 16) Here, the issues of plant cover, biomass, and moisture are investigated, as they are believed to be the most directly correlated with tundra vegetation spectral reflectance characteristics.

### 4.3 Percent Cover

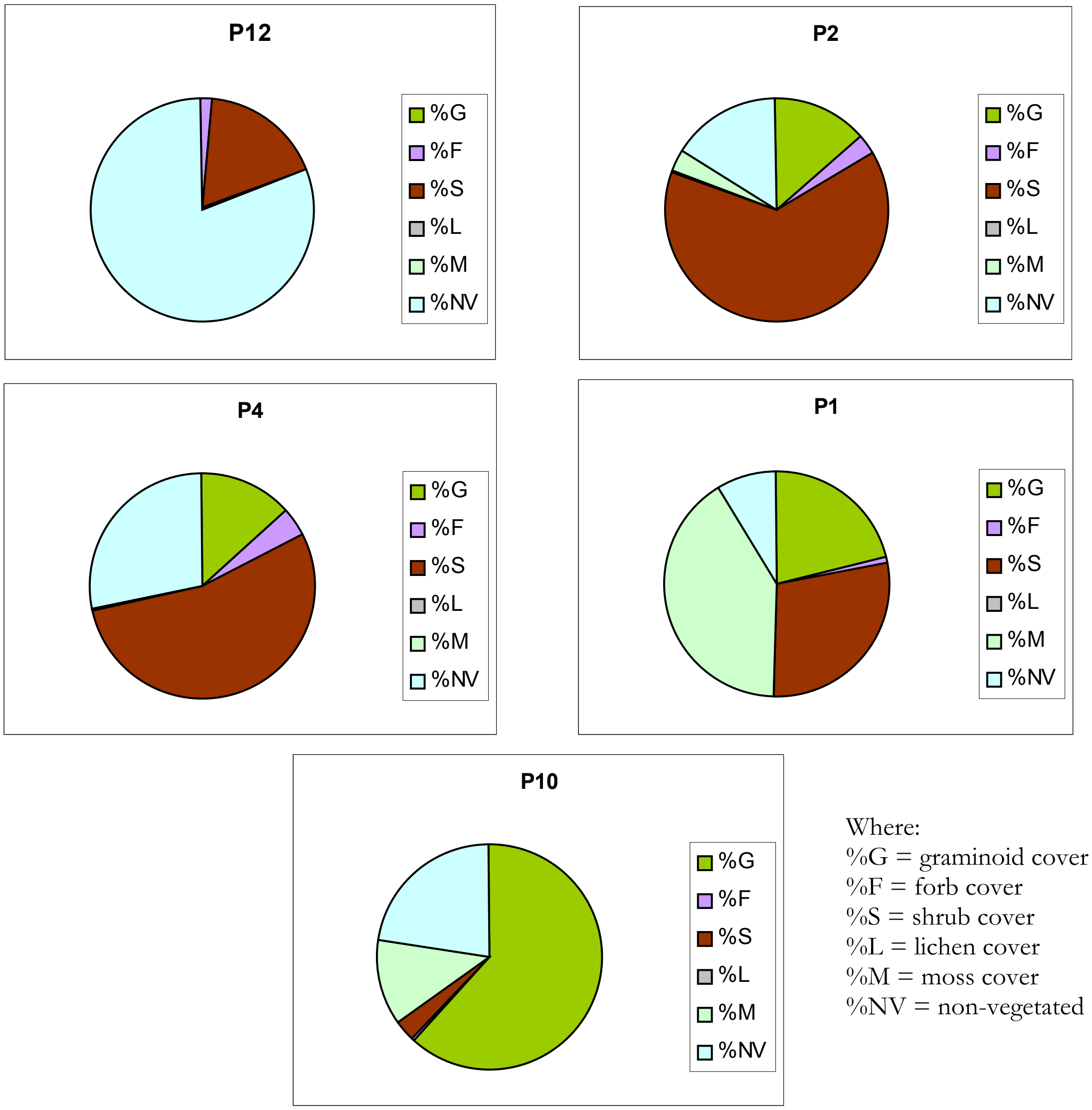
The 50-quadrat visual percent cover estimates made within each plot are considered more representative of community cover types than the ten biomass quadrats alone. To ensure that 50-quadrat cover estimates may be compared to biomass estimates from 10 quadrats, the 10-quadrat %cover values (X) were regressed on the 50-quadrat estimates (Y) (Appendix 33). Because the two cover estimates demonstrate a strong linear relationship ($R^2$=0.921, *p*<0.0001), and high degree of correlation (R=0.959, p<0.0001), further analysis employing the 50-quadrat %cover values are considered representative. Despite the two cover estimates being highly correlated, a one-way analysis of variance verifies that there is no significant difference between the two means (F=0.033, p<0.857) (Appendix 33), further justifying the use of 50-quadrat cover estimates. Relatively high standard deviation values for %cover estimates (20 – 40%) (Appendix 34) may be attributed to the flexible BB cover classes where ranges of 25% are common for each category.

Plot %cover estimates include all vegetation functional groups, vascular and non-vascular, as well as non-vegetated cover types. For drier plots, non-vegetated areas dominate the community, while shrubs contribute the most to vegetation coverage. As plot moisture increases, or elevation decreases, shrubs take over as the dominant cover type, while non-vegetated ground continues to contribute about one quarter of %cover – graminoids and forbs are increasingly present. As plot moisture increases further, graminoids become dominant. Non-vegetated cover does not disappear in wet plots, but its characteristics are much different (i.e., dark, absorbent, open organic layer compared to the rocky, baked soil, or sandy exposed surfaces on dry plots). Lichens are listed in many %cover estimates but, often falling in the <1% category, they do not appear in plot-level %cover graphic summaries for any community type encountered within the study site.

Study plot P12 demonstrates the greatest dominance of exposed soil surfaces (79.15%), P2 shows the greatest coverage of shrubs (52.7%), and P10 depicts the greatest %cover of graminoids (56.9%) (Figure 4.7). Forbs never dominate overall cover, but they are most prominent in P4 (3.5%) (Figure 4.7). Non-vascular plant cover dominates P1 with bryophyte cover of 42.6% (Figure 4.7). As mentioned previously, lichens do not contribute much to overall cover, but they are most prominent in P7 (0.2%). A full listing of %cover values is shown in Table 4.2, while a visual representation of vegetated and non-vegetated plot cover fractions are provided in Appendix 35.

Results presented for plot %cover estimates follow expected trends in vegetation community composition and functional type dominance described in other tundra vegetation research (e.g., Bliss and Matveyeva, 1992; Lloyd *et. al.*, 1994; Walker *et. al.*, 1994; Murray, 1997; Henry, 1998; Young *et. al.*, 1999). Spatial heterogeneity of the study area, regarded as the irregularity of the physical environment that translates into different kinds of plant habitats, demonstrates the importance of local influences on creating a diversity of habitats that can maintain a diversity of species cover (Murray, 1997). Murray (1997, 12) explains that spatial heterogeneity in tundra environments play an important role in defining vegetation composition, for: "[t]he tundra landscape, arctic or alpine, no matter how apparently flat and monotonous, is a series of convexities and concavities. All landscapes are hills and hollows of various sizes, and the differences in plant cover associated with them are often sharply defined." Habitats are colonized by particular species, in relative vegetation cover dominance, following a series of microsite influences: i) topography (Bliss and Peterson, 1992; Schaefer and Messier, 1995; Henry, 1998; Ostendorf and Reynolds, 1998); ii)

Figure 4.7 – Percent cover distribution for select plots



Where:
%G = graminoid cover
%F = forb cover
%S = shrub cover
%L = lichen cover
%M = moss cover
%NV = non-vegetated cover

Table 4.2 – Total vegetation cover and functional type percent cover values for all study plots

| Plot | veg cover (50) | Std. Cover (50) | %G | %F | %S | %L | %M | %NV |
|---|---|---|---|---|---|---|---|---|
| P6 | 40.68 | 28.86 | 0.57 | 1.07 | 31.87 | 0.07 | 7.10 | 47.95 |
| P12 | 19.00 | 20.18 | 0.10 | 1.60 | 17.30 | 0.10 | 0.00 | 79.10 |
| P7 | 36.55 | 24.18 | 1.30 | 1.03 | 34.32 | 0.19 | 0.75 | 48.15 |
| P11 | 48.92 | 29.31 | 0.30 | 1.33 | 44.37 | 0.07 | 2.85 | 46.85 |
| P4 | 54.06 | 19.00 | 10.01 | 3.51 | 40.36 | 0.18 | 0.00 | 21.45 |
| P2 | 69.50 | 36.45 | 11.51 | 2.47 | 52.66 | 0.06 | 2.80 | 13.41 |
| P5 | 60.17 | 34.32 | 7.77 | 2.51 | 38.18 | 0.06 | 11.65 | 26.30 |
| P1 | 94.61 | 35.10 | 22.11 | 0.96 | 28.92 | 0.01 | 42.60 | 8.85 |
| P9 | 85.66 | 31.61 | 26.01 | 0.27 | 39.42 | 0.11 | 19.85 | 7.45 |
| P3 | 100.85 | 27.73 | 39.96 | 0.10 | 20.79 | 0.00 | 40.00 | 3.55 |
| P8 | 62.98 | 32.51 | 30.22 | 0.89 | 17.27 | 0.00 | 14.60 | 19.76 |
| P10 | 71.38 | 33.87 | 56.90 | 0.22 | 2.95 | 0.00 | 11.30 | 20.95 |

soil moisture (Oechel, 1989; Bliss and Matveyeva, 1992; Oberbauer and Dawson, 1992; Henry, 1998; Ostendorf and Reynolds, 1998); iii) nutrient availability (Oechel, 1989; Bliss and Peterson, 1992; Henry, 1998); iv) soil pH (Bliss and Peterson, 1992; Yu, 1994; Walker *et. al.*, 1995); v) snow cover (Walker *et. al.*, 1993; Yu, 1994; Schaefer and Messier, 1995); vi) microclimate (Edwards *et. al.*, 2000); vii) grazing intensity (Henry, 1998); and viii) exposure (Larsen, 1964; McFadden and Chapin, 1998). These environmental factors affect study plot tundra vegetation cover distribution and composition; therefore, they are referred to when evaluating plot community types. Little documentation is available describing typical vegetation community composition on Boothia Peninsula, so comparisons with the closest resembling arctic environments are incorporated to evaluate %cover functional type estimates.

Mires are sedge-moss and grass-moss tundra habitats dominated by graminoids – mainly *Eriophorum spp.* and *Carex spp.* (Bliss and Matveyeva, 1992). These environments occur only where water remains on the landscape much of the summer because drainage is blocked at snowmelt by raised ridges (Bliss and Matveyeva, 1992). Mosses tend to establish themselves first, where early graminoid dominance is maintained by *Dupontia fisheri* with *Eriophorum scheuchzeri* as codominant (Bliss and Peterson, 1992). The slower growing *Eriophorum angustifolium* and *Carex aquatilis* establish themselves after vascular plant canopy is more developed, slowly expanding circles of tillers within the vegetation (Bliss and Peterson, 1992). Mires in early successional stage do not appear prominent within the study area, but plots P10, P1, P3, P9 and P8 may be considered later mire successional stage communities according to %cover dominance (Appendix 35) and species composition (Appendix 30). Dominated by graminoids, these plots are thought to be progressing towards the final mire successional stage in which decreases in availability of phosphorus, as well as decreased pH levels and depth of thaw may be experienced, while accumulation of soil organic matter may become obvious (Bliss and Peterson, 1992). Lacking the prominence of standing water, plots P10, P1, P3, P9, and P8 are therefore considered to range from wet to moist sedge meadow communities, typically underlain by a well-developed bryophyte layer.

Dwarf-shrub heath tundra is dominated by prostrate and hemiprostrate dwarf shrubs (e.g., *Dryas integrifolia*, and *Salix arctica*), as well as cushion forbs (e.g. *Saxifrage oppositifolia, Cerastium alpinum, Papaver radicaturm,* and several *Stellaria spp.*) (Bliss and Matveyeva, 1992). These habitats develop on well-drained, neutral to slightly alkaline soils with limited snow cover (2-10cm) and a relatively deep summer active layer (50-100cm) (Bliss and Matveyeva, 1992). Graminoid species present tend to be dryland *Carex spp.* Study plots associated with this cover type tend to be found on ridge tops, or broad expanses of flat fell field surfaces (e.g., P4, P12, P7, P6, P11). There is significant variety in the appearance of these communities (Appendix 15) but they tend to fall within the dominant species and cover type categories often described as polar semideserts. Study plots P5 and P2 do not fit neatly into sedge meadow or dwarf-shrub heath community descriptions, maintaining unique plant and environmental composition that share microsite similarities to both dwarf-shrub heath and sedge meadow communities. The above discussion is meant as a description of potential community characterization, while further evaluations of biomass will supplement community delineations.

### 4.4 Biomass

In calculating average above-ground biomass estimates for the twelve sample plots, it became evident that bryophyte biomass results were skewed and inaccurate. Seven of the twelve plots had entries for moss biomass, yet of the ten quadrats within each plot there were rarely more than three moss collections. Not only are these bryophyte estimates extremely high in comparison to other plant functional type dry weights, there is little confidence in the samples themselves. Because of the methods employed for moss collection (Section 3.2.5), it is impossible to validate bryophyte weights. Reference samples were collected, instead of the entire moss mat (for *in situ* efficiency and time purposes), a protocol that is now deemed ineffective for characterizing bryophyte biomass. In addition to methodological discrepancies, there were additional uncertainties encountered in separating the moss reference layer:

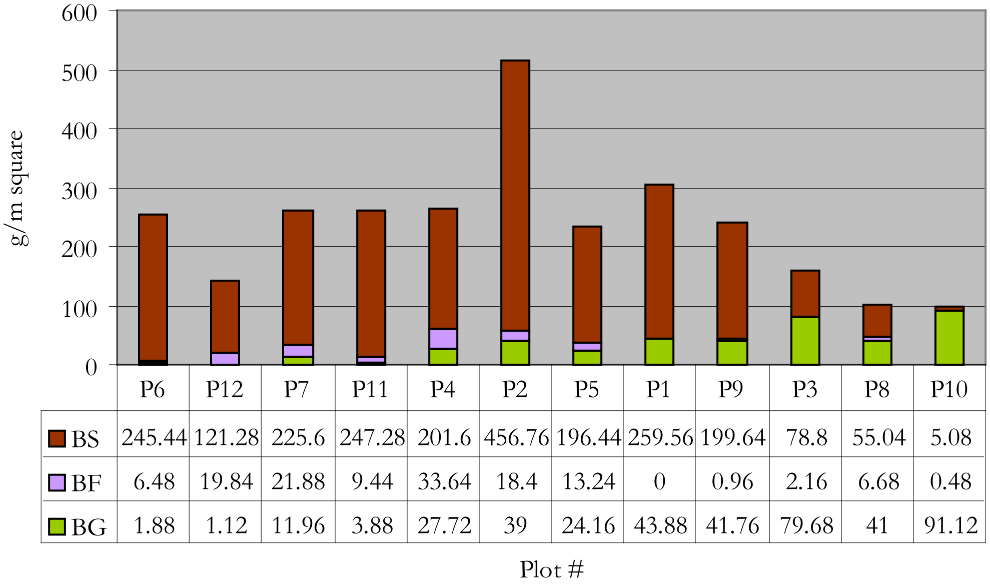
i. Moss carpets were not always harvested if they were not included in visual percent cover analysis (i.e., they were not seen until graminoid layer was clipped away); therefore, the moss dataset is incomplete.
ii. Extrapolating a 10cm x 10cm moss square (2.5 – 3.8cm thick) is very difficult to gain accurate representation of actual moss coverage.
iii. Determining where the moss layer ends and the soil layer begins was extremely challenging – sometimes no soil layer was found, and the bryophyte layer extended deep into the layer of organic material.
iv. While bryophyte biomass is an important component of relatively wet vegetation communities, the uncertainty and error surrounding moss collection (i.e., values appear artificially high in many plots) prevents an accurate assessment of non-vascular plant biomass.

Total aboveground biomass estimates seem greatly impacted by the high moss values (Appendix 36, Figure A). Furthermore, standard deviation values for bryophyte biomass tend to exceed the average plot biomass values in all but one case, which flags these estimates as non-representative (Appendix 36, Figure B). For these unfortunate reasons, it is deemed necessary to exclude non-vascular plant biomass from all further analysis.

For biodiversity studies it is considered prudent to limit studies to vascular plants because of their shared/similar biological attributes (Glaser, 1992); however, despite the necessity involved, restricting aboveground biomass samples to vascular plants does not bode well for establishing relationships between vegetation %cover, spectral reflectance, and biomass.

Some expected vascular plant trends are revealed, whereby shrub biomass forms the majority of aboveground vascular plant matter on drier plots, and decreases in importance along an increasing moisture gradient to the point where graminoids represent the majority of vascular plant biomass (Figure 4.8). Forbs contribute most on dry to moist plots, but never comprise the majority of dry plant matter. Plot 2 reveals the highest vascular plant biomass (514.16 g/m$^2$) while Plot 10 maintains the lowest vascular plant biomass (99.68 g/m$^2$) (Figure 4.8). While vascular biomass estimates are much more representative of plot community characteristics, variance within plots remains high (Appendix 37). This trend may be a function of the small within-plot sample size (i.e., 10 quadrats harvested for a 1ha area), resulting from the limited sampling window during a single season field campaign.

Figure 4.8 - Vascular Plant Plot Biomass Estimates



| | P6 | P12 | P7 | P11 | P4 | P2 | P5 | P1 | P9 | P3 | P8 | P10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 🟥 BS | 245.44 | 121.28 | 225.6 | 247.28 | 201.6 | 456.76 | 196.44 | 259.56 | 199.64 | 78.8 | 55.04 | 5.08 |
| 🟪 BF | 6.48 | 19.84 | 21.88 | 9.44 | 33.64 | 18.4 | 13.24 | 0 | 0.96 | 2.16 | 6.68 | 0.48 |
| 🟩 BG | 1.88 | 1.12 | 11.96 | 3.88 | 27.72 | 39 | 24.16 | 43.88 | 41.76 | 79.68 | 41 | 91.12 |

Where: BS = Shrub biomass, BF = Forb biomass, BG = Graminoid biomass.

Shaver and Chapin (1991, 5) state that "the inclusion of below-ground stems and non-vascular plants in the comparison [tends] to reduce the apparent differences in biomass among sites." Therefore, having to reduce biomass analysis to above-ground vascular plant dry weight is perhaps not so detrimental to subsequent analyses. The majority of plots (i.e., P6, P12, P7, P11, P4, P2, P5, P1, P9) are dominated by shrub biomass, especially *Dryas integrifolia*, while graminoids are most important in P3, P9, and P10. The contribution of forbs to above-ground biomass is minimal on any site, even though there are more forb species in each plot than any other species (Section 4.2) – a reflection of the presumed correlation between species dominance and biomass. Vascular plant biomass tends to follow trends of relative growth form abundance (Shaver and Chapin, 1991); however, above-ground dry weight results are also reflective of functional type biomass allocation characteristics. For example, approximately 80% of wet graminoid biomass is allocated below-ground, whilst approximately 50% of dry dwarf-shrub biomass is allocated below-ground (Shaver and Chapin, 1991). These aspects may help explain why biomass is lowest on the wettest, graminoid-dominant plot (P10), whereas P12 biomass is higher despite much lower vegetation coverage. Furthermore, enhanced graminoid turgidity and less dense plant fibres, in comparison to prostrate or hemiprostrate shrubs, may lead to lower dry weights for wet sites.

Vascular plant biomass seems to decrease towards moisture level extremes, as evidenced by results showing lowest biomass at the driest (P12) and wettest plots (P8, and P10) (Figure 4.1 and 4.8). Study plot P6 is a notable exception, where exposed soil was hard packed, exhibiting the lowest moisture value, but higher biomass than P12 (Figure 4.1 and 4.8). The increasing importance of moss biomass on wetter sites (i.e., minimum of 30% according to Shaver and Chapin (1991)), is not accounted for in plot biomass results. This absence must be acknowledged as a likely influence in shifting the biomass/moisture relationship towards a more linear trend.

Water interactions affect whole-plant function through multiple direct and indirect linkages, where one of particular interest is the amount of leaf area. Oberbauer and Dawson (1992) suggest that leaf area (commonly measured as the leaf area index – LAI – in remote sensing studies), and hence photosynthetic potential, is regulated by water status. This conclusion has important implications for remote sensing research because if percent cover estimates may be successfully related to spectral vegetation indices (VIs), results may be extrapolated to represent other important tundra biophysical variables (e.g., plant photosynthetic potential, water stress, and plant vigour). In addition, plot moisture, biomass, and percent cover variables serve to define vegetation community types in the current study. Incorporating these plot variables aids the interpretation of results discussed in the following chapter, whereby relationships between biophysical properties and remotely sensed vegetation indices are evaluated.