

# **Vegetation and Soil Patterns at a Mountain Wetland Ecotone**

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## **Abstract**

This study analyzes tree, soil, and microtopographic patterns present within the Cranberry Glades, a bog wetland complex located in the mountains of West Virginia. The Cranberry Glades are comprised of four open bog meadows, which provide unique habitat to several rare and endangered plant species. However, these meadows are filling in with trees and alder. This research is a study on the factors that may be involved in the processes and patterns influencing tree encroachment into the bog meadows across the open meadow – bog forest ecotone. To determine the patterns of infilling and the potential relationships among the trees, microtopography, and soil conditions, I collected and analyzed data on each of these factors within nine belt transects located across the ecotone. I gathered tree data on the following: location within transect, species, diameter at breast height or diameter at ground level, height class, associated microtopography, and growing conditions on 1,389 trees. Soil samples were gathered across the ecotone and analyzed for percent moisture, pH, and various nutrients and metals. I assessed historical aerial photographs to gain a temporal history on the patterns of infilling. The results indicate that trees decrease in density across the ecotone towards the peatland interior, and that trees are likely to be growing on hummock features and within tree islands. Soil properties also showed significant differences among the variables of interest. The aerial photograph assessment revealed that trees and alders have been steadily encroaching into the open peatlands for at least the past 52 years. The finding of this research lead to increased knowledge on southern peatlands, wetland succession, and the Cranberry Glades Botanical Area.

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## Chapter 1: Introduction and Hypotheses

### 1.1 Introduction

Biogeomorphology, formally defined as the bridge between the disciplines of earth science and biology, is a relatively new field recognizing the relationships among geomorphologic features and the distribution of biological organisms (Osterkamp and Friedman, 1997; Naylor et al., 2002; Stallins, 2006). Likewise, biogeomorphology is closely aligned with the field of biogeography. Biogeomorphic studies often focus on how organisms interact and/or affect geomorphic features, and conversely, how landforms or geomorphic features affect the distribution and patterns of organisms (Swanson et al., 1988). Naylor et al. (2002) stated that biogeomorphology can go beyond the definition of the term and act as a link between ecological and geomorphologic theories, and as a result, lend a different perspective on problems and questions.

The Cranberry Glades is a bog wetland complex containing four open peatland meadows located in West Virginia, however, the open peatlands are being transformed by tree infilling (Darlington, 1942, 1943; Edens, 1973; Kokesh, 1988) (Fig. 1.1). The Cranberry Glades is a unique wetland system that stands in stark contrast to its surrounding deciduous forest environment. Peatlands, though widespread in the northern latitudes of North America, are rare, disjunct and ecologically important systems in this more southerly location. The isolated conditions characterizing the Glades provide an island of refuge for several rare and unique plant species (i.e. *Cornus canadensis*) as well as forming the southernmost distribution of several plants (i.e. *Saxifraga pennsylvanica*, *Menyanthes trifoliata*, *Andromeda polifolia*) found otherwise only in northern boreal environments (Strausbaugh, 1934; Braun, 1947; Core, 1974; Stewart and Nilson, 1993; Murdock, 1994). The complex ecosystem and formation of the Glades





Figure 1.1. Trees encroaching into the open peatland meadow (10 June 2008).

also make it an ideal location for studying landscapes created by a past colder climate and from unique geologic features (Darlington, 1942, 1943).

The process of tree infilling and succession at the Cranberry Glades may involve multiple complex and interrelated factors, as at other ecotones that are characterized by tree infilling (e.g. Moore and Huffman, 2004; Bekker, 2005; Resler, 2006). This study, grounded in the framework of biogeomorphology and biogeography, analyzed biogeographic/geomorphic relationships operating in the Cranberry Glades (also referred to as the Glades), and resultant vegetation patterns. It is not our goal to understand all possible causes and processes of infilling, but rather to explore some of the primary reasons and their potential applications to the processes occurring in the Glades.

Observable vegetation changes within the Glades are most evident within the ecotone, or transition zone, between the forest and open meadow. This study assesses the current state of the Cranberry Glades, with particular emphasis on ecotone change of the bog meadows and adjacent forests due to tree encroachment. We analyzed pattern of tree infilling as they relate to soil conditions, microtopography, and plant facilitation across the ecotone. In order to characterize the ecotone and the various factors involved in the tree infilling, we addressed both landscape and fine scales. For this study, the fine scale encompasses features less than 100 m<sup>2</sup> in area. The landscape scale is defined as the level that focuses on patterns and processes that occur from 100 m<sup>2</sup> to 10 km<sup>2</sup>.

Specific objectives of the study are to:

- 1) Characterize tree establishment patterns and soil properties across the meadow-forest ecotone;
- 2) Determine relationships among fine scale soil properties, microtopography, and tree establishment;
- 3) Assess tree infilling patterns and soil properties at the scale of each Glade;
- 4) Perform a landscape scale spatio-temporal assessment of the tree infilling patterns using historical aerial photographs.

Several investigators have studied the Glades during the past several decades to examine vegetation, origin, soils, and plant succession (Darlington, 1942, 1943; Edens, 1973; Core, 1974; Kokesh, 1988; Byers et al., 2007). Darlington (1942, 1943) performed an extensive study on the vegetation communities, soil properties, and potential origins of the Glades. His data have become the baseline for subsequent studies on the Glades. Edens (1973) completed a study in the early 1970's on the succession of the Glades and how the vegetation communities have changed since Darlington's study. Kokesh (1988) performed a subsequent analysis of bog forests changes since Darlington (1942, 1943) and Edens' (1973) studies. The West Virginia Natural Heritage Program (WVNHP) completed a wetlands inventory in December 2007 of West Virginia and collected and compiled data from the Glades (Byers et al., 2007). The resulting report provided a conservation ranking of wetlands in West Virginia; it characterized the Cranberry Glades as a cranberry – beakrush peatland, listed as S2/G2 (imperiled with global and state conservation importance).

This study fills a gap in the literature concerning tree infilling patterns in southern peatlands, especially with regard to the relationships between microtopography, facilitation, and soil and the encroachment of trees. Several studies have examined the correlations between microtopography and tree growth (Lewis and Dowding, 1926; Edens, 1973; Collins *et al.*, 1982), tree islands and large wetlands (van der Valk and Warner, 2008 and references), and soils and

peatland patterns (Wetzel et al., 2005), however, literature lacks studies that have assessed all of these factors with regard to succession in southern peatlands.

The basic component of the research utilizes the theories of ecotone hierarchy (Gosz, 1993), systems theory (Chorley, 1962), and bog succession (Dansereau and Segadas-Vianna, 1952) to analyze the abiotic and biotic processes operating within the Glades. Integrating the fields of biogeography, geomorphology, and ecology will present a diversified and encompassing perspective in addressing the complex process associated with the Glades and tree infilling.

Results of this study should also have management implications. Findings from this research may assist in the understanding and management of rare plants found in the peatland meadows, plants that are potentially threatened by tree encroachment. In addition, the Cranberry Glades are a frequently visited destination with people coming to the Glades primarily for the scenery and the novelty of the bog meadow features (Hammit, 1978). Knowledge of how the Glades are changing may inform interpretation efforts.

## **1.2 Hypotheses**

This study assesses the ecotone dynamics of the Cranberry Glades. Spatial pattern of the tree infilling will be analyzed both temporally and spatially as related specifically to geomorphic features. This study identifies factors related to the changing ecotone of the Glades and current conditions of tree infilling. The following hypotheses will assist in meeting the objectives of this study (stated on page 3).

Research question 1 and null hypothesis 1 address Objective 1 through an analysis of tree density and establishment patterns and soil properties across the bog forest – peatland meadow ecotone at the landscape scale.

Objective 1: Characterize tree establishment patterns and density and soil properties across the meadow-forest ecotone with the use of field data.

Research question 1: Do tree density and infilling patterns and soil properties vary across the bog forest – peatland meadow ecotone?

H<sub>0</sub>1: There is no variation in tree density or soil properties across the ecotone.

Research question 2 and null hypothesis 2 address Objective 2 by assessing the potential relationships among fine scale soil properties, microtopography, and tree establishment.

Objective 2: Determine the relationship among fine scale soil properties, microtopography, and tree establishment.

Research question 2: Are correlations evident among soil properties, tree establishment, and microtopography?

H<sub>0</sub>2: Tree presence is random with respect to microtopography and soil properties.

Research question 3 and null hypothesis 3 address Objective 3 by analyzing the differences and similarities among the three Glades.

Objective 3: Assess tree infilling patterns and soil properties at the scale of each Glade.

H<sub>0</sub>3: There are no significant differences in tree density or soil properties among the three Glades.

Research question 4 and null hypothesis 4 address Objective 4 by assessing tree infilling patterns at a temporal scale with the use of historical aerial photographs.

Objective 4: Perform a landscape scale, spatio-temporal assessment of the tree infilling patterns with the use of historical aerial photographs.

Research question 4: Have tree infilling patterns changed over the time period in which we have aerial photographs (1957-2007)?

H<sub>0</sub>4: There are no discernable changes in tree infilling over the time frame that we have aerial photographs.

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## Chapter 2: Literature Review

### *2.1 Bogs and fens: definitions and description*

Bogs are open wetland meadows and are typically characterized by plants that can tolerate moist soil, low nutrients, and greater acidity than those in many other ecosystems (Conway, 1949; Core, 1974; Bedford et al., 1997; Aerts et al., 1999). However, there is no consensus in the literature concerning terms used to describe, identify, and characterize bogs (Moore and Bellamy, 1974; Gore, 1983; Wieder et al., 1981; Walbridge, 1982; Aerts et al., 1999). Gore (1983) differentiated bogs and fens by defining bogs as treeless areas dominated by shrubs, and fens as environments containing more trees and greater species diversity. Moore and Bellamy (1974) stated that a fen is a predecessor to bogs and forests. Aerts et al. (1999) distinguish between bogs and fens based on the primary nutrient source. They stated that fens receive nutrients from precipitation, surface water and groundwater, whereas bogs acquire nutrients from precipitation only. Following Darlington (1942, 1943), Edens (1973), and Kokesh's (1988) notation, the Cranberry Glades will be referred to as a bog throughout this paper.

Bogs and fens may be considered widespread in regions of North America above 41° N latitude (Wieder and Lang, 1983); however, few are found in the more southern latitudes. Southern bogs are primarily found in the mountains of West Virginia, Virginia, North Carolina, South Carolina, Georgia, Kentucky, and Tennessee. Bogs of the southeastern United States highlands are often found in concave basins among mountain peaks (Moorhead and Rossell, 1998). These unique ecosystems form islands of habitat for species found otherwise only in more northerly regions. Some plant species found in the bogs are remnants of the conditions found during the last glacial period. The unique features of southern bogs make them especially important for study in order to gain a greater understanding of bog processes and distributions of rare plant species.

Southern bogs differ from their northern counterparts in several respects, including soil characteristics, mineralization, and origin (Moorhead and Rossell, 1998). At northern latitudes, bogs may have formed from glacier-carved lakes, whereas in southern unglaciated regions, the colder, periglacial climates and increased precipitation contributed to the formation of bogs



during the Pleistocene (Gates, 1942; Darlington, 1942, 1943; Conway, 1949; Walbridge, 1982). Southern bogs receive more ions from the soil and have a higher pH than bogs of northern regions. Northern bogs often are dome-shaped due to the greater accumulation of peat on the surface (Heinselman, 1970), whereas southern bogs are generally bowl-shaped. Southern bogs are generally found near headwater streams in high valleys, which facilitate poor water drainage and the collection of cold air (Moorhead and Rossell, 1998). Horizontal deposition may account for significant amounts of precipitation in these southern areas (Reiners and Lang, 1979).

Minerotrophic bogs receive most of their moisture and nutrients from groundwater, whereas ombrotrophic bogs, which are more common in the north, derive their water and nutrients primarily from precipitation (Almquist-Jacobson and Foster, 1995; Feehan and O'Donovan, 1996; Moorhead and Rossell, 1998). Characterization as minerotrophic or ombrotrophic is easily assigned to northern bogs, which can characteristically be placed into one of the two categories. Southern bogs, however, are often more difficult to classify. The Cranberry Glades, for example, have been recently classified as ombrotrophic (Byers et al., 2007). However, other studies claim that the Glades contain features of both ombrotrophic and minerotrophic bogs (Darlington, 1943; Rigg and Strausbaugh, 1949; Stewart and Nilsen, 1993). Wieder et al. (1981) also lists several other factors which include climate, topography, and island biogeographic features that vary between northern and southern bogs. However, southern and northern bogs do share the following characteristics: dwarf shrubs are the dominant vegetation, the soil is acidic and contains low nutrients, *Sphagnum* is common, and the surface layer is comprised of peat (Stewart and Nilsen, 1993).

## *2.2 Geomorphology, soil, and zoogeomorphic processes*

Geomorphology and other abiotic factors are important in the development of bog vegetation patterns (Dansereau and Segadas-Vianna, 1952; Isaak et al., 1959; Moore and Bellamy, 1974; Edens, 1973; Schwintzer, 1978; van der Valk, 1981; Stewart and Nilsen, 1993; Almquist-Jacobson and Foster, 1995). Soil, hydrotopography, and climate are the primary factors related to the formation of bogs (Isaac et al., 1959, Almquist-Jacobson and Foster, 1995). Landscape features suitable for bogs, such as large depressions, mountains and mountain basins, are also important components related to bog development (Diehl, 1981; Walbridge, 1982; Moorhead and Rossell, 1998).

The interaction between the vegetation and the geomorphology may also influence the development and growth of bogs. Vegetation may influence accumulation and erosion of soils, which in turn, affects the topography, hydrology and subsequent vegetation establishment. Raised areas within bogs may foster the growth of certain types of plants while others prefer moist hollows. However, there is debate in the literature concerning the influence of vegetation on the development of topographic features within bogs. Some studies have noted that hummocks erode down to a hollow and hollows form into hummocks, and that this process repeats itself (Watt, 1947; Gorham, 1957). *Sphagnum* species that prefer the wetter hollows may colonize a hollow to the extent that they fill it completely, and as a result, create drier, less habitable conditions for that species – an example of negative feedback (Gorham, 1957; Bever, 1994; Packer and Clay, 2004). This condition allows for other species to grow in the former hollow, which results in the surface being raised over time. The area may reach an elevation that fosters the growth of mosses and lichens at about 5 to 50 cm or more before again being eroded back into a pool or hollow. However, others have stated that the climate and underlying topography control the surface topography (e.g. Boatman et al., 1981) and that topographic features do not change but remain stable as hummocks or hollows throughout time (Moore, 1977; Foster and Wright, 1990).

The vegetation of bog systems is characteristically tolerant of acidic and hydric conditions. Low nutrients, high levels of light, and water saturated soils also prevent all but the bog adapted plants to grow in such harsh conditions. The undulating hummock/hollow topography of bogs may facilitate the growth of vegetation by providing varying levels of moisture and pH values. Some plant species are characteristically found either on the hummocks or in the hollows (Lewis and Dowding, 1926; Gorham, 1957). Perhaps also, as in other extreme environments (deserts – Parker, 1989 and alpine environments – Resler et al., 2005) there is a sheltering effect caused by the microtopography that would enhance seedling survival and germination.

Several studies have indicated that trees and other woody vegetation are more commonly located on hummocks rather than in hollows (Lewis and Dowding, 1926; Edens, 1973; Collins et al., 1982). Lewis and Dowding (1926) observed in their study on retrogression of bogs in Alberta that small trees were often found on hummocks. Collins et al. (1982) found that woody vegetation was more common on the raised hummocks in their study on an Ohio fen. Both

studies attribute this effect to the more mesic conditions associated with slightly increased elevations of the hummocks. Collins et al. (1982) also looked at over-winter seedling survival but did not find a correlation between survival and microelevation. They concluded that germination may be related to elevation while survival is random - a conclusion, however, based on very few seedling counts. Edens (1973) found that shrub age and presence were related to hummock formation and size. He noted that the larger hummocks contained larger, older shrubs. He also found that most trees occur in hummock clumps with several to 32 trees per clump.

The importance of microelevation (as it related to microtopography) for tree establishment may be related to the location of the water table and the resulting acidity and moisture concentration of the soil (Darlington 1942, 1943; van der Valk, 1981). Darlington (1942, 1943) hypothesized that the tree infilling of the bog meadow at the Cranberry Glades was at least a partial result of the down-cutting of the Cranberry River and the resulting drop in the water table. Lewis and Dowding (1926) concluded that the loss of bog-like conditions was partially the result of drainage of lakes and streams in the region. Conversely, some studies noted that a rise in the water table is associated with bog expansion in northern areas (Isaac et al., 1959; Beals, 1965). Beals (1965) attributed retrogression succession of a Wisconsin swamp to rising water conditions caused by beaver dams on a stream that had formerly drained the swamp.

Geology and resulting pedogenesis largely determines the formation of bogs and the vegetation patterns (Diehl, 1981; Walbridge, 1982). Almquist-Jacobson and Foster (1995) determined soil to be the primary factor influencing spatial patterns in bog formation and growth. The underlying soil of bogs must be conducive to saturation and be poorly drained in order for a bog to develop and remain a bog (Lewis and Dowding, 1929; Darlington, 1942, 1943) or the underlying rock must be impervious. The mineral and nutrient content of bog soils is relatively low and is, therefore, an inhibiting factor to vegetation not adapted to bog-like conditions (Lewis and Dowding, 1929; Darlington, 1942, 1943; Edens, 1973; Kokesh, 1988). Percent organic material and acidity are also often high - a study on several bogs (including the Cranberry Glades) in West Virginia found that pH ranged from 3.6 to 4.0, and percent organic matter was 91 to 94 (Stewart and Nilson, 1993). Byers et al. (2007) determined that a pH of 3.7 as the average for the cranberry-beakrush communities.

Zoogeomorphology (defined as the study of the influence that animals have on geomorphology) has also shown to have significant impacts on the formation of bogs. Beavers,

for example, have been shown to profoundly affect vegetation patterns by altering local geomorphic and hydrologic processes (Edens, 1973; Walbridge, 1982; Mitchell and Niering, 1993; Butler and Malanson, 1995; Butler, 1995). Edens (1973) attributed a significant responsibility of the vegetation patterning to beaver activity at the Cranberry Glades. Whereas the Cranberry Glades are experiencing tree succession in the four bog meadows (Darlington, 1943; Edens, 1973; Kokesh, 1988), some areas are experiencing retrosuccession due to beaver dams (Edens, 1973; Kokesh, 1988).

Walbridge (1982) discussed the impact of beavers on four wetlands in the highlands of West Virginia. Beavers were extirpated from West Virginia by 1825, but reintroduced beginning in the 1930's (Bailey, 1954). Beavers influence the successional sequences of vegetation through dam building, which ponds water behind their dams (Walbridge, 1982).

In general, beaver ponds lead to changes in the hydrologic features of the affected area, which results in an inundation and loss of the vegetation influenced by the pond (Edens, 1973; Butler, 1995; Butler and Malanson, 1995). Sediment deposited behind the dam forms a layer of inorganic material on what otherwise may have been organic material. Once the dam breaks or degrades, the water drains the area and early stages of succession begin. Initial vegetation will then likely return to the area.

### *2.3 Theoretical context: ecotones and ecotone hierarchy*

An ecotone is defined as the zone of transition between two adjacent ecosystems or vegetation types (Gosz, 1993; Risser, 1993b). An ecotone may vary in abruptness as one ecosystem transitions into another. Traditionally, the ecotone concept was viewed at three spatial scales - scale as defined geographically in terms of area and distance – that corresponded to different types of environments – edge habitat for wildlife, treelines, and continental scale biomes (Risser, 1993b). However, over the past two decades, the ecotone concept has come to encompass more environmental scales (Gosz, 1993) and has been recognized as an important feature of the landscape (Risser, 1993b; Malanson, 1997). Ecotones, because they include the species of two ecological communities, have high biodiversity. As such, their distinction as unique landscape features has received increasing attention over the past several decades (Risser, 1993b).

Spatial scale is an important determinant in the understanding of landscape features and processes (Phillips, 1995, 1999). As such, it is necessary to define or characterize the scale(s) at which an ecotone is studied. Geomorphic features and vegetation, though interrelated, may vary spatially and temporally in relation to each other (Phillips, 1995). Ecotones can be studied at many scales, and the nature of the research question asked often determines the spatial and temporal scale at which it is analyzed (Gosz, 1993; Risser, 1993a; Phillips, 1999).

Gosz (1993) addressed the issue of spatial scale as it defines, controls, and determines the properties of a given ecotone, and recognizes the levels of plant, population, patch, landscape, and biome as the hierarchical scales of ecotones. The scale at which an ecotone is analyzed is an important factor in determining the processes that are taking place within the ecotone. For example, at the level of an individual plant, changes occurring among individual plants or plant communities within a small (i.e. 1 m x 1 m) area characterize the ecotone. These micro-scale features however, may influence and determine larger scale patterns in the population and patch scales. Population and patch-scale features include changes in vegetation communities within the landscape, which then influence the mosaic of patterns and processes associated with the landscape scale. At the landscape scale, ecotones represent changes between macro-scale ecosystems; for example, a wetland may be considered the ecotone between the aquatic and terrestrial systems at the landscape scale (Risser, 1993a). The biome scale encompasses ecosystem changes that occur on a continental scale and is primarily determined by climate and topography (Gonz, 1993). The biome scale constraints, in turn, influence landscape features. The number of constraints and the interactions among constraints increase as the scale becomes finer, and therefore, processes and patterns occurring at fine scales create patterns within the limitations of the broader scales.

The conceptual framework on ecotone hierarchies as expressed by Gosz (1993) can apply to bogs in the following way. Bogs often contain elements of, or are, ecotones at certain scales. The bog itself may be considered an ecotone within the landscape scale. At the community and patch scales, bogs are often bordered by ecotones of varying width (e.g. the bog meadow- forest boundary) and are characterized by vegetation compositions that differ from both the bog and the surrounding landscape (Carter et al., 1994). The vegetation and width of the ecotone is often determined by the gradient of the topography and hydrology of the area and soil conditions. However, though vegetation patterns are sometimes abrupt or patchy, edaphic, topographic, and

hydrologic factors often change gradually (Watkinson, 1985; Pennings and Callaway, 1992). Abrupt or more defined ecotone transitions may indicate that vegetation patterns are not controlled by physical factors, but rather, vegetation processes (i.e. competition, facilitation) may be taking place and controlling the ecotone dynamics (Malanson, 1997).

#### *2.4 Boundary dynamics and edaphic factors*

Whereas studies on ecotones generally focus on transition zones as related to species diversity and pattern (Risser, 1993b), the field of boundary dynamics concentrates on why the ecotone is positioned where it is (Weins et al., 1985). Wiens et al., (1985) published a paper proposing “boundary dynamics” and the various factors that influence and control the boundary among patches of vegetation communities at multiple scales. Boundaries are defined as the “locations where the rates or magnitudes of ecological transfers (e.g. energy flow, nitrogen exchange) change abruptly in relation to those within the patches” (Wiens et al., 1985, 422). They proposed that boundaries may be controlled primarily by edaphic factors but also may be influenced by biotic and other abiotic vectors and features. The study of boundary dynamics is differentiated from ecotone and edge effects in that its focus is on determining why the location of the boundary is where it is, the processes and vectors influencing the boundary, and the flow of material across the boundary.

Wiens et al. (1985) asserted that edaphic factors are primary controllers of boundary location. They proposed that changes in vegetation, patch dynamics, and energy production are the result of changes in soil characteristics. Soil properties such as organic content, texture, moisture, and composition may predict vegetation distribution.

Factors other than soil may influence boundaries and complicate predictions of boundary lines (Weins et al., 1985; Wilson and Agnew, 1992; Carter et al., 1994; Callaway and Walker, 1997). Disturbances such as fire, human activities, herbivory, animal activity, vegetation dynamics, wind, and flooding may alter an otherwise expected boundary (Wiens et al., 1985; Callaway, 1994). Some processes, including fire and human activity, may eliminate a vegetation community altogether, while others may convert patches into heterogeneous landscapes. Wiens et al., (1985) termed animals and agents to be vectors that influence a boundary and transport material across the boundary. Wind may be considered a vector as it influences seed and pollen dispersal across boundary lines and transports materials in and out of patches. Wind also

complicates patterns by being variable in nature and changing with regard to season, weather patterns, daily fluctuations and influences of topography.

Animal activity can affect boundary determinations and influence soil factors and vegetation distribution (Edens, 1973; Weins et al., 1985; Butler, 2006). The influence that an animal may have will vary in relation to the environment and the activity and behavior of the animal (Wiens et al., 1985; Butler, 1995; Butler, 2006). Beavers are classic examples of how an animal can influence and alter its habitat (Edens, 1973; Butler and Malason, 1995; Butler, 2006). Beaver dams can result in shifts in boundaries, changes in the ecotone, and alterations in the hydrology and soil properties (Mitchell and Niering, 1993). Weins et al. (1985) listed several other animals as examples of vectors of boundary dynamics including ants.

Whereas vegetation patterns and distribution are often reflective of edaphic factors, vegetation may also modify local soil conditions to its own benefit. Individual plants and vegetation communities can increase soil fertility, increase water infiltration, influence organic content, and capture sediment and build up soil, and in doing so, create conditions more favorable for the community (Wilson and Agnew, 1992). This process of plants improving their environment for their own benefit and facilitating the growth of other plants is addressed by numerous studies (e.g. Wilson and Agnew, 1992; Callaway, 1994; Greenlee and Callaway, 1996; Butler et al., 2004; Resler, 2006) and is a type of positive feedback effect.

### *2.5 Positive feedback systems in bogs*

Ecotones and boundaries are determined by the biotic and abiotic factors that influence the vegetation and topography of an area. Plants themselves, are among these influencing factors. Plant facilitation, a type of positive feedback mechanism in which plants assist in the establishment and subsequent growth of other plants, may assist in the gradual migration of vegetation into a hostile environment and result in changes in the ecotone (Wilson and Agnew, 1992; Malanson, 1997; Choler et al., 2001). Eventually, the effects of such processes on plants may result in a spatial shift of the ecotone (e.g. Zeng and Malanson, 2006). Positive feedbacks indicate that there is a non-random spatial association among the vegetation (Choler et al., 2001). Salt marshes, alpine, arctic, and desert systems are classic examples of how vegetation, limited by stressful conditions, can facilitate the growth of more plants through modification of its local environment (e.g. Parker 1989; Kikvidze and Nakhutsrishvili, 1998; Bekker 2005; Resler et al.

2005, among many others). While competition among individual plants and plant species is a strong factor in the distribution of vegetation (Wilson and Keddy, 1986), numerous studies have demonstrated the importance of feedback in the distribution of plants (e.g. Wilson and Agnew, 1992; Callaway, 1994; Greenlee and Callaway, 1996; Callaway, 2007).

Positive feedback effects may be an important aspect of ecotone processes and patterns and can be observed at various spatial scales (Wilson and Agnew, 1992; Malanson, 1997). At the landscape scale, for example, Malanson (1997) found that abrupt treelines in alpine regions may indicate a strong feedback, while more gradual transitions may be representative of weak or no feedback. Many biogeographic processes discussed in the literature deal with features at the local and micro-scale (e.g. Collins et al., 1983; Chen et al., 1995). At the local scale, communities are often discussed in relation to altering their environment in order to help that community advance. A micro-scale perspective would include processes that occur over fine spatio-temporal scales, - for example, at the individual plant level, a benefactor plant may improve the growing conditions for another plant beneath benefactor plant's leaves by providing shade and improving local soil conditions.

Wilson and Agnew (1992) discussed the varying factors that may be related to positive feedback effects in vegetation communities. Plants may alter soil chemistry, water or moisture content of the soil or air, light intensity, temperature, wind, and herbivory, and in effect, benefit the plant community (Wilson and Agnew, 1992; Greenlee and Callaway, 1996). Vegetation can increase the water input into the soil via fog drip, increased infiltration, and decrease evaporation (Vogelman et al., 1968; Wilson and Agnew, 1992). These processes are particularly apparent in arid and semiarid regions, during periods of drought, and on hill slopes (Belsky, 1986; Pugnaire et al., 1996). Sediment entrapment is another process of facilitation in which vegetation takes hold of sediment and improves the site conditions for more vegetation by increasing sediment buildup, deflecting inundation, and decreasing salinity in salt marshes (Wilson and Agnew, 1992; Hacker and Bertness, 1995). This process can be seen in salt marshes and other areas frequently inundated with silt laden water. Woody vegetation in freshwater wetlands, including bogs, may capture inorganic sediment during flood events, which may improve growing in an otherwise highly organic environment. Vegetation can also decrease light intensity and temperature, creating facilitative growing conditions for beneficiaries, including tree seedlings (Valiente-Banuet and Ezcurra, 1991). The buffering capacities provided by plants in deflecting wind or herbivores are also examples of important ecological feedbacks (Wilson and Agnew, 1992).

Positive feedback mechanisms in ecological systems may fluctuate in importance and function according to various factors, including life stages, plant species, and ecosystem and



environmental stress. Environmental stress is noted to be a determining factor in the relative function of competition and facilitation in vegetation on a landscape (e.g. Greenlee and Callaway, 1996; Pugnaire et al., 1996; Callaway and Walker, 1997). Facilitation is defined as the process in which vegetation or objects (i.e. rocks) assist in the growth of plants (Callaway, 1994; Greenlee and Callaway, 1996) and is a type of positive feedback. Though competition, defined as a resource limiting activity, has received considerable attention on its affect on vegetation communities and structure (e.g. Campbell, 1991; Wilson, 1993; Davis et al., 1998), facilitation has received recent attention in the scientific community as an important process in vegetation structure (Callaway, 1994; Pugnaire et al., 1996; Callaway and Walker, 1997; Callaway, 2007). Callaway and Walker (1997) discussed the two factors of competition and facilitation as interrelated processes that often are at work in the same community. Environmental and abiotic stresses may be controlling factors in the extent of what process is dominating (Wilson and Angew, 1992; Greenlee and Callaway, 1996; Callaway and Walker, 1997; Choler et al., 2001). Callaway (1994) proposed that as abiotic stress increases, the importance of facilitation increases, and likewise as stress decreases, competition increases. Other studies support this hypothesis (Wilson and Keddy, 1986; Greenlee and Callaway, 1996; Callaway and Walker, 1997). Choler et al. (2001) found that competition was the dominant mechanism in alpine areas within the optimum conditions for a species, whereas above the optimum elevation for a species; facilitation appeared to be the controlling factor in plant interactions. Like alpine and desert environments, bogs are harsh systems in which facilitation may be the dominating process in the competition/facilitation dynamic.

Tree infilling of the Cranberry Glades may be partially explained in the context of positive feedbacks. Darlington (1942, 1943) and Edens (1973) observed that trees growing in the meadow often were growing in clumps. Based on the reported clumping of the trees and the stressful nature of the bogs, trees may be influencing the topography and soils of the glades and in effect, contributing to the improved growing conditions and establishment of subsequent trees.

### *2.6 Spatial pattern: tree succession and seedling establishment*

Interactions among abiotic and biotic factors determine the spatial patterning of trees (Gates, 1942; Beals, 1965; Diehl, 1981; Collins et al., 1982). Microclimate, microtopography, facilitation and competition, niche limitations, and local soil properties are important

determinants of the spatial pattern of trees at the micro-scale (Gates, 1942; Zedler and Zedler, 1969; Schwintzer, 1978; Reiners and Lang, 1979; Boatman et al., 1981; Hacker and Bertness, 1996; Kikvidze et al., 2005). Changes in vegetation communities, plant distributions, and shifts in ecosystems - processes that occur and define an ecotone - are generally controlled by factors at the micro-scale within the limitations of the macro-scale features (e.g. climate, geology) (Gosz, 1993).

Tree succession, establishment, competition, and death are the primary factors influencing the spatial pattern of tree communities. Succession, defined as the “sequential change in the relative abundances of the dominant species in a community” (Huston and Smith, 1987), is one factor that may cause a change in the ecotone and implies a progression from an initial community towards a more stable, well-developed community (Glenn-Lewis et al., 1992). Primary succession describes the process of a community establishing an area that has never before had vegetation (i.e. volcanic material, alluvium) (Glenn-Lewis et al., 1992). Secondary succession occurs when a species or community becomes established in an area that previously had vegetation (Glenn-Lewis et al., 1992). Bogs often experience natural processes of secondary succession (Dansereau and Segadas-Vianna, 1952; Walbridge, 1982).

Tree succession is strongly dependent on the successful establishment and survival of tree seedlings. Climate, soil conditions, established vegetation (including parent material), seed rain, light, and predation are some of the influential factors of seedling establishment (Ingram, 1967; Wilson and Agnew, 1992; Ribbens et al., 1994; Malason, 1997). Likewise, the death of trees or the inability of seedlings to establish in bogs is often related to hydrology and soil conditions in bogs (Lewis and Dowding, 1956; Isaak et al., 1959; Ingram, 1967).

### *2.7 Succession of the Cranberry Glades*

The hydrology and soil properties of the Cranberry Glades are thought to be one of the controlling factors of tree succession. The moisture and acidity of the peat material may be a strong inhibitor of seedling establishment. However, changes may occur that result in more hospitable growing conditions, and allow for successional processes. The bogs of West Virginia may be in the late successional stage characterized by the slow transition from bog to forest community (Darlington, 1942, 1943; Core, 1974; Walbridge, 1982). Darlington (1942, 1943), Edens (1973), and Kokesh (1988) all concurred that the Glades are experiencing successional

stages. Darlington (1942, 1943) listed the stages of the Cranberry Glades, based on sediment and pollen, as follows: shallow water, sedge swamp, sphagnum, shrub and bog forest before stabilizing as a forest once the peat has been eroded away and drainage of the Glades has occurred. Some currently open wetlands were forested before logging activities. Walbridge (1982) hypothesized that the eventual succession of bogs in West Virginia ends in wetland forest community. However, the nature of bogs hinders the development of forests and Walbridge (1982) questions the actuality of successful establishment of trees in the *Sphagnum* bogs.

Darlington (1942, 1943), Edens (1973), and Kokesh (1988) all addressed the successional changes that have been occurring at the Glades. Kokesh (1988) observed in the 1980's that the *Sphagnum-Vaccinium-Rhynchospora*, which characteristically forms very open areas, and *Polytrichum-Cladonia* communities had drastically decreased from Darlington's (1942, 1943) study in the 1930's and 1940's. These moss-lichen communities were overtaken by shrub communities and trees. *Alnus* thickets are also noted to be increasing throughout the valley of the Glade area.

Darlington (1942, 1943) noted that there is a straight channel of the Cranberry River that runs alongside of Big Glade and proposed that this channel is down-cutting and therefore influencing the encroachment of the bog forest into the bog meadow and shrub communities. He observed that it was especially evident in Flag Glade and Round Glade where spruce were growing in the moss communities. One *Pinus strobus* was also observed growing in the moss community as well as three or four *P. rigida* growing in the Big Glade bog. Edens and Ash (1969) recorded that 339 *P. strobus* were growing in Big Glade by the late 1960's.

It is likely difficult for trees to begin growing in established moss communities because the mosses form a thick barricade over the surface. The trees must penetrate their roots through the *Sphagnum* and other mosses in order to establish themselves; otherwise, they would likely be blown over in the windswept Glades. Darlington (1942, 1943) found that tree establishment is much more successful, however, when a group of four to eight trees grow together and offer protection to each other from the wind. He observed that there are several such groups of trees in Big Glade and Flag Glade.

Tree growth within the open peatland is slow. In order to acquire a relative age of the trees in the Cranberry Glades, Darlington (1942, 1943) determined the age of a tree from near-by Kennison Mountain, one from the bog forest, and one from the moss-lichen community in the

glade; all were 6.4 cm in diameter. He found the Kennison Mountain tree to be 19 years old, the one in the bog forest to be 49 years old, and the one in the open bog to be 31 years old. These differences were attributed to the lack of sunlight and the water absorption limitation faced by the trees in the bog forest, while the trees in the bog meadow were limited by the lack of nutrients and exposed to wind. Trees in Big Glade of eight to ten inches in diameter would therefore be about 125 years old (Darlington, 1942, 1943). Trees were also found to have been blown over and their trunks covered in mosses. Trunks of trees were found up to about 4 meters deep, and lends evidence to the idea that trees have been attempting to establish themselves in the bog meadow for hundreds or thousands of years (Darlington, 1942, 1943).

Darlington (1942, 1943) and Edens (1973) observed that trees and shrub communities were often associated with hummocks. Sphagnum and other mosses form the hummocks, and the shrubs may assist in the growth of the hummocks by offering protection from the elements for the mosses. The Cranberry Glades are often windy and evaporation can be high in the summer and the water table can drop down to 30 cm below the surface (Darlington, 1942, 1943). Shrubs may assist in the growth of mosses by creating moister habitat under the shrub's leaf cover. Likewise, hummocks may facilitate the growth of trees and shrubs by offering areas above the more hydric conditions of the hollows. Trees may also offer protection from the wind for other trees, and therefore facilitate the establishment and growth of nearby seedlings.

The influence of edaphic and hydrologic factors on vegetation patterns is well documented (e.g. Walbridge, 1982; Kokesh, 1988; Stewart and Nilson, 1993; Aerts et al., 1999; Stolt et al., 2001) and is likely a key component to the vegetation patterning of the tree infilling at the Glades. The tree patterns and ecotone dynamics at the Glades however, may not be fully explained by abiotic factors. Edens (1973) and Darlington (1942, 1943) both found that trees were often growing in clumps. Clumping has been associated with positive feedback mechanisms in alpine, desert, and other high stress systems (Sohlberg and Bliss, 1984; Kikvidze, 1993; Nunez et al., 1999). Darlington (1942, 1943) noted that strong winds frequently affect the Glades and proposed that trees grow in clumps for protection. The ecotone and the processes of infilling are largely determined by seedling establishment and survival. Conditions associated with seedling establishment will be assessed as they relate to edaphic and topographical features as well as vegetations patterns. The importance of the topography of the bogs may be related to the water table and soil properties, which are thought to be important factors controlling or

influencing the vegetation and tree secession (Darlington, 1942, 1943; Stewart and Nilson, 1993). Other geomorphic processes operating at various spatial scales, including beaver dam formation and river down-cutting, are likely to impact vegetation patterns as well (Darlington, 1942, 1943; Edens, 1973; Butler 2006).

## *2.8 Summary*

Southern peatlands serve as important ecosystems due to their unique habitat and often isolated conditions they form within temperate forest systems. Loss of open peatland to forest however, will change the conditions and habitat that the peatlands provide. The Cranberry Glades Botanical Area is experiencing succession by encroachment of trees and alders into the open peatland meadows. The factors and processes responsible for this shift in the ecosystems are likely many and interdependent, and may include soil conditions, climate variability, vegetation dynamics, and geomorphic processes. Analyzing vegetation patterns and how they may be influenced or controlled by various biotic and abiotic factors will lend information the processes that may be occurring within the bog meadow-forest ecotone.

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## Chapter 3: Manuscript

Vegetation and soil patterns at a mountain wetland ecotone

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## **Abstract**

Tree encroachment patterns and associated microtopography and soil conditions were examined across the bog meadow-forest ecotone at the Cranberry Glades Botanical Area, West Virginia, USA. Peatlands are gaining increasing attention for their role in the carbon cycle, however, any process that shifts peat landscapes to those dominated by trees may influence amounts of carbon that can be sequestered. Patterns and mechanisms of tree infilling into peatland meadows are little understood within the southern Appalachian Mountains. The goal of this research was to understand patterns of tree encroachment into the bog meadows. Specific objectives were to define relationships between tree encroachment and distance from the forest edge, microtopography, soil properties, and the growth of other trees. Data on the growing conditions of individual trees and tree islands, soil properties, and microtopographic features across the peatland meadow-forest ecotone were collected. Results indicate that there is a significant relationship between tree density and distance from the forest edge, and that most trees within the ecotone are located within tree islands and on hummocks. Findings contribute to understanding fine-scale vegetation and soil patterns and processes of peatland ecotones within remaining boreal ecosystems of the southern Appalachians.

Keywords: southern peatlands, tree infilling, Cranberry Glades, biogeography

## **Introduction**

In recent years, boreal and subalpine peatlands have attracted increasing attention for their important role in the carbon cycle (e.g. Gorham, 1991; Vitt et al., 2000; Weltzin et al., 2003; Belyea and Malmer, 2004). Though boreal peatlands comprise only ~ 2 percent of the earth's surface (Matthews and Fung, 1987; Aselmann and Crutzen, 1989; Bridgham et al., 2001), they contain about 15-30 percent of the world's stored carbon (Limpens et al., 2008). Positive feedback mechanisms may decrease the role peatlands serve as reservoirs of carbon (Weltzin et al., 2003) as they succumb to the process of forest succession (Dansereau and Segadas-Vianna, 1952; Walbridge, 1982). Any loss of peatlands to trees will shift the ecosystem from a moss-dominated system to a forested system (Weltzin et al., 2003). Such losses will likely decrease

their ability to store carbon (Heathwaite, 1993; Belyea and Malmer, 2004). Knowledge of the processes of infilling peatlands may assist in the understanding of their potential role for altering the carbon cycle and drivers of tree encroachment.

Southern Appalachian peatlands are located in cool basins within the highlands of West Virginia, Virginia, North Carolina, South Carolina, Tennessee, Georgia, and Kentucky (Moorhead and Rossell, 1998). They have received considerably little attention with regard to their successional patterns and processes and how these factors may relate to larger scale processes (e.g. carbon cycle, plant biogeography, climate change) (Wieder et al., 1981; Moorhead and Rossel, 1998). Even though southern peatlands comprise less area than boreal or subalpine peatlands, they are important ecosystems that host a variety of plant species that may otherwise not exist in the southern Appalachians (Braun, 1947; Strausbaugh, 1934; Core, 1974; Murdock, 1994). Southern peatlands are biogeographic islands within an overall warmer region and many represent the southernmost range for certain plant species. Assessing changes in vegetation patterns in southern peatlands is necessary because they differ from their northern counterparts in several respects (Wieder et al., 1981; Stewart and Nilsen, 1993), and an assessment of how the patterns and processes of southern peatlands compare to boreal peatlands is needed.

The goal of this research was to understand patterns of tree encroachment into the bog meadow at fine scales and at the landscape scale, in order to better understand why trees grow in some locations, and not in others. For this study we define “fine scale” as  $< 100 \text{ m}^2$  and landscape scales as  $100 \text{ m}^2 - 10 \text{ km}^2$ . The scale at which ecotone processes are analyzed is an important variable when assessing the factors of vegetation patterns and change (Gosz 1993; Phillips 1995, 1999; Risser, 1993; Malanson 1997). Analyzing (fine and landscape scale) processes is necessary in determining controlling factors or influencing features of the vegetation patterns within context of larger scale controls such as climate (Gosz, 1993). Due to the multiple factors that may be influencing the tree encroachment, this study examines several potential aspects related to the tree infilling, geomorphic features, and ecotone processes.

Specific objectives were to: 1) characterize tree establishment and soil properties across the bog meadow-forest ecotone, 2) determine the relationships among fine-scale soil properties, microtopographic features and tree establishment, 3) assess tree infilling patterns and soil properties at the scale of each Glade, and 4) perform a landscape scale, spatio-temporal

assessment of the tree infilling patterns using historical aerial photographs. The study location is particularly significant since documentation of the Glades extends back to 1911 (Brooks, 1911) and several studies in the past have been performed in the Glades (Strausbaugh, 1934; Darlington, 1942, 1943; Core, 1974; Edens, 1973; Kokesh, 1988; Stewart and Nilsen, 1993), and it is a naturally occurring open peatland (Brooks, 1911; Strausbaugh, 1934; Darlington, 1942, 1943). The Cranberry Glades is also the largest and southern-most bog of its type (cranberry – beakrush peatland) and home to several rare and endangered plant species (Byers et al., 2007). We hypothesize that there is a significant spatial association present in the trees in relation to their position within the ecotone and each other, to microtopographic features, and to soil conditions.

### *CONTRASTS AND COMPARISONS AMONG NORTHERN AND SOUTHERN BOGS*

Bogs and fens are widespread in North America above 41° N latitude (Wieder and Lang, 1983); however, substantially fewer are found in the more southern latitudes. Bogs of the southeastern United States highlands are often characterized by a concave morphology, nestled among mountain peaks (Moorhead and Rossell, 1998). These unique ecosystems form islands of habitat for species found otherwise only at more northerly locations. Some plant species are remnants of conditions characteristic of the last glacial period. Unique features of southern bogs make them especially important as a research focus in order to gain a greater understanding of bog processes and distributions of rare plant species.

Southern bogs differ from their northern counterparts in several respects, including soil, mineralization, and origin (Moorhead and Rossell, 1998). At northern latitudes, bogs may have formed from glacier-carved lakes, whereas in southern unglaciated regions, colder climates and differences in precipitation and vegetation cover may have contributed to the formation of bogs during and following the Pleistocene (Darlington, 1942, 1943; Gates, 1942; Conway, 1949; Walbridge, 1982). Southern bogs receive more ions from the soil and have a higher pH than bogs of the northern regions. Northern bogs often have convex topographic profiles due to the greater accumulation of peat on the surface (Heinselman, 1970), whereas southern bogs are generally bowl-shaped in profile. The position of southern bogs near headwater streams in high valleys or synclines, facilitates poor water drainage and the collection of cold air (Moorhead and Rossell, 1998). Horizontal deposition may account for significant amounts of precipitation in

these areas (Reiners and Lang, 1979). Minerotrophic fens receive much of their nutrients from the soil whereas ombrotrophic bogs, which are more common in the north, receive their nutrients primarily from rainwater (Almquist-Jacobson and Foster, 1995; Moorhead and Rossell, 1998). Wieder et al. (1981) also list several other factors, including climate, topography, and island biogeographic features that vary between northern and southern bogs.

However, southern and northern bogs do share several characteristics; dwarf shrubs are the dominant vegetation, soils are acidic and contain low nutrients, *Sphagnum* is common, and the surface layer is comprised of peat (Stewart and Nilsen, 1993). Saturated soils, low nutrients, and high acidity often prevent many trees and other vegetation from establishing in subalpine, boreal, and southern bogs (Lewis and Dowding, 1956; Isaak et al., 1959; Ingram, 1967). Peatland plants are especially adapted to the low nutrient and harsh conditions; however, the increasing establishment of trees indicates a change in the conditions, which allows for growth of vegetation not commonly found in bog environments.

## **Methods**

### *STUDY SITE*

The Cranberry Glades Botanical Area (the Glades) is a series of open peatlands infilling with trees from the surrounding mixed temperate forest (Darlington, 1942, 1943; Edens, 1973; Kokesh, 1988) and is located at ~ 38.20° N, -80.27° E in Pocahontas County, West Virginia (Fig. 3.1). The Glades are situated on Cranberry Mountain within the Cranberry Glades Wilderness Area and Monongalia National Forest at elevations ranging from 1024 to 1037 m. The Botanical Area is comprised of 243 hectares, and within the Botanical Area lie four peatlands – Big Glade (60 ha), Flag Glade (28 ha), Round Glade (8 ha), and Long Glade (20 ha) (Kokesh, 1988) (Fig. 3.2).

The Botanical Area is situated in a bowl-shaped basin with poor drainage - a feature that likely facilitated its formation and its continued existence during periods of climate warming at the end of the Pleistocene and into the Holocene (Darlington, 1942, 1943). Darlington (1942, 1943) hypothesized that the cooler climate, vegetation, and precipitation regimes during and following the Pleistocene and the retreat of the Laurentide ice sheet were instrumental in the formation of the Glades. The ice sheet did not reach into West Virginia and glaciers did not form the Glades as they commonly did in northern regions, but rather the colder, periglacial

environment that extended south from the ice sheet into the Smoky Mountains during the Pleistocene glacial period influenced the formation of the Glades (Darlington, 1942, 1943; Edens, 1973; Core, 1974). Locally wet and cool climate conditions, exacerbated by lake-effect precipitation from the Great Lakes, and the Glades' location within western slopes of the Appalachians have helped to maintain the peatlands (Darlington, 1942, 1943; Johnson, 1986). The headwaters of the Cranberry River and numerous other streams flow through or nearby the Glades and were key agents to the formation of the Glades (Darlington, 1942, 1943). Edens (1973) stated that the Glades experience about a 3° (C) cooler temperature difference compared to those recorded at surrounding higher elevations due to the sinking and settling of cooler air from surrounding mountains. The Glades also experience a significant amount of wind (Darlington, 1942, 1943).

Past and present biogeography of the Cranberry Glades was substantially influenced by its glacial history. This region of the Appalachians was thought to be dominated by boreal forest of pine-spruce-birch-hemlock (Core, 1974). The isolated conditions characterizing the Glades have created a biogeographic island of refuge for several rare (i.e. *Cornus canadensis*) and unique plant species, as well as forming the southern-most distribution of several plants (i.e. *Saxifraga pennsylvanica*, *Menyanthes trifoliata*, *Andromeda polifolia*) found otherwise only in northern boreal environments (Strausbaugh, 1934; Braun, 1947; Core, 1974; Stewart and Nilson, 1993; Murdock, 1994). Stewart and Nilson (1993) determined that *Vaccinium oxycoccus* (small cranberry) was the dominant vegetation in the Cranberry Glades bogs. Other plants include *Vaccinium macrocarpan* (large cranberry), *Rhynchospora alba* (white beaksedge), and *Sphagnum* spp. (*Sphagnum* spp.) (Byers et al., 2007). Two carnivorous plants are found in the Glades – *Utricularia cornula* and *Drosera rotundifolia* (Darlington, 1942, 1943). *Picea rubras* (red spruce), is the dominant tree species encroaching into the open Glades. Other tree species include *Pinus strobus* (white pine), *Acer rubrum* (red maple), *Betula alleghaniensis* (yellow birch), *Tsuga canadensis* (Eastern hemlock), and *Sorbus americana* (mountain ash) (personal observation).

The three primary vegetation communities found within the Cranberry Glades Botanical Area are the open bog, shrub, and bog forest communities (Darlington, 1942, 1943; Edens, 1973). The four open bogs are dominated by *Sphagnum* moss and contain up to 3 m of decaying peat material (Darlington, 1942, 1943). Shrub communities cover extensive parts of the Glade



area, particularly along the streams that flow through the area. Also, portions of Big Glade and Flag Glade contain shrubs, and shrubs border all four of the bog meadows to some extent. The edge between the bog forest and the ecotone is generally distinct at the Glades. The forest is often accompanied by shrubs and is dominated by trees rather than by mosses as in the ecotone and the open meadow (Kokesh, 1988).

### *FIELD SAMPLING*

We collected samples in Big, Flag, and Round Glades; Long Glade was excluded from the study because it is surrounded by alder thickets rather than forests. Grasses also cover a significant portion of the open area of Long Glade compared to the other Glades and the presence of grasses appear to preclude tree establishment.

Sampling areas were initially scouted using aerial photographs in order to find glades with tree infilling. To measure potential changes along the forest – bog meadow transition, vegetation and soil sampling locations were delineated in the field with belt transects, with randomly determined starting positions along the edge of the forest. We placed three 10 m x 100 m belt transects (e.g. Collins et al., 1982; Copenheaver et al., 2004) in each of the three Glades. Each transect began 5 m inside the forest edge (defined as the boundary between forest dominated ecosystem of trees and the ecotone and peatland ecosystem of mosses, peatland plants, and incontiguous groups of trees) and extended outward toward the interior of the open glade meadow, following a constant compass bearing. Each belt was partitioned into 5 m<sup>2</sup> contiguous segments, resulting in 40, 5 m<sup>2</sup> quadrats along the length of each belt (e.g. Veblen et al., 1979). Subdividing the belts into 5 m<sup>2</sup> quadrats aided in recording the location of trees and tree islands, and helped to determine regular intervals for soil samples.

For the purpose of understanding vegetation composition within the ecotone, we collected information on trees and their growing conditions. Diameter at breast height (DBH) (for trees greater than 1.37 m in height) or diameter at ground level (DGL) (for trees less than 1.37 m and greater than 10 cm in height), height class, and species composition were recorded for individual trees and trees within tree islands (defined here as aggregations of at least three trees) that had at least 25% of their crown cover within belt transects. Location of each tree or tree island relative to the forest edge was determined. We applied a line-intercept method to measure the composition and dimensions of all tree islands greater than 4 m<sup>2</sup> (e.g. Resler and

Fonstad, 2008). A lengthwise transect tape was placed down the center of the tree island, and a transect tape was placed perpendicular to this lengthwise transect tape in order to acquire the maximum width (two width lines were placed for tree islands equal to or in excess of 15 m in length). Diameter at breast height, height class, and species composition were recorded for each tree that was in contact or immediately underneath or above the line.

Microtopographic features were of interest to us because they have been associated with tree seedling establishment in abiotically stressful environments (e.g. Titus, 1990; Resler, 2006). Hummocks were identified as mounds of at least 10 cm in height; this classification included asymmetrical hummock features. Hollows were topographically depressed areas, often interspersed among hummock features.

Soil samples were collected every 20 m across the extent of the ecotone for subsequent lab analysis. Specifically, we were interested in soil properties important for vegetation growth and establishment, such as moisture, nutrients, and pH (Brady and Weil, 2008). We collected soil samples (~240 cm<sup>3</sup>) from ten point locations within each belt transect; one sample at 20 cm below the surface was extracted with a peat auger, and another sample was obtained at 120 cm depth using a bucket auger. At each quadrat, two samples were collected in the 5 m<sup>2</sup> forest quadrats for use as a reference. Additional soil samples were taken from the open peatland in quadrats positioned at 15-20 m, 40-45 m, 65-70 m, and 90-95 m from the forest edge to characterize soil properties across the ecotone. Within each 5 m<sup>2</sup> quadrat, the exact location of soil collection was selected using a random number generator and an overlay grid. Differences in soil characteristics between hummocks and hollows were also assessed because tree pattern appeared to be related to microtopography; therefore soil was collected from hummocks and nearby hollows for subsequent lab analysis. We collected a total of 162 soil samples (2 per quadrat, 18 per transect, 54 per glade) over a three day period during similar weather conditions. Percent soil moisture and pH were determined using SSSA (Soil Science Society of America, 1996) standard methods. Soil pH was determined from a buffer pH at a 1:3 ratio due to the small sizes of some of the samples and the nature of the peat samples to soak up the water. Carbon and nitrogen were analyzed in the Virginia Tech Department of Crop and Soils Environmental Sciences' lab. Selected macronutrients, micronutrients, and metals (P, K, Ca, Mg, Mn, Zn, Fe, Cu, B, Al) were analyzed by the Virginia Tech Extension Soil Testing Laboratory (Mullins and Heckendorn, 2005).

## *STATISTICAL ANALYSIS*

Data were entered into a spreadsheet and analyzed using JMP® (JMP) version 7.0. All data were analyzed for normality and equality of variance, and log transformations were applied where appropriate. On normally distributed data, we used ANOVA or a *t* test to determine significant differences among means. Non-parametric Wilcoxon tests were used on data sets that were not normally distributed. With data that were normally distributed but of unequal variance, we used Welch's ANOVA. G-tests were used on nominal data (Sokol and Rohlf, 1981). All tests were run and analyzed at the 0.05 significance level. For analysis of tree density across the ecotone, each belt transect was divided into four intervals (0-25 m, 25-50 m, 50-75 m, and 75-95 m) from the forest edge. The last interval (75-95 m) only contains 20 linear meters rather than 25 as with the other intervals, and this discrepancy was taken into account when calculating tree density. Standard deviations are reported with means.

## *AERIAL PHOTO ANALYSIS*

In order to assess changes in temporal and spatial patterns of ecotone change, we examined sequential aerial photographs of the Glades acquired in 1957, 1969, 1975, 1986, and 2007. The 1957, 1969, and 1975 images are panchromatic images (black and white). The 1986 image is in color infrared (CIR), and the 2007 image is in natural color. The 1957, 1969, and 1975 images are available through the USDA. The 1986 photo was acquired from the USGS Spatial Data Gateway. The 2007 image was downloaded from the USGS Global Visualization Viewer.

A quantitative assessment of changes in the area (1969-2007) of the open bog was performed using ESRI ArcGIS. The two images were registered with each other, then the edges of each Glade were digitized and the areas calculated. The area of the meadows in 2007 was subtracted from the area of the 1969 image to estimate the change in area.

## **Results**

### *VEGETATION AND SOIL PROPERTIES ACROSS THE ECOTONE*

A total of 1,389 trees were sampled within the peatland belt transects; these trees represented six species: *Picea rubras*, *Acer rubrum*, *Betula alleganensis*, *Tsuga canadensis*, and

*Sorbus americana*. *Picea rubras* (red spruce) was the most abundant tree (72.8% of total, 1147/1389) recorded growing in the open meadow. Other trees surveyed within the belt transects included *Acer rubrum* (red maple, 13.0%, 201/1389), *Betula alleganensis* (yellow birch, 1.2%, 19/1389), *Tsuga canadensis* (Eastern hemlock, 1.0%, 15/1389), and *Sorbus americana* (mountain ash, 0.06%, 1/1389). Diameter at breast height (DBH) for all species ranged from 0.2 to 60.4 cm (mean =  $8.87 \pm 7.86$ ,  $n = 561$ ), and diameter at ground level (DGL) ranged from 0.1 to 9.4 cm (mean =  $1.28 \pm 1.14$ ,  $n = 817$ ). Trees ranged in age from seedlings to cone producing trees (Table 1).

There is a significant difference in tree numbers ( $F < 0.001$ ,  $F$  ratio = 16.14,  $df = 3, 114$ ,  $P < 0.05$ , one-way ANOVA on log transformed data, Tukey-Kramer,  $P < 0.05$ ) and density ( $F < 0.0001$ ,  $F$  ratio = 14.30,  $df = 3, 114$ ,  $P < 0.05$ , one-way ANOVA on log transformed data, Tukey-Kramer,  $P < 0.05$ ) among the four sections of the ecotone (0-25 m, 25-50 m, 50-75 m, and 75-95 m from the forest edge). Average tree density ( $0.3231$  trees  $\pm 0.2987$ ) at 0-20 m from the forest edge was found to be significantly different from all other ecotone positions (Figure 3.3). Tree density at the bog meadow interior was found to be significantly different from tree density within the first 50 m from the forest edge and this interior-most section contained an average density of  $0.014$  trees  $\pm 0.036$  per  $m^{-2}$ . We also looked at tree counts and density within smaller sections, 2 adjacent quadrats -  $50 m^2$ , across the ecotone. For the nine transects combined, the two quadrats immediately adjacent to the forest edge contained an average tree/tree island count of  $21.00 \pm 12.81$  (Figure 3.4) and a tree/tree island density of  $0.42 \pm 0.26$ , compared to a mean count of  $0.22 \pm 0.44$  and mean tree/tree island density of  $0.004 \pm 0.01$  for the two quadrats located at the interior of the glade. Regression analysis shows this trend of decreasing density from the forest edge out towards the open meadow to have an  $R^2$  value of 0.31 (Figure 3.5).

Moisture, N, P, K, and Cu varied significantly across the transect (Figure 3.6). Tukey-Kramer *post hoc* ( $P < 0.05$ ) showed that the soil collected from just inside the forest varied significantly from the soil collected 90-95 m from the forest edge. Mean moisture, N, K, and Cu were lower within the forest than that found towards the interior of the open peatland. Lower moisture content within the forest is expected due to the general nature of the open peatland to have highly saturated conditions. Nitrogen uptake within the forest is also probably greater than that within the open meadow due to the greater number of trees within the forest. Potassium and Cu may also be lower within the forest due to uptake from the vegetation.

### *TREE ISLANDS AND ROLE OF MICROTOPOGRAPHY AND SOIL IN TREE INFILLING*

In order to gain a better understanding of the spatial pattern of tree establishment we examined microtopography associated with tree locations and whether trees tend to be found as individuals or growing as part of tree islands. A significant proportion of the trees within the ecotone were found within tree islands as analyzed per quad and determined with G-test goodness of fit ( $G=16.094$ ,  $df=1$ ,  $1140$ ,  $P < 0.0001$ ,  $n=1141$ ) with expected proportions of island:individual, set at 3:1. Eighty percent of trees measured across the ecotone were found to be associated with tree islands (913/1141), and 20% were growing as individuals (228/1141).

Trees and tree islands were located on hummocks significantly more than they were spatially associated with hollows as determined with a G-test goodness of fit ( $G=931$ ,  $df=1$ ,  $1111$ ,  $P < 0.0001$ ,  $n=1112$ , 1:1). The average hummock height for all three glades was about  $21 \pm 8.5$  cm, with a range from 10 to 56 cm ( $n=189$ ).

Potassium and Al varied significantly between soil samples collected near a tree or trees and those where trees were absent (Table 2). Potassium, K, %C, and Fe varied significantly between hummock and hollow features (Tables 3). The differences found between hummocks and hollows may be related to weathering mechanisms or the relative distance to the water table.

### *TREE AND SOIL PATTERNS AMONG THE GLADES*

Once we determined significant patterns overall, we then compared the differences between the three Glades. Each Glade shows the same general trend with the overall mean of tree numbers decreasing from the forest edge extending out towards the open meadow (Table 4, Figures 3.7-3.12). Within the three transects in Big Glade, 490 trees were recorded within the ecotone. Flag Glade contained 308 trees within the ecotone, and Round Glade totaled 350 trees. Of these totals, 407 trees in Big Glade were located in tree islands (83% of total trees located in ecotone, 407/490), 203 trees in Flag Glade (66%, 203/308), and 301 trees in Round Glade (86%, 301/350).

As determined by ANOVA, mean soil pH, moisture, N, Mg, B, and Al were found to be significantly different ( $P < 0.05$ ) among the three Glades (Table 5) (moisture,  $F$  ( $df=2$ , 85) =

0.0014; pH,  $F (df=2, 86) =0.0001$ ; %N,  $F (df=2, 75)=0.0002$ ; Mg,  $F (df=2, 62) <0.0001$ ; B,  $F (df=2, 14) 0.0039$ ; Al,  $F (df=2, 62) 0.0001$ ).

### *SPATIO-TEMPORAL ASSESSMENT AT THE LANDSCAPE SCALE WITH THE USE OF AERIAL PHOTOS*

Repeat, historical aerial photographs of the Glades were analyzed to gain a broader temporal and spatial scale of the infilling patterns. First we assessed sequential photographs for changes in the forest edge and for tree and other vegetation patterns within the ecotone for each of the Glades. Aerial photographs acquired in 1957, 1969, 1975, 1986, and 2007 were used for this qualitative assessment. For the quantitative analysis of change, we examined two photos, one from 1969 and the second from 2007. A measure of the perimeter of each of the four Glades was determined by manually digitizing the forest edge using ArcGIS on the two aerial photographs (Ueckert et al., 2001).

The resulting images and numbers indicate that the area in all four glades decreased from 1969 to 2007 (Table 6, Figures 3.13-16). This process did not however, consider the trees and tree islands within the meadows but rather just the location of the border between the meadow and the forest.

Tree infilling of the peatlands appears to have produced a different pattern in each Glade. In Flag Glade, the encroachment of the trees into the open meadow is primarily from the west and northwest directions. A large group of trees is extending from the forest into the Glade in a rather continuous mass on the western side. Individual trees and smaller tree islands are infilling from the northwestern side of the Glade. Round Glade has infilling occurring from the northwestern side, however in a different manner than Flag Glade. Tree islands in Round Glade are generally smaller and in greater number than in Flag Glade. Long Glade however, appears to have only one discernable tree. Big Glade has patches of trees within the open meadow. An anomalous group of trees on the northern edge of the glade is a stand of *Pinus strobus* (white pine). Otherwise, most other infilling trees are located on the southwestern portion of the glade, with several tree islands scattered throughout the glade.

## Discussion

The specific objectives of our study were to: 1) characterize tree establishment across the bog meadow-forest ecotone, 2) characterize changes (if any) in soil properties across the ecotones, and 3) define the relationships among soil properties and microtopography, and microtopography and tree establishment, and 4) assess spatio-temporal patterns of infilling with the use of aerial photographs. Overall, we found that tree density decreased significantly with increasing distance from the forest edge. We also found that tree presence was strongly associated with hummock features and that trees within the ecotone were more likely to be growing within tree islands rather than as individuals. Finally, we did note that changes in tree cover within the peatlands and among the four Glades have occurred over time.

### *TRENDS IN TREE INFILLING AND SOIL PROPERTIES ACROSS THE BOG FOREST-MEADOW ECOTONE*

The density of trees decreased across the ecotone from the forest edge towards the open peatland of the Glades. This observed pattern is in accordance with the typical pattern of wetland secession, in which trees migrate from the forest inward towards the center of the wetland, changing the dominant plant community from that of mosses or other wetland-specific plants to forest (Darlington 1942, 1943; Edens, 1973; Walbridge, 1982; Dansereau and Segadas-Vianna, 1952). Darlington (1942, 1943), Edens (1973), and Kokesh (1988) all concur that the Glades are experiencing succession. Kokesh (1988) observed in the 1980's that the *Sphagnum-Vaccinium-Rhynchospora*, which characteristically forms very open areas, and *Polytrichum-Cladonia* communities had drastically decreased from Darlington's (1942, 1943) study in the 1930's and 1940's. These moss-lichen communities were overtaken by shrub communities and trees. Kokesh (1988) also noted that *Alnus* thickets were increasing throughout the valley of the Glades area in the 1980's.

It is difficult for trees to begin colonizing the moss-covered areas because the mosses inhibit tree seedling establishment by forming a thick barricade over the surface. Tree roots must penetrate through the *Sphagnum* and other mosses in order to establish themselves; otherwise, they would likely be blown over in the windswept Glades. Darlington (1942, 1943) found that tree establishment is much more successful, however, when a group of four to eight trees grow

together and protect each other from the wind. He observed several such groups of trees in Big Glade and Flag Glade.

#### *IMPORTANCE OF MICROTOPOGRAPHY IN TREE ESTABLISHMENT*

The two primary microtopographic features within the ecotone at the Cranberry Glades were hummocks and hollows. The role of these microtopographic features in tree growth were noted by Darlington (1942, 1943) and Edens (1973) who found that trees appeared to grow more commonly on hummocks features rather than in the hollows at the Cranberry Glades.

Furthermore, several studies on northern bogs have found a positive correlation between tree growth and hummock features (Lewis and Dowding, 1926; Edens, 1973; Collins et al., 1982).

Most trees within the bog meadow – forest ecotone were found growing on hummock features. Hummocks may initiate the tolerable conditions allowing for the establishment of a tree by providing a slightly elevated surface farther from the water table than they otherwise would be (Darlington, 1942, 1943; van der Valk, 1981), and subsequent tree establishment may continue to improve growing conditions (van der Valk and Warner, 2008; Wetzel, 2005, 2008). Even though soil moisture was not found to differ significantly between hummocks and hollows, and average moisture of hummocks and hollows was very similar in our study sites (89.75% for hollows and 89.74% for hummocks), the elevated hummocks increase the distance between the surface and the water table (Darlington 1942, 1943; Isaak et al., 1959; Collins et al., 1982). The increased distance between the surface and water table would benefit trees in the often saturated environment at the Glades. During the spring and summer months, the water table may be at or just below the surface of the ground (Darlington, 1942, 1943; per. observation). Such conditions inhibit tree growth, and any increase in distance from the water table to the surface may be beneficial for tree survival.

Phosphorus, K, and C were found to be significantly higher on the hummocks than within the hollows. The greater amount of P on the hummocks may be important to the growth of trees since P may be a limiting nutrient within bogs. The differences in these three properties may be due to weathering, mineralization, and/or dust.



## *THE ROLE OF TREE ISLANDS IN BOG MEADOW INFILLING*

Establishment as a part of tree islands has been considered advantageous to tree growth and survival in diverse environments characterized by extreme abiotic conditions (Marr, 1977; Parker, 1989; Resler 2006; van der Valk and Warner, 2008, Resler and Stine, 2009). We found that eighty percent of all trees recorded within the ecotone were growing in clusters, forming tree islands, suggesting that positive feedback mechanisms may be an important process in tree infilling (van der Valk, 2008). The establishment of a tree may improve conditions for the subsequent growth of other trees either by enhancing the soil conditions, offering protection from predation or wind, or providing seed rain (Malanson, 1997; van der Valk, 2008). Tree islands have been found in numerous high stress environments, such as alpine, desert, salt marsh, and large wetland ecosystems (Marr, 1977; Parker, 1989; Resler 2006; van der Valk and Warner, 2008, Resler and Stine, 2009). The facilitation mechanisms among plants in harsh environments have been well studied and results have indicated that facilitation processes can override competition mechanisms among plants in extreme growth conditions (e.g. Wilson and Agnew, 1992; Callaway, 1994; Greenlee and Callaway, 1996; Callaway, 2007).

A tree may become established in a slightly more suitable location and then improve the conditions and increase the chances of subsequent seedling survival (van der Valk, 2008). A number of islands contained a large tree surrounded by small trees either in a circular pattern or in a linear direction. These establishment patterns suggest that a tree becomes established at a suitable micro-site, and subsequently improves the conditions for the establishment of seedlings, by improving soil conditions, offering protection from the wind, and supplying seeds to the area.

Soil nutrients are often a limiting factor in peatlands (Almquist-Jacobson and Foster, 1995). Bog plants are adapted to such conditions, and may have unique features, (such as those associated with the carnivorous pitcher plant), in order to acquire or better utilize the sources of nutrients that are available. Most trees however, lack such ecophysiological features, but can still increase nutrient availability from leaf litter, and increased nutrients have been found in tree islands within wetlands (Troxler and Childers, 2008). This process fosters the facilitation of the growth of other trees and improves conditions for tree establishment and growth.

## LANDSCAPE SCALE PATTERNS

In order to provide a temporal component to understanding the patterns of tree infilling, we contextualized our results by examining historical aerial photographs of the area. We assessed these images for general changes in tree and alder infilling into each of the Glades. Even though we had photographs that were in different formats and some were older and therefore had less resolution than the more recent photos, the images were still useful for indicating trends.

Qualitative analysis of the aerial photography revealed that the open peatland area within Big and Round Glades has filled in more with trees within the meadow rather than a strong advancement of the forest edge into the open peatland. Flag and Long Glades however, appear to be experiencing a stronger movement of trees or *Alnus* thickets from the edge in towards the peatland interior. Trees present within the peatland in the 1957 and 1969 photos often appear to increase in size or an island of trees will form or become larger in later photos. This occurrence is particularly evident on the northwestern sides of Flag, Round, and Big Glades (Figure 3.17). However, this trend is also seen on the southwestern and southern sides of these Glades. Conversely, Long Glade appears to be experiencing encroachment from all sides by *Alnus* thickets. These patterns indicate that infilling processes are characterized by an increase of trees within the ecotone, rather than a predictable and uniform advancement of the forest edge toward the interior of the open bog. The sequence of photographs also indicates that the tree infilling is occurring in a steady, relatively constant rate, as opposed to establishment pulses. The 2007 image depicts the greatest tree coverage within the ecotone, as compared to other dates (Figure 3.17, example of Flag Glade).

These changes in tree distribution and abundance suggest simultaneous changes within one or more of the factors controlling the tree distributions. Soil and hydrology are considered the controlling processes for tree succession in wetlands (Wetzel et al., 2005) due to the generally wet conditions and low nutrients and high acidity of the soil which form harsh conditions for the establishment and success of tree seedlings. Our results show that soil conditions varied among the three Glades. Soil moisture was found to be lowest in Big Glade which corresponds to the Glade with the greatest tree density within the ecotone. Even though Round Glade, with the second greatest tree density, has the highest percent soil moisture, it has the highest pH of the three Glades.

The variations in tree pattern among the Glades at the landscape scale indicate that tree encroachment is strongly aligned with hydrology and soil conditions at the regional scale. Even though soil types should be relatively the same for the three Glades (Darlington 1942, 1943), other features are likely influencing the hydrology and soil conditions. Several streams flow through the Glades and may be influencing the water table within the peatlands. Also, topographic relief across each Glade, the surrounding topography and associated vegetation, and common wind direction are likely factors in the infilling process.

Streams have been noted to be an important factor in the infilling of several bogs in northern regions (Conway, 1949; Collins et al., 1982) due to their influence on the water table. If streams start draining the bog, then the water level within the bog will decrease as well as influence the nutrient dynamics available to the vegetation. Streams within the Botanical Area, as evident on the aerial photographs, are often meandering through vegetation. The Cranberry River flows by Flag Glade and then between Big Glade and Long Glade. The direction of flow through the Botanical Area is roughly to the northeast. Charles Creek comes in from the other direction and flows into the Cranberry River between Flag and Big Glades. Yew Creek flows between Flag and Round Glade and into Charles Creek. There are also several unnamed intermittent streams that flow through the Glades. In addition, there is a straight channel that runs alongside Big Glade. Darlington (1942, 1943) hypothesized that this straight channel feature was a natural occurrence due to the down-cutting of the river into softer strata. However, the straight nature of the channel and its close proximity to Big Glade indicate that it is a man-made feature.

The flow of the rivers is a key aspect of the formation and wetland features found at the Glades. The damming and/or overflow of the Cranberry are thought to be fundamental components to the formation of the glades area (Darlington 1942, 1943). Beavers influence flows of the river and location of wetland sites alongside of the streams. Several areas within the Botanical Area are in standing water due to beaver dams. Numerous dams are found on the Cranberry River and Charles Creek. An area of the forest between Flag and Round Glades are dying from the saturation of the soil from beaver activity.

Our findings highlight some of the fine scale patterns of infilling and their possible implications, as well as the need to address course scale factors such as processes occurring at the regional and biome scale. The mechanisms influencing and controlling the tree infilling may also be at work in northern bog environments. If peat-dominated areas succumb to woody

vegetation, soil conditions, vegetation patterns, and hydrologic processes will likely change. These factors will then, in turn, influence peatland roles in the carbon cycle. Knowledge of how these factors change the carbon dynamics in peatlands is necessary for the understanding of global carbon budgets.

## **Conclusions**

Our results indicate that soil conditions, microtopography, and facilitation mechanisms are important factors contributing to changing vegetation patterns in the Cranberry Glades. Patterns of tree encroachment and relationships between tree growth and topography and soil conditions suggest that facilitation and geomorphic processes are occurring within the bog forest – meadow ecotone and the Botanical Area. This study looked at patterns, such as soil, microtopography, and tree islands, which are significant factors in wetlands and wetland succession, and the findings may be applicable to other southern peatlands and used as a comparison to boreal peatlands. Even though boreal peatlands vary in several respects when compared to southern peatlands, the vegetation, microtopography, and soil relationships may be similar.

Further studies could include an expansion of this study to encompass more southern peatlands. Additionally, a comparative study of southern peatland infilling patterns and processes to boreal and subalpine peatlands would be beneficial in order to better understand the processes that are working within each and the differences and similarities that may exist. Within the Cranberry Glades Botanical Area, additional research on tree age as determined with tree cores, data on soil properties within Long Glade and how it compares to the other three Glades, underlying hydrologic processes including water table levels, and the relationship between groundwater flow and the streams that flow through the Glades, vegetation distributions and island biogeographic effects, and how regional climate may relate to tree growth need to be explored in order to better understand the processes that are occurring within the ecotone and Botanical Area. Also, broader scale analyses on how processes occurring within southern peatlands may relate to climate change should be explored.

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## Tables and Figures

Figure 3.1. Location of the Cranberry Glades Botanical Area, Pocahontas County, West Virginia.

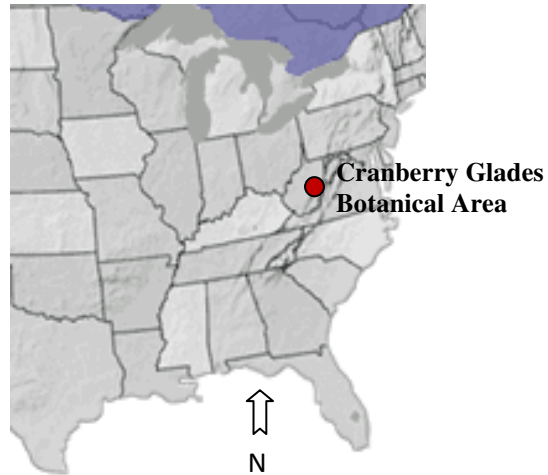


Figure 3.2. 2007 aerial photograph of the Cranberry Glades. The following letters correspond to the respective Glade: A – Flag Glade, B – Round Glade, C – Big Glade, D – Long Glade.



Table 1. Total tree species and mean measurements and ranges.

Species	Mean±Stdev	Range	<i>n</i>	Height Range	Total Number
<b><i>Acer rubrum</i></b>				10->200	170
DBH	5.713±1.399	0.7-19.6	31		
DGL	0.386±0.103	0.1-1.3	170		
<b><i>Betula alleganensis</i></b>				116->200	19
DBH	5.1±1.889	2.1-12.5	17		
DGL	1.3±0.951	1.1-1.5	2		
<b><i>Picea rubras</i></b>				10->200	1197
DBH	9.137±0.343	0.5-60.4	516		
DGL	1.768±0.052	0.1-9.4	681		
<b><i>Sorbus americana</i></b>				>200	1
DBH	5.2	-	1		
DGL	0	-	-		
<b><i>Tsuga canadensis</i></b>				25->200	17
DBH	1.05±3.894	0.2-2	4		
DGL	1.231±0.373	0.4-3	13		

Figure 3.3 Mean tree density per square meter across the ecotone. Error bars show SE±2. Tukey-Kramer *post hoc* significant differences ( $P<0.05$ ) are displayed as a, b, c.

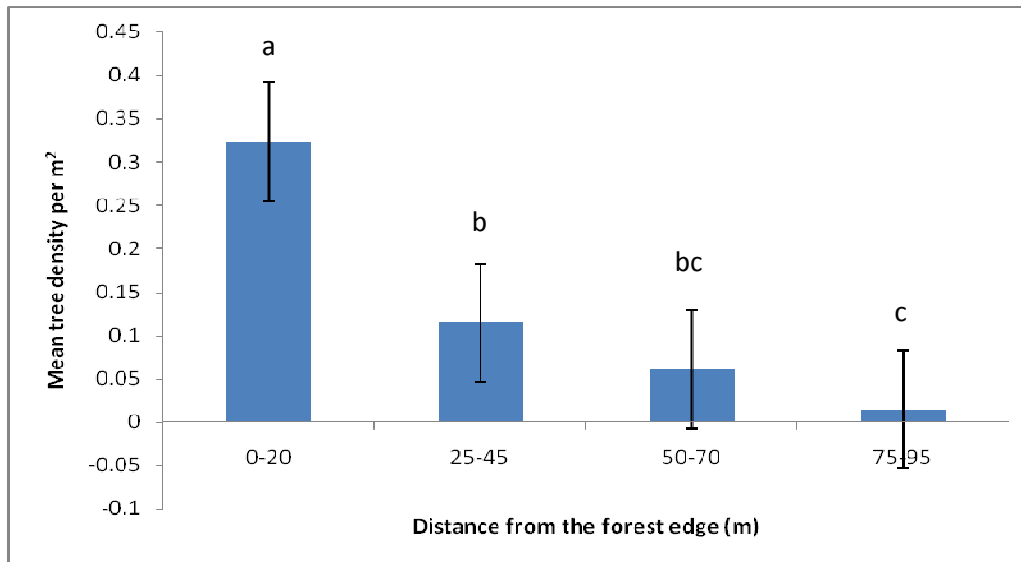


Figure 3.4. Mean tree counts across the ecotone. Error bars show SE±2.

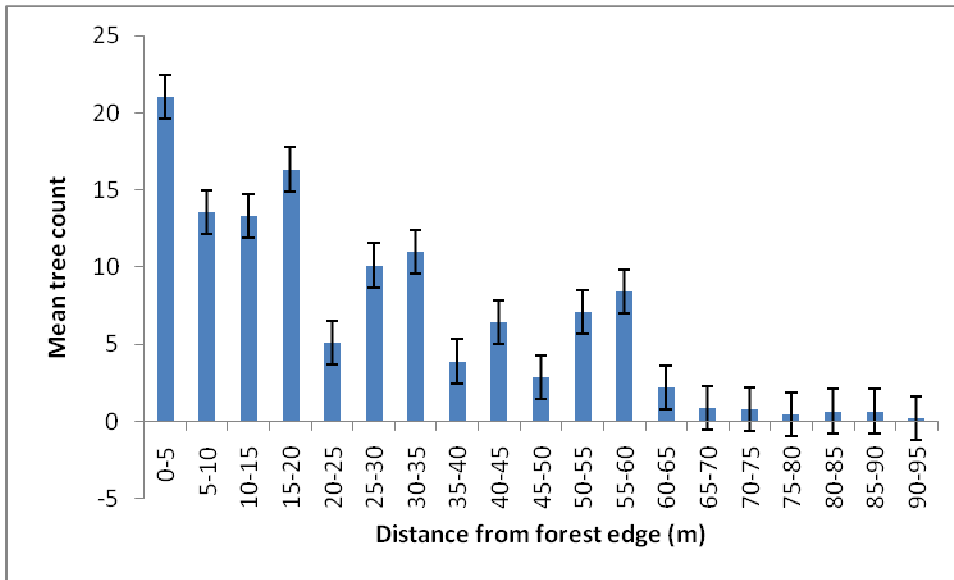


Figure 3.5. Linear regression of mean tree density across the ecotone.

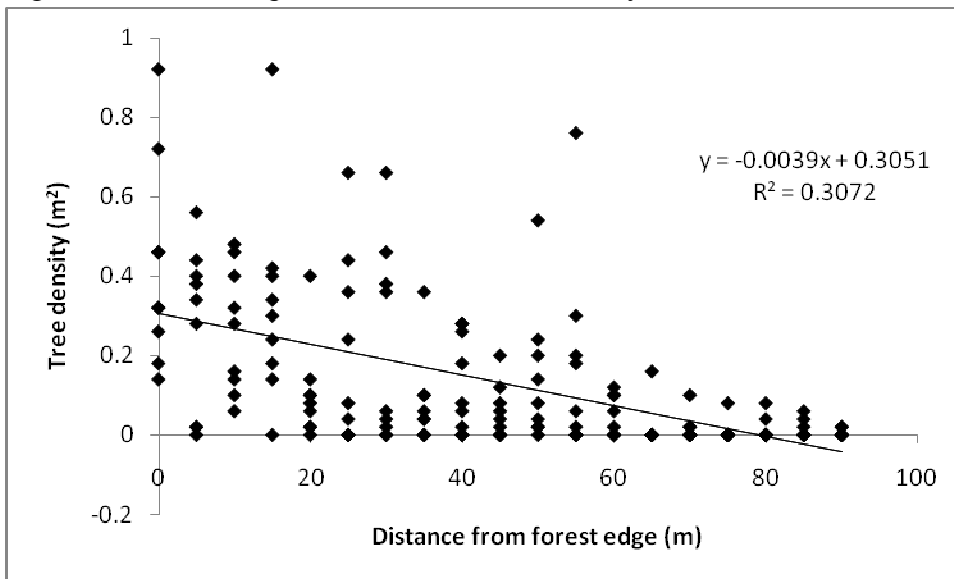
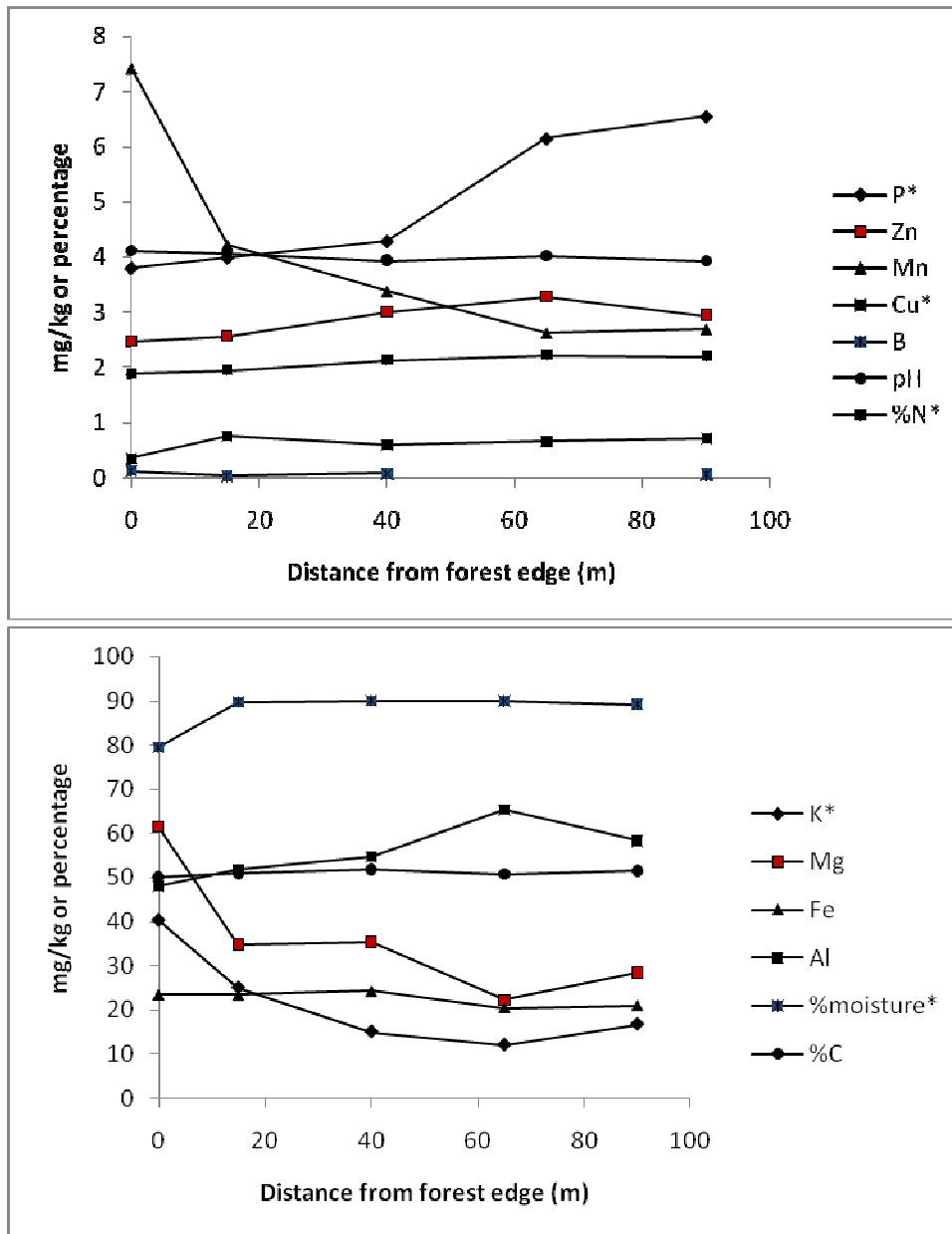


Figure 3.6. Mean soil properties collected at a depth of 20 cm across the transect (\* indicates significant difference,  $P < 0.05$ , as determined by ANOVA).



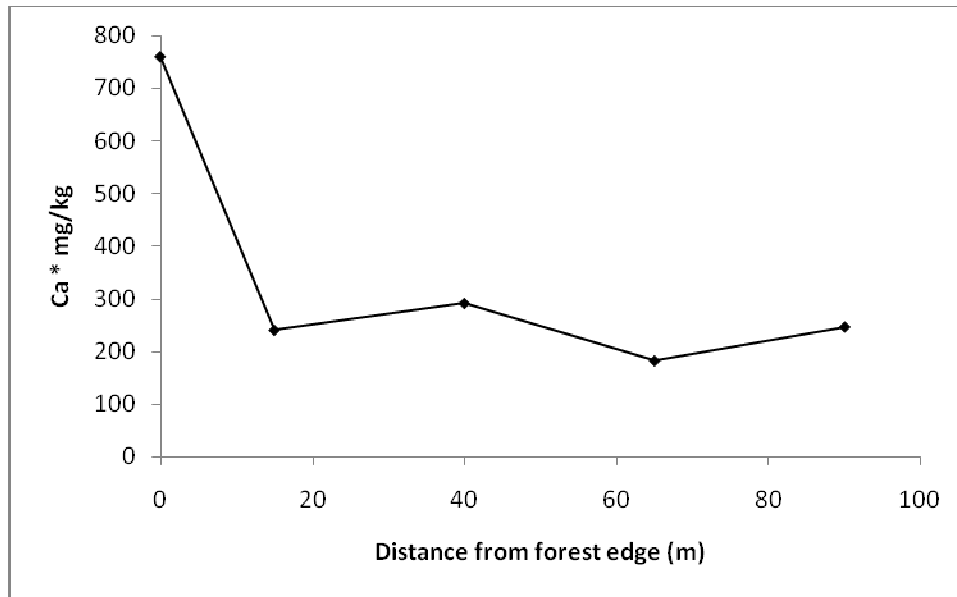


Table 2. Soil conditions in mg/kg (unless noted as a percentage) at 20 cm related to the presence or absence of trees within the ecotone (\* indicates significant difference,  $P < 0.05$ , as determined by  $t$  test).

Soil Property	Tree Present ( $n$ )	Tree Absent ( $n$ )	$t$ ratio	$P$
pH	3.99±0.24 (17)	3.96±0.218 (47)	0.7665	0.2248
% moisture	89.44±1.07 (18)	89.85±1.02 (52)	1.5116	0.751
%N	2.03±0.38 (15)	2.15±0.26 (44)	-1.5525	0.9308
%C	50.89±1.18 (16)	50.63±5.28 (44)	-1.3794	0.9114
P	4.08±1.69 (10)	5.26±2.88 (32)	-1.5939	0.9386
K*	39.65±45.16 (10)	23.55±12.12 (32)	1.8563	0.0354
Ca	365.38±225.79 (10)	397.19±225.23 (32)	-0.039	0.6506
Mg	55.64±31.80 (10)	46.43±21.23 (32)	1.0591	0.148
Zn	2.60±1.16 (10)	3.00±0.95 (32)	-1.0005	0.8324
Mn	5.23±6.51 (10)	2.86±1.12 (32)	1.1464	0.2807
Cu	0.59±0.30 (10)	0.69±0.43 (32)	-0.8283	0.7916
Fe	20.39±6.25 (10)	23.75±9.53 (32)	-1.0428	0.3033
B	0.04±0.01 (4)	0.07±0.05 (3)	0.9438	0.2171
Al*	43.24±24.36 (32)	61.39±19.45 (32)	-2.1508	0.0256

Table 3. Soil conditions in mg/kg (unless noted as a percentage) in relation to topography. Soil collected at 20 cm across the ecotone (\* indicates significant difference,  $P < 0.05$ , as determined by  $t$  test).

Soil Property	Hummock ( $n$ )	Hollow ( $n$ )	$t$ ratio	$P$
pH	3.98±0.23 (36)	3.97±0.24 (32)	-0.2059	0.5812
% moisture	89.74±1.00 (34)	89.75±1.16 (34)	-0.0426	0.5169
%N	2.11±0.35 (31)	2.14±0.24 (29)	-0.0587	0.7201
%C*	51.06±1.02 (31)	51.71±1.25 (28)	-2.1745	0.0171
P *	5.53±2.68 (18)	4.57±2.65 (24)	2.164	0.0183
K*	35.41±33.67 (18)	21.37±12.49 (24)	2.2762	0.0142
Ca	370.67±206.21 (18)	403.82±238.19 (24)	-0.1585	0.5625
Mg	50.87±25.25 (18)	46.94±23.51 (24)	0.8802	0.1926
Zn	2.83±1.07 (18)	2.96±0.97 (24)	-0.3465	0.6345
Mn	4.16±4.93 (18)	2.87±1.21 (24)	1.128	0.1368
Cu	0.64±0.34 (18)	0.69±0.45 (24)	-0.568	0.7133
Fe*	19.99±5.42 (18)	25.18±10.38 (24)	-2.0014	0.267
B	0.06±0.04 (4)	0.05±0.01 (3)	0.5815	0.2964
Al	52.49±26.18 (18)	60.49±17.78 (24)	-1.1595	0.8721

Table 4. Mean tree counts per Glade across the ecotone (BG = Big Glade, FG = Flag Glade, RG = Round Glade).

Distance (m)	BG Mean	FG Mean	RG Mean
0-5	28.333±15.695	19.333±14.572	15.333±8.021
5-10	23.333±4.163	5.333±7.506	12.000±10.440
10-15	14.333±6.658	12.000±9.644	13.667±10.504
15-20	22.667±20.599	12.333±10.786	14.000±6.245
20-25	2.333±2.082	2.333±2.309	10.667±8.145
25-30	7.333±12.702	15.667±15.822	7.333±9.452
30-35	6.000±10.392	9.000±12.166	18.000±15.524
35-40	7.667±9.292	3.333±1.528	0.667±1.155
40-45	10.333±6.351	1.667±2.082	7.333±6.658
45-50	2.333±2.082	4.000±5.292	2.333±3.215
50-55	16.333±9.292	2.000±2.000	3.000±3.464
55-60	15.667±19.858	4.333±5.132	5.333±8.386
60-65	1.333±1.528	3.667±3.215	1.667±2.887
65-70	0	0	2.667±4.619
70-75	0.333±0.577	0	2.000±2.646
75-80	0	1.333±2.309	0
80-85	0.667±1.155	1.333±2.309	0
85-90	0.667±1.155	1.000±1.732	0.333±0.577
90-95	0	0.333±0.577	0.333±0.577

Figure 3.7 Tree counts per transect across the ecotone of Big Glade. Error bars show SE±2.

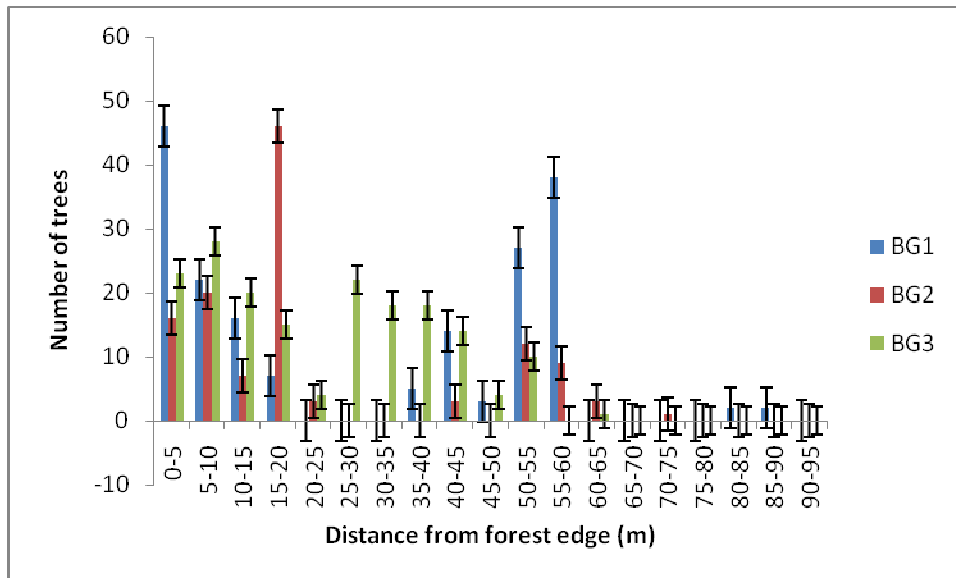




Figure 3.8 Tree counts per transect across the ecotone of Flag Glade. Error bars show SE±2.

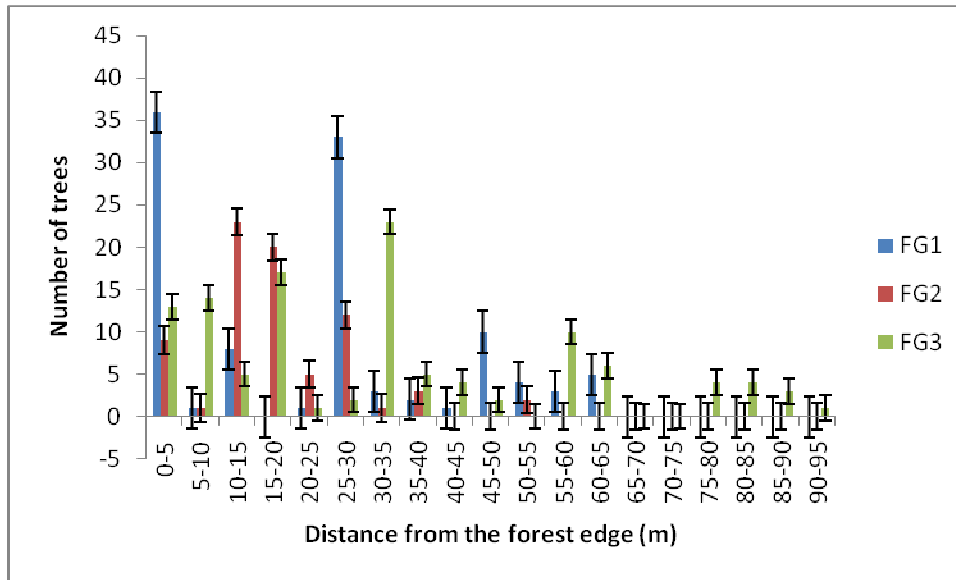


Figure 3.9 Tree counts per transect across the ecotone of Round Glade. Error bars show SE±2.

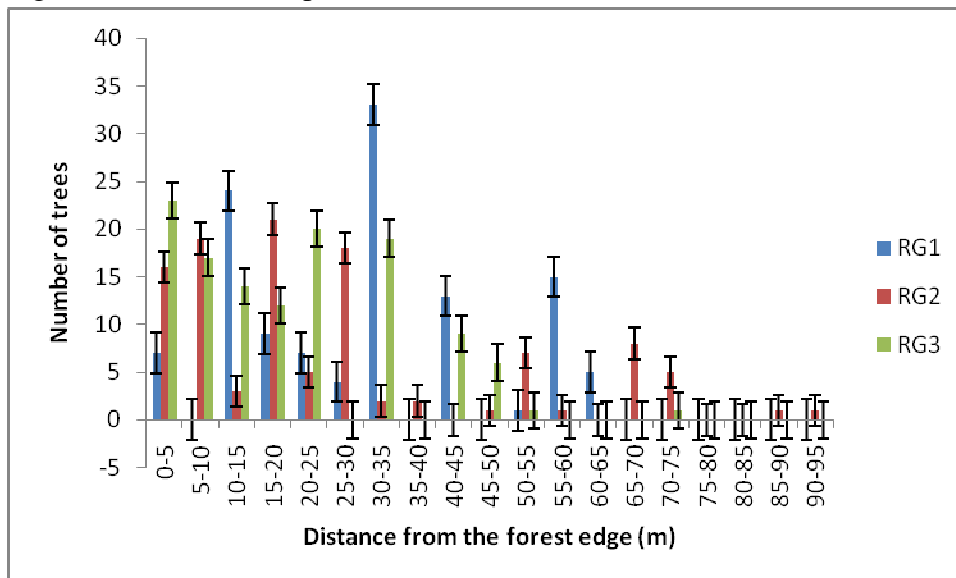


Figure 3.10. Tree density across the ecotone for each transect of Big Glade. Error bars show  $SE \pm 2$ .

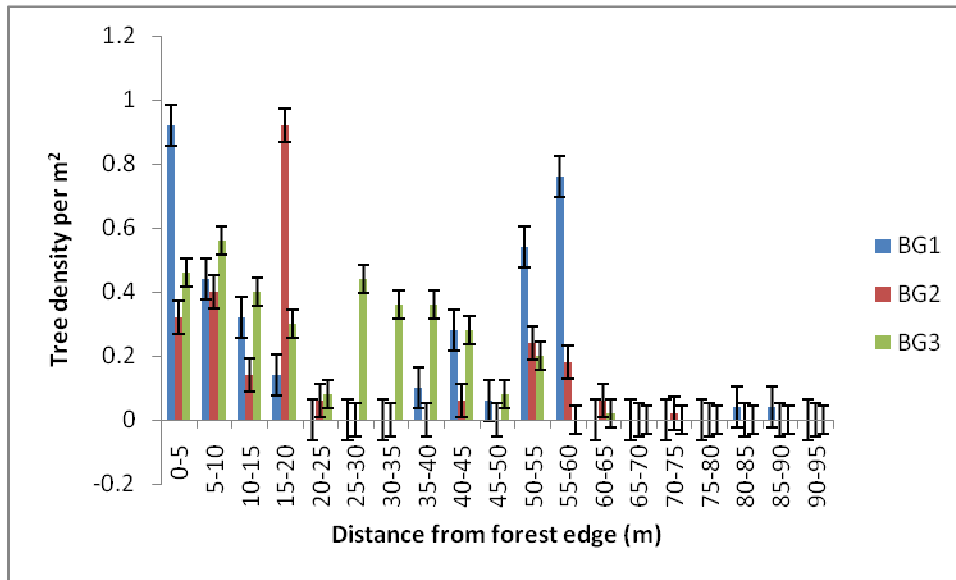


Figure 3.11. Tree density across the ecotone for each transect of Flag Glade. Error bars show  $SE \pm 2$ .

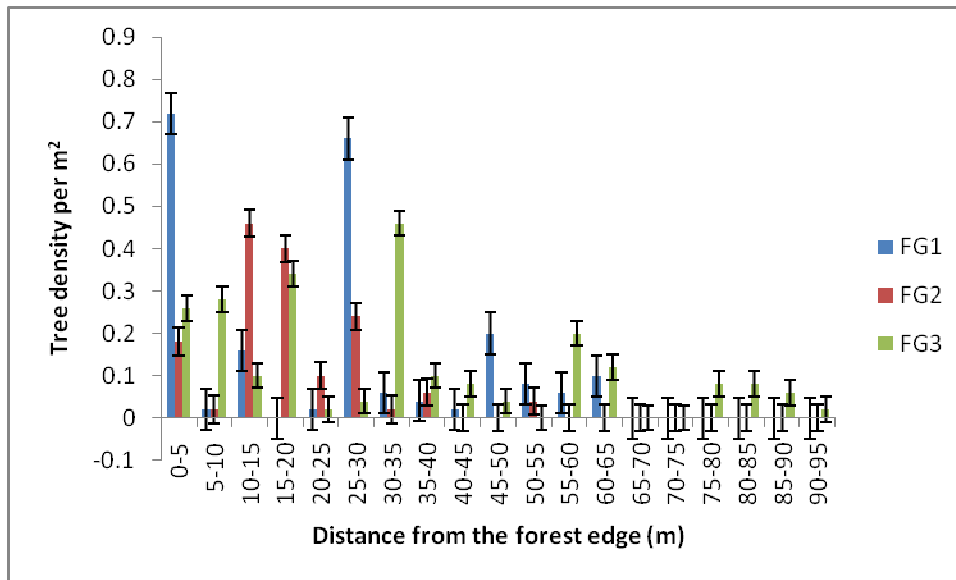


Figure 3.12. Tree density across the ecotone for each transect of Round Glade. Error bars show SE±2.

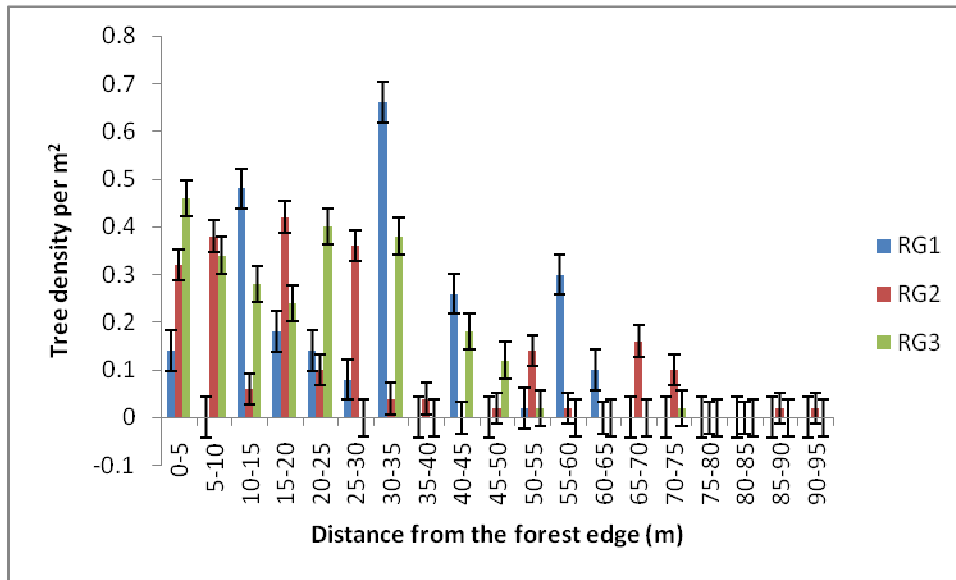


Table 5. Mean soil properties in mg/kg (unless noted as a percentage) for Big, Flag, and Round Glades. Samples taken from across the transect at 20 cm (\* indicates significant difference in means,  $P < 0.05$ , ANOVA, a and b indicate Tukey-Kramer differences, different letters signify significant differences,  $P < 0.05$ ).

Soil Property	Big Glade ( <i>n</i> )	Flag Glade ( <i>n</i> )	Round Glade ( <i>n</i> )	<i>F</i> ratio	<i>P</i>
pH*	3.91 <sup>b</sup> ±0.20 (29)	4.01 <sup>ab</sup> ±0.58 (29)	4.20 <sup>a</sup> ±0.30 (29)	3.8579	0.025
% moisture*	88.49±2.07 (29)	89.13±2.58 (29)	90.11±2.09 (27)	3.6021	0.0317
%N*	2.24 <sup>a</sup> ±0.41 (30)	1.91 <sup>b</sup> ±0.32 (23)	1.97 <sup>b</sup> ±0.40 (22)	5.918	0.0042
%C	51.93±2.31 (30)	50.19±3.42 (23)	50.75±3.45 (22)	0.1136	0.1136
P	4.1±1.1066 (14)	5.24±2.51 (27)	4.43±2.85 (22)	1.2372	0.2975
K	26.54±12.07 (14)	29.91±22.70 (27)	35.78±34.67 (22)	0.5991	0.5525
Ca	300.90±73.58 (14)	508.23±762.66 (27)	593.29±242.33 (22)	1.359	0.2647
Mg*	36.27 <sup>a</sup> ±7.27 (14)	43.71 <sup>a</sup> ±23.21 (27)	72.72 <sup>b</sup> ±21.98 (22)	17.8354	<0.0001
Zn	2.77±0.26 (14)	2.80±0.19 (27)	2.78±0.21 (22)	0.0033	0.9967
Mn	2.02±0.75 (14)	5.95±7.62 (27)	4.11±2.41 (22)	2.6717	0.0774
Cu	0.69±0.31 (13)	0.55±0.29 (27)	0.48±0.35 (22)	1.6461	0.2015
Fe	21.34±4.60 (14)	23.82±14.45 (27)	22.45±5.87 (22)	0.2822	0.7551
B*	0	0.14±0.07 (5)	0.05±0.03 (10)	12.23	0.0039
Al*	63.90±18.42 (14)	64.54±30.34 (27)	35.58±16.03 (22)	10.5099	0.0001

Table 6. The amount of decrease and percent change in the area of the forest-meadow boundary between 1969 and 2007.

Glade	Change in m <sup>2</sup>	Percent change
Big Glade	6540	-3.1%
Flag Glade	7251	-9.8%
Long Glade	5585	-13.4%
Round Glade	124	-4.5%

Figure 3.13 Change in forest-alder/open meadow edge between 1969 (pink) and 2007 (red) in Big Glade.

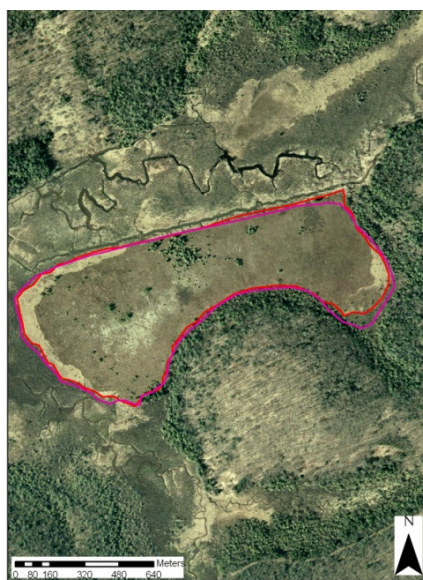


Figure 3.14. Change in forest-alder/open meadow edge between 1969 (pink) and 2007 (red) in Flag Glade.

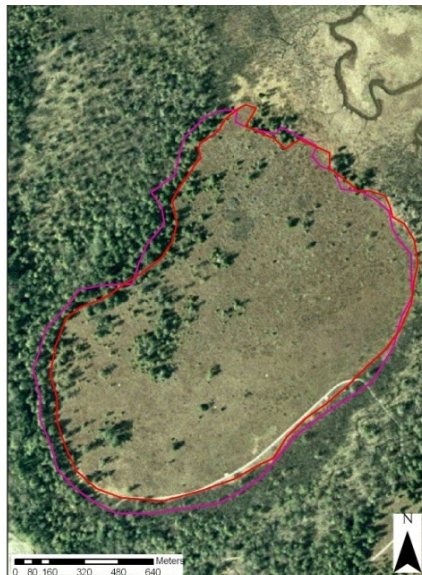


Figure 3.15. Change in forest-alder/open meadow edge between 1969 (pink) and 2007 (red) in Long Glade.

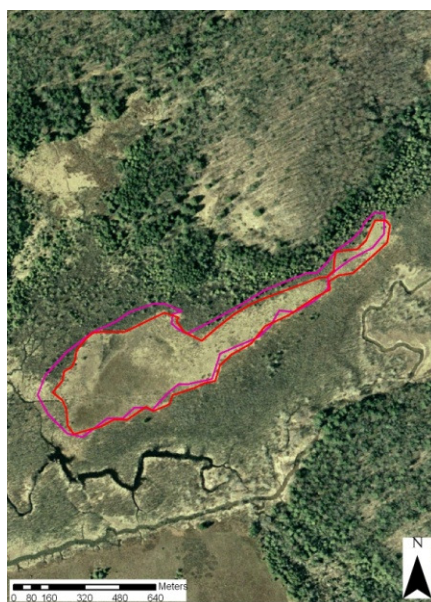
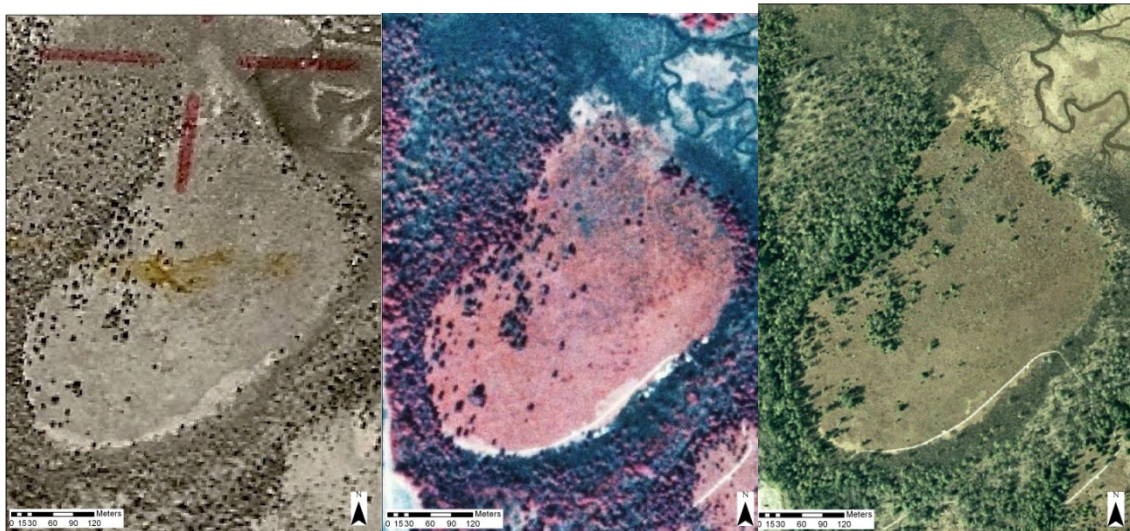


Figure 3.16. Change in forest-alder/open meadow edge between 1969 (pink) and 2007 (red) in Round Glade.



Figure 3.17. Aerial photo images of Flag Glade from (left to right) 1957, 1986, and 2007.



# Appendix

Appendix 1. Soil data.

Glade	Transect	Quad	depth (cm)	location	tree presence	C/N	%N	%C
BG	1	1	20	forest		29.05	1.87	54.22
BG	1	2	20	forest		25.47	2.43	61.94
BG	1	9	20	hummm	tree	19.84	0.43	49.56
BG	1	10	20	hollow	none	24.32	2.16	52.42
BG	1	19	20	hollow	none	22.16	2.33	51.64
BG	1	20	20	hummm	tree	18.71	2.71	50.67
BG	1	29	20	hummm	none	20.46	2.46	50.41
BG	1	30	20	hollow	none	24.40	2.04	49.72
BG	1	39	20	hummm	none	21.27	2.39	50.74
BG	1	40	20	hollow	none	24.45	2.12	51.91
BG	1	9	120	hummm	tree	22.39	2.18	48.77
BG	1	10	120	hollow				
BG	1	19	120	hummm				
BG	1	20	120	hummm	tree	24.17	2.13	51.42
BG	1	29	120	hummm	none	25.59	2.00	51.16
BG	1	30	120	hollow	none	25.00	2.03	50.84
BG	1	39	120	hummm	none	26.06	2.05	53.49
BG	1	40	120	hollow	none	25.64	1.96	50.16
BG	2	1	20	forest		22.54	2.36	53.09
BG	2	2	20	forest		21.09	2.49	52.44
BG	2	9	20	hummm	tree	25.20	2.11	53.17
BG	2	10	20	hollow	none	20.67	2.48	51.28
BG	2	19	20	hummm	tree	19.24	2.64	50.86
BG	2	20	20	hollow	none	28.63	1.89	54.04
BG	2	29	20	hollow	none	24.37	2.07	50.57
BG	2	30	20	hummm	none	20.98	2.43	51.04
BG	2	39	20	hollow	none	19.26	2.61	50.37
BG	2	40	20	hummm		22.29	2.34	52.21
BG	2	9	120	hummm	tree	22.65	2.38	53.98
BG	2	10	120	hollow	none			
BG	2	19	120	hummm	tree	24.68	2.05	50.60
BG	2	20	120	hollow	none	25.98	2.05	53.25
BG	2	29	120	hummm	tree	24.73	2.04	50.47
BG	2	30	120	hollow	none	23.51	2.14	50.44
BG	2	39	120	hollow	none	21.95	2.26	49.54
BG	2	40	120	hummm		24.21	2.09	50.64
BG	3	1	20	forest		18.16	2.70	49.00
BG	3	2	20	forest				



BG	3	9	20	hummm	tree			
BG	3	10	20	hollow	none	23.00	2.27	52.18
BG	3	19	20	hummm	tree	23.56	2.15	50.77
BG	3	20	20	hollow	none	24.68	2.16	53.31
BG	3	29	20	hummm	none	23.24	2.25	52.37
BG	3	30	20	hummm	none	21.83	2.36	51.48
BG	3	39	20	hollow	none	25.23	2.13	53.77
BG	3	40	20	hollow	none	22.32	2.31	51.64
BG	3	9	120	hummm	tree	22.48	2.22	49.96
BG	3	10	120	hollow	none	21.77	2.28	49.73
BG	3	19	120	hummm	none	20.12	2.52	50.71
BG	3	20	120	hollow	none	21.05	2.32	48.79
BG	3	29	120	hummm	none	23.69	2.14	50.60
BG	3	30	120	hummm	none	23.42	1.00	23.40
BG	3	39	120	hollow	none	14.70	0.85	12.53
BG	3	40	120	hummm	none			
FG	1	1	20	forest				
FG	1	2	20	forest		26.40	1.72	45.40
FG	1	9	20					
FG	1	10	20	hollow	none	27.44	1.89	51.80
FG	1	19	20	hollow	none	26.32	1.99	52.36
FG	1	20	20	hummm	tree			
FG	1	29	20	hummm	none	22.21	2.32	51.58
FG	1	30	20	hollow	none	26.54	1.96	52.08
FG	1	39	20	hummm	none	22.45	2.28	51.14
FG	1	40	20	hollow	none	29.41	1.73	50.77
FG	1	9	120	hummm	none	31.13	1.62	50.47
FG	1	10	120	hollow	none	31.66	1.59	50.21
FG	1	19	120	hollow	none	27.33	1.87	51.03
FG	1	20	120	hummm	tree	29.27	1.74	50.86
FG	1	29	120	hummm	none	30.42	1.69	51.28
FG	1	30	120	hollow	none	28.32	1.75	49.64
FG	1	39	120	hummm	none	30.06	1.71	51.51
FG	1	40	120	hollow	none	30.07	1.71	51.52
FG	2	1	20	forest		38.18	1.32	50.43
FG	2	2	20	forest		26.38	1.57	41.52
FG	2	9	20	hummm	tree	33.02	1.51	49.95
FG	2	10	20	hollow	none	21.41	2.34	50.17
FG	2	19	20	hummm	none	24.29	2.17	52.69
FG	2	20	20	hollow	none	32.14	1.62	51.94
FG	2	29	20	hummm	none	23.34	2.21	51.60

FG	2	30	20	hollow	none			
FG	2	39	20					
FG	2	40	20					
FG	2	9	120	hummm	tree	32.76	1.61	52.85
FG	2	10	120					
FG	2	19	120	hummm	tree	33.36	1.55	51.75
FG	2	20	120	hollow	none	37.62	1.37	51.68
FG	2	29	120	hummm	none	32.45	1.68	53.99
FG	2	30	120	hollow	none	32.31	1.66	53.49
FG	2	39	120					
FG	2	40	120	hummm		29.24	1.67	48.88
FG	3	1	20	forest		41.65	1.15	48.04
FG	3	2	20	forest		20.93	1.90	39.81
FG	3	9	20	hollow	none			
FG	3	10	20	hummm	tree	25.62	2.00	51.30
FG	3	19	20	hollow	none	24.33	2.11	51.42
FG	3	20	20	hummm	tree	26.86	1.95	52.38
FG	3	29	20	hummm	none	23.22	2.24	51.95
FG	3	30	20	hollow	none	25.41	2.04	51.90
FG	3	39	20	hollow	none	26.70	1.97	52.61
FG	3	40	20	hummm	tree	26.39	1.95	51.52
FG	3	9	120	hollow	none	30.43	1.66	50.60
FG	3	10	120	hummm	tree	29.05	1.74	50.55
FG	3	19	120	hollow	none	29.96	1.71	51.10
FG	3	20	120	hummm	tree	31.69	1.61	50.91
FG	3	29	120	hummm	none	30.19	1.67	50.47
FG	3	30	120	hollow	none	38.01	1.35	51.22
FG	3	39	120	hollow	none	30.98	1.62	50.15
FG	3	40	120	hummm	tree	31.80	1.60	50.78
RG	1	1	20					
RG	1	2	20	forest		25.81	1.87	48.23
RG	1	9	20	hummm	tree	31.59	1.58	49.94
RG	1	10	20	hollow	none	25.82	2.03	52.32
RG	1	19	20	hummm	tree	26.16	1.93	50.52
RG	1	20	20	hollow	none	24.47	2.12	51.96
RG	1	29	20	hummm	none	0.28	2.08	50.58
RG	1	30	20	hollow	none	19.69	2.32	45.73
RG	1	39	20	hummm	none			
RG	1	40	20	hollow	none	21.68	2.26	48.99
RG	1	9	120	hummm	tree	32.36	1.47	47.44
RG	1	10	120	hollow	none	28.89	1.61	46.45

RG	1	19	120	hummm	tree	46.18	1.11	51.18
RG	1	20	120	hollow	none	32.18	1.38	44.52
RG	1	29	120	hummm	none	26.11	1.76	45.94
RG	1	30	120	hollow	none	27.33	1.68	45.82
RG	1	39	120	hummm	none	24.42	1.29	31.50
RG	1	40	120	hollow	none	24.21	1.91	46.16
RG	2	1	20	forest		25.08	2.53	63.37
RG	2	2	20	forest		39.76	1.30	51.50
RG	2	9	20	hummm	tree	31.90	1.56	49.69
RG	2	10	20					
RG	2	19	20	hummm	none	15.29	1.16	17.68
RG	2	20	20	hollow	none	20.66	2.58	53.29
RG	2	29	20					
RG	2	30	20	hollow	none	22.82	2.30	52.39
RG	2	39	20	hummm	tree	24.84	2.14	53.17
RG	2	40	20					
RG	2	9	120	hummm	tree	43.95	1.09	48.06
RG	2	10	120	hollow	none	28.64	1.42	40.63
RG	2	19	120	hummm	none	25.71	1.77	45.40
RG	2	20	120	hollow	none	29.45	1.55	45.75
RG	2	29	120	hummm	tree	26.62	1.72	45.77
RG	2	30	120	hollow	none	28.22	1.67	47.07
RG	2	39	120	hummm	tree	28.80	1.67	48.06
RG	2	40	120					
RG	3	1	20	forest		31.46	1.48	46.57
RG	3	2	20	forest		30.63	1.51	46.11
RG	3	9	20	hummm	tree	31.94	1.55	49.41
RG	3	10	20	hollow	none	28.54	1.74	49.55
RG	3	19	20					
RG	3	20	20	hummm	tree	0.99	2.15	50.51
RG	3	29	20	hummm	none	22.59	2.20	49.77
RG	3	30	20	hollow	none	21.72	2.32	50.28
RG	3	39	20	hummm	none	21.38	2.39	51.00
RG	3	40	20	hollow	none	24.55	2.13	52.26
RG	3	9	120	hummm	tree	29.96	1.38	41.41
RG	3	10	120	hollow	none	28.29	1.32	37.33
RG	3	19	120	hollow	none	28.15	1.54	43.35
RG	3	20	120	hummm	tree	27.62	1.50	41.40
RG	3	29	120	hummm	none	31.28	1.56	48.69
RG	3	30	120	hollow	none	28.48	1.41	40.22
RG	3	39	120	hummm	none	31.87	1.56	49.76

RG	3	40	120	hollow	none	26.14	0.76	19.94
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Glade	Transect	Quad	depth (cm)	%moisture	pH	P (mg/kg)	K (mg/kg)	Ca (mg/kg)
BG	1	1	20	87.17	3.93	3.02	14.06	261.78
BG	1	2	20	87.11	3.88	3.75	38.69	300.55
BG	1	9	20	88.83	3.69	0.00	0.00	0.00
BG	1	10	20	88.79	4.26	4.02	22.33	316.29
BG	1	19	20	89.35	4.07	0.00	0.00	0.00
BG	1	20	20	88.76	3.87	0.00	0.00	0.00
BG	1	29	20	91.43	4.00	0.00	0.00	0.00
BG	1	30	20	89.52	3.77	0.00	0.00	0.00
BG	1	39	20	90.00	3.68	0.00	0.00	0.00
BG	1	40	20	87.08	3.73	4.40	19.46	251.51
BG	1	9	120	88.81	4.04	4.72	42.12	269.78
BG	1	10	120	90.45	4.14	3.13	28.64	324.78
BG	1	19	120	91.73		2.14	20.02	570.99
BG	1	20	120	90.82		2.34	11.60	475.36
BG	1	29	120	92.04	4.31	2.17	14.32	431.55
BG	1	30	120	90.83	4.04	3.34	20.18	444.24
BG	1	39	120	91.18	4.16	3.23	15.78	369.71
BG	1	40	120	92.02	3.99	3.19	20.40	425.40
BG	2	1	20	86.04	3.81	5.55	56.30	309.52
BG	2	2	20	85.59	3.78	4.94	33.21	334.46
BG	2	9	20	89.54	4.00	1.96	9.89	252.90
BG	2	10	20	89.86	4.28	0.00	0.00	0.00
BG	2	19	20	88.58	3.84	0.00	0.00	0.00
BG	2	20	20	89.15	3.84	4.54	24.63	310.45
BG	2	29	20	91.06	4.12	5.80	31.18	286.36
BG	2	30	20	89.80	4.31	0.00	0.00	0.00
BG	2	39	20	89.30	4.36	0.00	0.00	0.00
BG	2	40	20	88.84	3.87	0.00	0.00	0.00
BG	2	9	120	90.42	4.18	2.11	12.34	601.60
BG	2	10	120	90.00	4.20	2.14	22.10	348.15
BG	2	19	120	90.17	4.06	3.25	18.12	326.58
BG	2	20	120	91.03	4.72	2.22	13.09	386.08
BG	2	29	120	91.73	3.98	2.42	17.11	336.46
BG	2	30	120	90.43	4.18	2.82	25.00	582.00
BG	2	39	120	91.61	4.03	5.36	36.60	438.02
BG	2	40	120	90.85	3.94	3.22	23.12	324.64
BG	3	1	20	53.33	4.01	3.23	34.32	223.42

BG	3	2	20	80.11		0.00	0.00	0.00
BG	3	9	20	89.05	3.96	0.00	0.00	0.00
BG	3	10	20	89.57	3.93	4.82	31.90	316.92
BG	3	19	20	89.67	3.77	4.21	16.49	451.37
BG	3	20	20	87.99	3.75	4.63	20.73	427.86
BG	3	29	20	89.07	3.76	0.00	0.00	0.00
BG	3	30	20	88.76	3.74	0.00	0.00	0.00
BG	3	39	20	88.60	3.70	2.52	18.41	169.21
BG	3	40	20	87.55	3.74	0.00	0.00	0.00
BG	3	9	120	89.24	4.10	2.88	22.63	245.19
BG	3	10	120	89.38	4.25	2.15	13.37	385.08
BG	3	19	120	89.45	4.40	2.02	11.80	1011.79
BG	3	20	120		4.65	1.32	6.80	741.58
BG	3	29	120	90.32	4.10	3.01	29.16	404.33
BG	3	30	120	88.82	4.34	3.16	20.54	338.10
BG	3	39	120	67.44	4.92	3.51	15.78	579.07
BG	3	40	120	43.72	5.04	12.26	11.78	298.84
FG	1	1	20	61.33	3.62	3.24	36.94	201.05
FG	1	2	20	86.40	5.38	2.72	17.34	2529.18
FG	1	9	20	88.80	3.65	6.59	27.68	371.08
FG	1	10	20	90.37	3.61	1.15	5.27	252.90
FG	1	19	20	90.15	3.68	2.29	16.53	277.71
FG	1	20	20	90.51	3.82	1.64	6.26	138.24
FG	1	29	20	89.59	4.29	8.20	32.81	234.35
FG	1	30	20	89.35	3.93	5.96	24.32	286.16
FG	1	39	20	89.52	3.09	11.30	49.40	307.07
FG	1	40	20	89.88	3.67	0.00	0.00	0.00
FG	1	9	120	91.67	4.18	1.76	8.22	251.88
FG	1	10	120	92.28	4.13	1.50	11.75	288.02
FG	1	19	120	90.75	4.19	4.92	16.58	182.14
FG	1	20	120	91.67	4.00	2.94	12.41	205.57
FG	1	29	120		4.14	1.56	5.52	116.79
FG	1	30	120	91.47	3.73	4.76	32.46	321.47
FG	1	39	120	92.48	4.16	1.53	7.47	196.48
FG	1	40	120	91.06	4.10	1.28	6.13	223.54
FG	2	1	20	50.70		6.32	68.11	221.26
FG	2	2	20	86.29	5.40	3.53	16.16	2820.37
FG	2	9	20	88.38	4.36	5.50	109.16	193.00
FG	2	10	20	89.47	4.13	4.55	15.06	215.93
FG	2	19	20	90.38	4.12	5.45	27.22	207.52
FG	2	20	20	90.39	3.72	3.48	19.08	181.20

FG	2	29	20	89.47	4.02	10.33	29.98	243.21
FG	2	30	20	90.22		0.00	0.00	0.00
FG	2	39	20	89.19	3.83	4.39	20.55	201.38
FG	2	40	20	91.03		9.14	33.19	131.02
FG	2	9	120	93.40	3.92	2.18	10.01	252.59
FG	2	10	120	93.93	4.09	3.16	16.36	297.71
FG	2	19	120	91.26	4.04	1.06	3.30	128.19
FG	2	20	120	90.44	4.05	1.08	5.81	154.58
FG	2	29	120	92.62	4.14	1.14	6.88	163.71
FG	2	30	120	91.88	4.02	1.69	10.13	157.51
FG	2	39	120	92.86	3.94	0.00	0.00	0.00
FG	2	40	120	93.03	4.53	2.00	11.13	1493.29
FG	3	1	20	77.86	3.97	5.15	78.14	467.33
FG	3	2	20	85.26	5.81	3.59	25.30	2482.27
FG	3	9	20	90.68	3.93	7.46	21.53	326.52
FG	3	10	20	90.39	3.96	5.18	26.95	339.80
FG	3	19	20	89.93	3.75	4.80	24.42	216.80
FG	3	20	20	90.16	3.87	6.52	24.81	302.40
FG	3	29	20	90.23	3.83	6.04	22.63	201.58
FG	3	30	20	90.43	3.67	4.06	18.17	178.01
FG	3	39	20	89.35	3.76	2.85	10.55	194.98
FG	3	40	20	89.87		0.00	0.00	0.00
FG	3	9	120	93.10	4.18	0.92	7.74	286.42
FG	3	10	120	91.73	4.22	2.10	9.42	304.64
FG	3	19	120	92.25	4.37	1.42	5.73	156.07
FG	3	20	120	90.39	4.06	1.90	10.60	134.97
FG	3	29	120	90.98	3.93	1.69	14.06	153.02
FG	3	30	120	89.66	4.18	1.32	5.34	120.93
FG	3	39	120	90.27	3.85	2.70	13.38	190.84
FG	3	40	120	92.54	3.94	1.42	8.13	178.16
RG	1	1	20	83.72	4.27	4.84	95.34	460.46
RG	1	2	20		4.62	3.24	55.14	740.30
RG	1	9	20	90.15	3.78	0.00	0.00	0.00
RG	1	10	20	89.42	4.06	3.93	11.70	512.88
RG	1	19	20	90.05	4.03	5.17	17.26	587.06
RG	1	20	20	90.64	3.79	3.85	18.46	648.27
RG	1	29	20	91.24	3.87	5.04	24.00	605.69
RG	1	30	20	89.38	3.98	6.22	18.78	690.88
RG	1	39	20	91.43	4.15	8.47	29.76	623.61
RG	1	40	20	89.83	4.03	15.07	72.64	925.18
RG	1	9	120	89.35	4.13	4.11	55.09	760.35

RG	1	10	120	84.11	4.67	1.24	12.10	1506.26
RG	1	19	120	87.71	4.80	1.14	7.66	695.39
RG	1	20	120	83.08	4.62	1.16	5.38	777.18
RG	1	29	120	86.45	4.67	1.90	7.52	1981.04
RG	1	30	120	86.72	4.52	3.42	13.75	1109.88
RG	1	39	120	76.53	4.72	3.40	13.49	1505.17
RG	1	40	120	89.57	4.36	6.49	39.22	1154.10
RG	2	1	20	67.82	3.58	4.65	101.37	102.84
RG	2	2	20	87.76	4.86	2.67	19.75	958.64
RG	2	9	20	87.50	4.28	4.33	136.44	274.94
RG	2	10	20	90.08		2.51	9.01	251.99
RG	2	19	20	90.27	4.24	0.00	0.00	0.00
RG	2	20	20	92.40	4.30	4.52	18.60	610.63
RG	2	29	20	88.55	4.45	0.00	0.00	0.00
RG	2	30	20	91.28	4.28	3.62	15.10	563.37
RG	2	39	20	88.07	4.35	0.00	0.00	0.00
RG	2	40	20			0.00	0.00	0.00
RG	2	9	120	83.14	4.55	1.25	7.78	1145.42
RG	2	10	120	89.42	4.61	2.84	11.93	1182.59
RG	2	19	120	85.67	4.83	2.32	19.64	1852.38
RG	2	20	120	90.33	4.64	1.91	10.88	1419.82
RG	2	29	120	85.92	4.77	1.51	12.35	1653.08
RG	2	30	120	85.52	4.81	1.40	11.07	1696.74
RG	2	39	120	85.28	4.25	0.33	22.07	1500.98
RG	2	40	120			0.00	0.00	0.00
RG	3	1	20	90.43	4.53	1.68	23.43	515.63
RG	3	2	20	95.56	4.93	2.31	11.95	738.86
RG	3	9	20	91.40	4.15	1.88	12.63	223.83
RG	3	10	20	93.10	4.32	1.75	11.35	483.89
RG	3	19	20	90.98	4.14	0.00	0.00	0.00
RG	3	20	20	90.44	3.93	4.47	36.61	890.24
RG	3	29	20	90.24	3.97	0.00	0.00	0.00
RG	3	30	20	89.29	4.09	0.00	0.00	0.00
RG	3	39	20	89.43	4.11	3.88	25.06	595.29
RG	3	40	20	90.22	4.14	3.40	22.67	1047.97
RG	3	9	120	84.38	4.58	1.14	12.59	707.51
RG	3	10	120	87.50	4.69	0.12	8.53	1047.95
RG	3	19	120	86.09	4.56	1.02	13.78	1062.75
RG	3	20	120	83.60	4.60	0.36	18.17	1502.06
RG	3	29	120	85.77	4.62	0.07	12.39	1199.77
RG	3	30	120	81.27	4.75	-0.06	8.96	1604.49

RG	3	39	120	88.00	4.50	0.39	14.50	1242.12
RG	3	40	120	62.30	4.82	9.68	12.91	1067.58

Glade	Transect	Quad	depth (cm)	Mg (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	Cu (mg/kg)
BG	1	1	20	28.40	2.20	1.46	0.81
BG	1	2	20	34.95	2.64	3.37	0.55
BG	1	9	20	0.00	0.00	0.00	0.00
BG	1	10	20	33.44	2.90	1.91	0.29
BG	1	19	20	0.00	0.00	0.00	0.00
BG	1	20	20	0.00	0.00	0.00	0.00
BG	1	29	20	0.00	0.00	0.00	0.00
BG	1	30	20	0.00	0.00	0.00	0.00
BG	1	39	20	0.00	0.00	0.00	0.00
BG	1	40	20	33.48	3.47	2.84	2.31
BG	1	9	120	35.22	2.71	3.70	0.20
BG	1	10	120	32.94	2.14	1.74	0.27
BG	1	19	120	42.30	1.71	4.03	0.32
BG	1	20	120	34.54	1.05	2.88	0.16
BG	1	29	120	33.76	1.49	3.28	0.28
BG	1	30	120	37.92	2.45	3.15	0.43
BG	1	39	120	36.13	1.71	3.26	0.43
BG	1	40	120	42.07	2.55	4.02	0.51
BG	2	1	20	44.61	2.44	1.60	0.46
BG	2	2	20	37.80	2.53	1.83	0.50
BG	2	9	20	25.34	1.70	1.01	0.82
BG	2	10	20	0.00	0.00	0.00	0.00
BG	2	19	20	0.00	0.00	0.00	0.00
BG	2	20	20	38.76	3.62	3.11	0.74
BG	2	29	20	39.52	3.78	2.25	1.06
BG	2	30	20	0.00	0.00	0.00	0.00
BG	2	39	20	0.00	0.00	0.00	0.00
BG	2	40	20	0.00	0.00	0.00	0.00
BG	2	9	120	44.01	1.35	3.43	0.51
BG	2	10	120	32.44	1.35	2.84	0.80
BG	2	19	120	31.04	2.10	3.20	0.43
BG	2	20	120	31.32	1.68	2.89	0.93
BG	2	29	120	31.72	1.72	2.64	0.42
BG	2	30	120	47.65	2.18	5.06	0.65
BG	2	39	120	42.31	3.14	5.36	0.56
BG	2	40	120	31.74	2.04	2.72	0.74



BG	3	1	20	38.81	2.70	0.98	0.14
BG	3	2	20	0.00	0.00	0.00	0.00
BG	3	9	20	0.00	0.00	0.00	0.00
BG	3	10	20	37.93	3.14	1.67	0.83
BG	3	19	20	49.96	2.48	1.71	1.04
BG	3	20	20	41.70	3.40	2.77	0.52
BG	3	29	20	0.00	0.00	0.00	0.00
BG	3	30	20	0.00	0.00	0.00	0.00
BG	3	39	20	23.10	1.80	1.73	1.15
BG	3	40	20	0.00	0.00	0.00	0.00
BG	3	9	120	27.44	1.55	2.16	0.18
BG	3	10	120	32.96	1.18	2.95	0.21
BG	3	19	120	61.31	1.14	8.08	0.48
BG	3	20	120	47.95	0.38	5.25	0.26
BG	3	29	120	36.54	2.21	3.06	0.21
BG	3	30	120	37.07	1.62	3.77	0.88
BG	3	39	120	57.02	0.51	9.16	1.54
BG	3	40	120	57.07	0.87	8.91	2.04
FG	1	1	20	37.93	1.50	7.79	0.14
FG	1	2	20	109.05	3.90	25.85	0.22
FG	1	9	20	38.17	4.00	2.53	0.41
FG	1	10	20	20.55	0.58	2.79	0.33
FG	1	19	20	25.48	1.22	2.75	0.50
FG	1	20	20	16.42	0.60	1.68	0.30
FG	1	29	20	35.71	3.54	2.62	1.13
FG	1	30	20	37.37	3.90	2.68	0.57
FG	1	39	20	44.77	4.99	3.61	0.62
FG	1	40	20	0.00	0.00	0.00	0.00
FG	1	9	120	21.14	0.59	2.91	0.26
FG	1	10	120	27.68	1.19	5.18	0.43
FG	1	19	120	23.75	1.99	1.48	1.03
FG	1	20	120	25.09	1.85	2.18	0.51
FG	1	29	120	14.61	0.51	1.50	0.22
FG	1	30	120	40.92	4.40	3.50	1.00
FG	1	39	120	23.02	0.78	2.68	0.22
FG	1	40	120	23.43	1.18	2.56	0.52
FG	2	1	20	56.31	1.63	1.94	0.36
FG	2	2	20	101.84	4.58	20.86	0.53
FG	2	9	20	51.68	2.15	22.95	0.86
FG	2	10	20	30.09	2.21	1.58	0.96
FG	2	19	20	32.89	2.86	4.24	1.24

FG	2	20	20	27.64	2.40	1.52	0.88
FG	2	29	20	35.55	3.48	2.21	0.90
FG	2	30	20	0.00	0.00	0.00	0.00
FG	2	39	20	27.33	2.54	2.27	0.40
FG	2	40	20	40.99	2.49	2.04	0.63
FG	2	9	120	23.17	0.98	2.06	0.42
FG	2	10	120	29.24	1.43	2.54	0.39
FG	2	19	120	15.52	0.41	0.90	0.46
FG	2	20	120	17.75	0.72	1.06	0.57
FG	2	29	120	17.51	0.64	1.29	0.72
FG	2	30	120	18.61	0.77	1.71	0.37
FG	2	39	120	0.00	0.00	0.00	0.00
FG	2	40	120	182.87	1.85	13.64	0.40
FG	3	1	20	71.86	2.74	4.19	0.18
FG	3	2	20	86.58	2.63	24.34	0.18
FG	3	9	20	45.34	3.50	2.23	0.43
FG	3	10	20	45.96	3.70	6.23	0.47
FG	3	19	20	34.49	2.88	2.40	0.54
FG	3	20	20	40.85	4.14	3.46	0.32
FG	3	29	20	30.28	2.68	1.92	0.82
FG	3	30	20	29.52	2.38	1.76	0.36
FG	3	39	20	25.42	2.31	2.18	0.68
FG	3	40	20	0.00	0.00	0.00	0.00
FG	3	9	120	24.26	0.74	2.63	0.27
FG	3	10	120	30.84	1.57	3.60	0.22
FG	3	19	120	15.36	0.58	1.03	0.22
FG	3	20	120	17.22	0.67	1.41	0.16
FG	3	29	120	20.54	1.45	1.40	0.16
FG	3	30	120	14.45	0.43	1.27	0.34
FG	3	39	120	24.99	2.04	2.36	0.25
FG	3	40	120	20.98	1.20	1.72	0.18
RG	1	1	20	73.71	1.62	3.57	0.38
RG	1	2	20	84.58	1.53	3.69	0.56
RG	1	9	20	0.00	0.00	0.00	0.00
RG	1	10	20	60.78	2.34	2.80	0.57
RG	1	19	20	74.91	2.99	3.02	0.27
RG	1	20	20	84.24	5.12	6.83	0.61
RG	1	29	20	60.45	3.02	3.45	0.23
RG	1	30	20	72.68	3.73	3.69	0.32
RG	1	39	20	57.16	1.77	2.59	0.31
RG	1	40	20	104.90	3.53	4.03	0.28

RG	1	9	120	105.15	3.12	8.25	0.33
RG	1	10	120	185.10	2.47	20.53	1.29
RG	1	19	120	95.89	0.91	5.90	0.25
RG	1	20	120	99.22	1.03	8.02	0.26
RG	1	29	120	176.48	2.78	20.43	0.24
RG	1	30	120	113.40	2.61	10.95	0.36
RG	1	39	120	137.59	2.26	10.71	0.48
RG	1	40	120	110.97	2.83	7.06	0.18
RG	2	1	20	41.06	1.64	4.11	0.18
RG	2	2	20	89.74	3.16	13.08	0.32
RG	2	9	20	117.86	3.11	3.66	0.86
RG	2	10	20	32.74	2.61	2.66	1.46
RG	2	19	20	0.00	0.00	0.00	0.00
RG	2	20	20	73.81	3.50	3.61	0.45
RG	2	29	20	0.00	0.00	0.00	0.00
RG	2	30	20	61.49	2.92	3.02	0.46
RG	2	39	20	0.00	0.00	0.00	0.00
RG	2	40	20	0.00	0.00	0.00	0.00
RG	2	9	120	145.99	2.82	15.07	0.22
RG	2	10	120	137.56	2.48	16.91	0.35
RG	2	19	120	198.65	2.17	19.20	0.35
RG	2	20	120	151.47	2.54	12.99	0.30
RG	2	29	120	190.50	1.70	15.83	0.44
RG	2	30	120	196.35	1.88	17.79	0.22
RG	2	39	120	160.32	3.40	14.43	0.23
RG	2	40	120	0.00	0.00	0.00	0.00
RG	3	1	20	77.83	2.06	1.90	0.18
RG	3	2	20	91.42	2.42	5.29	0.18
RG	3	9	20	36.75	1.32	1.88	0.73
RG	3	10	20	51.30	2.59	5.16	1.38
RG	3	19	20	0.00	0.00	0.00	0.00
RG	3	20	20	96.69	3.77	6.75	0.23
RG	3	29	20	0.00	0.00	0.00	0.00
RG	3	30	20	0.00	0.00	0.00	0.00
RG	3	39	20	62.34	2.55	1.97	0.34
RG	3	40	20	93.51	3.92	3.67	0.36
RG	3	9	120	86.02	1.69	8.92	0.15
RG	3	10	120	115.76	1.77	14.57	0.15
RG	3	19	120	129.11	1.66	8.59	0.12
RG	3	20	120	174.05	2.58	13.60	0.18
RG	3	29	120	130.87	1.50	8.54	0.20

RG	3	30	120	180.60	1.94	12.27	0.06
RG	3	39	120	135.52	1.46	10.00	0.14
RG	3	40	120	143.60	2.50	10.02	0.36

Glade	Transect	Quad	depth (cm)	Fe (mg/kg)	B (mg/kg)	Al (mg/kg)
BG	1	1	20	14.74		43.01
BG	1	2	20	20.48		40.25
BG	1	9	20	0.00		0.00
BG	1	10	20	21.40		73.09
BG	1	19	20	0.00		0.00
BG	1	20	20	0.00		0.00
BG	1	29	20	0.00		0.00
BG	1	30	20	0.00		0.00
BG	1	39	20	0.00		0.00
BG	1	40	20	20.12		65.64
BG	1	9	120	16.49		42.20
BG	1	10	120	31.97		62.14
BG	1	19	120	44.62		98.51
BG	1	20	120	38.54		62.00
BG	1	29	120	35.97		61.86
BG	1	30	120	39.04		86.40
BG	1	39	120	37.57		67.18
BG	1	40	120	46.86	0.05	87.18
BG	2	1	20	31.00		78.12
BG	2	2	20	19.52		84.84
BG	2	9	20	19.96		57.38
BG	2	10	20	0.00		0.00
BG	2	19	20	0.00		0.00
BG	2	20	20	20.54		74.22
BG	2	29	20	23.66		72.78
BG	2	30	20	0.00		0.00
BG	2	39	20	0.00		0.00
BG	2	40	20	0.00		0.00
BG	2	9	120	51.08		91.17
BG	2	10	120	30.52		60.14
BG	2	19	120	26.48		54.91
BG	2	20	120	38.27		68.51
BG	2	29	120	50.92		59.59
BG	2	30	120	98.54		142.56
BG	2	39	120	54.12	0.05	105.60

BG	2	40	120	33.70		85.31
BG	3	1	20	12.78		37.56
BG	3	2	20	0.00		0.00
BG	3	9	20	0.00		0.00
BG	3	10	20	23.05		72.93
BG	3	19	20	21.30		45.44
BG	3	20	20	28.27		98.25
BG	3	29	20	0.00		0.00
BG	3	30	20	0.00		0.00
BG	3	39	20	22.01		51.11
BG	3	40	20	0.00		0.00
BG	3	9	120	17.56		34.11
BG	3	10	120	37.90		62.45
BG	3	19	120	90.30		236.83
BG	3	20	120	74.35		192.97
BG	3	29	120	44.29		98.52
BG	3	30	120	59.70		336.52
BG	3	39	120	196.76		635.90
BG	3	40	120	229.56		496.79
FG	1	1	20	14.35		44.47
FG	1	2	20	55.63	0.17	125.16
FG	1	9	20	27.92		96.17
FG	1	10	20	59.86		60.30
FG	1	19	20	52.01		52.10
FG	1	20	20	28.16		25.50
FG	1	29	20	18.40		80.19
FG	1	30	20	20.83		95.05
FG	1	39	20	24.98		110.64
FG	1	40	20	0.00		0.00
FG	1	9	120	33.07		42.32
FG	1	10	120	49.37		54.17
FG	1	19	120	16.46		55.95
FG	1	20	120	18.72		51.36
FG	1	29	120	23.44		22.03
FG	1	30	120	33.53		101.36
FG	1	39	120	43.76		39.23
FG	1	40	120	50.04		54.38
FG	2	1	20	11.57		18.53
FG	2	2	20	48.47	0.26	129.68
FG	2	9	20	7.58		17.83
FG	2	10	20	19.16		60.64

FG	2	19	20	12.93		47.86
FG	2	20	20	21.96		46.59
FG	2	29	20	18.21		81.93
FG	2	30	20	0.00		0.00
FG	2	39	20	16.54		57.75
FG	2	40	20	9.64	0.08	33.46
FG	2	9	120	24.07		52.02
FG	2	10	120	34.94		43.85
FG	2	19	120	17.45		20.51
FG	2	20	120	23.22		27.86
FG	2	29	120	30.78		29.65
FG	2	30	120	22.38		30.36
FG	2	39	120	0.00		0.00
FG	2	40	120	60.18	0.12	221.79
FG	3	1	20	10.26		20.34
FG	3	2	20	38.00	0.11	66.45
FG	3	9	20	24.76		86.02
FG	3	10	20	21.51		69.76
FG	3	19	20	16.25		56.27
FG	3	20	20	19.36	0.09	89.06
FG	3	29	20	16.70		63.74
FG	3	30	20	13.44		56.02
FG	3	39	20	14.69		50.60
FG	3	40	20	0.00		0.00
FG	3	9	120	25.08		27.72
FG	3	10	120	23.86		42.26
FG	3	19	120	17.28		15.10
FG	3	20	120	12.86		18.23
FG	3	29	120	15.04		33.76
FG	3	30	120	22.51		16.44
FG	3	39	120	18.54		54.10
FG	3	40	120	18.61		33.42
RG	1	1	20	17.91		10.46
RG	1	2	20	26.10	0.06	24.60
RG	1	9	20	0.00		0.00
RG	1	10	20	23.15		45.73
RG	1	19	20	24.88		43.96
RG	1	20	20	23.22	0.04	47.98
RG	1	29	20	20.72		42.75
RG	1	30	20	28.54		56.01
RG	1	39	20	26.79		41.74

RG	1	40	20	26.94		51.66
RG	1	9	120	32.18	0.06	69.80
RG	1	10	120	87.19	0.10	281.10
RG	1	19	120	31.71		47.38
RG	1	20	120	27.96		103.62
RG	1	29	120	51.12	0.12	226.37
RG	1	30	120	48.32	0.07	108.68
RG	1	39	120	54.74	0.04	304.51
RG	1	40	120	42.87		103.91
RG	2	1	20	8.72		22.24
RG	2	2	20	33.94	0.09	29.62
RG	2	9	20	26.09		21.79
RG	2	10	20	19.02		19.78
RG	2	19	20	0.00		0.00
RG	2	20	20	23.96		35.18
RG	2	29	20	0.00		0.00
RG	2	30	20	23.68		39.04
RG	2	39	20	0.00		0.00
RG	2	40	20	0.00		0.00
RG	2	9	120	46.97	0.05	121.22
RG	2	10	120	61.04	0.09	171.77
RG	2	19	120	58.65	0.10	169.30
RG	2	20	120	56.48	0.10	149.60
RG	2	29	120	65.74	0.08	215.67
RG	2	30	120	69.02	0.14	192.60
RG	2	39	120	45.20	0.14	181.87
RG	2	40	120	0.00	0.00	0.00
RG	3	1	20	17.72	0.03	17.84
RG	3	2	20	17.58	0.06	22.51
RG	3	9	20	12.28	0.02	13.45
RG	3	10	20	21.56	0.04	28.60
RG	3	19	20	0.00	0.00	0.00
RG	3	20	20	22.77	0.10	48.25
RG	3	29	20	0.00	0.00	0.00
RG	3	30	20	0.00	0.00	0.00
RG	3	39	20	17.12	0.03	43.63
RG	3	40	20	31.13	0.06	76.02
RG	3	9	120	31.91	0.03	70.82
RG	3	10	120	44.02	0.10	140.29
RG	3	19	120	43.75	0.11	160.58
RG	3	20	120	45.76	0.13	223.33

RG	3	29	120	37.17	0.10	104.85
RG	3	30	120	58.83	0.18	233.57
RG	3	39	120	34.50	0.12	100.23
RG	3	40	120	73.89	0.11	369.30



Appendix 2. Tree data.

BG1 Quad #	BG1 indv/island	BG1 species	BG1 DBH (cm)	BG1 DGL	BG1 height	BG1 topo
1	forest	AcRu	4.8		>200	
1	forest	PiRu	12.4		>200	
1	forest	PiRu		0.8	37	
1	forest	PiRu		0.8	40	
1	forest	PiRu		0.7	36	
1	forest	PiRu		0.7	28	
1	forest	PiRu		1.3	68	
1	forest	PiRu		1.2	59	
1	forest	PiRu		1	50	
1	forest	PiRu		1.9	71	
1	forest	AcRu		0.2	16	
1	forest	PiRu	0.8	3.2	180	
1	forest	AcRu	9.9		>200	
1	forest	PiRu		1	60	
1	forest	PiRu		0.4	30	
1	forest	PiRu		0.2	10	
1	forest	PiRu		0.4	14	
1	forest	PiRu		0.4	18	
2	forest	PiRu		2.4	98	
2	forest	AcRu		0.5	72	
2	forest	PiRu		0.2	12	
2	forest	PiRu	0.5	2.5	134	
2	forest	AcRu		0.1	16	
2	forest	PiRu		0.3	10	
2	forest	PiRu		0.4	23	
2	forest	PiRu		0.8	30	
2	forest	PiRu		1	45	
2	forest	PiRu		1	60	
2	forest	PiRu		0.6	38	
2	forest	PiRu		0.5	16	
2	forest	PiRu	21.3		>200	
2	forest	PiRu	3.3		>200	
2	forest	PiRu		0.4	20	
2	forest	PiRu		0.8	27	
2	forest	PiRu		0.5	25	
2	forest	PiRu		0.4	20	
2	forest	PiRu		1	34	

2	forest	PiRu		1.3	56	
2	forest	PiRu		0.3	19	
2	forest	PiRu	20		>200	
2	forest	PiRu	22.7		>200	
2	forest	PiRu	11		>200	
2	forest	PiRu	1.9		107	
2	forest	PiRu		0.9	37	
2	forest	PiRu		0.6	30	
2	forest	PiRu		0.3	18	
2	forest	PiRu		0.5	36	
2	forest	PiRu	0.2	1.9	140	
2	forest	PiRu	0.6	2.4	163	
2	forest	PiRu	3		>200	
3	island	PiRu	11.1		>200	hummm
3	island	PiRu	18.4		>200	
3	island	PiRu		1	50	
3	island	PiRu		0.5	15	
3	island	PiRu	5.9		>200	
3	island	PiRu	3.1		>200	
3	island	AcRu		0.3	26	
3	island	PiRu		2.4	99	
3	island	AcRu		0.5	42	
3	island	PiRu	2.1	5.9	195	
3	island	PiRu	4.4		137	
3	island	PiRu	20.6		>200	hummm complex
3	island	PiRu	18.2		>200	
3	island	PiRu	7.1		>200	
3	island	PiRu		2.8	130	
3	island	PiRu		2.4	113	
3	island	PiRu		0.2	10	
3	island	PiRu		0.3	13	
3	island	PiRu		0.3	13	
3	island	PiRu		0.4	17	
3	island	PiRu		0.3	15	
3	island	PiRu		0.9	56	
3	island	PiRu		2.5	121	
3	island	PiRu	0.9	4.1	170	
3	island	PiRu		1	34	
3	island	AcRu		0.2	15	
3	island	AcRu		0.1	12	
4	indv	PiRu	8.2		>200	flat

4	indv	PiRu		4.3	145	hummm
4	island	PiRu	10.6		>200	hummm complex
4	island	PiRu		1	33	
4	island	PiRu		1.9	80	
4	island	PiRu		0.5	40	
4	island	PiRu		1	104	
4	island	PiRu		0.5	40	
4	island	PiRu		0.8	45	
4	island	PiRu		0.9	40	
4	island	PiRu		3.5	147	
4	island	AcRu		0.2	15	
4	island	PiRu		2	132	
4	island	PiRu	2.6		>200	hummm complex
4	island	PiRu		2.6	122	
4	island	PiRu		2	118	
4	island	PiRu		0.5	27	
4	indv	PiRu		2.5	84	hummm
4	indv	PiRu		2.5	93	uneven topo
5	island	PiRu	13.3		>200	hummm
5	island	PiRu		0.5	22	
5	island	PiRu		0.9	26	
5	island	AcRu		0.7	80	
5	island	AcRu		0.3	29	
5	island	PiRu	1.3	5.8	180	
5	island	PiRu	1.9	6	190	hummm complex
5	island	PiRu		1.5	60	
5	island	PiRu		2.7	77	
5	indv	AcRu		0.6	39	uneven topo
6	island	PiRu	13.4		>200	hummm complex
6	island	PiRu		2	75	
6	island	PiRu		0.4	20	
6	island	AcRu		0.3	17	
6	island	AcRu		0.3	17	
6	island	PiRu		1	31	
6	island	PiRu		0.5	24	
6	island	AcRu		0.1	14	
6	island	AcRu		0.2	15	

6	island	AcRu		0.1	12	
6	island	AcRu		0.2	19	
6	island	AcRu		0.3	17	
7	indv	PiRu	1	5.8	160	hummm complex
7	indv	PiRu		6.5	112	hummm
8	island	PiRu	6.9		>200	hummm complex
8	island	PiRu		4	121	
8	island	PiRu		0.9	38	
8	island	PiRu	2.4	4.2	190	
8	island	PiRu		0.4	18	
8	island	AcRu		0.2	27	
8	island	PiRu	2.9		>200	
8	island	AcRu		0.3	26	
8	island	AcRu		0.3	29	
8	island	PiRu	21		adult	hummm
8	island	PiRu	3.8		>200	
8	island	PiRu	3	8.1	190	
8	island	PiRu		0.9	17	
8	island	AcRu		0.8	76	
9	island	PiRu	7.6		>200	hummm complex
9	island	PiRu	0.9	4.3	132	
9	island	PiRu	1.8	5.5	168	
9	island	PiRu	0.9	5.2	155	
9	island	PiRu	3	8	190	hummm complex
9	island	PiRu		3.8	73	
9	island	AcRu		0.2	15	
10	no trees					
11	no trees					
12	no trees					
13	no trees					
14	no trees					
15	no trees					
16	no trees					
17	no trees					
18	island	PiRu	5.2		>200	hummm complex
18	island	PiRu	2.9		>200	
18	island	PiRu	1.2	5.2	150	

18	island	PiRu		2	44	
18	island	PiRu		1.5	43	
19	no trees					
20	island	PiRu	10.4		>200	hummm
20	island	PiRu		3.7	98	
20	island	PiRu		2.9	58	
20	island	PiRu		1	29	
20	island	AcRu		1	105	
20	island	PiRu		0.5	12	
20	island	AcRu		0.3	51	
20	island	PiRu		1.4	45	
20	island	PiRu		0.9	41	
20	island	PiRu		1.3	33	
20	island	PiRu		1	24	
20	island	PiRu		0.9	19	
20	island	PiRu		0.5	18	
20	island	PiRu		0.3	12	
21	island	PiRu		2	68	hummm complex
21	island	PiRu		1.5	75	
21	island	PiRu		3.5	73	
22	No trees					
23	island	PiRu	5.1		>200	hummm complex
23	island	PiRu	17.1		>200	
23	island	PiRu		2.6	106	
23	island	PiRu		0.2	10	
23	island	PiRu		0.2	10	
23	island	PiRu	0.8	3.9	141	
23	island	PiRu	7.8		>200	
23	island	PiRu	25.6		>200	
23	island	PiRu	13		>200	
23	island	PiRu		1.9	53	
23	island	PiRu		1.3	36	
23	island	PiRu	1.9	4.5	198	
23	island	PiRu	3.2		>200	
23	island	PiRu	22.5		>200	
23	island	PiRu		1	31	
23	island	PiRu	3.3		>200	
23	island	PiRu	1.8	4.2	180	
23	island	PiRu	3		>200	
23	island	PiRu		4	111	

23	island	PiRu		1.1	24	
23	island	PiRu	4.5		>200	
23	island	PiRu	5		>200	
24	indv	AcRu	6		>200	hummm
24	island	PiRu		4	120	hummm
24	island	PiRu		2.1	92	
24	island	PiRu	3.2		>200	
24	island	PiRu		2.1	75	
25	no trees					
26	island	PiRu	16.3		>200	hummm complex
26	island	PiRu	4.8		>200	
26	island	PiRu	7.8		>200	
26	island	PiRu	3.7		>200	
26	island	PiRu	2.4		>200	
26	island	PiRu	21.2		>200	
26	island	PiRu	4		>200	
26	island	PiRu	3.4		>200	
26	island	PiRu	7		>200	
26	island	PiRu	2.7		>200	
26	island	PiRu	2.1		>200	
26	island	PiRu		3.5	103	
26	island	AcRu	7		>200	
26	island	PiRu	3.7		>200	
26	island	PiRu	1.7	3.3	170	
26	island	PiRu		1.2	36	
26	island	PiRu		1.6	88	
26	island	PiRu		2	90	
26	island	PiRu		1.9	61	
26	island	PiRu	1.5	4.2	155	
26	island	PiRu	4.3		>200	
26	island	PiRu		5	127	
26	island	PiRu	3		>200	
26	island	PiRu		1.2	62	
26	island	PiRu		2.1	82	
26	island	PiRu	5.1		>200	
26	island	PiRu	5.2		>200	
26	island	PiRu		3.5	92	
26	island	PiRu	5		>200	
26	island	PiRu	3.3		>200	
26	island	PiRu	4		>200	
26	island	PiRu	3.9		>200	

26	island	PiRu	5.1		>200	
26	island	PiRu		2.2	113	
26	island	PiRu	0.8	5.3	155	
26	island	PiRu	5.3		>200	
26	island	PiRu	5.3		>200	
26	island	PiRu		1.8	46	
27	no trees					
28	no trees					
29	no trees					
30	no trees					
31	no trees					
32	no trees					
33	no trees					
34	no trees					
35	indv	PiRu		1	70	uneven topo
35	indv	PiRu		3	29	uneven topo
36	no trees					
37	no trees					
38	indv	PiRu	6.5		>200	hummm
38	indv	PiRu		5	84	hummm
39	no trees					
40	no trees					

BG2 Quad #	BG2 indv/island	BG2 species	BG2 DBH (cm)	BG2 DGL	BG2 height	BG2 topo
1	forest	PiRu	10.9		>200	
1	forest	PiRu	14.4		>200	
1	forest	PiRu	19.9		>200	
2	forest	PiRu		1.4	55	
2	forest	PiRu	19.5		>200	
2	forest	PiRu	16.8		>200	
2	forest	AcRu	19.1		>200	
2	forest	PiRu	60.4		>200	
2	forest	PiRu	0.5	3.5	145	
2	forest	PiRu		2.8	129	
2	forest	PiRu		1	29	
2	forest	PiRu	0.5	3.2	143	
2	forest	PiRu		0.5	24	

3	island	PiRu	19.3		>200	
3	island	PiRu		0.4	20	
3	island	AcRu		0.5	57	
3	island	PiRu		0.4	18	
3	island	PiRu		0.8	36	
3	island	AcRu		0.2	16	
4	indv	PiRu		1.8	62	flat
4	indv	PiRu	1.1	4	190	uneven
4	indv	PiRu	2.4		>200	hummm
4	indv	PiRu		1.5	78	hummm
4	indv	AcRu		0.1	16	uneven
4	indv	PiRu	0.5	2.6	143	hummm
4	indv	PiRu		1	33	hummm
4	indv	PiRu		0.9	32	hummm
4	indv	PiRu		1	52	hummm
4	indv	fir ?		1	73	hummm
5	island	PiRu	3.5		>200	hummm complex
5	island	PiRu		1.5	52	
5	island	PiRu	24		>200	
5	island	PiRu		1.2	61	
5	island	PiRu	14.3		>200	
5	island	PiRu	9.3		>200	
5	island	PiRu	9.3		>200	
5	island	PiRu		0.3	20	
5	island	PiRu		1.5	74	
5	island	PiRu		1.8	76	
5	island	PiRu	0.7	3.1	125	
5	island	PiRu		0.5	24	
5	island	PiRu		0.5	26	
5	island	PiRu		1	45	
6	indv	PiRu		1.9	62	hummm
6	indv	PiRu		1.5	55	hummm
6	indv	PiRu		1.5	51	hummm
6	indv	PiRu		0.9	35	hummm
6	indv	PiRu		1.4	50	hummm
6	indv	AcRu		0.2	13	uneven
7	island	PiRu	9.9		>200	hummm complex
7	island	PiRu		0.5	29	
7	island	AcRu		0.3	60	
8	indv	PiRu	11.8		>200	hummm



8	indv	AcRu		0.3	22	hummm
8	indv	AcRu		0.4	24	hummm
8	indv	AcRu		0.2	14	uneven
9	island	PiRu	5.6		>200	hummm complex
9	island	PiRu	5.2		>200	
9	island	PiRu	3.3		>200	
9	island	PiRu	1.1	5.1	162	
9	island	PiRu	17.7		adult	hummm complex
9	island	PiRu		5	148	
9	island	PiRu		1	35	
9	island	AcRu		0.4	32	
9	island	PiRu		0.9	22	
9	island	PiRu		1	29	
9	island	PiRu		0.5	14	
9	island	PiRu	5.6		>200	
9	island	PiRu	5.2		>200	
9	island	PiRu	3.3		>200	
9	island	PiRu	1.1	5.1	162	
9	island	PiRu		0.8	20	
9	island	PiRu		0.5	22	
9	island	PiRu		1	39	
9	island	PiRu		1	45	
9	island	PiRu		1	32	
9	island	PiRu		0.2	12	
9	island	PiRu		1.2	40	
9	island	PiRu		0.1	20	
9	island	PiRu		0.1	35	
9	island	AcRu		0.2	25	
9	island	PiRu		1.5	67	
9	island	PiRu		1	58	
9	island	PiRu		2	72	
9	island	PiRu		1	41	
9	island	PiRu		3.3	123	
9	island	PiRu		2.8	117	
9	island	PiRu		0.5	22	
9	island	PiRu		1.6	24	
10	island	PiRu	9.4		>200	hummm complex
10	island	AcRu		0.1	10	
10	island	AcRu		0.2	14	

10	island	AcRu		0.2	16	
10	island	AcRu		0.2	12	
10	island	AcRu		0.2	13	
10	island	AcRu		0.2	11	
10	island	AcRu		0.2	21	
10	island	AcRu		0.2	14	
10	island	AcRu		0.3	28	
10	island	PiRu	6.9		>200	hummm complex
10	island	PiRu	6.5		>200	
10	island	PiRu	1.7		>200	
11	island	PiRu	6.3		>200	hummm complex
11	island	AcRu		0.6	71	
11	island	AcRu		0.2	22	
12	no trees					
13	no trees					
14	no trees					
15	no trees					
16	no trees					
17	no trees					
18	no trees					
19	indv	PiRu		2	73	hummm
19	indv	PiRu		0.5	20	hollow
19	indv	PiRu		0.3	15	hummm
20	no trees					
21	no trees					
22	no trees					
23	island	PiRu	3.6		>200	hummm complex
23	island	PiRu		2.5	84	
23	island	PiRu		0.7	24	
23	island	PiRu		1.5	21	
23	island	PiRu		1.8	44	
23	island	PiRu		0.5	15	
23	island	PiRu		1.5	60	
23	island	PiRu		1	23	
23	island	PiRu		1	30	
23	island	PiRu		1.8	44	
23	island	PiRu		1.5	63	
23	indv	PiRu		1.3	28	hummm
24	no trees					

25	island	PiRu	17		>200	hummm complex
25	island	PiRu	6.1		>200	
25	island	PiRu		3.5	69	
25	island	PiRu		2.5	54	
25	island	PiRu		1.5	45	
25	island	PiRu		0.9	56	
25	island	PiRu		2.5	72	
25	island	PiRu		0.9	17	
25	island	PiRu		0.9	16	
26	no trees					
27	indv	PiRu	3.9		>200	hummm complex
27	indv	PiRu		7.5	128	hummm complex
27	indv	PiRu		1.5	40	hummm
28	no trees					
29	no trees					
30	no trees					
31	indv	PiRu	1	7.9	175	flat
32	no trees					
33	no trees					
34	no trees					
35	no trees					
36	no trees					
37	no trees					
38	no trees					
39	no trees					
40	no trees					

BG3 Quad #	BG3 indv/island	BG3 species	BG3 DBH (cm)	BG3 DGL	BG3 height	BG3 topo
1	forest	PiRu		0.9	28	
1	forest	PiRu	44.1		>200	
1	forest	PiRu	18.4		>200	
1	forest	PiRu		1.5	86	
1	forest	PiRu		2	127	
1	forest	PiRu		0.9	40	
1	forest	PiRu		0.9	28	
1	forest	PiRu		1	46	
1	forest	PiRu		1	42	

1	forest	PiRu		0.8	36	
1	forest	PiRu		0.5	27	
1	forest	PiRu		1.5	85	
1	forest	PiRu		1	26	
1	forest	PiRu		1.4	63	
1	forest	PiRu		1.5	70	
1	forest	AcRu		0.5	64	
1	forest	PiRu		1.4	42	
1	forest	PiRu		2.4	>200	
1	forest	PiRu		2.5	116	
1	forest	AcRu		0.2	18	
2	forest	PiRu		3.3	130	
2	forest	PiRu	2		>200	
2	forest	PiRu		1	56	
2	forest	PiRu		1	47	
2	forest	PiRu	0.5	3.8	150	
2	forest	TsCa		0.9	53	
2	forest	PiRu	0.8		184	
2	forest	PiRu		0.8	31	
2	forest	PiRu		0.2	14	
2	forest	PiRu		0.5	34	
2	forest	TsCa		0.9	52	
2	forest	PiRu		1.5	102	
2	forest	PiRu		0.9	53	
2	forest	PiRu		0.9	50	
2	forest	TsCa		0.5	36	
2	forest	PiRu		1.9	115	
2	forest	PiRu		1.9	80	
2	forest	PiRu		0.3	15	
2	forest	PiRu		1	49	
2	forest	PiRu	15.9		>200	
2	forest	PiRu		1.1	38	
2	forest	PiRu	0.5	3	170	
2	forest	PiRu		2.5	116	
2	forest	PiRu		1.5	56	
2	forest	PiRu		1.5	67	
2	forest	PiRu		1	30	
2	forest	TsCa		0.4	25	
2	forest	PiRu		1	55	
2	forest	AcRu	19.6		>200	
2	forest	PiRu	31		>200	

2	forest	PiRu		1	38	
3	indv	AcRu		0.2	18	hummm
3	indv	TsCa		0.5	44	hummm
3	indv	AcRu		0.1	11	uneven
3	indv	AcRu		0.1	12	hummm complex
3	indv	PiRu		2	63	hummm
3	indv	PiRu		0.9	26	uneven
3	indv	AcRu		0.2	16	hollow
4	island	TsCa	0.5	3	175	flat
4	island	PiRu		1.9	95	
4	island	PiRu	0.5	2.5	130	
4	island	TsCa		2	122	
4	island	TsCa	0.9	2.6	190	
4	island	PiRu		2.5	82	
4	island	TsCa		0.6	40	
4	island	TsCa		0.7	52	
4	island	PiRu	2		>200	
4	island	PiRu	2		>200	
4	island	PiRu		2	120	
4	island	PiRu		0.8	33	
4	island	PiRu		2	122	
4	island	TsCa		1.5	87	
4	island	PiRu		1.5	76	
4	island	PiRu		2.5	124	
5	island	PiRu	17.5		>200	hummm complex
5	island	PiRu	18.4		>200	
5	island	PiRu		0.9	33	
5	island	PiRu		2.1	96	
5	island	PiRu	1.5	4.2	190	
5	island	PiRu	7.8		>200	
5	island	PiRu	2.5		>200	
5	island	PiRu	1.5		>200	
5	island	PiRu	18.8		>200	
5	island	PiRu	11.2		>200	
5	island	PiRu		1	89	
5	island	PiRu	0.9	3	170	
5	island	PiRu		1.5	118	
5	island	PiRu		0.5	15	
6	island	AcRu	9.4		>200	hummm complex

6	island	AcRu		0.9	90	
6	island	AcRu		0.3	20	
6	island	AcRu		1.1	49	
6	island	PiRu	2.4		>200	
6	island	PiRu	0.7	4.4	170	
6	island	PiRu		3.3	120	
6	island	PiRu	6.2		>200	hummm
6	island	PiRu		2.5	83	
6	island	AcRu		0.2	12	
6	island	AcRu		0.2	12	
6	island	AcRu		0.5	30	
6	island	AcRu		0.3	24	
6	island	PiRu		0.5	20	
7	island	PiRu	5.5		>200	hummm complex
7	island	PiRu	3.2		>200	
7	island	AcRu		0.5	44	
7	indv	AcRu		0.8	34	uneven
8	indv	PiRu		0.5	32	uneven
8	indv	AcRu		0.4	16	uneven
8	indv	AcRu		0.3	19	hollow
8	indv	AcRu		0.5	16	hollow
8	indv	AcRu		0.3	20	hollow
8	indv	AcRu		0.3	22	hollow
8	indv	PiRu		1.1	42	hummm
8	indv	AcRu		0.5	18	hummm
8	indv	AcRu		0.2	15	hummm
8	indv	AcRu		0.5	18	uneven
8	indv	AcRu		0.2	16	uneven
8	indv	AcRu		0.7	23	uneven
8	indv	AcRu		0.3	36	uneven
8	indv	AcRu		0.5	35	uneven
8	indv	AcRu		0.3	34	uneven
8	indv	AcRu		0.4	30	uneven
9	island	PiRu		3.5	98	hummm
9	island	PiRu		1.5	50	
9	island	PiRu		2	60	
9	island	PiRu		2	44	
9	island	PiRu	3.3	9.4	180	
9	island	PiRu		0.5	14	
9	indv	AcRu		0.2	16	uneven
9	indv	AcRu		0.4	20	uneven

10	indv	AcRu		0.5	35	uneven
10	indv	AcRu		0.4	33	uneven
10	indv	AcRu		0.4	31	uneven
10	indv	AcRu		0.3	31	uneven
10	indv	AcRu		0.6	44	uneven
10	indv	AcRu		0.4	40	uneven
10	indv	AcRu		0.4	25	hummm
11	no trees					
12	indv	AcRu		0.2	15	uneven
12	indv	AcRu		0.3	30	uneven
12	indv	AcRu		0.2	17	hummm
12	indv	AcRu		0.2	12	uneven
13	island	PiRu	1.9		>200	hummm
13	island	AcRu		0.4	48	
13	island	PiRu		0.5	20	
13	island	PiRu	15		>200	hummm
13	island	PiRu		5.6	103	
13	island	AcRu		0.5	69	
13	island	PiRu		1.8	52	
13	island	AcRu		1	36	
14	island	PiRu	10.2		>200	hummm complex
14	island	PiRu	2.5		>200	
14	island	PiRu		1.3	52	
14	island	AcRu		0.3	30	
14	island	PiRu	7.8		>200	
14	island	PiRu	7.2		>200	
14	island	PiRu	7		>200	
14	island	PiRu	9		>200	
14	island	PiRu	3.7		>200	
14	island	PiRu	1.2	4.9	150	
14	island	PiRu	16.5		>200	
14	island	PiRu	2.1		>200	
14	island	PiRu		4	98	
14	island	PiRu	1	6.3	150	
15	island	PiRu	1.9	9	185	hummm
15	island	PiRu	1.3	5.4	166	
15	island	PiRu	2.4	5.8	174	
15	indv	PiRu	6.4		>200	hummm
16	island	PiRu		2	69	hummm complex
16	island	PiRu	5.3		>200	

16	island	PiRu	7.8		>200	
16	island	PiRu	0.5	5.2	144	hummm complex
16	island	PiRu		2.5	71	
16	island	PiRu		2.5	79	
16	island	PiRu		1.1	59	
16	island	PiRu		2.5	117	
16	island	PiRu		2	78	
16	island	PiRu		0.5	18	
16	island	PiRu	20.5		>200	
16	island	PiRu	9.5		>200	
16	island	PiRu	2.4	5.2	195	
16	island	PiRu	8.2		>200	
17	island	PiRu	1.5	9.2	190	hummm complex
17	island	PiRu	0.8	5.8	185	
17	island	PiRu	2.1		>200	
17	island	PiRu	4.6		>200	
17	island	PiRu		6	148	
17	island	PiRu		3.5	120	
17	island	PiRu	1.4	4.4	165	
17	island	PiRu	4.5		>200	
18	island	PiRu		3.8	110	hummm complex
18	island	PiRu		0.5	15	
18	island	PiRu	6.1		>200	
18	island	PiRu	19		>200	
18	island	PiRu	13.7		>200	
18	island	PiRu		0.9	22	
18	island	PiRu		0.8	14	
18	island	PiRu		1.5	42	
18	island	PiRu		2.5	65	
18	island	PiRu		0.5	11	
19	island	TsCa	2		>200	hummm complex
19	island	PiRu	10		>200	
19	island	PiRu		1.8	68	
19	island	PiRu		2	72	
19	island	PiRu		5.6	95	
19	island	PiRu		3.2	86	
19	island	PiRu	14		>200	
19	island	PiRu		1.5	73	



20	island	PiRu	4.4		>200	hummm complex
20	island	PiRu	3.3		>200	
20	island	PiRu	1.4	5.5	175	
20	island	PiRu	5.3		>200	
20	island	PiRu		3.4	102	
20	island	PiRu		5	92	
21	island	PiRu		3	45	hummm complex
21	island	PiRu	11.5		>200	
21	island	PiRu	14.4		>200	
21	island	PiRu		2.7	48	
22	no trees					
23	island	PiRu	14.3		>200	hummm complex
23	island	PiRu	0.5	3.9	156	
23	island	PiRu		4.5	88	
23	island	PiRu		0.9	35	
23	island	PiRu		1.5	48	
23	island	PiRu		1.4	30	
23	island	PiRu		1	23	
23	island	PiRu		1.4	39	
23	island	PiRu	2.7	6.1	180	
23	island	PiRu		4.7	66	
24	no trees					
25	no trees					
26	no trees					
27	indv	PiRu		4.3	96	hummm
28	no trees					
29	no trees					
30	no trees					
31	no trees					
32	no trees					
33	no trees					
34	no trees					
35	no trees					
36	no trees					
37	no trees					
38	no trees					
39	indv	PiRu		4.8	111	hummm
39	indv	PiRu		5	124	
39	island	PiRu		3.8	127	hummm

						complex
39	island	PiRu		5	137	
39	island	PiRu		7.2	54	
39	indv	PiRu		4	78	hummm
40	island	PiRu	15.5		>200	hummm complex
40	island	PiRu	9		>200	
40	island	PiRu	3.8		>200	
40	island	PiRu		1.6	68	

FG1 Quad #	FG1 indv/island	FG 1 species	FG1 DBH (cm)	FG1 DGL	FG1 height	FG 1 Location
1	ind	Picea rubras	17.2		>200	
1	ind	Picea rubras	26.2		>200	
1	ind	Picea rubras	29.3		>200	
1	ind	Picea rubras	8		>200	
2	ind	Picea rubras	14.6		>200	
2	ind	picea rubras	19.4		>200	
3	island	acer rubram		0.1	16	hummm complex
3	island	acer rubram		0.1	20	
3	island	Picea rubras		0.5	20	
3	island	Picea rubras		0.5	20	
3	island	Picea rubras		0.4	16	
3	island	Picea rubras		0.4	11	
3	island	Picea rubras		0.4	14	
3	island	Picea rubras		0.4	18	
3	island	Picea rubras		1	34	
3	island	Picea rubras	1.4		170	
3	island	Picea rubras		1.5	52	
3	island	Picea rubras		1.5	47	
3	island	Picea rubras		1.5	60	
3	island	Picea rubras		1.4	48	
3	ind	Picea rubras		0.5	16	hummm
3	ind	Picea rubras		1.3	27	hummm
3	ind	Picea rubras		1.5	32	hummm
4	ind	acer rubram		0.3	14	hollow
4	ind	acer rubram		0.3	20	hollow
4	ind	acer rubram		0.1	11	hummm
4	ind	acer rubram		0.5	32	hummm

4	ind	acer rubram		0.4	35	hummm
4	ind	acer rubram		0.1	14	hummm complex
4	ind	Picea rubras		0.2	13	hummm complex
4	ind	Picea rubras		0.3	15	hummm complex
4	ind	Picea rubras		0.2	13	hummm complex
4	ind	Picea rubras		0.2	12	hummm complex
4	ind	Picea rubras		0.4	24	hummm complex
4	ind	Picea rubras		0.4	21	hummm complex
4	ind	acer rubram		0.9	51	hummm complex
4		acer rubram		1	50	
4		Picea rubras		0.5	20	
4		acer rubram		0.3	20	
4		Picea rubras		0.4	24	
4		Picea rubras	2.5		205	
4		Picea rubras	2.9		>200	
5	No trees					
6	ind	Picea rubras		0.3	16	hollow hummm complex
7	island	Picea rubras		0.4	33	hummm complex
7	island	Picea rubras		1.3	48	
7	island	Picea rubras	1.8		170	
7	island	Picea rubras		1	25	
7	island	Picea rubras		0.2	13	
7	island	Picea rubras	40.7		>200	
7	island	acer rubram	7.1		>200	
7	island	Picea rubras		1.3	32	
8	no trees					
9	no trees					
10	no trees					
11	no trees					
12	ind	Picea rubras		0.3	16	flat
13	no trees					
14	island	Picea rubras		1.5	38	hummm complex
14	island	Picea rubras	3.2		150	
14	island	Picea rubras	4.6		>200	

14	island	Picea rubras		1.8	67	
14	island	Picea rubras		1.6	65	
14	island	Picea rubras		2.4	110	
14	island	Picea rubras		1	35	
14	island	Picea rubras	1.2		150-200	
14	island	Picea rubras		1.8	82	
14	island	Picea rubras		1.3	47	
14	island	Picea rubras		2.4	106	
14	island	Picea rubras		1	44	
14	island	Picea rubras		1.5	76	
14	island	Picea rubras		1.5	63	
14	island	Picea rubras		1.5	63	
14	island	Picea rubras		2.5	102	
14	island	Picea rubras	2.8		203	
14	island	Picea rubras		2	89	
14	island	Picea rubras	13.7		>200	
14	island	Picea rubras	25		>200	
14	island	Picea rubras		2.4	102	
14	island	Picea rubras		1.4	64	
14	island	Picea rubras		1.3	43	
14	island	Picea rubras		1.9	104	
14	island	Picea rubras		2.4	66	
14	island	Picea rubras		2	38	
14	island	Picea rubras		1.4	43	
14	island	Picea rubras		1.9	66	
14	island	Picea rubras	3		>200	
14	island	Picea rubras	4		>200	
14	island	Picea rubras	6.7		>200	
14	island	Picea rubras		1.7	38	
14	indv	Picea rubras		0.5	14	flat
15	indv	Picea rubras		0.9	140	hummm
15	indv	acer rubram		0.2	12	hummm
15	indv	acer rubram		0.3	19	hummm
16	no trees					
17	indv	Picea rubras		5.3	115	hummm
17	indv	Picea rubras	3		>200	flat
18	no trees					
19	no trees					
20	indv	Picea rubras	5.6		>200	flat
21	island	Picea rubras	2		>200	flat
21	island	Picea rubras	8.9		>200	

21	island	Picea rubras	2.1		>200	
21	island	acer rubram	6.8		>200	
21	island	Picea rubras	8.2		>200	
21	island2	Picea rubras		4	109	hummm
21	island2	Picea rubras		0.6	16	
21	island2	Picea rubras	2.5		~200	
21	island2	Picea rubras	2.3		~200	
22	indv	picea rubras		0.9	15	hummm
23	indv	acer rubram		0.2	11	hummm
23	indv	Picea rubras		1.1	140	hummm
24	island	Picea rubras	21.8		>200 adult	hummm
24	island	acer rubram		0.8	24	
25	indv	Picea rubras	7.3		>200	hummm complex
25	indv	Picea rubras		3.2	70	hummm
26	indv	Picea rubras		3	78	hummm complex
27	island	Picea rubras	6.2		>200	hummm
27	island	Picea rubras	6		>200	
27	island	Picea rubras	7.7		>200	
27	island	Picea rubras		4.2	120	
27	island	Picea rubras		1.8	70	
28	no trees					
29	no trees					
30	no trees					
31	no trees					
32	no trees					
33	no trees					
34	no trees					
35	no trees					
36	no trees					
37	no trees					
38	no trees					
39	no trees					
40	no trees					

FG2			DBH		ht class	
Quad #	indv/island	species	(cm)	DGL	(cm)	location
1	forest	PiRu	18.9		adult	
1	forest	PiRu	13.3		adult	
1	forest	PiRu		0.8	24	

1	forest	PiRu	30.9		adult	
1	forest	PiRu	7.3		>200	
1	forest	PiRu		2.2	52	
1	forest	AcRu	6.4		>200	
1	forest	PiRu		0.3	>200	
2	forest	PiRu	3.3		16	
2	forest	PiRu	15		>200	
2	forest	PiRu	18.9		adult	
2	forest	PiRu	3.1		adult	
2	forest	PiRu	23.7		150-200	
2	forest	PiRu	8.4		adult	
2	forest	PiRu		0.4	adult	
2	forest	PiRu	11.2		14	
2	forest	PiRu	11		adult	
2	forest	PiRu	14.8		adult	
2	forest	PiRu		0.9	adult; dead	
2	forest	PiRu		1.6	27	
2	forest	PiRu		0.3	53	
2	forest	AcRu	5.2		12	
2	forest	PiRu		0.6	>200	
2	indv	AcRu		0.5	12	
3	island	PiRu		1.9	26	
3	island	PiRu		1.5	195	hummm complex
3	island	PiRu		2	57	
3	island	PiRu		2.4	102	
3	indv	PiRu		1.9	92	
4	indv	PiRu		0.4	90	hummm
4	indv	PiRu		0.5	32	hummm
4	indv	PiRu		2.3	33	hummm
4	indv	PiRu	4.4		115	hummm
5	no trees					
6	island	PiRu	5.2		>200	hummm complex
7	island	PiRu	2.1			
7	island	PiRu		0.5	>200	hummm complex
7	island	PiRu	3.1		175	
7	island	PiRu		0.2	19	
7	island	PiRu		0.7	>200	
7	island	PiRu	35.5		10	

7	island	PiRu		1.5	17	
7	island	PiRu		1.6	adult	
7	island	PiRu		0.8	55	
7	island	PiRu		0.7	80	
7	island	PiRu	17.3		28	
7	island	PiRu	19		32	
7	island	PiRu		1.9	adult; dead	
7	island	PiRu		1	adult	
7	island	PiRu		0.5	48	
7	indv	AcRu		0.5	33	
7	island	AcRu		0.4	20	
8	island	PiRu	5		30	hummm
8	island	PiRu	5.2		27	hummm
8	indv	PiRu		1.5	>200	
8	indv	AcRu		1	>200	
8	indv	PiRu		1	43	hummm
8	island	PiRu	4		36	hummm
9	island	AcRu		0.8	17	
9	island	AcRu		0.9	>200	hummm
9	island	PiRu	4.3		50	
9	island	PiRu	3.2		44	
9	island	PiRu	3		>200	hummm
9	island	PiRu		2.6	>200	
9	island	PiRu		2	>200	
10	island	PiRu		1	110	
10	island	PiRu		1	54	hummm complex
10	island	PiRu	29		35	
10	island	PiRu	14.3		38	
10	island	PiRu	20.5		adult	
10	island	PiRu		1.3	adult	
10	island	PiRu	33.4		adult	
10	island	PiRu		3.2	29	
10	island	PiRu		2.3	adult	
10	island	PiRu	11		132	
10	island	PiRu	8.8		71	
10	island	PiRu		7	>200	
10	island	PiRu		1.9	>200	
11	island	PiRu	3.5		21	
11	island	PiRu		3	66	hummm
11	indv	AcRu		0.3	>200	

11	indv	PiRu		0.9	200	
12	island	PiRu	1.5		22	hummm
13	island	PiRu	3.4		29	hummm
13	island	PiRu		1.5	152	hummm
13	island	PiRu		0.9	>200	
14	island	PiRu		0.8	41	
14	island	PiRu		1	27	hummm
14	island	PiRu		2	19	
14	island	PiRu		0.6	19	
14	island	PiRu	15.2		50	
14	indv	PiRu		2	17	
14	indv	AcRu		0.3	adult	
14	indv	PiRu		2	39	
14	no trees					
15	indv	PiRu	11.8		23	
16	indv	PiRu		3.1	57	
17	indv	PiRu	4.8			
18	indv	PiRu		1.9	adult	flat
18	no trees		15.2		90	hummm
19	no trees			1.3	>200	hummm
20	no trees				52	hummm
21	no trees					
22	no trees					
23	indv	PiRu			>200	
24	indv	PiRu			23	
24	no trees					
25	no trees					
26	no trees					
27	no trees					
28	no trees					
29	no trees					
30	no trees					
31	no trees					
32	no trees					
33	no trees					
34	no trees					
35	no trees					
36	no trees					
37	no trees					
38	no trees					
39	no trees					



40	no trees					
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FG3 Quad #	FG3 indv/island	FG3 species	FG3 DBH (cm)	FG3 DGL	FG3 ht class	FG3 Location
1	forest	PiRu	20.8		adult	
1	forest	PiRu	2.9		>200	
1	forest	AcRu	6		>200	
1	forest	PiRu	16		adult	
1	forest	PiRu	6.2		>200	
1	forest	BeAl	8.6		>200	
1	forest	PiRu	27		adult	
1	forest	PiRu		0.5	12	
1	forest	PiRu		2	71	
1	forest	PiRu		0.4	17	
1	forest	PiRu	8.4		>200	
1	forest	PiRu	17.2		adult	
1	forest	BeAl	12.5		adult	
1	forest	PiRu	3.2		>200	
2	forest	PiRu		1.3	42	
2	forest	PiRu	4.1		>200	
2	forest	PiRu		1.5	55	
2	forest	PiRu		2.5	122	
2	forest	PiRu		0.8	23	
2	forest	PiRu		2.7	130	
2	forest	PiRu		1.5	76	
3	indv	AcRu		0.3	25	hummm
3	indv	AcRu		0.4	16	uneven
3	indv	PiRu	2.8		>200	hummm
3	indv	AcRu		0.1	11	
3	indv	BeAl	3.8		>200	hummm
3	indv	PiRu		0.7	20	hummm
3	indv	PiRu	15.2		adult	hummm
3	indv	BeAl	3.8		>200	hummm
3	indv	BeAl	3.1		>200	hummm
4	indv	BeAl	2.5		>200	hummm
4	indv	PiRu		1.9	80	hummm
4	indv	BeAl		1.5	116	
4	indv	BeAl		1.1	120	
5	no trees					
6	island	PiRu	31.5		adult	hummm complex

6	island	PiRu		0.8	26	
6	island	PiRu	34.2		adult	
6	island	PiRu		1.3	43	
6	island	PiRu		0.8	22	
6	island	PiRu	8.4		>200	
6	island	PiRu	17.5		adult	
6	island	PiRu	15.1		adult	
6	island	PiRu	16.5		adult	
6	island	PiRu	4.2		>200	
6	island	PiRu		0.5	15	
6	island	PiRu		1.9	58	
6	island	PiRu		0.3	13	
6	island	AcRu	3.4		>200	
7	island	PiRu	5.8		>200	hummm
7	island	PiRu	2.2		>200	
7	island	PiRu		1.5	91	
8	indv	PiRu		1.1	75	hummm
8	indv	PiRu		1	28	hummm
9	island	PiRu		0.4	19	hummm complex
9	island	PiRu	12		>200	
9	island	PiRu	18.1		adult	
9	island	PiRu	16		>200	
9	island	PiRu		0.2	11	
9	island	PiRu	13.2		>200	
9	island	PiRu	19.7		adult	
9	island	PiRu	15		>200	
9	island	PiRu	19.1		adult	
9	island	PiRu		0.5	17	
9	island	PiRu	21.2		adult	
9	island	PiRu		0.5	21	
10	island	PiRu		0.3	11	hummm
10	island	PiRu	5.8		>200	
10	island	AcRu		0.5	17	
10	indv	PiRu		2	198	hummm
10	indv	AcRu		0.9	195	hummm
11	indv	AcRu	3.9		>200	hummm
12	no trees					
13	no trees					
14	indv	PiRu		2.5	95	flat
14	indv	PiRu		1.8	76	flat
15	island	PiRu	22.8		adult	hummm

					(dead)	
15	island	PiRu		4.8	125	
15	island	PiRu		1	42	
15	island	PiRu		0.7	14	
15	island	PiRu		0.2	11	
15	island	AcRu		1.3	118	
15	island	AcRu		1	55	
15	island	PiRu		1	17	
15	island	PiRu		0.5	15	
15	island	PiRu		1.5	57	
15	island	PiRu		0.9	48	
15	island	PiRu		0.5	15	
15	island	PiRu		1	27	
15	island	PiRu		0.6	21	
15	island	PiRu		0.5	23	
15	island	PiRu		0.6	26	
15	island	PiRu		0.9	29	
15	island	PiRu		0.5	21	
15	island	PiRu		1.4	53	
15	island	PiRu		0.2	10	
16	indv	PiRu		2.5	80	hummm
16	indv	PiRu	0.8		142	hummm
16	indv	PiRu	3.1		115	hummm
17	indv	PiRu		4.8	130	hummm
17	indv	PiRu		2.4	59	hummm
18	indv	PiRu	4.1		>200	hummm
18	indv	PiRu	4		>200	hummm
18	indv	PiRu		4	92	hummm
19	no trees					
20	island	PiRu	14.2 (DEAD)		>200	hummm
20	island	PiRu	9.1		>200	
20	island	PiRu	7.6		>200	
20	island	AcRu		0.3	22	
21	indv	PiRu		2.3	63	hummm
22	indv	PiRu		3.9	73	hummm
23	no trees					
24	no trees					
25	island	PiRu	8.8		>200	hummm complex
25	island	PiRu	22		adult	
25	island	PiRu	37.7		adult	
25	island	PiRu	16.7		>200	

25	island	PiRu	23.5		adult	
25	island	PiRu	3.1		>200	
25	island	PiRu	1.5		153	
25	island	PiRu		1	29	
25	island	AcRu	4		>200	
26	indv	PiRu		1	65	hummm
27	island	PiRu		0.9	80	hummm
27	island	PiRu		0.4	46	
27	island	PiRu		0.4	34	hummm
27	indv	PiRu		0.9	45	hummm
27	indv	PiRu		1.1	92	hummm
28	indv	PiRu		0.8	39	hummm complex
29	no trees					
30	no trees	1 hummm				
31	no trees	1 hummm				
32	no trees					
33	no trees	2 hummm				
34	indv	PiRu		2.5	56	hummm
34	indv	PiRu		2	66	hummm
34	indv	PiRu		2	79	
34	indv	PiRu			59 (dead)	
35	no trees					
36	island	PiRu		4.1	123	hummm complex
36	island	PiRu		3.5	115	
36	island	PiRu	2.7		187	
36	island	AcRu		0.3	23	
37	no trees	1 hummm				
38	island	PiRu		5	135	hummm
38	island	PiRu		1	30	
38	island	PiRu		1.3	34	
39	no trees					
40	indv	PiRu		5.1	103	hummm

RG1 Quad #	RG1 indv/island	RG1 species	RG1 DBH (cm)	RG1 DGL	RG1 ht class	RG1 Location
1	forest	PiRu	7.3		>200	forest
1		PiRu	19.1		adult	
1		PiRu	7.1		>200	
1		AcRu	3.5		>200	

1		PiRu		0.7	14	
1		PiRu	11.5		>200	
1		PiRu	14.8		adult	
2	forest	PiRu	15		adult	
3	indv	PiRu		4	130	hummm
4	indv	PiRu	9.4		>200	hummm
4	island	PiRu	21		adult	hummm complex
4	island	PiRu		1.2	40	
4	island	PiRu		0.9	33	
4	island	AcRu	4.7		>200	
4	island	PiRu		0.7	10	
5	no trees					
6	no trees					
7	island	PiRu	17.9		adult	hummm complex
7	island	PiRu		1.1	24	
7	island	PiRu		0.5	14	
7	island	PiRu		1.3	22	
7	island	PiRu		1	22	
7	island	PiRu		1.4	32	
7	island	PiRu		1.6	55	
7	island	PiRu		1	21	
7	island	PiRu		1.7	43	
7	island	AcRu	3.5		>200	
8	indv	PiRu	14.1		adult	hummm complex
8	island	PiRu	4.1		>200	hummm complex
8	island	PiRu	20		adult	
8	island	PiRu	13		>200	
8	island	PiRu		3.2	135	
8	island	PiRu		1.4	27	
8	island	PiRu		0.3	13	
8	island	PiRu		1.1	34	
8	island	PiRu		1.3	35	
8	island	PiRu	14.3		adult	
8	island	PiRu		3.3	121	
8	island	PiRu	7		>200	
8	island	PiRu		1.4	20	
8	island	PiRu	8.4		>200	
9	island	PiRu	14.5		adult	hummm

						complex
9	island	PiRu	8		>200	
9	island	PiRu	7.1		>200	
9	island	AcRu		0.7	63	
9	island	PiRu		0.5	14	
9	island	AcRu		0.3	17	
9	island	PiRu		1.4	34	
9	island	PiRu		1.4	34	
9	island	AcRu		0.6	28	
10	no trees					
11	island	PiRu	17.7		adult	hummm complex
11	island	PiRu	3.6		>200	
11	island	PiRu		1.4	37	
11	island	PiRu		0.3	13	
11	island	PiRu		0.5	13	
11	island	PiRu		0.7	16	
11	island	PiRu		0.9	20	
12	no trees					
13	no trees					
14	island	PiRu	13.8		adult	hummm complex
14	island	PiRu		5	106	
14	island	PiRu		1.1	14	
14	island	PiRu		1.5	56	
15	island	PiRu	22.3		adult	hummm complex
15	island	PiRu	3.4		>200	
15	island	PiRu	6.8		>200	
15	island	PiRu	1.5		150	
15	island	PiRu		1.4	47	
15	island	PiRu		1.9	67	
15	island	PiRu	4.3		>200	
15	island	PiRu		0.9	20	
15	island	PiRu		1.5	30	
15	island	PiRu		1.9	49	
15	island	PiRu		1.9	65	
15	island	PiRu		2	58	
15	island	PiRu		2.3	104	
15	island	PiRu	12.2		>200	hummm
15	island	PiRu		0.5	12	
15	island	PiRu		2.3	30	

15	island	PiRu		1	24	
15	island	PiRu		1	19	
15	island	PiRu		0.9	20	
15	island	PiRu		0.6	11	
15	island	AcRu		0.2	12	
16	island	PiRu	23		adult	hummm complex
16	island	PiRu		1.5	17	
16	island	PiRu		1.7	50	
16	island	PiRu		1.7	51	
16	island	PiRu		1.4	24	
16	island	PiRu		1.8	33	
16	island	PiRu		0.5	15	
16	island	PiRu		0.6	19	
16	island	PiRu		1.3	23	
16	island	PiRu	17.8		adult	
16	island	PiRu	3.5		190	
16	island	PiRu		3.5	137	
17	no trees					
18	no trees					
19	island	PiRu	8.7		>200	hummm
19	island	PiRu		2	50	
19	island	PiRu		2.1	54	
19	island	PiRu		2.1	46	
19	island	PiRu	21		adult	
19	island	PiRu	2.6		185	
19	island	PiRu	2		152	
19	island	PiRu	13.4		>200	
19	island	PiRu		3.6	121	
19	island	PiRu		1.4	32	
19	island	AcRu		0.8	16	
19	island	AcRu		1.3	35	
19	island	PiRu	15.8		adult	
20	no trees					
21	no trees					
22	no trees					
23	indv	PiRu	7.5		>200	hummm
24	no trees					
25	island	PiRu		4.2	85	hummm
25	island	PiRu	8.3		>200	
25	island	PiRu	10.6		>200	
25	island	PiRu	3.1		170	

25	island	PiRu	5.1		>200	
25	island	PiRu	16.3		adult	
25	island	PiRu		3.2	135	
25	island	PiRu	3.5		>200	
25	island	PiRu	2.7		>200	
25	island	PiRu		2	82	
25	island	PiRu		1.3	44	
25	island	PiRu	9.5		>200	
25	island	PiRu		2.1	82	
25	island	PiRu	22.7		adult	
26	indv	AcRu		0.2	16	uneven topo
27	no trees					
28	island	PiRu	13.5		>200	hummm
28	island	PiRu	32.6		adult	
28	island	PiRu		1	18	
28	island	PiRu	3		>200	
28	island	PiRu	9.4		>200	
29	no trees					
30	no trees					
31	no trees					
32	no trees					
33	no trees					
34	no trees					
35	no trees					
36	no trees					
37	no trees					
38	no trees					
39	no trees					
40	no trees					

RG2

Quad #	RG2 indv/island	RG2 species	RG2 DBH (cm)	RG2 DGL	RG2 ht class	RG2 Location
1	forest	piru	15.2		adult	
1	forest	beal	3.8		>200	
1	forest	beal	4.7		>200	
1	forest	beal	7.7		>200	
1	forest	beal	2.4		>200	
2	forest	piru	18.6		adult	
2	forest	AcRu	6.1		>200	
2	forest	piru	21.5		adult	



2	forest	piru	7.4		>200	
2	forest	piru	20.4		adult	
2	forest	piru	12.1		>200	
2	forest	piru	6.6		>200	
2	forest	piru	7.5		>200	
3	island	piru	8.1		>200	hummm
3	island	beal	9		>200	
3	island	piru		1.4	70	
3	island	beal	2.1		>200	
3	island	piru	2.5		150	
3	island	beal	2.7		>200	
3	island	beal	9		>200	
3	island	piru	2.3		>200	
3	island	piru	5.5		>200	
3	island	piru		1	75	
3	island	beal	2.5		190	
3	island	piru		1.5	45	
4	indv	piru	14		adult	hummm
4	indv	ash	5.2		>200	hummm
4	indv	piru		1.8	88	hummm
4	indv	piru	19.2		adult	hummm
5	no trees	no trees				
6	island	piru	3		>200	hummm complex
6	island	piru	8.1		>200	
6	island	AcRu	7		>200	
6	island	piru	14.8		adult	
6	island	piru	13.4		adult	
6	island	piru	11.1		adult	
6	island	piru	5.2		>200	
6	island	piru	11.3		adult	
6	island	piru	3.2		>200	
6	island	piru	1.5		153	
6	island	beal	3.2		>200	
6	island	piru	17.3		adult	
6	island	piru	3		>200	
6	island	piru	1.8		190	
6	island	piru	22.2		adult	
6	island	piru	15.1		adult	
6	island	AcRu		0.4	34	
6	island	AcRu		0.3	22	
6	island	piru	7.4		>200	

7	indv	AcRu		0.2	23	hummm
7	indv	piru	7.4		>200	hummm
7	indv	AcRu	2.3		>200	hummm
8	no trees					
9	island	piru		1	20	hummm
9	island	AcRu		0.5	21	
9	island	AcRu		0.4	22	
9	island	AcRu		0.5	35	
9	island	piru	15.5		adult	
9	island	AcRu	3.6		>200	
9	island	piru		1.4	39	
9	island	piru		1.4	57	
9	island	AcRu		0.2	12	
9	island	AcRu		0.5	58	
9	island	AcRu		0.3	21	
9	island	AcRu		0.2	15	
9	island	AcRu		0.2	14	
9	island	AcRu	0.7		160	
9	island	AcRu		0.3	35	
9	indv	piru		1.3	26	uneven
9	indv	AcRu		0.3	22	hummm
9	indv	piru		0.5	23	hummm
9	indv	AcRu		0.4	36	uneven
9	indv	AcRu		0.1	13	uneven
9	indv	AcRu		0.1	15	hummm
10	no trees					
11	indv	AcRu		0.2	20	hummm
11	indv	AcRu		0.2	16	hummm
11	indv	AcRu		0.3	22	hummm
11	indv	AcRu		0.2	12	hummm complex
12	indv	piru		2	64	hummm
13	island	piru	11.3		>200	hummm complex
13	island	AcRu		0.5	34	
13	island	AcRu		0.9	32	
13	island	AcRu		0.9	52	
13	island	AcRu		0.5	25	
13	island	AcRu	3.8		>200	
13	island	piru	6.4		>200	
13	island	piru	8.9		>200	
13	island	piru		2.5	81	

13	island	piru	6.2		>200	
13	island	piru	14.5		adult	hummm
13	island	piru		0.8	11	
13	island	piru		2.6	199	
13	island	piru	0.7		155	
13	island	piru	3		190	
13	island	piru		0.5	24	
13	island	piru		0.5	17	
13	island	piru		0.3	12	
14	no trees					
15	no trees					
16	indv	piru		0.8	27	hummm complex
16	indv	piru		0.7	27	hummm complex
17	no trees					
18	indv	piru	17.3		adult	hummm
18	indv	piru	12.7		>200	hummm
19	no trees					
20	no trees					
21	no trees					
22	indv	piru		1.5	68	hummm complex
23	island	piru	24.3		adult	hummm
23	island	piru		0.8	17	hummm
23	island	piru		1	20	
23	island	piru		1	22	
23	island	piru		0.6	19	
23	island	piru		1	32	
23	indv	piru		0.5	24	hummm
25	indv					
26	no trees					
27	no trees					
28	no trees					
30	island	piru	28		adult	hummm
30	island	piru	7.3		>200	
30	island	piru	18.1		adult	
30	island	piru	2.3		164	
30	island	piru	6.2		>200	
30	island	piru	7.2		>200	
30	island	piru	10		>200	
31	indv	piru	2		>200	

32	island	piru		0.8	32	hummm complex
32	island	piru	21.6		adult	hummm complex
32	island	piru	12		>200	
32	island	piru	12.1		>200	
33	no trees	piru		1	40	
34	no trees					
35	no trees					
36	no trees					
37	indv	AcRu		0.4	38	hummm
38	no trees					
39	indv	piru	17.2		adult	hummm
40	no trees					

RG3 Quad #	RG3 indv/island	RG3 species	RG3 DBH (cm)	RG3 DGL	RG3 ht class	RG3 Location
1	forest	PiRu	27.5		adult	
1	forest	PiRu	9.5		>200	
1	forest	PiRu	4.5		>200	
1	forest	PiRu		0.8	17	
1	forest	PiRu		2	55	
1	forest	PiRu		0.5	30	
1	forest	PiRu	0.5		141	
1	forest	PiRu	0.8		153	
1	forest	PiRu	2.5		>200	
1	forest	PiRu	0.5	0.5	17	
1	forest	PiRu	0.9		152	
1	forest	PiRu	1.5		170	
1	forest	PiRu	1.9		197	
1	forest	PiRu	2.8		>200	
1	forest	PiRu		1.5	62	
1	forest	PiRu		1.9	88	
1	forest	PiRu		1.5	77	
1	forest	PiRu		1.4	72	
1	forest	PiRu	5.1		>200	
1	forest	PiRu		1.5	55	
1	forest	PiRu		0.8	26	
1	forest	PiRu		0.8	23	

1	forest	BeAl	5.3		>200
1	forest	PiRu		1	55
1	forest	PiRu		1.4	90
1	forest	PiRu		1.5	78
1	forest	PiRu		0.5	34
1	forest	PiRu	1.4		164
1	forest	PiRu		2.5	127
2	forest	PiRu		1.5	68
2	forest	PiRu	2.9		>200
2	forest	PiRu	1		177
2	forest	PiRu	0.9		143
2	forest	PiRu		1.5	124
2	forest	PiRu		0.5	33
2	forest	PiRu	2		>200
2	forest	PiRu	3		>200
2	forest	PiRu	1.4		180
2	forest	PiRu	3		>200
2	forest	PiRu	3.3		>200
2	forest	PiRu	5.9		>200
2	forest	PiRu	3.4		>200
2	forest	PiRu	3.7		>200
2	forest	PiRu	5		>200
2	forest	PiRu	6.1		>200
2	forest	PiRu	2.8		>200
2	forest	PiRu	2.3		>200
2	forest	PiRu		1.3	64
2	forest	PiRu		1.3	56
2	forest	PiRu	3.2		>200
2	forest	PiRu	3.5		>200
2	forest	PiRu	2.7		>200
2	forest	PiRu	3.4		>200
2	forest	PiRu	2.5		>200
2	forest	PiRu	3.4		>200
2	forest	PiRu	4.3		>200
2	forest	PiRu	2.6		>200
2	forest	PiRu		0.3	15
2	forest	PiRu		1.5	69
2	forest	PiRu		0.5	19
2	forest	PiRu		1.8	70
2	forest	PiRu		2.5	139
2	forest	TsCa	0.8		184

3	indv	PiRu		0.4	15	hollow
3	indv	PiRu		0.5	22	hollow
3	indv	PiRu		1.5	46	hollow
3	indv	PiRu	4		>200	hummm
3	indv	PiRu		0.4	23	hummm
3	island	PiRu		1.4	46	hummm complex
3	island	PiRu		1.6	66	
3	island	PiRu		1.2	60	
3	island	PiRu		1	26	
3	indv	PiRu		1	43	hummm
3	indv	AcRu		1.3	84	hummm
3	indv	TsCa		1.4	124	hummm
4	indv	PiRu		1.4	39	hummm
4	island	PiRu		2.4	130	hummm
4	island	PiRu		2.4	120	
4	island	AcRu	1.5		>200	
4	island	PiRu		2.9	70	uneven topo
4	island	AcRu		0.2	20	
4	island	PiRu		2	125	
4	island	PiRu	3.2		145	
4	island	PiRu		1.5	62	
4	island	AcRu		0.2	18	
4	island	PiRu		2	74	
5	island	PiRu	25.5		adult	hummm
5	island	AcRu		0.2	55	
5	island	PiRu	22.5		adult	
5	island	PiRu	4.5		>200	
5	island	PiRu	20		adult	
5	island	PiRu		0.5	23	
5	island	AcRu		0.4	40	
5	island	PiRu	12.5		>200	
6	island	PiRu	22		adult	hummm complex
6	island	PiRu	0.5		164	
6	island	AcRu	2.6		>200	
6	island	PiRu	4		>200	
6	island	PiRu	3.4		>200	
6	island	PiRu	7		>200	
6	island	PiRu	5.8		>200	
6	island	AcRu	2.8		>200	
6	island	AcRu	3.5		>200	

7	island	PiRu	5.8		>200	hummm complex
7	island	PiRu	10.1		>200	
7	island	PiRu	11		>200	
7	island	PiRu		1.5	42	
7	island	AcRu		0.3	16	
8	island	AcRu	5.3		>200	hummm complex
8	island	PiRu	6.8		>200	
8	island	PiRu	4.6		>200	
8	island	PiRu	3.7		>200	
8	island	PiRu	27		adult	
8	island	PiRu		1.4	40	
8	island	PiRu	12.8		adult	
8	island	PiRu	11.4		>200	
8	island	PiRu	1.4		175	
9	island	PiRu	18		adult	hummm complex
9	island	PiRu	9.2		>200	
9	island	PiRu	8.3		>200	
9	island	PiRu	11.1		>200	
9	island	PiRu	7.9		>200	
9	island	PiRu	10.6		>200	
9	island	PiRu	4.2		103	
10	island	PiRu	22.5		adult	hummm complex
10	island	AcRu	4.4		>200	
10	island	PiRu	3.9		>200	
10	island	PiRu		3.2	132	
10	island	AcRu		0.2	17	
11	island	PiRu	2.9		>200	hummm complex
11	island	PiRu	11.9		>200	
11	island	PiRu	9.2		>200	
11	island	PiRu	1.9		190	
11	island	PiRu	18.5		adult	
11	island	PiRu	11.8		>200	
11	island	AcRu		0.4	25	
11	island	PiRu	3.8		>200	
11	island	PiRu	15.6		adult	
11	island	PiRu	3.2		>200	
11	island	PiRu	4.7		>200	

11	island	AcRu		0.4	39	
12	island	PiRu	14.5		adult	hummm complex
12	island	PiRu	17.7		adult	
12	island	AcRu	3.2		>200	
12	island	PiRu	10.1		adult	
12	island	PiRu	18.1		adult	
12	island	PiRu		1.5	64	
12	island	PiRu		1	31	
12	island	PiRu		0.8	21	
13	no trees					
14	no trees					
15	island	PiRu	16.5		adult	hummm complex
15	island	PiRu	3		>200	
15	island	PiRu		0.8	20	
15	island	PiRu		0.5	14	
15	island	PiRu		0.5	22	
15	island	PiRu		0.9	33	
15	island	PiRu		2.4	130	
15	indv	AcRu		0.2	10	hollow
15	island	PiRu	14.3		adult	hummm complex
15	island	PiRu	7.9		>200	
15	island	PiRu	6.8		>200	
15	island	AcRu		0.5	54	
15	island	PiRu		0.3	17	
15	island	PiRu		0.9	26	
15	island	AcRu		0.4	31	
15	island	PiRu		1.4	35	
15	island	PiRu		0.3	11	
16	indv	PiRu	13.2		adult	hummm
16	indv	PiRu	10.7		>200	hummm complex
17	no trees					
18	no trees					
19	island	PiRu	14		>200	hummm
19	island	AcRu		0.3	17	
19	island	AcRu		0.3	18	
19	island	PiRu		0.5	10	
20	indv	PiRu	14		>200	hummm
20	indv	PiRu		0.8	29	hummm



20	island	PiRu	8		>200	hummm
20	island	PiRu		3.8	118	
20	island	PiRu		0.9	26	
21	island	PiRu	5.7		adult	hummm complex
21	island	PiRu		0.4	14	
21	island	PiRu		0.9	43	
21	island	PiRu		1.5	38	
21	island	PiRu		0.5	14	
21	island	PiRu		0.5	26	
22	no trees					
23	no trees					
24	indv	PiRu	7		>200	hummm
25	no trees					
26	no trees					
27	no trees					
28	no trees					
29	no trees					
30	no trees					
31	no trees					
32	indv	PiRu	16.6		adult	hummm
33	no trees					
34	no trees					
35	no trees					
36	no trees					
37	no trees					
38	no trees					
39	no trees					
40	no trees					