A COMPARISON OF ABOVEGROUND AND BELOWGROUND COMMUNITY SUCCESSION ALONG A PROGLACIAL CHRONOSEQUENCE IN KENAI FJORDS, ALASKA

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A COMPARISON OF ABOVEGROUND AND BELOWGROUND COMMUNITY SUCCESSION ALONG A PROGLACIAL CHRONOSEQUENCE IN KENAI FJORDS, ALASKA

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Abstract

The links among aboveground and belowground biotic communities are believed to be multiple, reciprocal, and specific, but the patterns of these interactions are not well-established in space and time. To better understand aboveground-belowground interactions, terrestrial plant and soil protozoan (testate amoeba) communities were surveyed along a proglacial chronosequence in Kenai Fjords, Alaska. Unlike many comparisons among functionally different groups, the diversity patterns and the communities' response to site variables shown in this study are remarkably similar for both plants and testate amoebae. Tight correlations between these groups suggest that, contrary to traditional successional theory, biotic interactions may influence ecosystem development more than changes in abiotic site conditions. The apparent importance of interactions between aboveground and belowground biota in this boreal-maritime ecosystem highlights the controlling role of soil organisms in ecosystem development and supports the correlation of diversity patterns for different groups across extended spatial and temporal gradients.

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Dedication Page

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1. An introduction to community interactions in developing ecosystems and the Kenai Fjords study system

Understanding how functionally different communities are linked within ecosystems presents a major challenge in ecology. Unraveling linkages between species groups is particularly germane to conservation efforts as the accurate and consistent prediction of the diversity patterns of a threatened or endangered species based on the distribution of a more easily-surveyed taxonomic group would facilitate the identification of biological hotspots and would thereby enable more efficient conservation. Intra-specific diversity correlations are thought to exist where the survey group directly controls the status of the species of concern, the species of concern directly controls the status of the survey group, or where both groups are dependent on the same control factor. Unfortunately, diversities of terrestrial groups have not proved to be consistently correlated (Vessby et. al. 2002, Prendergast et. al. 1993) and where groups are correlated, change in diversity relationships are difficult to predict with changes in space and time (Loreau et. al. 2001). Recent work (Wardle et. al. 2004a) suggests that biotic interactions between aboveground and belowground communities may have greater influence on the development of ecosystems than previously recognized and is thus an ecological linkage meriting further research. Because our knowledge of soil organism ecology is sparse and the effect of scale on their interactions with aboveground communities is not well-understood, the comparative analysis of aboveground and belowground biota across a landscape-scale gradient provides an excellent system in which to improve our understanding of this fundamental aspect of ecology. Towards this end, this thesis documents the primary successional patterns of terrestrial plants and a group of soil protists (testate amoebae) along a proglacial chronosequence in Southcentral Alaska.

General theories of primary succession and mechanisms of interaction between aboveground and belowground biotic communities are discussed, the study system is introduced, and research objectives and hypotheses are presented in Chapter 1. The findings of this study are presented and discussed in Chapter 2, entitled “How tightly are aboveground and belowground communities linked? A comparison of primary successional patterns along a proglacial chronosequence in Kenai Fjords, Alaska”.

Patterns of primary succession

The concept of succession has long captivated ecologists as it provides a window through which interactions among individuals, species, and communities can be observed in a changing habitat.

Early theories of primary succession emphasizing a directional and predictable pathway produced by holistic interactions within an ecosystem (Clements 1916) gained considerable flexibility from challenges by proponents of probabilistic interactions between individuals, variable initial site conditions, stochastic events, and neutral models (Gleason 1926, Fastie 1995, Hubbell 2001, Whitfield 2002). Historically, successional research has focused on plant community dynamics and with this approach coarse-scale successional patterns repeated in most ecosystems have been identified. Examples of such trends with successional development include: increase in species cover and richness (Reiners et al. 1971); transition from r- to K-selected species (Chapin et al. 1994), increase in community complexity, and stability; and transition from abiotic to biotic structuring mechanisms (Odum 1969, Matthews 1992).

The reoccurrence of these patterns in geographically and compositionally disparate ecosystems suggest an underlying mechanism for their generation, although there is little agreement on what this mechanism might be (Tilman 1988). Proposed underlying mechanisms relate to the facilitating, inhibitory, or neutral effects of an established plant community by a colonizing species (Connell and Slatyer 1977); the balance between recruitment and mortality in plant populations (Peet and Christensen 1980); and the differential abilities of plant species to compete for limited resources (Tilman 1985). Failure to comprehensively explain community succession may relate to the taxonomically narrow and macroscopic focus of traditional successional studies. In an effort towards a more holistic approach to community succession, ecologists have begun to incorporate multiple taxonomic or functional biotic groups representing both aboveground and belowground communities.

In this study terrestrial plants and testate amoebae were chosen to represent the aboveground and belowground communities and were evaluated in terms of their shared habitat, ecological sensitivities and trophic linkages. Terrestrial plants and soil organisms are physically linked through the soil medium and functionally linked through their mutual and bidirectional effects on soil fertility. Through the “microbial loop” plant communities contribute resources to soil decomposers as litterfall, root exfoliates, and root exudates and in return, soil organisms promote plant growth by converting the minerals immobilized in plant biomass to forms readily assimilated by plant roots (Figure 1.1, Clarholm 1985). In forest soils, testate amoebae are the primary grazers of bacteria and are also the greatest contributors to the mineralization of N and C in the soil (Schröter et al. 2003).

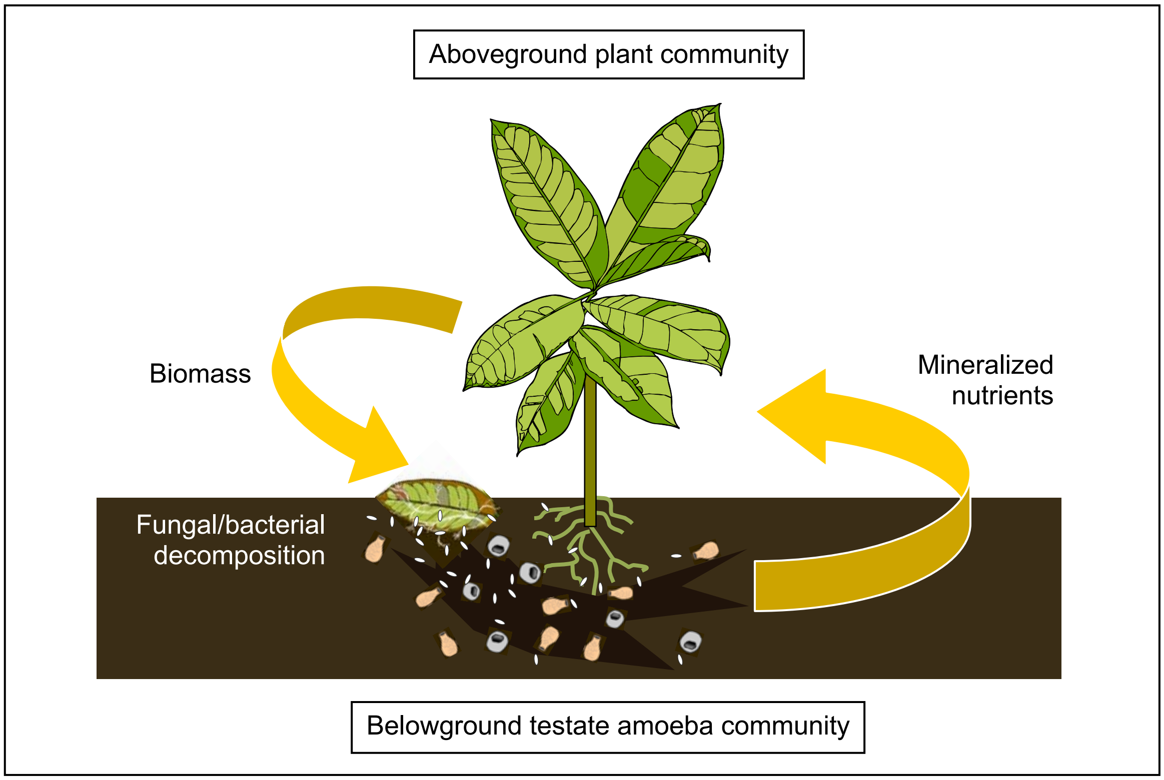


Figure 1.1: Schematic drawing of the microbial loop

Both plants and testate amoebae can be used to indicate environmental character. The species composition of plant communities changes in response to local climate, aspect, exposure, drainage pattern, and soil development. In the context of primary succession, the species diversity, biomass, and structural and functional complexity of plant communities typically increase with time (Matthews 1992). In the boreal-maritime ecoregion, small, short-lived, r-selected, herbaceous species are associated with exposed, dry, and mineral substrates, whereas larger, long-lived, K-selected, woody species are associated with protected, moist, and organic substrates (Chapin et al. 1994).

Both the species composition of testate amoeba communities and the morphology of testate amoeba individuals respond to changes in environmental conditions, with community composition as the more sensitive indicator of environmental conditions (Booth 2001). The occurrence and activity of testate amoebae is ecologically sorted by soil pore space structure plus the nature and availability of water. Terrestrial testate amoeba species with morphologic traits similar to their aquatic ancestors are more common in wet habitats, whereas derived species with traits that retard desiccation or facilitate encystment are more common in dry habitats or habitats where the availability of water fluctuates (Foissner 1987). Because these traits are often taxon-specific, predictable assemblages of testate amoeba species form in accordance with the soil moisture and structural conditions of a given habitat. Short generation times (days) allow testate amoebae to respond quickly to changing conditions and their small size and sessile nature makes population-level responses highly location specific (Griffiths 2001). Empty tests degrade within weeks in aerated litter and soil, thereby eliminating the ecological noise created by the presence of residual tests that no longer reflect current site conditions (Lousier and Parkinson 1981). On this basis, community compositions can be used as a spatially and temporally sensitive indicator of belowground condition and in sequence can be used to reconstruct the paleoecology of a given site (Mitchell et al. 1999, Booth 2002). The phenotypic morphology of individual terrestrial testate amoebae is also influenced by soil condition; individuals generally increase the size of their tests in the presence of abundant soil moisture and larger pore spaces (Foissner 1987) and species-specific changes in phenotype morphology are influenced by the type and availability of food and raw materials for test construction (Wanner 1999).

Introduction to testate amoebae

Testate amoebae are small (10-500 µm), single-celled eukaryotes that produce a persistent shell (test) that is diagnostic to the species level (Figure 1.2). Terrestrial species are able to survive in any moist environment but are most common in wet soil and freshwater sediment with highest abundance in the top 5-10 cm of soil (Heal 1962, Mitchell et al. 2000a, Vincke et al. 2006). Most genera of terrestrial testate amoebae are able to survive temporary water stress by reducing their cytoplasm volume and closing their aperture (mouth opening) with a membrane to which detritus is added externally (Foissner 1987). Due to their ubiquitous and random dispersal, species smaller than 150 µm are thought to have a cosmopolitan distribution (Finlay et al. 2001, Wilkinson 2001). However, geographic distributions may be artificially enlarged by the lumping of taxa or restricted where poor habitat connectivity limits dispersal (Mitchell and Meisterfeld 2005). Collectively, testate amoebae are comprised of at least two divisions differentiated by pseudopod morphology. Order Euglyphida is characterized by filose pseudopodia, whereas order Arcellinida is characterized by lobose pseudopodia. The number and membership of these divisions is rooted in morphology; however, molecular analysis will continue to present phylogenic revisions (see Wylezich et al. 2002, Nikolaev et al. 2005, Lara et al. 2007 for recent developments).

The morphology and composition of the test provides the basis of species identification using light microscopy. Tests are typically single chambered with one opening (aperture) through which pseudopodia are extended for locomotion and feeding. Test composition can be agglutinate, proteinaceous, siliceous or calcareous. Agglutinate tests are constructed by the addition of organic or mineral material (xenosomes) to a protein matrix. Proteinaceous tests are constructed by the secretion of a continuous layer or discrete blocks of protein. Siliceous tests are composed of plates (idosomes) glued together with organic cement, that are either manufactured by the amoebae or recycled from ingested testate amoebae. Calcareous tests are uncommon and are composed of a thin outer organic layer underlain by a thick inner layer of amorphous calcium phosphate (Ogden and Hedley 1980).

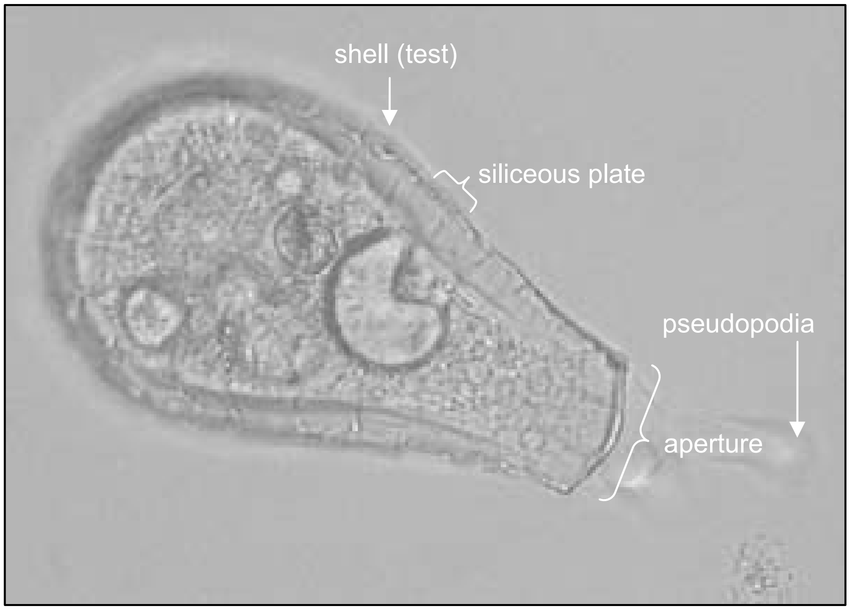


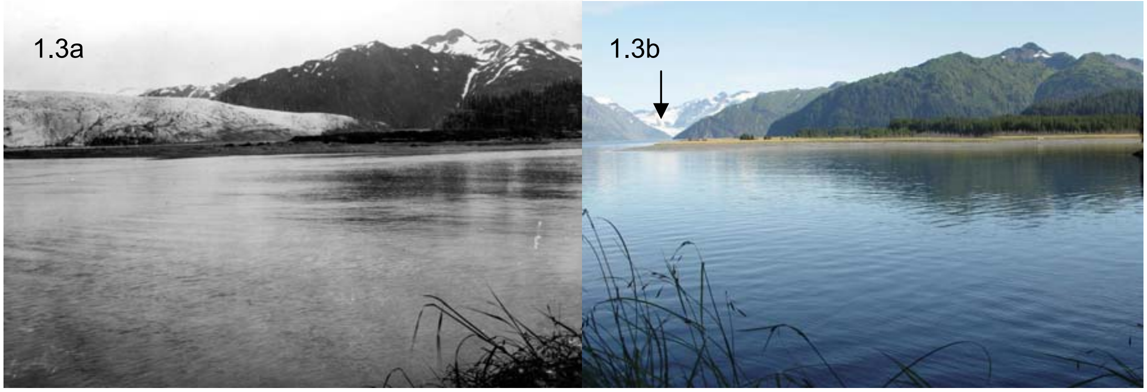
Figure 1.2: Image of *Quadrulella symmetrica* (Order Arcellinida) taken under phase contrast using light microscopy

Functional importance of testate amoebae

Testate amoebae are predominately heterotrophic (some mixotrophic species host endosymbiotic algae) and represent the primary grazers of bacteria in terrestrial communities. They are the dominant protozoan group in coniferous forest soils, and among these groups, are the greatest contributors to the mineralization of C and N (Schröter et al. 2003). Because grazing stimulates bacteria turnover, the feeding activity of testate amoebae results in greater mineralization of nutrients and consequently greater plant productivity. This soil microbe-plant interaction may be more specific than initially thought; recent evidence shows that protozoa selectively consume bacteria that produce root-growth hormones. In this way the feeding activity of testate amoebae may promote plant growth by increasing lateral root production which allows the plant to more efficiently harvest soil resources (Bonkowski and Brandt 2002).

Study system

Kenai Fjords is a dynamic glacial landscape located in the boreal-maritime ecoregion of Southcentral Alaska. The Harding Icefield mantels much of the region and feeds multiple distributary glaciers, many of which terminate at tidewater. In the period postdating the Little Ice Age (LIA) maxima (*ca*. 1850 A.D.) most tidewater glaciers in Kenai Fjords have receded (Wiles and Calkin 1994). The most impressive example of glacial recession is the 20 km retreat of the McCarty Glacier over the 55 year period following 1905 (Figure 1.3, Wiles and Calkin 1993).



Figures 1.3a and 1.3b: Repeat photography of the McCarty Glacier, Kenai Fjords, Alaska. Figure 1.3a: Terminus of the McCarty Glacier in 1909 (Grant and Higgins 1913) and Figure 1.3b: terminus of the McCarty Glacier in 2004 (Molnia 2004).

The McCarty Fjord chronosequence was selected as the location for this study for its consistent topography, well-established glacial history, and remote location that reduces the potential for anthropogenic disturbance. The linearity of the fjord minimizes variation in aspect, and steep continuous sidewalls minimize the disturbance effects associated with side valley and hanging glaciers. The terrains exposed by the recession of the McCarty Glacier have been dated by a combination of bathymetry (Post 1980), historic aerial photography *ca.* 1950, 1984, 2000 (Crowell and Mann 1995, Environmental Systems Research Institute 1998, National Park Service 2002) and dendrochronology (this study, Appendix IV) and thus comprise a study system with good chronological control from which patterns of primary succession can be inferred.

The recessional history of the McCarty glacier and sampling locations used in this study are presented in Figure 1.4. Sites located outside the range of the LIA maxima (beyond the 1860 moraine) were considered to represent equivalent successional stages as these sites have had sufficient time to recover since the last glacial maximum, 10500 ybp (Harris et al. 1997) and thus intersite differences likely relate more to local environmental conditions than terrain age.

McCarty Fjord has two environmental gradients that parallel the path of glacial recession; maritime influence increases with distance from the glacier front and there is a change in bedrock type coincident with the terminal moraine formed between 1860 and 1905. These gradients complicate our ability to separate the influence of site age from local climate and parent material on the assembly of plant and testate amoeba communities. It is also worth mentioning that sites are located on either side of the fjord, possibly allowing aspect to confound analysis of community development. However, this study did not identify site aspect as a significant influence on plant or testate amoeba community composition when tested in non-metric multidimensional scaling (NMS).

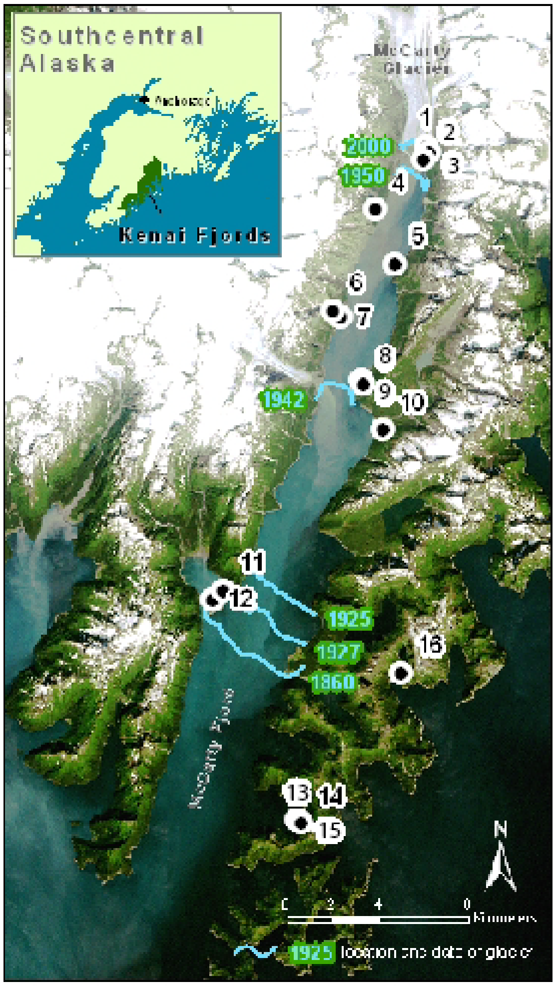


Figure 1.4: Map of the McCarty Fjord chronosequence, Kenai Fjords, Alaska, showing sampling locations and historical glacier positions.

Climate

Kenai Fjords has a wet, maritime climate with cool, rainy summers and mild, snowy winters. Aleutian atmospheric low-pressure centers cause counter-clockwise air circulation over the Gulf of Alaska that imports voluminous amounts of precipitation as snow, rain and fog to the outer Kenai Fjords coast. The mean annual temperature in Seward is 4.6 °C, while the mean annual precipitation is 182.42 cm (average of monthly normals 1971-2000, National Climatic Data Center).

Geologic history

The geology of Kenai Fjords is principally structured by the subduction of the Pacific plate beneath the North American plate along the Aleutian Trench. Kenai Fjords is located on the exposed edge of the North American Plate, which has been deformed by the varied forces active at a consumptive plate margin. Compression has thrust the geologic backbone of Kenai Fjords, the coastal Kenai Mountains, approximately 1,800 m skyward while downwarping has produced the region's characteristic sunken coastline replete with drowned cirques and deep fjords (Hamilton and Nelson 1989). Subduction-induced subsidence has dropped the landscape an estimated 100 m since the Wisconsin glaciation (Wiles and Calkin 1990).

Tectonic releases along the Aleutian Trench produce earthquakes of moderate frequency and occasionally high intensity (Haeusser and Plafker 1995). The 9.2-magnitude Good Friday Earthquake dropped the Kenai Fjords region approximately 2 m in 1964 (Plafker 1969). Dead coastal forests killed by salt water inundation after this earthquake stand testament to the power of this tectonic event. Post-seismic tectonic uplift raised the Kenai Fjords coast between 20 and 40 cm between 1964 and 1995 (Cohen and Freymueller, 1997, 2001). This rate of uplift far exceeds the 1.8 mm/yr rate of the eustatic (global) sea-level rise (Pendelton et al. 2006) and results in a positive net rate of rise for the Kenai Fjords landmass.

The dominant lithologies present in Kenai Fjords are, listed from oldest to youngest: 1) the Mesozoic era McHugh Complex; 2) the Upper Cretaceous period Valdez group; and 3) the Tertiary period granitic intrusives (Tysdal and Case 1979, Bradley et al. 1999). The McHugh Complex is a mélange of siltstone, sandstone, conglomerate, tuff, pillow basalt, chert, limestone and argillite that has been deformed by subduction activity. This unit is exposed at the surface in small outcrops around Nuka Bay. The Valdez group forms the dominant lithology in Kenai Fjords and was created by the accretion of an exotic terrane to the North American Plate in the early Tertiary. This group is a flysch comprised of thinly-bedded marine sandstones, siltstones, mudstones and pebble conglomerates that have been intensely folded and regionally metamorphosed by the stresses produced by accretion, partial subduction and subsequent faulting of the terrane. Granitic intrusives were emplaced under the Harding Icefield as a large batholith and associated plutons and felsic dikes in the mid-Tertiary. The batholith is expressed at the surface as the Aialik and Harris Peninsulas and several near-shore islands in the northeastern Kenai Fjords region (Harris et al. 1997).

Glacial history

Kenai Fjords is a landscape sculpted by ice. The region has experienced multiple glaciations in both the Pleistocene and Holocene epochs. The last Pleistocene maximum (10500 ybp) is delineated by the modern 90 m depth contour on the ocean bottom off shore from the Kenai Fjords coast. This late Wisconsin ice was estimated to be 900 m thick and would have obscured much of the Kenai Fjords landscape (Harris et al. 1997). The Kenai Fjords region experienced three major intervals of glacial expansion in the late Holocene. Advances occurred 3600 ybp, in 600 A.D. and during the Little Ice Age from 1300 to 1850 A.D.

General methodology

Plant and testate amoeba communities were surveyed on terrains of known age along the McCarty Fjord chronosequence. The plant community was quantified following a modification of the Braun-Blanquet technique of vegetation analysis (Braun-Blanquet 1932). The testate amoeba community was quantified from soil suspensions by the direct counting of morphospecies under light microscopy. Site variables were measured and soil physical and chemical character was quantified for each of the 16 sampling locations. Plant and testate amoeba communities were defined by cluster analysis and characterized using indicator species analysis. The assembly of plant and testate amoeba communities was compared using standard measures of diversity, correlation and similarity. The influence of site variables on community succession was estimated using multivariate techniques.

Objectives, expectations and hypotheses tested

In light of the unpredictability of diversity correlations among different functional groups, the overarching objective of this study was to determine if aboveground and belowground communities are linked during primary succession. As the first landscape-scale investigation of testate amoebae in a boreal-maritime ecosystem, a secondary objective was to extend our understanding of testate amoeba ecology and morphologic patterns across a variety of habitats. Successional change in plant and testate amoeba diversity and community composition and structure is described, the site variables that best predict this change are identified and a conceptual model of aboveground and belowground community succession from primary substrates is proposed in Chapter 2. New testate amoeba species records and changes in test morphology and test composition are presented in Appendix I. The bioindication potential of this group of protists is also evaluated in Appendix I.

With respect to aboveground-belowground successional patterns, it was expected that the diversities of plant and testate amoeba communities would increase along the chronosequence in response to greater structural complexity of the environment (Matthews 1992), and that on late-seral terrains, where presumably the frequency and specificity of species interactions are greater, successive plant or testate amoeba communities would be more similar in species composition and structure (Kowalchuck et al. 2002). It was also predicted that, due to the connection of plants and testate amoebae through the soil environment and the influence of abiotic site variables on community dynamics, succession of plant and testate amoeba communities would be best explained by site variables relating to soil development. Successional change in soil condition was also expected to select morphospecies of testate amoeba. Specific predictions were that small individuals with protected apertures would be replaced by larger individuals with exposed apertures as soil moisture and resource availability increased with successional time; and that siliceous tests would replace agglutinated mineral tests due to a successional increase in the availability of raw materials for test construction (Foissner 1987). Due to the length of the successional gradient investigated, it was also predicted that the assembly of plant and testate amoeba communities would predominantly occur by successive replacement of species (Hodkinson et al. 2004).

2. How tightly are aboveground and belowground communities linked? A comparison of primary successional patterns along a proglacial chronosequence in Kenai Fjords, Alaska

Abstract

The links among aboveground and belowground biotic communities are well understood to be multiple, reciprocal and specific (Wardle et al. 2004a), but the patterns of community interaction are not well-established in space and time (van der Putten 2005). To gain a better understanding of the links between aboveground and belowground communities and to determine the consistency of community assembly patterns across scales and between functional groups, terrestrial plant and soil protozoan (testate amoeba) communities were surveyed along a proglacial chronosequence located in Kenai Fjords, Alaska. It was found that the assembly patterns of plant and testate amoeba communities are remarkably similar. The diversity of both communities increases rapidly on recently deglaciated terrains then stabilizes across older terrains. Terrain age, soil development, and mesotopography influence the composition and structure of both plant and testate amoeba communities across the chronosequence. However, the correlations between biotic (plant and testate amoeba) community structures are generally stronger and more significant than correlations between biotic communities and abiotic site variables. The tighter correlation between plant and testate amoeba community development relative to the couplings between either of these groups and measures of site condition suggest that interactions between aboveground and belowground biota are more important than change in site condition to ecosystem development in this system. If future studies in diverse ecosystems corroborate the present findings, it may force reconsideration of the importance of macro-scale, abiotic site complexity in traditional successional theory.

Introduction

Understanding interactions among communities is a major challenge in ecology. Diversity patterns of different terrestrial groups are often not correlated or tend to decouple when extended across broader gradients of space or time (Prendergast et al. 1993, Scheu and Schultz 1996, Vessby et al. 2002, de Deyn and van der Putten 2005). The lack of diversity correlations among functionally different communities at local scales is somewhat surprising considering that diversity patterns are well-established at global scales. At the global scale, species richness tends to decrease with increasing elevation and latitude (von Humboldt 1849), community diversity is generally reduced by competitive interactions between species and by constraints of their environment (Diamond 1975, Keddy 1992), and may be variably influenced by facilitation, tolerance, and inhibition mechanisms (Connell and Slayter 1977) in the context of resource availability (Tilman 1985). The reoccurrence of these successional patterns in geographically and compositionally disparate ecosystems suggests that an underlying mechanism is present, yet there is little consensus on what this mechanism might be (Tilman 1988).

Traditional ecological theory proposes that abiotic conditions drive species diversity and in turn species diversity drives ecosystem function. However, recent work indicates that biotic interactions, specifically those linking aboveground and belowground communities, may have a greater influence on the development of ecosystems than previously recognized (Wardle et al. 2004a). Failure to comprehensively explain the generation of aboveground successional patterns has expanded the traditionally narrow and macroscopic focus of successional investigations to include belowground communities.

The difficulty of visualizing the *in situ* soil environment and of replicating its complexity under experimental conditions, coupled to our incomplete taxonomic knowledge of soil organisms (Atlas and Bartha 1998, Young and Crawford 2004), limits our understanding of the primary successional patterns of micro- and mesofaunal groups and the interactions of these groups with aboveground biota. Despite the general ambiguity of successional patterns of soil organisms, some trends have been recognized. For example, primary substrates are frequently colonized by a heterotrophic community that is delivered from remote locations, and survives on the allochthonous input of live and dead organic material. Such communities precede and facilitate the establishment of pioneer plant species (Edwards and Sugg 1993, Kaufmann 2001, Hodkinson et al. 2002). Following this initial heterotrophic phase, it is generally accepted that the abundance, activity, and diversity of pioneer communities increases with successional age and that this change is largely mediated by the functional diversity of the plant community (Jumpponen et al. 2002, Ledeganck et al. 2003, Zak et al. 2003, de Deyn et al. 2004). Correlations between terrestrial plants and soil organisms should be particularly tight as the two groups are intimately connected through the soil environment and because lower trophic groups are typically more responsive to change in environmental condition. The evidence for lower trophic responsiveness, however, is mixed (de Deyn et al. 2004, Bardgett 2005). Plants and soil organisms interact via direct and indirect pathways. The activity of root herbivores, root pathogens and symbionts directly affect plant communities, whereas members of the belowground decomposer system, including testate amoebae, indirectly affect plant communities through their influence on soil fertility, chemistry, and physical structure. How these interactions play out over time is largely dependant on the type and specificity of the interaction, the relative abundances of the organisms involved, and initial site conditions (Al-Mufti et al. 1977, Reynolds et al. 2003, van der Putten 2005).

Terrestrial plants are linked to decomposing soil organisms via the “microbial loop”. Through this loop plant communities contribute resources to belowground organisms as litterfall and rhizodeposition (root exfoliates and exudates). In return, belowground organisms promote plant growth by converting the minerals immobilized in plant biomass and soil organic matter to chemical forms that plant roots are able to assimilate (Clarholm 1985). Plant diversity theoretically controls the diversity of decomposer organisms through biomass inputs that vary in quantity, quality and structure; whereas the diversity of the decomposer community controls plant diversity by providing a variety of mineralized nutrients that are differentially useful to and thus partitioned among the plant community (Hooper et al. 2000, Reynolds et al. 2003, Harrison et al. 2007). The magnitude of the influence soil decomposers have on plant community composition can be moderated by the initial site conditions. Mineralization of plant biomass in infertile soils tends to increase plant community richness, but depresses plant richness in fertile soils (van der Putten 2005).

Testate amoebae were chosen to represent the belowground soil community in this study on the basis of their functional importance, ecological sensitivity, ubiquity, and ease of sampling. Testate amoebae are the primary grazers of bacteria in terrestrial communities. In coniferous forest soils they are identified as the dominant protozoan group and the greatest contributors to the mineralization of N and C (Schröter et al. 2003). Through grazing, testate amoebae return nutrients to the plant community; depending on the specificity of grazing activity, they may stimulate the release of root-growth hormones (Bonkowski and Brandt 2002). The tight ecological niches of most testate amoeba species produce a well-partitioned sequence of communities across spatial and temporal gradients. Specifically, testate amoebae have proved useful indicators of habitat, soil type, disturbance (Foissner 1987), and paleoclimate (Mitchell et al. 1999, Booth 2002) since their occurrence and activity are chiefly governed by soil pore space structure and the nature and availability of water. Short generation times (days) allow testate amoebae to respond quickly to changing microsite conditions; their small size (10-500 μm) and sessile nature makes population-level responses highly location specific. Testate amoebae are able to survive in any periodically moist environment but are most abundant in wet soils and freshwater sediments. The persistent test produced by testate amoebae (Figure 1.2) is well-preserved in dry soil or fossil peat and test morphology can be used to identify species in soil suspensions using light microscopy.

Considering the unpredictability of correlations between different functional groups across gradients of space and time, this investigation aims to describe how aboveground and belowground communities are linked in primary succession. Description of plant and testate amoeba community assembly patterns across a successional gradient provides insight to the mechanisms of aboveground-belowground interactions and the influence of these interactions on greater ecosystem condition. Successional change in terrestrial plant and testate amoeba diversity, and community structure and composition is described and the site variables that best predict this change are identified along a proglacial chronosequence in Southcentral Alaska. It was expected that the: 1) diversity of plant and testate amoeba communities would covary and the diversity would increase in concert in response to greater structural complexity of the environment along the chronosequence; 2) similarity in community structure between successive pairs of plant and testate amoeba communities would increase across late-seral terrains where presumably the frequency and specificity of species interactions are higher; and 3) successional change in plant and testate amoeba communities would be best explained by site variables relating to soil development.

Materials and methods

Study Area

Successional change can be described from the long-term monitoring of a single site or inferred from a sequence of variably-aged terrains. Because successional timescales typically exceed human longevity, a chronosequence approach is often adopted as an alternative to long-term monitoring. The chronosequence approach, as applied to proglacial systems, represents a space for time substitution wherein distance from the front of a receding glacier is correlated to time since deglaciation. Although spatial and temporal variations in local conditions along a proglacial chronosequence preclude the exact reconstruction or prediction of successional pathways, this technique provides the best short-term approximation (Matthews 1992).

This investigation uses the McCarty Fjord proglacial chronosequence in the Kenai Fjords region of Alaska to infer primary successional processes. Kenai Fjords is a dynamic glacial landscape located in the Northern Pacific maritime ecoregion of Southcentral Alaska (Figure 1.4). In the period postdating the LIA maximum (*ca.* 1850 A.D.) most tidewater glaciers in Kenai Fjords receded dramatically (Wiles and Calkin 1994). The most impressive example of this glacial recession is the 20 km retreat of the McCarty Glacier over the 55 year period following 1905 (Wiles and Calkin 1993). The terrains exposed by this recession have been dated by a combination of bathymetry (Post 1980), historic aerial photography *ca.* 1950, 1984, and 2000

(Crowell and Mann 1995, Environmental Systems Research Institute 1998, National Park Service 2002), and dendrochronology (see Appendix IV); all comprise a study system with good chronological control across which patterns of primary succession can be investigated.

Site Selection

Sites for vegetation and testate amoeba characterization were located to capture the variety of plant community types developing on differently aged terrains along the McCarty Fjord. Young terrains located close to the glacier are barren or sparsely vegetated. With increasing distance from the glacier the plant community transitions from *Alnus viridis* ssp. *sinuata* (Sitka alder) and *Alnus viridis* ssp. *sinuata-Salix sitchensis* (Sitka Alder-Sitka Willow) shrublands to *Picea sitchensis* (Sitka Spruce) and *Tsuga mertensiana* (Mountain Hemlock) forests, to peatlands dominated by sedge and *Sphagnum* species. A total of 16 sites were selected, 15 of which are located along the length of McCarty Fjord. An additional site was added from the adjacent Northwestern Fjord so that one of the oldest plant community types, a *Sphagnum*-dominated peatland, could be represented in the dataset. Distances from the glacier to sampling locations were measured using the digital measurement tool in ArcMap (Environmental Systems Research Institute 2006). The distance measurements for Sites 1-12 are taken from the year 2000 terminus of the McCarty Fjord glacier; Sites 13-16 have not been glaciated since recession of the Wisconsin advance (10000 ybp) and are included as reference sites without an associated distance.

Vegetation Survey

At each site all vascular and the dominant non-vascular plant species (defined as those species with foliar cover exceeding 10%) growing in a 10 by 10 m plot were identified. Percent covers for plant species and types of unvegetated groundcover (*e.g.* gravel, cobble) were estimated for each plot (See Appendix X for a complete list of site variables). Where multiple vegetation strata were present, total foliar cover often exceed 100%. The soil profile was described from a shallow pit (30 cm maximum depth) dug at each site. Soil samples were collected at each site for testate amoeba survey and for physical and chemical analysis. Site soil samples were aggregated from three subsample locations that were located within the dominant groundcover and at a minimum separation distance of 2 m at each site. At each subsample location the top 10 cm of soil was collected using a push hand auger. At sites with co-dominant groundcover types, three subsamples were collected from each groundcover type for a total of two aggregate samples per site. The fine fraction (<0.075 mm minimum diameter) of each soil sample was analyzed for pH from a 1:1 slurry preparation, total organic C and total N using combustion analysis, and available nitrogen (NH_4^+, NO_3^-), Na, Mg, P, K, Ca, Mn, Fe, Cu, and Zn by inductively coupled plasma emission spectroscopy. Field work was conducted in July and August 2005; soil analysis and the testate amoeba survey was completed in 2006.

Testate Amoeba Survey

Samples were prepared for testate amoeba survey following a modification of the stepwise filtration method of Hendon and Charman (1997). Air dried samples were shaken with 40 ml of deionized water for one minute. The soil solution was then sequentially washed twice through a 300 µm nylon mesh filter, once each through 100 and 20 µm filters, and finally back-washed through a 10 µm filter. The 10-100 µm fraction was retained for analysis and allowed to settle for 24 h after which the surface water was decanted. Sediment was pipetted from the settling containers to 1 ml, capped eppendorf tubes. After a second settling period of approximately 0.5 h any remaining water was pipetted from the tube and a volume of anhydrous glycerol approximately equal to the volume of sediment was added both to prevent microbial growth and to act as mounting media for slide preparation. The tube contents were mixed and added drop-wise to a glass microscope slide. The ratio of glycerol to sample was adjusted for samples that were especially dense or sparse with respect to soil particles.

Testate amoebae were enumerated by direct counting. Slides were surveyed for testate amoebae in grid fashion using light microscopy at 400x magnification under phase contrast. One or more slide(s) were systematically scanned for a standardized total of six hours of survey effort. Species were identified in accordance with keys developed by Thomas (1958), Odgen and Hedley (1980), Ogden (1983), Meisterfeld (2000a, 2000b), and Mitchell (2003a, 2003b, 2003c, 2003d, 2003e).

Numerical Analysis

Taxonomic ranks were assigned at the species level for vascular plants unless the subspecies was the only representative of the species or genus in the dataset. Non-vascular plant species were classified as peat mosses (genus *Sphagnum*), true mosses (all other bryophyte genera), lichen or fungi. Bedrock type was inferred from the Geologic Maps of the Seldovia, Seward, and Blying Sound Quadrangles (Tysdall and Case 1979, Bradley et al. 1999). The following plots, site variables and species abundances had values greater than two standard deviations from the sample mean were considered outliers: Site 1 (based on the absence of plant and testate amoeba species), Site 3 (based on site variable values), and Site 6 (based on the high abundance [148 individuals] and richness [21 species] of testate amoebae); the percent groundcover of sand and bedrock (based on anomalously high cover on young and old terrains, respectively); and the plant species *Agrostis aequivalvis, Erigeron peregrinus, Geum calthifolium,* and *Gentiana douglasiana* (based on anomalously high cover on older terrains). Due to the paucity of species data, Site 1 was not included in cluster, non-metric multidimensional scaling (NMS), Mantel or moving window analyses. Similarly, the percent groundcover of sand and bedrock for all sites were not included in NMS analysis. Otherwise, outlying plots, site variables, and species abundances were included in analyses to capture the natural range of variation in the dataset.

Plant and testate amoeba community types were delineated by both unconstrained and chronologically constrained cluster analysis. Unconstrained cluster analysis groups sites on the basis of species type and abundance and was performed using a group average linkage method and Sørenson distance measure. The group average method is a hierarchical, agglomerative clustering algorithm that associates sites based on their mean abundance values for each species. The Sørenson distance (dissimilarity) measure is a proportional coefficient that expresses city block (orthogonal) distance as a proportion of the maximum distance possible between two sites. Because this distance measure is expressed as a proportion, it does not return zero values and in this way circumvents our inability to assess how unfavorable an environment may be for a species when the species is not present (McCune and Grace 2002). Unconstrained community types were delineated from the dendrograms produced at a cut level where approximately 30% information remained. Plant communities were named after structurally dominant species, whereas testate amoeba communities were named after the species that best indicated their cluster. Indicator values were calculated for species following the method of Dufrene and Legendre (1997). Indicator species were then selected for their significant p values ($p < 0.05$) and high indicator values. Unconstrained cluster and indicator species analyses were performed using the multivariate software application, PC-ORD (McCune and Mefford 1999).

Chronologically constrained cluster analysis is used to identify disjunctions in community composition along an ecological gradient, such as the McCarty Fjord chronosequence. Probability describes the likelihood that a cluster represents a distinct community. Connectedness describes the level of similarity required for a site to be included in a sample. Both levels of probability and connectedness can the varied in the analysis. For present purposes, sites were held (constrained) in successional order and distinct communities were identified along the chronosequence based on species type and abundance. Significant breaks in community continuity are based on significant dissimilarity between chronologically adjacent sites. Chronologically constrained cluster analysis was performed using R Package (Casgrain and Legendre 2006).

Plant and testate amoeba species occurrences across the chronosequence are presented in diagonalized matrixes produced by the software program WellPlot (Zippi 2003). To consider a meaningful number of species (63), plant species occurring at a frequency less than 1 or at trace foliar cover (<1%) were not included in this output. All testate amoeba species (58) were included in diagonalized matrixes because their communities are comparatively species poor. Both plant and testate amoeba species are ordered by first appearance in the chronosequence and secondarily by their relative persistence across the chronosequence. For example, species occurring early in the chronosequence and across few sites would be listed before a species occurring over several sites late in the chronosequence.

Both plant and testate amoeba species diversity was quantified using Shannon's index. This index was selected for its ability to discriminate between similar sites, its low sensitivity to sample size, and its wide use in community ecology literature (Magurran 2004). The Shannon index is calculated by the following equation:

$$H = - \sum p_i \ln p_i$$

Where p_i is the abundance of the $i^{\underline{th}}$ species and ln is the natural log. Beta diversities were calculated as the product of mean alpha diversity (the average number of species across all samples) and gamma diversity (the total number of species in the dataset). Species evenness was calculated as:

$$E = H / \ln (S)$$

Where H is Shannon's diversity and ln (S) is the natural log of species richness. Species richness is simply the number of species recorded for a given site. Plant species cover was recorded as the sum of foliar cover for each individual species at a site. Testate amoeba abundance was recorded as the total number of individuals observed in a sample over 6 hours of microscopic survey. Plant covers and testate amoeba abundances were relativized to a proportion of 1 to facilitate comparison by linear correlation analysis. Species diversity and evenness measures were calculated using PC-ORD. Plant and testate amoeba diversity, richness, evenness, cover/abundance and distance from the glacier were compared using the linear correlation function in SPSS (2004). Slopes of linear equations were compared by computing the test statistic by the following formula (Zar 1996):

$$t = (b_1 - b_2)/(s_{b1-b2})$$

where the regression coefficient is:

$$b = \sum xy / \sum x^2$$

with $\sum xy$ as the sum of cross products and $\sum x^2$ as the sum of squares. The difference between regression coefficients is:

$$s_{b1\text{-}b2} = \sqrt{\frac{(s^2_{Y*X})p}{(\sum x^2)_1} + \frac{(s^2_{Y*X})p}{(\sum x^2)_2}}$$

where $(s^2_{Y*X})p$ is the pooled residual mean and is calculated as:

$$(s^2_{Y*X})p = \frac{(\text{residual sum of squares})_1 + (\text{residual sum of squares})_2}{(\text{residual degrees of freedom})_1 + (\text{residual degrees of freedom})_2}$$

The Sørenson quantitative index was used to evaluate the similarity of successive sites with respect to species presence and abundance along the chronosequence. This index was chosen because it accounts for species abundance, differentiates samples well, and is not affected by the use of different measurement units (Magurran 2004). The Sørenson quantitative index is calculated by the following formula:

$$C_N = 2jN / (N_a + N_b)$$

Where N_a and N_b represent the number of individuals in communities *a* and *b*, respectively, and *jN* represents the sum of the lower of two abundances for a species present in both communities. For example, if Sitka alder was present in community *a* at 20% cover and at chronologically adjacent community *b* at 45%, then the 20% value would be included in the sum *jN*. Pairwise comparisons began with Sites 2 and 3 and ended with Sites 15 and 16. Because this index is a measure of similarity, higher values indicate greater similarity.

The structure in plant and testate amoeba communities was displayed using NMS. This analysis is particularly applicable to ecological questions since it does not assume that species are distributed normally along a gradient or that they respond linearly to change in environmental conditions (McCune and Grace 2002). NMS was run in autopilot mode in PC-ORD (McCune and Mefford 1999). The number of axes presented in the final solution was determined by the reductions in stress that inclusion of each successive axis produced. Additional axes that only minimally reduced stress were not included in the final solution. Only site vectors with an r^2 value greater than 0.200 were displayed and considered in the evaluation of organizing gradients. Graphs were scaled in proportion to the longest axis (the axis with the greatest range in ordination scores); vector lengths were not scaled. Site position and vector orientation were rotated in multivariate space as noted in the results section. Plant and testate amoeba communities, as defined by unconstrained cluster analysis, were used in ordination biplots to help visualize the successional relationships between sites and to site variables.

Simple Mantel tests were used to evaluate the structural relationships between the plant, testate amoeba and site variable matrixes. Due to the high number of zero values, plant and testate amoeba matrixes were transformed by Beals smoothing prior to Mantel test analysis. Beals smoothing replaces each species abundance value with a probability of the species occurring at a given site and in this way eliminates zero values that might otherwise create artificial similarity between two sparsely populated matrixes (McCune and Grace 2002). The site variable matrix did not contain many zeros and was therefore not transformed. Mantel test results are evaluated in terms of the standardized Mantel statistic *r* (Sokal and Rohlf 1995), which ranges from -1 to 1 and the *p* value generated using the Monte Carlo randomization test. Because the plant species cover, testate amoeba abundance, and site variables are not necessarily independent within and between matrixes, the *p* value cannot be assessed with respect to traditional certainty levels, but is instead used to indicate the relative reliabilities of the *r* value. Mantel tests were performed in PC-ORD (McCune and Mefford 1999).

Moving window analysis was performed to evaluate change in the plant, testate amoeba and site variable comparisons over successional time. Moving window techniques allow the analysis of multivariate data across a gradient and are particularly useful for the detection of sharp transitions in species composition between independent sites (Kent et al. 1997). Moving window Mantel tests were calculated from a reduced sample of ten consecutive sites (Legendre and Legendre 1998). The ten-sample window was advanced across the chronosequence one sample at a time to quantify the change significance and strength of correlations over successional time. The sample window began with Sites 2-11 and was advanced six times to end with Sites 7-16.

Results

Plant and testate amoeba communities were classified on the basis of species associations documented along the McCarty Fjord chronosequence. Both unconstrained and chronologically constrained communities are identified. Refer to Appendix VI for plant community data, Appendix VII for plant species list and cover values, Appendix IX for testate amoeba community data, and Appendix X for testate amoeba species list and abundances.

Plant Community Types

Five plant communities that generally increase in cover, stature and complexity with terrain age were identified by unconstrained cluster analysis of plant species occurrence and percent foliar cover (Figure 2.1). Plant community types are numbered in successional order and are named in general accordance with Level III of the vegetation classification developed for Alaska, by Viereck et al. (1992). Site 6 split out due to high moss cover but was regrouped with the open alder cluster (Plant Community 1) on the basis of structurally dominant vegetation. Site 9 split out due to an abundance of *Equisetum arvense* in the understory but was similarly regrouped with the alder-willow cluster (Plant Community 2) also on the basis of structurally dominant vegetation. Plant indicator species were selected for their low *p*-values, which express the probability of that species occurring within a community by chance ($p \leq 0.05$), and high indicator values (Table 2.1).

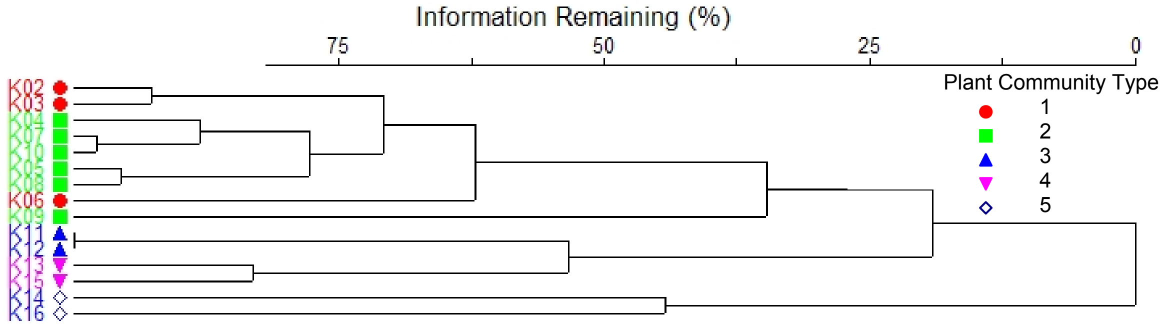


Figure 2.1: Unconstrained cluster dendrogram delineating plant community types along the McCarty Fjord chronosequence, Kenai Fjords, Alaska.

Plant community type	Indicator species	Indicator value	*p* value
1) Open Alder	*Chamerion latifolium*	100.0	0.005
	Alnus viridis ssp. *sinuata*	50.2	0.015
2) Closed tall alder-willow	*Salix sitchensis*	87.9	0.001
	Calamagrostis canadensis	73.8	0.002
	Equisetum arvense	78.0	0.036
3) Closed spruce	*Picea sitchensis*	88.9	0.030
4) Open hemlock	*Cornus canadensis*	100.0	0.045
	Lycopodium annotinum	100.0	0.045
	Menziesia ferruginea	100.0	0.045
	Veratrum viride	100.0	0.045
	Tsuga mertensiana	95.8	0.050
5) Wetland	Lichen species	93.7	0.013
	Andromeda polifolia	100.0	0.030
	Carex stylosa	100.0	0.030
	Drosera rotundifolia	100.0	0.030
	Gentiana platypetala	100.0	0.030
	Loiseleuria procumbens	100.0	0.030
	Selaginella selaginoides	100.0	0.030
	Spiranthes romanzoffiana	100.0	0.030
	Trichophorum caespitosum	100.0	0.030

Table 2.1: Indicator species and indicator and *p* values for plant community types occurring along the McCarty Fjord chronosequence, Kenai Fjords, Alaska.

0. The **Depauperate** plant community is represented by a single site (Site 1) that was not included in cluster analysis due to its low vegetative cover. The proximity of this site to the glacier (0.2 km) creates an extreme local climate where trace covers of crustose lichen species are the only representatives of the biotic community. The substrate is comprised of cobble to boulder size material underlain by remnant ice.

1. The **Open alder** community type, represented by Sites 2, 3, and 6, is characterized by 30-75% *Alnus viridis* ssp. *sinuata*, and is indicated by the presence of *Chamerion latifolium*. The plant species comprising this community typically establish in patches of organic matter that accumulate in protected sites between cobbles.

2. The **Closed tall alder-willow** community type, represented by Sites 4, 5, 7, 8, 9, and 10, is co-dominated by *Alnus viridis* ssp. *sinuata* (20-80% cover) and *Salix sitchensis* (2-30% cover), and is indicated by *Calamagrostis canadensis* and *Equisetum arvense*. *Picea*

sitchensis saplings are common on older sites of this type. A thin yet continuous organic horizon is typical.

3. The **Closed spruce** community type, represented by Sites 11 and 12, is indicated by the presence of *Picea sitchensis* (70-80% cover), and is characterized by a nearly continuous moss mat comprised of the forest mosses *Rhytidiadelphus loreus* and *Hylocomium splendens*. The depth of the organic horizon ranges from 13 to 15 cm.

4. The **Open hemlock** community type, represented by Sites 13 and 15, is characterized by *Tsuga mertensiana* (45-70% cover), and is indicated by the understory species *Lycopodium annotinum, Mensiesia ferruginea, Veratrum viride*, and *Cornus canadensis*. The thick organic horizon (25-33 cm) supports a nearly continuous moss carpet (80-90% cover) and a low shrub understory dominated by *Vaccinium ovalifolium*.

5. The **Wetland** community type is represented by the compositionally different Sites 14 and 16 established on terrains that differ in slope and depth to bedrock. Sedge fens with relatively thin organic horizons (18 cm) develop on steep (20 degree) slopes with shallow bedrock, whereas *Sphagnum* peatlands with relatively thick organic horizons (76 cm) develop on flat terrains with a greater depth to bedrock. Together these sites are characterized by over 60% cover of sedge species, 10-30% cover of *Sphagnum* species, and 15-20% cover of *Nephrophyllidium crista-galli*.

Testate Amoeba Community Types

Three testate amoeba communities were identified by unconstrained cluster analysis of species occurrence and abundance (Figure 2.2). Unlike the plant communities identified along the same chronosequence, testate amoeba communities are not successionally ordered. Community type 3 includes most (three of four) older sites. However, both Communities 1 and 2 include younger, recently deglaciated sites, indicating no correlation between community type and distance from the glacier or site age. Testate amoeba communities are named for their significant indicator species (Table 2.2). Site soil physical and chemical data are presented in Appendix IV, and a broad review of testate amoeba ecology is provided in Appendix XIV.

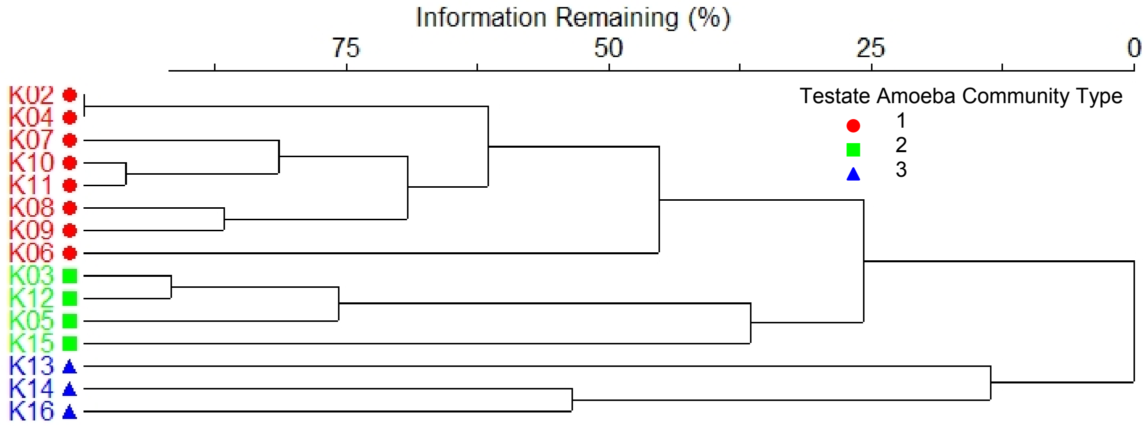


Figure 2.2: Unconstrained cluster dendrogram showing testate amoeba community types along the McCarty Fjord chronosequence, Kenai Fjords, Alaska.

Community number	Community indicator species	Indicator value	*p* value
1	*Corythion dubium*	81.8	0.007
2	*Centropyxis areophila* var. *aerophila*	78.4	0.003
	Centropyxis areophila var. *sylvatica*	76.2	0.011
	Trinema complanatum	87.5	0.015
3	*Quadrulella symmetrica*	100.0	0.004

Table 2.2: Indicator species, and indicator and *p* values for testate amoeba community types occurring along the McCarty Fjord chronosequence, Kenai Fjords, Alaska.

0. The **Depauperate** testate amoeba community is represented by a single site (Site 1) and characterized by young mineral substrate comprised of cobble to boulder size material underlain by remnant ice. The local climate is extreme due to the sites' proximity to the glacier (0.2 km). This site was not included in cluster analysis as no testate amoebae were detected.

1. The ***Corythion dubium* community,** represented by Sites 2, 4, 6, 7, 8, 9, 10, and 11, is associated with well-drained mineral soils and a diverse herbaceous understory. In addition to the presence of its indicator species, this community is characterized by high abundances of *Trinema* species (*T. lineare* and *T. complanatum*), *Phyrganella acropodia,*

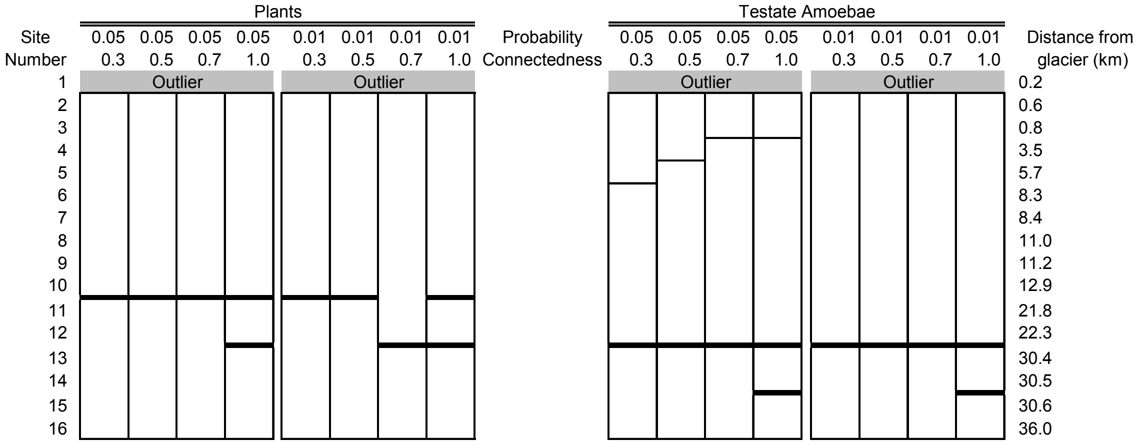
Euglypha laevis, Schoenbornia species (*S. viscicula and S. humicola*), *Centropyxis aerophila* var. *aerophila* and *Centropyxis aerophila* var*. sylvatica*.

2. The ***Centropyxis aerophila-Trinema complanatum* community** is associated with mesic organo-mineral soils and dry and forest mosses. In addition to the presence of its indicator species, this community is characterized by high abundances of *Corythion dubium, Euglypha laevis,* and *Phyrganella acropodia.*

3. The ***Quadrulella symmetrica* community** is associated with poorly-drained organic soils, *Nephrophyllidium crista-galli* understory, sedge fens, and *Sphagnum* peatlands. In addition to the presence of its indicator species, this community is characterized by high abundances of *Nebela* species (*N. parvula, N. penardiana* and *N. tubulata,* and *Argynnia dentistoma*).

Chronologically Constrained Community Types

When sites are constrained in chronological order, both plants and testate amoebae separate into two communities at all levels of connectedness and probability (Table 2.3). The break in plant community continuity occurs between Site 10, a recently deglaciated shrubland and Site 11, an older coniferous forest. The break in testate amoeba community continuity occurs between young, recently deglaciated Site 12, a Sitka spruce forest located just within the maximal extent of McCarty Glacier LIA advance and Site 13, a mountain hemlock forest located beyond the McCarty Glacier terminal moraine on unglaciated terrain. The break between Sites 12 and 13 is also seen for plants at higher levels of connectedness (0.7, 1.0). An additional break in testate amoeba community continuity is seen between coniferous forest Site 13 and sedge fen Site 14 at maximum connectedness (1.0). A weaker break, seen for testate amoebae at lower probability (0.05), shifts from Sites 3 and 4, to 4 and 5, to 5 and 6 with increasing connectedness. Site 1 is an outlier at all levels of connectedness and probability due to the paucity of plant species and the absence of testate amoeba species detected.



Site Number	Plants								Probability Connectedness	Testate Amoebae								Distance from glacier (km)
	0.05 0.3	0.05 0.5	0.05 0.7	0.05 1.0	0.01 0.3	0.01 0.5	0.01 0.7	0.01 1.0		0.05 0.3	0.05 0.5	0.05 0.7	0.05 1.0	0.01 0.3	0.01 0.5	0.01 0.7	0.01 1.0	
1	Outlier				Outlier					Outlier				Outlier				0.2
2																		0.6
3																		0.8
4																		3.5
5																		5.7
6																		8.3
7																		8.4
8																		11.0
9																		11.2
10																		12.9
11																		21.8
12																		22.3
13																		30.4
14																		30.5
15																		30.6
16																		36.0

Table 2.3: Plant and testate amoeba communities as delineated by chronologically constrained cluster analysis. Thick horizontal lines indicate a significant change in community continuity; thin horizontal lines indicate significant, yet unstable change in community continuity. Grey fill indicates an outlying site.

The breaks in community continuity indicated by chronologically constrained cluster analysis are also apparent in diagonalized matrixes (Figures 2.3 and 2.4). For both plants and testate amoebae, compositional breaks are evident between young, recently deglaciated sites (located 0.2 - 22.3 km from the glacier) and older sites that predate the LIA (located at distances greater than 22.3 km from the glacier). For testate amoebae, this break also reflects greater evenness on older terrains. A depression in plant species richness is coincident with the forested community located at 21.8 and 22.3 km from the glacier.

Both plant and testate amoeba communities are assembled by the addition of species without a commensurate loss of species across recently deglaciated terrains, whereas communities established on older reference sites have been assembled with notable species loss and replacement.

Testate amoeba species are more widely distributed across the chronosequence than plant species. Of the vascular plant and testate amoeba species included in the diagonalized matrixes, 38% of testate amoeba species occur on both pre- and post-LIA terrains compared to 23% of plant species. There is an even division of plant species with distributions restricted to either pre- or post-LIA terrains; 39% of plant species occur on recently deglaciated terrains and 38% of plant species occur on terrains that predate the LIA. Alternatively, a greater proportion of testate amoeba species are restricted to post-LIA terrains; 41% of testate amoeba species occur on recently deglaciated terrains, whereas the occurrence of only 21% of testate amoeba species are restricted to older, pre-LIA terrains.

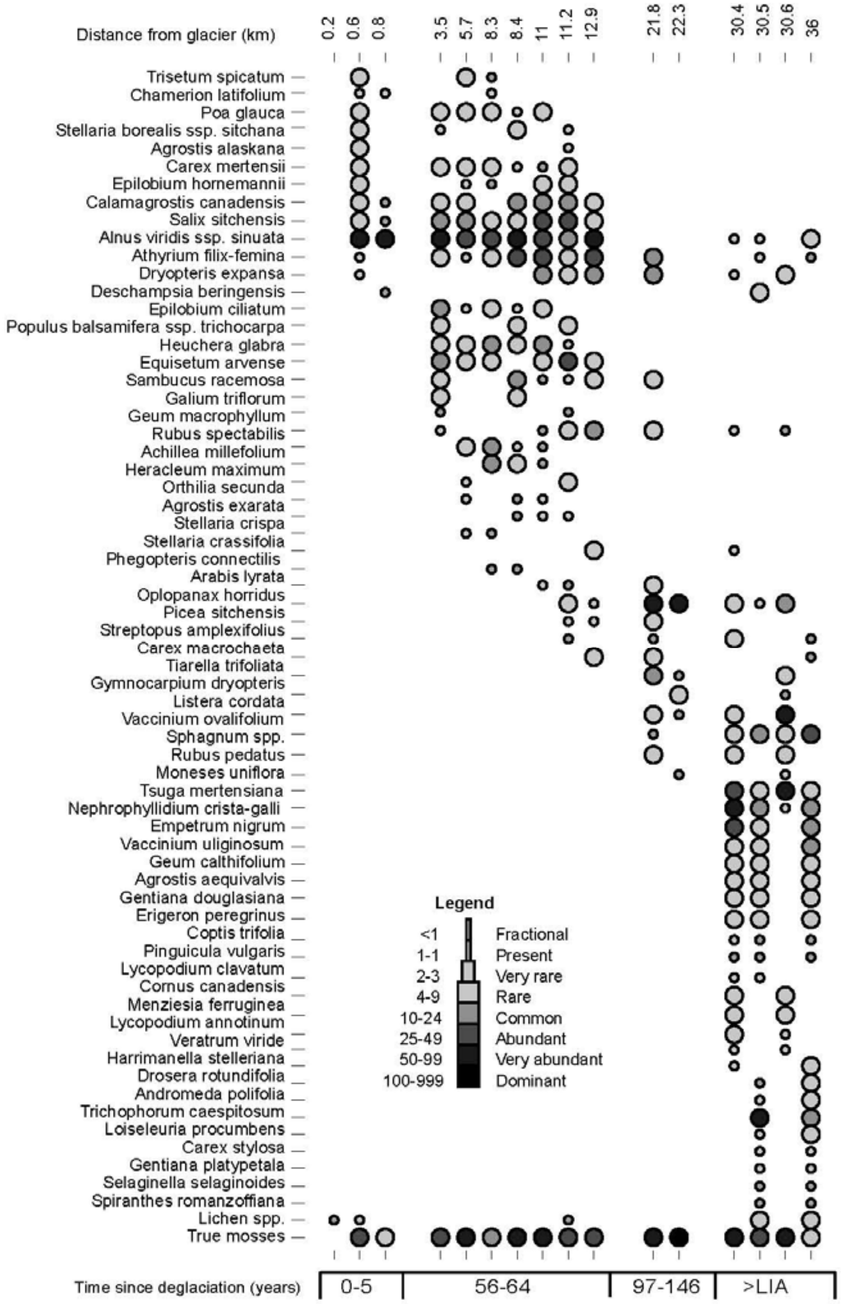


Figure 2.3: Diagonalized matrix of plant species occurrence and cover ordered by increasing distance from the McCarty Glacier, Kenai Fjords, Alaska. Breaks in community continuity identified from chronologically constrained cluster analysis are indicated by a gap in the distance gradient. Plant species occurring along the McCarty Fjord chronosequence at a frequency less than one or at a cover less than 1% are not included in this figure.

Breaks in testate amoeba community continuity between Sites 3 and 4, 4 and 5, and 5 and 6, are coincident with fluctuations in testate amoeba abundance. Abundance is low at Sites 3 and 5, located 0.8 and 5.7 km from the glacier, respectively, but high at Sites 4 and 6, located 3.5 and 8.3 km from the glacier, respectively. The break in testate amoeba community continuity between Sites 14 and 15, located 30.5 and 30.6 km from the glacier, respectively, is coincident with a change in species composition.

Figure 2.4: Diagonalized matrix of testate amoeba species occurrence and cover ordered by increasing distance from the McCarty Glacier, Kenai Fjords, Alaska. Breaks in community continuity identified from chronologically constrained cluster analysis are indicated by a gap in the distance gradient. All testate amoeba species detected along the McCarty Fjord chronosequence are included in this figure.

Diversity Trends

Changes in plant and testate amoeba community diversities are remarkably similar along the McCarty Fjord chronosequence. Both communities quickly diversify within the first five years of deglaciation and stabilize on older terrains (Figure 2.5). Testate amoeba community diversity is generally higher than plant community diversity but regression of plant and testate amoeba diversity shows that they are strongly and positively correlated ($r^2 = 0.769$, $p < 0.001$) with testate amoeba diversity saturating more quickly (Figure 2.6). The greater strength and significance of the correlation between plant and testate amoeba species evenness ($r^2 = 0.566$, $p = 0.001$) relative to the correlation between plant and testate amoeba species richness ($r^2 = 0.303$, $p = 0.027$) indicates the tight diversity relationship is likely driven by synchronous change in species occurrences as opposed to change in species number. There appear to be coincident, temporary depressions in plant and testate amoeba diversity on terrains deglaciated approximately 100 years ago (Figure 2.5). These lower diversity sites have the greatest percent coniferous canopy cover (70-80%), moss groundcover (85-100%) and the lowest soil pH (3.56-3.63) and soil nitrate concentration (0.9-1.2 ppm) of any site. Beta diversity values for plant and testate amoeba communities are similar; plant beta diversity is 0.172 and testate amoeba beta diversity is 0.190. Neither plant ($r^2 = 0.170$, $p = 0.112$) nor testate amoeba ($r^2 = 0.087$, $p = 0.266$) diversities are significantly correlated to distance from the glacier.

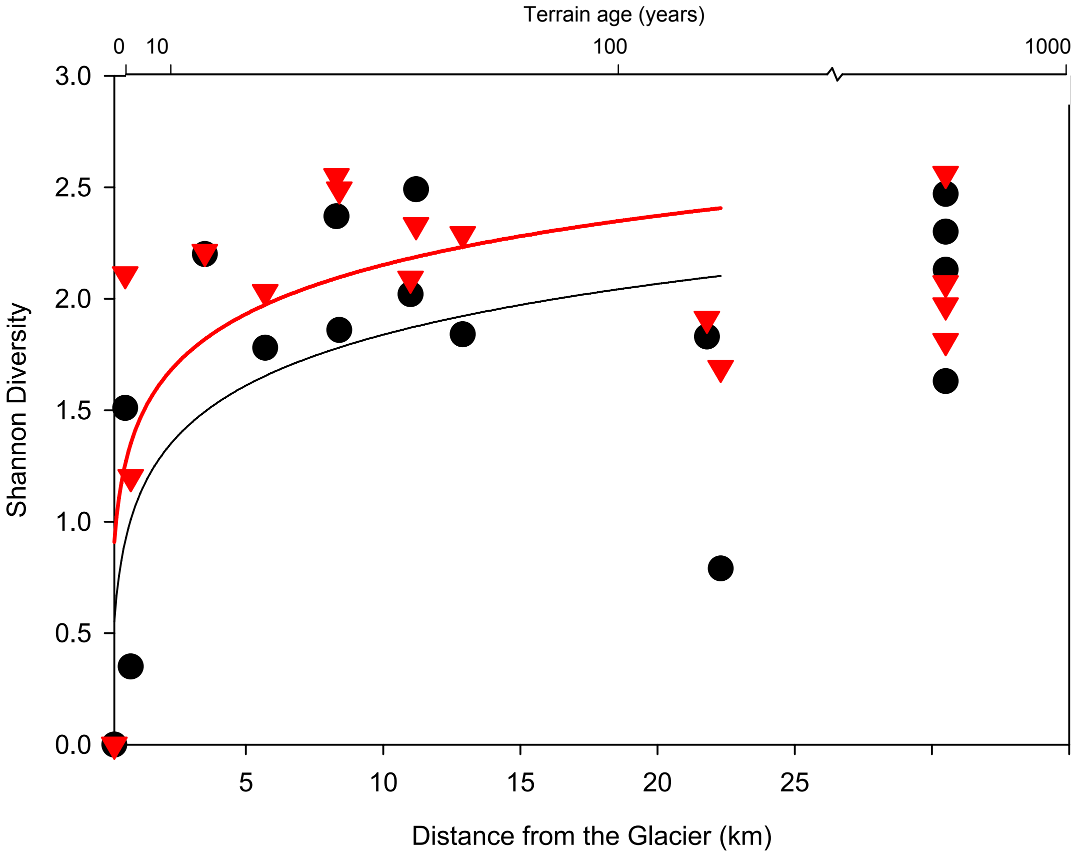


Figure 2.5: Comparison of plant (circles) and testate amoeba diversity (triangles) along the McCarty Fjord chronosequence, Kenai Fjords, Alaska. Two parameter power function best-fit lines are shown as the thin black line for plants and the thick red line for testate amoebae.

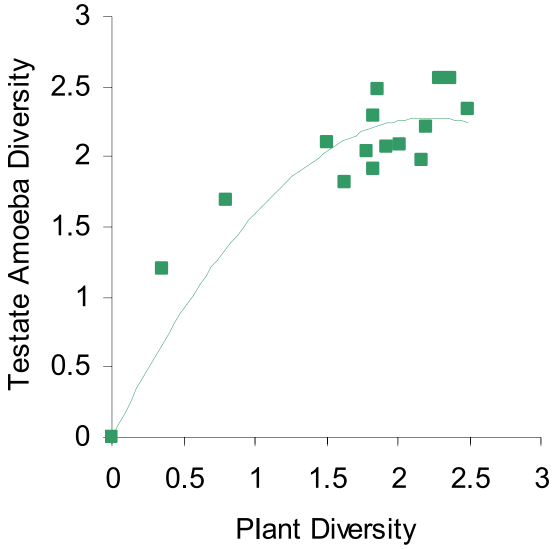


Figure 2.6: Correlation between plant and testate amoeba diversity (Shannon Index), McCarty Fjord chronosequence, Kenai Fjords, Alaska. A logarithmic function best-fit line is shown.

Plant and testate amoeba community richness values are similar on early-seral terrains but appear to diverge across mid- and late-seral terrains (Figure 2.7). Average plant community richness (18.7 species) is higher than average testate amoeba community richness (10 species) and plant species richness is significantly correlated with distance from the glacier ($r^2 = 0.321$, $p = 0.022$). Testate amoeba species richness is not significantly correlated to distance from the glacier ($r^2 = 0.017$, $p = 0.634$).

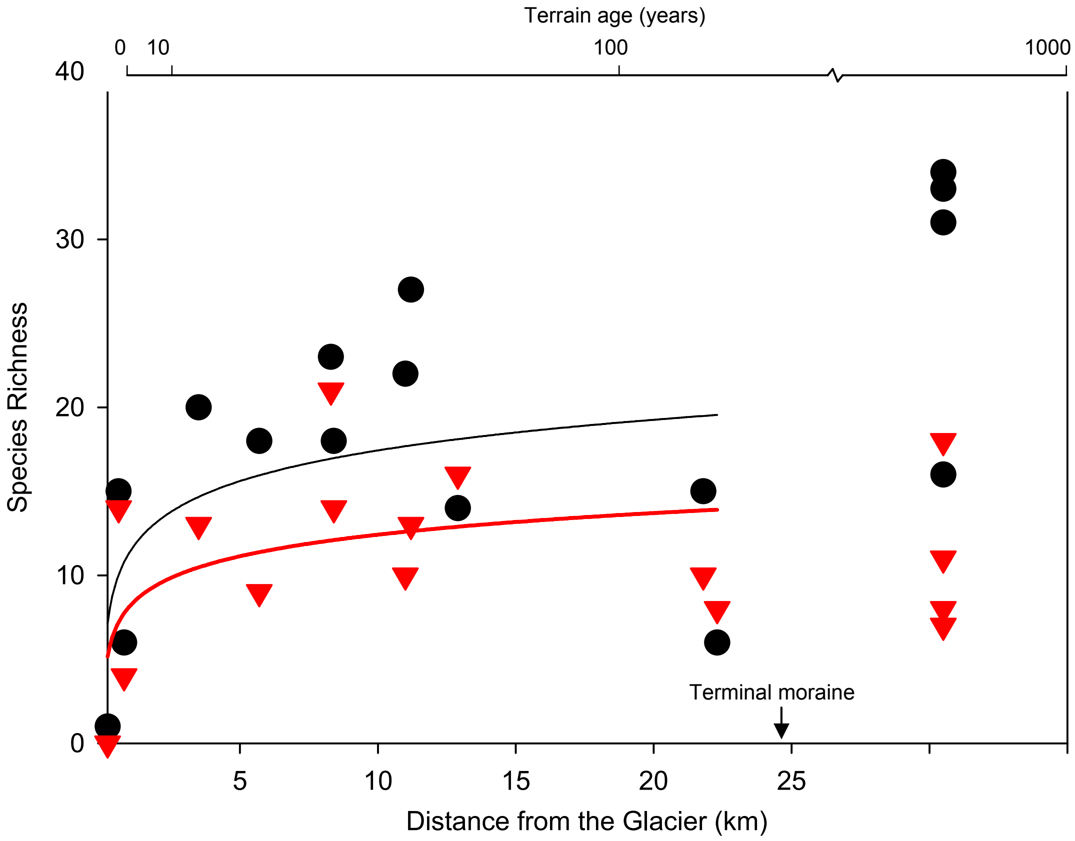


Figure 2.7: Comparison of plant (circles) and testate amoeba species richness (triangles) along the McCarty Fjord chronosequence, Kenai Fjords, Alaska. Two parameter power function best-fit lines are shown as the thin black line for plants and the thick red line for testate amoebae.

Plant species evenness is generally lower than testate amoeba evenness across all terrain types (Figure 2.8). Neither plant (r^2 = 0.130, p =0 .170) nor testate amoeba (r^2 = 0.123, p = 0.183) evenness are significantly correlated to distance from the glacier.

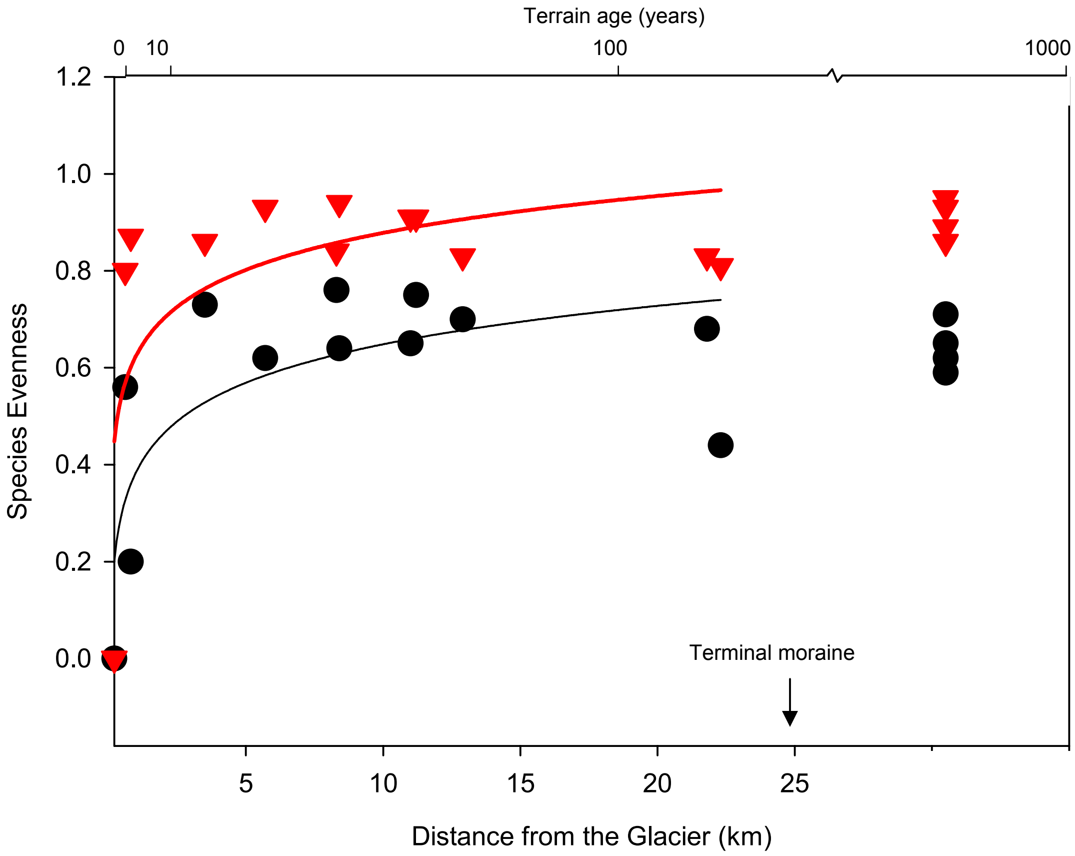


Figure 2.8: Comparison of plant (circles) and testate amoeba species evenness (triangles) along the McCarty Fjord chronosequence, Kenai Fjords, Alaska. Two parameter power function best-fit lines are shown as the thin black line for plants and the thick red line for testate amoebae.

Plant relative foliar cover increases across the McCarty Fjord chronosequence compared to the generally lower and more stable relative abundance of testate amoebae (Figure 2.9). Plant foliar cover is significantly correlated to distance from the glacier (r^2 = 0.315, p = 0.024); however, testate amoeba abundance is not significantly correlated to distance from the glacier (r^2 = 0.054, p = 0.385). Presumably due to the high variation in abundance values, the slopes describing the linear relation of plant and testate amoeba abundance to distance from the glacier are not statistically different ($|t|$ = 0.468, $t_{0.05(2),28}$ = 2.048). The average percent foliar cover of plants is 181%; the average number of testate amoebae per site is 39 individuals.

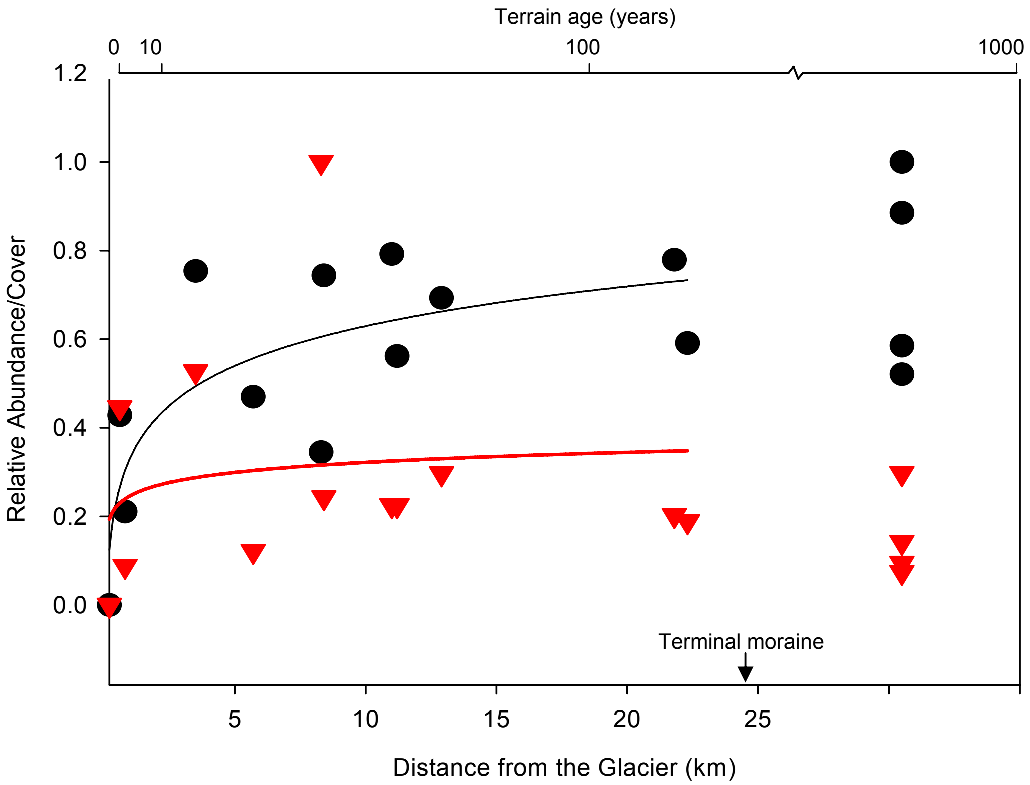


Figure 2.9: Comparison of plant relative foliar cover (circles) and testate amoeba relative abundance (triangles) along the McCarty Fjord chronosequence, Kenai Fjords, Alaska. Two parameter power function best-fit lines are shown as the thin black line for plants and the thick red line for testate amoebae.

The quantitative similarity for successive sites, calculated from abundance data, is not correlated between plant and testate amoeba communities (Figure 2.10, $r^2 = 0.184$, $p < 0.126$). Plant community similarity is variable yet stable across all terrain ages whereas testate amoeba community similarity appears to be low on early-seral sites, peaks on mid-seral sites and declines across late-seral sites.

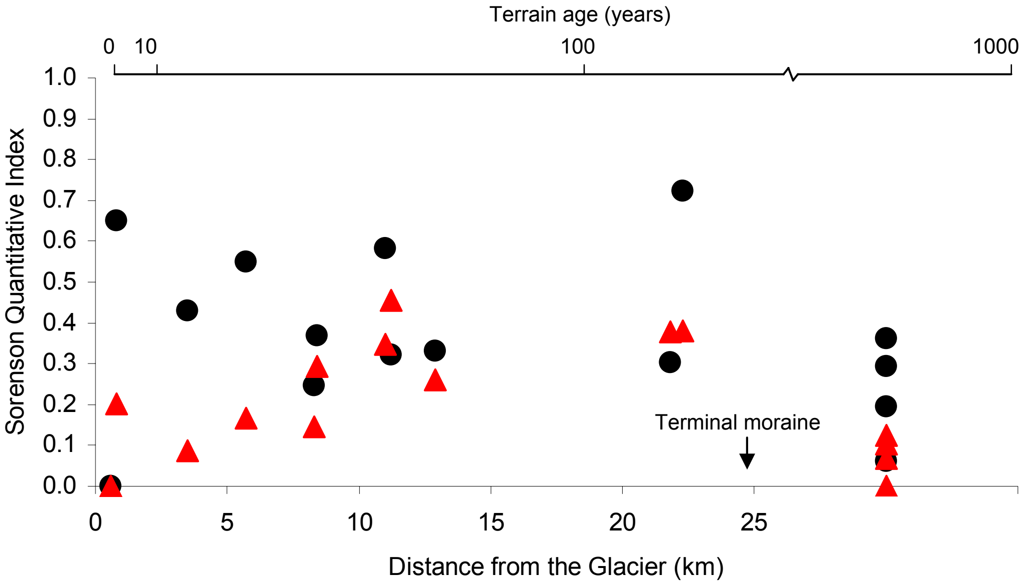
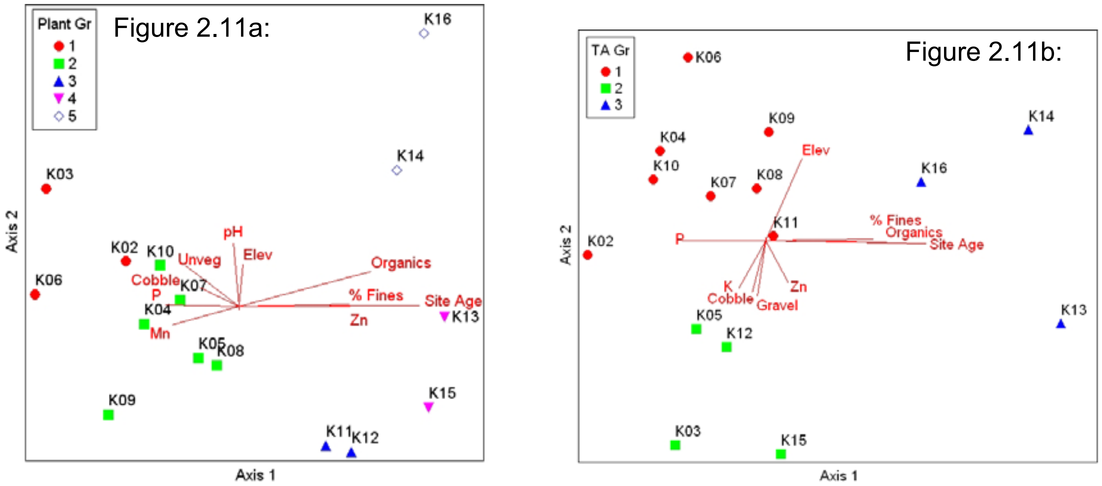


Figure 2.10: Comparison of Sørenson quantitative index of similarity values for successive pairs of plant (circles) or testate amoeba (triangles) sites along the McCarty Fjord chronosequence, Kenai Fjords, Alaska.

Influence of Site Variables on Biotic Communities

The structure of plant and testate amoeba communities is influenced by a remarkably similar set of site variables (Figure 2.11). Both plant and testate amoeba communities are principally structured by variables relating to site successional status (axis 1) and secondarily by site mesotopography (axis 2). Site age and soil development best describe the successional status of sites and organize plant communities in rough chronological order. The organization of testate amoeba communities appears to be more tightly related to understory type and soil character. Regardless of successional status, testate amoeba communities associated with herbaceous understory and mineral soils are located to the upper left, communities associated with dry forest mosses and organo-mineral soils are located to the low center, and communities associated with peat mosses and organic soils are located to the upper right (Figure 2.11a). Physical soil development is indicated by greater retention of organic matter in the system and decreases in grain size for both plant and testate amoeba communities, and also by decreases in unvegetated and cobbled surface area for plant communities. Chemical soil development is characterized by a decrease in P for both communities and by an increase in Zn and decrease in Mn for plant communities.

Plant and testate amoeba communities are spread orthogonally along the successional axis by site elevation. Although an attempt was made to control for change in elevation by restricting sites to a topographic band ranging from 11.0 to 169.2 m in elevation, this variable still provides significant influence on the position of both plant and testate amoeba communities in multivariate space. In addition to elevation, plant communities are also influenced by pH and testate amoeba communities are also influenced by soil concentrations of K and Zn and the presence of surface gravel and cobble.



Legend:

Cobble	percent ground surface area comprised of mineral material >20 cm diameter
Elev	elevation (m above sea level)
% Fines	percent weight of fine soil material (<0.075 mm minimum dimension)
Gravel	percent ground surface area comprised of mineral material with diameter between 2 mm - 20 cm
Mn	concentration of Manganese in the soil (ppm)
Organics	thickness of the organic horizon (cm)
P	concentration of Phosphorus in the soil (ppm)
pH	soil pH measured from 1:1 slurry preparation
Site Age	for sites 2-12, Site Age corresponds to distance from the position of the glacier in 2000, for sites 13-16 Site Age corresponds to an equal yet arbitrary distance (30 km) which locates these reference sites outside the extent of LIA glaciation
Unveg	percent unvegetated ground surface area
Zn	concentration of Zinc in the soil (ppm)

Figures 2.11a and 2.11b: NMS biplots of plant (2.11a) and testate amoeba (2.11b) communities located along the McCarty Fjord chronosequence, Kenai Fjords, Alaska, ordinated by site variables. Community types are defined by unconstrained cluster analysis and are numbered in successional order. Figure 2.11a: axes 1 and 2 capture 55% and 35% of the variation in the plant community dataset, respectively. Figure 2.11b: axes 1 and 2 capture 60% and 16% of the variation in the testate amoeba dataset, respectively. Vector orientation and site locations were reflected horizontally and vertically in Figure 2.11a and were reflected vertically and rotated 90 degrees counterclockwise in Figure 2.11b to facilitate comparison.

Comparison of Community Structures

Contrary to expectations, plant and testate amoeba communities display a much tighter relationship to each other than they do to variables describing site condition. The similarity between testate amoeba communities and site variables is stronger than the similarity between plant communities and site variables; however, neither of the relationships are statistically significant (Figure 2.12).

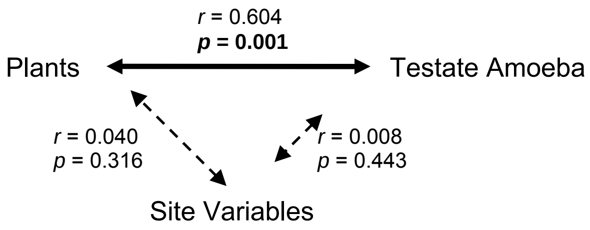


Figure 2.12: Graphic representation of the relationships between plant and testate amoeba communities and site variables along the McCarty Fjord chronosequence, Kenai Fjords, Alaska. Significant *p* values ($p < 0.05$) are in bold. Line length and thickness correspond to the strength and significance of the relationship where longer lines indicate a stronger relationship and thick lines indicate a significant relationship.

The Mantel moving window analysis allows comparison of variable correlations with increasing distance from the glacier front. This analysis shows that the relative strength and significance of the plant-testate amoeba relationship is maintained along the chronosequence. In contrast to the simple Mantel test, the testate amoeba-site variable relationship is stronger and more significant than the plant-site variable relationship when projected over a time-space gradient (Figure 2.13). Interestingly, the change in correlation strength and significance is not consistent for each variable pair. The average strength of the correlations increases and becomes more significant for comparisons between plants and testate amoebae and between plants and site variables, but remains relatively stable for comparisons between testate amoebae and site variables.

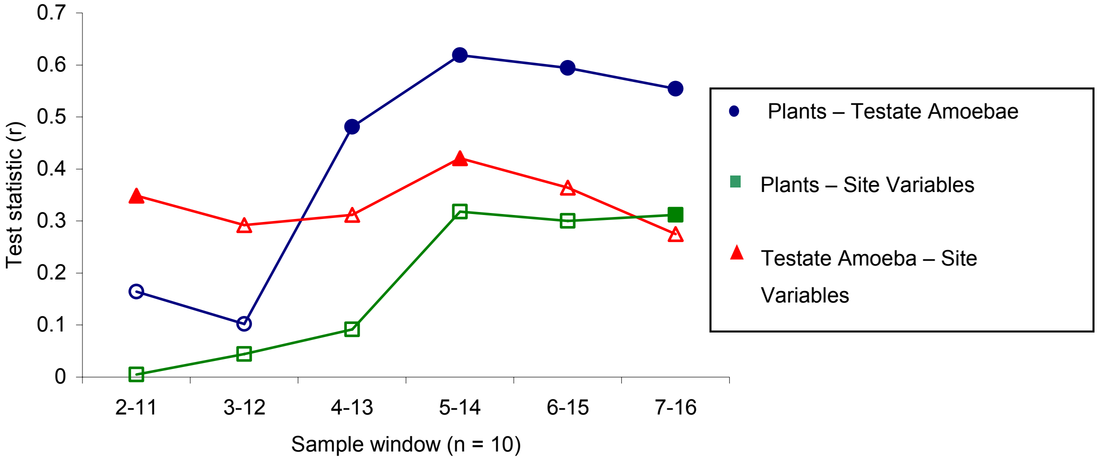


Figure 2.13: Mantel moving window correlations between variable pairs along the McCarty Fjord chronosequence, Kenai Fjords, Alaska. X-axis labels indicate the ten consecutive sites that were used to calculate the average Mantel test statistic. The plant-testate amoeba variable pair is represented by circles, the plant-site variable pair is represented by squares, and the testate amoeba-site variable pair is represented by triangles. Significant ($p < 0.05$) comparisons are shown as filled symbols.

Discussion

Despite differences in the resolution and successional ordering of plant and testate amoeba communities, the assembly of these functionally different communities appears to be highly related. The diversity patterns and responses of these groups to site variables are strikingly similar along the McCarty Fjord chronosequence, but most interesting are the strong correlations between plant and testate amoeba communities relative to weaker correlations between these biotic communities and (abiotic) site variables.

Evaluation of Communities

Plant communities show greater resolution and are more responsive than testate amoeba communities to the successional gradients measured in this study. The greater number of plant communities identified in the cluster analyses and their strong successional ordering relative to testate amoeba communities suggest that plants are better indicators of landscape-scale successional change. The five plant communities identified along the McCarty Fjord chronosequence show significant increases in foliar cover and species richness with increasing terrain age that are similar to patterns of plant community development along proglacial chronosequences worldwide (Matthews 1992). While the three testate amoeba communities identified correlate to variables as described earlier, they are not successionally ordered and diversity measures describing these communities do not correlate with terrain age (Figure 2.14).

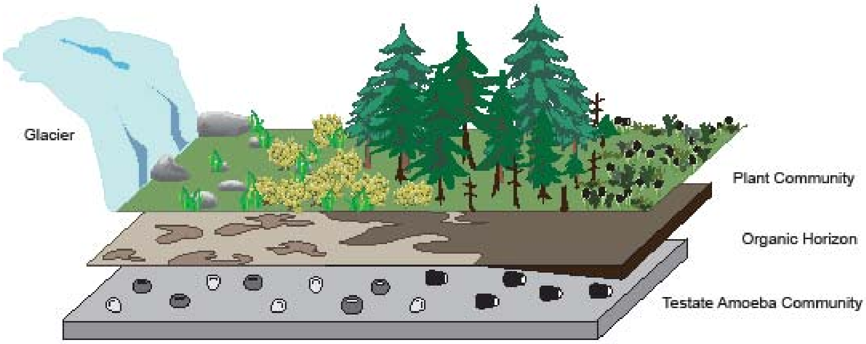


Figure 2.14: Schematic drawing of plant, testate amoeba, and site variable successional change along the McCarty Fjord chronosequence, Kenai Fjords, Alaska.

It is presumed that the discrepancy in bioindication utility between these two functionally different groups may relate to the coarse scale of site variable measurements employed in this study. For example, change in terrain age was measured on a decadal scale and as a result, change in site variables was captured over scales ranging from hundreds of meters to kilometers. By nature of their larger lifeform and longer lifespan plants are more sensitive to broad scale and persistent change in environmental conditions; whereas small, short-lived microorganisms better indicate small-scale and transient environmental change (Sauberer et al. 2004).

Along the McCarty Fjord chronosequence, breaks in plant community continuity coincide with the establishment of large coniferous tree species and to a lesser extent, with the diversification of the groundcover community. This suggests that the occurrence of plant species is responsive to large-scale successional change in landcover structure and species composition. Alternatively, breaks in testate amoeba community continuity coincide with transitions in soil type and to a lesser extent with transitions in soil moisture and site elevation. A strong break in testate amoeba community continuity is observed across the McCarty Fjord terminal moraine where soils transition from thin organo-mineral layers to thick organic horizons. Weaker breaks are seen on older reference sites between mesic forest soils and saturated wetland soils and on variably-aged terrains between low and high elevations. The apparent response of testate amoeba communities to soil condition is consistent with numerous studies (Bonnet 1961, Coûteaux 1975, Chardez and Lambert 1981, Booth 2002) that have correlated testate amoeba occurrence and activity to the moisture and developmental status of soils.

Breaks in community continuity associated with elevation are thought to relate to change in soil condition in so far that high elevation sites may have experienced a longer ice-free period over which soils could develop. High elevation Sites 4 and 6 are proximal to the trimline formed by the McCarty glacier during the LIA (interpreted from field observations and satellite imagery captured in 2000). The rate of glacial thinning has been estimated at 1.2 m/yr between 1860 and 1909 as the glacier receded over its terminal moraine and at 27 m/yr between 1942 and 1960 as recession proceeded through deep water (Post 1980). If high elevations sites were deglaciated by lateral thinning before the glacier front receded upfjord of these locations, then these high elevation soils would be more developed and likely support a greater number and type of testate amoebae compared to chronologically adjacent, lower elevation Sites 3 and 5.

The coarseness of the testate amoeba communities defined in this study and the predominance of generalist species in community composition weakens their usefulness as bioindicators of site character on a landscape scale. The pattern of testate amoeba community assembly shows that species do transition into and out of the community and that no one species is dominant across the McCarty Fjord chronosequence. Generalist species such as *Phryganella acropodia*, *Centropyxis* species, and *Trinema* species that are associated with a variety of habitat types (Bobrov 2005) are common, and thus sites of differing abiotic or vegetative character often support similar assemblages of testate amoebae. The bioindication potential of testate amoebae has been largely demonstrated from peatland habitats because the ecological tolerance of most testate amoeba species are restricted to a narrow range of moisture and pH conditions (Mitchell et al. 1999, Mitchell et al. 2000b). To a lesser extent testate amoeba communities have been separated on the basis of marine, freshwater, and terrestrial habitat (Foissner 1987) and across finer divisions of soil development from acidic or basic mineral substrate (Bonnet 1964). It is suspected that the coarsening of testate amoeba communities outside of peatland habitats relates to the lower availability of water and is confounded by the generally larger scale of investigations. In herbaceous meadows, the response of the soil microorganism community to change in plant diversity is restricted to the rhizosphere; little response is measured in the bulk soil (Kowalchuk et al. 2002). Thus, in drier soils, secondary parameters relating to rhizosphere condition may have greater influence on testate amoeba community composition. To determine if the lesser sensitivity of testate amoeba communities to site condition shown in this study is a result of insufficient sampling or a result of the generalist nature of testate amoeba species, future studies should test a nested sampling approach designed to capture site conditions at a range of scales.

As an aside, the average test length and test composition of testate amoebae documented along the McCarty Fjord chronosequence are significantly different for recently deglaciated (Sites 2-12) and older reference sites (Sites 13-16) with longer and siliceous tests more common on older reference sites (p = 0.015, p = 0.030 for length and test composition, respectively, independent samples t-tests, not controlled for phylogenetic effects, see Appendix I for further discussion). The greater correlation of testate amoeba size and composition to successional variables suggests that morphological parameters may better indicate landscape-scale environmental conditions than species presence (but see Booth 2001).

Comparison of Diversity Patterns

The patterns of plant and testate amoeba diversity shown in this study are consistent with general patterns of plant community development from primary substrates (Reiners et al. 1971, Matthews and Whittaker 1987, del Moral and Bliss 1993) and are generally supported for the primary succession of testate amoebae (Hodkinson et al. 2004, Wanner and Xylander 2005). Despite differences in survey methodology and inherent taxonomic richness between functional groups (the potential pool of vascular plant species is more than double that of testate amoeba species), plant and testate amoeba communities show similar trends of diversity, richness, evenness, and abundance. This similarity suggests that the assembly of their communities follow similar patterns. The stronger correlation between plant and testate amoeba evenness relative to species richness correlations indicates that highly-correlated diversity relationships are generally driven by synchronous change in species occurrence as opposed to change in species number, and suggests that the nature of the plant-testate amoeba link may be more functional than species-specific. The greater influence of plant function relative to plant identity on heterotrophic microbial populations has been shown in several field experiments (Tilman et al. 1997, Ledeganck et al. 2003, Zak et al. 2003, de Deyn et al. 2004) and may relate to underlying trends in biomass or carbon.

Interestingly, the strong correlation between plant and testate amoeba community diversity is maintained by low evenness in a rich plant community and high evenness in a species-poor testate amoeba community. Differences in species richness and evenness over successional time have been documented for diverse taxonomic groups (Bock et al. 2007) and may relate to different successional mechanisms operating for aboveground and belowground communities.

It is here proposed that the plant community may develop along divergent successional pathways towards a variety of rich community types, whereas testate amoeba communities may converge towards types characterized by an even distribution of species. Sub-alpine terrains not glaciated during the LIA support a variety of plant community types including *Picea sitchensis-Tsuga mertensiana* forests, Open *Tsuga mertensiana* wetlands, sedge fens, and *Sphagnum* peatlands. The larger species pools associated with mature terrains, combined with smaller patch size of late-seral landcover types, and ecoclinal effects produced by intergradation of these types, elevate plant richness on older terrains. Alternatively, increase in testate amoeba evenness with successional age and consistently lower species richness may be produced by convergent succession in an increasingly homogenous, late-seral belowground environment. The late-seral belowground environment along the Kenai Fjords chronosequence is composed of continuous, moist to saturated, heavily organic and acidic soils. The early-seral belowground environment, on the other hand, is significantly more heterogeneous, with smaller patches of thin organic soil in a matrix of coarse mineral substrates. A diverse assemblage of testate amoebae may disperse to and establish in these isolated soil microhabitats.

The change in soil heterogeneity along the McCarty Fjord chronosequence is approximately related to the character of testate amoeba communities collected from different groundcover types at the same site. Three pairs of such samples were collected from terrains of increasing successional status along the McCarty Fjord chronosequence. The Bray-curtis distance (dissimilarity) measures for these pairs, listed in successional order are: 1.00, 0.76 and 0.69, where a value of 1.00 indicates complete dissimilarity and 0.00 indicates complete similarity. The 1.00 value describes the early-seral site because no testate amoebae were detected in one of the samples included in the sample pair. Although this is an extremely small sample size (n=3), the decreasing distance (i.e. increasing similarity) between testate amoeba communities with increasing successional age is suggestive that soil is more heterogeneous at younger sites and supports observations contained in this study. Thus, there is limited support for the idea that substrate heterogeneity drives the variability of testate amoeba abundance, richness, and diversity on recently deglaciated terrains.

Testate amoeba communities appear to converge towards a more even community type as the organic horizon coalesces and develops into a highly-decomposed, laterally continuous, and well-hydrated organic horizon. The existence of a truly late-seral testate amoeba community type provides additional support for a convergent successional pathway for belowground biota. Convergence of the testate amoeba communities has been shown to parallel the convergence of calcareous and siliceous soils to a brown forest soil (Bonnet 1961). Similar successional increases in evenness and corresponding decreases in diversity seen for soil invertebrates in related studies have been attributed to the more even use of resources in mature soils (Scheu and Schultz 1996). The operation of alternate successional mechanisms for aboveground and belowground communities may help explain why successional patterns for functionally compatible biotic groups tend to decouple when extended across temporal gradients.

While plant and testate amoeba diversity patterns are correlated, testate amoeba diversity saturates more rapidly across early-seral terrains. This more rapid addition of testate amoeba species is a likely consequence of their small size, short lifespan, and greater ability to disperse and survive adverse conditions. Moreover, a larger species pool of vascular plants with variable dispersal capabilities likely results in a more prolonged addition of new propagules and thus a less rapid saturation of plant species on early-seral terrains. Testate amoebae are able to disperse passively (predominantly by wind) or actively (by direct migration from adjacent soils) to primary substrates where they can establish founding populations in small pockets of organic material (Wanner and Dunger 2001). Such founders are exposed to a reduced range of environmental conditions during their short lives and are able to encyst when conditions exceed their biophysical tolerances (Foissner 1987). The early arrival and proliferation of testate amoebae on newly exposed terrain shown in this study provides limited support for the presence of a pioneer heterotrophic phase that is thought to facilitate plant establishment through the retention of nutrients (Edwards and Sugg 1993, Kaufmann 2001, Hodkinson et al. 2002).

The generally greater and more stable plant community similarity along the McCarty Fjord chronosequence compared to the lower and more variable testate amoeba community similarity may also relate to differences in size and life span in combination with sampling design. Study sites were located and characterized at scales to capture the gradual change in landcover type along the McCarty Fjord. It is likely that the testate amoebae community makes large compositional jumps between sampling locations due to the comparatively small size and short life span of its members and the large distance between sites. On early-seral terrains, different testate amoeba communities could develop from the random colonization of isolated and heterogeneous pockets of organic matter, which would contribute to the low community similarity found at such sites (Fastie 1995, Jumpponen et al. 1999, Treves et al. 2003). The weak peak in testate amoeba community similarity on mid-seral terrains may be due to the abundance of generalist species that are able to survive over a greater range of environmental conditions. In addition, the late-seral decline in testate amoeba community similarity may relate to the development of even, yet compositionally different communities.

Temporary depressions in plant and testate amoeba diversity at coniferous forest Sites 11 and 12 (located 21.8 and 22.3 km from the glacier, respectively) may be related to shading and acidic litter inputs from the *Picea sitchensis* overstory, acidic exudates from the moss understory, and soil nutrient leaching. Canopy cover reaches a maximum (70-80%) at these two sites. Soil pH (3.56, 3.63) and nitrate (NO_3^-, a highly soluble form of nitrogen (1.2, 0.9 ppm)) levels reach minimum values also at these two sites. Plant diversity is likely depressed by shading and low nutrient availability due to the general recalcitrance of phenol-rich coniferous litter (Clarholm 2002), whereas depressions in testate amoeba diversity are thought to relate to the relatively greater presence of mycorrhizae in coniferous forests. Testate amoeba communities from coniferous forest soils have been shown to be less diverse than communities sampled in deciduous forest soils (Balík 1996). Moreover, mycorrhizae on *Picea* roots are known to reduce the presence of both bacteria and protozoa due to lower rates of root exudation (Bonkowski et al. 2001), which altogether compromise the quality of bacterial food for testate amoebae (Timonen et al. 2004).

Patterns of Community Assembly

The similarity of diversity patterns observed for both plant and testate amoeba communities along the McCarty Fjord chronosequence suggests that these communities are assembled in a similar manner. For example, pant and testate amoeba species rapidly colonize recently deglaciated terrain, after which, the addition of species is balanced by commensurate species losses. The transition from addition to replacement of species with successional time is particularly clear for the plant community where very few early-seral species are present in late-seral communities. This early-seral addition of species followed by the replacement and loss of species is a well-documented pattern in the primary succession of plant communities and is related to abiotic, dispersal, and competition limitations (Anderson 2007). The persistence of generalist testate amoeba species *Phryganella acropodia*, *Centropyxis* species, and *Trinema* species across the chronosequence weakens a similar transition assembly pattern for the testate amoeba community.

In addition to the likelihood of some species being limited by their poor dispersal capabilities, harsh abiotic conditions of recently deglaciated terrains certainly limit the early-seral addition of both plant and testate amoeba species along the McCarty Fjord chronosequence. After colonization of the early terrains, plant species are added in accordance with life history traits that are associated with an increasingly resource-limited and thus, competitive environment (Tilman 1985, Chapin et al. 1994). Due to the proximity of mature terrains along the McCarty Fjord chronosequence, dispersal is not considered a significant limitation to the development testate amoeba communities. However, species of vascular plants comprising mature communities are expected to vary considerably in their ability to disperse propagules to recently deglaciated terrains.

At first appearance, the few studies addressing the primary succession of testate amoebae present a contradictory picture of community assembly. Testate amoeba communities have been shown to assemble by the addition of species without commensurate species losses along a temperate microchronosequence (Wanner and Xylander 2005). Whereas those along a high arctic, proglacial chronosequence (Hodkinson et al. 2004) are purported to be assembled by successive replacement and loss of species. It is here suggested that this discrepancy can be explained by the length of the successional gradient investigated. The assembly of any community begins with the addition of species. Therefore, if focus is limited to the time interval or spatial sequence representing early colonization (e.g. Wanner and Xylander 2005) the pattern of assembly appears additive, while extended time-space gradients shows an eventual pattern of replacement and possibly species loss (e.g. Hodkinson et al. 2004). Although late-seral declines in diversity were not observed along the McCarty Fjord chronosequence, declines have been observed for testate amoeba and microbial communities across long-term chronosequences in a variety of ecosystems (Hodkinson et al. 2004, Wardle et al. 2004b). Similar to plant community patterns, these late-seral declines are attributed to nutrient limitation.

Influence of Site Variables on Biotic Communities

The composition and structure of plant and testate amoeba communities are influenced by a remarkably similar set of site variables. Both plant and testate amoeba communities are principally structured by successional variables and secondarily by variables related to site mesotopography. Variables relating to terrain age and soil development organize both plant and testate amoeba sites in rough successional order across multivariate space. Because this and other chronosequence studies substitute distance from the glacier for time since deglaciation, the relative influences of time and soil development are not easily separated. Similar to biotic communities developing along most proglacial chronosequences (Matthews 1992), site age (approximated as distance from the glacier) is the strongest single organizing variable for both plant and testate amoeba communities. The McCarty Fjord chronosequence site age is also paralleled by a suite of biological, physical, and chemical soil development vectors describing the thickness of the organic horizon, the percent weight of fine soil material and the concentration of soil phosphorous.

Soil Organo-mineral Character

Organic horizon thickness generally increases across primary chronosequences as the plant community increases biomass and subsequently the addition of litter to the soil environment (Crocker and Major 1955). Along the McCarty Fjord chronosequence, the increasing presence of coniferous, ericaceous, and *Sphagnum* species may accelerate the rate of organic matter accumulation on late-seral terrains through the addition of recalcitrant litter and the creation of acidic and anoxic soil conditions that retard decomposition (van Breemen 1995, Clarhom 2002, Mallik 2003). The increase in percent weight fine mineral material that organizes both plant and testate amoeba communities and the simultaneous decrease in percent cobbled surface area that organizes plant communities only, are measures of physical soil development. Weathering processes reduce the integrity and grain size of parent material over time, thereby increasing the presence of smaller grain sizes at the expense of larger material such as cobbles. In contrast to plants, the percent surface area of cobble and gravel organizes testate amoebae along the secondary axis that is related to mesotopography. It appears that, regardless of their age, both low elevation and rocky sites encourage the establishment of a testate amoeba community dominated by *Centropyxis* and *Trinema* species whereas, irrespective of their elevation, young and rocky sites encourage the establishment of Open alder and Closed Tall alder-willow plant communities. This discrepancy again highlights the greater sensitivity of the plant community to landscape-scale successional gradients and of the testate amoeba community to smaller-scale soil conditions. The decreasing prevalence of unvegetated surfaces in the succession of plant communities is simply a reflection of increasing plant biomass along the chronosequence.

Soil Phosphorous

Because phosphorus (P) is not biologically renewable yet is integral to life processes, declines in soil P concentration over time is common across primary successional gradients where biomass increases with substrate age (Crews et al. 1995). Across the nearby Exit Glacier chronosequence, foliar concentration of P and K increased in *Populus balsamifera* ssp. *trichocarpa* and Mn increased in *Anlus viridis* ssp. *sinuata* (Cusick 2001) presumably at the expense of soil concentrations. The P gradient along the McCarty Fjord chronosequence is likely strengthened by a change in parent material from P-rich, marine-derived metasediments (Budnik 1974) to P-poor granitics that are spatially coincident with the McCarty Fjord terminal moraine (glacial position labeled “1860”, Figure 1.4). The importance of Mn to the location of early-seral plant communities in multivariate space suggests that P may precipitate out of soil solution with bivalent Mn^{+2} in young soils and that this occlusion of P may limit growth in early-seral plant communities (Atlas and Bartha 1998). Unlike autotrophic plants, heterotrophic testate amoeba communities are not significantly affected by high soil concentrations of Mn, likely because testate amoebae are able to metabolize organic P from a variety of sources including dead organic material, bacteria, micro-algae, ciliates, and other testate amoebae (Gilbert et al. 1998).

Soil Zinc

The different influence of Zn on plant and testate amoeba communities may relate to a combination of Zn harvest by plant roots, the changing vertical position of the rhizosphere relative to the zone of testate amoeba activity, and the soil sampling design employed in this study. Zinc is immobile and therefore uptake by plants depletes reserves around the root zone (Larcher 1995). In young soils with shallow organic layers the zone of Zn depletion and testate amoeba activity coincide in surface soils. However, on older terrains with thicker organic horizons, plant roots establish at greater depths causing the zone of Zn depletion to shift below the surface zone of testate amoeba activity. For this reason, the concentration of Zn in soils sampled may increase with plant community succession as the zone of Zn depletion becomes increasingly distanced from the soil sampling interval. Because testate amoeba activity is restricted to surface soils, the downward shifting zone of Zn depletion may not affect the succession of their communities. The variability of Zn concentration in surface soils may instead stem from change in mesotopography as the greater concentration of Zn in surface soils at low elevation could relate to the continual erosion and redeposition of upgradient, Zn-rich materials. It is also worth noting that Zn availability is inhibited by both high pH (>6.5) and phosphate presence (Barrow 1987) and is therefore oriented away from these vectors in multivariate space. The influence of K on testate amoeba communities in the process of becoming established on low-elevation, mineral sites is not known but may be an indirect measure of high pH at low elevations.

It is important to note that the soil nutrient values presented in this study are measured as relative abundances (ppm) and therefore cannot be interpreted as volumetric concentrations. Since soil bulk density decreases along the chronosequence as soils become more organic, the increases in soil nutrient abundance with terrain age for Zn might be diminished (or reversed) if values were analyzed as volumetric concentrations. Alternatively, the relationship between nutrients and terrain age would be strengthened for nutrients that decrease (P, K and Mn) in abundance along the chronosequence. Therefore, soil nutrient values should be used as a general index of nutrient availability only, in an approach similar to that of Potts et al. (2002), McDonald and Urban (2004), and Macel et al. (2007).

Site Elevation

Elevation is presumed to influence plant community composition primarily through change in exposure and local climate. Change in plant litter types and root exudates with increasing elevation has been shown to influence microbial biomass, composition, and activity and likely produces commensurate changes in the testate amoeba community (Zak et al. 2003, de Deyn et al. 2004). Mesotopography is thought to affect soil pH through its influence on drainage pattern and soil moisture. Due to the broadly u-shaped profile of the McCarty Fjord sidewalls, higher elevation communities are typically located on steeper, well-drained slopes where higher pH values would be expected. Lower elevation communities are located close to a break in slope where runoff has a greater residence time and anoxic and acidic soil conditions may be more frequent and persistent and would contribute to lower pH. Soil pH influences the composition of plant communities by changing the type and form of nutrients available in soil solution (Larcher 1995) and although the mechanism by which pH influences testate amoebae is not fully understood, numerous studies have separated testate amoeba communities on the basis of soil acidity (Bonnet 1961, Mitchell et al. 2000b, Tolonen et al. 1994).

Comparison of Community Structures

The increasingly tight coupling of plant and testate amoeba community structures over successional time may relate to a greater frequency and specificity of plant-testate amoeba interactions at high diversities (Kowalchuk et al. 2002) and a transition from allogenic to autogenic succession (Matthews 1992). Assuming that the sites included in the present McCarty Fjord chronosequence represent a true primary succession and that pertinent site variables were measured, the strong plant-testate amoeba covariation suggests that interactions between aboveground and belowground biota exert more influence on ecosystem development than broad-scale site condition. Site variables are secondarily important to aboveground-belowground community succession in so far that the breakdown of mineral material and the accumulation of organic matter over time produce the environment through which plants, microbes, and testate amoebae interact.

Experiments testing the links between plant and protozoan communities suggest that the interaction between the groups is reciprocal as the manipulation of one group produces a response in the other, and that this interaction is mediated by microbial heterotrophic primary producers (Clarholm 1985, Jentschke et al. 1995, Ledeganck et al. 2003). Increase in plant functional diversity has been shown to promote a proportional increase in testate amoeba species number and abundance, presumably initiated by the higher biomass and/or diversity of bacteria (Ledeganck et al. 2003). Complementary studies show that increases in microbial functional diversity promote plant uptake of N (Clarholm 1985) and increase root growth and branching (Jentschke et al. 1995) through the grazing activity of protozoa on bacteria and the subsequent release of mineralized N to plants. Microbial diversity patterns along proglacial chronosequences that are similar to those documented for plants and testate amoebae in this study provide additional support for a relationship between plants, microbes and testate amoebae (Tscherko et al. 2003, Nemergut et al. 2007). For these reasons, it is here proposed that the succession of plant and testate amoeba communities along the McCarty Fjord chronosequence is influenced by both an increasing presence of microbial heterotrophic primary producers and frequency of interactions between plant roots, microbes and testate amoebae. The reciprocal influence of plant roots, microbes, and testate amoebae is invoked over the influence of site variables on the basis of the greater strength of biotic correlations demonstrated in this study. Microbial heterotrophic primary producers are identified as the “missing link” because they are present at all stages of primary succession (Sigler and Zeyer 2002) and connect plants and protozoa directly via the microbial loop (Clarholm 1985). Plus, their community composition and structure change predictably across successional gradients (Ohtonen et al. 1999) and provides mutual influences on the diversity of both plant and protozoan communities (Ledeganck 2003).

Conclusions

The strong correlations between plant and testate amoeba communities shown in this study provide additional support for the importance of interactions between aboveground and belowground biota to ecosystem condition and development. As this study is descriptive in nature, the mechanism of the aboveground-belowground linkage cannot be determined absolutely, but is inferred to be driven by the quantity and quality of plant carbon inputs and the variety of mineralized nutrients made available by heterotrophic soil organisms. The secondary influence of abiotic site variables to biotic community structuring is an important finding that, if corroborated by experimental and descriptive studies conducted in ecologically and geographically disparate locations, may force reconsideration of the importance of abiotic site complexity in traditional successional theory.

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Appendices

Appendix I: Morphologic characters of testate amoebae and their relationship to successional gradients

Testate amoebae are small (10-500 µm), single-celled protozoa that produce a persistent shell (test). Because the tests of terrestrial testate amoebae are morphologically unique at the species level and species are sensitive to soil conditions, the occurrence of individuals in a given habitat can be used to indicate environmental condition (Foissner 1987). On this basis, the species compositions of testate amoeba communities have been successfully used to quantify landscape-scale soil gradients (Bonnet 1961) and to reconstruct peatland paleoecology (Booth 2002). Because soil conditions also influence the morphology of terrestrial testate amoebae, change in morphology at the species or individual level can also be used to indicate environmental condition (Wanner 1999).

The morphology of individual species of testate amoebae is influenced by water conditions, habitat structure, food resources (Wanner 1999), as well as phylogenetic ancestry. The early migration of testate amoebae from aquatic to terrestrial environments is thought to have paralleled evolutionary adaptation to lower water availability in a soil environment (Schöenborn 1966). To promote survival during low water availability, specific adaptations include decrease in overall size, reduction and protection of the aperture, and adoption of a more globular shape, all of which act to retard the rate of cytoplasm desiccation and facilitate encystment (Coûteaux 1975). Across shorter time scales, the phenotypic morphology of terrestrial testate amoebae is also influenced by soil conditions. Abundant soil moisture and larger pore spaces are shown to increase test size (Foissner 1987) and the type and availability of food and raw materials for test construction influences testate amoeba phenotypes on a species-specific basis (Wanner 1999).

Because the McCarty Fjord chronosequence terrains represent a gradient of increasing soil organics and depth, it was expected that the test morphologies and test compositions of testate amoeba species would demonstrate predictable transitions. This appendix describes the variations of test morphology and test composition with change in site condition and presents new testate amoeba species records for the Kenai Fjords region. A general introduction to testate amoebae and description of the McCarty Fjord chronosequence are presented in Chapter 1 “An introduction to community interactions in developing ecosystems”. Sample preparation and site variable measurement methods are presented in Chapter 2, “How tightly are aboveground and belowground communities linked? A comparison of primary successional patterns along a proglacial chronosequence in Kenai Fjords, Alaska”.

Test length, shape, test composition, aperture morphology, and taxonomic order were measured or assigned by the following methods. To calculate an average test length for each site, the longest dimension of the first individual of each species observed in a sample was measured using a digital micrometer. Additional measurements were taken as necessary, for example, to confirm the identity of an individual or to better capture the size range of a particularly abundant species. All measurements recorded for a given site were averaged to obtain a mean test length. This average was not weighted to account for species abundances. Average test lengths were regressed against site variables to evaluate the influence of site condition on test size. Site variables tested are listed in Appendices II, III and IV.

To evaluate the response of test shape to changes in site conditions, a ratio of the proportion of compressed test shapes to the proportion of terete (non-compressed) test shapes (Figure A.1) were compared to site variables. A proportional ratio comparing the two dominant test compositions, agglutinate and siliceous, was used to evaluate the response of test composition to changes in site conditions. Although proteinaceous and proteinaceous-agglutinate test compositions are represented in this dataset, 98% of all recorded species have either agglutinate or siliceous test composition. Similarly, a ratio of the most common aperture morphologies, acrostomic and plagiostomic, was used to evaluate the response of aperture morphology to changes in site conditions. Aperture morphologies were classified as axial, cryptostomic, plagiostomic, cotylostomic, or acrostomic (Figure A.1) following a simplification of the types presented by Chardez and Lambert (1981). Although axial, cryptostomic and cotylostomic apertures are represented in the dataset, 85% of all species have either acrostomic or plagiostomic types.

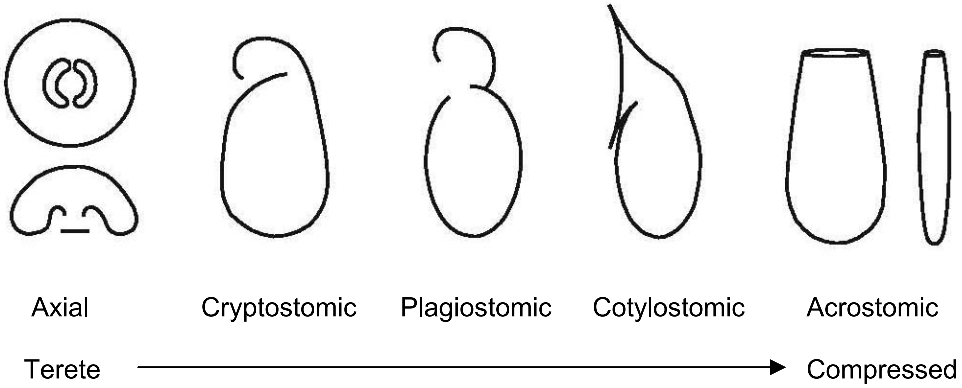


Figure AI.1: Aperture and test morphologies used to describe testate amoeba species occurring in Kenai Fjords, Alaska.

Transition in taxonomic order was assessed by the ratio of species representing the Order Arcellinida to species representing the Order Euglyphida at a given site (See Appendix XIII for species membership). This ratio was compared to site variables to determine if site condition produced a phylogenetic signal. Test shapes, test compositions, and taxonomic designations were taken from the taxa descriptions prepared by Ogden and Hedley (1980) and Meisterfeld (2000a, 2000b).

Change in average test length, test shape, test composition, aperture morphology, and taxonomic representation was compared to change in site variables for only those terrains glaciated during the Little Ice Age (Sites 1-12, hereafter referred to as recently deglaciated sites). The validity of these comparisons was determined using linear regression. Differences between recently deglaciated sites and sites that have not been glaciated since the Wisconsin (10,000 ybp, Sites 13-16, hereafter referred to as reference sites) were assessed by comparing the mean test length, test shape (assessed as the mean ratio of compressed to terete forms), test composition (assessed as the mean ratio of siliceous to agglutinate compositions), aperture morphology (assessed as the mean ratio of acrostomic to plagiostomic aperture types), and taxonomic membership (assessed as the ratio of Arcellinida to Euglyphida members) for each age group. Equality of means was determined using an independent t-test. Equal or unequal variances were assumed depending on the significance of the Levene's test for equality of variances (Levene 1960). Normal distribution of the variable values, an assumption of the Levene's test, was determined using the D'Agostino-Pearson K^2 test (Zar 1996) which evaluates the normality of variance in terms of the kurtosis statistic. Significance of the kurtosis statistic is evaluated by comparison to the chi-squared distribution where the distribution is assumed to be normal if K^2 is greater than the chi-squared critical values.

Response of Test Morphology and Composition to Environmental Conditions

The test length, test shape and aperture morphology of testate amoebae occurring on recently deglaciated McCarty Fjord sites are best predicted by site variables related to soil nutrients, and variables describing the mineral soil fraction or general classes of plant cover (Table A.1). The average length of tests at a given site increases with total organic N, total organic C, the availability of Ca, NH_4, Fe, and Na and the percent weight of the fine soil fraction (listed in decreasing order of significance). Average test length decreases with greater availability of K. Terete tests become more common as the foliar cover of tall shrubs (with height greater than 1.5 m) and forbs increases, whereas compressed tests become more common with increase in the percent area of the ground surface occupied by cobbles. Less protected acrostomic apertures become more common with increasing availability of Mn. The representation of species belonging to the Order Euglyphida increases with the availability of K and P, and the percent of the ground surface not vegetated; those belonging to the Order Arcellinida increases with elevation and the availability of Mn. Proportional change in test composition across recently deglaciated sites was not significantly related to any of the site variables measured.

Response variable	Predictor variable	Direction	r^2	p value
Average test length	total organic N	+	0.711	0.001
	total organic C	+	0.579	0.007
	Ca concentration	+	0.552	0.009
	NH_4 concentration	+	0.546	0.009
	Fe concentration	+	0.493	0.016
	Na concentration	+	0.386	0.041
	percent weight fine soil fraction	+	0.378	0.044
	K concentration	-	0.374	0.045
Test shape (compressed:terete)	cobble ground cover	+	0.651	0.003
	tall shrub ground cover	-	0.436	0.027
	forb species ground cover	-	0.433	0.028
Aperture morphology (acrostomic:plagiostomic)	Mn concentration	+	0.552	0.009
Taxonomic order (Arcellinida:Euglyphida)	K concentration	-	0.598	0.005
	unvegetated ground cover	-	0.471	0.020
	elevation	+	0.416	0.032
	Mn concentration	+	0.370	0.047
	P concentration	-	0.368	0.048

Table AI.1: Strength and significance of significant linear regressions of testate amoeba test morphology and taxonomic order to site variables on recently deglaciated McCarty Fjord sites.

Mean test length and test composition are significantly different between recently deglaciated and older reference sites. No significant differences were found for test shape, aperture morphology or taxonomic order between recently deglaciated and reference sites. Tests are longer, and siliceous tests are more common on older reference sites (Table A.2).

Variable	Means for recently deglaciated Sites 2-12	Means for reference Sites 13-16	Kurtosis statistic	Equality of variances *p* value	Equality of means *p* value
Average test length (um)	56.6	79.3	-0.141	0.448	**0.015**
Test composition (siliceous:agglutinate)	1.716	3.418	2.432	0.180	**0.030**
Test shape (compressed:terete)	1.366	3.268	2.151	0.000	0.208
Aperture morphology (acrostomic:plagiostomic)	1.912	4.085	2.199	0.026	0.166
Taxonomic order (Arcellinida:Euglyphida)	1.774	4.313	0.610	0.006	0.292

Table AI.2: Variable means for testate amoebae occurring at recently deglaciated and reference sites. *P* values indicating a significant difference of means are in bold.

New Testate Amoeba Species for Alaska

Twenty-three (40%) of the 58 species recorded in the 16 soil samples are new records for Alaska (Table A.3). Four additional taxa, (*Argynnia vitraea* var*. sphagni, Centropyxis constricta, Plagiopyxis callida* var*. grandis,* and *Playfairina valkanoivi*) were collected from within the Kenai Fjords region and are also new records but were not included in analyses since they were collected outside of the McCarty Fjord chronosequence. *Phyrganella acropodia, Trinema complanatum, Euglypha laevis, Centropyxis aerophila* and *Schoenbornia viscicula*, listed in order of decreasing dominance, comprise 48% of the total community membership.

Taxon
Centropyxis aerophila var. *sylvatica*
Centropyxis minuta
Difflugia ampulla
Difflugia gassowskii
Difflugia lithophila
Difflugia parva
Difflugia paulii
Difflugia stoutii
Difflugia tenuis
Edaphonobiotus campascoides
Nebela bohemica
Nebela collaris var. *retorta*
Nebela gracilis
Nebela parvula
Nebela sp. 1*
Nebela tincta var. *rotunda*
Nebela tubulata
Plagiopyxis callidia
Plagiopyxis declivis
Plagiopyxis declivis var. *major*
Plagiopyxis minuta
Porosia bigibbosa
Schoenbornia visicicula

Table AI.3: Testate amoeba species recorded from the McCarty Fjord study area representing new records for Alaska and science. *Indicates a species likely new to science.

One testate amoeba, *Nebela* sp. 1, may also be new to science (Figure A.2). However, confirmation of this individual as a new species is subject to detailed morphologic and molecular analysis. The single individual of *Nebela* sp. 1 observed was 161 µm long and 62 µm wide. The test is oblanceolate in shape and terete. The aperture is oval with an irregular margin, possibly due to the agglutination of particles or plates. The test margins and base are rounded. No spines were observed. This individual was collected from the highly organic soils of an *Eriophorum angustifolium-Sphagnum papillosum* peatland (Site 16). See Chapter 2 for description of Site 16 and Appendixes II, III, and IV for pertinent site variables.

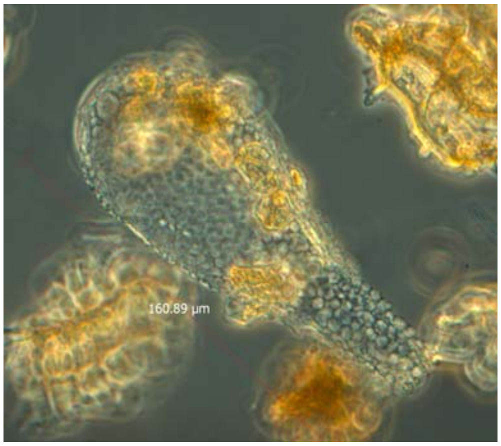


Figure AI.2: Image of *Nebela* sp. 1 taken using light microscopy under phase contrast.

Including previous studies performed in Alaska, 117 testate amoeba taxa are now known from Alaska (Beyens and Chardez 1995, Mitchell 2004, Eisner et al. 2005, Nikolaev et al. 2005, Payne et al. 2006, n.b. this total does not include subspecific taxa, see Appendix XV for a list of species records and citations). The record of at least one species, *Edaphonobiotus campascoides*, represents a significant range extension. *Edaphonobiotus campascoides* was previously thought to have a distribution restricted to Gondwana but was subsequently recorded in the Laurasian continents of Europe (Schöenborn et al. 1983), Russia (Bobrov 2005), and now North America (this study).

Discussion of Morphological Trends

The influence of soil chemical and physical character and vegetation on the test size, test shape, aperture morphology and taxonomic occurrence of testate amoeba species suggest that the nutritional and structural quality of the soil habitat are important to the occurrence of testate amoeba morphospecies across recently deglaciated sites.

Greater nutrient availability is thought to allow larger testate amoeba species to establish and for all species to increase their test length or volume within their natural range of variation. Nitrogen and C are macronutrients essential to the production of biomass, whereas, the micronutrients Ca, Fe, and Na are essential to life processes in significantly smaller quantities. Nutrient availability has been related to testate amoeba community structure in several studies, although the mechanics of these relationships are largely unknown (Mitchell 2004). The response of testate amoeba species to several macro- and micronutrients, including C, Ca, Fe and Na concentrations in conspecific moss tissue along elevational gradients has been tentatively attributed to an effect on prey availability (Mitchell et al. 2004). Whereas change in species occurrence in relation to concentration of Al-Fe complexes, P, Ca, Mg, and pH level is attributed to the release of nutrients in bogs following anthropogenic draining (Jauhiainen 2002). Testate amoeba communities were shown to be closely related to water chemistry, specifically Ca, NO_3 and SO_4 in bogs (Mitchell et al. 2000b). The C/N ratio and N content of peat and the dissolved organic C and Ca concentration of water were important influences on testate amoeba community composition in mires (Tolonen et al. 1994). The reason for increasing test length with decreasing K availability shown in this study is not known. Potassium is essential to processes such as the regulation of cellular osmotic pressure and was therefore expected to be directly related to measures of testate amoeba productivity, such as test length; however, the present findings indicate an opposite relationship. Increase in the percent weight of the fine soil fraction may indirectly relate to soil nutrient condition and promote larger tests as smaller particles provide a greater surface area over which ions may be exchanged. Future studies targeting the mechanism through which nutrients affect testate amoeba morphology and occurrence will hopefully grant insight to the relationships documented here.

It is important to note that the soil nutrient values presented in this study are measured as relative abundances (ppm) and therefore cannot be interpreted as volumetric concentrations. Because soil bulk density decreases along the chronosequence as soils become more organic, the increases in soil nutrient abundance with terrain age for total organic C, Cu and Zn might be diminished (or reversed) if values were analyzed as volumetric concentrations. Alternatively, the relationship between nutrients and terrain age would be strengthened for nutrients that decrease (P, K and Mn) in abundance along the chronosequence. Due to this limitation, soil nutrient values should be used as a general index of nutrient availability only (e.g. see Potts et al. 2002).

The structure of soil pore spaces appears to influence the establishment of testate amoeba species in a given habitat on the basis of test shape. Sites with a high presence of cobbles are typically well-drained due to the high connectivity of large pore spaces. The greater frequency of species with compressed tests at these sites suggests that water is present in pore spaces as a water film that is most efficiently used by species with low-profile tests (Foissner 1987). The greater frequency of terete tests at sites with high foliar cover of tall shrub and forb species may also relate to pore space structure. Litter input from deciduous species amends the ability of soil to absorb and retain water and thus increases the pooling of soil water in pore spaces. Under conditions of abundant and pooled soil water, a compressed test provides no distinct advantage.

The reason that less protected acrostomic apertures become more common with increasing availability of Mn is not clear. This correlation may be purely coincidental or may relate to an effect of general nutrient availability on prey species that are preferred by testate amoeba species with acrostomic apertures. Response to increase in Mn is also reflected in the transition in taxonomic order from Euglyphida (dominated by species with filose pseudopodia and siliceous tests) to Arcellinida (dominated by species with lobose pseudopodia and agglutinate tests). Species belonging to Order Euglyphida become more common in communities associated with greater availability of K and P and low vegetation cover. Similarly, the reasons for this correlation are not obvious but may relate to a trophic or compositional division between orders. For example, species may have different nutrient requirements, pseudopod morphology, and test composition. These characters are used to define orders and together may influence where species can feed and construct their tests most efficiently. Additional research describing the requirements of testate amoeba taxonomic orders is necessary to answer these questions.

The transition in test composition from agglutinate to siliceous types with increase in distance from the glacier may relate to the relative availability of raw materials for test construction. Agglutinated mineral tests likely require less energy to manufacture in young soils where the appropriate sized mineral grains are common. Similarily, the silica necessary to manufacture siliceous plates becomes more available on late-seral terrains as quartz-rich soils age and weather (Kendrick and Graham 2004) and in organic soils where biogenic silica accumulates more rapidly, due in part to the death of siliceous testate amoebae (Bobrov 2005). For carnivorous testate amoeba species that integrate recycled plates in the construction of their siliceous tests, more frequent interactions with prey species in well-hydrated, organic soils would facilitate predation. The successional transition from filose to lobose testate amoebae observed by Wanner and Xylander (2005) was not supported by the results of this study, thus the change in test composition along McCarty Fjord is not phylogenetic in nature.

Conclusions

Although this dataset has not been phylogenetically corrected (see Felsenstein 1985, Armbruster et al. 2002 for discussions of phylogenetic comparative methods), the occurrence of testate amoeba morphospecies and phenotype morphology along the McCarty Fjord chronosequence does not respond significantly to change in terrain age. Variation in species morphology and taxonomy is instead related to measurements of soil nutrient availability and soil pore space structure. Stronger correlations to small-scale variables such as these suggest that testate amoebae may be better indicators of mesoscale soil gradients opposed to macroscale landscape gradients.

Appendix II: Positional Data for McCarty Fjord Sites. Distances from the glacier were measured using the digital measurement tool in ArcMap (Environmental Systems Research Institute 2006). The distance measurements for Sites 1-15 are taken from the year 2000 terminus of the McCarty Fjord glacier. The distance measurement for Site 16 is not applicable since the site is located outside of the McCarty Fjord and the range of Little Ice Age glaciation. Latitude, longitude and elevation were recorded for each site with a handheld Garmin 76SMap GPS unit. Longitude references the North American Datum 1927. Terrain slope was calculated using a Suunuto clinometer. Aspect was recorded in degrees from magnetic north using a compass.

Site number	Distance from glacier (km)	Latitude (decimal degrees)	Longitude (decimal degrees)	Elevation (m)	Slope (degrees)	Aspect (degrees from magnetic North)
1	0.2	59.74090543	-150.21324595	19.2	11	268
2	0.6	59.73825088	-150.21060959	42.7	15	270
3	0.8	59.73571267	-150.21535585	11.0	10	227
4	3.5	59.71675582	-150.25594329	81.4	23	80
5	5.7	59.69492926	-150.24284480	27.4	35	260
6	8.3	59.67801148	-150.29331802	144.5	40	100
7	8.4	59.67557880	-150.28769611	17.4	12.5	140
8	11.0	59.64999614	-150.27411726	23.5	37	310
9	11.2	59.64817710	-150.27305528	110.0	5	320
10	12.9	59.62988787	-150.25950233	19.8	30	310
11	21.8	59.56984260	-150.39088639	53.6	50	200
12	22.3	59.56627141	-150.39993868	16.5	5	135
13	30.4	59.47810946	-150.34305741	36.6	23	208
14	30.5	59.47643702	-150.33965092	131.7	20	283
15	30.6	59.47775440	-150.34162075	61.9	20	275
16	not applicable	59.53368005	-150.25583616	169.2	0	not avalible

Appendix III: Unvegetated Groundcover Data for McCarty Fjord Sites. Cobbles are rocks with diameters greater than 20 cm. Gravel are rocks with diameters between 20 cm and 2 mm. Sand is material between 2 mm and 0.02 mm in diameter. Silt is material less than 0.02 mm in diameter. Wood is defined as material greater than 1 cm in diameter. Litter is poorly decomposed organic material less than 1 cm in diameter.

Site Number	Unvegetated cover (%)	Bedrock cover (%)	Cobble cover (%)	Gravel cover (%)	Sand cover (%)	Silt cover (%)	Wood cover (%)	Litter cover (%)
1	100	0.0	65.0	30.0	5.0	0.0	0.0	0.0
2	70	0.0	1.4	0.0	0.0	0.0	0.0	68.6
3	95	0.0	52.3	38.0	1.0	0.0	0.0	4.8
4	60	0.0	0.6	0.0	0.0	0.0	0.0	59.4
5	30	0.0	12.0	0.0	0.0	0.0	3.0	15.0
6	15	0.0	6.0	0.0	0.0	0.0	0.8	8.3
7	40	0.0	4.0	0.0	0.0	0.0	12.0	24.0
8	3	0.0	0.9	0.0	0.0	0.0	2.1	0.0
9	3	0.0	0.0	0.0	0.0	0.0	0.0	2.1
10	50	0.0	0.0	0.0	0.0	0.0	2.5	47.5
11	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	60	1.8	0.0	0.0	0.0	0.0	0.0	58.2
15	5	0.0	0.0	0.0	0.0	0.0	1.0	4.0
16	3	0.0	3.0	0.0	0.0	0.0	0.0	0.0

Appendix IV: Soil Physical and Chemical Data for McCarty Fjord Sites. Bedrock type was assigned based on the Geologic Maps of the Seldovia, Seward and Blying Sound Quadrangles (Bradley et al. 1999, Tysdall and Case 1979). Organic horizons were characterized in accordance with the USDA Keys to Soil Taxonomy (Soil Survey Staff 2006). Fine material was separated using a <0.075 mm diameter hand sieve. The fine fraction of each soil sample was analyzed for pH from a 1:1 slurry preparation, total organic C, total N using combustion analysis, and available nitrogen (NH_4^+, NO_3^-), Na, Mg, P, K, Ca, Mn, Fe, Cu and Zn by inductively coupled plasma emission spectroscopy.

Site number	Bedrock type	Organic horizon thickness (cm)	Percent weight fine material	pH	Total organic C	Total orgainc N	NH4+ (ppm)	NO3- (ppm)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Mn (ppm)	Fe (ppm)
1	Metasediment	0.0	37	4.71	0.2	0.01	0.8	2.2	250	452	12	24	110	37	8	1.5	0.7
2	Metasediment	2.5	36	3.96	6.18	0.38	8.1	28.1	117	399	39	60	671	152	8	1.5	7.7
3	Metasediment	0.0	13	4.78	0.31	0.01	0.6	2.1	106	928	9	16	79	46	7	1.7	0.7
4	Metasediment	5.1	27	4.3	7.06	0.49	4.7	43.5	180	490	20	61	1400	155	11	2.1	3.9
5	Metasediment	5.1	30	4.96	39.36	2.19	52.3	4.5	99	321	106	928	3840	1390	54	2.8	35
6	Metasediment	7.6	25	4.87	19.92	1.26	13.9	58.6	56	19	117	399	3618	589	32	2.1	18.5
7	Metasediment	10.2	62	4.13	40.32	2.86	259	423	44	39	250	452	4322	650	34	2.4	34.2
8	Metasediment	2.5	35	4.13	2.37	0.15	4.8	4.1	45	50	11	100	380	138	17	1.4	2
9	Metasediment	5.1	27	4.17	9.23	0.57	7.3	11.5	12	24	20	79	727	158	16	8.7	7.5
10	Metasediment	2.5	57	3.83	45.57	3.04	248	215	9	16	180	490	3256	820	42	2.6	36.2
11	Metasediment	12.7	55	3.56	24.05	1.43	35.1	1.2	11	100	31	130	534	316	74	0.6	2.1
12	Metasediment	15.2	73	3.63	39.82	1.15	71.7	0.9	20	61	54	588	1572	802	113	1.4	9.3
13	Granodiorite	33.0	84	4.82	17.36	1.05	312	12.6	1	124	19	173	179	139	58	0.1	0.9
14	Granodiorite	17.8	79	4.49	21.26	1.39	65.6	1.9	4	83	1	124	106	65	40	0.6	0.7
15	Granodiorite	25.4	33	3.72	38.05	0.71	58.3	1.7	5	73	46	566	780	746	212	0.2	5.2
16	Granodiorite	53.3	60	4.76	39.83	0.91	50.8	11.2	18	104	4	348	2372	844	156	0.1	7.6

Appendix V: Dendrochronological Data for Tall Shrub and Tree Species Cored at McCarty Fjord Sites. The number of annual rings counted indicates the minimum time since deglaciation in years.

Site Number	Species	Diameter (cm) measured at breast height (1.4 m)	Height (m)	Number of rings
2	*Alnus viridis* ssp. *sinuata*	6.35	3.7	20
3	*Alnus viridis* ssp. *sinuata*	2.54	1.2	3
4	*Populus balsamifera* ssp. *trichocarpa*	20.574	10.7	26
4	*Alnus viridis* ssp. *sinuata*	9.398	4.6	24
7	*Populus balsamifera* ssp. *trichocarpa*	not recorded	9.1	31
8	*Alnus viridis* ssp. *sinuata*	6.858	5.5	23
8	*Salix sitchensis*	10.16	4.6	12
9	*Picea sitchensis*	19.812	9.1	23
9	*Populus balsamifera* ssp. *trichocarpa*	11.684	9.1	21
10	*Picea sitchensis*	17.78	6.1	37
11	*Picea sitchensis*	55.88	24.4	92
12	*Picea sitchensis*	32.131	18.3	70
12	*Picea sitchensis*	13.716	18.3	59
13	*Tsuga mertensiana*	35.306	10.7	390
14	*Tsuga mertensiana*	22.606	6.1	246
15	*Tsuga mertensiana*	60.452	18.3	334

Appendix VI: Plant Community Data for McCarty Fjord Sites. Plant communities were defined by cluster analysis using PC-ORD (McCune and Mefford 1999). Moisture classes were determined from the type and percent cover of plant species present at a site in accordance with the classification developed by Viereck et al. (1992). Percent foliar cover was summed from the percent covers of individual species recorded at a site. Percent foliar cover may exceed 100% when multiple strata of vegetation are present.

Site number	Communtiy type	Moisture class	Percent foliar cover	Species richness	Shannon's diversity
1	Depauperate	Dry	0	1	0.00
2	Open Alder	Dry	136	16	1.66
3	Open Alder	Dry	66	6	0.34
4	Closed Tall Alder-Willow	Mesic	248	21	2.26
5	Closed Tall Alder-Willow	Mesic	147	20	2.23
6	Open Alder	Mesic	109	23	2.36
7	Closed Tall Alder-Willow	Mesic	236	19	2.01
8	Closed Tall Alder-Willow	Mesic	247	26	2.18
9	Closed Tall Alder-Willow	Wet	177	35	2.72
10	Closed Tall Alder-Willow	Mesic	221	15	1.94
11	Closed Spruce	Mesic	239	17	2.03
12	Closed Spruce	Mesic	185	7	1.06
13	Open Hemlock	Wet	326	38	2.59
14	Wetland	Wet	164	34	2.29
15	Open Hemlock	Mesic	274	19	1.92
16	Wetland	Wet	184	35	2.50

Appendix VII: Percent Foliar Cover of Plant Species at McCarty Fjord Sites. Taxonomic ranks are assigned at the species level for vascular plants. Vascular plant taxa not identifiable to the specific or generic level are identified by genus or life form, respectively. Non-vascular species were classified as moss, *Sphagnum*, lichen or fungi.

	Site number															
Species name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Achillea millefolium var. *borealis*					3	10	1	0.01								
Agrostis aequivalvis													3	3		2
Agrostis alaskana		3							1							
Agrostis exarata					1		0.01	1								
Alnus viridis ssp. *sinuata*		75	60	65	30	30	80	40	20	80			1	1		2
Anaphalis margaritacea						4										
Andromeda polifolia														1		3
Anemone narcissiflora														1		
Arabis lyrata						0.01	0.01									
Aruncus dioicus											2					
Athyrium filix-femina		1		7	1	6	35	30	3	40	20					
Calamagrostis canadensis		7	0.01	3	7		10	10	15	3				1		0.01
Calamagrostis nutkaensis													5			
Campanula rotundifolia						2										
Cardamine oligosperma var. *kamtschatica*				1												
Carex anthoxanthea													6			
Carex macrochaeta									0.01		0.01		2			0.01
Carex mertensii		2		5	2	2	1	0.01	5							
Carex spp.										0.01						
Carex stylosa														1		1
Castilleja unalaschcensis						0.01										
Chamerion angustifolium ssp. *angustifolium*		2														
Chamerion latifolium		1	1			1										

Appendix VII: Plant Percent Foliar Cover of Plants at McCarty Fjord Sites (continued).

	Site number															
Species name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Conioselinum chinense																0.01
Coptis trifolia													1	0.01		0.01
Corallorrhiza trifida									0.01							
Cornus canadensis													3		3	
Cryptogramma sitchensis						1										
Deschampsia beringensis			0.01											2		
Deschampsia cespitosa ssp. *cespitosa*													2			
Dodecatheon jeffreyi																3
Dodecatheon spp.														0.01		
Drosera rotundifolia														0.01		4
Dryopteris expansa		1						10	5	20	20		1		3	
Elliottia pyroliflorus																5
Empetrum nigrum													40	5		10
Epilobium ciliatum				15	1.5	4	1	2								
Epilobium hornemannii		2			1.5	0.01		8	2							
Epilobium spp.					1											
Equisetum arvense				20	3	2		2	30	3						
Equisetum variegatum				0.01												
Erigeron peregrinus													2	2		2
Eriophorum angustifolium																55
FORB						0.01										
FUNGI								0.01								
Galium triflorum				2			3									

Appendix VII: Plant Percent Foliar Cover of Plants at McCarty Fjord Sites (continued).

	Site number															
Species name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Gentiana douglasiana													3	3		2
Gentiana platypetala														1		1
Geum calthifolium													5	3		6
Geum macrophyllum				0.01					0.01							
GRASS					0.01											
Gymnocarpium dryopteris											20	0.01			5	
Harrimanella stelleriana													1			4
Heracleum maximum						10	5	0.01								
Heuchera glabra				2	2	10	3	20	1							
Huperzia selago														0.01		
Iris setosa														0.01		
LICHEN	0.01	1							0.02					5		5
Listera cordata												5			0.01	
Loiseleuria procumbens														1		2
Lycopodium annotinum													3		1	
Lycopodium clavatum													1	1		
Malus fusca													1			
Menziesia ferruginea													3		3	
Moneses uniflora												0.01			1	
MOSS		30	5	47	70	15	60	86	25	36	85	100	85	33	94	6
Nephrophyllidium crista-galli													70	20	1	15
Oplopanax horridus								1	0.01		5					
Orthilia secunda					1				2							

Appendix VII: Plant Percent Foliar Cover of Plants at McCarty Fjord Sites (continued).

	Site number															
Species name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Pedicularis parviflora														0.01		
Phegopteris connectilis										3			1			
Phleum alpinum				1												
Picea sitchensis									7	1	70	80	5	1	10	
Pinguicula vulgaris													0.01	0.01		0.01
Platanthera hyperborea													1			
Poa glauca		3		3	5	2	1	5								
Populus balsamifera ssp. *trichocarpa*				9			5		3							
Pyrola asarifolia									2							
Pyrola minor									4							
Rubus pedatus											3		3		5	
Rubus spectabilis				1				0.01	2	20	7		1		0.01	
Salix barclayi									15							
Salix sitchensis		2	0.01	20	15	5	5	30	30	2						
Sambucus racemosa				4			20	0.01	1	4	5					
Sanguisorba canadensis																0.01
Saxifraga nelsoniana								1								
Selaginella selaginoides														0.01		0.01
Senecio lugens						1										
Sorbus sitchensis var. *sitchensis*													1			
Sphagnum spp.											0.01		5	10	5	30

Appendix VII: Plant Percent Foliar Cover of Plants at McCarty Fjord Sites (continued).

	Site number															
Species name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Spiranthes romanzoffiana														0.01		0.01
Stellaria borealis ssp. *sitchana*		2		1			3		1							
Stellaria crassifolia					1.5	0.01										
Stellaria crispa							0.01	1	1							
Stellaria longipes				30												
Stellaria sitchana								1								
Stellaria spp.						3										
Streptopus amplexifolius									1	1	2					
Thelypteris quelpaertensis													0.01			
Tiarella trifoliata										4	2					0.01
Trichophorum caespitosum														60		10
Trisetum spicatum		2			2	0.01										
Tsuga mertensiana													45	3	70	2
Vaccinium ovalifolium											3	0.01	5		75	
Vaccinium oxycoccos																1
Vaccinium uliginosum													5	5		12
Vaccinium vitis-idaea													2			
Vahlodea atropurpurea																0.01
Veratrum viride													1		1	

Appendix VIII*:* List of Plant Taxa and Life Forms Recorded at McCarty Fjord Sites*.* Species names and authority are in accordance with the Integrated Taxonomic Information System (www.itis.gov, accessed Fall 2006).

Species Name	Species Code	Life Form
Achillea millefolium var. *borealis* (Bong.) Farw.	ACMI	forb
Agrostis aequivalvis (Trin.) Trin.	AGAE	grass
Agrostis alaskana Hulten	AGAL2	grass
Agrostis exarata Trin.	AGEX	grass
Alnus viridis ssp. *sinuata* (Regel) A.& D. Love	ALVIS	shrub
Anaphalis margaritacea (L.) Benth. & Hook. f.	ANMA	forb
Andromeda polifolia L.	ANPO	dwarf shrub
Anemone narcissiflora L.	ANNA	forb
Arabis lyrata L.	ARLY2	forb
Aruncus dioicus var. *vulgaris* (Maxim.) Hara	ARDI8	forb
Athyrium filix-femina (L.) Roth	ATFI	forb
Calamagrostis canadensis (Michx.) Beauv.	CACA4	grass
Calamagrostis nutkaensis (J. Presl) J. Presl ex Steud.	CANU	grass
Campanula rotundifolia L.	CARO2	forb
Cardamine oligosperma var. *kamtschatica* (Regel) Detling	CAOLK	forb
Carex anthoxanthea J.& K. Presl	CAAN10	sedge
Carex L.	CAREX	sedge
Carex macrochaeta C.A. Mey.	CAMA11	sedge
Carex mertensii Prescott ex Bong.	CAME6	sedge
Carex stylosa C.A. Mey.	CAST10	sedge
Castilleja unalaschcensis (Cham. & Schlecht.) Malte	CAUN4	forb
Chamerion angustifolium ssp. *angustifolium* (L.) Holub	CHANA2	forb
Chamerion latifolium (L.) Holub	CHLA13	forb
Cladina (Nyl.) Nyl.	LICHEN	lichen
Cladina rangiferina (L.) Nyl.	LICHEN	lichen
Cladonia P. Browne	LICHEN	lichen
Conioselinum chinense (L.) B.S.P.	COCH2	forb
Coptis trifolia (L.) Salisb.	COTR2	forb
Corallorrhiza trifida Chatelain	COTR3	forb

Appendix VIII: List of Plant Taxa Recorded at McCarty Fjord Sites (continued).

Species name	Species Code	Life form
Cornus canadensis L.	COCA13	dwarf shrub
Cryptogramma sitchensis (Rupr.) T. Moore	CRSI7	forb
Deschampsia beringensis Hulten	DEBE2	grass
Deschampsia cespitosa ssp. *cespitosa* (L.) Beauv.	DECA18	grass
Dicranum Hedw.	MOSS	moss
Dodecatheon L.	DODEC	forb
Dodecatheon jeffreyi Van Houtte	DOJE	forb
Drosera rotundifolia L.	DRRO	forb
Dryopteris expansa (K. Presl) Fraser-Jenkins & Jermy	DREX2	forb
Elliottia pyroliflorus (Bong.) S.W. Brim & P.F. Stevens	ELPY	shrub
Empetrum nigrum L.	EMNI	dwarf shrub
Epilobium L.	EPILO	forb
Epilobium ciliatum ssp. *ciliatum* Raf.	EPCI	forb
Epilobium ciliatum ssp. *glandulosum* (Lehm.) Hoch & Raven	EPCI	forb
Epilobium hornemannii Reichenb.	EPHO	forb
Epilobium hornemannii ssp. *behringianum* (Hausskn.) Hoch & Raven	EPHO	forb
Equisetum arvense L.	EQAR	forb
Equisetum variegatum Schleich. ex F. Weber & D.M.H. Mohr	EQVA	forb
Erigeron peregrinus (Banks ex Pursh) Greene	ERPE3	forb
Eriophorum angustifolium Honckeny	ERAN6	sedge
Forb species	FORB	forb
Fungi species	FUNGI	fungi
Galium triflorum Michx.	GATR3	forb
Gentiana douglasiana Bong.	GEDO	forb
Gentiana platypetala Griseb.	GEPL	forb
Geum calthifolium Menzies ex Sm.	GECA6	forb
Geum macrophyllum Willd.	GEMA4	forb
Gramminoid species	GRASS	grass
Gymnocarpium dryopteris (L.) Newman	GYDR	forb
Harrimanella stelleriana (Pallas) Coville	HAST3	dwarf shrub
Heracleum maximum Bartr.	HEMA80	forb

Appendix VIII: List of Plant Taxa Recorded at McCarty Fjord Sites (continued).

Species name	Species Code	Life form
Heuchera glabra Willd. ex Roemer & J.A. Schultes	HEGL5	forb
Huperzia selago (L.) Bernh.	HUSE	forb
Hylocomium splendens (Hedw.) Schimp. in B.S.G.	MOSS	moss
Iris setosa Pallas ex Link	IRSE	forb
Lichen species	LICHEN	lichen
Listera cordata (L.) R. Br. ex Ait. f.	LICO6	forb
Loiseleuria procumbens (L.) Desv.	LOPR	dwarf shrub
Lycopodium annotinum L.	LYAN2	forb
Lycopodium clavatum L.	LYCL	forb
Malus fusca (Raf.) Schneid.	MAFU	tree
Menziesia ferruginea Sm.	MEFE	shrub
Moneses uniflora (L.) Gray	MOUN2	forb
Bryophyte species	MOSS	moss
Nephrophyllidium crista-galli (Menzies ex Hook.) Gilg	NECR2	forb
Oplopanax horridus Miq.	OPHO	shrub
Orthilia secunda (L.) House	ORSE	forb
Pedicularis parviflora Sm. ex Rees	PEPA4	forb
Peltigera Willd.	LICHEN	lichen
Phegopteris connectilis (Michx.) Watt	PHCO24	forb
Phleum alpinum L.	PHAL2	grass
Picea sitchensis (Bong.) Carr.	PISI	tree
Pinguicula vulgaris L.	PIVU	forb
Plagiomnium insigne (Mitt.) T. Kop.	MOSS	moss
Platanthera hyperborea var. *gracilis* (Lindl.) Luer	PLHY2	forb
Pleurozium schreberi (Brid.) Mitt.	MOSS	moss
Poa glauca Vahl	POGL	grass
Polytrichum Hedw.	MOSS	moss
Polytrichum juniperinum Hedw.	MOSS	moss
Populus balsamifera ssp. *trichocarpa* (Torr. & Gray ex Hook.) Brayshaw	POBAT	tree
Ptilium crista-castrensis (Hedw.) De Not.	MOSS	moss

Appendix VIII: List of Plant Taxa Recorded at McCarty Fjord Sites (continued).

Species name	Species Code	Life form
Pyrola asarifolia Michx.	PYAS	forb
Pyrola minor L.	PYMI	forb
Racomitrium canescens (Hedw.) Brid.	MOSS	moss
Racomitrium lanuginosum (Hedw.) Brid.	MOSS	moss
Rhizomnium glabrescens (Kindb.) T. Kop.	MOSS	moss
Rhytidiadelphus (Lindb. ex Limpr.) Warnst.	MOSS	moss
Rhytidiadelphus loreus (Hedw.) Warnst.	MOSS	moss
Rubus pedatus Sm.	RUPE	dwarf shrub
Rubus spectabilis Pursh	RUSP	shrub
Salix barclayi Anderss.	SABA3	shrub
Salix sitchensis Sanson ex Bong.	SASI2	shrub
Sambucus racemosa L.	SARA2	shrub
Sanguisorba canadensis L.	SACA14	forb
Saxifraga nelsoniana ssp. *nelsoniana* D. Don	SANE3	forb
Selaginella selaginoides (L.) Beauv. ex Mart. & Schrank	SESE	forb
Senecio lugens Richards.	SELU	forb
Sorbus sitchensis M. Roemer	SOSI2	shrub
Sphagnum L.	SPHAG2	moss
Sphagnum papillosum Lindb.	SPHAG2	moss
Spiranthes romanzoffiana Cham.	SPRO	forb
Stellaria L.	STELL	forb
Stellaria borealis ssp. *sitchana* (Steud.) Piper	STBOS	forb
Stellaria crassifolia Ehrh.	STCR	forb
Stellaria crispa Cham. & Schlecht.	STCR2	forb
Stellaria longipes Goldie	STLO2	forb
Stellaria sitchana Steud.	STSI3	forb
Stereocaulon Hoffm.	LICHEN	lichen
Streptopus amplexifolius (L.) DC.	STAM2	forb

Appendix VIII: List of Plant Taxa Recorded at McCarty Fjord Sites (continued).

Species name	Species Code	Life form
Thelypteris quelpaertensis (Christ) Ching	THQU2	forb
Tiarella trifoliata L.	TITR	forb
Trichophorum caespitosum (L.) Hartman	TRCE3	sedge
Trisetum spicatum (L.) Richter	TRSP2	grass
Trisetum spicatum ssp. *alaskanum* (Nash) Hulten	TRSP2	grass
Tsuga mertensiana (Bong.) Carr.	TSME	tree
Vaccinium ovalifolium Sm.	VAOV	shrub
Vaccinium oxycoccos L.	VAOX	dwarf shrub
Vaccinium uliginosum L.	VAUL	dwarf shrub
Vaccinium vitis-idaea L.	VAVI	dwarf shrub
Vahlodea atropurpurea (Wahlenb.) Fries ex Hartman	VAAT2	grass
Veratrum viride Ait.	VEVI	forb

Appendix IX: Testate Amoeba Community Data for McCarty Fjord Sites. Testate amoeba communities were defined by cluster analysis using PC-ORD (McCune and Mefford 1999).

Site number	Community type	Abundance (number of individuals)	Species richness	Shannon's diversity
1	Depauperate	0	0	0.00
2	*Corythion dubium*	66	14	2.11
3	*Centropyxis aerophila -Trinema complanatum*	13	4	1.20
4	*Corythion dubium*	78	13	2.21
5	*Centropyxis aerophila -Trinema complanatum*	18	9	2.03
6	*Corythion dubium*	148	21	2.55
7	*Corythion dubium*	36	14	2.49
8	*Corythion dubium*	33	10	2.09
9	*Corythion dubium*	33	13	2.33
10	*Corythion dubium*	44	16	2.29
11	*Corythion dubium*	30	10	1.91
12	*Centropyxis aerophila -Trinema complanatum*	28	8	1.69
13	*Quadrulella symmetrica*	11	8	1.97
14	*Quadrulella symmetrica*	21	11	2.07
15	*Centropyxis aerophila -Trinema complanatum*	14	7	1.81
16	*Quadrulella symmetrica*	44	18	2.56

Appendix X: Abundance of Testate Amoeba Species at McCarty Fjord Sites.

	Site number															
Species name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Arcella arenaria var. *sphagnicola*		1								1						
Argynnia dentistoma											2			1	1	7
Assulina muscorum					1	1								2		2
Assulina scandinavica															1	
Centropyxis aerophila var. *aerophila*		5		5	1	13	2	5	6	4				1		
Centropyxis aerophila var. *sphagnicola*		1				4										
Centropyxis aerophila var. *sylvatica*				5		1	3	1	2	3	3					1
Centropyxis minuta						3										
Centropyxis orbicularis							4							1		
Centropyxis platystoma						2		2					2	1		
Corythion dubium		7	6		3					1		7			2	
Cyclopyxis arcelloides					1											
Difflugia ampulla																2
Difflugia gassowskii				1												
Difflugia glans				1												
Difflugia lithophila									1							
Difflugia lucida				1		9	2									
Difflugia parva																3
Difflugia paulii																1
Difflugia pristis		4							3							
Difflugia pulex													1			
Difflugia stoutii										1						
Difflugia tenuis					1											
Edaphonobiotus campascoides								1								
Euglypha ciliata		4	2			10	2		1						1	1
Euglypha laevis		4	4	10	4	10	1	6	3		3	3				5
Heleopera rosea									1					1		1
Heleopera sylvatica					1	3					1					
Nebela bohemica										1	1			1		1
Nebela collaris var. *collaris*				1												
Nebela collaris var. *retorta*														1		
Nebela gracilis													1			
Nebela lageniformis		1								2						
Nebela parvula												2	3			
Nebela penardiana var. *major*																8
Nebela sp. 1																1
Nebela tincta var. *tincta*															3	
Nebela tincta var. *major*		1														
Nebela tincta var. *rotunda*												2				
Nebela tubulata											1			7		
Nebela walesii						3	4									
Phryganella acropodia				12	3	22	6	5	2	15	12	11			4	1
Phryganella paradoxa			1						1			1				
Placocista spinosa															2	

Appendix IX: Abundance of Testate Amoeba Species at McCarty Fjord Sites (continued).

Species name	Site number															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Plagiopyxis callidia						2				1						
Plagiopyxis declivis var. *declivis*		1				2	1		2							1
Plagiopyxis declivis var. *major*						1										
Plagiopyxis minuta												1				
Porosia bigibbosa						1	1			2						
Pseudodifflugia gracillis		1														
Quadrulella symmetrica													1	4		5
Schoenbornia humicola				7		10	2	7	3		4		1	1		1
Schoenbornia visicicula						34		1	7	1						1
Tracheleuglypha dentata		2		3	3	10	4		1	2						
Trigonopyxis arcula										1						
Trinema complanatum		22		19		4	3	3		6	2					
Trinema enchelys				4		3				1	1		1			2
Trinema lineare		12		9			1	2		2		1	1			

Appendix XI: Testate Amoeba Taxonomic and Test Composition Data for McCarty Fjord Sites. Order membership and test composition type were taken from the taxa descriptions prepared by Ogden and Hedley (1980) and Meisterfeld (2000a, 2000b).

	Taxonomy		Test Composition			
Site Number	Proportional representation of order **Arcellinida**	Proportional representation of order **Euglyphida**	Proportional representation of **agglutinate** test compositions	Proportional representation of **proteinaceous** test compositions	Proportional representation of **siliceous** test compositions	Proportional representation of **proteinaceous/agglutinate** test compositions
1	0.00	0.00	0.00	0.00	0.00	0.00
2	0.50	0.50	0.29	0.07	0.57	0.07
3	0.25	0.75	0.25	0.00	0.75	0.00
4	0.62	0.38	0.46	0.00	0.54	0.00
5	0.56	0.44	0.44	0.00	0.56	0.00
6	0.71	0.29	0.48	0.00	0.52	0.00
7	0.64	0.36	0.43	0.00	0.57	0.00
8	0.60	0.40	0.50	0.00	0.50	0.00
9	0.77	0.23	0.54	0.00	0.46	0.00
10	0.69	0.31	0.38	0.06	0.56	0.00
11	0.70	0.30	0.20	0.00	0.80	0.00
12	0.63	0.38	0.38	0.00	0.63	0.00
13	0.75	0.25	0.25	0.00	0.75	0.00
14	0.91	0.09	0.27	0.00	0.73	0.00
15	0.43	0.57	0.14	0.00	0.86	0.00
16	0.78	0.22	0.33	0.00	0.67	0.00

Appendix XII: Testate Amoeba Test and Aperture Morphology Data for McCarty Fjord Sites. Aperture morphologies were classified following a simplification of the types presented by Chardez and Lambert (1981). Test shapes were taken from the taxa descriptions prepared by Ogden and Hedley (1980) and Meisterfeld (2000a, 2000b).

			Aperture Morphology					Test Shape	
Site Number	Average test length (um)	Number of tests measured	Proportional representation of **acrostomic** aperture morphologies	Proportional representation of **axial** aperture morphologies	Proportional representation of **cotylostomic** aperture morphologies	Proportional representation of **cryptostomic** aperture morphologies	Proportional representation of **plagiostomic** aperture morphologies	Proportional representation of **compressed** test morphologies	Proportional representation of **terete** test morphologies
1	na	0	na	na	na	na	na	0.00	0.00
2	59.30	16	0.43	0.14	0.00	0.07	0.36	0.57	0.43
3	36.27	23	0.75	0.00	0.00	0.00	0.25	0.75	0.25
4	45.43	33	0.54	0.08	0.00	0.00	0.38	0.38	0.62
5	56.80	17	0.56	0.22	0.00	0.00	0.22	0.56	0.44
6	60.94	11	0.48	0.05	0.00	0.14	0.33	0.67	0.33
7	69.43	22	0.50	0.07	0.00	0.07	0.36	0.57	0.43
8	39.00	18	0.30	0.10	0.10	0.00	0.50	0.40	0.60
9	56.35	10	0.69	0.08	0.00	0.08	0.15	0.46	0.54
10	79.05	6	0.38	0.19	0.00	0.06	0.38	0.44	0.56
11	64.67	9	0.60	0.10	0.00	0.00	0.30	0.60	0.40
12	55.68	10	0.50	0.13	0.00	0.13	0.25	0.63	0.38
13	62.00	12	0.63	0.00	0.00	0.00	0.38	0.50	0.50
14	82.38	8	0.73	0.00	0.00	0.00	0.27	0.82	0.18
15	70.65	14	0.71	0.14	0.00	0.00	0.14	0.86	0.14
16	102.31	28	0.78	0.06	0.00	0.06	0.11	0.61	0.39

Appendix XIII: List of Testate Amoeba Species Recorded from the Kenai Fjords Region. Taxonomy, test compositions and test morphologies and were taken from the taxon descriptions prepared by Ogden and Hedley (1980) and Meisterfeld (2000a, 2000b). Hemispherical and cylindrical test shapes were treated as "terete" test morphologies in this study. Aperture morphologies were classified following a simplification of the types presented by Chardez and Lambert (1981).

Scientific name	Species Code	Taxonomic order	Test composition	Aperture morphology	Test morphology
Arcella arenaria var. *sphagnicola*	ARCARESPH	Arcellinida	proteinaceous	axial	hemispherical
Argynnia dentistoma	ARGDEN	Arcellinida	siliceous	acrostomy	compressed
Argynnia vitraea var. *sphagni*	ARGVITSP	Arcellinida	siliceous	acrostomy	compressed
Assulina muscorum	ASSMUS	Euglyphida	siliceous	acrostomy	compressed
Assulina scandinavica	ASSSCA	Euglyphida	siliceous	acrostomy	compressed
Centropyxis aerophila	CENAER	Arcellinida	agglutinate	plagiostomy	compressed
Centropyxis aerophila var. *sphagnicola*	CENAERSPH	Arcellinida	agglutinate	plagiostomy	compressed
Centropyxis aerophila var. *sylvatica*	CENAERSYL	Arcellinida	agglutinate	plagiostomy	compressed
Centropyxis constricta	CENCON	Arcellinida	agglutinate	plagiostomy	compressed
Centropyxis minuta	CENMIN	Arcellinida	agglutinate	plagiostomy	hemispherical
Centropyxis orbicularis	CENORB	Arcellinida	agglutinate	plagiostomy	hemispherical
Centropyxis platystoma	CENPLA	Arcellinida	agglutinate	plagiostomy	compressed
Corythion dubium	CORDUB	Euglyphida	siliceous	plagiostomy	compressed
Cyclopyxis arcelloides	CYCARC	Arcellinida	agglutinate	axial	hemispherical
Cyclopyxis eurystoma	CYCEUR	Arcellinida	agglutinate	axial	hemispherical
Difflugia ampulla	DIFAMP	Arcellinida	agglutinate	acrostomy	cylindrical
Difflugia angulostoma	DIFANG	Arcellinida	agglutinate	axial	hemispherical
Difflugia gassowskii	DIFGAS	Arcellinida	agglutinate	acrostomy	cylindrical
Difflugia glans	DIFGLA	Arcellinida	agglutinate	acrostomy	cylindrical
Difflugia globulosa	DIFGLO	Arcellinida	agglutinate	axial	hemispherical
Difflugia lithophila	DIFLIT	Arcellinida	agglutinate	acrostomy	cylindrical
Difflugia lucida	DIFLUC	Arcellinida	agglutinate	acrostomy	compressed
Difflugia parva	DIFPAR	Arcellinida	agglutinate	acrostomy	cylindrical
Difflugia paulii	DIFPAU	Arcellinida	agglutinate	acrostomy	cylindrical
Difflugia pristis	DIFPRI	Arcellinida	agglutinate	acrostomy	cylindrical
Difflugia pulex	DIFPUL	Arcellinida	agglutinate	acrostomy	cylindrical
Difflugia stoutii	DIFSTO	Arcellinida	agglutinate	acrostomy	cylindrical
Difflugia tenuis	DIFTEN	Arcellinida	agglutinate	acrostomy	cylindrical

Appendix XIII: List of Testate Amoeba Species Recorded from the Kenai Fjords Region (continued).

Scientific name	Species Code	Taxonomic order	Test composition	Aperture morphology	Test morphology
Edaphonobiotus campascoides	EDACAM	Euglyphida	agglutinate	cotylostomy	cylindrical
Euglypha ciliata	EUGCIL	Euglyphida	siliceous	acrostomy	compressed
Euglypha laevis	EUGLAE	Euglyphida	siliceous	acrostomy	compressed
Euglypha rotunda	EUGROT	Euglyphida	siliceous	acrostomy	compressed
Euglypha tuberculata	EUGTUB	Euglyphida	siliceous	acrostomy	cylindrical
Heleopera rosea	HELROS	Arcellinida	siliceous	acrostomy	compressed
Heleopera sylvatica	HELSYL	Arcellinida	siliceous	acrostomy	compressed
Nebela bohemica	NEBBOH	Arcellinida	siliceous	acrostomy	compressed
Nebela collaris	NEBCOL	Arcellinida	siliceous	acrostomy	compressed
Nebela collaris var. *retorta*	NEBCOLRET	Arcellinida	siliceous	acrostomy	compressed
Nebela gracilis	NEBGRA	Arcellinida	siliceous	acrostomy	compressed
Nebela lageniformis	NEBLAG	Arcellinida	siliceous	acrostomy	compressed
Nebela militaris	NEBMIL	Arcellinida	siliceous	acrostomy	compressed
Nebela parvula	NEBPAR	Arcellinida	siliceous	acrostomy	compressed
Nebela penardiana var. *major*	NEBPENMAJ	Arcellinida	siliceous	acrostomy	compressed
Nebela sp. 1	NEBSP1	Arcellinida	siliceous	acrostomy	compressed
Nebela tincta	NEBTIN	Arcellinida	siliceous	acrostomy	compressed
Nebela tincta var. *major*	NEBTINMAJ	Arcellinida	siliceous	acrostomy	compressed
Nebela tincta var. *rotunda*	NEBTINROT	Arcellinida	siliceous	acrostomy	compressed
Nebela tubulata	NEBTUB	Arcellinida	siliceous	acrostomy	compressed
Nebela walesii	NEBWAL	Arcellinida	siliceous	acrostomy	compressed
Phryganella acropodia	PHRACR	Arcellinida	agglutinate	axial	hemispherical
Phryganella paradoxa	PHRPAR	Arcellinida	agglutinate	acrostomy	cylindrical
Placocista spinosa	PLASPI	Euglyphida	siliceous	acrostomy	compressed
Plagiopyxis callidia	PLACAL	Arcellinida	agglutinate	cryptostomy	compressed
Plagiopyxis callidia var. *grandis*	PLACALGRA	Arcellinida	agglutinate	cryptostomy	compressed
Plagiopyxis declivis	PLADEC	Arcellinida	agglutinate	cryptostomy	compressed
Plagiopyxis declivis var. *major*	PLADECMAJ	Arcellinida	agglutinate	cryptostomy	compressed
Plagiopyxis minuta	PLAMIN	Arcellinida	agglutinate	cryptostomy	compressed

Appendix XIII: List of Testate Amoeba Species Recorded from the Kenai Fjords Region (continued).

Scientific name	Species Code	Taxonomic order	Test composition	Aperture morphology	Test morphology
Playfairina valkanoivi	PLAVAL	Euglyphida	siliceous	acrostomy	cylindrical
Porosia bigibbosa	PORBIG	Arcellinida	siliceous	acrostomy	compressed
Pseudodifflugia gracillis	PSEGRA	Euglyphida	proteinaceous/agglutinate	axial	cylindrical
Quadrulella symmetrica	QUASYM	Arcellinida	siliceous	acrostomy	compressed
Schoenbornia humicola	SCHHUM	Arcellinida	siliceous	acrostomy	cylindrical
Schoenbornia visicicula	SCHVIS	Arcellinida	siliceous	acrostomy	cylindrical
Tracheleuglypha dentata	TRADEN	Euglyphida	siliceous	acrostomy	cylindrical
Trigonopyxis arcula	TRIARC	Arcellinida	agglutinate	axial	hemispherical
Trinema complanatum	TRICOM	Euglyphida	siliceous	plagiostomy	cylindrical
Trinema enchelys	TRIENC	Euglyphida	siliceous	plagiostomy	cylindrical
Trinema lineare	TRILIN	Euglyphida	siliceous	plagiostomy	cylindrical

Appendix XIV: The Ecology of Select Testate Amoeba Genera and Species Recorded at McCarty Fjord Sites. Synonyms are listed parenthetically.

Genus or species name	Ecology	Citation
Arcella spp.	water, *Sphagnum* and mosses	Chardez 1968
	all species found in freshwater biotypes, wet and dry mosses, a few species in soils	Meisterfeld 2000a
Arcella arenaria	aerated moss and lichen	Grospietsch 1958
Arcella arenaria var. *sphagnicola*	skeletal soils	Coûteaux 1975
	aerated conditions, moss and soil, carbonates, psammophytes, pH optimum 7	Bonnet and Thomas 1960
	sub-aerated, *Sphagnum* lake mosses	Deflandre 1928
Argynnia spp.	*Sphagnum* mosses, herbivorous	Meisterfeld 2000a
Argynnia dentistoma (Nebela dentistoma)	wet and moist *Sphagnum* and other mosses in peatland and siliceous (acidic?) ponds with an accumulation of organic matter	Mitchell 2003e
	moss, *Sphagnum*	Grospietsch 1958
Argynnia vitraea var. *sphagni*	wet *Sphagnum* mosses in raised bogs	Mitchell 2003e
	Sphagnum and wet mosses of raised bogs	Deflandre 1936
Assulina spp.	*Sphagnum* and mosses	Chardez 1968
	mosses, soil, herbivorous	Meisterfeld 2000b
Assulina muscorum	mosses	Chardez 1968
	common in mosses, rare in soils, found in alpine mor in skeletal, acidic soils, pH optimum 6	Bonnet and Thomas 1960
	moss and commonly *Sphagnum*	Grospietsch 1958
Centropyxis spp.	wet, well-developed soil	Coûteaux 1975
	water, *Sphagnum,* mosses and soil	Chardez 1968

Appendix XIV: The Ecology of Select Testate Amoeba Genera and Species Recorded at McCarty Sites (continued).

Genus or species name	Ecology	Citation
Centropyxis aerophila var. *aerophila*	soil	Chardez 1968
	mosses growing on tree bark, soil generalist	Bonnet and Thomas 1960
	dry mosses and humus	Meisterfeld 2000a
	aerated soils	Grospietsch 1958
	clearly aerated, restricted to moss corticoles, rare or accidental in forest moss and *Sphagnum*	Deflandre 1929
Centropyxis aerophila var. *sphagnicola*	acidophile, common in aerated mor soil, humid alpine soils, brown forest soils	Bonnet and Thomas 1960
	Sphagnum	Grospietsch 1958
	sub-aerated, humid forest mosses and *Sphagnum*	Deflandre 1929
Centropyxis aerophila var. *sylvatica*	generalist, all types of soils but most common in brown forest soils	Bonnet and Thomas 1960
	aerated conditions	Grospietsch 1958
	humid with constant water, forest mosses and rocky habitats	Deflandre 1929
Centropyxis minuta	skeletal soils of varied types	Bonnet and Thomas 1960
	humid moss and *Sphagnum*	Deflandre 1929
Centropyxis orbicularis	varied soil types but generally humid soils	Bonnet and Thomas 1960
	humid *Sphagnum,* wet peat bogs, *Sphagnum* ponds	Deflandre 1929
Centropyxis platystoma	not well known, acidic soils?	Bonnet and Thomas 1960
	Sphagnum and mosses	Grospietsch 1958
	wet mosses or *Sphagnum,* boggy marshes	Deflandre 1929
Corythion spp.	*Sphagnum* and mosses	Chardez 1968
	mosses, *Sphagnum,* soils, bacterivorus	Meisterfeld 2000b

Appendix XIV: The Ecology of Select Testate Amoeba Genera and Species Recorded at McCarty Sites (continued).

Genus or species name	Ecology	Citation
Corythion dubium	acid soil	Coûteaux 1975
	mosses	Chardez 1968
	acidophile, well-drained soils, rare on carbonaceous substrates, pH optimum 5.8	Bonnet and Thomas 1960
	moss, *Sphagnum*	Grospietsch 1958
Cyclopyxis spp.	water, mosses and soil	Chardez 1968
	Sphagnum mosses, soil	Meisterfeld 2000a
Cyclopyxis arcelloides	generalist, most common in skeletal soil	Bonnet and Thomas 1960
	Sphagnum and mosses	Grospietsch 1958
	mosses or very wet or submerged *Sphagnum*	Deflandre 1929
Cyclopyxis eurystoma	generalist, all soil types	Bonnet and Thomas 1960
	aerophilic	Grospietsch 1958
	humid forest mosses	Deflandre 1929
Difflugia spp.	water, *Sphagnum* and mosses	Chardez 1968
	freshwater sediment, between water plants, planktonic, eats algae and fungi	Meisterfeld 2000a
Difflugia ampulla	described from aquatic plants	Ogden 1983
Difflugia angulostoma	described from *Sphagnum*	Ogden 1983
Difflugia gassowskii	described from *Sphagnum*	Ogden 1983
Difflugia glans	described from water plants	Ogden 1983
Difflugia lucida	mosses and humid soil	Bonnet and Thomas 1960
	dry mosses and soil	Meisterfeld 2000a
	uses quartz for test construction, found in *Sphagnum*	Grospietsch 1958
	described from *Sphagnum* and water plants	Ogden 1983

Appendix XIV: The Ecology of Select Testate Amoeba Genera and Species Recorded at McCarty Sites (continued).

Genus or species name	Ecology	Citation
Difflugia parva	described from *Sphagnum*	Ogden 1983
Difflugia paulii	described from *Sphagnum*	Ogden 1983
Difflugia pristis	described from *Sphagnum*	Ogden 1983
Difflugia pulex	described from *Sphagnum*	Ogden 1983
Difflugia stoutii	described from *Sphagnum*	Ogden 1983
Difflugia tenuis	described from *Sphagnum*	Ogden 1983
Edaphonobiotus campascoides	humus	Meisterfeld 2000b
Euglypha spp.	water, *Sphagnum,* mosses and soil	Chardez 1968
	common in mosses, *Sphagnum,* and organic soils, herbivorous	Meisterfeld 2000b
Euglypha ciliata	mosses, rare in soils	Bonnet and Thomas 1960
	fen *Sphagnum*	Mitchell 2003b
	wet *Sphagnum,* moss, aquatic plants	Grospietsch 1958
Euglypha laevis	mosses and soils	Bonnet and Thomas 1960
	Sphagnum and moss	Grospietsch 1958
Euglypha rotunda	soil	Chardez 1968
	all types of humid soils	Bonnet and Thomas 1960
	wet moss, common in fen *Sphagnum*	Mitchell 2003b
	wet moss	Grospietsch 1958
Euglypha tuberculata	water	Chardez 1968
Heleopera spp.	water, *Sphagnum* and mosses	Chardez 1968
	lake sediments, mosses, soil, except for *H. sphagni* , most species predaceous on small Euglyphida	Meisterfeld 2000a
Heleopera rosea	acidic, humid soil	Bonnet and Thomas 1960
	Sphagnum	Grospietsch 1958
Heleopera sylvatica	mosses and A horizon of brown forest soils	Bonnet and Thomas 1960

Appendix XIV: The Ecology of Select Testate Amoeba Genera and Species Recorded at McCarty Sites (continued).

Genus or species name	Ecology	Citation
Nebela spp.	water, *Sphagnum,* mosses and soil	Chardez 1968
	common in mosses *(Sphagnum)* and soil, predators of small Eugyphida	Meisterfeld 2000a
Nebela bohemica	moist and wet *Sphagnum* and other mosses in peatlands, forests and siliceous humic ponds	Mitchell 2003e
	same as *N. collaris*	Deflandre 1936
Nebela collaris	*Sphagnum*	Chardez 1968
	well-drained, acidic and humid soils	Bonnet and Thomas 1960
	moist and wet sphagnum and other mosses in peatlands, forests and siliceous humic ponds	Mitchell 2003e
	mosses and *Sphagnum* very humid or wet in high ponds of transition and siliceous ponds	Deflandre 1936
Nebela gracilis	wet *Sphagnum* mosses	Mitchell 2003e
	wet *Sphagnum*	Deflandre 1936
Nebela lageniformis	*Sphagnum* and other moist and wet mosses, in forests, peatlands and ponds with an accumulation with organic matter	Mitchell 2003e
	Sphagnum and other moist and wet mosses, in forests, peatlands and ponds with an accumulation with organic matter	Deflandre 1936
	moss, *Sphagnum*	Grospietsch 1958
Nebela militaris	*Sphagnum* and other moist mosses in peatlands and forests	Mitchell 2003e
	Sphagnum and moist forest mosses, frequent in alder forests at the margin of *Sphagnum* bogs	Deflandre 1936
	moist moss, *Sphagnum*	Grospietsch 1958
Nebela parvula	*Sphagnum* and moist forest mosses	Mitchell 2003e
	Sphagnum and moist moss	Deflandre 1936
	Sphagnum and forest moss	Grospietsch 1958

Appendix XIV: The Ecology of Select Testate Amoeba Genera and Species Recorded at McCarty Sites (continued).

Genus or species name	Ecology	Citation
Nebela penardiana	hygrophilous or aquatic species, wet *Sphagnum* and other mosses in peatlands and transitional mires	Mitchell 2003e
	wet to aquatic habitats, wet *Sphagnum* and other mosses in peatlands and transitional mires	Deflandre 1936
	very wet *Sphagnum*	Grospietsch 1958
Nebela tincta var. *tincta*	mosses	Chardez 1968
	Sphagnum, eats dead or live micro-algae, diatoms, mycelia of fungi	Gilbert et al. 2003
	moist and very moist *Sphagnum* and other mosses in peatlands and forests	Mitchell 2003e
	moist moss, *Sphagnum*	Grospietsch 1958
Nebela tincta var. *major*	moist and very moist *Sphagnum* and other mosses in peatlands and forests	Mitchell 2003e
Nebela tincta var. *rotunda*	moist and very moist *Sphagnum* and other mosses in peatlands and forests	Mitchell 2003e
Nebela tubulata	*Sphagnum* mosses	Mitchell 2003e
	Sphagnum mosses	Deflandre 1936
Nebela walesii	*Sphagnum* and other wet mosses	Mitchell 2003e
	Sphagnum and humid mosses, aerophilic	Deflandre 1936
	dry moss, *Sphagnum*	Grospietsch 1958
Phryganella spp.	water, *Sphagnum,* mosses and soil	Chardez 1968
Phryganella acropodia	aquatic, lacustrine sediments, moss, soil	Chardez 1969
	soil generalist	Coûteaux 1975
	soil	Chardez 1968
	ubiquitous, found in 95% of samples	Bonnet and Thomas 1960
	one of the most common species in *Sphagnum* and soils	Meisterfeld 2000a

Appendix XIV: The Ecology of Select Testate Amoeba Genera and Species Recorded at McCarty Sites (continued).

Genus or species name	Ecology	Citation
Porosia spp.	*Sphagnum,* soil, herbivorous, possibly carnivorous	Meisterfeld 2000a
Porosia bigibbosa (Nebela bigibbosa)	frequent in litter of deciduous forests, can be used as an indicator of this biotope	Todorov 2002
	Sphagnum and other mosses	Mitchell 2003e
	Sphagnum	Deflandre 1936
Pseudodifflugia spp.	water, *Sphagnum,* mosses and soil	Chardez 1968
	freshwater, soil, and marine and littoral sands	Meisterfeld 2000b
Pseudodifflugia gracillis	hummus, ericaceous, subalpine habitats	Bonnet and Thomas 1960
Quadrulella spp.	water, *Sphagnum*	Chardez 1968
	Sphagnum mosses, soil	Meisterfeld 2000a
Quadrulella symmetrica	avoiding calcium, acidophilus, aquatic, *Sphagnum* mosses, possibly carnivorous	Chardez 1967
	Sphagnum and humid mosses, wet or submerged, broad tolerance for ion content	Deflandre 1929
Schoenbornia spp.	soil	Chardez 1968
	acid moder and raw humus, collects detritus with bacteria and stores it around the aperture	Meisterfeld 2000a
Schoenbornia humicola	soil humus, especially acid humus, (moder and raw humus), rare in mull	Mitchell 2003e
Schoenbornia visicicula	soil humus, especially acid humus, (moder and raw humus)	Mitchell 2003e
Tracheleuglypha	mosses, soil and aquatic vegetation	Meisterfeld 2000b
Tracheleuglypha dentata	water plants, wet moss and *Sphagnum*	Grospietsch 1958

Appendix XIV: The Ecology of Select Testate Amoeba Genera and Species Recorded at McCarty Sites (continued).

Genus or species name	Ecology	Citation
Trigonopyxis spp.	*Sphagnum,* mosses and soil	Chardez 1968
	acid forest soil, litter, mosses (e.g. *Sphagnum*), eats bacteria and fungi	Meisterfeld 2000a
Trigonopyxis arcula	mor	Coûteaux 1975
	Sphagnum	Chardez 1968
	brown forest soils, mor, pH optimum 5.8	Bonnet and Thomas 1960
	dry *Sphagnum,* moss	Grospietsch 1958
Trinema spp.	*Sphagnum,* mosses and soil	Chardez 1968
	common in freshwater, moss and soil, herbivorous	Meisterfeld 2000b
Trinema complanatum	mosses, found in all types of soils, most common in humid soils	Bonnet and Thomas 1960
	moss, *Sphagnum*	Grospietsch 1958
Trinema enchelys	mosses	Chardez 1968
	ubiquitous, found in soils at all stages of development	Bonnet and Thomas 1960
	moss, *Sphagnum*	Grospietsch 1958
Trinema lineare	ubiquitous, abundant in soils at all stages of development	Bonnet and Thomas 1960
	moss, *Sphagnum*	Grospietsch 1958

Appendix XV: List of Testate Amoeba Species Recorded in Alaska. Synonyms are provided parenthetically. Footnotes indicate: [1]species is new to Alaska; [2]species is new to Alaska but was not included in analyses.

Species name	Beyens and Chardez 1995	Mitchell 2004	Eisner et al. 2005	Nikolaev et al. 2005	Payne et al. 2006	this study
Amphitrema stenostoma					x	
Amphitrema wrightianum		x			x	
Arcella arenaria	x					
Arcella arenaria var. *sphagnicola*						x
Arcella artocrea					x	
Arcella costata	x					
Arcella catinus					x	
Arcella discoides	x	x			x	
Arcella gibbosa	x					
Arcella hemisphaerica	x					
Arcella hemisphaerica cf. *undulata*	x					
Arcella ocaliformis	x					
Arcella rotundata var. *rotundata*	x					
Arcella rotundata var. *aplanata*	x					
Arcella rotundata var. *undulata*	x					
Archerella flavum (Amphitrema flavum)		x			x	
Argynnia dentistoma (Nebela dentistoma)	x	x			x	x
Argynnia vitraea var. *sphagni*						x [1, 2]
Assulina muscorum	x	x			x	x
Assulina scandinavica					x	x
Assulina seminulum	x	x			x	
Bullinularia indica	x				x	
Centropyxis aculeata var. *aculeata*	x	x			x	
Centropyxis aculeata var. *oblonga*	x					
Centropyxis aerophila	x	x			x	x
Centropyxis aerophila var. *sphagnicola*		x			x	x
Centropyxis aerophila var. *sylvatica*						x [1]

Appendix XV: List of Testate Amoeba Species Recorded in Alaska (continued).

Species name	Beyens and Chardez 1995	Mitchell 2004	Eisner et al. 2005	Nikolaev et al. 2005	Payne et al. 2006	this study
Centropyxis cf. *discoides*					x	
Centropyxis cassis					x	
Centropyxis constricta						x [1,2]
Centropyxis ecornis	x				x	
Centropyxis ecornis var. *minuta*	x					
Centropyxis gasparella	x					
Centropyxis laevigata				x	x	
Centropyxis minuta						x [1]
Centropyxis orbicularis					x	x
Centropyxis platystoma var. *platystoma*	x	x			x	x
Centropyxis platystoma var. *armata*	x					
Corythion dubium	x	x			x	x
Corythion dubium cf. *gigas*	x					
Corythion dubium var. *orbicularis*	x					
Corythion pulchellum					x	
Cryptodifflugia oviformis					x	
Cyclopyxis arcelloides	x				x	x
Cyclopyxis eurystoma					x	x
Cyclopyxis Kahli		x			x	
Difflugia ampulla						x [1]
Difflugia angulostoma					x	x
Difflugia bacillifera	x	x			x	
Difflugia bryophila	x					
Difflugia diatomosus	x					
Difflugia cf. *rubescens*					x	
Difflugia elegans					x	
Difflugia gassowskii						x [1]
Difflugia glans					x	x
Difflugia globulosa		x			x	x
Difflugia globulus	x					

Appendix XV: List of Testate Amoeba Species Recorded in Alaska (continued).

Species name	Beyens and Chardez 1995	Mitchell 2004	Eisner et al. 2005	Nikolaev et al. 2005	Payne et al. 2006	this study
Difflugia humilis	x				x	
Difflugia lithophila						x[1]
Difflugia lucida					x	x
Difflugia manicata					x	
Difflugia minuta					x	
Difflugia oviformis		x				
Difflugia parva						x[1]
Difflugia paulii						x[1]
Difflugia pristis					x	x
Difflugia pulex	x					x
Difflugia rubescens	x					
Difflugia stoutii						x[1]
Difflugia tenuis						x[1]
Ditrema flavum	x					
Edaphonobiotus campascoides						x[1]
Euglypha acanthophora	x					
Euglypha ciliata		x			x	x
Euglypha compressa					x	
Euglypha cristata					x	
Euglypha laevis					x	x
Euglypha polyepis	x					
Euglypha rotunda	x	x			x	x
Euglypha strigosa	x				x	
Euglypha strigosa cf. *glabra*	x					
Euglypha tuberculata	x				x	x
Heleopera petricola var. *petricola*	x				x	
Heleopera petricola var. *amethystea*	x					
Heleopera rosea		x			x	x
Heleopera sphagni				x	x	
Heleopera sylvatica					x	x

Appendix XV: List of Testate Amoeba Species Recorded in Alaska (continued).

Species name	Beyens and Chardez 1995	Mitchell 2004	Eisner et al. 2005	Nikolaev et al. 2005	Payne et al. 2006	this study
Hyalosphenia elegans	x	x			x	
Hyalosphenia minuta					x	
Hyalosphenia papilio	x	x		x	x	
Hyalosphenia subflava					x	
Lesquereusia epistomium	x				x	
Lesquereusia spiralis	x				x	
Mycrocorycia flava	x					
Nebela bohemica						x [1]
Nebela carinata					x	
Nebela collaris var. *collaris*	x	x			x	x
Nebela collaris var. *retorta*						x [1]
Nebela galeata					x	
Nebela gracilis						x [1]
Nebela lageniformis					x	x
Nebela marginata					x	
Nebela militaris	x	x			x	x
Nebela minor	x				x	
Nebela parvula						x [1]
Nebela penardiana	x				x	
Nebela penardiana var. *major*						x
Nebela tincta var. *tincta*	x	x			x	x
*Nebela tincta c*f. *stenostoma*	x					
Nebela tincta var. *major*		x			x	x
Nebela tincta var. *rotunda*						x [1]
Nebela tubulata						x [1]
Nebela tubulosa	x	x				
Nebela walesii	x					x
Paulinella chromatophora	x					
Phryganella acropodia	x	x			x	x
Phryganella paradoxa		x			x	x
Physochila griseola (*Nebela griseola*)		x			x	
Placosysta glabra	x					
Placocista spinosa (*Placocysta spinosa*)	x	x			x	x
Placocista spinosa hyalina					x	

Appendix XV: List of Testate Amoeba Species Recorded in Alaska (continued).

Species name	Beyens and Chardez 1995	Mitchell 2004	Eisner et al. 2005	Nikolaev et al. 2005	Payne et al. 2006	this study
Plagiopyxis callidia var. *callidia*						x [1]
Plagiopyxis callidia var. *grandis*						x [1,2]
Plagiopyxis declivis var. *declivis*						x [1]
Plagiopyxis declivis var. *major*						x [1]
Plagiopyxis minuta						x [1]
Playfairina valkanoivi						x [1,2]
Porosia bigibbosa						x [1]
Pseudodifflugia gracilis					x	x
Quadrulella symmetrica		x			x	x
Schoenbornia humicola					x	x
Schoenbornia visicicula						x [1]
Sphenoderia lenta	x				x	
Toquepyxis leclercqi	x					
Tracheleuglypha dentata		x			x	x
Tracheleuglypha pulchellum	x					
Trigonopyxis arcula	x			x	x	x
Trinema complanatum	x				x	x
Trinema enchelys	x	x			x	x
Trinema lineare	x	x			x	x
Unidentified taxa						
Centropyxis type			x			
Cyclopyxis sp.					x	
Difflugia sp.					x	
Nebela sp. 1						x [1]
Netzelia sp. A	x					
Phryganella sp.					x	

Appendix XVI: McCarty Fjord Site Photos.

Site 1 – Depauperate

Site 2 – Open alder

Appendix XVI: McCarty Fjord Site Photos (continued).

Site 3 – Open alder

Site 4 – Closed tall alder-willow

Appendix XVI: McCarty Fjord Site Photos (continued).

Site 5 – Closed tall alder-willow

Site 6 – Open alder

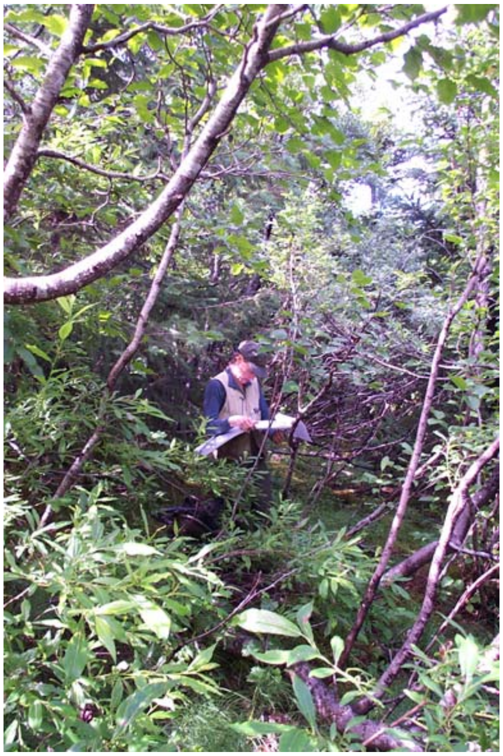
Appendix XVI: McCarty Fjord Site Photos (continued).

Site 7 – Closed tall alder-willow

Site 8 – Closed tall alder-willow

Appendix XVI: McCarty Fjord Site Photos (continued).

Site 9 – Closed tall alder-willow



Site 10 – Closed tall alder-willow

Appendix XVI: McCarty Fjord Site Photos (continued).

Site 11 – Closed spruce

Site 12 – Closed spruce

Appendix XVI: McCarty Fjord Site Photos (continued).

Site 13 – Open hemlock

Site 14 – Wetland (sedge fen)

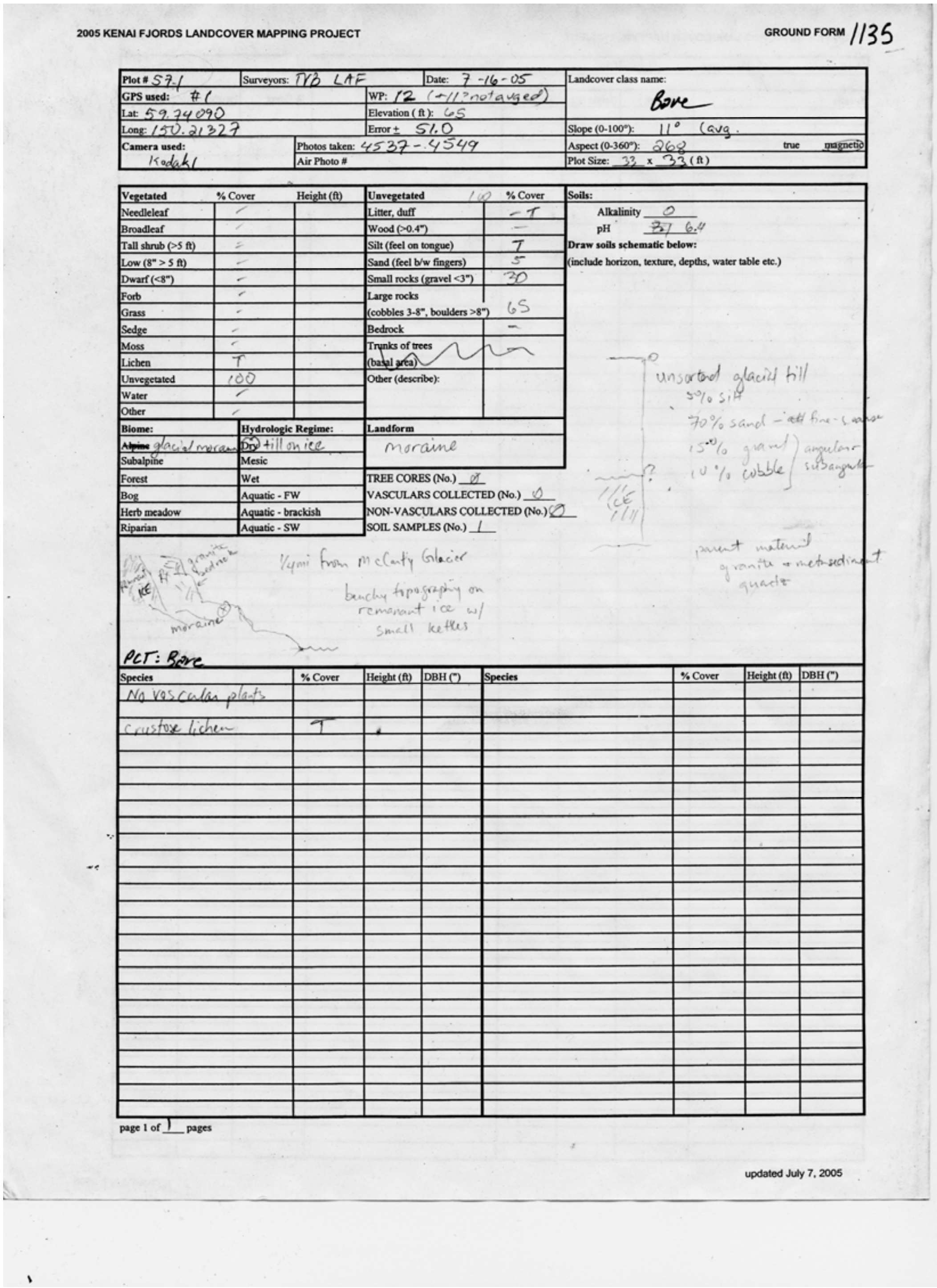
Appendix XVI: McCarty Fjord Site Photos (continued).

Site 15 – Open hemlock

Site 16 – Wetland (*Sphagnum* peatland)

Appendix XVII: McCarty Fjord Site Forms.

Site 1



2005 KENAI FJORDS LANDCOVER MAPPING PROJECT GROUND FORM 1135

Plot # 57-1
Surveyors: TYB LAF
Date: 7-16-05
Landcover class name: Bare
GPS used: #1
WP: 12 (+11? not avged)
Lat: 59.74090
Elevation (ft): 65
Long: 150.21327
Error ± 51.0
Slope (0-100°): 11° (avg.
Camera used: Kodak1
Photos taken: 4537-4549
Aspect (0-360°): 268 true [✓ magnetic]
Air Photo #
Plot Size: 33 x 33 (ft)

Vegetated	% Cover	Height (ft)
Needleleaf	-	
Broadleaf	-	
Tall shrub (>5 ft)	-	
Low (8" > 5 ft)	-	
Dwarf (<8")	-	
Forb	-	
Grass	-	
Sedge	-	
Moss	-	
Lichen	T	
Unvegetated	100	
Water	-	
Other	-	

Unvegetated 100	% Cover
Litter, duff	- T
Wood (>0.4")	-
Silt (feel on tongue)	T
Sand (feel b/w fingers)	5
Small rocks (gravel <3")	30
Large rocks (cobbles 3-8", boulders >8")	65
Bedrock	-
Trunks of trees (basal area)	-
Other (describe):	

Biome:	Hydrologic Regime:
~~Alpine~~ glacial moraine	[✓ Dry] till on ice
Subalpine	Mesic
Forest	Wet
Bog	Aquatic - FW
Herb meadow	Aquatic - brackish
Riparian	Aquatic - SW

Landform: moraine

TREE CORES (No.) 0
VASCULARS COLLECTED (No.) 0
NON-VASCULARS COLLECTED (No.) 0
SOIL SAMPLES (No.) 1

Soils:
Alkalinity 0
pH ~~7~~ 6.4
Draw soils schematic below:
(include horizon, texture, depths, water table etc.)

0
unsorted glacial till
5% silt
70% sand - fine-coarse
15% gravel
10% cobble
angular subangular
?
ICE

parent material
granite + metasediment
quartz

granite bedrock
ICE
moraine

1/4 mi from McCarty Glacier

benchy topography on remanant ice w/ small kettles

PCT: Bare

Species	% Cover	Height (ft)	DBH (")	Species	% Cover	Height (ft)	DBH (")
No vascular plants							
crustose lichen	T						

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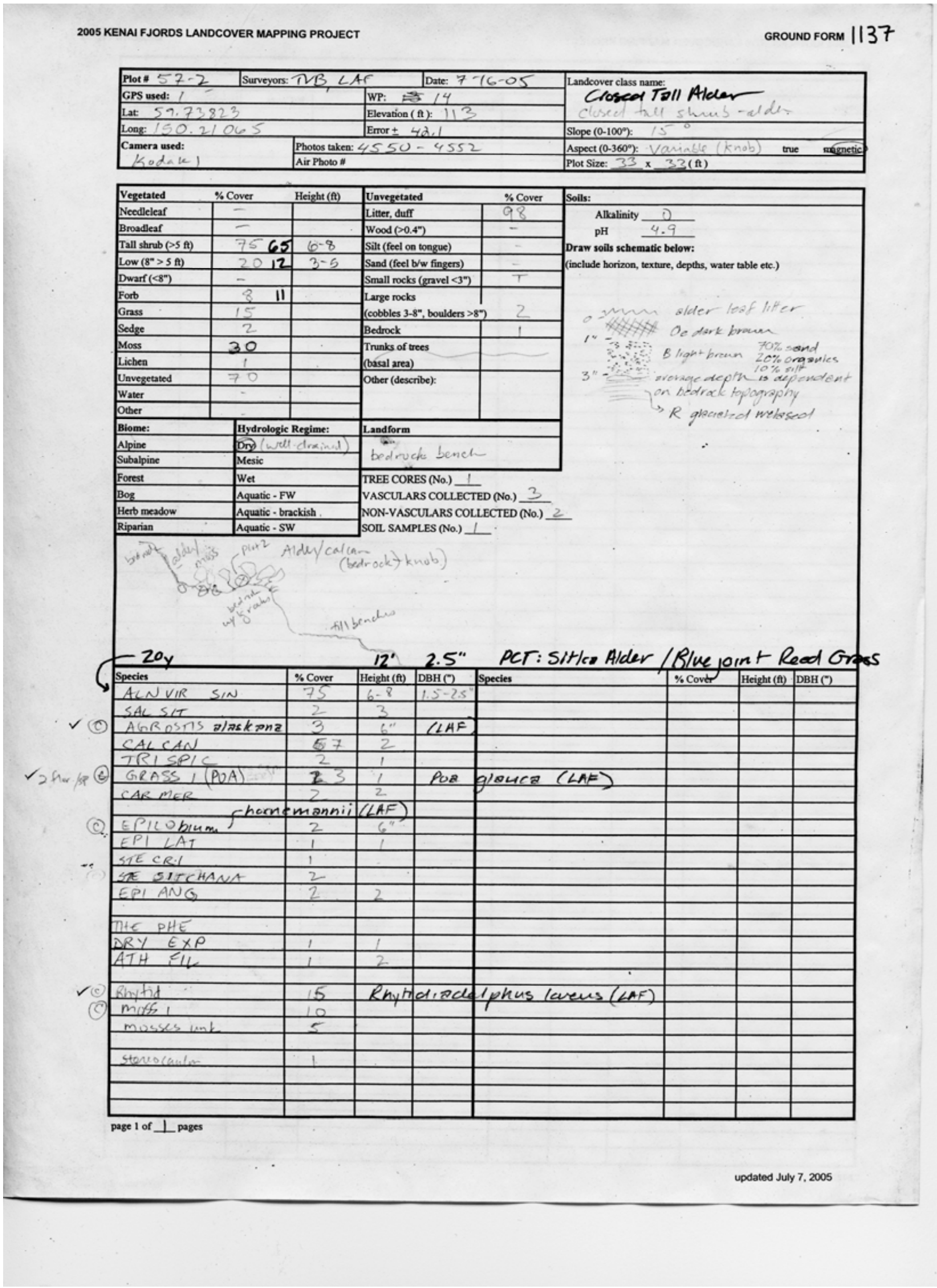
Appendix XVII: McCarty Fjord Site Forms (continued).

Site 2



2005 KENAI FJORDS LANDCOVER MAPPING PROJECT

GROUND FORM 1137

Plot # 57-2
Surveyors: TVB, LAF
Date: 7-16-05
GPS used: 1
WP: 14
Lat: 59.73823
Elevation (ft): 113
Long: 150.21065
Error ± 42.1
Camera used: Kodak)
Photos taken: 4550 - 4552
Air Photo #
Landcover class name: Closed Tall Alder
closed tall shrub-alder
Slope (0-100°): 15°
Aspect (0-360°): Variable (knob) true [✓ magnetic]
Plot Size: 33 x 32 (ft)

Vegetated	% Cover	Height (ft)
Needleleaf	–	
Broadleaf	–	
Tall shrub (>5 ft)	75 65	6-8
Low (8" > 5 ft)	20 12	3-5
Dwarf (<8")	–	
Forb	8 11	
Grass	15	
Sedge	2	
Moss	30	
Lichen	1	
Unvegetated	70	
Water	-	
Other	-	

Unvegetated	% Cover
Litter, duff	98
Wood (>0.4")	–
Silt (feel on tongue)	-
Sand (feel b/w fingers)	–
Small rocks (gravel <3")	T
Large rocks (cobbles 3-8", boulders >8")	2
Bedrock	1
Trunks of trees (basal area)	
Other (describe):	

Soils:
Alkalinity 0
pH 4.9
Draw soils schematic below:
(include horizon, texture, depths, water table etc.)

0 - alder leaf litter
Oe dark brown
1" -
B light brown 70% sand 20% organics 10% silt
3" - average depth is dependent on bedrock topography
→ R glaciated metased

Biome:	Hydrologic Regime:
Alpine	[✓ Dry] (well-drained)
Subalpine	Mesic
Forest	Wet
Bog	Aquatic - FW
Herb meadow	Aquatic - brackish
Riparian	Aquatic - SW

Landform
bedrock bench

TREE CORES (No.) 1
VASCULARS COLLECTED (No.) 3
NON-VASCULARS COLLECTED (No.) 2
SOIL SAMPLES (No.) 1

bedrock
alder/moss
plot 2
Alder/calcan (bedrock knob)
bedrock w/ grasses
till benches

20y 12' 2.5" PCT: Sitka Alder / Bluejoint Reed Grass

	Species	% Cover	Height (ft)	DBH (")	Species	% Cover	Height (ft)	DBH (")
	ALN VIR SIN	75	6-8	1.5-2.5"				
	SAL SIT	2	3					
✓ ©	AGROSTIS alaskana	3	6"	(LAF)				
	CAL CAN	6 7	2					
	TRI SPIC	2	1					
✓2 flw/sp ©	GRASS 1 (POA)	2 3	1		Poa glauca (LAF)			
	CAR MER	2	2					
	hornemannii (LAF)							
©	EPILOBium	2	6"					
	EPI LAT	1	1					
	STE CRI	1						
	STE SITCHANA	2						
	EPI ANG	2	2					
	THE PHE							
	DRY EXP	1	1					
	ATH FIL	1	2					
✓©	Rhytid	15	Rhytidiadelphus lareus (LAF)					
©	moss 1	10						
	mosses unk	5						
	Stereocaulon	1						

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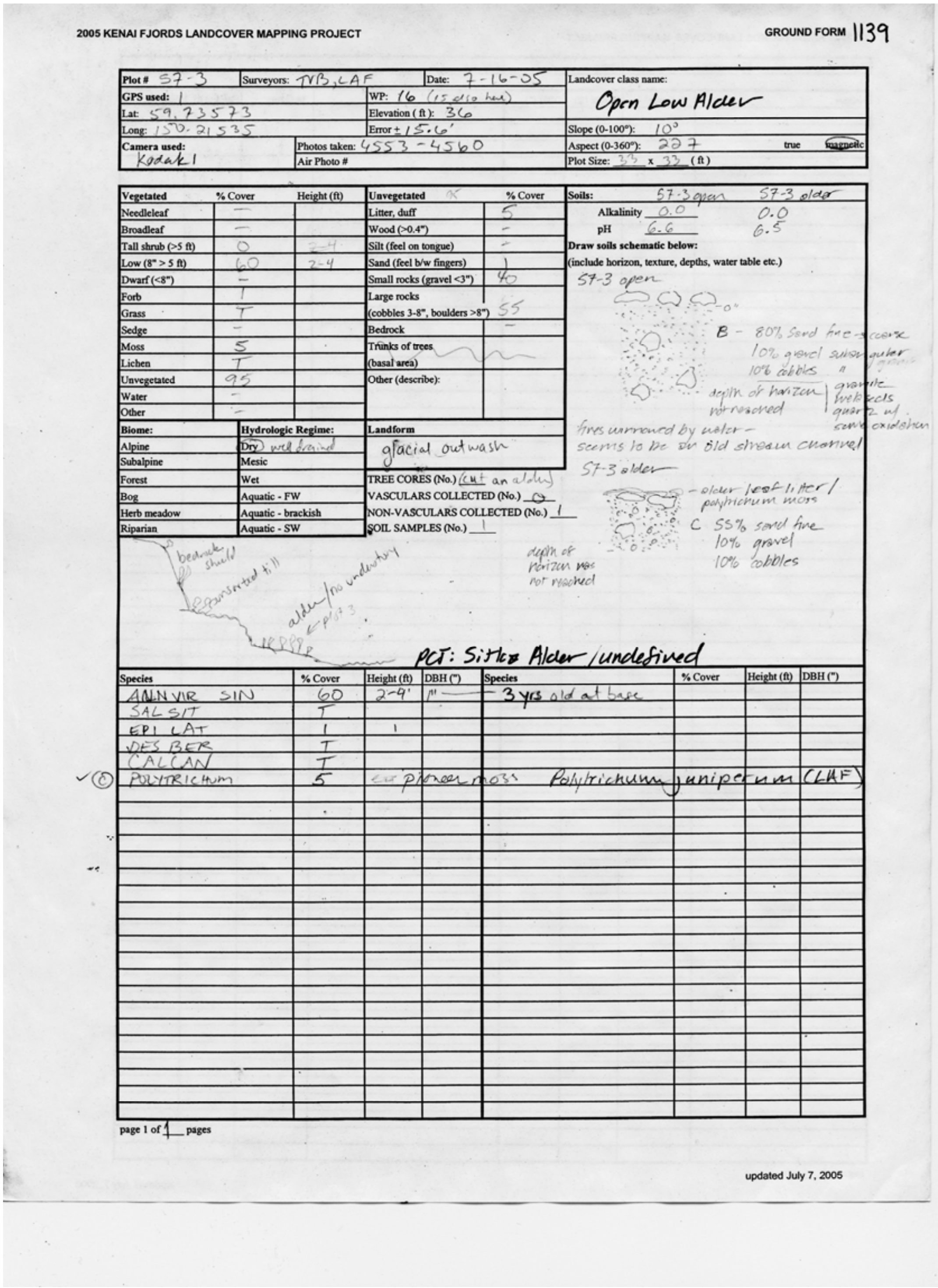
Appendix XVII: McCarty Fjord Site Forms (continued).

Site 3



2005 KENAI FJORDS LANDCOVER MAPPING PROJECT

GROUND FORM 1139

Plot # 57-3	**Surveyors:** TVB, LAF	**Date:** 7-16-05	**Landcover class name:** Open Low Alder
GPS used: 1		**WP:** 16 (15 also here)	
Lat: 59.73573		**Elevation (ft):** 36	
Long: 150.21535		**Error** ± 15.6'	**Slope (0-100°):** 10°
Camera used: Kodak 1	**Photos taken:** 4553 - 4560		**Aspect (0-360°):** 227 true [✓ magnetic]
	Air Photo #		**Plot Size:** 33 x 33 (ft)

Vegetated	**% Cover**	**Height (ft)**	**Unvegetated** OK	**% Cover**
Needleleaf	–		Litter, duff	5
Broadleaf	–		Wood (>0.4")	–
Tall shrub (>5 ft)	0	2-4	Silt (feel on tongue)	–
Low (8" > 5 ft)	60	2-4	Sand (feel b/w fingers)	1
Dwarf (<8")	–		Small rocks (gravel <3")	40
Forb	T		Large rocks (cobbles 3-8", boulders >8")	55
Grass	T		Bedrock	–
Sedge	–		Trunks of trees (basal area)	
Moss	5		Other (describe):	
Lichen	T			
Unvegetated	95			
Water	–			
Other	–			

Biome:	**Hydrologic Regime:**
Alpine	[✓ Dry] well drained
Subalpine	Mesic
Forest	Wet
Bog	Aquatic - FW
Herb meadow	Aquatic - brackish
Riparian	Aquatic - SW

Landform

glacial outwash

TREE CORES (No.) (cut an alder)

VASCULARS COLLECTED (No.) 0

NON-VASCULARS COLLECTED (No.) 1

SOIL SAMPLES (No.) 1

Soils: 57-3 open 57-3 older

Alkalinity 0.0 0.0

pH 6.6 6.5

Draw soils schematic below:

(include horizon, texture, depths, water table etc.)

57-3 open

-0"

B - 80% Sand fine-coarse
10% gravel subangular
10% cobbles "

depth of horizon not reached

granite
weak beds
quartz w/
some oxidation

fines winnowed by water -
seems to be an old stream channel

57-3 older

- older leaf litter /
polytrichum moss

C 55% sand fine
10% gravel
10% cobbles

depth of horizon was not reached

bedrock shield

unsorted till

alder/no understory

← plot 3

PCT: Sitka Alder / undefined

Species	**% Cover**	**Height (ft)**	**DBH (")**	**Species**	**% Cover**	**Height (ft)**	**DBH (")**
ALN VIR SIN	60	2-9'	1"	— 3 yrs old at base			
SAL SIT	T						
EPI LAT	1	1					
DES BER	T						
CAL CAN	T						
✓ Ⓒ POLYTRICHUM	5	pioneer moss		Polytrichum juniperum (LAF)			

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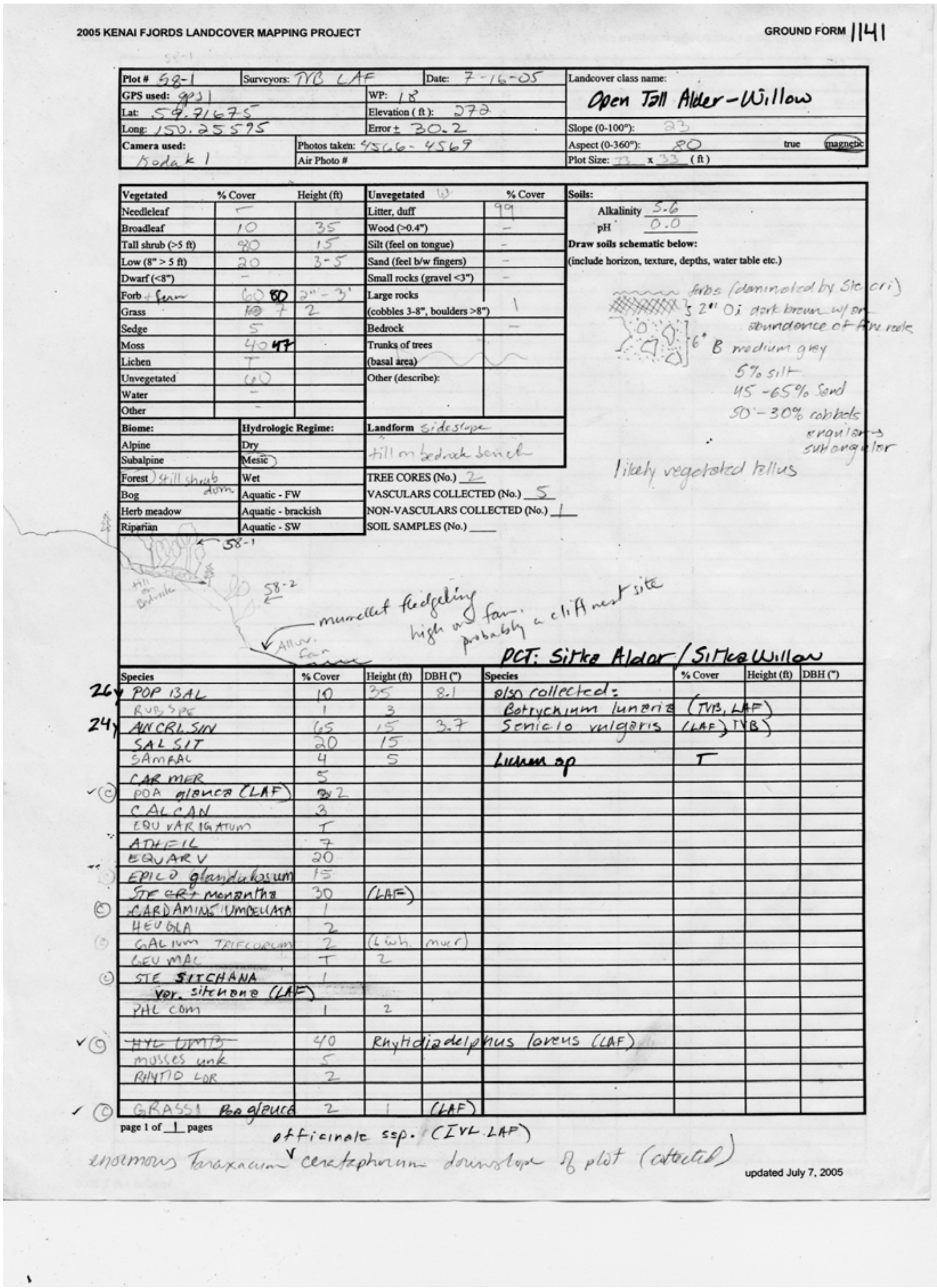
Appendix XVII: McCarty Fjord Site Forms (continued).

Site 4



2005 KENAI FJORDS LANDCOVER MAPPING PROJECT GROUND FORM 1141

Plot # 58-1	Surveyors: TVB LAF	Date: 7-16-05	Landcover class name: Open Tall Alder-Willow
GPS used: gps1	WP: 18		
Lat: 59.71675	Elevation (ft): 272		
Long: 150.25595	Error ± 30.2		Slope (0-100°): 23
Camera used: Kodak 1	Photos taken: 4566-4569		Aspect (0-360°): 80 true [✓ magnetic]
	Air Photo #		Plot Size: 33 x 33 (ft)

Vegetated	% Cover	Height (ft)	Unvegetated	% Cover
Needleleaf	–		Litter, duff	99
Broadleaf	10	35	Wood (>0.4")	–
Tall shrub (>5 ft)	80	15	Silt (feel on tongue)	–
Low (8" > 5 ft)	20	3-5	Sand (feel b/w fingers)	–
Dwarf (<8")	–		Small rocks (gravel <3")	–
Forb + fern	60 80	2"-3'	Large rocks (cobbles 3-8", boulders >8")	1
Grass	~~10~~ 7	2	Bedrock	–
Sedge	5		Trunks of trees (basal area)	
Moss	40 47		Other (describe):	
Lichen	T			
Unvegetated	60			
Water	–			
Other	–			

Soils:

Alkalinity 5.6

pH 0.0

Draw soils schematic below:

(include horizon, texture, depths, water table etc.)

forbs (dominated by Ste cri)

2" Oi dark brown w/ an abundance of fine roots

6" B medium grey

5% silt

45-65% Sand

50-30% cobbels

angular → subangular

likely vegetated tallus

Biome:	Hydrologic Regime:
Alpine	Dry
Subalpine	[✓ Mesic]
[✓ Forest] tall shrub dom.	Wet
Bog	Aquatic - FW
Herb meadow	Aquatic - brackish
Riparian	Aquatic - SW

Landform sideslope

till on bedrock bench

TREE CORES (No.) 2

VASCULARS COLLECTED (No.) 5

NON-VASCULARS COLLECTED (No.) 1

SOIL SAMPLES (No.) ____

58-1

till on Bedrock

58-2

Alluv. fan

murrelet fledgeling high on fan. probably a cliff nest site

PCT: Sitka Alder / Sitka Willow

	Species	% Cover	Height (ft)	DBH (")	Species	% Cover	Height (ft)	DBH (")
26	POP BAL	10	35	8.1	also collected:			
	RUB SPE	1	3		Botrychium lunaria	(TVB, LAF)		
24	ANCRI SIN	65	15	3.7	Senecio vulgaris	(LAF, TVB)		
	SAL SIT	20	15					
	SAMRAL	4	5		Lichen sp	T		
	CAR MER	5						
✓ ⓒ	POA glauca (LAF)	~~3~~ 2						
	CALCAN	3						
	EQU VARIGATUM	T						
	ATHFIL	7						
	EQUARV	20						
ⓒ	EPILO glandulosum	15						
	STE ~~CRI~~ monantha	30	(LAF)					
ⓒ	CARDAMINE UMBELLATA	1						
	HEUGLA	2						
ⓒ	GALIUM TRIFLORUM	2	(Linh.	muer)				
	GEU MAC	T	2					
ⓒ	STE SITCHANA	1						
	var. sitchana (LAF)							
	PHL COM	1	2					
✓ ⓒ	~~HYL UMB~~	40	Rhytidiadelphus loreus (LAF)					
	mosses unk	5						
	RHYTID LOR	2						
✓ ⓒ	GRASS1 Poa glauca	2	1	(LAF)				

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officinale ssp. (IVL. LAF)

enormous Taraxacum ceratophorum downslope of plot (collected)

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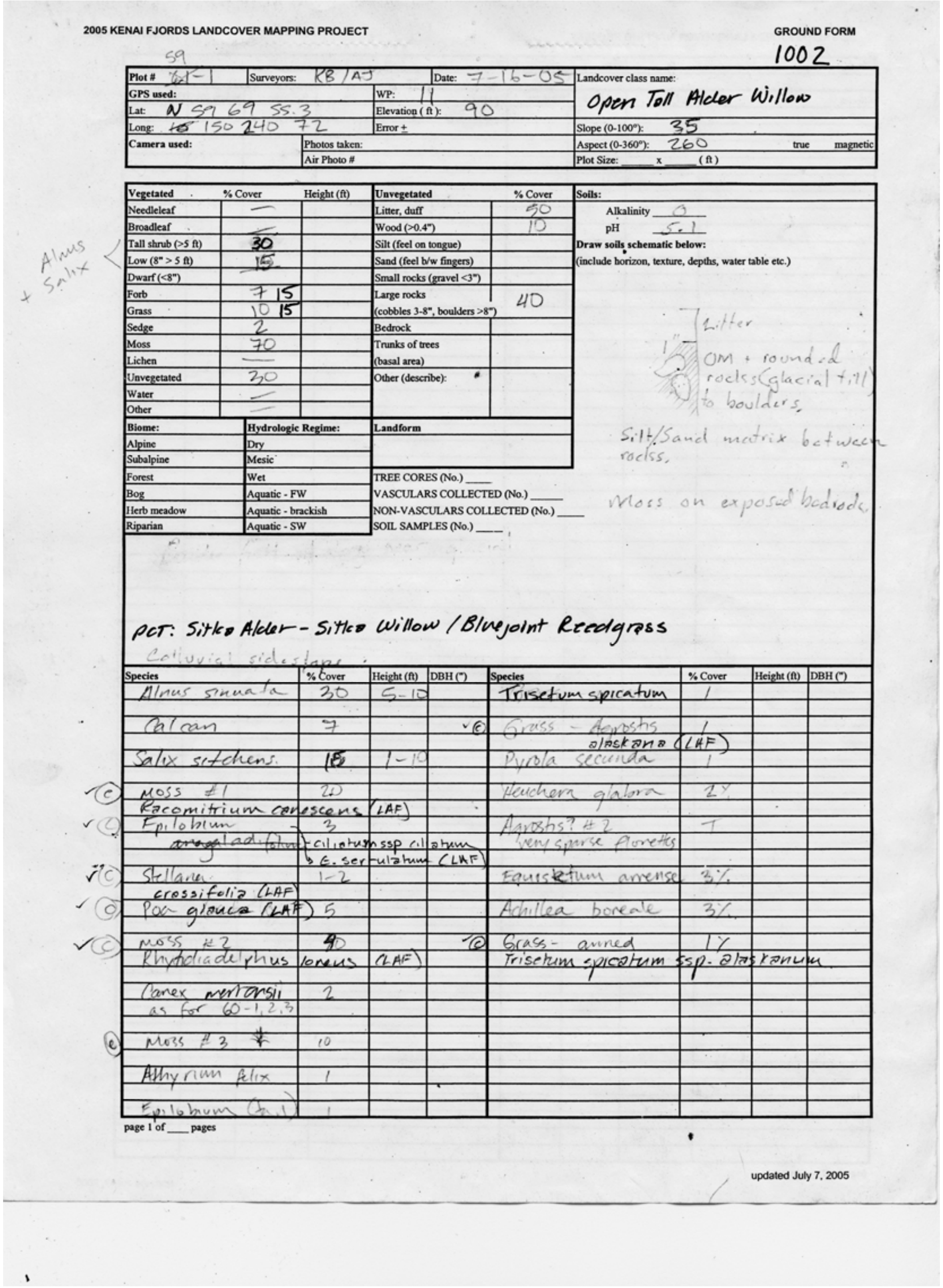
Appendix XVII: McCarty Fjord Site Forms (continued).

Site 5



2005 KENAI FJORDS LANDCOVER MAPPING PROJECT

GROUND FORM 1002

Plot # 59 ~~61~~-1	Surveyors: KB / AJ	Date: 7-16-05	Landcover class name: Open Tall Alder Willow
GPS used:		WP: 11	
Lat: N 59 69 55.3		Elevation (ft): 90	
Long: ~~[illegible]~~ 150 240 72		Error ±	Slope (0-100°): 35
Camera used:	Photos taken:		Aspect (0-360°): 260 true magnetic
	Air Photo #		Plot Size: ____ x ____ (ft)

Vegetated	% Cover	Height (ft)	**Unvegetated**	% Cover
Needleleaf	—		Litter, duff	50
Broadleaf	—		Wood (>0.4")	10
Tall shrub (>5 ft)	30		Silt (feel on tongue)	
Low (8" > 5 ft)	15		Sand (feel b/w fingers)	
Dwarf (<8")			Small rocks (gravel <3")	
Forb	7 15		Large rocks (cobbles 3-8", boulders >8")	40
Grass	10 15			
Sedge	2		Bedrock	
Moss	70		Trunks of trees (basal area)	
Lichen	—			
Unvegetated	30		Other (describe):	
Water	—			
Other	—			

Alnus + Salix

Soils:

Alkalinity 0

pH 5.1

Draw soils schematic below:

(include horizon, texture, depths, water table etc.)

Litter

1"

OM + rounded rocks (glacial till) to boulders,

Silt/Sand matrix between rocks,

Moss on exposed bedrock.

Biome:	**Hydrologic Regime:**	**Landform**
Alpine	Dry	
Subalpine	Mesic	
Forest	Wet	
Bog	Aquatic - FW	
Herb meadow	Aquatic - brackish	
Riparian	Aquatic - SW	

TREE CORES (No.) ____

VASCULARS COLLECTED (No.) ______

NON-VASCULARS COLLECTED (No.) ____

SOIL SAMPLES (No.) ____

PCT: Sitka Alder - Sitka Willow / Bluejoint Reedgrass

Colluvial sideslope.

Species	% Cover	Height (ft)	DBH (")	Species	% Cover	Height (ft)	DBH (")
Alnus sinuata	30	5-10		Trisetum spicatum	1		
Calcan	7			✓(c) Grass – Agrostis alaskana (LAF)	1		
Salix sitchens.	15	1-10		Pyrola secunda	1		
✓(c) moss #1 Racomitrium canescens (LAF)	20			Heuchera glabra	2%		
✓(c) Epilobium ~~anagallidifolium~~ – ciliatum ssp ciliatum → E. serrulatum (LAF)	3			Agrostis? #2 very sparse florettes	T		
✓(c) Stellaria crassifolia (LAF)	1-2			Equisetum arvense	3%		
✓(c) Poa glauca (LAF)	5			Achillea boreale	3%		
✓(c) moss #2 Rhytidiadelphus loreus (LAF)	40			✓(c) Grass – awned Trisetum spicatum ssp. alaskanum	1%		
Carex mertensii as for 60-1, 2, 3	2						
(c) Moss #3	10						
Athyrium felix	1						
Epilobium (?)	1						

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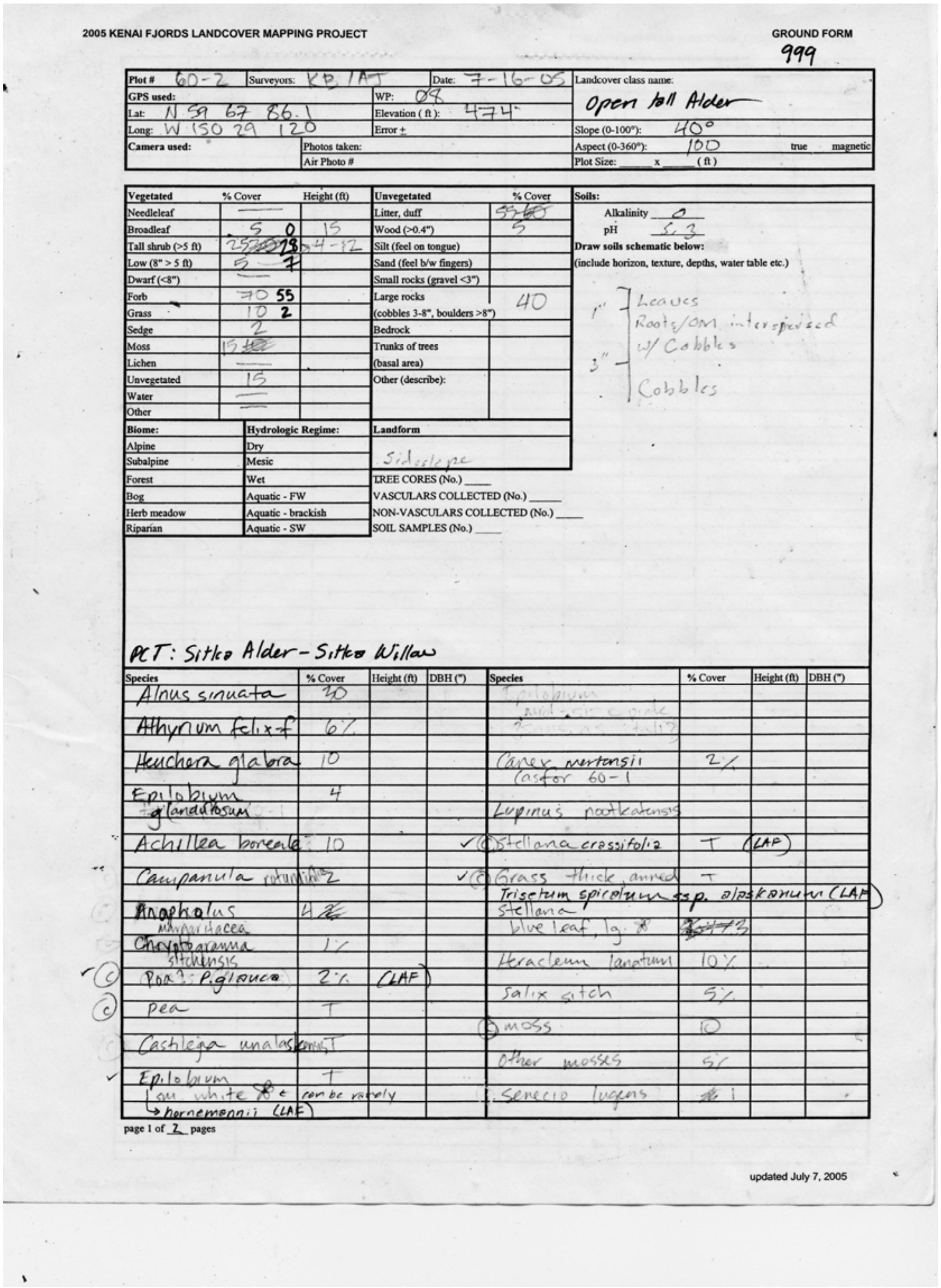
Appendix XVII: McCarty Fjord Site Forms (continued).

Site 6



2005 KENAI FJORDS LANDCOVER MAPPING PROJECT

GROUND FORM
999

Plot # 60-2	**Surveyors:** KB/AJ	**Date:** 7-16-05	**Landcover class name:**
GPS used:		**WP:** 08	Open tall Alder
Lat: N 59 67 86.1		**Elevation (ft):** 474'	
Long: W 150 29 120		**Error ±**	**Slope (0-100°):** 40°
Camera used:	**Photos taken:**		**Aspect (0-360°):** 100 true magnetic
	Air Photo #		**Plot Size:** ____ x ____ (ft)

Vegetated	**% Cover**	**Height (ft)**	**Unvegetated**	**% Cover**
Needleleaf	—		Litter, duff	55 ~~60~~
Broadleaf	5 0	15	Wood (>0.4")	5
Tall shrub (>5 ft)	~~25~~ ~~20~~ 28	4-12	Silt (feel on tongue)	
Low (8" > 5 ft)	~~5~~ 7		Sand (feel b/w fingers)	
Dwarf (<8")	—		Small rocks (gravel <3")	
Forb	~~70~~ 55		Large rocks (cobbles 3-8", boulders >8")	40
Grass	~~10~~ 2			
Sedge	2		Bedrock	
Moss	15 ~~10~~		Trunks of trees (basal area)	
Lichen	—			
Unvegetated	15		Other (describe):	
Water	—			
Other	—			

Soils:
Alkalinity 0
pH 5.3
Draw soils schematic below:
(include horizon, texture, depths, water table etc.)

1"] Leaves
Roots/OM interspersed
w/ Cobbles
3"]
Cobbles

Biome:	**Hydrologic Regime:**
Alpine	Dry
Subalpine	Mesic
Forest	Wet
Bog	Aquatic - FW
Herb meadow	Aquatic - brackish
Riparian	Aquatic - SW

Landform
Sideslope

TREE CORES (No.) ____
VASCULARS COLLECTED (No.) ____
NON-VASCULARS COLLECTED (No.) ____
SOIL SAMPLES (No.) ____

PCT: Sitka Alder - Sitka Willow

Species	**% Cover**	**Height (ft)**	**DBH (")**	**Species**	**% Cover**	**Height (ft)**	**DBH (")**
Alnus sinuata	30			Epilobium			
Athyrium felix-f	6%			mid-size pink (same as tall?)			
Heuchera glabra	10			Carex mertensii (as for 60-1	2%		
Epilobium glandulosum	4			Lupinus nootkatensis			
Achillea boreale	10			✓ ⓒ Stellaria crassifolia	T	(LAF)	
Campanula rotundifolia	2			✓ ⓒ Grass thick, awned Trisetum spicatum ssp. alaskanum (LAF)	T		
Anaphalus margaritacea	4 ~~2~~			Stellaria blue leaf, lg. ✿	~~[illegible]~~ 3		
Chryptogramma sitchensis	1%			Heracleum lanatum	10%		
✓ ⓒ Poa?: P. glauca	2%	(LAF)		Salix sitch	5%		
ⓒ pea	T			ⓒ moss	10		
Castilega unalaskensis	T			other mosses	5%		
✓ Epilobium sm. white ✿ can be rarely → hornemannii (LAF)	T			Senecio lugens	~~[illegible]~~ 1		

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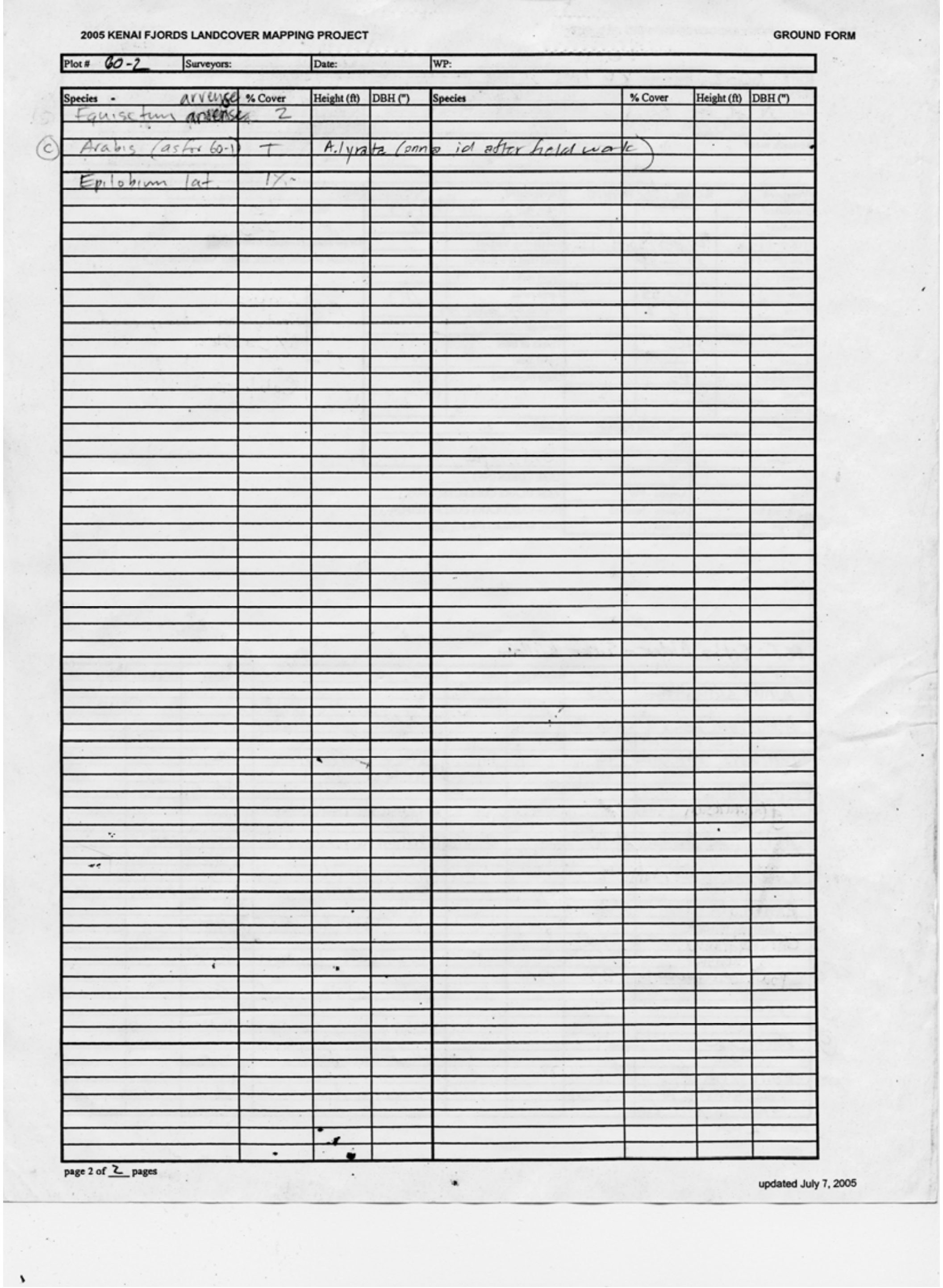
Appendix XVII: McCarty Fjord Site Forms (continued).

Site 6 (continued)



2005 KENAI FJORDS LANDCOVER MAPPING PROJECT **GROUND FORM**

Plot # 60-2	Surveyors:	Date:	WP:

Species	% Cover	Height (ft)	DBH (")	Species	% Cover	Height (ft)	DBH (")
Equisetum arvense	2						
ⓒ Arabis (as for 60-1)	T	A. lyrata (confirm id after field work)					
Epilobium lat.	1%						

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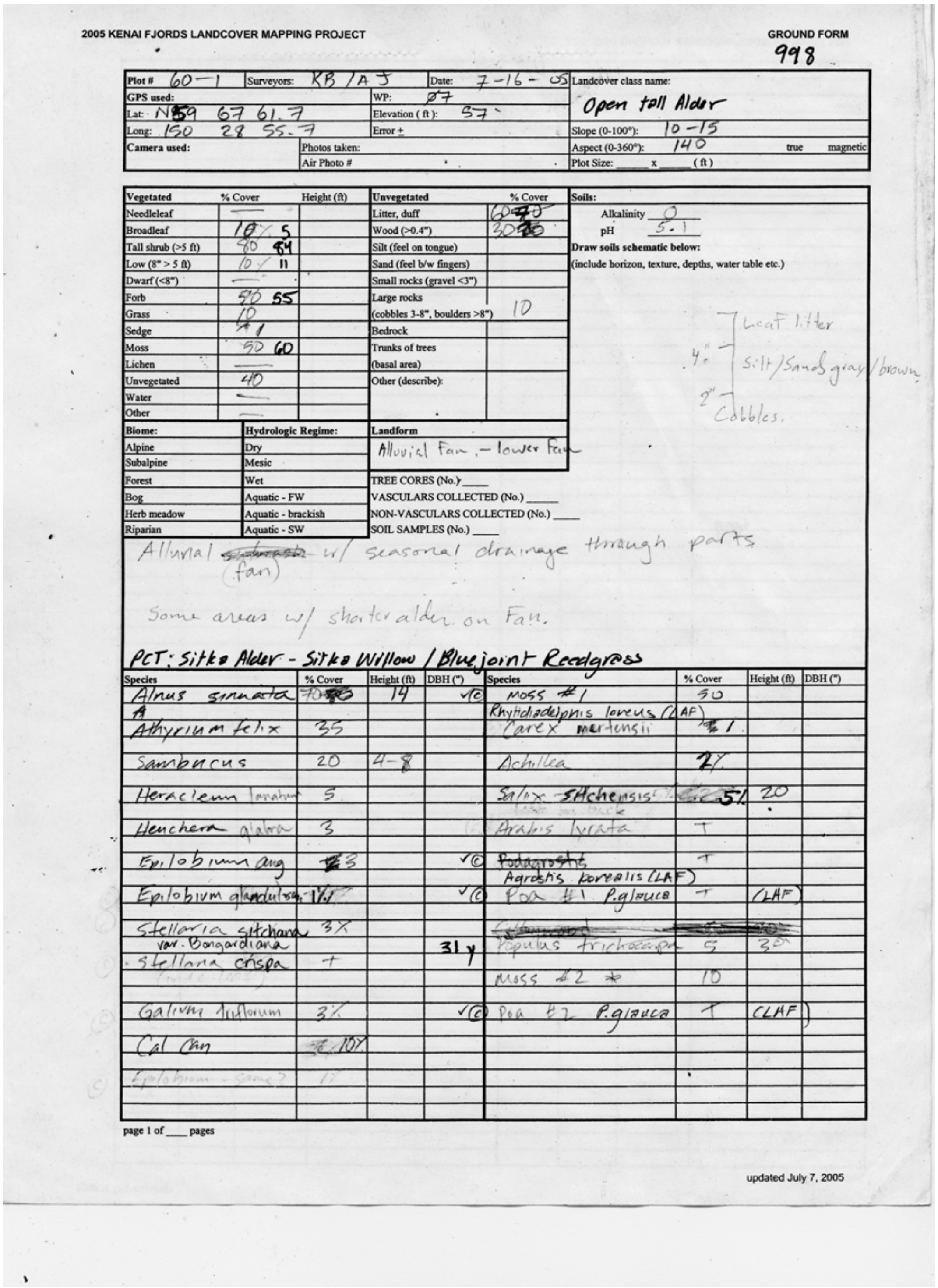
Appendix XVII: McCarty Fjord Site Forms (continued).
Site 7



2005 KENAI FJORDS LANDCOVER MAPPING PROJECT

GROUND FORM 998

Plot # 60-1	**Surveyors:** KB / AJ	**Date:** 7-16-05	**Landcover class name:** Open tall Alder
GPS used:	**WP:** 07		
Lat: N59 67 61.7	**Elevation (ft):** 57'		
Long: 150 28 55.7	**Error ±**		**Slope (0-100°):** 10-15
Camera used:	**Photos taken:**		**Aspect (0-360°):** 140 true magnetic
	Air Photo #		**Plot Size:** _____ x _____ (ft)

Vegetated	**% Cover**	**Height (ft)**	**Unvegetated**	**% Cover**
Needleleaf	—		Litter, duff	60 ~~70~~
Broadleaf	~~10%~~ 5		Wood (>0.4")	30 ~~20~~
Tall shrub (>5 ft)	~~80~~ 84		Silt (feel on tongue)	
Low (8" > 5 ft)	~~10%~~ 11		Sand (feel b/w fingers)	
Dwarf (<8")	—		Small rocks (gravel <3")	
Forb	~~50~~ 55		Large rocks (cobbles 3-8", boulders >8")	10
Grass	10			
Sedge	1		Bedrock	
Moss	~~50~~ 60		Trunks of trees (basal area)	
Lichen	—			
Unvegetated	40		Other (describe):	
Water	—			
Other	—			

Soils:

Alkalinity 0

pH 5.1

Draw soils schematic below:
(include horizon, texture, depths, water table etc.)

Leaf litter
4" Silt/Sands gray/brown
2"
Cobbles.

Biome:	**Hydrologic Regime:**
Alpine	Dry
Subalpine	Mesic
Forest	Wet
Bog	Aquatic - FW
Herb meadow	Aquatic - brackish
Riparian	Aquatic - SW

Landform
Alluvial Fan, - lower Fan

TREE CORES (No.) _____
VASCULARS COLLECTED (No.) _____
NON-VASCULARS COLLECTED (No.) _____
SOIL SAMPLES (No.) _____

Alluvial ~~[illegible]~~ (fan) w/ seasonal drainage through parts

Some areas w/ shorter alder on Fan.

PCT: Sitka Alder - Sitka Willow / Bluejoint Reedgrass

Species	**% Cover**	**Height (ft)**	**DBH (")**	**Species**	**% Cover**	**Height (ft)**	**DBH (")**
Alnus sinuata	70	14	✓©	moss #1	50		
A				Rhytidiadelphus loreus (LAF)			
Athyrium felix	35			Carex mertensii	1		
Sambucus	20	4-8		Achillea	2%		
Heracleum lanatum	5			Salix ~~sitchensis~~	5%	20	
Heuchera glabra	3			Arabis lyrata	T		
Epilobium ang	3		✓©	~~Podagrostis~~ Agrostis borealis (LAF)	T		
Epilobium glandulosum	1%		✓©	Poa #1 P.glauca	T	(LAF)	
Stellaria sitchana var. Bongardiana	3%			~~[illegible]~~			
			31 y	Populus trichocarpa	5	30'	
Stellaria crispa	+						
(wide leaf)				moss #2 *	10		
Galium triflorum	3%		✓©	Poa #2 P.glauca	T	(LAF)	
Cal Can	10%						
Epilobium - same?	1%						

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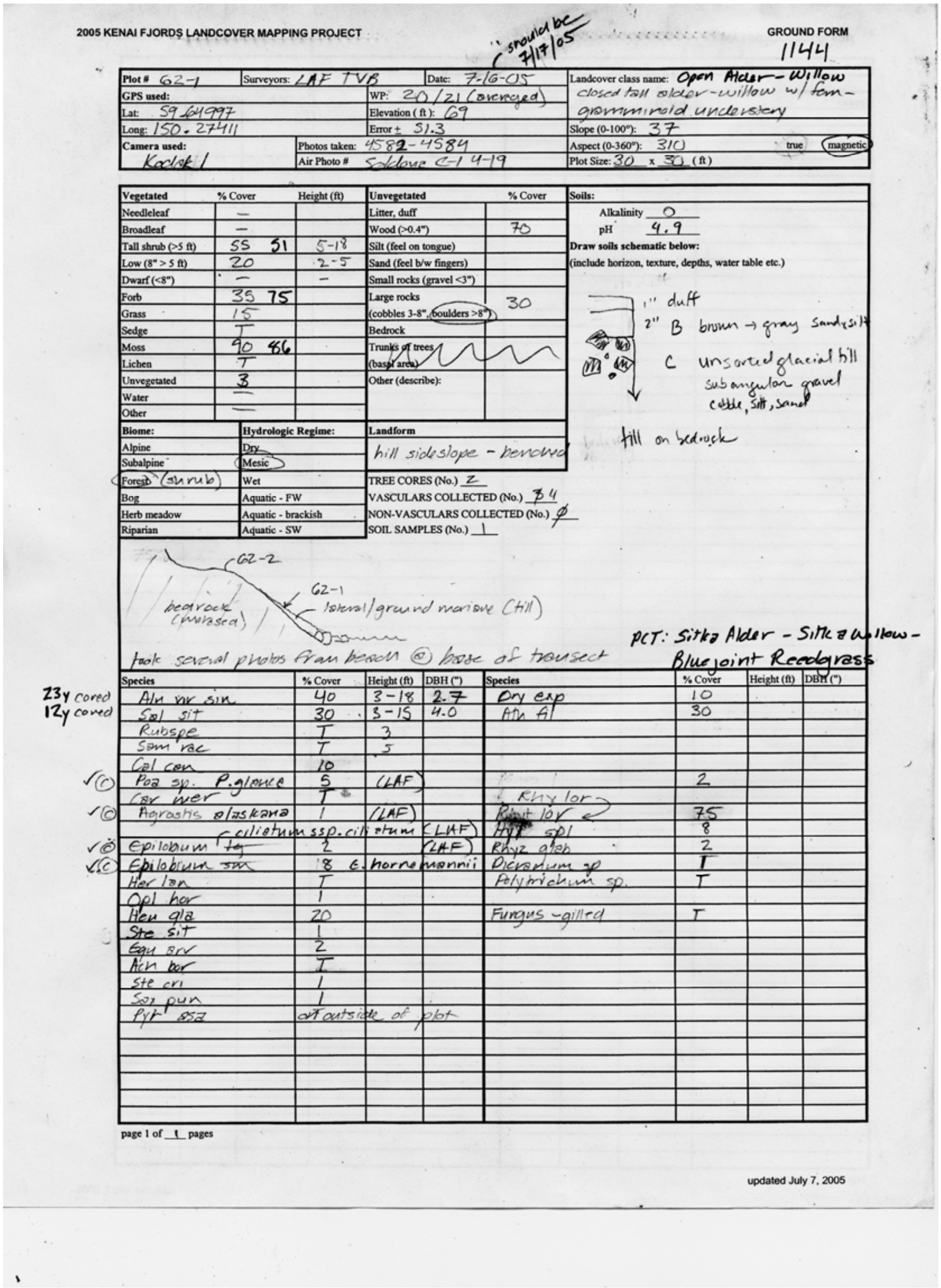
Appendix XVII: McCarty Fjord Site Forms (continued).

Site 8



2005 KENAI FJORDS LANDCOVER MAPPING PROJECT

" should be 7/17/05

GROUND FORM
1144

Plot # 62-1	Surveyors: LAF TVB	Date: 7-16-05	Landcover class name: Open Alder – Willow closed tall alder-willow w/ fern-graminoid understory
GPS used:		WP: 20/21 (averaged)	
Lat: 59.64997		Elevation (ft): 69	
Long: 150.27411		Error ± 31.3	Slope (0-100°): 37
Camera used: Kodak 1		Photos taken: 4582-4584	Aspect (0-360°): 310 true [✓ magnetic]
		Air Photo # Soldovia C-1 4-19	Plot Size: 30 x 30 (ft)

Vegetated	% Cover	Height (ft)	Unvegetated	% Cover
Needleleaf	—		Litter, duff	
Broadleaf	—		Wood (>0.4")	70
Tall shrub (>5 ft)	55 51	5-18	Silt (feel on tongue)	
Low (8" > 5 ft)	20	2-5	Sand (feel b/w fingers)	
Dwarf (<8")	—	—	Small rocks (gravel <3")	
Forb	35 75		Large rocks (cobbles 3-8", [✓ boulders >8"])	30
Grass	15			
Sedge	T		Bedrock	
Moss	90 86		Trunks of trees (basal area)	
Lichen	T			
Unvegetated	3		Other (describe):	
Water	—			
Other	—			

Soils:
Alkalinity 0
pH 4.9
Draw soils schematic below:
(include horizon, texture, depths, water table etc.)

1" duff
2" B brown → gray sand, silt
C unsorted glacial till
subangular gravel
cobble, silt, sand

till on bedrock

Biome:	Hydrologic Regime:
Alpine	Dry
Subalpine	[✓ Mesic]
[✓ Forest] (shrub)	Wet
Bog	Aquatic - FW
Herb meadow	Aquatic - brackish
Riparian	Aquatic - SW

Landform
hill sideslope - benched

TREE CORES (No.) 2
VASCULARS COLLECTED (No.) 34
NON-VASCULARS COLLECTED (No.) 0
SOIL SAMPLES (No.) 1

took several photos from beach @ base of transect

PCT: Sitka Alder – Sitka Willow – Bluejoint Reedgrass

	Species	% Cover	Height (ft)	DBH (")	Species	% Cover	Height (ft)	DBH (")
23y cored	Aln vir sin	40	3-18	2.7	Dry exp	10		
12y cored	Sal sit	30	3-15	4.0	Ath fil	30		
	Rubspe	T	3					
	Sam rac	T	5					
	Cal can	10						
✓ⓒ	Poa sp. P. glauca	5	(LAF)		Moss	2		
	Car mer	T			Rhy lor			
✓ⓒ	Agrostis alaskana	1	(LAF)		Rhyt lor	75		
	ciliatum ssp. ciliatum			(LAF)	Hyl spl	8		
✓ⓒ	Epilobium ~~lat~~	2		(LAF)	Rhyz glab	2		
✓ⓒ	Epilobium ~~sm~~	18	E. hornemannii		Dicranum sp	T		
	Her lan	T			Polytrichum sp.	T		
	Opl hor	1						
	Heu gla	20			Fungus - gilled	T		
	Ste sit	1						
	Equ arv	2						
	Ach bor	T						
	Ste cri	1						
	Sor pun	1						
	Pyr asa	at outside of plot						

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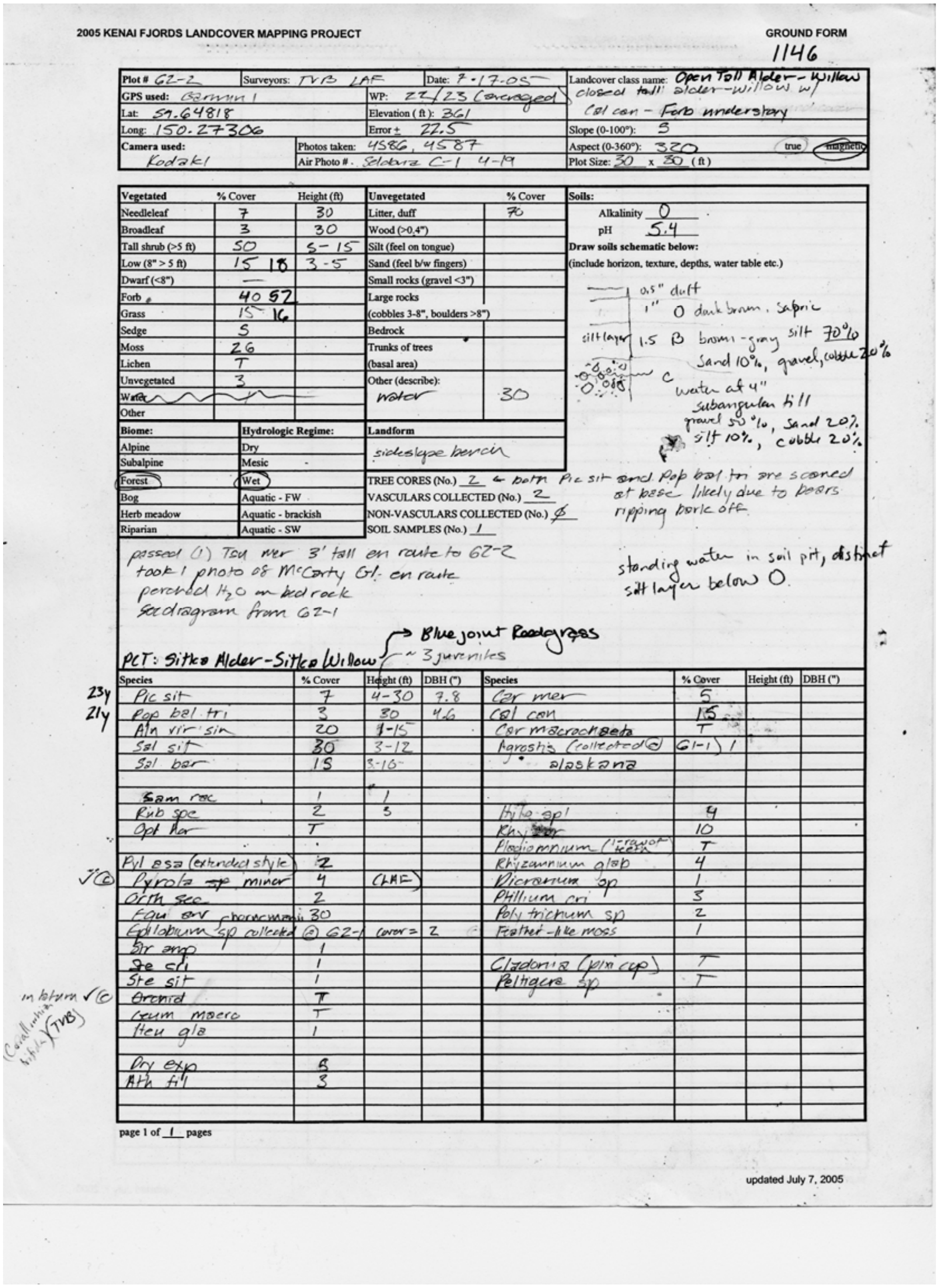
Appendix XVII: McCarty Fjord Site Forms (continued).

Site 9



2005 KENAI FJORDS LANDCOVER MAPPING PROJECT

GROUND FORM
1146

Plot # 62-2	Surveyors: TVB LAF	Date: 7-17-05	Landcover class name: Open Tall Alder - Willow closed tall alder-willow w/ Cal can - Forb understory
GPS used: Garmin 1		WP: 22/23 (averaged)	
Lat: 59.64818		Elevation (ft): 361	
Long: 150.27306		Error ± 22.5	Slope (0-100°): 5
Camera used: Kodak 1	Photos taken: 4586, 4587		Aspect (0-360°): 320 true [✓ magnetic]
	Air Photo #. Seldovia C-1 4-19		Plot Size: 30 x 30 (ft)

Vegetated	% Cover	Height (ft)	Unvegetated	% Cover
Needleleaf	7	30	Litter, duff	70
Broadleaf	3	30	Wood (>0.4")	
Tall shrub (>5 ft)	50	5-15	Silt (feel on tongue)	
Low (8" > 5 ft)	15 18	3-5	Sand (feel b/w fingers)	
Dwarf (<8")	—		Small rocks (gravel <3")	
Forb	40 52		Large rocks (cobbles 3-8", boulders >8")	
Grass	15 16			
Sedge	5		Bedrock	
Moss	26		Trunks of trees (basal area)	
Lichen	T			
Unvegetated	3		Other (describe): water	30
Water				
Other				

Soils:
Alkalinity 0
pH 5.4
Draw soils schematic below:
(include horizon, texture, depths, water table etc.)

0.5" duff
1" O dark brown, sapric
silt layer 1.5 B brown-gray silt 70% Sand 10%, gravel, cobble 20%
C water at 4"
subangular till
gravel 50%, sand 20%, silt 10%, cobble 20%

Biome:	Hydrologic Regime:
Alpine	Dry
Subalpine	Mesic
[✓ Forest]	[✓ Wet]
Bog	Aquatic - FW
Herb meadow	Aquatic - brackish
Riparian	Aquatic - SW

Landform: sideslope bench

TREE CORES (No.) 2 ← both Pic sit and Pop bal tri are scarred at base likely due to bears ripping bark off
VASCULARS COLLECTED (No.) 2
NON-VASCULARS COLLECTED (No.) 0
SOIL SAMPLES (No.) 1

passed (1) Tsu mer 3' tall en route to 62-2
took 1 photo of McCarty Gl. en route
perched H2O on bed rock
see diagram from 62-1

standing water in soil pit, distinct silt layer below O.

PCT: Sitka Alder-Sitka Willow → Bluejoint Reedgrass
~ 3 juveniles

	Species	% Cover	Height (ft)	DBH (")	Species	% Cover	Height (ft)	DBH (")
23y	Pic sit	7	4-30	7.8	Car mer	5		
21y	Pop bal tri	3	30	4.6	Cal can	15		
	Aln vir sin	20	1-15		Car macrochaeta	T		
	Sal sit	30	3-12		Agrostis (collected @ 61-1)	1		
	Sal bar	15	3-16		alaskana			
	Sam rac	1	1					
	Rub spe	2	3		Hylo spl	4		
	Opl hor	T			Rhy [illegible]	10		
					Plagiomnium (1-row of teeth)	T		
	Pyl asa (extended style)	2			Rhyzomnium glab	4		
√©	Pyrola ~~sp~~ minor	4	(LAF)		Dicranum sp	1		
	Orth sec	2			Phillium cri	3		
	Equ arv	30			Poly trichum sp	2		
	Epilobium sp collected @ 62-1 hornemanii	cover = 2			Feather-like moss	1		
	Str amp	1						
	Ste cri	1			Cladonia (pixi cup)	T		
	Ste sit	1			Peltigera sp	T		
in bloom √© (Corallorhiza trifida) (TVB)	Orchid	T						
	Geum macro	T						
	Heu gla	1						
	Dry exp	6						
	Ath fil	3						

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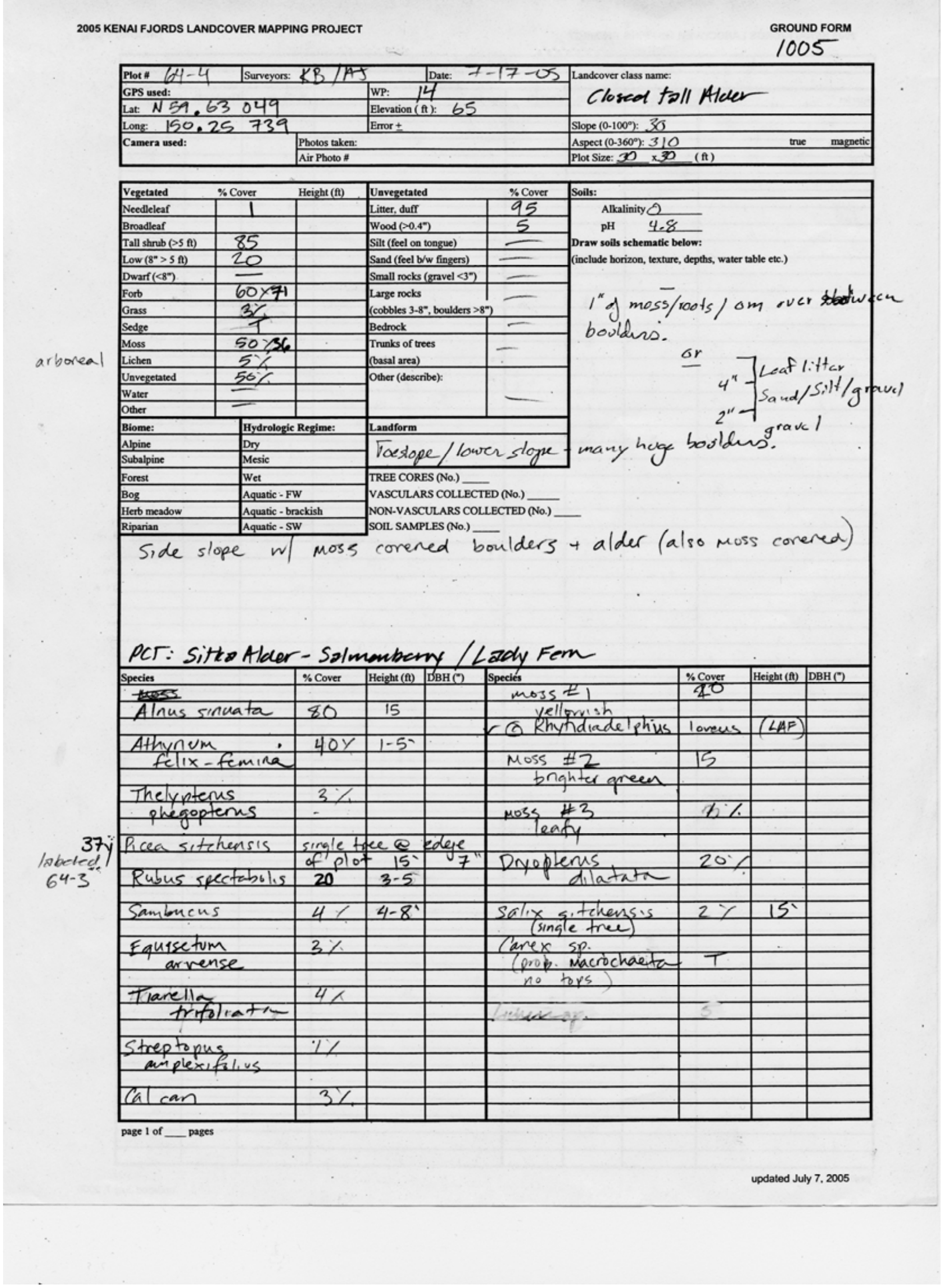
Appendix XVII: McCarty Fjord Site Forms (continued).

Site 10



2005 KENAI FJORDS LANDCOVER MAPPING PROJECT

GROUND FORM
1005

Plot # 64-4	Surveyors: KB / AJ	Date: 7-17-05	**Landcover class name:** Closed tall Alder
GPS used:		WP: 14	
Lat: N 59.63 049		Elevation (ft): 65	
Long: 150.25 739		Error ±	Slope (0-100°): 30
Camera used:	Photos taken:		Aspect (0-360°): 310 true magnetic
	Air Photo #		Plot Size: 30 x 30 (ft)

Vegetated	**% Cover**	**Height (ft)**	**Unvegetated**	**% Cover**
Needleleaf	1		Litter, duff	95
Broadleaf			Wood (>0.4")	5
Tall shrub (>5 ft)	85		Silt (feel on tongue)	—
Low (8" > 5 ft)	20		Sand (feel b/w fingers)	—
Dwarf (<8")	—		Small rocks (gravel <3")	—
Forb	60 ~~71~~		Large rocks (cobbles 3-8", boulders >8")	—
Grass	3%			
Sedge	T		Bedrock	—
Moss	50% ~~36~~		Trunks of trees (basal area)	—
Lichen	5%			
Unvegetated	50%		Other (describe):	—
Water	—			
Other	—			

arboreal

Soils:
Alkalinity 0
pH 4.8
Draw soils schematic below:
(include horizon, texture, depths, water table etc.)

1" of moss/roots / om over ~~bo~~ between boulders.

or

4"] Leaf litter
Sand/Silt/gravel
2" gravel

Biome:	**Hydrologic Regime:**	**Landform**
Alpine	Dry	Toeslope / lower slope - many huge boulders.
Subalpine	Mesic	
Forest	Wet	TREE CORES (No.) ____
Bog	Aquatic - FW	VASCULARS COLLECTED (No.) ____
Herb meadow	Aquatic - brackish	NON-VASCULARS COLLECTED (No.) ____
Riparian	Aquatic - SW	SOIL SAMPLES (No.) ____

Side slope w/ moss covered boulders + alder (also moss covered)

PCT: Sitka Alder - Salmonberry / Lady Fern

Species	**% Cover**	**Height (ft)**	**DBH (")**	**Species**	**% Cover**	**Height (ft)**	**DBH (")**
~~moss~~				moss #1 yellowish	40		
Alnus sinuata	80	15		r © Rhytidiadelphus loreus		(LAF)	
Athyrium felix-femina	40%	1-5'		Moss #2 brighter green	15		
Thelypterus phegopterus	3%			moss #3 leafy	[illegible]%		
Picea sitchensis	single tree @ edge of plot	15'	7"	Dryopterus dilatata	20%		
Rubus spectabilis	20	3-5					
Sambucus	4%	4-8'		Salix sitchensis (single tree)	2%	15'	
Equisetum arvense	3%			Carex sp. (prob. macrochaeta no tops)	T		
Tiarella trifoliata	4%			~~Lichen sp.~~	~~5~~		
Streptopus amplexifolius	1%						
Cal can	3%						

37 y labeled 64-3

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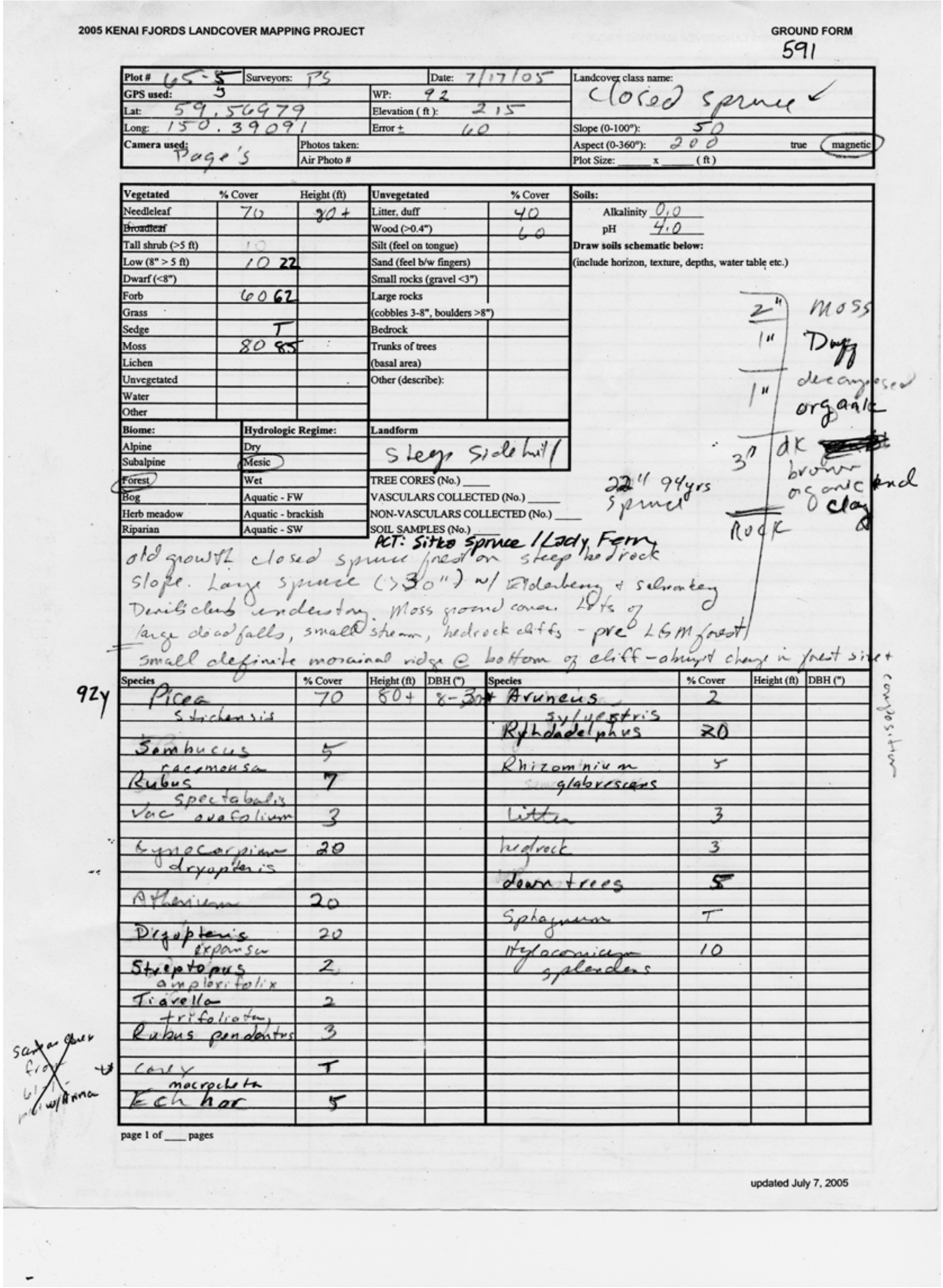
Appendix XVII: McCarty Fjord Site Forms (continued).

Site 11



2005 KENAI FJORDS LANDCOVER MAPPING PROJECT

GROUND FORM
591

Plot # 65-5	Surveyors: PS	Date: 7/17/05	Landcover class name: closed spruce ✓
GPS used: 3	WP: 92		
Lat: 59.56979	Elevation (ft): 215		
Long: 150.39091	Error ± 60		Slope (0-100°): 50
Camera used: Page's	Photos taken:		Aspect (0-360°): 200 true [✓ magnetic]
	Air Photo #		Plot Size: ____ x ____ (ft)

Vegetated	% Cover	Height (ft)	**Unvegetated**	% Cover
Needleleaf	70	80+	Litter, duff	40
~~Broadleaf~~			Wood (>0.4")	60
Tall shrub (>5 ft)	10		Silt (feel on tongue)	
Low (8" > 5 ft)	10 22		Sand (feel b/w fingers)	
Dwarf (<8")			Small rocks (gravel <3")	
Forb	60 62		Large rocks (cobbles 3-8", boulders >8")	
Grass				
Sedge	T		Bedrock	
Moss	80 85		Trunks of trees (basal area)	
Lichen				
Unvegetated			Other (describe):	
Water				
Other				

Soils:
Alkalinity 0.0
pH 4.0
Draw soils schematic below:
(include horizon, texture, depths, water table etc.)

2" moss
1" Duff
1" decomposed organic
3" dk brown organic and clay
ROCK

Biome:	**Hydrologic Regime:**
Alpine	Dry
Subalpine	[✓ Mesic]
[✓ Forest]	Wet
Bog	Aquatic - FW
Herb meadow	Aquatic - brackish
Riparian	Aquatic - SW

Landform
Steep sidehill

TREE CORES (No.) ____
VASCULARS COLLECTED (No.) ____
NON-VASCULARS COLLECTED (No.) ____
SOIL SAMPLES (No.) ____

22" 94yrs spruce

PCT: Sitka Spruce / Lady Fern

old growth closed spruce forest on steep bedrock slope. Large spruce (>30") w/ Elderberry + Salmonberry Devil's club understory. Moss ground cover. Lots of large deadfalls, small stream, bedrock cliffs - pre LGM forest

small definite morainal ridge @ bottom of cliff - abrupt change in forest size + composition

92y

Species	% Cover	Height (ft)	DBH (")	Species	% Cover	Height (ft)	DBH (")
Picea stichensis	70	80+	8-30+	Aruncus sylvestris	2		
Sambucus racemonsa	5			Rytidadelphus	20		
Rubus spectabalis	7			Rhizomnium glabrescens	5		
Vac ovafolium	3			litter	3		
Gymnocarpium dryopteris	20			bedrock	3		
Athyrium	20			down trees	5		
Dryopteris expansa	20			Sphagnum	T		
Streptopus amplexifolius	2			Hylocomium splendens	10		
Tiarella trifoliata	2						
Rubus pendentus	3						
Carex macrochaeta	T						
Ech hor	5						

~~Santa Claus fig 6/1 pic w/Anna~~

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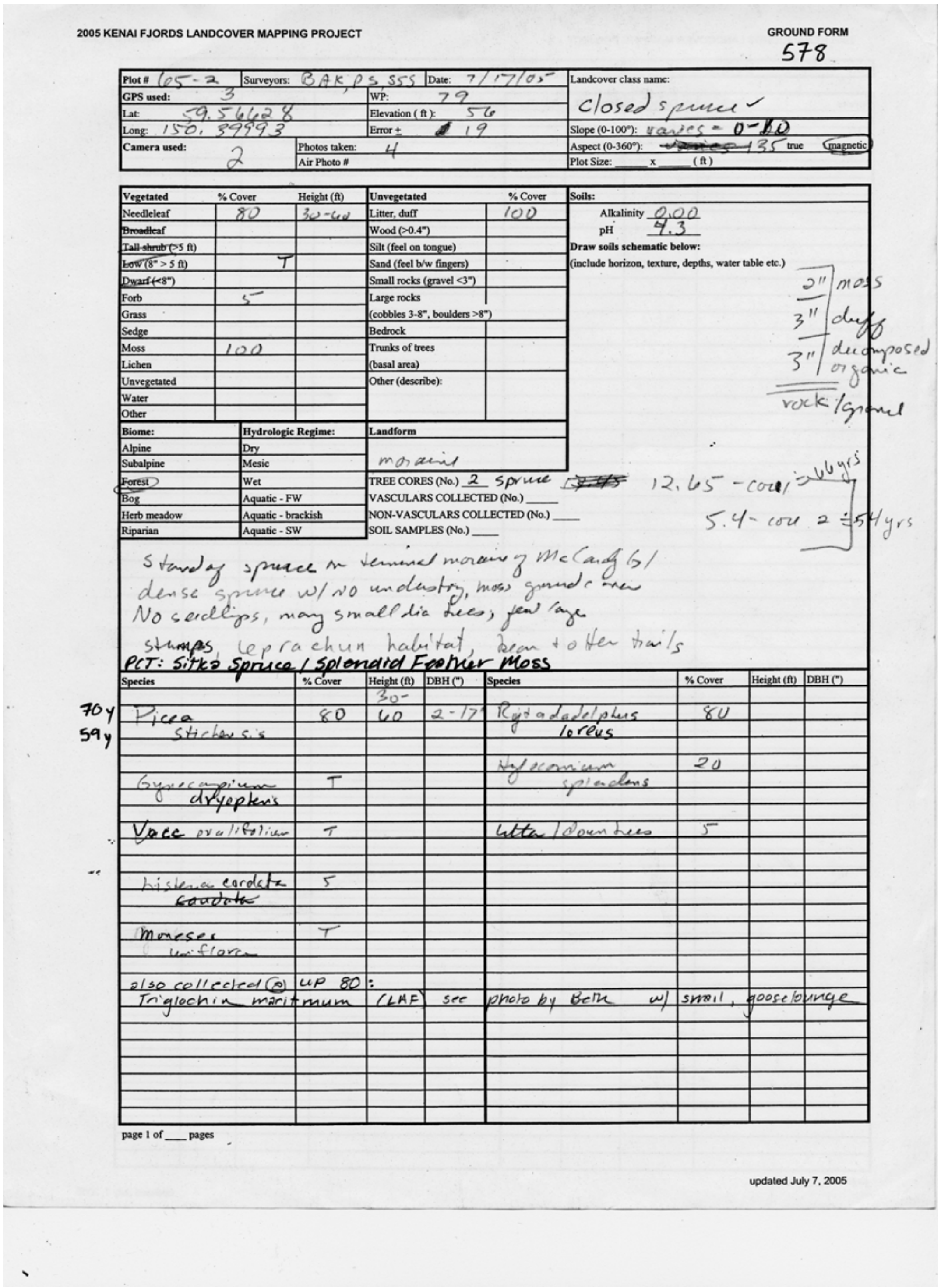
Appendix XVII: McCarty Fjord Site Forms (continued).

Site 12



2005 KENAI FJORDS LANDCOVER MAPPING PROJECT

GROUND FORM 578

Plot # 05-2	Surveyors: BAK, PS, SSS	Date: 7/17/05	Landcover class name: closed spruce ✓
GPS used: 3		WP: 79	
Lat: 59.56628		Elevation (ft): 56	
Long: 150.39993		Error ± ~~[illegible]~~ 19	Slope (0-100°): varies = 0-80
Camera used: 2	Photos taken: 4		Aspect (0-360°): ~~varies~~ 135 true [✓ magnetic]
	Air Photo #		Plot Size: ____ x ____ (ft)

Vegetated	% Cover	Height (ft)	Unvegetated	% Cover
Needleleaf	80	30-60	Litter, duff	100
~~Broadleaf~~			Wood (>0.4")	
~~Tall shrub~~ (>5 ft)			Silt (feel on tongue)	
~~Low~~ (8" > 5 ft)	T		Sand (feel b/w fingers)	
~~Dwarf~~ (<8")			Small rocks (gravel <3")	
Forb	5		Large rocks (cobbles 3-8", boulders >8")	
Grass				
Sedge			Bedrock	
Moss	100		Trunks of trees (basal area)	
Lichen				
Unvegetated			Other (describe):	
Water				
Other				

Soils:

Alkalinity 0.00

pH 4.3

Draw soils schematic below:

(include horizon, texture, depths, water table etc.)

2" moss

3" duff

3" decomposed organic

rock/gravel

Biome:	Hydrologic Regime:
Alpine	Dry
Subalpine	Mesic
[✓ Forest]	Wet
Bog	Aquatic - FW
Herb meadow	Aquatic - brackish
Riparian	Aquatic - SW

Landform: moraine

TREE CORES (No.) 2 spruce ~~[illegible]~~ 12.65 - core 1 = 66 yrs; 5.4 - core 2 = 54 yrs

VASCULARS COLLECTED (No.) ____

NON-VASCULARS COLLECTED (No.) ____

SOIL SAMPLES (No.) ____

Stand of spruce on terminal moraine of McCarty Gl / dense spruce w/ no understory, moss ground cover. No seedlings, many small dia trees, few large stumps, leprachun habitat, bear + otter trails

PCT: Sitka Spruce / Splendid Feather Moss

Species	% Cover	Height (ft)	DBH (")	Species	% Cover	Height (ft)	DBH (")
70y 59y Picea sitchensis	80	30-60	2-17"	Rytadadelphus loreus	80		
				Hylocomium splendens	20		
Gymnocarpium dryopteris	T						
Vacc ovalifolium	T			Litter / Down trees	5		
Listera cordata ~~caudata~~	5						
Moneses uniflora	T						
also collected @ WP 80:							
Triglochin maritimum (LAF) see photo by Beth w/ snail, gooselounge							

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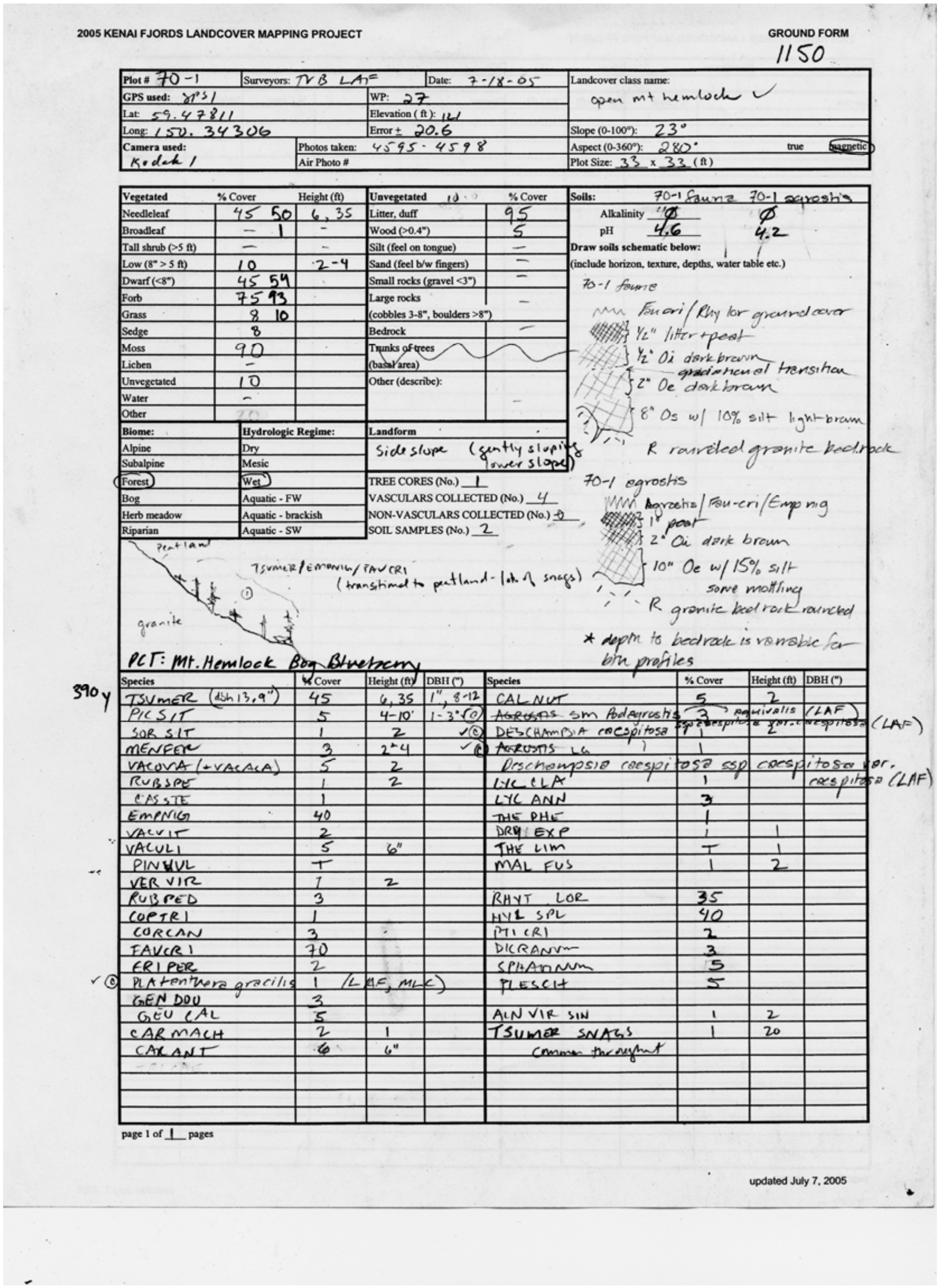
Appendix XVII: McCarty Fjord Site Forms (continued).

Site 13



2005 KENAI FJORDS LANDCOVER MAPPING PROJECT

GROUND FORM
1150

Plot # 70-1	Surveyors: TVB LAF	Date: 7-18-05	Landcover class name: open mt hemlock ✓
GPS used: gps1	WP: 27		
Lat: 59.47811	Elevation (ft): 121		
Long: 150.34306	Error ± 20.6		Slope (0-100°): 23°
Camera used: Kodak 1	Photos taken: 4595 - 4598		Aspect (0-360°): 280° true [✓ magnetic]
	Air Photo #		Plot Size: 33 x 33 (ft)

Vegetated	% Cover	Height (ft)	Unvegetated 10	% Cover
Needleleaf	45 50	6, 35	Litter, duff	95
Broadleaf	– 1	-	Wood (>0.4")	5
Tall shrub (>5 ft)	–	-	Silt (feel on tongue)	–
Low (8" > 5 ft)	10	2-4	Sand (feel b/w fingers)	–
Dwarf (<8")	45 54		Small rocks (gravel <3")	–
Forb	75 93		Large rocks (cobbles 3-8", boulders >8")	–
Grass	8 10			
Sedge	8		Bedrock	–
Moss	90		Trunks of trees (basal area)	
Lichen	–		Other (describe):	–
Unvegetated	10			
Water	–			
Other				

Biome:	Hydrologic Regime:	Landform
Alpine	Dry	Side slope (gently sloping lower slope)
Subalpine	Mesic	
[✓ Forest]	[✓ Wet]	TREE CORES (No.) 1
Bog	Aquatic - FW	VASCULARS COLLECTED (No.) 4
Herb meadow	Aquatic - brackish	NON-VASCULARS COLLECTED (No.) 0
Riparian	Aquatic - SW	SOIL SAMPLES (No.) 2

Soils: 70-1 fauna 70-1 agrostis

	70-1 fauna	70-1 agrostis
Alkalinity	0	0
pH	4.6	4.2

Draw soils schematic below:
(include horizon, texture, depths, water table etc.)

70-1 fauna
Fau cri / Rhy lor groundcover
½" litter + peat
½" Oi dark brown
gradational transition
2" Oe dark brown
8" Os w/ 10% silt light brown
R rounded granite bedrock

70-1 agrostis
Agrostis / Fau-cri / Emp nig
1" peat
2" Oi dark brown
10" Oe w/ 15% silt
some mottling
R granite bedrock rounded

* depth to bedrock is variable for both profiles

peatland
TSUMER / EMPNIG / FAVCRI
(transitional to peatland - lots of snags)
①
granite

PCT: Mt. Hemlock Bog Blueberry

390 y

Species	% Cover	Height (ft)	DBH (")	Species	% Cover	Height (ft)	DBH (")
TSUMER (dbh 13,9")	45	6, 35	1", 8-12	CAL NUT	5	2	
PIC SIT	5	4-10'	1-3" ✓ⓒ	~~AGROSTIS~~ sm Podagrostis → aequivalis (LAF)	3		
SOR SIT	1	2	✓ⓒ	DESCHAMPSIA caespitosa ssp caespitosa var. caespitosa (LAF)	1	2	
MENFER	3	2-4	✓ⓒ	~~AGROSTIS~~ LG	1		
VACOVA (+VACALA)	5	2		Deschampsia caespitosa ssp caespitosa var. caespitosa (LAF)			
RUBSPE	1	2		LYC CLA	1		
CAS STE	1			LYC ANN	3		
EMPNIG	40			~~THE PHE~~	1		
VACVIT	2			DRY EXP	1	1	
VACULI	5	6"		THE LIM	T	1	
PINVUL	T			MAL FUS	1	2	
VER VIR	1	2					
RUBPED	3			RHYT LOR	35		
COPTRI	1			HYL SPL	40		
CORCAN	3			PTI CRI	2		
FAVCRI	70			DICRANUM	3		
ERIPER	2			SPHAGNUM	5		
✓ⓒ PLAtanthera gracilis (LAF, MLC)	1			PLESCH	5		
GEN DOU	3						
GEU CAL	5			ALN VIR SIN	1	2	
CARMACH	2	1		TSUMER SNAGS	1	20	
CARANT	6	6"		common throughout			

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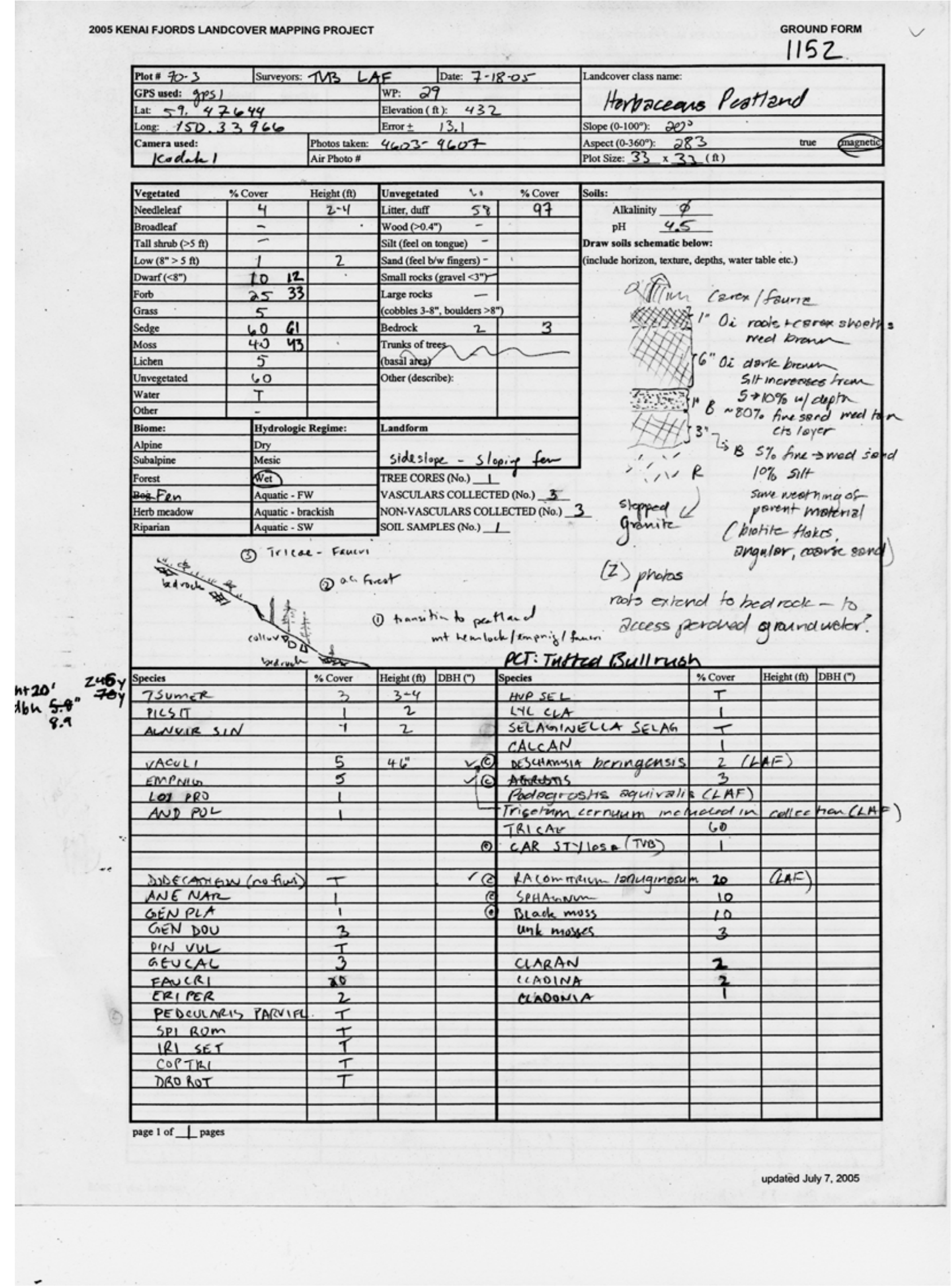
Appendix XVII: McCarty Fjord Site Forms (continued).

Site 14



2005 KENAI FJORDS LANDCOVER MAPPING PROJECT

GROUND FORM 1152

Plot # 70-3	Surveyors: TVB LAF	Date: 7-18-05	Landcover class name: Herbaceous Peatland
GPS used: gps1		WP: 29	
Lat: 59.47644		Elevation (ft): 432	
Long: 150.33966		Error ± 13.1	Slope (0-100°): 20°
Camera used: Kodak 1	Photos taken: 4603-9607		Aspect (0-360°): 283 true [✓ magnetic]
	Air Photo #		Plot Size: 33 x 33 (ft)

Vegetated	% Cover	Height (ft)	Unvegetated		% Cover
Needleleaf	4	2-4	Litter, duff	58	97
Broadleaf	–		Wood (>0.4")	–	
Tall shrub (>5 ft)	–		Silt (feel on tongue)	–	
Low (8" > 5 ft)	1	2	Sand (feel b/w fingers)	–	
Dwarf (<8")	10 12		Small rocks (gravel <3")	–	
Forb	25 33		Large rocks (cobbles 3-8", boulders >8")	–	
Grass	5				
Sedge	60 61		Bedrock	2	3
Moss	40 43		Trunks of trees (basal area)		
Lichen	5		Other (describe):		
Unvegetated	60				
Water	T				
Other	–				

Biome:	Hydrologic Regime:
Alpine	Dry
Subalpine	Mesic
Forest	[✓ Wet]
~~Bog~~ Fen	Aquatic - FW
Herb meadow	Aquatic - brackish
Riparian	Aquatic - SW

Landform: sideslope - sloping fen

TREE CORES (No.) 1

VASCULARS COLLECTED (No.) 3

NON-VASCULARS COLLECTED (No.) 3

SOIL SAMPLES (No.) 1

Soils:

Alkalinity ø

pH 4.5

Draw soils schematic below:

(include horizon, texture, depths, water table etc.)

Carex / fauria

1" Oi roots + carex sheaths med brown

6" Oi dark brown silt increases from 5→10% w/ depth

1" B ~80% fine sand med tan cts layer

3" → B 5% fine → med sand 10% silt some weathering of parent material (biotite flakes, angular, coarse sand)

R

slopped granite

(2) photos

roots extend to bedrock – to access perched groundwater?

③ Tricae - Faucri

② oc forest

① transition to peatland mt hemlock / empnig / faucri

bedrock

colluv

bedrock

PCT: Tufted Bullrush

ht 20'

dbh ~~5.8~~" 8.9

246y ~~70~~y

Species	% Cover	Height (ft)	DBH (")	Species	% Cover	Height (ft)	DBH (")
TSUMER	3	3-4		HUP SEL	T		
PICSIT	1	2		LYC CLA	1		
ALNVIR SIN	1	2		SELAGINELLA SELAG	T		
				CALCAN	1		
VACULI	5	4-6"	✓ⓒ	DESCHAMPSIA beringensis	2	(LAF)	
EMPNIG	5		✓ⓒ	~~AGROSTIS~~	3		
LOI PRO	1			Podagrostis aquivalis (LAF)			
AND POL	1			Trisetum cernuum included in collection (LAF)			
				TRICAE	60		
			ⓒ	CAR STYlosa (TVB)	1		
DODECATHEON (no flws)	T		✓ⓒ	RACOMITRIUM lanuginosum	20	(LAF)	
ANE NAR	1		ⓒ	SPHAGNUM	10		
GEN PLA	1		ⓒ	Black moss	10		
GEN DOU	3			unk mosses	3		
PIN VUL	T						
GEUCAL	3			CLARAN	2		
FAUCRI	20			CLADINA	2		
ERI PER	2			CLADONIA	1		
PEDCULARIS PARVIFL.	T						
SPI ROM	T						
IRI SET	T						
COPTRI	T						
DRO ROT	T						

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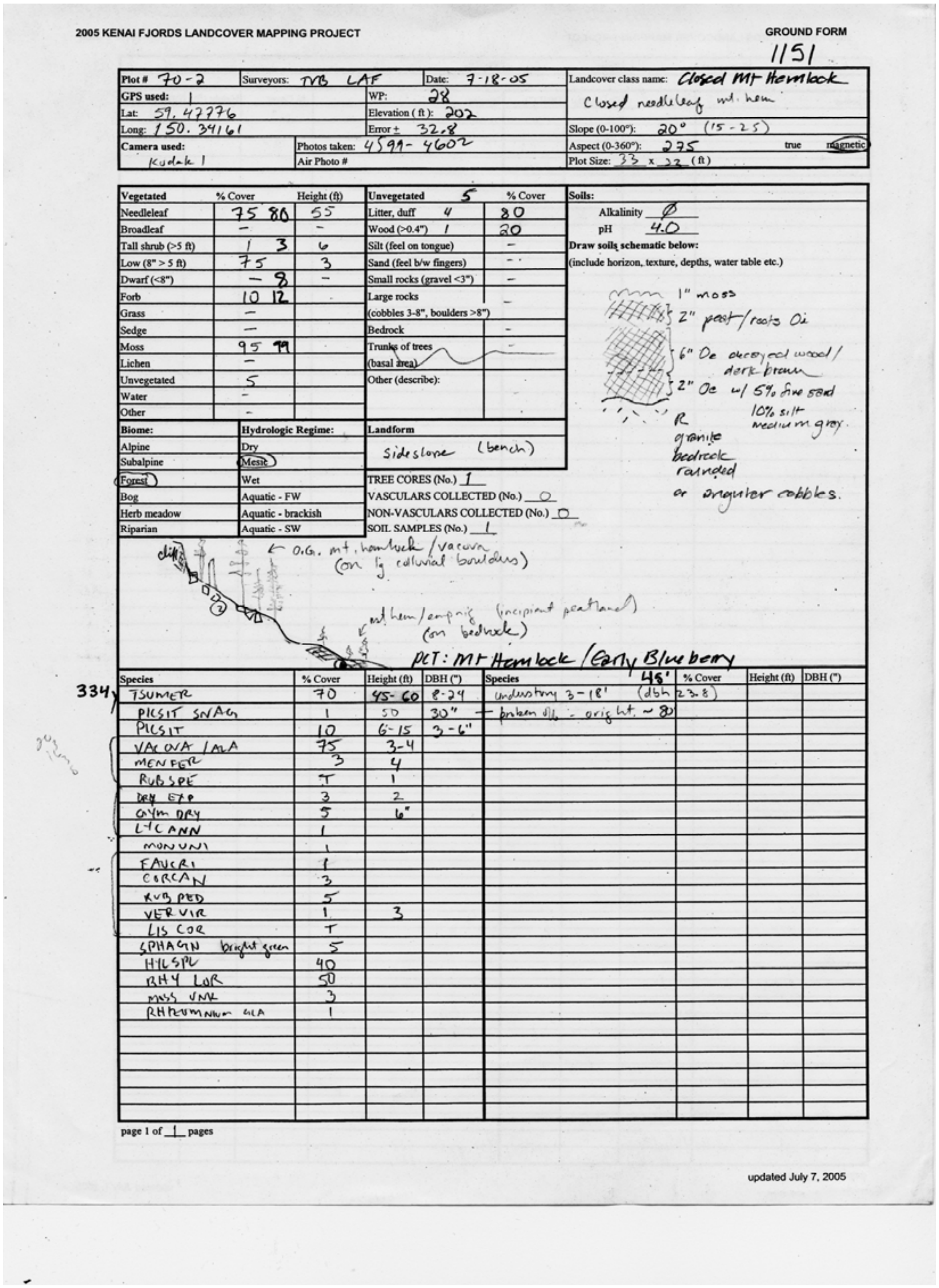
Appendix XVII: McCarty Fjord Site Forms (continued).

Site 15



2005 KENAI FJORDS LANDCOVER MAPPING PROJECT

GROUND FORM

1151

Plot # 70-2	Surveyors: TVB LAF	Date: 7-18-05	Landcover class name: Closed Mt Hemlock Closed needleleaf mt. hem
GPS used: 1	WP: 28		
Lat: 59. 47776	Elevation (ft): 202		
Long: 150. 34161	Error ± 32.8		Slope (0-100°): 20° (15-25)
Camera used: Kodak 1	Photos taken: 4599- 4602		Aspect (0-360°): 275 true [✓ magnetic]
	Air Photo #		Plot Size: 33 x 33 (ft)

Vegetated	**% Cover**	**Height (ft)**
Needleleaf	75 80	55
Broadleaf	–	–
Tall shrub (>5 ft)	1 3	6
Low (8" > 5 ft)	75	3
Dwarf (<8")	– 8	–
Forb	10 12	
Grass	–	
Sedge	–	
Moss	95 99	
Lichen	–	
Unvegetated	5	
Water	–	
Other	–	

Unvegetated 5	**% Cover**
Litter, duff 4	80
Wood (>0.4") 1	20
Silt (feel on tongue)	–
Sand (feel b/w fingers)	–
Small rocks (gravel <3")	–
Large rocks (cobbles 3-8", boulders >8")	–
Bedrock	–
Trunks of trees (basal area)	–
Other (describe):	

Soils:

Alkalinity Ø

pH 4.0

Draw soils schematic below:

(include horizon, texture, depths, water table etc.)

1" moss

2" peat / roots Oi

6" Oe decayed wood / dark brown

2" Oe w/ 5% fine sand 10% silt medium grey.

R granite bedrock rounded or angular cobbles.

Biome:	**Hydrologic Regime:**
Alpine	Dry
Subalpine	[✓ Mesic]
[✓ Forest]	Wet
Bog	Aquatic - FW
Herb meadow	Aquatic - brackish
Riparian	Aquatic - SW

Landform

sideslope (bench)

TREE CORES (No.) 1

VASCULARS COLLECTED (No.) 0

NON-VASCULARS COLLECTED (No.) 0

SOIL SAMPLES (No.) 1

cliff

← O.G. mt. hemlock / vacova (on lg colluvial boulders)

2

mt hem / empnig (incipient peatland) (on bedrock)

PCT: Mt Hemlock / Early Blueberry

334

Species	**% Cover**	**Height (ft)**	**DBH (")**	**Species** 48'	**% Cover**	**Height (ft)**	**DBH (")**
TSUMER	70	45-60	8-24	understory 3-18' (dbh 23.8)			
PICSIT SNAG	1	50	30"	— broken off - orig ht. ~ 80'			
PICSIT	10	6-15	3-6"				
VACOVA / ALA	75	3-4					
MENFER	3	4					
RUBSPE	T	1					
DRY EXP	3	2					
GYM DRY	5	6"					
LYC ANN	1						
MONUNI	1						
FAUCRI	1						
CORCAN	3						
RUB PED	5						
VER VIR	1	3					
LIS COR	T						
SPHAGN bright green	5						
HYLSPL	40						
RHY LOR	50						
MISS UNK	3						
RHYTIDIADELPHUS GLA	1						

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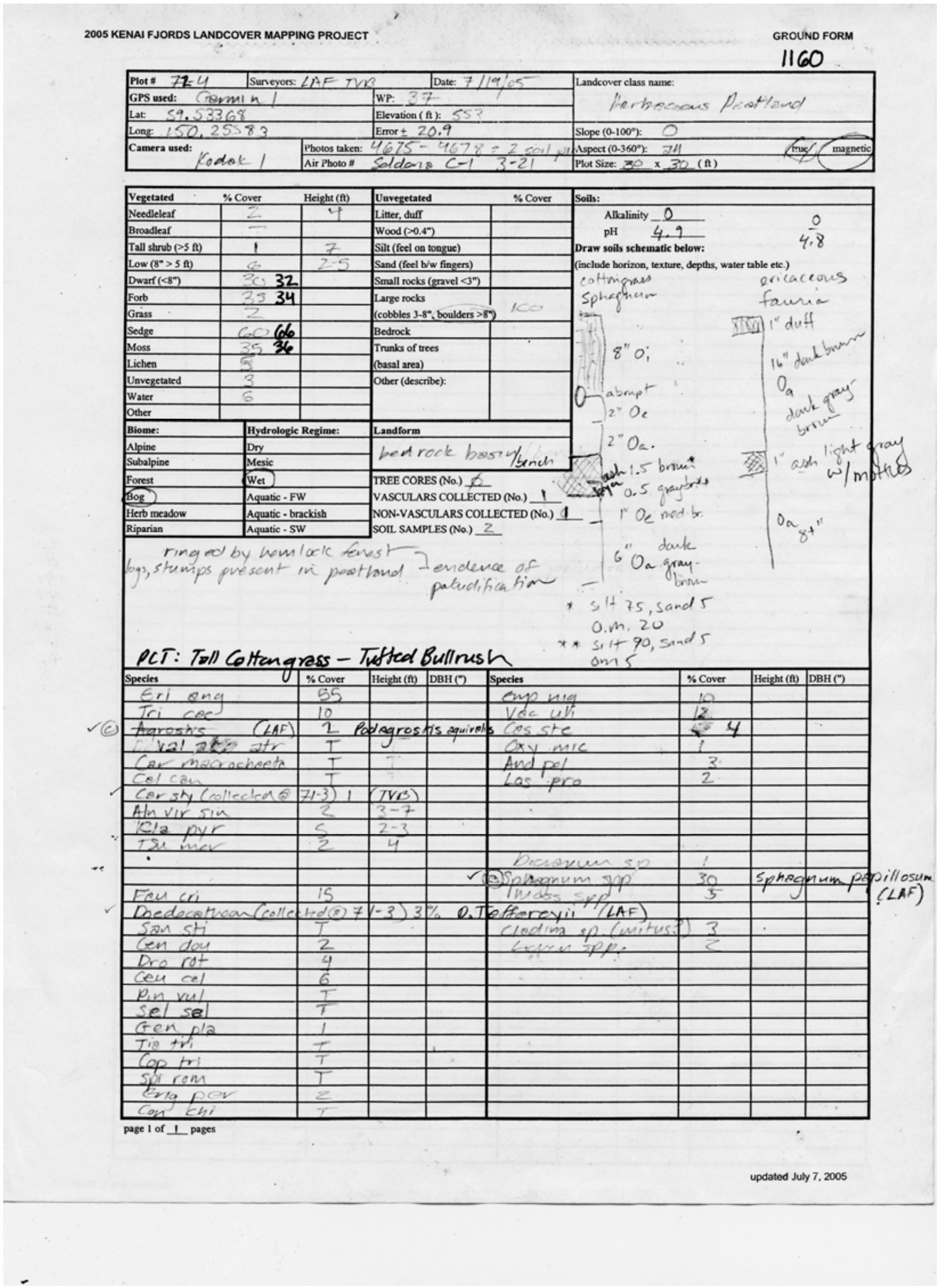
Appendix XVII: McCarty Fjord Site Forms (continued).

Site 16



2005 KENAI FJORDS LANDCOVER MAPPING PROJECT

GROUND FORM
1160

Plot # ~~72~~-4	**Surveyors:** LAF TVB	**Date:** 7/19/05	**Landcover class name:** Herbaceous Peatland
GPS used: Garmin 1		WP: 37	
Lat: 59.53368		Elevation (ft): 553	
Long: 150.25583		Error ± 20.9	Slope (0-100°): 0
Camera used: Kodak 1	Photos taken: 4675 - 4678 = 2 soil pi		Aspect (0-360°): 211 true/ [✓ magnetic]
	Air Photo # Seldovia C-1 3-21		Plot Size: 30 x 30 (ft)

Vegetated	% Cover	Height (ft)	**Unvegetated**	% Cover
Needleleaf	2	4	Litter, duff	
Broadleaf	—		Wood (>0.4")	
Tall shrub (>5 ft)	1	7	Silt (feel on tongue)	
Low (8" > 5 ft)	6	2-5	Sand (feel b/w fingers)	
Dwarf (<8")	30 **32**		Small rocks (gravel <3")	
Forb	35 **34**		Large rocks (cobbles 3-8", boulders >8")	100
Grass	2			
Sedge	60 **66**		Bedrock	
Moss	35 **36**		Trunks of trees (basal area)	
Lichen	5			
Unvegetated	3		Other (describe):	
Water	6			
Other				

Biome:	**Hydrologic Regime:**
Alpine	Dry
Subalpine	Mesic
Forest	[✓ Wet]
[✓ Bog]	Aquatic - FW
Herb meadow	Aquatic - brackish
Riparian	Aquatic - SW

Landform
bedrock basin/bench

TREE CORES (No.) 0
VASCULARS COLLECTED (No.) 1
NON-VASCULARS COLLECTED (No.) 1
SOIL SAMPLES (No.) 2

Soils:
Alkalinity 0 | 0
pH 4.9 | 4.8
Draw soils schematic below:
(include horizon, texture, depths, water table etc.)

cottongrass
Sphagnum
8" Oi
abrupt
2" Oe
2" Oa.
ash layer 1.5 brown*
0.5 graybrown**
1" Oe med-br.
6" Oa dark gray-brown

ericaceous
fauria
1" duff
16" dark brown Oa
dark gray brown
1" ash light gray w/mottles
Oa 8+"

* silt 75, sand 5
O.m. 20
** silt 90, sand 5
om 5

ringed by hemlock forest
logs, stumps present in peatland
] evidence of paludification

PCT: Tall Cottongrass – Tufted Bullrush

Species	% Cover	Height (ft)	DBH (")	Species	% Cover	Height (ft)	DBH (")
Eri ang	55			Emp nig	10		
Tri cae	10			Vac uli	12		
✓© ~~Agrostis~~ (LAF)	2	Podagrostis aquivalis		Cas ste	4		
Val ~~[illegible]~~ atr	T			Oxy mic	1		
Car macrochaeta	T	T		And pol	3		
Cal can	T			Los pro	2		
✓ Car sty (collected @ 71-3)	1	(TVB)					
Aln vir sin	2	3-7					
Cla pyr	5	2-3					
Tsu mer	2	4					
				Dicranum sp	1		
				✓© Sphagnum spp	30	Sphagnum papillosum (LAF)	
Fau cri	15			Moss spp	5		
✓ Dodecatheon (collected @ 71-3)	3%	D. Jefferyii (LAF)					
San sti	T			Cladina sp. (mitis?)	3		
Gen dou	2			[illegible] spp.	2		
Dro rot	4						
Ceu cel	6						
Pin vul	T						
Sel sel	T						
Gen pla	1						
Tie tri	T						
Cop tri	T						
Spi rom	T						
Erig per	2						
Con chi	T						

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updated July 7, 2005