

Vegetation succession patterns near the terminus of the Kennicott Glacier, Wrangell-St. Elias National
Park, Alaska

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Abstract

This project looked at patterns of vegetation primary succession near the terminus of the Kennicott Glacier in Wrangell-St. Elias National Park, Alaska. Using a combination of field data collection, GIS mapping, statistical analysis, and ordination analysis the pattern of plant succession was determined. Percent cover of plants was recorded at each of 89 sample sites near the terminus of the glacier. Environmental factors including geomorphologic habitat type, slope, angle, concavity, soil particle size, depth of the dead organic layer, and age of each site were also determined. These aspects of the physical and biological environment were used to determine which factors have the most impact on the pattern of vegetation succession. The age of each site was calculated using existing aerial photography and maps of the area. Landform age was determined to be driving the pattern of vegetation growth within the study area. The most abundant species and those representing the large-scale pattern of vegetation succession include *Dryas drummondii*, *Picea*, a *Hylocomium* species, and *Shepherdia canadensis*. This result along with other observations largely agrees with other succession research done on glacier forelands.

Introduction

Glaciers are retreating worldwide due to climate change (Barry, 2006). This phenomenon offers scientists the ability to study primary succession. Matthews (1992) defined succession as many processes that together produce gradual, directional changes in the species compositions of ecosystems. Glacier forelands (lands from which glaciers have recently retreated) are used for ecological studies due to their relatively small size, support of relatively simple ecosystems, and they have only had a short time to develop and change in composition. Succession in general has been studied extensively, yet the driving forces behind this process remain debated. Landscapes in valleys below large glaciers provide one of the most beneficial areas to study succession (Ellenberg, 1988). Observations of this succession process have led ecologists to hypothesize that different species colonize progressively older terrain in a predictable pattern (Matthews, 1992). Richard W. Scott studied succession patterns of the Frederika Glacier in the Wrangell Mountains in Alaska in 1974. His research showed a strong relationship between the sequence and distribution of species and age of the study surface. Data collected from the Klutlan Glacier moraines also shows little overlap in age between different observed vegetation communities (Birks, 1980).

In recent years, ordination techniques have become useful in determining if age of study sites correlates to vegetation succession patterns. Different ordination techniques have developed through the years, however the nonmetric multidimensional scaling (NMS) method of ordination has proved to be extremely useful in community ecology. This method works well with data that aren't arranged on any specific gradient or scale. Using NMS ordination has allowed scientists to test the age-succession correlation pattern that seems to occur on glacier forelands without any pre-determined factor bias. Use of ordination graphing techniques allows scientists to group study sites with similar vegetation qualities together while ignoring other environmental factors. This ordering is then represented on a graph with synthetic axes. The axes are made up of interactions between species and can be correlated with environmental factors that may be driving observed patterns. In the case of primary succession studies, usually at least one axis represents terrain age.

Although age of the substrate material has proved to correlate with the patterns of vegetation growth in primary succession areas, other factors also need to be considered. Extensive research on primary succession has occurred at Glacier Bay, Alaska where a 220-year glacial retreat chronosequence has been inferred (Fastie, 1995). Four main succession stages of plants have been recorded here using dendrochronology and historic data to locate locations of past glacier termini. In a 1994 study, Chapin et al. tested the processes of facilitation, life history factors, and competition among species to determine which of these, if any, drive the pattern of succession. Nitrogen is a key nutrient for plant growth but usually rare in severe environments, such as glacier forelands. Facilitation of later-succession plant

growth by nitrogen-fixing plants is believed to be a major successional mechanism. Other life history traits of species also play a role in primary succession. For example, seeds of early-successional species are lighter and easier to transport than late-successional species such as spruce (Chapin et al., 1994). Competition amongst species is another ecological factor that has been seen to impact succession at Glacier Bay. Shading and lack of nutrients in late successional stages inhibits growth of young spruce seedlings and causes early successional plants to disappear (Chapin et al., 1994). Results from the 1994 Chapin et. al. study show that primary succession at Glacier Bay is not a result of any one factor or mechanism, but a combination of all three of their tested mechanisms.

Despite various investigations of plant succession on glacier forelands, little has been studied regarding the habitat characteristics of glacier forelands and their effects on plant population structures and primary succession following deglaciation (Mori et. al., 2007). I have recently become familiar with the McCarthy and Kennecott area in the Wrangell-St. Elias National Park in Alaska (Figure 1). This area has a long and rich history that has provided a fairly detailed record of natural events, and changes that have occurred over the past century. These towns are also located near the terminus of the Kennicott Glacier, which has continued to recede similar to many glaciers in Alaska. This has provided a natural laboratory to study primary succession. This project used a combination of geographic information system, statistical, and ordination data analysis to answer three main research questions.

1. What is the pattern of vegetation primary succession in the first 100+ years after deglaciation near the terminus of the Kennicott Glacier in the Wrangell-St. Elias National Park, Alaska?
2. Do primary succession patterns differ on moraine and outwash surfaces of similar ages?
3. Which aspects of the physical or biological environment most closely control the pattern of succession?

Historical data and previous research were used to define a study area near the terminus of the Kennicott Glacier. Randomly chosen study sites were sampled and data was later analyzed to answer the three research questions.

Methods

Study Area

The Kennicott glacier is located in the Wrangell-St. Elias National Park and Preserve in Alaska. It starts on Mt. Blackburn and travels over 20 miles to its terminus at the Kennicott River. This glacier is fairly large and sits in a typical U-shaped valley. Because of the size of the glacier, a large amount of moraine has built up on the terminus of the glacier. The most recent advance of the glacier occurred around 1860. Since then the glacier has continued to retreat and thin, especially near its terminus. Historic terminal and lateral moraines can be seen in this area. Located nearby is the Stairway Icefall at the head of the Root Glacier, which joins the Kennicott glacier just north of the Kennecott townsite.

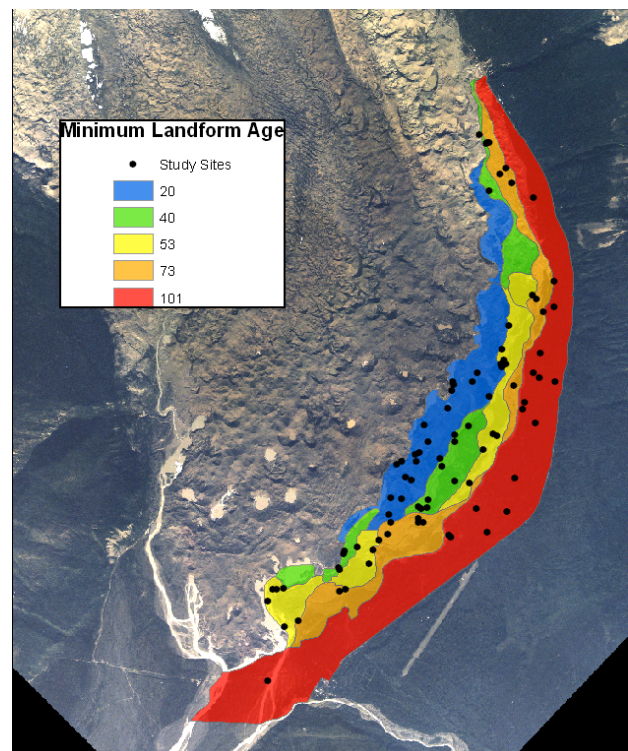
The towns of Kennecott and McCarthy are located near the terminus of the glacier. Kennecott was the base of operations for a rich copper mine between 1908 and 1938. McCarthy, roughly 5 miles to the south of Kennecott was a place for workers to relax and a place for families to live (See Figure 1). After the mine closed operations in 1938, the towns were nearly abandoned except for a few inhabitants. The area became a part of the National Park Service in 1980 and tourism has risen as visitors continue to enjoy the historic mine buildings and natural landscape. Due to the long and rich history of the area, a fairly detailed record of natural events and changes has been documented with photographs as well as written accounts.



Figure 1. Map of southeastern Alaska and location of the Wrangell-St. Elias National Park and Preserve. Area in the circle is approximately where the Kennecott glacier, and the towns of Kennecott and McCarthy are located.

Existing aerial photography and aged landform maps from *Hydrologic Conditions and Hazards in the Kennecott River Basin* (Rickman & Rosenkrans, 1997) were scanned and georeferenced using a geographic information system (ArcGIS ArcMap v. 10). Ages of the land were estimated using historical aerial photographs of the glacier terminus. Stratified sample sites were randomly selected from each of five terrain age-classes using a random points generator (Figure 2). The latitude and longitude of these sites was entered into a GPS unit (Trimble GeoXT) to enable location of the sites in the field.

Figure 2. Aerial photo and map of the Kennecott Glacier with entire study area shaded with color. Different colored polygons correspond to dates where the glacier terminus was known to have been located. Sites within the polygons were therefore deglaciated between known dates and give a minimum age for the landform.



Fieldwork

A total of 89 plots were sampled with between 15-20 plots from each landform age class (Table 1). More sites were generated than sampled because I wanted to sample approximately similar numbers of sites within each landform age class on moraine and outwash. Sites located in lakes or streams were discarded and the next site on the list of randomly generated points was chosen for sampling.

Sample sites were surveyed according to United States Forest Service (USFS) Forest Inventory and Analysis Program (Anonymous, 2005) standards. Each plot included a large circular area (7.3 m radius) to represent tree and large shrub coverage and a smaller subplot (2.1 m radius) to represent all other plant coverage. Plant species coverage was determined for each sample site using plant identification key books. It was a goal of this project to key each vascular plant species to the highest classification possible. A total of 23 plants were keyed to the species classification. White and black spruce species (*Picea glauca* and *Picea mariana*) were grouped together because very few black spruce trees were observed in the area. Non-vascular species were recorded and identified, but not to the highest classification possible. More knowledge of bryophytes was needed to correctly the species of mosses, lichens and liverworts in the area. Two distinct moss species were observed and recorded, but only the most abundant moss was identified after sampling as a species of feather moss (*Hylocomium*). Several lichens were observed but grouped into one species category because of lack of knowledge of specific lichen species. Environmental variables were also recorded at each site. Soil particle size within the top 10 cm was determined based on the United States Department of Agriculture Soil Texturing Field Flow Chart. The depth of dead organic matter was also measured to the nearest centimeter within the top 10 cm where this layer was present. The top 10 centimeters of soil were estimated to be the location of most of the root concentration and also easily accessible, which is why deeper measurements were not taken. Slope of each sample site was measured using a basic clinometer. Aspect of each site was determined by which compass direction most of the study site was facing. Curvature of the land was also measured at each site. Sites were classified as concave if they had a bowl shape into the ground surface or convex if they were hill or dome shaped. Ages of the land were measured using an increment borer on the two largest spruce trees within plots where spruce was present. Tree cores were saved and examined under a dissecting microscope in a lab. Where spruce trees were present but not large enough to core, ages were estimated by counting tree branch whorls. New latitude and longitude data was recorded at each site using the GPS unit and differentially corrected using post-processing data from a Thompson Pass site, the Bureau of Land Management Glennallen Field Office, and a UNAVCO station located along the Nabesna Road.

Analysis

Species richness, total cover of all species, and thickness of the dead organic (duff) layer at each site were compared with age on moraine and outwash to determine whether plants respond differently to these habitat types. A covariate analysis was performed using PASW v. 18.0 with landform age as the covariate, environmental factors (species richness, total cover, duff thickness) as the dependent variables and habitat type (moraine or outwash) as the fixed factor. To determine if landform age is really driving the pattern of vegetation in the study area, NMS ordination was used. This exposed species gradients as well as sites and environmental variables associated with these gradients. The PC-ORD v. 5 program was used to conduct NMS ordination in the autopilot mode. Linear regressions were performed to determine if significant patterns in vegetation and other environmental variables existed along an age gradient.

Results

Environmental Variables

A total of 89 sites were sampled. The age classes and number of points sampled within each area is shown in Table 1.

Table 1. Table showing the number of sites sampled within each age class.

Time of Deglaciation (years)	Number of Sites Sampled	Minimum Landform Age of Sample Sites (years)	Number of Sites on Moraine	Number of Sites on Outwash
1860-1909	20	101	10	10
1909-1937	15	73	9	6
1937-1957	19	53	15	4
1957-1970	18	40	6	12
1970-1990	17	20	15	2

Forty-seven sites were classified as located on moraine, with the other forty-two sites classified as located on outwash. Thicknesses of the duff layer ranged from 0-10 cm among sites with a mean of 2.8 cm with a standard deviation of 3.7 cm. Slopes ranged from 0-46° (mean of 11.3° with standard deviation of 10.6). Only nine sites had slopes greater than 22°. Forty-six sites were classified as bowl-shaped (concave) with forty-three sites classified as hill-shaped (convex). Aspects of the sites ranged though all the compass directions. Soil particle sizes ranged from clay to cobbles. Only a few sites consisted of only clay. Many sites were loam, sand, or gravel with a fair amount of stones or cobbles mixed in. There were also 11 sites that consisted mostly of cobbles, the largest particle size recorded as the most prominent soil type among the plots. Total cover of vegetation ranged from 1-365% among sites (Figure 3). The average total cover of vegetation was 99.3% with a standard deviation of 79.7%. The average total cover, however, for the four youngest landform age classes was 66.6% and 194.8% for the oldest (101 years) landform age class.

Spruce Tree Ages

Ages of *Picea* (spruce) were only recorded on 41 sites. Average spruce ages for each age class were determined using both the tree cores and estimation of tree age by counting whorls. The 47 sites where tree ages were not recorded did not contain any Spruce and were therefore not factored into this part of the project. Table 2 shows the average age of spruce for each age class and the average time it takes for spruce to colonize a site.

Table 2. Table showing the average age of spruce for each age class as well as the average time between deglaciation and spruce colonization.

Time of Deglaciation (years)	Number of Sites Sampled	Minimum Landform Age of Sample Sites (years)	Average age of Spruce trees (years)	Minimum number of years for spruce colonization to occur
1860-1909	20	101	62	39
1909-1937	15	73	25	48
1937-1957	19	53	36	17
1957-1970	18	40	22	18
1970-1990	17	20	8.5	11.5

Moraine vs. Outwash

Analyses of covariance were conducted on species richness, total cover, and thickness of the dead organic (duff) layer of sites to determine if colonization of plants behaved differently on moraine or outwash channels. The independent variable was geomorphic habitat type (moraine or outwash channel) and the covariate was age of the study site. Interaction of factors was first analyzed by creating scatter plots, which demonstrated mixed interactions (Figures 3, 4, and 5). ANCOVA results indicate

that species richness and total cover increase with landform age but do not differ between habitat types. Thickness of the duff layer also increased with increasing landform age, but the rate of increase was higher on moraine sites than on outwash.

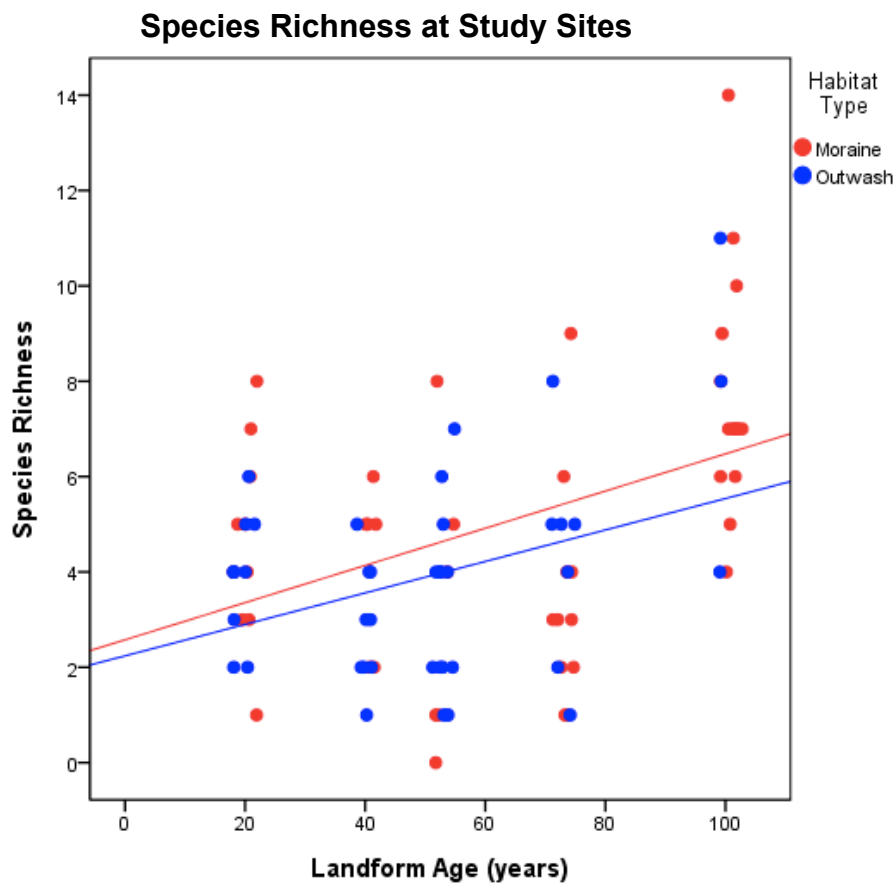


Figure 3. Scatterplot shows the species richness at each site of increasing age. Regression lines and equations are shown for sites located on moraine and outwash areas. Species richness increases with age on both moraine and outwash sites. Slopes and y-intercepts of regression lines are not significantly different between moraine and outwash; therefore species richness values are essentially the same on both habitat types.

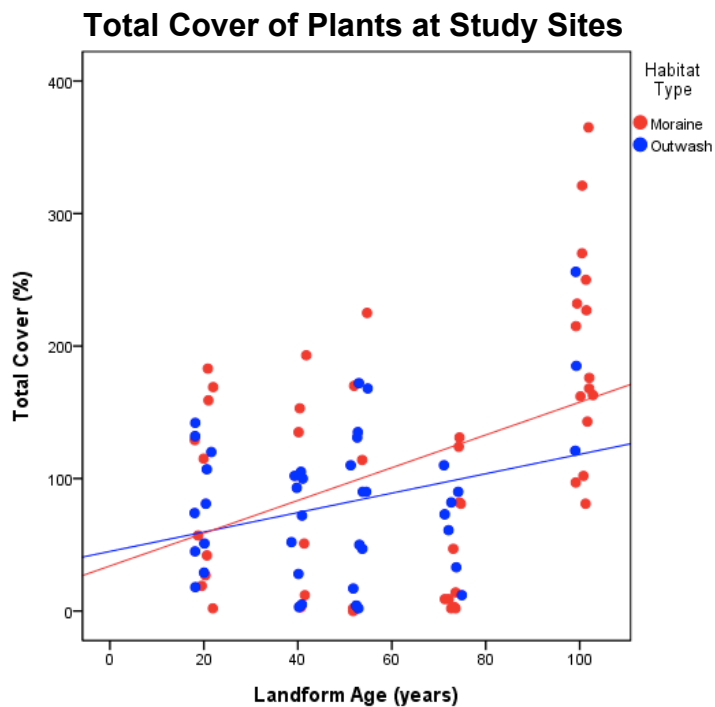


Figure 4. Scatterplot shows the total percentage of cover at sites of increasing age. Regression lines with equations are shown for sites located on moraine and outwash areas. There is a moderate correlation with age on moraine sites and total cover ($R = 0.408$) and a weak correlation with age on outwash sites and total cover ($R = 0.295$).

Thickness of the Duff Layer

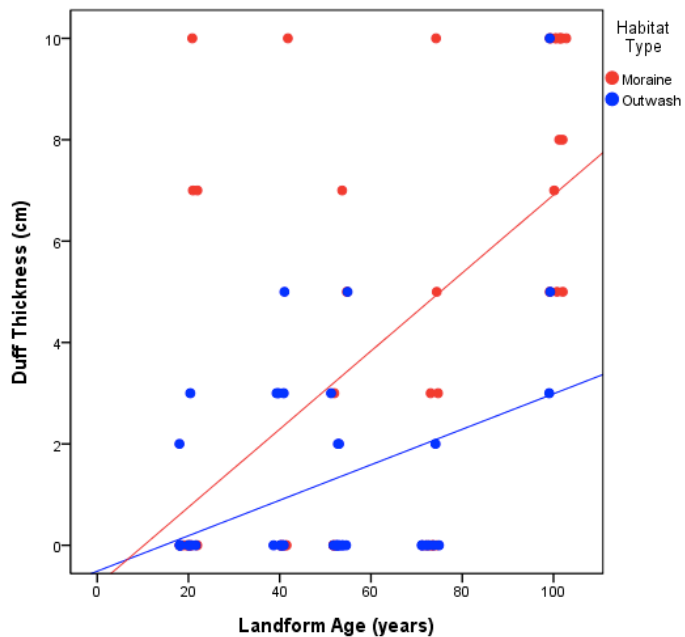


Figure 5. Scatterplot shows the thickness of the dead organic (duff) layer at sites of increasing age. Regression lines with equations are shown for sites located on moraine and outwash areas. There is a moderate correlation with age on moraine sites and duff thickness ($R = 0.555$) and a weak correlation with age on outwash sites and duff thickness ($R = 0.381$).

Species Specific Responses

Scatterplot and linear regression analyses were performed to determine if age is an accurate predictor of several variables collected at each site. Variables that were analyzed include species richness, total cover, thickness of duff layer, soil particle size, slope, aspect, curvature of the ground surface, and percent cover of the most prevalent species (dryas, soapberry, spruce, and feather moss).

Regression results indicate that age significantly predicts species richness ($R^2 = 0.185$, $F(1,86)=19.982$, $p<0.001$), total cover ($R^2=0.166$, $F(1,86)=17.553$, $p<0.001$), thickness of the duff layer ($R^2=0.304$, $F(1,86)=38.5522$, $p<0.001$), percent cover of spruce ($R^2=0.314$, $F(1,86)=39.763$, $p<0.001$), and percent cover of unknown moss ($R^2=0.302$, $F(1,86)=37.657$, $p<0.001$). The values for each of these variables increased as age of the sites increased (Figures 12, 13, and 14). The oldest sites in this study had the highest species richness, total cover, thickness of duff layer, percent cover of spruce and an unknown moss species. Age does not significantly predict curvature of the ground, slope of the ground surface, percent cover of *Dryas drummondii*, percent cover of *Shepherdia canadensis*, or soil particle size.

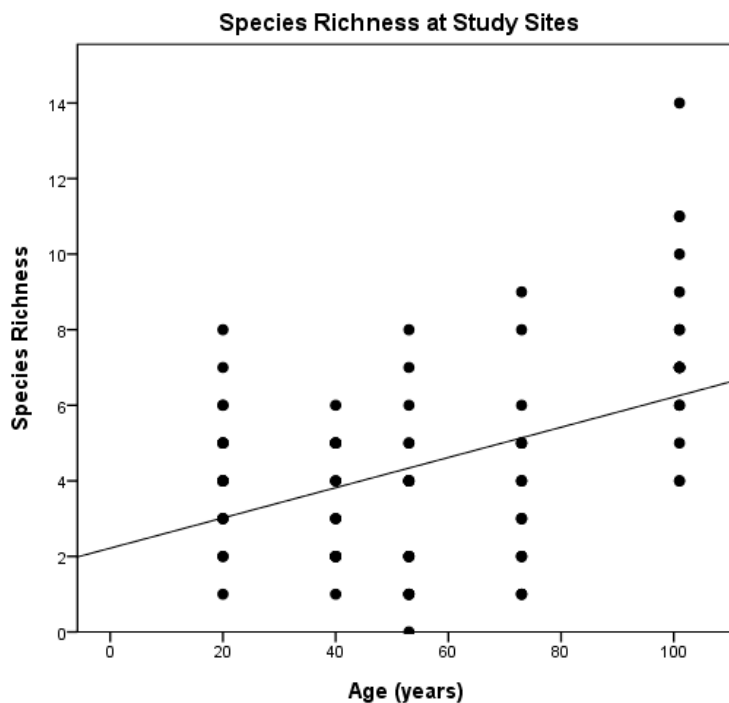


Figure 12. Species richness increases as age of study sites increases. Dots may represent more than one site with the same species richness. Regression line shows prediction of species richness with varying age ($y = 0.040x + 2.219$, $R^2=0.185$).

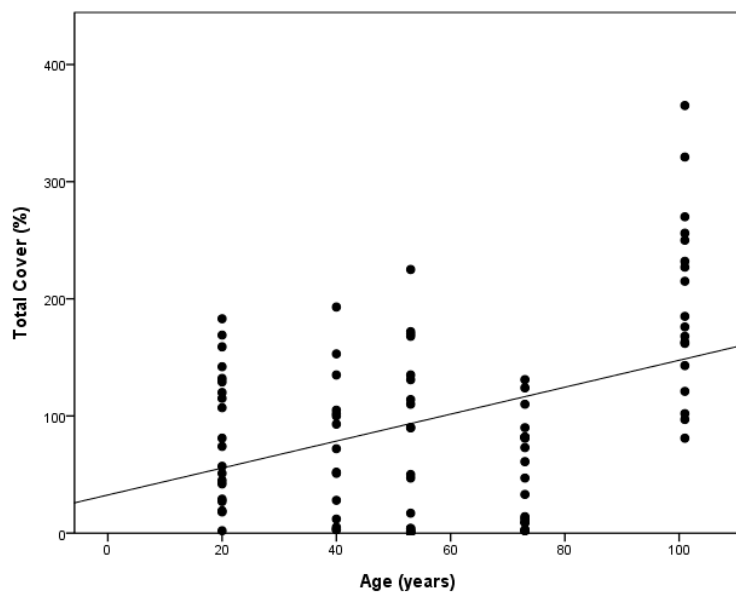


Figure 13. Total cover of vegetation increases with increasing age of sites. Regression line shows prediction of total cover with varying age ($y = 1.150x + 32.568$, $R^2 = 0.166$).

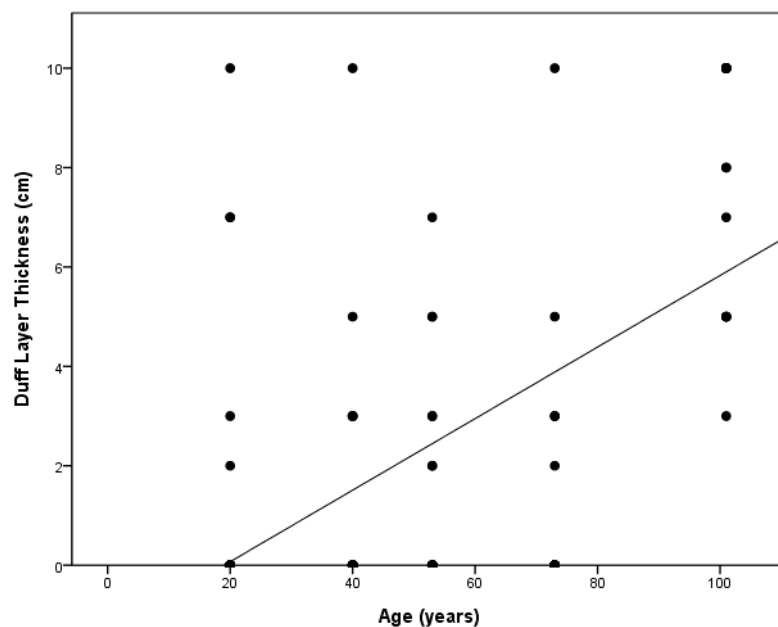


Figure 14. Thickness of the duff layer increases with increasing age of study sites. Dots may represent more than one site with the same value for duff layer thickness. Regression line shows the prediction of thickness of the duff layer with varying age ($y = 0.072x + -1.370$, $R^2 = 0.304$).

Plant Community Ordination

Ordination was used in this project in order to objectively determine the pattern of vegetation and aspects of the physical and biological environment that may be driving that pattern. The ordination method arranges sample sites along axes that are made up of complex combinations of species' coverage. Testing various methods of ordination a two dimensional solution was used. This result showed that Axis 1, the first of two calculated dimensions, was most highly correlated with sites

containing high abundances of *Dryas drummondii*, *Picea*, and the *Hylocomium* species. Axis 2, the other of the calculated dimensions, was most highly correlated with *Shepherdia canadensis*. Of the environmental factors measured, age seemed to be the most obviously significant predictor of species' coverage among sample sites.

Running the ordination in different ways allowed for determination of the most accurate representation of the data. Random starting configuration was used to conduct the NMS ordination. This provides a more objective display of the results. Autopilot mode using the Euclidian distance measure was used with fifty runs of the real data and fifty runs of randomized data. Based on stress in relation to dimensionality results, two dimensions were used in the final solution of the ordination. Final stress of the two-dimension ordination was 11.7518. Typically stress values around 10 are considered significant. The result from the Monte Carlo test shows that stress in the runs of the randomized data was greater than that of the real data ($p=0.0196$). Stability criterion of the final solution was based on 0.00001 standard deviations over the last ten iterations. The final instability of the solution was 0.00019 with 200 iterations. If the final instability of the solution is greater than 0.001, the solution is typically not used in analysis of results.

Proportion of variance represented by each axis is based on the r^2 values between distance in the ordination space and distance in the original space. For the final solution, Axis 1 ($r^2=0.408$) and Axis 2 ($r^2=0.482$) have a cumulative r^2 -value of 0.890. Each ordination axis is comprised of a combination of the 23 most common species in the study area. Study sites are arranged within this species space according to their percent cover of each species. Sites (represented by dots) located close to each other on the ordination graph are more similar in terms of species composition than other sites located farther apart.

From the main ordination graph, it is clear that older aged sites are located on the right side of the graph and younger sites on the left side, which would indicate that landform age is driving the pattern of vegetation associated with Axis 1 (Figure 6). Gradients in species composition of *Dryas drummondii*, *Picea*, the *Hylocomium* (feather moss) species, and *Shepherdia canadensis* represented in scatterplots (Figures 7, 8, 9, and 10) show relatively large correlation coefficients between ordination axes. Axis 1 is highly correlated with *Dryas drummondii* ($R=-0.821$), *Picea* ($R=0.659$), and the *Hylocomium* species ($R=0.747$). *Dryas drummondii* is most abundant on younger sites, while *Picea* and the *Hylocomium* species are most abundant on old sites. These species are most closely associated with the pattern of vegetation on Axis 1. Axis 2 is highly correlated only with *Shepherdia canadensis* ($R=0.821$). The species is most abundant in sites on the lower half of the graph regardless of the site's age. No measured environmental variable was highly correlated with Axis 2.

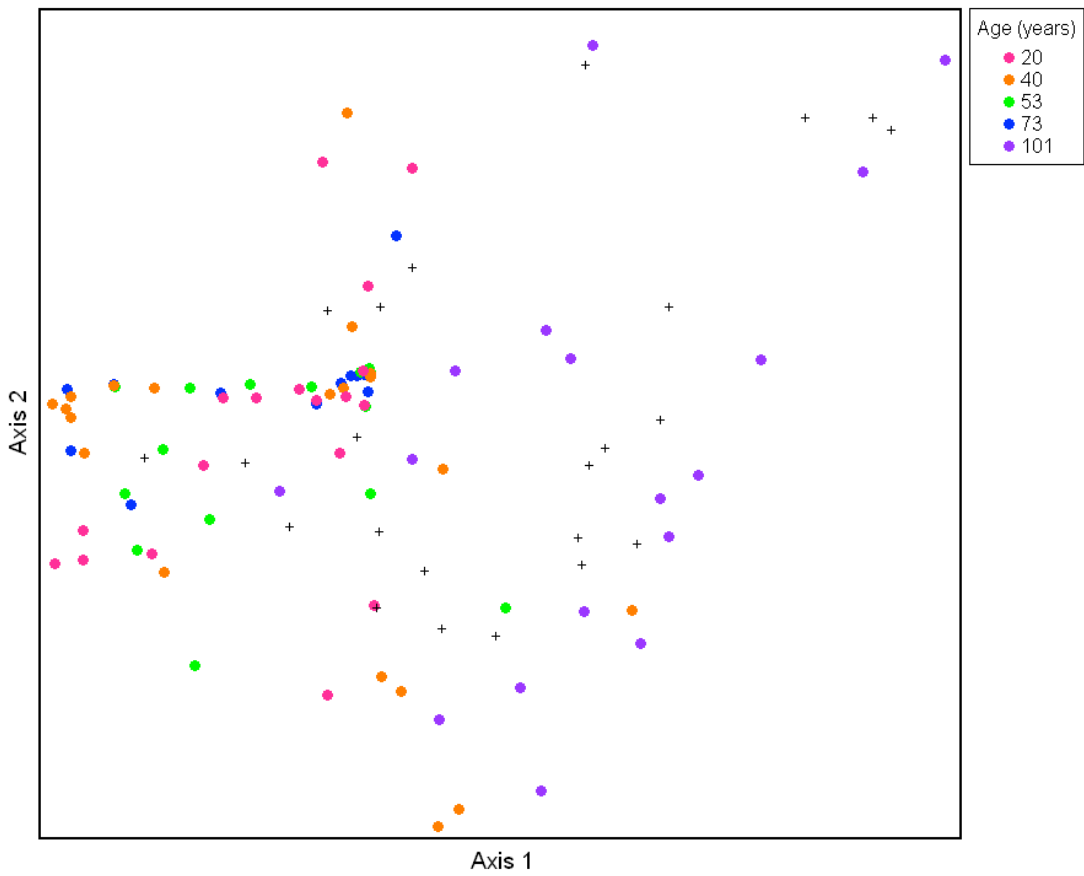


Figure 6. Ordination graph shows more older sites on the right side of the graph and other, younger sites located on the left side of the graph. Each sample site is represented by a dot, with distances between sample sites approximately equal to dissimilarity in species composition. Species are represented by crosses.

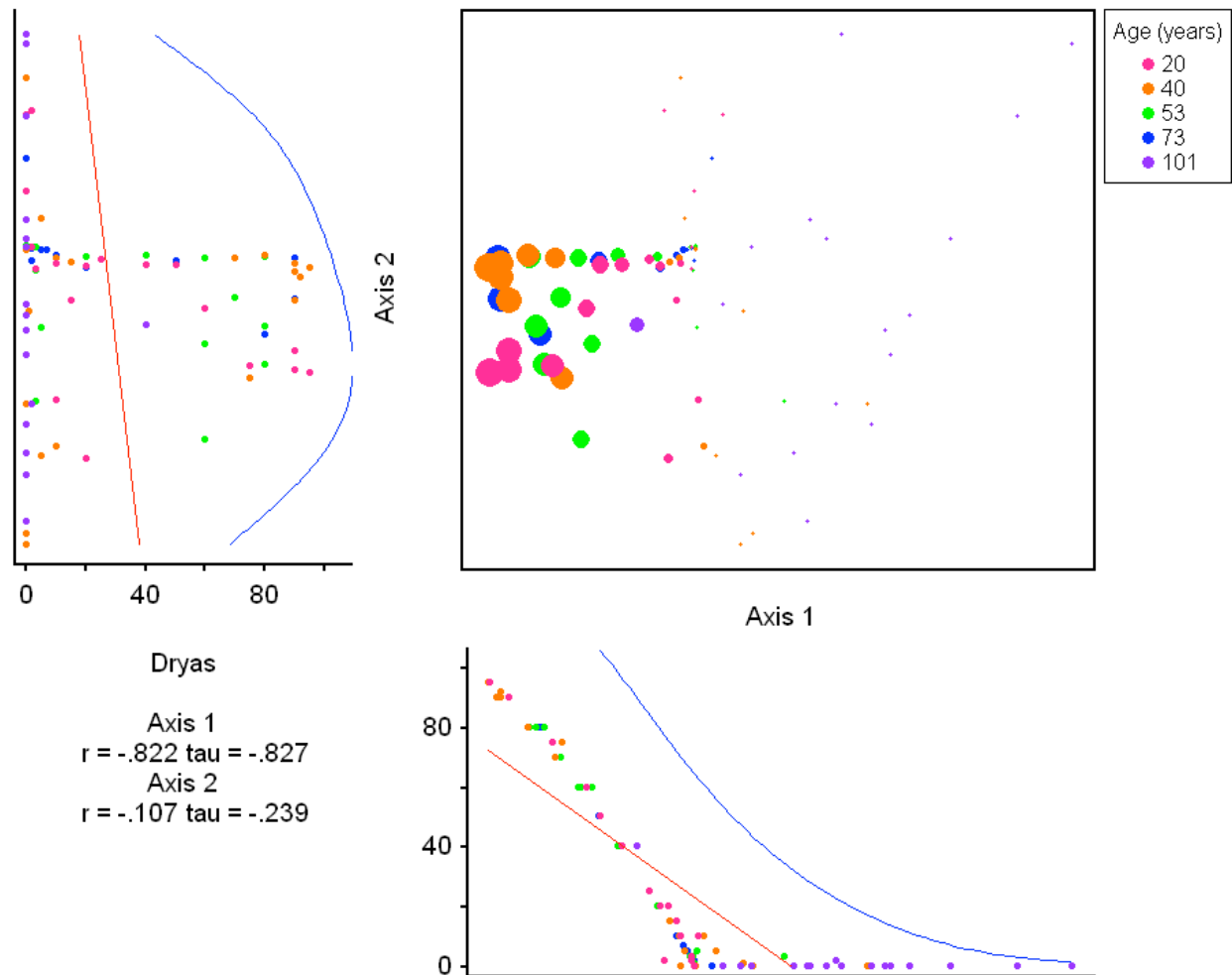


Figure 7. Scatterplot of abundance, measured as cover, of *Dryas drummondii* in relation to ordination axes. Each point represents a sample site. Symbol size is proportional to species abundance. Upper right: 2-D ordination of sample sites. Lower right: scatterplot of abundance of *Dryas drummondii* (“DryDrum”) against score on Axis 1. Upper left: scatterplot of abundance of DryDrum against axis 2. Superimposed on the two abundance scatterplots are the least squares regression lines (red) and a smoothed envelope (blue) showing points falling within two standard deviations of a running mean of DryDrum abundance along the gradient.

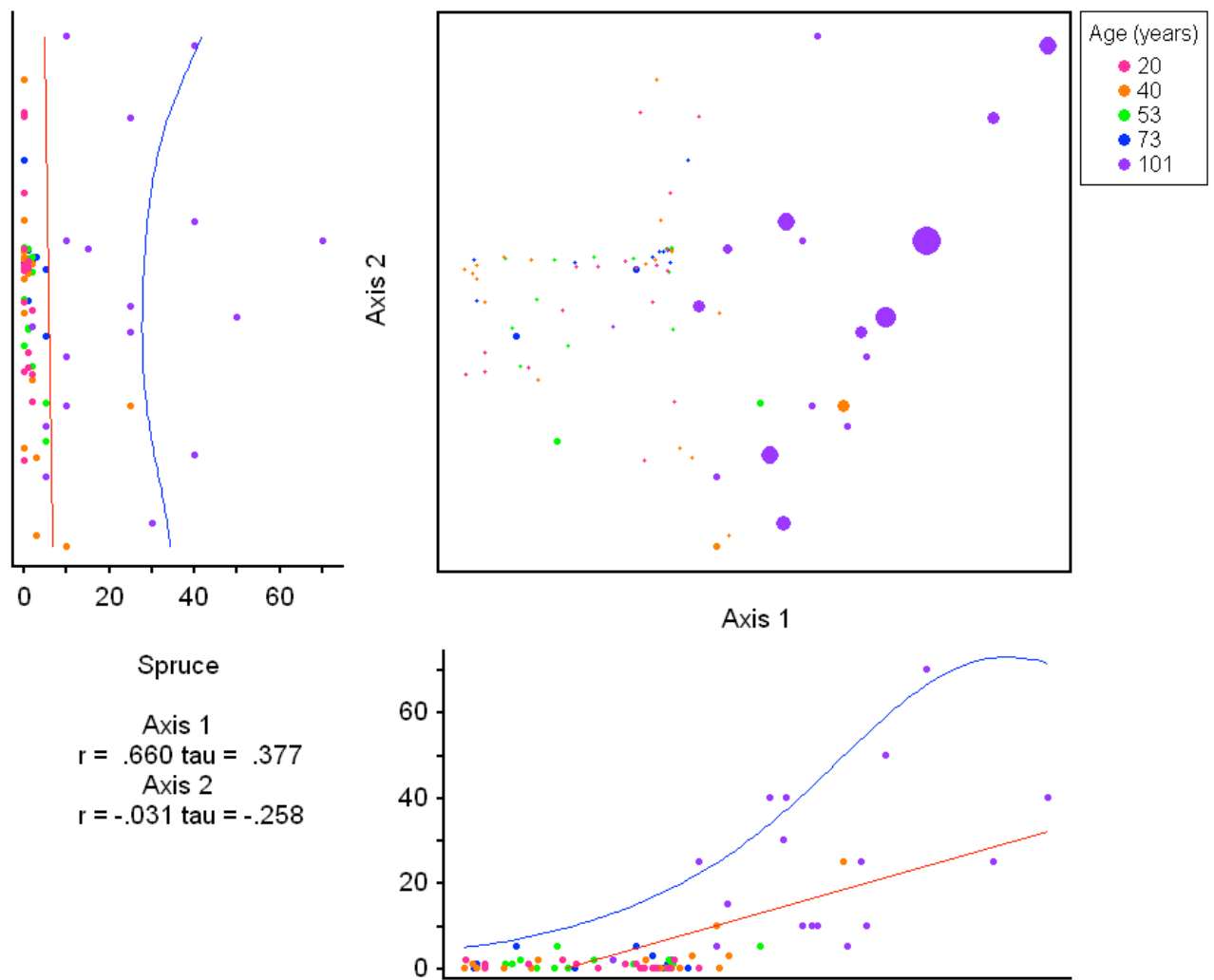


Figure 8. Scatterplot of abundance, measured as cover, of Spruce (*Picea*) in relation to ordination axes. Each point represents a sample site. Symbol size is proportional to species abundance. Upper right: 2-D ordination of sample sites. Lower right: scatterplot of abundance of *Picea* against score on Axis 1. Upper left: scatterplot of abundance of *Picea* against axis 2. Superimposed on the two abundance scatterplots are the least squares regression lines (red) and a smoothed envelope (blue) showing points falling within two standard deviations of a running mean of *Picea* abundance along the gradient.

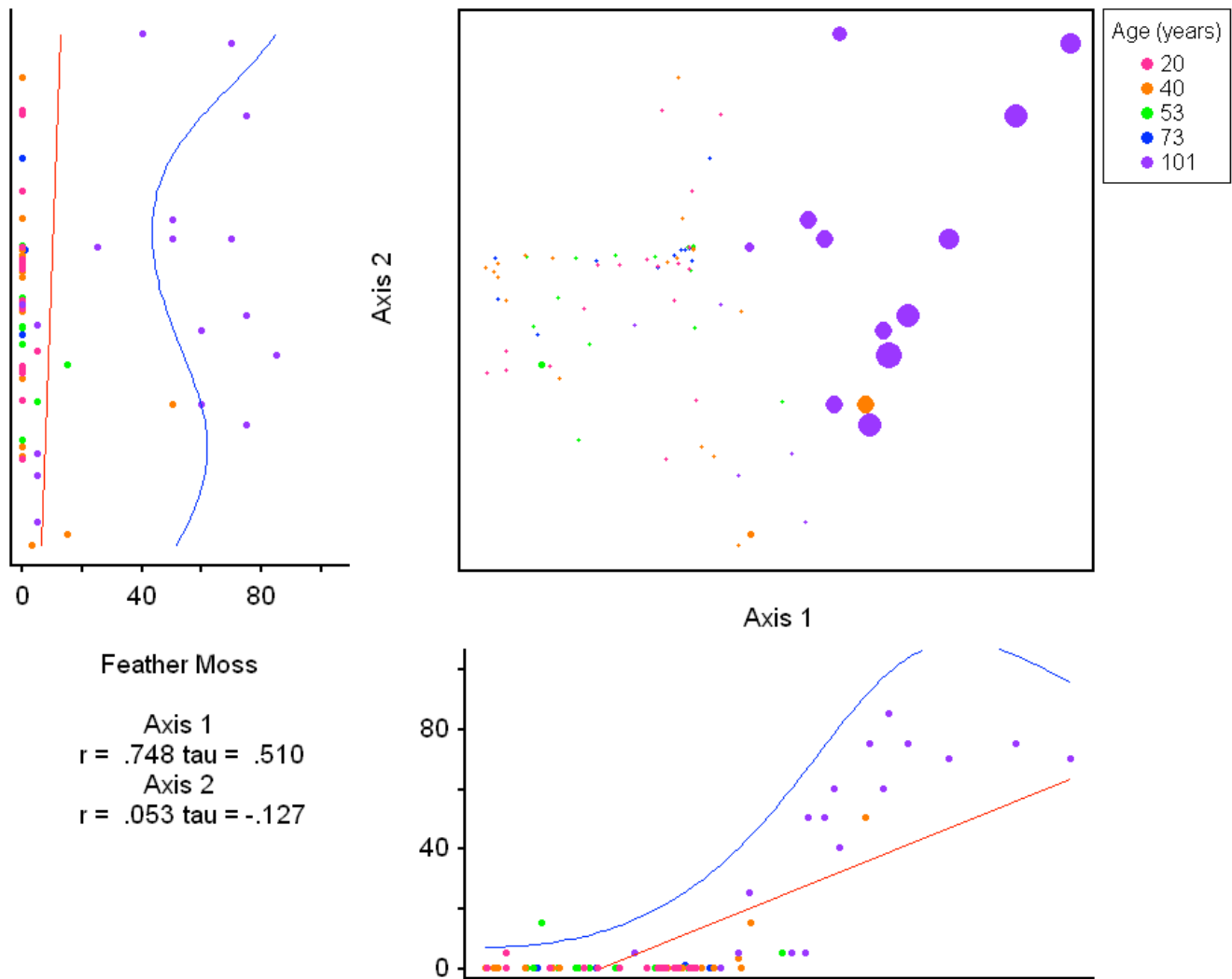


Figure 9. Scatterplot of abundance, measured as cover, of unknown *Hylocomium* (feather moss) species in relation to ordination axes. Each point represents a sample site. Symbol size is proportional to species abundance. Upper right: 2-D ordination of sample sites. Lower right: scatterplot of abundance of feather moss against score on Axis 1. Upper left: scatterplot of abundance of Bryoph against axis 2. Superimposed on the two abundance scatterplots are the least squares regression lines (red) and a smoothed envelope (blue) showing points falling within two standard deviations of a running mean of feather moss abundance along the gradient.

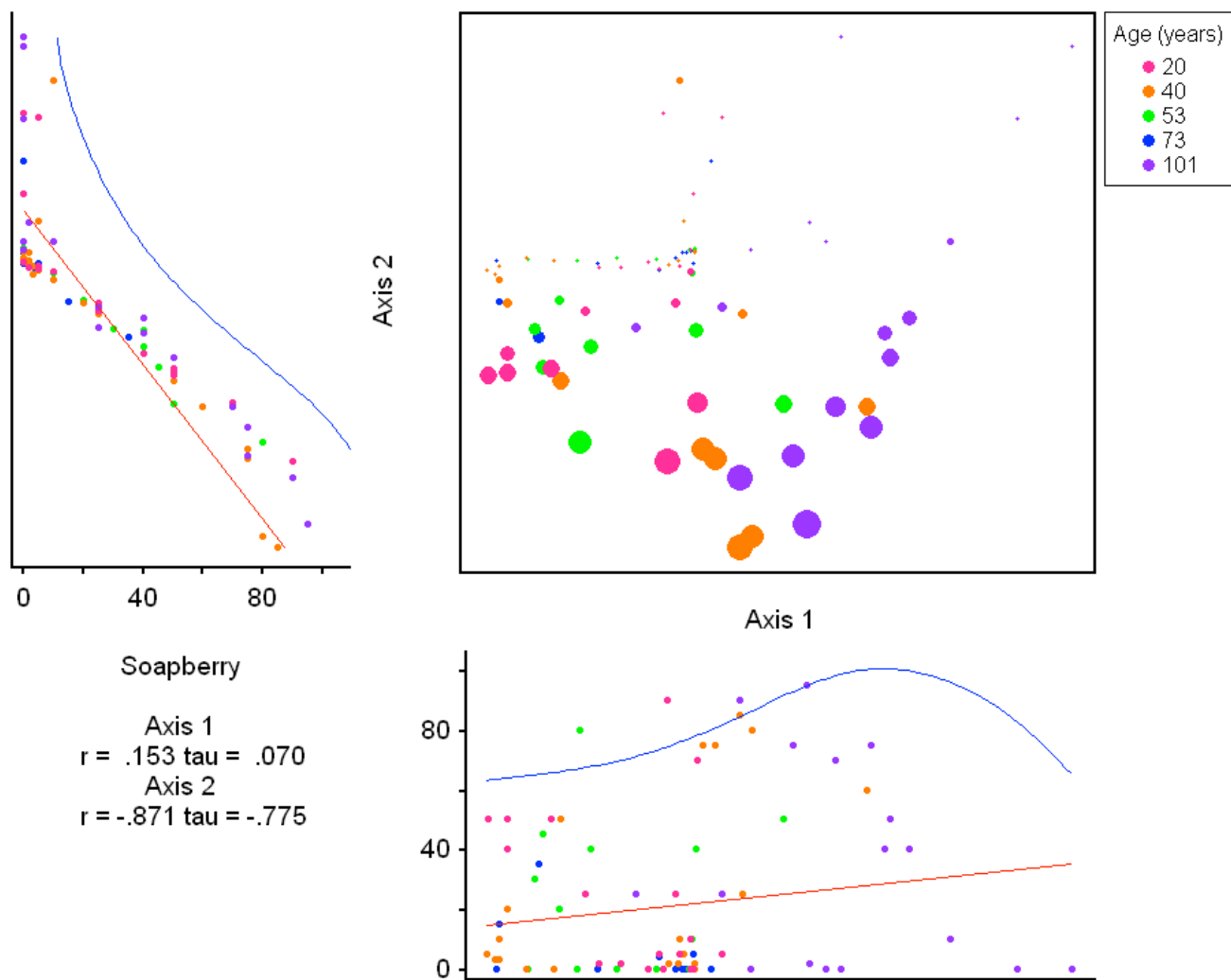


Figure 10. Scatterplot of abundance, measured as cover, of *Shepherdia canadensis* (ShepCan) in relation to ordination axes. Each point represents a sample site. Symbol size is proportional to species abundance. Upper right: 2-D ordination of sample sites. Lower right: scatterplot of abundance of ShepCan against score on Axis 1. Upper left: scatterplot of abundance of ShepCan against axis 2. Superimposed on the two abundance scatterplots are the least squares regression lines (red) and a smoothed envelope (blue) showing points falling within two standard deviations of a running mean of ShepCan abundance along the gradient.

Results from the ordination indicate no major difference between sites located on moraine and outwash. There seems to be more moraine sites located on the right side of the graph, however, only two of the oldest sites were located on outwash, the rest were moraine.

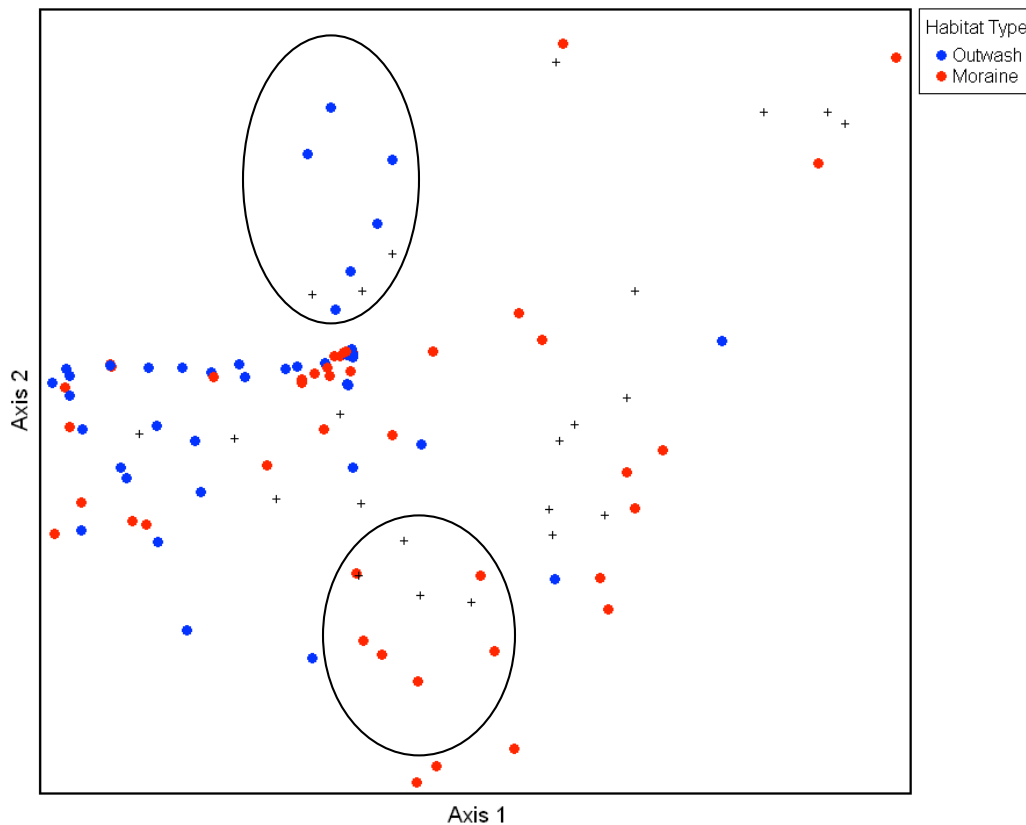


Figure 11. Two-dimensional graph of ordination results differentiated by habitat types (moraine and outwash). The oval on the top half of the graph encircles sites most closely associated with *Epilobium latifolium*, *Equisetum fluviatile*, and *Hedysarum alpinum*. The oval on the bottom half of the graph encircles sites most closely associated with *Shepherdia canadensis*.

Discussion

In general, this study aimed at interpreting any patterns in vegetation succession near the terminus of the Kennicott glacier. A variety of methods were used to first describe the pattern of vegetation that occurs and then to determine what, if any, environmental variables are controlling this pattern. Initially, sites were grouped by those located on moraines and those located on historical outwash plains. Although it seems that the pattern of vegetation on moraine sites is similar to that on outwash sites, the ordination graphs showed that the level of moisture in the soil at sample sites may have an impact on the vegetation pattern. Sites were also grouped by age, which ended up being a primary factor as to where and how abundantly certain species grow. This agrees with the basic idea of succession in that younger sites will have fewer species and less percent cover of those species than older sites in the same area.

Spruce Tree Ages

Results show that the average age of spruce trees increases as the age of the study sites increases. However, the average time it takes for spruce to colonize an area differs for each age class. It would make sense for these times to be relatively similar because spruce trees would colonize successively younger areas in the same proportion of time that the glacier retreats from these areas. For example, it doesn't make sense that it would take spruce trees 39 years to colonize the oldest sites and only 11.5 years to colonize younger sites. One explanation for this discrepancy is that the oldest trees in the study area, located within the oldest age classes, could have been rotten and decayed and unable to accurately measure their age. Several tree cores had to be thrown out because they were rotten and unable to read. Therefore, there were very likely older trees than what was measured within the oldest age classes. Due to these measurements, it doesn't seem like there is a clear time in which spruce will grow at a site after it is deglaciated.

Moraine vs. Outwash

Based on results from ANCOVA tests and NMS ordination, no major difference exists between sites located on moraines or outwash plains. Although there was a significant difference between the correlation of thickness of the duff layer and age of sample site on moraine or outwash, the majority of data suggests no difference between the two geomorphologic habitat types. Ordination results showing differences between habitat types (Figure 11) seem to show a grouping of moraine sites on the right side of the graph. This can be explained by the fact that only two sites sampled from the oldest age class were located on outwash areas. These sample sites can be seen on Figure 10 as the two red dots located on the right side of the graph. The rest of the graph shows a more accurate depiction of whether moraine and outwash sites are different in terms of vegetation composition.

A closer look at the ordination result shown in Figure 11 shows that there may be a difference in habitat types only in middle-age sites as opposed to young and old sites. Young sites tend to all have similar vegetation compositions. This is likely due to the fact that the youngest sites in this environment are all harsh and barren no matter what type of landform they are on. However, as age increases, sites tend to diverge between moraine and outwash. This could be due to differences in soil sizes as well as concavity and possibly other environmental variables. Outwash sites tend to have pockets of fine soils where plants that grow in wetter environments would thrive here and not on dryer moraine sites. However, as sites continue to age, they become more similar in terms of species composition and habitat type no longer impacts vegetation patterns. The thickness of the duff layer seems to be so large in all of the oldest sites that habitat type doesn't really have an impact on the pattern of vegetation any longer. This result is unexpected and cannot fully be explained by the data from this study. More investigation should be conducted in order to determine if this pattern is real and if so, what is causing the pattern to occur.

Effects of Age

Age ended up being the primary force driving succession in this study. Age significantly predicted species richness, total cover, thickness of the duff layer, and percent cover of spruce and feather moss species. This result makes sense ecologically. For example, the longer a site has been free of ice, the more time plants have had to develop and grow in that area. This leads to more species being able to grow on sites as they age, as well as allowing existing vegetation to spread and cover more area. Thickness of the duff layer also increased with age of sample sites. On sample sites, *Dryas drummondii* seemed to be most prevalent in young sites located very near the glacier's edge. In the oldest sites, over 101 years old, *Dryas drummondii* was not prevalent, but spruce and the unknown moss species were. Other species did not show a linear correlation pattern with age, except a few species (*Rosa acicularis*, *moneses uniflora*, *Lupinus arcticus*, *Viburnum edule*, *Pyrola grandiflora*, *Cornus canadensis*, *Salix Scouleriana*) that were only seen in the oldest sites. This could be due to a sort of threshold or benchmark in vegetation composition and age. When sites reach a certain age, the environment may reach an

optimum and plants not present at other sites are now able to grow. There is no data from this study specifically looking at this theory, however and more investigation is needed to support this idea.

Ordination results show age as the only environmental variable measured in this study that is clearly driving the pattern of vegetation succession. This age variable shows up on Axis 1, along with cover of *Dryas drummondii*, *Picea*, and *Hylocomium*. These species were already shown to correlate with age. The Axis 2 from the ordination does not relate strongly to any environmental variable measured in this study. *Shepherdia canadensis* is the only species that shows a pattern along the Axis 2 gradient. With a closer look at Figure 10, one can see that the three species (*Epilobium latifolium*, *Equisetum fluviatile*, and *Hedysarum alpinum*) in the circle on the top half of the graph are all plants that thrive in wetter environments. These species are located on the opposite end of Axis 2 from *Shepherdia canadensis*, which we know is the only species really showing a significant pattern along Axis 2. This leads me to believe that Axis 2 may be related to a moisture gradient. Species on the top half of the graph grow in wetter environments and species on the bottom half of the graph grow in drier environments. This also makes sense when we look again at Figure 10 and think about the differences in moraine and outwash in middle-age sites. The sites on the top of the graph in the middle-age range are located on outwash, which we would assume would be wetter than moraine sites. Moisture was not measured in this study, but it would be valuable for future succession studies to look at moisture of soils as an environmental gradient that may be driving vegetation patterns.

Overview

Results of this study largely agree with other primary succession research. Two of the most prevalent species near the Kennicott Glacier (*Dryas* and *Spruce*) were also two of the most prominent species found at Glacier Bay, the Frederika Glacier, and the Klutlan Glacier. *Dryas* showed up mostly in younger early succession sites and as vegetation richness and cover increased with age, *Spruce* cover became more abundant. Landform age proved to be driving the pattern of vegetation in this area, supporting other succession theories and results. Ordination results indicate that there may be another environmental factor driving the pattern of vegetation succession. The studies at Glacier Bay have showed that other factors besides age have an impact on succession patterns. Although the environmental factors at Glacier Bay were studied thoroughly, there is only a theory that moisture of the soil may be driving the vegetation pattern near the Kennicott Glacier. There may also be a threshold at which vegetation composition changes when sites reach a certain age. These two theories need to be examined in more depth and more investigation of this area needs to be done to support these ideas.

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