Plant Successional Changes Over 67 Years on the Gothic Earthflow

Student: Lydia Paradiso
Mentors: Rick Williams, Stephanie Zorio

Independent Research and Methods in Field Ecology
Summer 2014

ABSTRACT

Long term data on stages of plant succession on bare areas is extremely useful in determining patterns of revegetation over longer periods of time. Understanding of these patterns can have application in conservation and restoration. This study examined plant community composition data for a subalpine earthflow in Gothic, Gunnison County, Colorado, covering a period of 67 years. Ten plots permanent plots were established in disturbed areas in 1947 and surveyed from 1947-1954, with subsequent re-surveys in 1969, 1989-1991, and 2014. Species abundance data shows a peak in diversity around 1970, with subsequent years shows diversity stabilizing. There has also been a significant species turnover rate, shifting from domination by pioneer species to domination by more common perennial forbs adapted for the environment. Additionally, major plant communities were identified and described , and compared between 1947 and 2014. Changes in abundance and composition on a community scale were apparent, but minimal shifts of community boundaries were observed. Overall, the community succession on the Gothic Earthflow has been slow, limited by slow breakdown of shale fragments, lack of nutrients in substrate, and persistent dryness.

INTRODUCTION

Observing stages of plant succession on bare areas is of significant interest to plant ecologists. Studies in naturally disturbed areas, such as avalanche zones (Walsh et al. 2004) , landslides (Highland & Sun 2013) and lava flows(Lawrence & Ripple 2000, Taylor 1957) offer insights into plant colonization and revegetation, with potential applications in fields such as ecological restoration, in places such as previous mining sites (Frouz et al 2008) and farmed land (Myster & Pickett 1994). Studies incorporating long term data to investigate these patterns are of particular importance in understanding long term ecological processes. This study aims to characterize stages of plant succession at both the community scale and on the areas as a whole by examining data covering 67 years on a subalpine earthflow in southwestern Colorado.

An earthflow is a mass movement in which completely saturated earth or rock combined with several other geological and topographical factors provides an environment for flowage and slippage of earth (Sharpe 1938). The Gothic earthflow, located approximately three miles south of Gothic, Gunnison County, Colorado, can be classified as an earthflow with associated slump block. The flow is approximately one mile long and one quarter mile wide, facing southwest at an elevation of 9200 - 9950 feet (Langenheim 1956). The main cause was saturation of the substratum of the area, but several other factors were also important. The stratigraphy of the mass provided optimum conditions for movement. The morainal mantle, ranging from 2 to 40 feet thick, allowed for easy penetration of water. Underneath, the Pierre shale is jointed and fractured, allowing water to penetrate. The shale weathers rapidly, and provided an excellent flow matrix when saturated. A thin impermeable layer of brick clay reportedly lies underneath the shale, and could have contributed to saturation of the mass above by trapping water. The slump block area was also "located in a minor fold on the eastern limb of a larger syncline", with the bedding plane surfaces parallel to the slip surface, thus facilitating movement, and possibly accounting for the unit of the slump block as a unit (Langenheim, 1956).

Jean Langenheim was the first to extensively study the Gothic Earthflow, from 1947-1954. Based on eyewitness accounts, weather data, and tree ring analysis, she dated the occurrence of earthflow to be around 1923. There are two possible sites where the movement may have been initiated. The slump region may have begun to move first, with the addition of its weight causing flowage in lower areas. Alternatively, the lower area may have begun movement first, with the subsequent removal of support causing the upper areas to slump. While the exact mechanism in which the earthflow occurred is unclear, areas of flowage are often sloped and rocky, with very little soil nutrients, while the slump block slipped as one unit and remained relatively intact (Langenheim 1949).

Langenheim classified the flow into six major areas based on observed physiographic conditions. (Figure 1) Area I is the upper breakaway scarp, a v-shaped, stable slope where 30 to 40 feet of moraine is exposed above layers of shale. The foot of the scarp is covered by a layer of soil and talus. Area II, the slump block, is a large meadow relatively unaltered by the earthflow movements. Area III is the lower breakaway scarp, with an incline of 36°. The eastern portion of the scarp is composed of extremely unstable shale particles, and has very little vegetation, while the western portion is relatively stable with islands of vegetation. Area IV constitutes the main body of the earthflow, with a general appearance of a ‘dump ground’ – there are scattered boulders of various sizes as well as large, persistent seepage areas. Area V, the slope descending to the valley floor, contains several 'slump islands' of relatively undisturbed aspen stands, flanked by deep drainage tongues. Area VI is the original valley floor environment, with some shale particles washed down through seepage in area V. Each of these areas provides a different set of environmental factors that influence plant community composition and succession.

Langenheim’s initial data collection, performed in 1947, consisted of several transects across the site, as well as several random 1 m x 1 m quadrats. Langenheim also established ten 1 m x 1 m permanent plots, eight in severely disturbed areas and two in relatively undisturbed areas, and collected data from these for the years 1947-1954, excluding 1953. Her findings were published as a master’s thesis (Langenheim 1949) and in a 1956 paper in *Ecology.* In 1969, Susan Turbak resurveyed Langenheim's 10 permanent plots as part of an undergraduate research project at RMBL. Charles Curtin studied the earthflow from 1989-1991, resurveying the permanent plots and characterizing changes in vegetation. Curtin also looked at soil composition and other possible limiting factors on plant community succession. His findings were published as a master’s thesis (Curtin 1991) and in a 1994 paper.

In her initial study approximately twenty years after the occurrence of the flow, Langenheim observed many bare, rocky areas populated by very few species. Certain species best suited for the environment made up most of the vegetation. Over several years of study Langenheim noticed a decrease in these pioneer plants and an increase in the number of perennial forbs and grasses. Turbak's observations further displayed a decrease in the abundance of pioneer species, as well as an increase in species diversity. Curtin’s study, approximately twenty years later, found that very few pioneer species remained, and that diversity may have begun to level off.

Langenheim also described several important plant communities on the earthflow, delimiting their boundaries on a map (Figure 2). Most notable was the *Chaenactis alpina* community. This community existed on the vegetated areas of the second breakaway scarp as well as extremely disturbed sections of Areas III and IV. In these areas, there were nearly pure stands of *C. alpina*, the only plant able to establish itself. It's extremely deep, woody taproot along with rhizomatous proliferation enabled individuals to anchor themselves in unstable substratum.

On the more stable sections of the flow area, pure stands of *C. alpina* gave way to a mix of *C. alpina* and perennial forbs such as *Achillea millefolium, Oligosporus dracunculus*, and *Taraxacum officinale.* There are also established thickets of *Rosa woodsii* on both stable and unstable portions of the flow. Langenheim hypothesized that the presence of *R. woodsii* was due to persistence of rhizomes from before the disturbance (Langenheim 1956).

The entire slump block area (Area III) is populated by a *Festuca thurberi* community. *F. thurberi* is a perennial bunch grass that often grows up to two feet in height, forming a dense stand when fruiting. Several associated grasses and forbs are also characteristic of the community.

Langenheim briefly mentions several hydric communities around persistent and temporal seepage areas throughout the earthflow, concentrated mostly in areas IV and V. These communities included aspen stands on slump islands in area IV, and persistent seepage areas with communities of willows and showy hydric wildflowers such as *Pedicularis groenlandica* and *Iris missouriensis.*

Upon describing these communities, Langenheim then inferred a proposed successional pathway for plant communities on the earthflow (Figure 3). This pathway followed that as the shale particles in the substratum became progressively smaller and more stable, the pioneer *Chaenactis alpina* would give way to a perennial forb community. Langenheim could see two possible pathways after this - one leading to a *Seriphidium tridentatum* dominated community, and the other leading to a *Festuca thurberi* dominated community. From Langenheim's studies on the permanent plots, she could see evidence for a shift from pure *C. alpina* to a perennial forb community, 30 years after the initial disturbance. Twenty years later, Turbak continued to see a decline in *C. alpina*. By 1990, observations by Curtin revealed that individuals of *C. alpina* were very few in number.

Across previous studies, it has been noted that plant community succession has been slow in the years since the disturbance occurred. Langenheim hypothesized that this was due to the lack of nitrogen producing plants and negligible soil profile. Curtin asserted that the hot, dry microclimate on the earthflow during its relatively short growing season was a major factor in prohibiting increases in diversity. This study will aim to identify shifts in plant communities during the last 67 years, characterize major community types, and pinpoint factors that may have slowed the succession of plant communities on the Gothic earthflow.

METHODS

Field Site

The Gothic earthflow is located approximately 3 miles south of Gothic, in Sec. 11, T 13 S, R 86W, Gunnison County, Colorado . It is approximately one mile long and a quarter mile wide. Elevation ranges from 9,200 to 9,950 feet. The GPS coordinates for the earthflow are N 38.93449 W 106.955423, with an error radius of 577 meters.

Survey

Langenheim's 10 original 1 m x 1 m permanent plots were located using maps, GPS coordinates, and the presence of stakes and rock cairns (Figure 4). For each plot, all species and their abundances were recorded, as well as any other species within 5 meters of the plot. Abundance was recorded as number of individuals per square meter. For plants that grew in mats, such as *Eriogonum umbellatum*, the number of flowering heads was recorded.

A total of twenty 50 meter transects were taken in five distinct community types (aspen groves, *Festuca* meadows, flow areas, *Rosa* thickets, willow stands), with one m^2 quadrats every 10 meters (Figure 5). In each quadrat, species abundance, as well as species cover, was recorded.

A complete list of plants encountered on the earthflow is available in the appendix (Table 3). A majority of species identifications were determined using Weber (2010), as well as Shaw (2012). All species names used here are according to Weber. In some cases, the FNA accepted name is also listed. Voucher specimens of most species encountered were collected and are stored in the RMBL Herbarium.

Analysis

Permanent Plots

Data collected from the permanent plots 1-8 was aggregated with data from Langenheim (1947-1954), Turbak (1969), and Curtin (1989-1991) to examine plant community succession. The average number of species for each year of observation was plotted (Figure 6), as well as the total number of species in all plots per year (Figure 7), in order to compare species diversity and richness. Species composition was also compared across years.

Community Types

For each community type surveyed, percent frequency of each species was calculated (Table 1), and the five most frequent species noted. Historical information from 1947 about species dominance in *Festuca* and flow communities was available for comparison to current data (Figures 8 & 9). Community composition was compared to Langenheim's descriptions of the historical composition in order to infer community scale changes. AGNES clustering was performed in R with presence-absence data for species in each community type, to characterize relationships between types (Figure 10). The plant successional pathways proposed by Langenheim were re-examined to determine the current status of successional patterns on the earthflow.

RESULTS

Permanent Plots

Examining changes in both average number of species per plot (Figure 6) as well as total number of species in plots (Figure 7) from 1947 to present day reveals that diversity in the plots reached a peak around 1970, approximately 50 years after the initial disturbance. Since then, diversity has leveled off. It is important to note that although current numbers for diversity are similar to those from the 1950s, community composition on the flow is extremely different and there has been significant species turnover. Many species that are currently abundant in the flow area were present in extremely small numbers, if at all in 1947, and those species most abundant in 1947 are currently present in much smaller numbers (Figure 9). In comparison, the slump meadow has functioned as a control, with much less species turnover in the years since the initial disturbance (Figure 8).

Community Composition and Succession

A total of 61 species in 24 families were encountered in the community transects. Six of these occurred in all community types; *Achillea millefolium, Taraxacum officinale, Potentilla pulcherrima, Lupinus sericeus, Oligosporus dracunculus* and *Erigeron speciosus.* Four of these species were among the five most abundant species in at least two communities. However, with the exception of the *Rosa* community, the most abundant species in each community type was unique.

Comparison between current and historical community composition revealed that some changes have occurred on a community level. However, community boundaries have remained roughly the same, indicating that community succession as a whole on the earthflow was been slow.

AGNES clustering analysis revealed that the flow and *Rosa* communities were the most similar. The willow community was the most removed from the other communities, due to its large number of unique species. The agglomerative coefficient was .32, indicating a relatively small amount of variation between the communities surveyed.

DISCUSSION

Permanent Plots

The striking absence of *Chaenactis alpina* on many areas of the flow that were previously pure stands is extremely important in considering succession patterns. Langenheim observed high densities of *C. alpina* in the most severely disturbed areas of the flow, as well as a mixture of *C. alpina* and perennial forbs in less disturbed areas. However, even during the years of her studies, Langenheim saw a decrease in the number of individuals both in permanent plots and on the flow. Turbak's survey in 1969 corroborated that numbers of *C. alpina* were on the decline. Throughout the course of observations in 2014, only a handful of individuals of *C. alpina* were observed, mainly in the areas of continuous movement of shale particles. *C. alpina* was an extremely successful pioneer plant, with a deep taproot and abundant wind dispersal, but once the substratum began to stabilize, *C. alpina* was outcompeted by other plant species on the flow.

However, the overall environment of the flow is still in flux. Transects in the flow communities revealed an average of 68% bare ground. With the exception of persistent seepage areas, which have a very different community composition, the flow area is extremely dry. The substratum is mostly composed of shale fragments in various stages of weathering, creating areas that are in constant movement as well as more stable areas. In order to better withstand the constantly shifting substratum, many plants on the flow have developed somewhat woody bases that are often exposed. This allows plants better support and anchorage in the rocky substratum. Many individuals observed on the flow are low to the ground and grow in mats, especially *Heterotheca villosa* and *Eriogonum umbellatum.*

Several limitations on the accuracy of the long term data on the permanent plots must be acknowledged. Exact boundaries and orientations of the plots were approximated for this study, as few cairns or markers were present, and exact coordinates were not available. Both Turbak (1969) and Curtin (1991) acknowledged this difficulty as well. Additionally, all previous observations recorded only numbers of individuals. Data on percent cover of species in the plots was collected during the study, but no other data points were available for comparison.

Plant Community Characterization and Small Scale Successional Patterns

Five major community types on the earthflow were surveyed aspen groves, *Festuca* meadows, flow areas, *Rosa* thickets, and willow stands. Many of the plant communities on the earthflow still fit into the original boundaries defined by Langenheim (Figure 2). The most notable difference is the turnover from *C. alpina* dominated to perennial forb communities. Otherwise, the persistent seepage areas, rose thickets, and aspen stands are present in generally the same areas as they were 67 years ago.

Aspen community

Populus tremuloides groves are found in area VI, on the slope to the valley floor, as well as on the edges of area III, the flow area, close to the steep scarps. The groves are part of slump islands, which slid down the flow area with vegetation and soil profile intact. These areas are wetter than surrounding areas, and several seepage areas are interspersed. There is almost complete ground cover by leaf litter and small plants, and aspen foliage provides canopy cover. *Populus tremuloides* is the most abundant species in this community type, with *Taraxacum officinale, Lathyrus leucanthus, Poa pratensis,* and *Lupinus sericeus* present in at least 50 percent of quadrats. *Lathyrus leucanthus, Lupinus sericeus,* and *Vicia americana* are at their highest abundances in the aspen community. Legumes such as these fix nitrogen into the soil, increasing its nutrient content, which explains the density of the aspen understory.

Flanking the slump islands are steep drainage tongues, effectively preventing the species found on the islands from dispersing further. Clusters of *P. tremuloides* seedlings are present on flow areas above the boundaries of the slump islands, suggesting dispersal to these areas, but success of dispersion is still dependent on presence of stable substrate with adequate nutrients. Contrary to Langenheim's observations of a sparsely populated understory density, current understory populations have a significant density, especially when compared to surrounding areas. This is most likely attributable to the presence of a soil profile, albeit a minimal one, enriched by nitrogen-fixing plants, and a greater ability to trap water because of foliar cover.

Flow community

The transects and observations throughout the flow area, the largest portion of the earthflow, paired with data from the permanent plots, revealed several trends both in time and space.

High levels of species turnover from 1947 to present is indicative of continued stabilization of substrate. The extreme decline in populations of *Chaenactis alpina*, a pioneer plant able to thrive in unstable substratum, paired with the increase in abundance of several perennial forbs, illustrates the out-competition of a pioneer species by more generalist plants once conditions have improved. However, these perennial plants still exhibit traits adapted to the conditions of the earthflow. Woody shrubs, including *Seriphidium tridentatum, Symphoricarpos rotundifolius* and *Chrysothamnus nauseosus* are well established throughout the flow, and forbs such as *Heterotheca villosa* and *Eriogonum lonchophyllum* exhibit thickened aboveground stems, providing support and anchorage when exposed by substratum movement.

Heterotheca villosa is the most abundant species in most areas of the earthflow. In surveys by both Langenheim and Turbak, *H. villosa* was present in three of the permanent plots, but overall was present on the flow in very low densities. In the most recent survey, large individuals were observed in five of the permanent plots, and *H. villosa* was the most frequently encountered species on the flow. In contrast to individuals of *H. villosa* found in environments near the flow, individuals on the earthflow grow very close to the ground, often with a large percentage of vegetative growth, and a small cluster of flowering heads. This presumable adaptation to the dry and mobile environment aided *H. villosa* in becoming the dominant species. As the environment became more amenable to colonization by other species, it is likely that these new species were able to out-compete *Chaenactis alpina*.

The flow areas surveyed in transects possessed an average of 68% bare ground. While cover varies over the entire area, the general area of bare ground is quite high. The large boulders and shale pieces scattered throughout the flow are weathering slowly, and inhibit growth in some areas. Additionally, the marked lack of nitrogen fixing plants common to the surrounding areas, in conjunction with absolutely no soil profile makes it difficult for most plants to survive and proliferate, especially annuals and less hardy perennials.

Through drainage tongues in area VI, on the slope to the valley floor, some shale particles have been washed down to the valley floor, but this has not affected the area composition significantly. Some aspen seedlings have spread near the slump islands, and *Rosa woodsii* thickets have established more in the southwest portion of area IV, but dispersal of these species is slow. The plant community as a whole on the flow has shifted from a *Chaenactis alpina* dominated site to a community of hardy perennial forbs, grasses, and shrubs. This pathway matches the one outlined by Langenheim (Figure 3, 1956). However, *Seriphidium tridentatum* is not necessarily characteristic of the community as a whole, but rather coexists with the established forbs and grasses. As the substratum continues to break down and stabilize, a greater number of species will presumably be able to establish, but the timeline for this will likely be a long one.

Festuca community

The *Festuca* meadow occupies the entire slump block area. Since the slump block remained intact during the movement, the original soil profile and plant community were preserved. Most of the meadow is relatively dry, with wetter areas occurring in small valleys created by the hilly topography of the area. Some large morainal boulders are embedded in the ground, but do not greatly impede vegetative growth. The bunch grass *Festuca thurberi* dominates the area, with *Vicia americana, Achillea millefolium,* and *Erigeron speciosus* present in 50 percent or more of the quadrats. Bunches of *F. thurberi* monopolize soil resources and ground cover, so many other species in the community are found close to the ground, or growing up through the *Festuca* bunches. The wetter areas in the community mostly lack *F. thurberi*. Instead, large individuals of plants such as *Heracleum sphondyllum, Ligusticum porteri,* and *Osmorhiza occidentalis* are present.

Dispersal of species from this community to the flow is spatially inhibited by the steep scarp between the two areas. The western portion of the area III scarp does support some small slump islands of vegetation, including bunches of *F. thurberi*, but this is as far as the species seems to have been dispersed. Aside from this spatial limitation, the absence of soil on the flow is the main factor inhibiting dispersal. The *Festuca* community is contiguous with adjacent vegetation on the westernmost portion, but is mostly separated from the surrounding plant communities by a stand of *Veratrum tenuipetalum* just past the boundary of the flow area.

Rosa community

Rosa thickets represented intermediate areas between the flow and persistent seepage areas. With the exception of *R. woodsii*, the area possessed a similar community composition to the flow, with some more hydric species present. Langenheim noted that individuals of *R. woodsii* did not seem particularly confined to one set of conditions, and actually seemed to prefer shaly environments (Langenheim 1956). Indeed, *R. woodsii* was observed on the earthflow both as scattered individuals in the perennial forb community, as well as in dense thickets in the southwest portion of area IV, the flow area. However, it does not necessarily seem as if the *Rosa* community has taken over much more of the surrounding areas. The exact reasons for this are currently unclear.

Willow community

Willow communities are found in areas I, IV, V and VI, in locations with permanent or temporal seepage areas. Here there are many willows and showy hydric wildflowers such as

Pedicularis groenlandica, Iris missouriensis and *Sidalcea candida*, as well as several species of *Carex* and *Juncus.* These areas contain many unique species not found elsewhere on the earthflow. There are several species of willow, including *Salix monticola, S. brachycarpa*, and *S. exigua.* A large portion of the species found in the willow communities are confined to these areas. They are able to thrive in these areas because of the presence of water and soil, both amenities that are extremely scarce in the flow area surrounding the seepage areas. Presumably many of these species colonized the area from the river edge and valley floor just south of the earthflow. There is almost zero spreading of the willow community to adjacent areas, as they thrive in a set of conditions barely present on the earthflow.

Relatedness of Community Types

The relatively low value for the agglomerative coefficient indicates that the communities are significantly related, which is expected given that there are many shared species and that the communities exist adjacent to each other, possessing some of the same general conditions. The *Rosa* and flow communities are shown to be the most similar, sharing 78% of species. The aspen community is the next most related, with around 50% in common with the previous two communities. The *Festuca* community is somewhat removed from the aspen, *Rosa* and flow communities, most likely mainly due to spatial separation and differences in environment. The willow community is the least related to any of the other community types, due to its unusually wet environment and number of unique species.

Summary of Successional patterns

Overall, little has happened on the earthflow in terms of major shifts in dominant community types. The most significant change was the decline in dominance of *Chaenactis alpina*, giving way to a community of perennial forbs. Species diversity on the flow has stabilized, but the community composition has seen major turnover. Species density in the aspen understory has increased, but dispersal into other areas has been limited. Both *Festuca* and willow community types are severely inhibited from dispersal by lack of suitable environment. So far, overall community succession on the flow has been slow, and will continue to move at a slow pace for the foreseeable future.

LITERATURE CITED

Curtin, C. (1994). The gothic earthflow revisited: A chronosequence examination of colonization on a subalpine earthflow. *Vegetatio, 111*(2), 137-147.

Curtin, C. (1991) *Chronosequence and Toposequence Examinations of the Colonization of Disturbed Subalpine Plant Communities*. (Master's dissertation) University of Madison, Wisconsin. Rocky Mountain Biological Laboratory Library.

Frouz, J.; Prach, K.; Pižl, V.; Háněl, L,; Starý, J.; Tajovský, K.; Materna, J.; Balík, V.; Kalčík, J.; Řehounková K. (2008) Interactions between soil development, vegetation and soil fauna during spontaneous succession in post mining sites. *European Journal of Soil Biology, 44(1),* 109-121.

Highland, L. & Sun, P. (2013). Environmental Impact of the Landslides Caused by the 12 May 2008, Wenchuan, China Earthquake. *Landslide Science and Practice Vol. 5,* 179-184.

Langenheim, J. (1956). Plant Succession on a Subalpine Earthflow in Colorado. *Ecology, 37*(2), 301-317.

Langenheim, J. (1949) *Physiography and Plant Ecology of a Subalpine Earthflow, Gunnison County, Colorado*. (Master's dissertation) University of Minnesota. Rocky Mountain Biological Laboratory Library.

Lawrence, R., & Ripple, W. (2000). Fifteen Years of Revegetation of Mount St. Helens: A Landscape-Scale Analysis. *Ecology, 81(10),* 2742-2752.

Myster, R., & Pickett, S. (1994). A Comparison of Rate of Succession Over 18 Yr in 10 Contrasting Old Fields. *Ecology, 75*, 387-392.

Sharpe, C. (1938). *Landslides and related phenomena: A study of mass-movements of soil and rock*. New York: Columbia University Press.

Shaw, R. (2012). *Grasses of Colorado.* Boulder: University of Colorado.

Taylor, B. (1957) . Plant Succession on Recent Volcanoes in Papua. *Journal of Ecology, 45(1),* 233-243.

Turbak, S. (1969). *A Study of Plant Succession on the Gothic Earthflow*. NSF Undergraduate Research Projects -Unpublished Study, Rocky Mountain Biological Laboratory Library. Gothic, Colorado.

Walsh, S.; Weiss, D.; Butler, D.; Malanson, G. (2004) An Assessment of Snow Avalanche Paths and Forest Dynamics using Ikonos Satellite Data. *Geocarto International, 19(2).*

Weber, W., & Wittmann, R. (2012). *Colorado Flora - Western Slope* (5th Ed.). Boulder: University of Colorado.

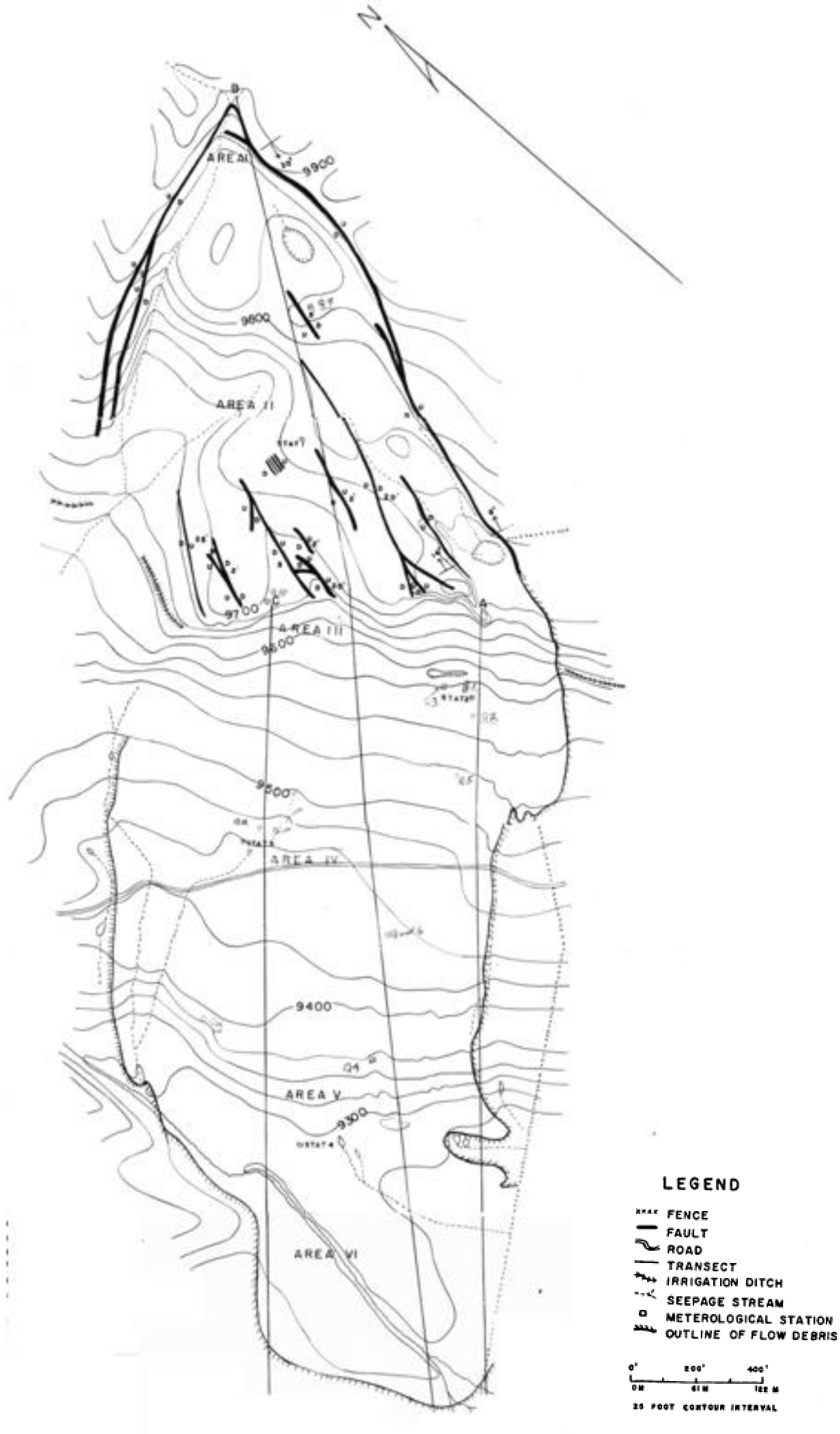

Figure 1 – Topographic map of the Gothic Earthflow created with plane table and alidade by Jean Langenheim (1949).

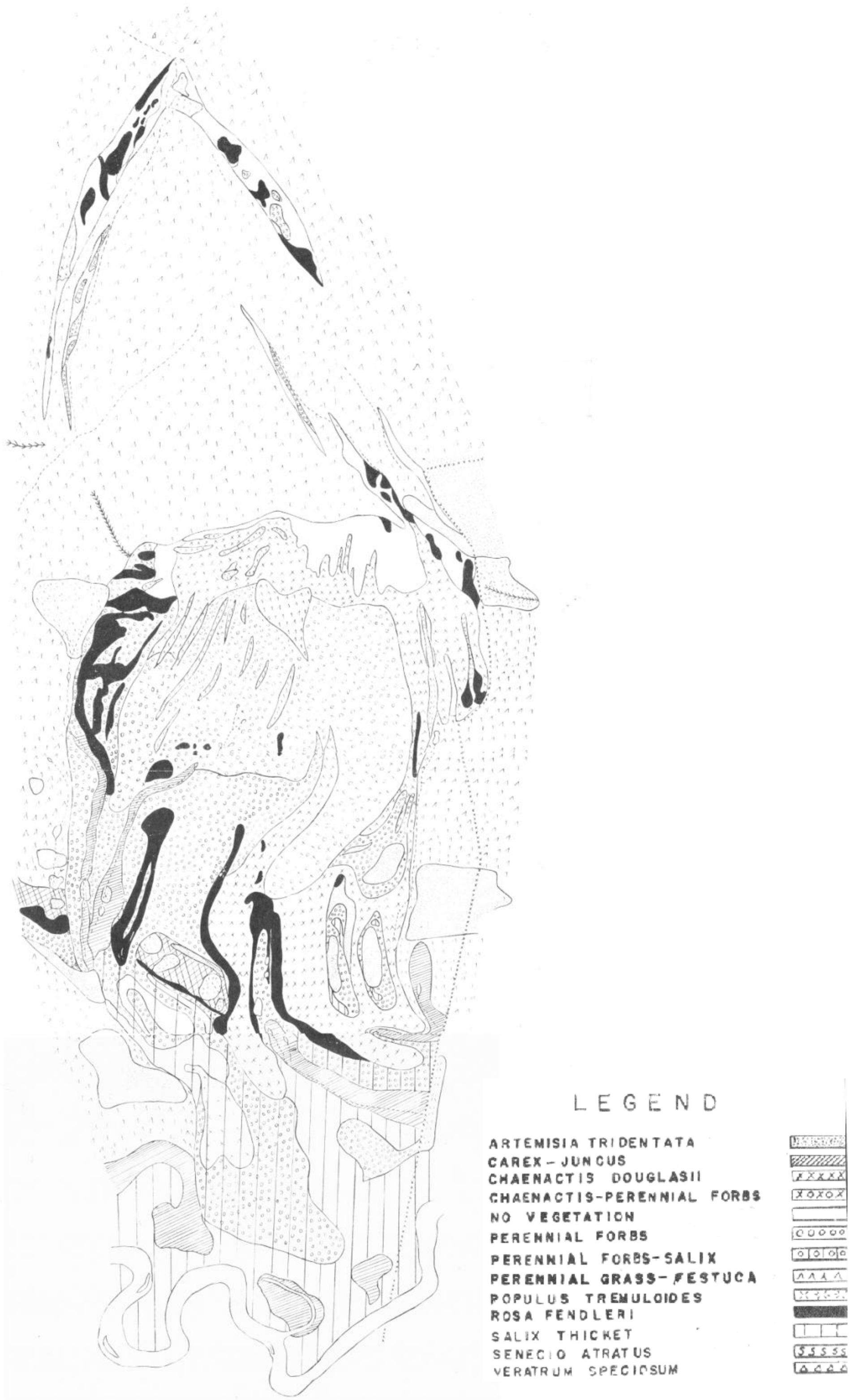

Figure 2 – Map of the distribution of plant communities on the Gothic Earthflow created by Jean Langenheim (1949).

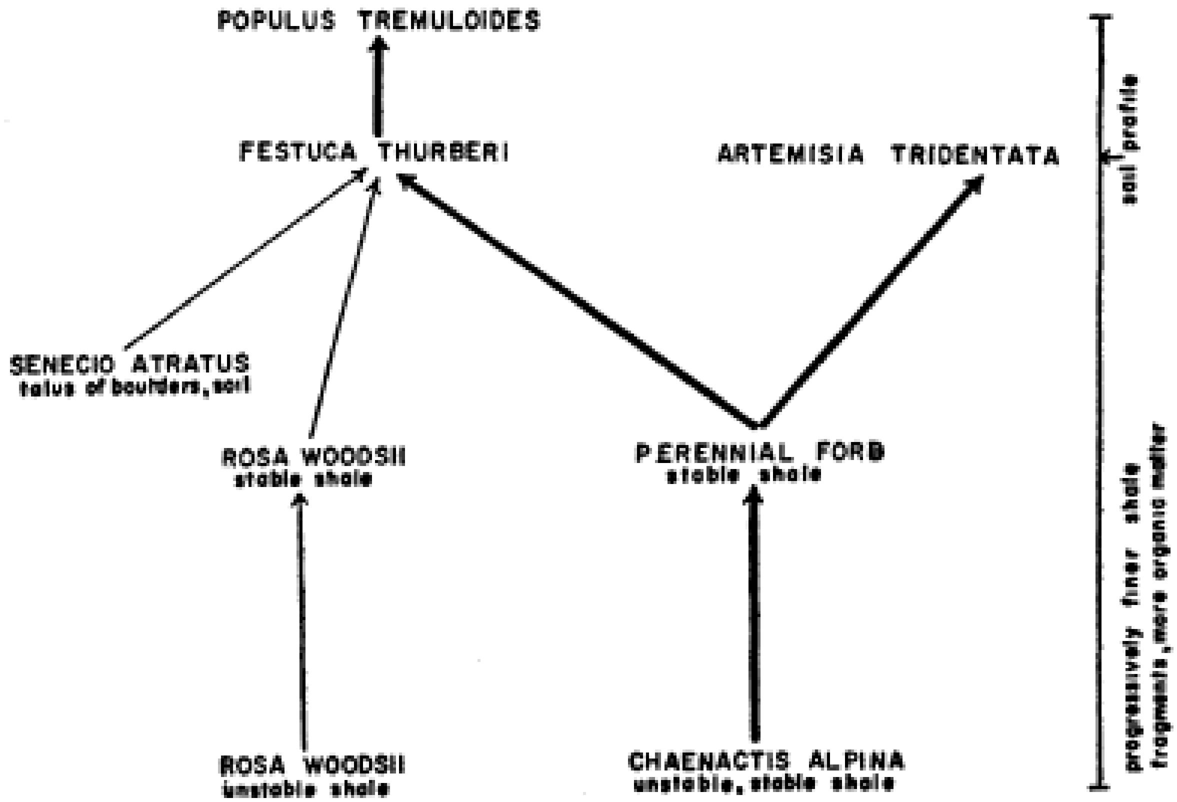

Figure 3 – Successional relationships on the Gothic Earthflow created by Langenheim (1949).

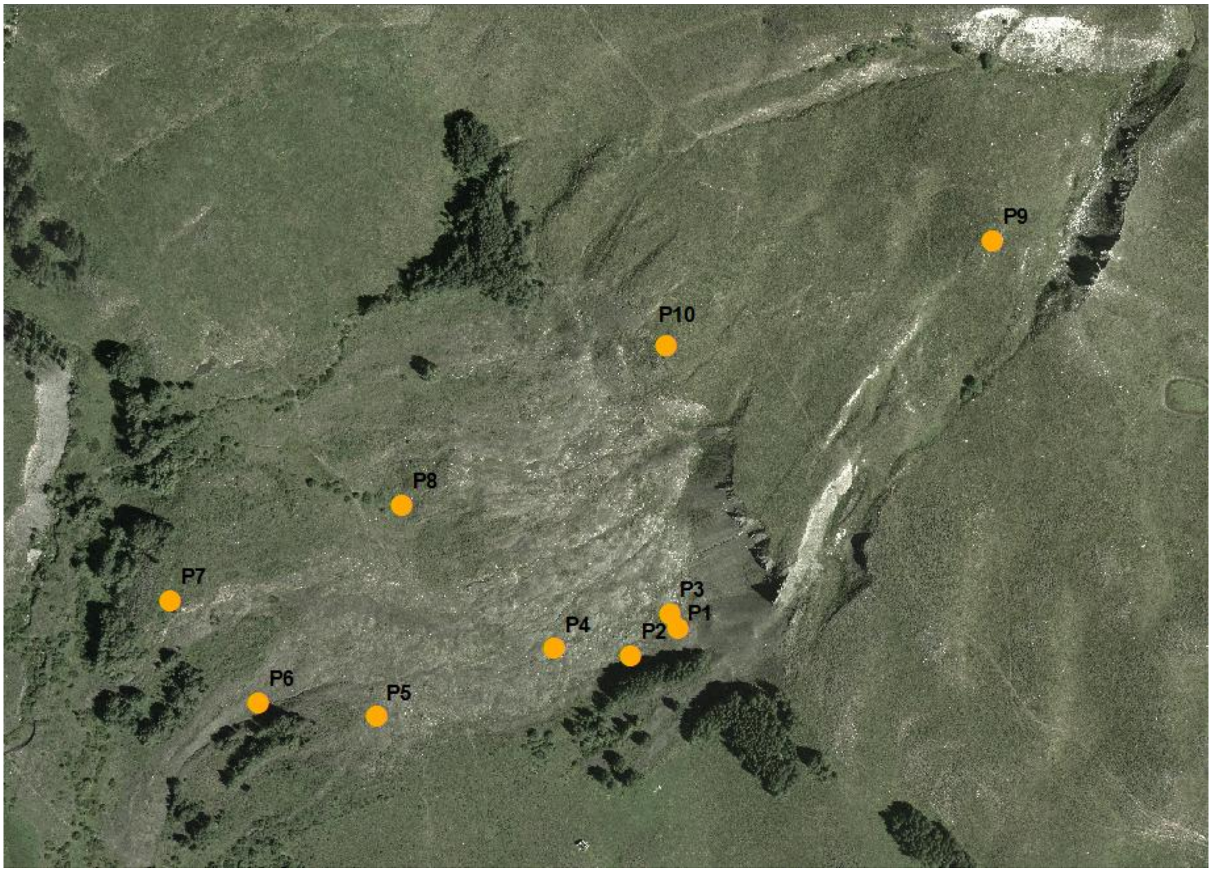

Figure 4 – Aerial photograph of the Gothic Earthflow with permanent plots indicated.

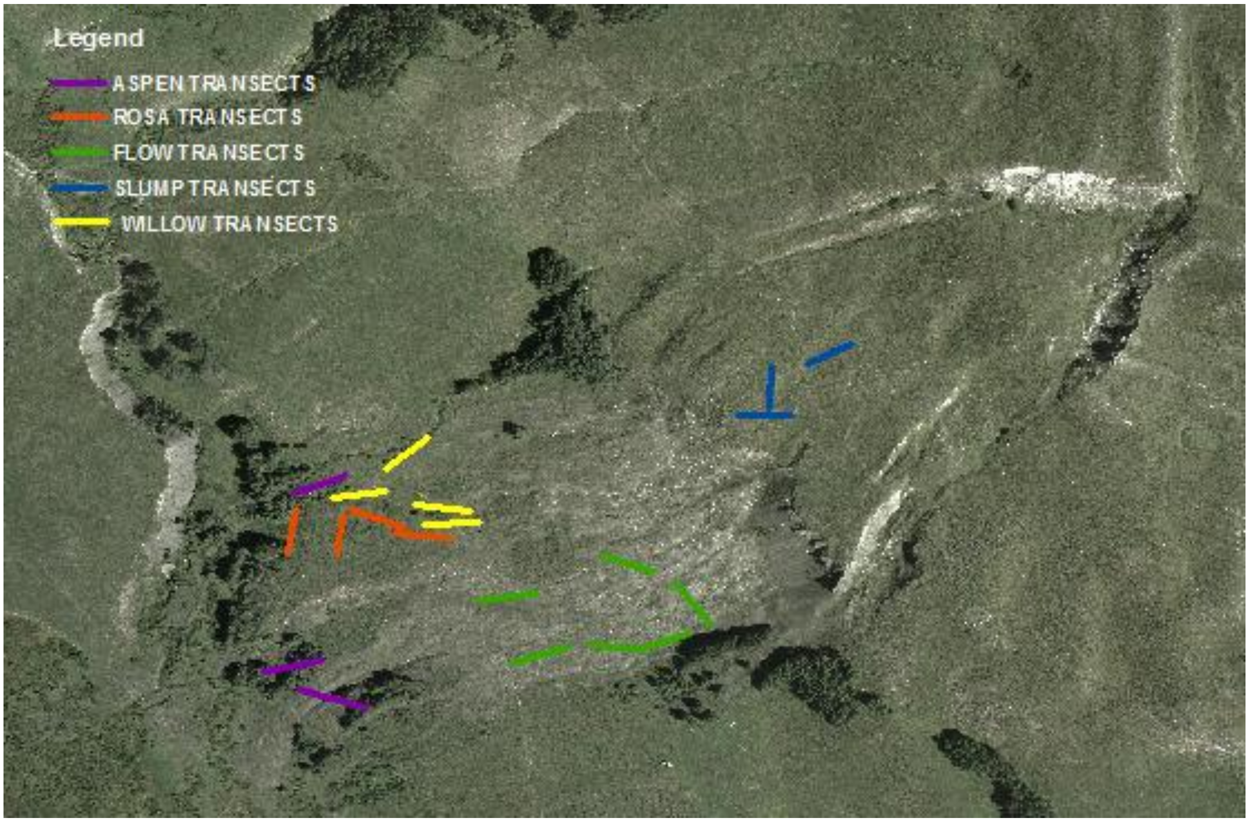

Figure 5 – Aerial photograph of the Gothic Earthflow with transects indicated.

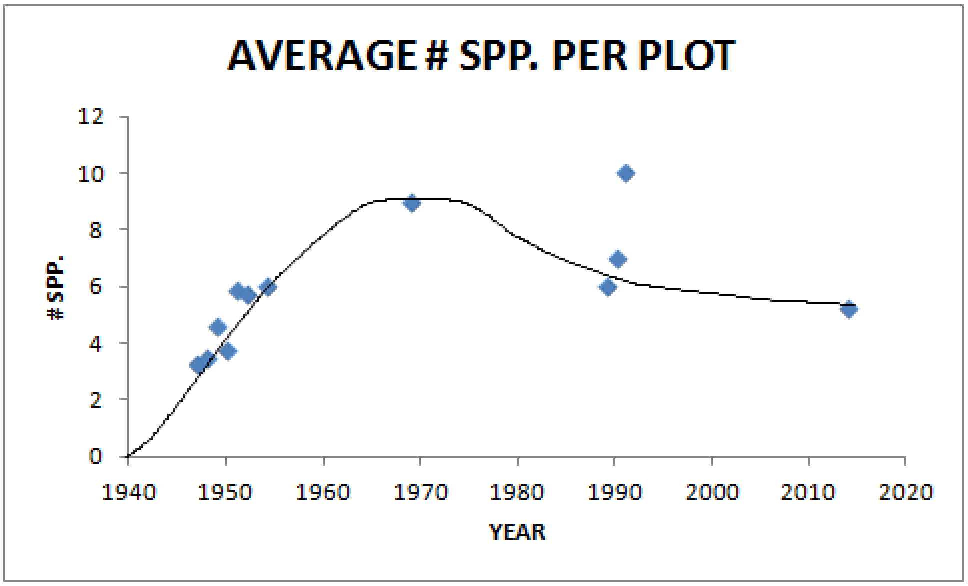

Figure 6 – Average number of species in permanent plots 1-8, 1947-2014.

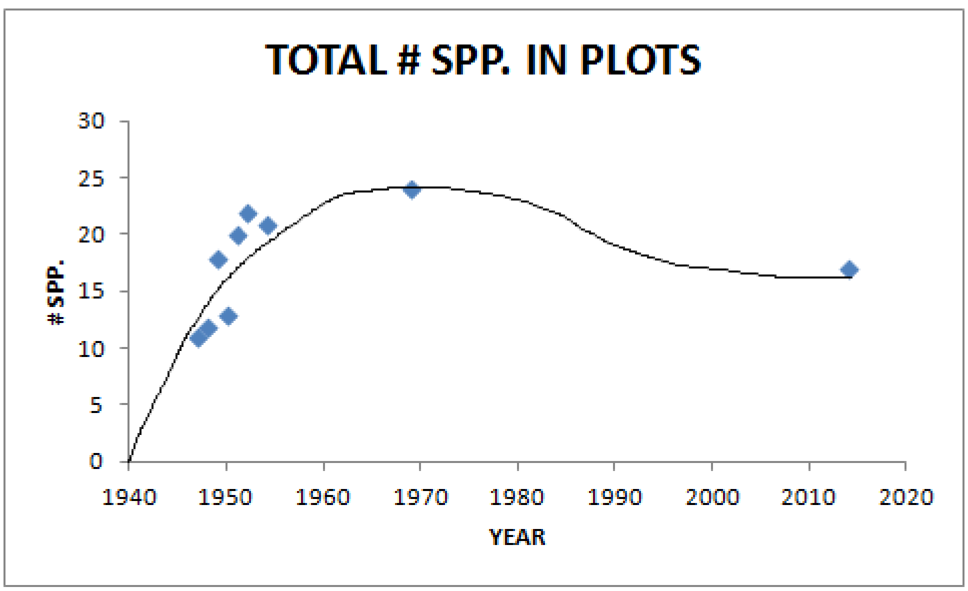

Figure 7 – Total number of species in permanent plots 1-8, 1947-2014.

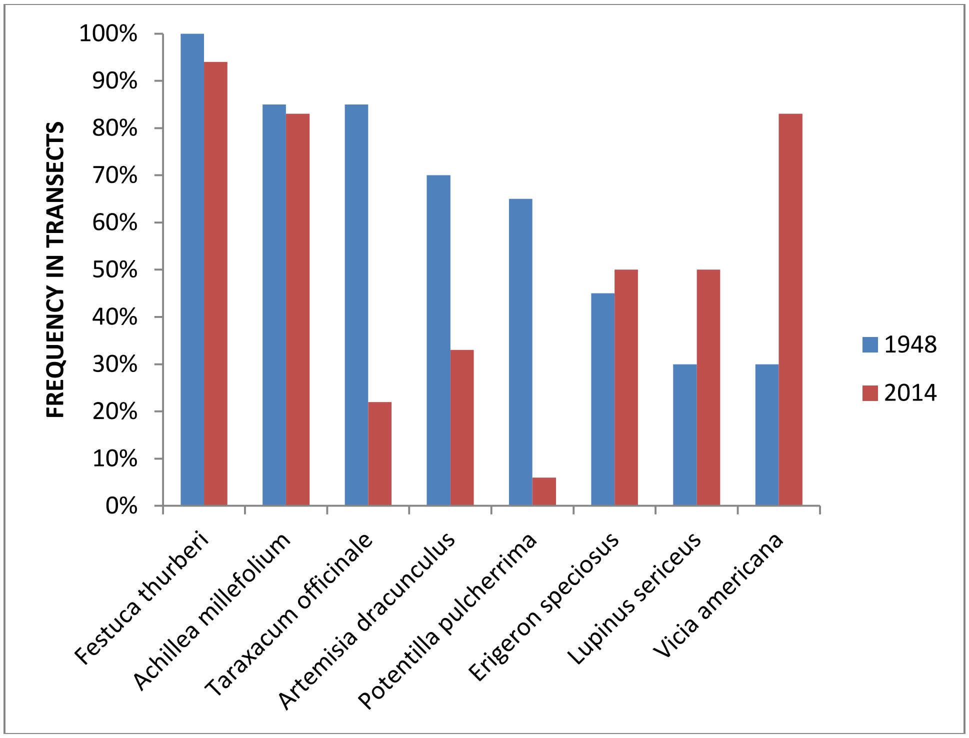

Figure 8 – Comparison of 5 most frequent species in festuca meadow communities, 1947 versus 2014.

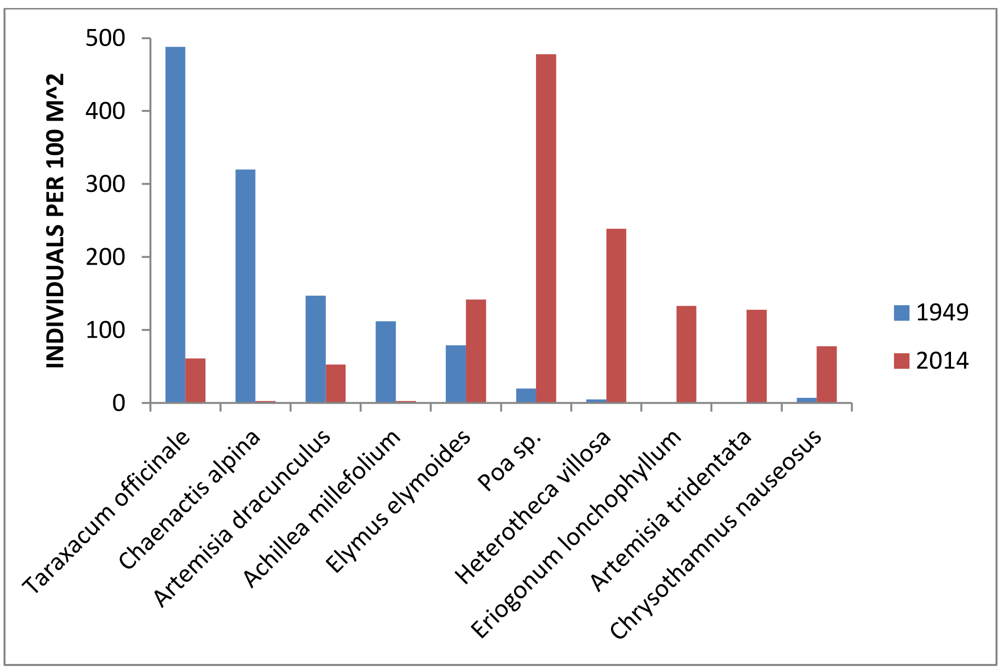

Figure 9 – Comparison of 5 most abundant species in flow communities, 1947 versus 2014.

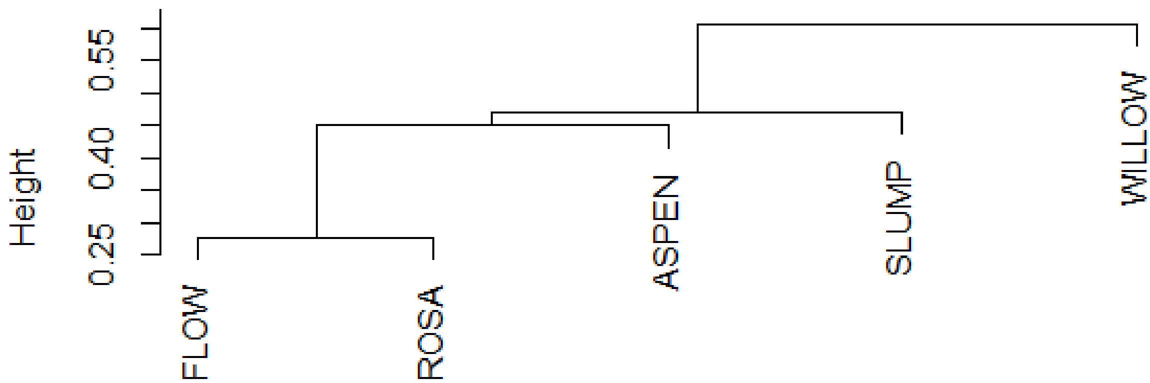

Figure 10 – AGNES clustering of surveyed community types. Agglomerative Coefficient = 0.32

Table 1 - Percent frequency of species in community types surveyed on the Gothic Earthflow.

FLOW COMMUNITY		**ROSA COMMUNITY**		**ASPEN COMMUNITY**		**FESTUCA COMMUNITY**		**WILLOW COMMUNITY**	
Heterotheca villosa	78%	*Poa sp.*	88%	*Populus tremuloides*	75%	*Festuca thurberi*	94%	*Salix sp.*	63%
Poa sp.	56%	*Taraxacum officinale*	75%	*Taraxacum officinale*	63%	*Vicia Americana*	83%	*Taraxacum officinale*	54%
Chrysothamnus nauseosus	53%	*Oligosporus dracunculus*	50%	*Lathyrus leucanthus*	58%	*Achillea millefolium*	67%	*Achillea millefolium*	50%
Eriogonum lonchophyllum	44%	*Chrysothamnus nauseosus*	50%	*Poa sp.*	54%	*Erigeron speciosus*	50%	*Trifolium pretense*	50%
Seriphidium tridentatum	39%	*Eriogonum umbellatum*	42%	*Lupinus sericeus*	50%	*Lupinus sericeus*	50%	*Poa sp.*	38%
Elymus elymoides	31%	*Lathyrus leucanthus*	38%	*Erigeron speciosus*	42%	*Poa sp.*	39%	*Potentilla pulcherrima*	33%
Eriogonum umbellatum	22%	*Achillea millefolium*	29%	*Vicia Americana*	42%	*Lathyrus leucanthus*	33%	*Lupinus sericeus*	29%
Taraxacum officinale	19%	*Elymus elymoides*	29%	*Achillea millefolium*	29%	*Oligosporus dracunculus*	22%	*Iris missouriensis*	25%
Erigeron speciosus	14%	*Potentilla pulcherrima*	29	*Potentilla pulcherrima*	29%	*Taraxacum officinale*	17%	*Phleum pretense*	25%
Ipomopsis aggregate	11%	*Rosa woodsii*	25%	*Oligosporus dracunculus*	21%	*Mertensia sp.*	11%	*Oligosporus dracunculus*	17%
Potentilla hippiana	11%	*Salix sp.*	21%	*Thalictrum fendleri*	21%	*Ligusticum porteri*	6%	*Equisetum arvense*	17%
Potentilla pulcherrima	11%	*Boechera stricta*	17%	*Bromopsis inermis*	17%	*Androsace sp.*	6%	*Unidentified grass*	17%
Bromopsis inermis	8%	*Erigeron speciosus*	17%	*Rosa woodsii*	17%	*Boechera stricta*	6%	*Pedicularis groenlandica*	13%
Erigeron flagellaris	8%	*Lupinus sericeus*	17%	*Castilleja linariifolia*	13%	*Eriogonum umbellatum*	6%	*Pentaphylloides floribunda*	13%
Fragaria virginiana	6%	*Eriogonum lonchophyllum*	13%	*Elymus elymoides*	13%	*Galium boreale*	6%	*Veratrum californicum*	13%
Galium boreale	6%	*Potentilla hippiana*	13%	*Maianthemum stellatum*	13%	*Potentilla pulcherrima*	6%	*Chrysothamnus nauseosus*	8%
Heterostipa comata	6%	*Vicia americana*	13%	*Ligusticum porteri*	8%	*Thalictrum fendleri*	6%	*Ipomopsis aggregate*	8%
Vicia Americana	6%	*Castilleja linariifolia*	8%	*Symphoricarpos rotundifolius*	8%			*Ribes sp.*	8%
efolium	3%	*Equisetum arvense*	8%	*Agostache urticifolia*	4%			*Rosa woodsii*	8%
Androsace sp.	3%	*Ligusticum porteri*	8%	*Agropogon sp.*	4%			*Senecio serra*	8%

Boechera stricta	3%	*Androsace sp.*	4%	*Chrysothamnus nauseosus*	4%			*Bromopsis inermis*	4%
Chaenactis alpina	3%	*Seriphidium tridentatum*	4%	*Festuca thurberi*	4%			*Castilleja sulphurea*	4%
Lupinus sericeus	3%	*Bromopsis inermis*	4%	*Geranium sp.*	4%			*Erigeron flagellaris*	4%
Penstemon strictus	3%	*Heterotheca villosa*	4%	*Heracleum sphondyllium*	4%			*Erigeron speciosus*	4%
Rosa woodsii	3%	*Ipomopsis aggregata*	4%	*Mahonia repens*	4%			*Hackelia floribunda*	4%
Bare Ground Average	68%	*Iris missouriensis*	4%	*Penstemon strictus*	4%			*Maianthemum stellatum*	4%
		Lepidium sp.	4%	*Phleum pretense*	4%			*Osmorhiza sp.*	4%
		Maianthemum stellatum	4%	*Rumex sp.*	4%			*Populus angustifolia*	4%
		Penstemon strictus	4%					*Rumex multiflora*	4%
		Symphoricarpos rotundifolius	4%					*Sidalcea candida*	4%
		Trifolium sp.	4%					*Tragopogon dubius*	4%

Table 2 – Complete floral list by family

Alsinaceae
Eremogone congesta (Nuttall) Ikonnikov

Apiaceae
Heracleum sphondyllum L. subsp. *montanum* (Schleicher) Briquet
Ligusticum porteri Coulter & Rose
Osmorhiza occidentalis (Nuttall) Torrey
Pseudocymopterus montanus (A. Gray) Coulter & Rose

Asclepidaceae
Asclepias halii A. Gray

Asteraceae
Agoseris glauca (Pursh) Rafinesque
Antennaria parvifolia Nuttall
A. rosea Greene
Chaenactis alpina (A. Gray) Jones (FNA name *C. douglasii* var. *alpina)*
Chrysothamnus nauseosus (Pallas ex Pursh) Britton
C. parryi (A. Gray) Greene
Dugaldia hoopesii (A. Gray) Rydberg
Erigeron flagellaris A. Gray
E. speciosus (Lindley) de Candolle
Heliomeris multiflora Nuttall
Heterotheca villosa (Pursh) Shinners
Oligosporus dracunculus (L.) Poljakov subsp. *glaucus* (Pallas) Löve & Löve (*Artemisia dracunculus)*
Packera streptanthifolia (Greene) Weber and Löve
Senecio eremophilus Rydberg subsp. *kingii* (Rydberg) Douglas & Ruyle-Douglas
Senecio serra Hooker var. *admirabilis* (Greene) A. Nelson
Seriphidium tridentatum (Nuttall) W.A. Weber
Solidago sp. L.
Taraxacum officinale Wiggers
Tragopogon dubius Scopoli subsp. *major* (Jacquin) Vollman
Wyethia amplexicaulis (Nuttall) Nuttall

Berberidaceae
Mahonia repens (Lindley) Don

Boraginaceae
Hackelia floribunda (Lehmann) Johnston
Mertensia sp. Roth

Brassicaceae
Boechera stricta (Graham) Al-Shehbaz

Descurainia incisa (Engelmann ex A. Gray) Britton
Erysimum capitatum (Douglas ex Hooker) Greene
Lepidium sp. L.

Calochortaceae
Calochortus gunnisonii S. Watson

Caprifoliaceae
Symphoricarpos rotundifolius A. Gray

Convallariaceae
Maianthemum stellatum (L.) Link

Cupressaceae
Juniperus communis L. subsp. *alpina* (Smith) Čelakovsky

Cyperaceae
Carex hystericina Mühlenberg
C. microptera Mackenzie
C. occidentalis Bailey

Equisetaceae
Equisetum arvense L.

Fabaceae
Lathyrus leucanthus Greene (*Lathyrus lanszwertii* Kellogg var. *leucanthus* (Rydberg) Dorn)
Lupinus sericeus Pursh
Trifolium pratense L.
Trifolium sp. L.
Vicia americana Mühlenberg

Geraniaceae
Geranium richardsonii Fischer & Trautvetter

Grossulariaceae
Ribes inerme Rydberg

Helleboraceae
Aquilegia coerula James
Delphinium barbeyi Huth

Hydrophyllaceae
Phacelia heterophylla Pursh

Iridaceae
Iris missouriensis Nuttall

Lamiaceae
Agastache urticifolia (Bentham) Kuntze

Linaceae
Adenolinum lewisii (Pursh) Löve & Löve (*Linum lewisii* Pursh)

Malvaceae
Sidalcea candida A. Gray

Melanthiaceae
Veratrum tenuipetalum Heller

Orchidaceae
Limnorchis hyperborea (L.) Rydberg

Poaceae
Agropyron sp. Gaertner
Bromopsis inermis (Leysser) Holub
Bromopsis porteri (Coulter) Holub
Elymus elymoides (Rafinesque) Swezey subsp. *brevifolius* (J.G. Smith) Dorn
Festuca thurberi Vasey
Hesperostipa comata (Trinius & Ruprecht) Barkworth
Muhlenbergia sp. Schreber
Phleum pratense L.
Poa cusickii Vasey
Poa fendleriana (von Steudel) Vasey
Poa leptocoma Trinius
Poa pratensis L.

Polemoniaceae
Collomia linearis Nuttall
Ipomopsis aggregata (Pursh) V.E. Grant

Polygonaceae
Eriogonum lonchophyllum Torrey & Gray
E. umbellatum Torrey
Rumex sp. L.
R. crispus L.
R. densiflora Osterhout
R. utahensis Rechinger

Primulaceae
Androsace sp. L.

Rosaceae

Amelanchier alnifolia (Nuttall) Nuttall ex M. Roemer
Fragaria virginiana Miller subsp. *glauca* (S. Watson) Staudt
Erythrocoma triflora (Pursh) Greene (*Geum triflorum* Pursh)
Pentaphylloides floribunda Á. Löve
Potentilla flabelliformis Lehmann
P. hippiana Lehmann
P. pulcherrima Lehmann
Rosa woodsii Lindley

Rubiaceae
Galium septentrionale Roemer & Schultes

Salicaeae
Populus angustifolia James
P. tremuloides Michaux
Salix sp. L.
S. brachycarpa Nuttall
S. exigua Nuttall
S. monticola Bebb

Scrophulariaceae
Castilleja linariifolia Bentham
Castilleja sulphurea Rydberg
Linaria vulgaris Miller
Pedicularis groenlandica Retzius
Penstemon strictus Bentham
Veronica americana (Rafinesque) Schweinitz

Thalictraceae
Thalictrum fendleri Engelmann