

Species Richness Along an Elevational Gradient

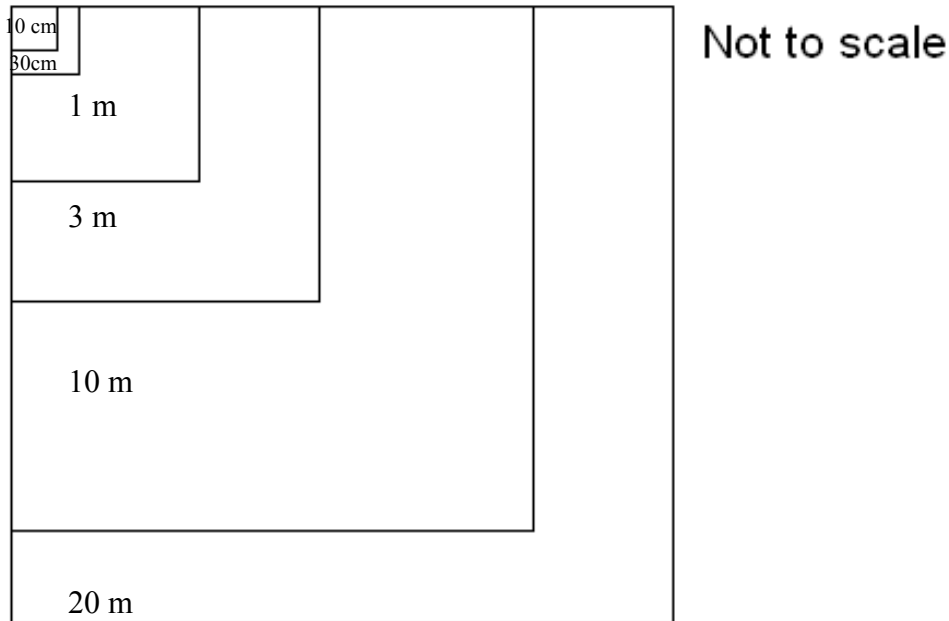
INTRODUCTION

For my group project, we quantified plant community composition, specifically species richness, in relation to changes in altitude. Elevation gradients are characterized by dramatic changes in climate and biotic turnover within short geographical distances. As you go up a mountain, the temperature drops, moisture levels increase, slopes incline, the growing season shortens, wind speeds increase, and the terrain becomes rocky. These differences affect many aspects of animal and plant life. Given an altitudinal gradient in a community, species evolve to use different parts of this gradient, reducing competition and increasing biodiversity (Whittaker 1972). Each species evolves toward their individual niche, creating a complex and diverse community. However, species populations have scattered centers and usually overlap. The Rocky Mountains provide a perfect setting to study how altitude affects the diversity of flowering plants. At lower elevations, it is too arid of a climate for a diverse plant community to flourish. At very high elevations, it is too cold to support a diverse plant community. Therefore, biodiversity and plant cover peak at mid-altitude. Extreme climates may also limit the ability of any single or group of species to dominate. With increasing altitude, plant communities seem to become more dispersed and contain distantly related taxa. Most plant communities consist of several species that compete for light, water, and nutrients. These species form a working plant community by finding their individual niches in a given habitat. "Species tend to evolve toward habitat differentiation, toward scattering of their centers of maximum population density in relation to environmental gradients, so that few species are competing with one another in their population centers" (Whittaker 1965). Evolution of both niche and habitat differentiation allows many species to coexist in communities, with overlapping distributions. Changes in altitude affect the diversity of a plant community since different species find their own niche in different environment. This project is also an interesting area of study in light of global warming. As the climate warms, plants may climb higher up the mountains to find ideal conditions. Improved knowledge of altitudinal gradients could help predict the potential consequences of climate change. Biogeographical variation in species richness is also important to understand and conserve biological diversity in high altitude meadow ecosystems.

METHODS

To conduct this research project, my group chose four different elevations at which to measure plant species diversity. “Diversity in the strict sense is richness in species, and is appropriately measured as the number of species in a sample of standard size” (Whittaker 1972). We had a 20 x 20 meter nested plot at each elevation to quantify the plant community composition, with 6 nests, at 10 cm, 30 cm, 1 m, 3 m, 10 m, and 20 m. (see Figure 1).

Figure 1: Nested Plots



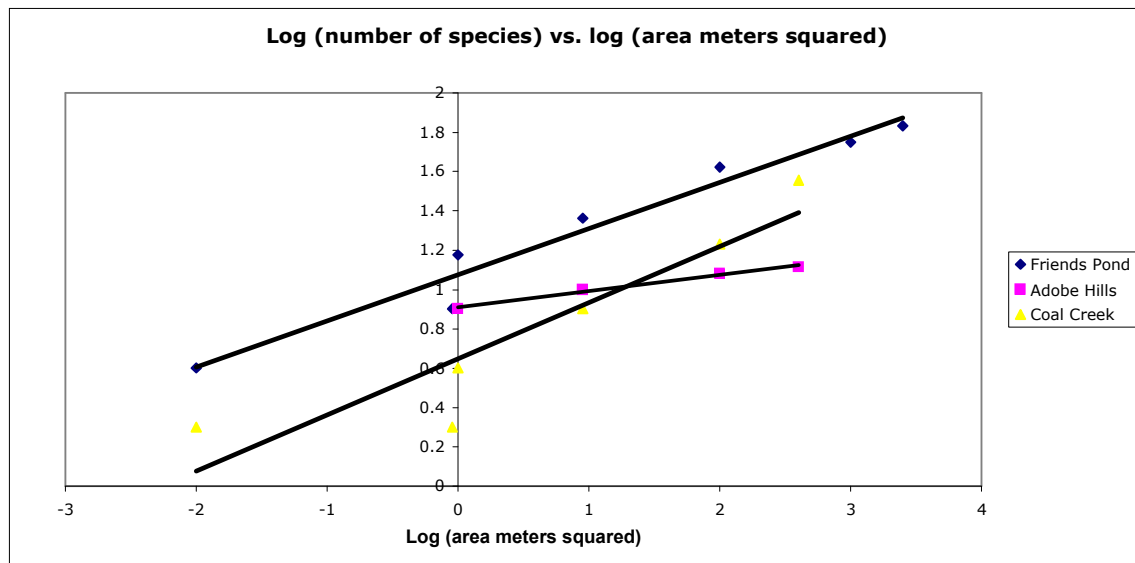
For the Friends Pond site, we did a 50 x 50 meter nested plot and estimated where the 20 x 20 meter cut off would be in order to compare the sites. At our sites we counted how many species were in each plot, identified and pressed them. Our group also determined the species-area relationship for each site to estimate the diversity of plants occurring in a particular habitat. This helped us see if our plot size was sufficient to get a good picture of species richness. We needed to sample a large area, but in a homogenous community, the rate of species accumulation decreases as area increases. Once we knew how many species were found in each nested plot, we graphed the species-area curve and the $\log(\text{species})$ vs. $\log(\text{area})$ curve to determine the constants to the equation $S=cA^z$ (S =number of species, A =area sampled, c and z = constants). Our group quantified species richness at 3,413 meters (Virginia Basin, N 38° 52.414' W 106° 57.220'), 3,200 meters (Friends Pond, N 39° 00' W 107° 01'), 2,073 meters (Coal Creek, N 38° 33.025' W 107° 20.090'), and 1,726 meters (Adobe Hills, N 38° 46.875' W 107° 39.113'). In addition to comparing number of species, we also looked at the pair-wise similarity in species composition among all plots. We defined similar species as same family, genus,

and species according to our identification using Weber and Wittman's "Colorado Flora: Western Slope. Third Edition." The percent similarity was calculated by dividing number of similar species by total number of species between two given sites. By doing this, we will see the percent similar species two plots contain. Our group also used a Mantel test to analyze the relationship between community similarity and rainfall, altitude, and geographical distance. We also took rainfall data into account to see if there was a stronger correlation between number of species and rainfall, or number of species and elevation.

RESULTS

Our data representing which species were found at each of our four sites can be seen in the Appendix. There were 129 different species between the four sites, with Asteraceae, Poaceae, and Brassicaceae being the most common plant families. See Figure 2 for the graph of $\log(\text{species})$ vs. $\log(\text{area})$ for the three nested plot sites (Coal Creek, Adobe Hills, and Friends Pond). This graph shows the relationship between the species-area curves for each site (how much they differ).

Figure 2: $\log(\text{species})$ vs. $\log(\text{area})$



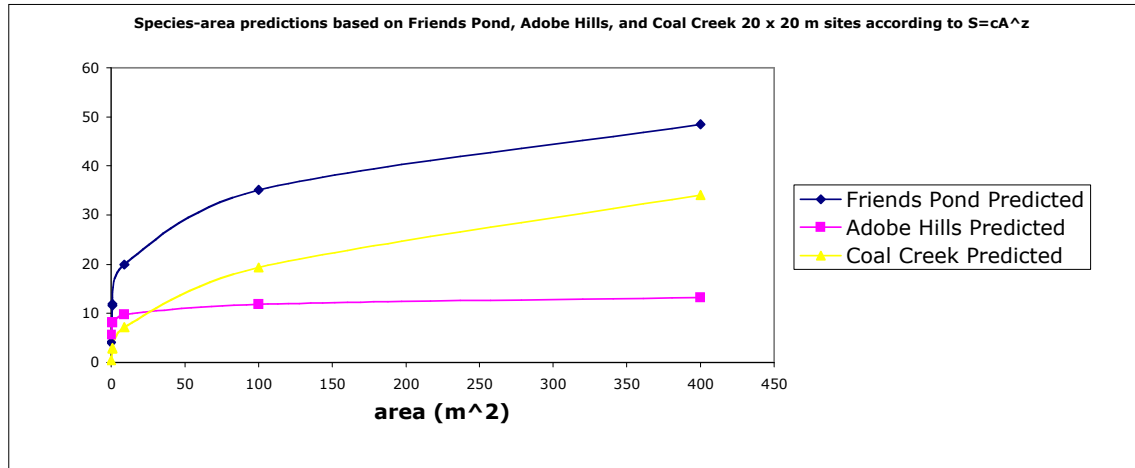
This graph gave us the constants c and z for the equation $S=cA^z$ (see Table 1).

Table 1: Numbers for the equation $S=cA^z$

Plot	c (intercept ¹⁰)	z (slope)	R ²
Friends Pond	2.08415434	0.2344	0.9608
Coal Creek	0.01315527	0.2856	0.853
Adobe Hills	0.39588289	0.081	0.9887

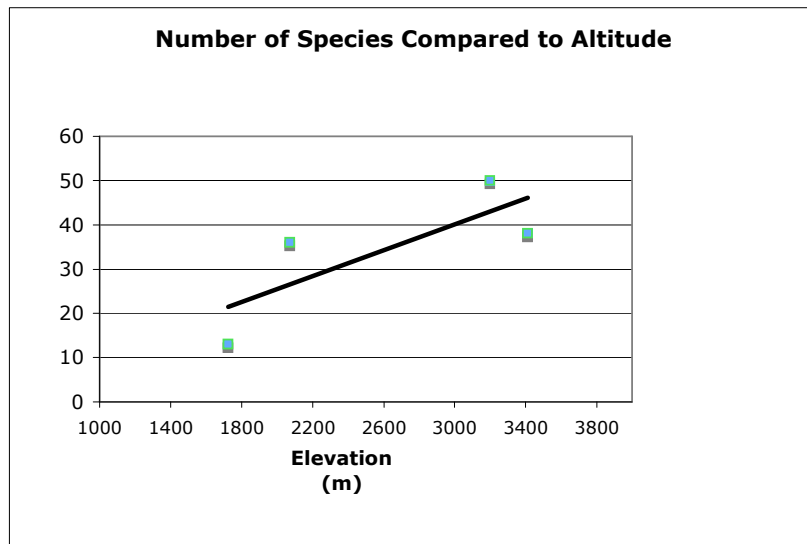
The species area curves show the relationship between number of species as size of plot increases. It also shows if the 20 x 20 meter area we sampled was adequate for calculating species richness of a site (see Figure 3).

Figure 3: Species-Area Curve



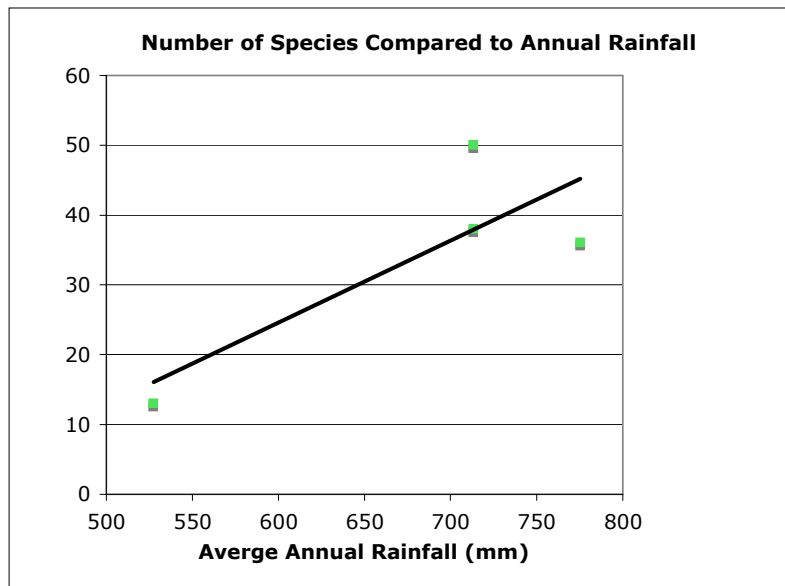
When comparing number of species to altitude, we found that as elevation increases, number of species increases (see Figure 4).

Figure 4: Number of Species Compared to Altitude, $R=.7839$



We also compared number of species to amount of average annual rainfall and found that generally as rainfall increases, number of species increases (see Figure 5).

Figure 5: Number of Species Compared to Rainfall, $R=.8155$



To compare community similarity, we used a pair-wise similarity matrix (see Table 2).

Table 2: Similarity of Species between 20 x 20 meter vegetation plots at different sites

	Friends Pond	Virginia Basin	Coal Creek	Adobe Hills
Friends Pond	--	26.10%	6.30%	0%
Virginia Basin		--	7.00%	0%
Coal Creek			--	2%
Adobe Hills				--

We found that Virginia Basin and Friends Pond had the highest number of similar species, while Adobe Hills had the lowest number of similar species to the other sites.

We used a Mantel test to determine the affect of rainfall, geographical distance, and altitude on community structure similarity (see Table 3).

Table 3: Mantel Test of community similarity vs. rainfall, distance, and altitude.

	R value	Critical Value	Accept or Reject Null Hypothesis
Community Similarity X Difference in Annual Average Rainfall	-0.7997	$p < .05$	Reject
Community Similarity X Geographical Distance	-0.8767	$p < .05$	Reject
Community Similarity X Difference in Altitude	-0.556	$p > .05$	Accept

This test shows that geographical distance has the greatest affect on community structure, followed by annual average rainfall and difference in altitude. Difference in altitude did not have a significant affect on community structure.

DISCUSSION

Based on our species-area curves (see Figure 3), we can conclude that the 20 x 20 meter sampled area was sufficient to characterize plant species richness at Adobe Hills. Once the curve reaches 400 square meters, it starts to level off, indicating that the

maximal number of species has been reached. However, in the case of Coal Creek and Friends Pond, the curves do not seem to level off. Therefore, a larger area is needed to capture the species richness at these particular sites. When looking at the relationship between number of species and elevation, no significant data could back up our hypothesis of a mid-altitude peak in species richness. It seemed to better correlate with a linear trend line, indicating an increase in number of species as altitude increases (see Figure 4). Our sample size of four data points was quite low, so it is hard to determine a strong trend between number of species and altitude. This fact also holds true when comparing number of species to rainfall. The correlation between increase in rainfall and increase in number of species was a little stronger, but it is still difficult to determine given the few data points (see Figure 5). Virginia Basin and Friends Pond shared the highest number of similar species (see Table 2). This could be due to the close proximity and similar ecosystems of the two sites. Both are near Gothic, Colorado and are high-altitude meadow ecosystems. This is quite different compared to the mid-altitude meadow at Coal Creek and the sagebrush community of Adobe Hills. Adobe Hills was a completely different ecosystem, with alkaline rich soil. This could account for the very low percent similarity to the other three sites. Based on the Mantel test, we can conclude that altitude does not have a significant affect on plant community structure similarity. Rather, geographical distance and annual average rainfall have a larger effect on the species similarity between plant communities.

Appendix: Species List Reference (Note: ns = no specimen)

Genus	Species	Family	Virginia Basin (VB)	Friends Pond (FP)	Coal Creek (CC)	Adobe Hills (AH)
Abies	lasiocarpus	Pinaceae		FP67		
Achilea	millefolium	Asteraceae	VB13	FP19	CC11	
Adenolinum	lewisii	Linaceae	VB3			
Agrostis		Poaceae			CC2	
Alyssum	parviflorum	Brassicaceae				AH8
Amelanchier	ainifolia	Rosaceae			CC27	
Androsace	septentrionalis	Primulaceae	VB9	FP2		
Anisantha	diandra	Poaceae				AH3
Anisantha		Poaceae			CC3	
Antennaria		Asteraceae	ns			
Aquilegia	coerulea	Ranunculaceae		FP78		
Arabis		Brassicaceae	VB34			
Arnica	rydbergii	Asteraceae			CC14	
Arnica	cordifolia	Asteraceae	VB27	ns		
Artemisia	novum	Asteraceae				AH14
Artemisia	tridentata	Asteraceae			CC40	
Astragalus	alpinis	Fabaceae	VB26			

Atriplex	canescens	Chenopodiaceae			AH5
Atriplex	confertifolia	Chenopodiaceae			AH7
Atriplex	gardneri	Chenopodiaceae			AH11
Boechera	divaricarpa	Brassicaceae	VB32	FP18	
Bromelica	spectabilis	Poaceae		FP83	
Bromopsis	pubescens	Poaceae		FP62	
Carex	egglestoni	Cyperaceae		FP16	
Castilleja	miniata	Orobanchaceae		FP59	CC19
Castilleja	occidentalis	Orobanchaceae	VB15		
Ceanothus	martinii	Rhamnaceae			CC31
Ceratochloa	carinata	Poaceae		FP1	
Chamerion	angustifolium	Onagraceae		ns	
Chenopodium		Chenopodiaceae		FP3	
Chrysothamus	viscidiflorous	Asteraceae			AH6
Cirsium	hesperium	Asteraceae	VB6		
Cirsium	parryi	Asteraceae		FP75	
Cirsium	tioganum	Asteraceae			CC10
Collomia	linearis	Polemoniaceae			CC39
Delphinium	barbeyi	Ranunculaceae		FP38	
Draba	albertina	Brassicaceae		FP45	
Draba	aurea	Brassicaceae	VB7		
Draba	crassifolia	Brassicaceae		FP25	
Draba	ventosa	Brassicaceae		FP29	
Dugaldia	hoopsii	Asteraceae		FP22	
Elymus	glaucus	Poaceae			CC5
Elymus		Poaceae			AH12
Eremogone	congesta	Alsiniaceae	VB21		
Eremogone	fendleri	Caryophyllaceae		FP71	
Erigeron	coulteri	Asteraceae	VB30	FP79	
Erigeron	elatior	Asteraceae	VB23	FP40	
Erigeron	flagellaris	Asteraceae			CC30
Erigeron	speciosus	Asteraceae			CC13
Erigeron	subtrinervis	Asteraceae		FP64	
Eriogonum	gordoni	Polygonaceae			AH13
Eriogonum	umbellatum	Polygonaceae	VB20		CC17
Festuca	thurberi	Poaceae	VB12	FP12	
Fragaria	virginiana	Rosaceae	VB1	FP34	CC38
Galium	septentrionale	Rubiaceae			CC36
Gastrolychnis	drummondii	Caryophyllaceae		FP39	
Gentianopsis	thermalis	Gentianaceae	VB24		
Geranium	caespitosum	Geraniaceae			CC7
Geranium	richardsonii	Geraniaceae	VB17	FP33	
Helianthella	quinquenervis	Asteraceae		FP32	
Heliomeris	multiflora	Asteraceae			CC9
Heracleum	sphondylium	Apiaceae		FP49	
Heterotheca	pumilla	Asteraceae		ns	
Heterotheca	villosa	Asteraceae	VB25		
Hydrophyllum	capitatum	Boraginaceae		FP36	
Indetermined 1					AH1
Indetermined 1					CC4
Indetermined 1			ns		
Indetermined 1				FP14	

Indetermined 2		Asteraceae				AH10
Indetermined 2					ns	
Indetermined 2				FP27		
Indetermined 3					ns	
Indetermined 3				FP44		
Indetermined 4		Polygonaceae			CC33	
Indetermined 4		Asteraceae		FP63		
Ipomopsis	aggregata	Polemoniaceae		FP53		
Juniperis	communis	Cupressaceae		FP56		
Juniperis	coniferus	Cupressaceae			CC18	
Lathyrus	leucanthus	Fabaceae	VB2	FP47		
Ligularia	bigelovi	Asteraceae		FP7		
Ligusticum	porteri	Apiaceae		FP46		
Ligusticum		Apiaceae	VB31			
Lonicera	involucrata	Caprifoliaceae		FP70		
Lupinus	bakeri	Fabaceae		FP58		
Mahonia	repens	Berberidaceae			CC28	
Medicago	lupuina	Fabaceae			CC34	
Mertensia	ciliata	Boraginaceae	VB4	FP9		
Oligosporous	dracunculus	Asteraceae		ns	CC1	
Osmorhiza	occidentalis	Apiaceae		FP35		
Pedicularis	racemosa	Scrophulariaceae		FP73		
Penstemon	whippleanus	Plantaginaceae		FP37		
Phleum	alpinum	Poaceae		FP82		
Phleum	pratense	Poaceae			CC16	
Pneumonanthe	affinis	Gentianaceae	VB16			
Poa	alpina	Poaceae	VB11			
Poa	bigelovi	Poaceae	VB36			
Poa	pratensis	Poaceae		FP5		
Poa	aretica	Poaceae	VB18	FP6		
Polemonium	pulcherrimum	Polemoniaceae		FP66		
Potentilla	gracilis	Rosaceae	VB8	FP15	CC6	
Prenanthes	racemosa	Asteraceae		FP42		
Promopsis	inermis	Poaceae		FP81		
Prunus	virginiana	Rosaceae			CC23	
Pseudocymopterus	montanus	Apiaceae	VB37	FP72		
Pseudorogeneria		Poaceae				AH9
Ranunculus	uncinatus	Ranunculaceae		FP43		
Ribes	montigenum	Grossulariaceae	VB19	FP65		
Ribes	wolfii	Grossulariaceae		FP74		
Rumex	crispus	Polygonaceae		FP52		
Sambucus	microbotrys	Caprifoliaceae		FP68		
Sceleropogon	brevifolius	Poaceae			CC25	
Silene	dichotoma	Caryophyllaceae			CC32	
Symphoricarpos	rotundiflorous	Caprifoliaceae			CC21	
Taraxacum	eriphorum	Asteraceae	VB33			
Taraxacum	officinale	Asteraceae	VB5		CC8	
Thalictrum	fendleri	Thalictraceae	VB10	FP8		
Tragopogon	dubius	Asteraceae			CC22	AH2
Vaccinium	cespitosum			ns		
Vaccinium	myrtillus	Ericaceae	VB28	FP77		
Valeriana	edulis	Valerianaceae	VB22	FP11		

Veratrum	californicum	Lilaceae		FP23		
Vexibia	nuttalliana	Fabaceae			CC37	
Vicia	americana	Fabaceae		FP17		
Viola	nuttalli	Violaceae		ns		
Viola		Violaceae		ns		
Wyethia	amplexicaulis	Asteraceae			CC12	
Zigadenus	elegans	Lilaceae	VB35			

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