Quantification of *Polypodium glycyrrhiza* epiphyte loads on two common Pacific Northwest deciduous trees in relation to riparian zone proximity

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Abstract

The Pacific Northwest is home to lush temperate rainforests that cover a large portion of land west of the Cascade Mountain Range. Contained within these massive forests are an abundance of vascular and non-vascular epiphytes growing on the stems and branches of many native trees. While non-vascular epiphytes have received the majority of research attention, little investigation has gone into the ecological preferences of the Pacific Northwest's most common vascular arboreal epiphyte, *Polypodium glycyrrhiza*, commonly known as the licorice fern. This study sets out to quantify *P. glycyrrhiza* abundance on two of the most prominent species of deciduous tree in this ecoregion and investigate how these abundances change with proximity to a riparian zone. It was hypothesized in this research that *P. glycyrrhiza* would show a preference for growing on *Acer macrophyllum* individuals in comparison to the common hardwood species *Alnus rubra.* Additionally, I investigated whether proximity to streambeds affected abundance of licorice fern. *P. glycyrrhiza* consistently had a greater abundance on *A. macrophyllum* individuals when compared to *A. rubra*, and on *A. macrophyllum*, a clear decline in abundance occurred with distance from streambed. Conversely there was no relationship found when looking at a proximity-based gradient in the abundance of *P. glycyrrhiza* on *A. rubra*.

Introduction

The Pacific Northwest is known for its dense temperate rainforests that are home to an abundance of deciduous and coniferous trees, understory species, and epiphytic plants and lichens (MacKinnon et al., 1994). Epiphytes in particular contribute greatly to the general plant diversity found in rainforests around the world. (Dubuisson et al., 2009). The high moisture availability in the Pacific Northwest allows for many epiphytic species to survive on the stems and branches of common trees in the region (Nadkarni, 1984). Epiphytes utilize phorophytes (host trees) for support but are generally not reliant on hosts for nutrient uptake (Tejo et al., 2015). Most commonly, the epiphytes seen in the Pacific Northwest are bryophytes, lichens, and ferns. Due to their poikilohydric nature, non-vascular bryophytes are quite successful in environments that see a consistent amount of moisture, as their water content is strongly dictated by outer environmental factors such as precipitation (Pypker et al., 2006). These bryophytes form thick mats of growth on their host trees and are incredibly prevalent in the temperate rainforests of the Pacific Northwest. While bryophytes have been widely studied and can be composed of diverse species assemblages, vascular plant epiphytes in the Pacific Northwest consist of few species, and among the most common is the relatively understudied vascular epiphyte, licorice fern (*Polypodium glycyrrhiza*).

Arboreal epiphytes are highly abundant in the South Puget Sound area where *P. glycyrrhiza* can often be found extending from the moss mats present on *A. macrophyllum*. (McCune, 1990). *P. glycyrrhiza* ranges from Northern British Columbia south through Central California and generally grows west of the Cascade Mountain Range (Lang, 1969). Licorice fern tends to be a coastal species that forms new fronds starting in June and generates mature spores during the winter. The namesake of the licorice fern comes from the sweet black licorice like flavor present in the rhizome (Lang, 1971). *P. glycyrrhiza* are most commonly found as an epiphyte or growing on downed trees or rocks in association with dense moss mats (MacKinnon et al., 1994).

Two deciduous trees stand out in this region as having a greater abundance of *P. glycyrrhiza*, *A. macrophyllum* (bigleaf maple), and *Alnus rubra* (red alder), the latter of which is the most abundant hardwood in the Pacific Northwest (Burns and Honkala, 1990). While an extensive amount of research is present on the thick bryophyte mats that grow on *A. macrophyllum* there has been little research on its vascular epiphytes, the most common of which is *P. glycyrrhiza* (Tejo et al., 2015). Additionally, minimal studies have been done on the riparian, early succession pioneer, *A. rubra* (Burns and Honkala, 1990) and its relationship to both bryophytic and vascular epiphytes in the Pacific Northwest, although there has been ample research on its relationship to epiphytic lichens (Harrington, 2006). It is common to see these two species of deciduous tree growing near each other (Burns and Honkala, 1990) and the presence of epiphytic licorice fern on both is notable. The high abundance of epiphytes on *A. macrophyllum* could be due to a number of factors including the chemistry of the phorophyte substrate (Kenkel and Bradfield, 1986) and the deep grooves present in mature aged bigleaf maple bark (Pessin, 1925). These variables may not apply to red alder, which tends to have much smoother bark, a shorter comparative lifespan (MacKinnon et al., 1994), and potentially different bark chemistry.

The importance of understanding the abundance and ecological tendencies of *P. glycyrrhiza* has ample scientific value due to the ecosystem services that they may offer. Nadkarni (1984) suggested that epiphytes play a significant role in nutrient cycling in an ecosystem and can potentially offer other services like increasing moisture availability for the system and enhancing surface area of the phorophyte host. In fact, in the same study it was calculated that epiphytes on *A. macrophyllum* accounted for 6870 kg/ha of biomass in a temperate conifer dominated forest typical of the Pacific Northwest (Nadkarni, 1984). Additionally, it has been calculated that licorice ferns are responsible for 6% of epiphytic litterfall from the stems and branches of bigleaf maple and contribute carbon and crucial nitrogen back to the system (Tejo et al., 2015). Research and quantification have been limited on *A. rubra* and its relationship to both bryophyte and vascular epiphytes in the Pacific Northwest, leaving a gap in the understanding of the phorophyte's epiphytic contribution to the aforementioned ecosystem services.

While atmospheric moisture is generally high in The Pacific Northwest, humidity associated with proximity to streams may buffer epiphytic plants during annual summer drought. *P. glycyrrhiza* tends to decrease with increased distance from streambeds (pers. obs), which seems intuitive given the poikilohydric nature of the epiphytic bryophytes that *P. glycyrrhiza* grow in conjunction with, as the general water availability would see a decrease as one gained distance from a streambed. The work of Zotz and Hietz (2001) suggested that the main limiting factor for epiphytic environments is the availability of water in the system, further fueling the idea that riparian systems would see a greater abundance of *P. glycyrrhiza*.

Here, I quantified the abundance of *P. glycyrrhiza* both in accordance with stream proximity and between the two aforementioned deciduous tree species, *A. rubra* and *A. macrophyllum*. I hypothesized that abundance of epiphytic *P. glycyrrhiza* would be greatly increased with proximity to streambeds and riparian zones on both *A. rubra* and *A. macrophyllum*. Additionally, it was hypothesized that *P. glycyrrhiza* would be more abundant on *A. macrophyllum* when compared to *A. rubra* due to the increased presence of non-vascular bryophytes colonizing *A. macrophyllum* bark.

Methods and Materials

Study Site

All samples taken for this study were gathered along streams that reside within The Evergreen State College forest reserve, which contains 1,000-acres of second growth rainforest. This forest was last clearcut in the 1930's, was formerly dominated by conifers, and is now a mixed forest of coniferous and deciduous trees that has been left to naturally regenerate as a forest reserve (Kirsch et al, 2012). The climate of this area is typical of a Pacific Northwest temperate rainforest, with generally mild seasonal temperatures and distinct fluctuations of rainy and dry periods throughout the year. Average yearly precipitation is 134.9 centimeters a year, with the majority occurring between November and January (WRCC, 2020).

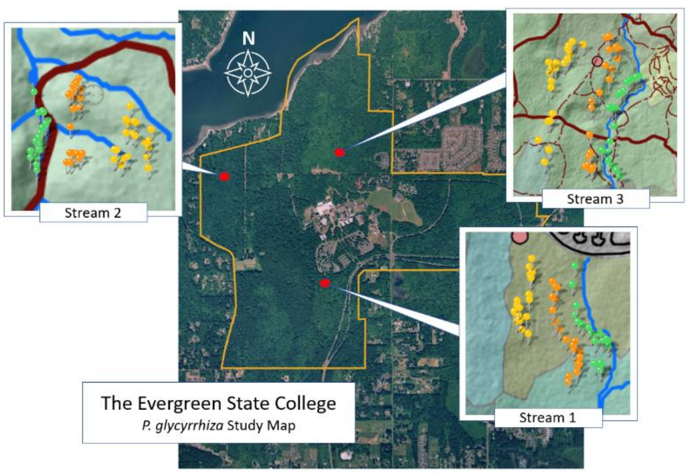

Figure 1. Figure created in Avenza maps and modified and stylized in PowerPoint. This figure represents the study map for the research in this paper. All three streams were marked with points of each individual tree sampled. Green dots represent Transect 1, orange dots represent Transect 2, and yellow dots represent Transect 3.

The three streams chosen for this study (Figure 1) occurred at different distances from the Puget sound. Stream 1 (47.068363, -122.977914) had a distance of 2300 m from the Puget Sound and ranged in elevation between 58 and 64 m across transects. Stream 2 (47.076322, -122.989784) had a distance of 630 m from the Puget Sounds and ranged in elevation between 40 and 64 m across transects. Stream 3 (47.079315, -122.975436) had a distance of 560 m from the Puget sound and ranged in elevation between 31 and 37 m across transects. Dominant deciduous overstory at each site was composed of *Acer macrophyllum* and *Alnus rubra*, additionally, many induvial *Pseudotsuga menziesii and Thuja plicata* were present, with an occasional *Tsuga heterophylla* (Kirsch et al., 2012). Dominant understory was generally composed of *Polystichum munitum* and *Gaultheria shallon*, with scattered *Mahonia nervosa* and *Lysichiton americanus,* especially in the riparian zones.

Sampling Methods

Samples were gathered during the daytime between the hours of 9 am and 7 pm on five separate days in May of 2021. All field data collection occurred on days that were clear/overcast with little to no precipitation. Three 10-m wide belt transects were created parallel to each streambed on a spatial gradient radiating away from each stream. The first transect on each stream was measured using a 50 m tape within 10 m of the streambed. The second transect was measured 30 m away from the stream bank. Finally, the third transect was measured at greater than 50 m in order to have a baseline of individual phorophytes which would more than likely not be affected by close proximity to a riparian zone. Along each transect ten individual *A. rubra* and ten individual *A. macrophyllum* were sampled. A stiff tape measurer was used to measure 3.66 m (12 ft) high from the ground along the stem of each tree, which was the height limit for counted *P. glycyrrhiza* individuals included in this study. Diameter at breast height (hereafter DBH) measurements were taken by using DBH tape and measuring the diameter of each tree at ~1.37 m (4.5 ft). Individual *P. glycyrrhriza* stems with fronds were counted along the stem up to the 3.66 m mark and recorded in a field notebook for later data analysis. Ten individuals of each species were counted at every transect, making 20 total samples per transect. Therefore, every stream had a total of 60 individual trees counted, 30 *Acer macrophyllum* and 30 *Alnus rubra*, making a sample size of 180 total individuals (n=180) across all streams sampled in this study.

In order to standardize counts of *P. glycyrrhiza* due to the average difference between measured *A. macrophyllum* and *A. rubra* DBH (ACMA = 53.83 cm, ALRU = 40.02 cm), a simple formula of (50/x)*y was utilized. Where x was equal to the recorded DBH of each tree and y was equal to the number of *P. glycyrrhiza* found on that individual. This calculation was done on every tree in order to account for the vastly different DBHs of each recorded individual in the study. With this, one could estimate the number of *P. glycyrrhiza* individuals that would be seen if each studied stem had a diameter of 50 cm.

The Avenza map app on iPhone was used to track the location of each sample taken by placing individual pins on a map of The Evergreen State College campus in the corresponding location of the tree sampled (Figure 1). Latitude and longitude as well as elevation ranges for each transect were recorded using this phone application as well.

Statistical Analysis

Statistical analysis was run in JMP Pro statistical software (Version 14.2.0, SAS inc., Cary, NC USA). Two-way ANOVAs were used in JMP to test variance in the abundance of *P. glycyrrhiza* based on the fixed factors of tree species and each transects proximity to streams using a P-value cutoff of 0.05. Additionally, a regression analysis was run in JMP with Transects plotted on the x axis and the Number of *P. glycyrrhiza* plotted on the y axis. These regressions were sorted by Stream and Tree Species to further clarify the trends in *P. glycyrrhiza* distribution.

Results

Stream Information

Stream 1 was the furthest from the Puget Sound at ~2300 m. Total recorded *P. glycyrrhiza* counts at Stream 1 were tallied at 5050 individuals, with an average of 83.99 per 50 cm of DBH on all trees. Total *P. glycyrrhiza* individuals present on *A. macrophyllum* were recorded at 3574 with an average per 50 cm of DBH on each individual of 114.26. Total *P.*

glycyrrhiza individuals present on *A. rubra* were recorded at 1476 with an average per 50 cm of DBH on each individual of 53.72. Stream 1 saw a reduction in total *P. glycyrrhiza* on both species of tree with increasing distance from the stream along all transects (Transect 1 = 1999, Transect 2 = 1675, Transect 3 = 1376).

Stream 2 was the second furthest from the Puget Sound at 630 m. Total recorded *P. glycyrrhiza* counts at Stream 2 were tallied at 2920 individuals, with an average of 55.81 per 50 cm of DBH on all trees. Total *P. glycyrrhiza* individuals present on *A. macrophyllum* were recorded at 2171 with an average per 50 cm of DBH on each individual of 79.54. Total *P. glycyrrhiza* individuals present on *A. rubra* were recorded at 749 with an average per 50 cm of DBH on each individual of 32.07. Stream 2 had the most *P. glycyrrhiza* present on *A. macrophyllum* on Transect 1 (1099), second most on Transect 3 (568), and third most on Transect 2 (504). *A. rubra* on the other hand had the most *P. glycyrrhiza*, on Transect 2 (328), second most on Transect 3 (289), and least on transect 1 (132).

Stream 3 was the closest to the Puget Sound at 560 m. Total recorded *P. glycyrrhiza* counts at Stream 3 were tallied at 2512 individuals, with an average of 43.09 per 50 cm of DBH on all trees. Total *P. glycyrrhiza* individuals present on *A. macrophyllum* were recorded at 1770 with an average per 50 cm of DBH on each individual of 54.86. Total *P. glycyrrhiza* individuals present on *A. rubra* were recorded at 742 with an average per 50 cm of DBH on each individual of 31.32. Stream 3 followed the expected trend of a reduction of *P. glycyrrhiza* with increasing distance to the streambed when it came to *A. macrophyllum* counts (Transect 1 = 917, Transect 2 = 451, Transect 3 = 402). Similar to Stream 2, *A. rubra* had the highest number of *P. glycyrrhiza* on Transect 2 (381), second highest on Transect 3 (194), and least on Transect 1 (167).

Transect Information

Transect 1 occurred within 10 m of the streambed at all locations. Total recorded *P. glycyrrhiza* counts at Transect 1 of all streams combined were tallied at 4314 individuals, with an average of 67.98 per 50 cm of DBH on all trees. Total *P. glycyrrhiza* individuals present on *A. macrophyllum* were recorded at 3486 with an average per 50 cm of DBH on each individual of 107.11. Total *P. glycyrrhiza* individuals present on *A. rubra* were recorded at 828 with an average per 50 cm of DBH on each individual of 28.85.

Transect 2 occurred at the 30 m mark away from the streambed at all locations. Total recorded *P. glycyrrhiza* counts at Transect 2 of all streams combined were tallied at 3339 individuals, with an average of 61.73 per 50 cm of DBH on all trees. Total *P. glycyrrhiza* individuals present on *A. macrophyllum* were recorded at 2121 with an average per 50 cm of DBH on each individual of 73.73. Total *P. glycyrrhiza* individuals present on *A. rubra* were recorded at 1218 with an average per 50 cm of DBH on each individual of 49.72.

	Total All Trees	Average per 50 cm DBH All Trees	Total ACMA	Average per 50 cm DBH ACMA	Total ALRU	Average per 50 cm DBH ALRU
Stream 1	5050	83.9	3574	114.3	1476	53.7
Stream 2	2920	55.8	2171	79.5	749	32.1
Stream 3	2512	43.1	1770	54.9	742	31.3
	Total All Trees	Average per 50 cm DBH All Trees	Total ACMA	Average per 50 cm DBH ACMA	Total ALRU	Average per 50 cm DBH ALRU
Transect 1	4314	67.9	3486	107.1	828	28.8
Transect 2	3339	61.7	2121	73.7	1218	49.7
Transect 3	2829	53.2	1908	67.8	921	38.5

Table 1. Table showing total and average counts of *P. glycyrrhiza* on both tree species over each stream and each combined transect.

Transect 3 occurred at 50 m or more away from the streambed at all locations. Total recorded *P. glycyrrhiza* counts at Transect 3 of all streams combined were tallied at 2829 individuals, with an average of 53.18 per 50 cm of DBH on all trees. Total *P. glycyrrhiza* individuals present on *A. macrophyllum* were recorded at 1908 with an average per 50 cm of DBH on each individual of 67.83. Total *P. glycyrrhiza* individuals present on *A. rubra* were recorded at 921 with an average per 50 cm of DBH on each individual of 38.54. The data recorded for the transects and streams can be seen summarized in Table 1(above) and Table 2 (below), with a visual representation of the data expressed in Figure 2 (below).

Stream 1	**Transect 1**	**Total**	**Average**	**Standard Deviation**	**Average per 50cm**
	ACMA	1470	147	97.6	128.2
	ALRU	529	52.9	53.4	47.9
	Transect 2	**Total**	**Average**	**Standard Deviation**	**Average per 50cm**
	ACMA	1166	116.6	81.9	118.3
	ALRU	509	50.9	35.4	58.4
	Transect 3	**Total**	**Average**	**Standard Deviation**	**Average per 50cm**
	ACMA	938	93.8	79.6	96.3
	ALRU	438	43.8	47.7	54.8
Stream 2	**Transect 1**	**Total**	**Average**	**Standard Deviation**	**Average per 50cm**
	ACMA	1099	109.9	103.2	115
	ALRU	132	13.2	10.4	18.2
	Transect 2	**Total**	**Average**	**Standard Deviation**	**Average per 50cm**
	ACMA	504	50.4	71.3	62.55
	ALRU	328	32.8	37.1	41.6
	Transect 3	**Total**	**Average**	**Standard Deviation**	**Average per 50cm**
	ACMA	568	56.8	41.2	61.1
	ALRU	289	28.9	26.7	36.5
Stream 3	**Transect 1**	**Total**	**Average**	**Standard Deviation**	**Average per 50cm**
	ACMA	917	91.7	70.9	78.1
	ALRU	167	16.7	44.7	20.4
	Transect 2	**Total**	**Average**	**Standard Deviation**	**Average per 50cm**
	ACMA	451	45.1	95.2	40.4
	ALRU	381	38.1	46.2	49.2
	Transect 3	**Total**	**Average**	**Standard Deviation**	**Average per 50cm**
	ACMA	402	40.2	34.2	46
	ALRU	194	19.4s	12.9	24.4

Table 2. Table showing the raw counts at each stream on each transect by each species. Averages, standard deviations, and the average per 50 cm DBH information is present as well.

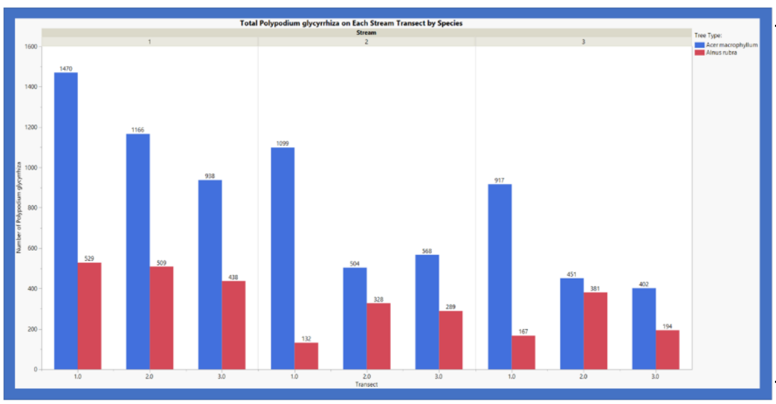

Figure 2. Bar graph showing total counts of *P. glycyrrhiza* for both species across all Streams and Transects. Total for each species and transect is shown above each bar. Blue bars represent *Acer macrophyllum* and red bars represent *Alnus rubra*. (All graphs created in JMP)

Summary and Statistics

Total number of *P. glycyrrhiza* counted in this study came in at 10482 individuals, with 7515 present on *A. macrophyllum* and 2967 present on *A. rubra*. Average *P. glycyrrhiza* per 50 cm DBH of each individual was recorded at 82.89 for *A. macrophyllum* and 39.04 for *A. rubra* (Table 3 below). *A. macrophyllum* showed a distinct reduction of licorice fern epiphytes as distance from the streambed was increased. Conversely, *A. rubra* showed the least abundance of licorice fern on Transect 1, with the second least on Transect 3, and the highest abundance in the 30 m range of Transect 2. Both species showed higher counts of epiphytes as distance from the Puget Sound was increased.

	All	ACMA	ALRU
Total POGL	10482	7515	2967
Average POGL	58.2	83.5	32.9
Average POGL per 50 cm DBH	60.9	82.9	39

Table 3. Table showing total and average counts for all *P. glycyrrhiza* in the study.

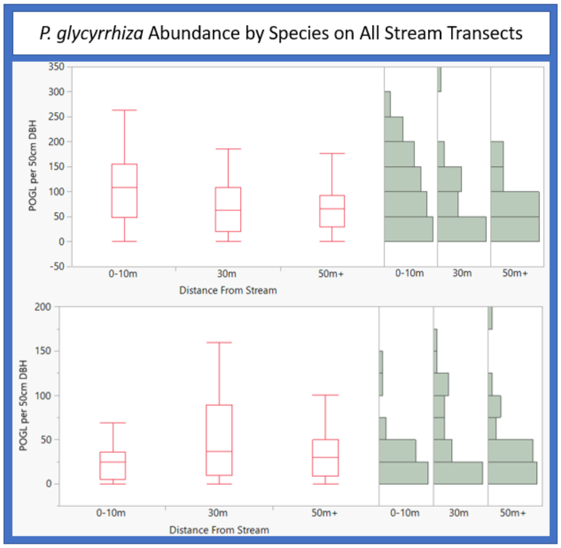

Figure 3. Box and whisker plots accompanied by histograms showing the distribution and variation of *P. glycyrrhiza* abundance across both species. Distance from stream represents transect totals across all three streams combined. Transect 1 is 0-10 m, 2 is 30 m, and 3 is 50 m+. The top image represents *A. macrophyllum* (P=0.045, F=3.22, R Square=0.69) and the bottom *A. rubra* (P=0.12, F=2.16, R Square=0.047).

It was found that we could reject the null hypothesis for *A. macrophyllum* as the ANOVA resulted in a P value of 0 5, and an F ratio of 3.22. Conversely, we were unable to reject the null hypothesis for *A. rubra* as the ANOVA gave us a P value of 0.12, and an F ratio of 2.16 (Figure 3 above). An additional ANOVA was run in JMP to see if there was significance with *P. glycyrrhiza* per 50 cm DBH in both *A. macrophyllum* and *A. rubra* when it came to stream proximity to the Puget Sound. The results from this analysis allowed us to reject the null hypothesis for both species. *A. macrophyllum* showed a P value of 0.0017, an F ratio of 6.89 and an R Square value of 0.14. While *A. rubra* showed a P value of 0.042, an F ratio of 3.28 and an R Square value of 0.07 (Figure 4). The results of the regression analysis (Figure 5) yielded similar results in which all streams produced a negatively sloped linear regression line with the exception of *A. rubra* on Streams 2 and 3.

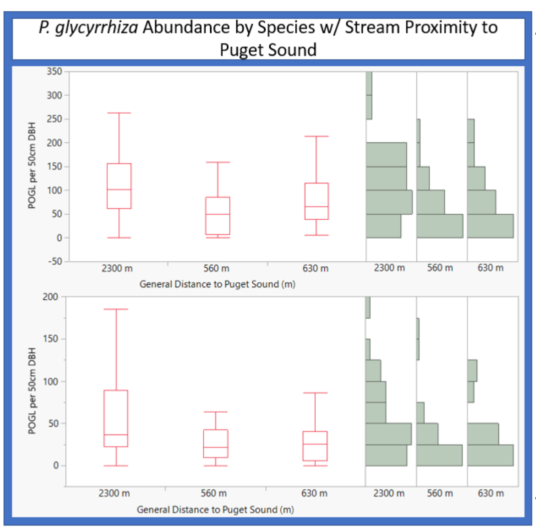

Figure 4. Box and whisker plots accompanied by histograms showing the distribution and variation of *P. glycyrrhiza* abundance on each stream by proximity to the Puget Sound. Stream 1 is 2300 m, 2 is 630 m, and 3 is 560 m. The top image represents *A. macrophyllum* (P=0.0017, F=6.89, R Square=0.14) and the bottom *A. rubra* (P=0.0422, F=3.28, R Square=0.07). Note: in this figure the x axis is not in order of proximity to the Puget Sound.

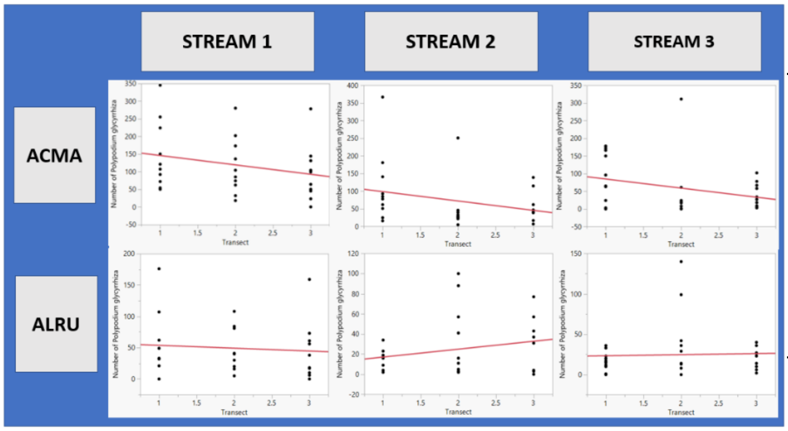

Figure 5. Scatter plots showing linear regression of *P. glycyrrhiza* abundance with increasing distance from streambeds. Trends across each species in accordance with each stream are shown.

Discussion

Clear differences can be seen when comparing the general abundance of *P. glycyrrhiza* on studied stems of *A. macrophyllum* and *A. rubra*. *A. macrophyllum* had a total count which was over twice as high as the studied *A. rubra,* which still had a significant 2967 counted across all individuals, confirming the hypothesis that *A. macrophyllum* would generally see more abundant counts of *P. glycyrrhiza* across all streams and transects. Although the explanation as to ***why*** *A. rubra* shows reduced abundance when compared to *A. macrophyllum* was not evaluated in this study, general tree architecture may be a factor. Additionally, Pessin (1925) observed that trees that were inclined tended to have a larger number of epiphytes present on the upper side of their stems, assumedly due to the increased light and moisture availability that an exposed surface provides, which may have been a determining factor in our study with *A. rubra* epiphyte loads.

While *A. macrophyllum* also followed the hypothesized trend of having a decreased amount of epiphytic *P. glycyrrhiza* as distance was gained from each stream, *A. rubra* followed a different and more unpredictable trend. The highest total volume of *P. glycyrrhiza* on *A. rubra* was found on the second transect with a total of 1218 individuals counted on all streams combined, suggesting there are more factors at play when it comes to predicting licorice fern loads on red alder stems. While *A. rubra* epiphyte counts did not follow the proximity trends of *A. macrophyllum* on Streams 2 and 3, Stream 1 did show a clear reduction in abundance as distance was gained from the streambed. Potential explanations for the unpredictable counts of Streams 2 and 3 could involve the aforementioned tree architecture or potential difference in soil types across transects measured. *A. rubra* growing along Transect 1 of Streams 2 and 3 seemed to have a reduced epiphytic bryophyte mat when compared to others sampled along the remaining two transects, but as the quantification of moss mat biomass was not part of the study this observation is left for future consideration. Interestingly, when epiphyte abundance and stream proximity to the Puget Sound were analyzed with a two-way ANOVA there was a clear trend of decreasing epiphyte abundance on both species along streams that were closer to the Puget Sound. As this was not the primary focus of this study there is more research that would need to happen to understand why this specific trend may occur.

The results from this study present good indicators as far as the differences in *P. glycyrrhiza* abundance between *A. macrophyllum* and *A. rubra* in conjunction with stream proximity and also suggests future research should focus on the three-way partnership between vascular epiphytes, the moss mats they reside in, and the phorophyte species that both colonize.

The quantification of moss mats in relation to stream proximity could help explain the differences in *P. glycyrrhiza* abundance found in this study. An additional follow up study could also consider the angle of each leaning tree in relation to epiphyte density, which may be increased on light exposed surfaces as suggested by Pessin (1925).

Overall, this study makes it clear that *A. macrophyllum* tends to have higher loads of *P. glycyrrhiza* in accordance with stream proximity at this second-growth temperate rainforest study site, and generally has a higher abundance when compared to the *A. rubra* it shares habitat with. The quantification of *P. glycyrrhiza* abundance on these two species fills a gap in ecological understanding when it comes to the epiphytic preferences of this understudied vascular fern.

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