Describing the Alpine-Treeline Ecotone on Mount Arrowsmith and its Response to Climate Change Over 20 years

by

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Abstract

The Alpine-Treeline Ecotone (ATE) is a temperature-sensitive transitional plant community, which has had various responses to climate change across the world. On Vancouver Island, it is predicted that the extent of alpine-tundra plant communities will be reduced and replaced with mountain hemlock forests as warming increases the ranges of lower elevation species. This study aims to describe the plant community composition within the ATE at Mount Arrowsmith, on Vancouver Island, and investigate directional changes in community composition over the last 20 years, using the GLORIA protocol. At Mt. Arrowsmith, the ATE is dominated by rock cover with low vascular plant cover and most closely resembles *Rhizocarpon geographicum* plant communities found elsewhere in the southern Coast Mountains. Microsites result in two vegetation associations being present: *Penstemon – Juniperus* on xeric sites and *Phyllodoce – Abies* on more developed soils. No significant changes in plant community composition over the last 20 years were detected, with vascular plant cover remaining stable and rock remaining the dominant cover. Species richness also remained stable over the study period; however, turnover occurred with species gained and lost with each survey and one new invasive species in 2025. The plant community within the ATE at Mt. Arrowsmith has not exhibited directional change over the last 20 years. Continued monitoring will be needed to assess plant community responses to ongoing climate change.

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Introduction

1.1 Mountain Ecosystems, Treeline Advancement and Climate Change

Mountain ecosystems have long been regarded as sentinels of change. Characterized by long-lived, cold-adapted plant species, alpine ecosystems host considerable amounts of endemic plant species and are among those most at risk of climate change (Lenoir et al., 2008; Dirnbock et al., 2011; Abeli et al., 2018). Warming climates can impede the growth of these cold-adapted species and allow lower elevation species to expand their ranges as temperatures increase (Lenoir et al., 2008; Dirnbock et al., 2011). This upward shift poses a major threat to range-restricted high-altitude species as the geographic isolation of mountain tops results in limited areas for species to shift to (Dirnbock et al., 2010; Wershow & DeChaine, 2023). The most visible evidence for the advancement of the lower-elevation species into the alpine zones is the establishment of trees at higher elevations than their previous extent, a process that has been referred to as 'treeline advancement' (Holtmeier & Broll, 2005).

Treelines are often defined as the uppermost limit at which trees reach a maximum height of 2 – 3 meters (Elloitt, 2017). Treelines exist within the Alpine-Treeline Ecotone (ATE), a temperature-sensitive transitional plant community, shaped by the physiological and reproductive abilities of the upper and lower elevational limits of the bordering plant communities, extending from the closed subalpine forest to the uppermost extent of tree establishment (Elliott, 2017). Given the ATE temperature sensitivity, the most anticipated change within these zones is the recruitment of lower elevation species into higher elevations, which has been well studied for tree species (Holtmeier & Broll, 2005). Treeline advancement has been detected around the world yet, treeline response to climate change remains regionally highly variable (Harsch et al., 2009). A global analysis reported that 52% of treeline sites have advanced, 1% have receded, and 47% remained stable concluding that treeline, and by extension ATE, are responding to climate warming; however, additional environmental factors influence if a treeline will advance (Harsch et al., 2009). Within North America, treeline advancement has been detected across the Rocky Mountains and the subarctic alpines (Dearnborn & Danby, 2017; Trant et al., 2020, Griesbauer & Bevington, 2023). In the Rocky Mountains, treelines have undergone pronounced changes with treeline advancement occurring and tree density increasing within the ATE (Trant et al., 2020). In the subarctic alpine, treeline advancement and shifts within the ATE have also occurred (Danby et al., 2007; Dearnborn & Danby, 2017). Conversely, summits in California and Nevada in the southern United States have shown no directional change in ATE plant community composition, suggesting stability despite climate warming (Goff et al., 2025). Together, these studies highlight the regional variability of plant community responses to climate change and further suggest that local factors determine how ATE plant communities respond to climatic shifts.

1.2 The Influence of Abiotic Factors on ATE Dynamics

Plant community dynamics within the ATE are controlled by complex interactions between temperature and precipitation (Sigdel et al., 2018; Huang et al., 2023). These interactions determine soil moisture availability, snow cover, and length of growing season, all of which determine the ATE plant community composition as well as likelihood of treeline advancement (Sigdel et al., 2018; Huang et al., 2023). Snow plays a critical role within the ATE, with early snow melt increasing soil moisture and alleviating early season drought stress, while snow cover plays a crucial role in insulating plants and reducing winter stress by insulating plant tissue (Korner, 1999; Li et al. 2022). In the Himalayas, treelines have shifted upwards in response to temperature increases; however, the rate at which they shift was mediated by spring precipitation, with most advancement occurring in warm moist spring conditions (Sigdel et al., 2018). Moreover, treeline elevation increases with summer temperatures and seasonal snowlines, with spring snowline and snow days cover contributing the most to determining treeline elevation (Huang et al., 2023). Snowline, which is the boundary between snow covered and snow free surfaces, play an important role protecting seedlings from frost damage and alleviating drought conditions; however, excess snow cover days can limit seedling growth (Huang et al., 2023). Precipitation and temperature are further influenced by continentality and as a result treelines at the same latitude are not at the same elevation (Kienle et al., 2022). The elevation of a treeline will increase with greater distances from the coast, as a result of increased continental growing temperature (Kienle et al., 2022). Moreover, the form of the treeline plays a role in whether it will advance or not; advancement of a treeline in krummholz form is more likely to occur when winter temperatures warm, as these treelines may be controlled by stress factors such as wind, snow and ice damage (Harsch et al., 2009). Given the highly dynamical interaction of abiotic factors influencing plant communities in the ATE, mountain ranges must be considered individually as one cannot draw conclusions between two geographically, climatically, and phenotypically different regions.

Aspect also drives microclimatic differences, resulting in different climatic conditions and different plant community compositions despite similar macroscale climatic conditions (Xue et al., 2018). Aspects create microclimatic conditions resulting in different soil moisture, soil temperature, and light availability (Warren, 2009; Xue et al., 2018). Slope aspects can drive plant community dynamics with south facing-slopes receiving more solar radiation, resulting in warmer and drier conditions that favor more drought-tolerant species (Warren, 2009). Conversely, northern aspects receive less sunlight throughout the day, creating cooler and moister soil condition that favor shade-tolerant, mesic species (Warren, 2009). These microclimatic differences mean that plant communities in different aspects are likely to respond differently to climate change. Within the Rocky Mountains, lower-elevation plant communities are more likely to advance on gradual slopes and warmer southern aspects, as warmer aspects have early snow melts and longer growing seasons (Trant et al., 2020). Notably the advancement of lower elevation species also corresponds with warmer aspects, with the greatest advancement occurring on the southern aspect, indicating that aspect plays a greater role in driving plant community composition than elevation within the subarctic alpine (Danby et al., 2007).

1.3 The Coast Mountains of British Columbia

Alpine plant communities are understudied in the Coast Mountains. This range extends 1600 km along the Pacific coast of British Columbia and is characterized by rugged peaks, extensive glaciation, and deep fjords. The Coast Mountains interact with moist Pacific air masses, producing heavy snowfall and resulting in a treeline 900 m lower than inland mountains (MacKenzie, 2006). Precipitation is greater on windward slopes of mountains; west-facing slopes in the Coast Mountains receive higher amounts of rain than east-facing slopes. Subalpine elevations in the Coast Mountains fall within the Mountain Hemlock (MH) biogeoclimatic zone, which is characterized by short cool summers and long wet winters with heavy snow cover (Meidinger et al., 1990). Above the MH zone is the Alpine Tundra zone, typically occurring at elevations greater than 1650 meters in southwestern British Columbia. The harsh alpine climate is cold, windy, and snowy and characterized by low growing-season temperatures (Meidinger et al., 1991). Encroachment of woody species from the MH zone into the Alpine Tundra zone is of growing concern, as it may result in the loss of alpine ecosystems (Jackson et al., 2015). Previous studies suggest that woody encroachment has occurred, particularly on north-facing slopes where soil moisture is greater (Jackson et al., 2015). Within the Vancouver Island mountains, pulses of tree establishment have been recorded, and continued infilling of alpine meadows is predicted (Laroque and Smith, 2003). Although treeline dynamics have been documented on Vancouver Island, there remains a notable lack of studies examining alpine communities, particularly with respect to how plant community composition is expected to change under a warming climate, as these communities are difficult to access.

1.4 Objectives of the Study

The overall aim of this study is to increase our understanding of the plant communities in the ATE on southern Vancouver Island, providing a foundation for understanding high-elevation plant communities and treeline dynamics in the Coast Mountains. To achieve this, a detailed account of plant community composition at Mt. Arrowsmith is presented, along with an assessment of the influence of aspect on ATE plant communities. In addition, an analysis of how these communities have changed over the past 20 years provides insight into potential directional changes that are occurring within the community. Together, these findings provide foundational information on how plant communities within the ATE of the Coast Mountains on Vancouver Island may respond in the coming years. Establishing this baseline is critical for understanding alpine plant community dynamics during a period of accelerated environmental change.

Materials and Methods

2.1 Study Area

Mt. Arrowsmith is located on Vancouver Island (Figure 1), British Columbia within the Mount Arrowsmith Biosphere Reserve (MABR), approximately 25 km east of Port Alberni. In 2000, the Mount Arrowsmith Biosphere Region was designated a UNESCO Biosphere Reserve, promoting sustainable development and conservation of biological and cultural diversity within the region (MABR, 2025). The region encompasses many endemic species and is stewarded by the Snaw-naw-as, Qualicum, Snuneymuxw, K'omoks, Tseshaht, Hupacasath, and Ditidaht First Nations (MABR, 2025) who have historical relationships to this land.

At 1819 m asl, Mt. Arrowsmith is the tallest mountain on southern Vancouver Island. The region is characterized by a climate moderated by maritime influences (Mackenzie, 2006). Climate estimates for Mt. Arrowsmith were obtained from ClimateNA (Wang et al., 2025), which provides a climate model based on geospatial interpolation among weather stations. Between 1991 and 2020, the site had a mean annual temperature of 3.8 ℃ and a mean annual precipitation of 2774 mm, which falls mostly in the form of rain (Wang et al., 2025). The mean temperature of the warmest month was 12.4 ℃ and the coldest month was −2.7 ℃ (Wang et al., 2025). During that period (1991-2020), the site had 145 frost-free days a year, on average.

On Mt. Arrowsmith, the ATE is a transitional community between the Mountain Hemlock and the Alpine Tundra biogeoclimatic zones (Meidinger and Pojar, 1991). In southwestern British Columbia, the Mountain Hemlock zone occurs at elevations between 900 m and 1800 m. This zone is characterized by short, cool summers and wet winters, with heavy snow cover that is slow to melt, resulting in a short growing period (Meidinger and Pojar, 1991). Within the Mountain Hemlock maritime subzones, the soils forming on upper slopes and ridges are predominantly podzols and folisols (Meidinger and Pojar, 1991).

Dominant tree species are *Tsuga mertensiana* (mountain hemlock), *Abies amabilis* (amabilis fir), and *Chamaecyparis nootkatensis* (yellow cedar) (Meidinger and Pojar, 1991). Other tree species that occur within higher elevation sites of the Mountain Hemlock zone are *Abies lasiocarpa* (subalpine fir), *Pinus albicaulis* (whitebark pine), and *Pinus contorta* (lodgepole pine) on very dry sites. The Alpine Tundra zone occurs above 1650 m in southwestern British Columbia, and it is defined by treeless plant communities dominated by shrubs, herbs, bryophytes, and lichen (Meidinger and Pojar, 1991). Characteristic shrubs of this zone are: *Cassiope* spp. and *Phyllodoce* spp. (mountain heathers), *Luetkea pectinata* (partridgefoot), *Arctostaphylos uva-ursi* (kinnikinnick), *Empetrum nigrum* (crowberry), and *Vaccinium vitis-idaea* (lingonberry). Botanical nomenclature follows the Flora of North America Editorial Committee (1993+).

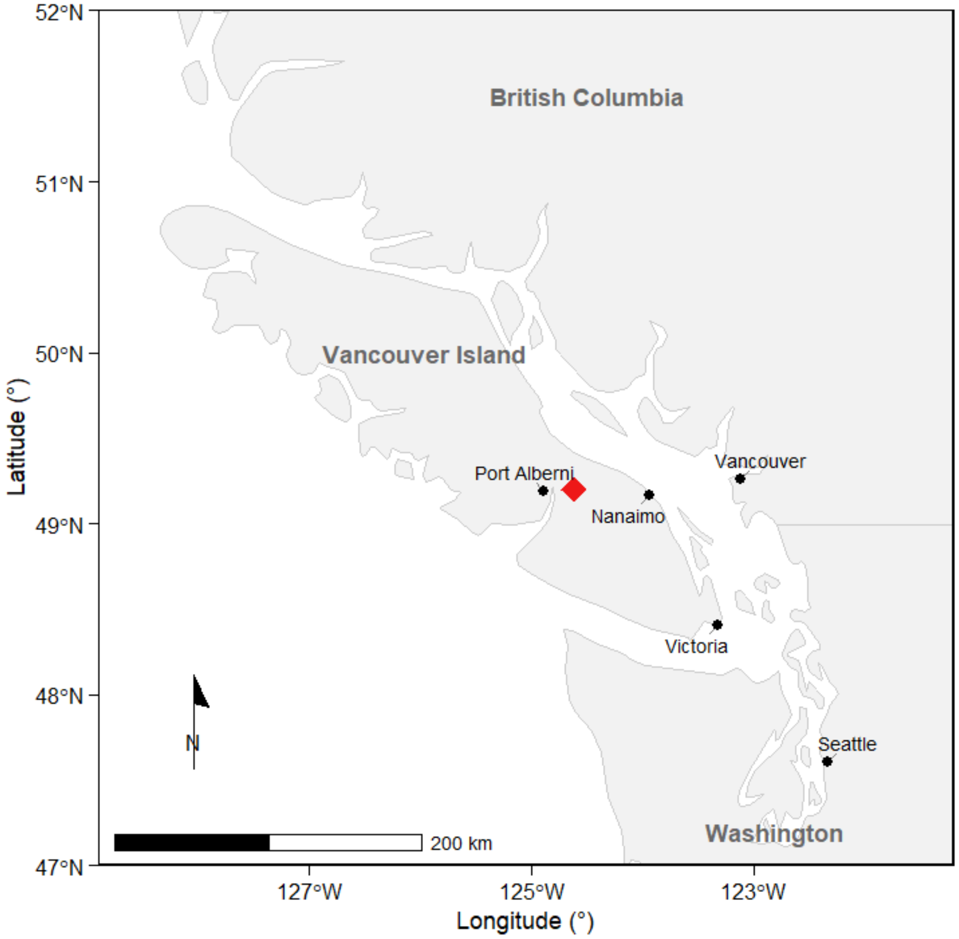

Figure 1. Location of the study site, Mount Arrowsmith on Vancouver Island, British Columbia, Canada. Mount Arrowsmith is represented by the red diamond. Base map is from South (2017).

To investigate the ATE at Mt. Arrowsmith, the alpine monitoring protocol established by the Global Observation Research Initiative of Alpine environments (GLORIA) was used. This is an international long-term monitoring initiative aimed at understanding the responses of alpine plant communities to climate change (Pauli et al., 2015). Permanent survey plots were established at four sites on Mt. Arrowsmith in 2006 (Swerhun et al., 2009) and surveyed, using the GLORIA protocol. The sites were surveyed again by the Mount Arrowsmith Biosphere Region Research Institute research group in 2016 and 2021. In late July 2025, the UVic team surveyed the two lower elevation study sites that are located within the treeline ecotone. These sites were named ‘Shari’s Summit’ (SHR) and Kristina’s Crag’ (KRS) by Swerhun et al. (2009) and are situated 1450 and 1514 m above sea level, respectively. The GLORIA protocol was followed for setting up survey plots and surveying surface cover types and plant communities; however, temperature was not measured as part of this study (Figure 2).

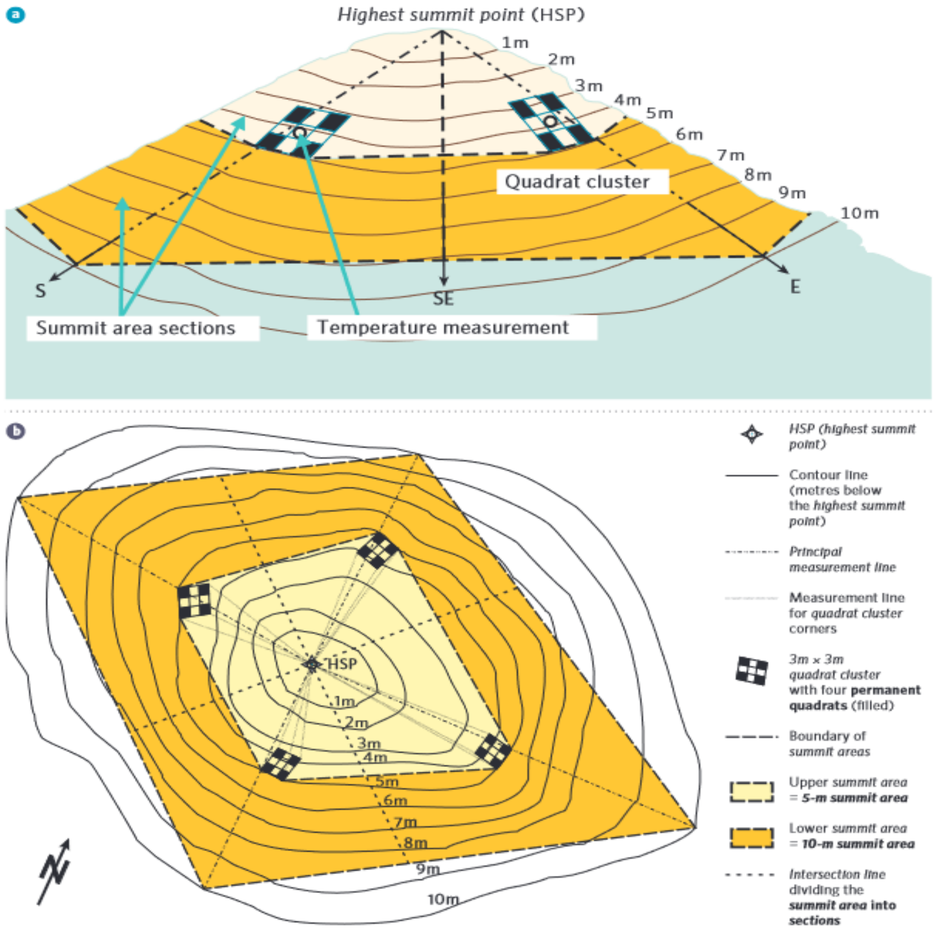

Figure 2. GLORIA plot setup. Yellow represents the summit-area section and black squares represents the quadrat surveys. a) Displays an oblique view of the plot set up with contour lines denoted. b) Top view of the plot set up. The 3m x 3m quadrats and the corner points on the summit area sections are arranged in the main geographic direction. The quadrat is placed on

either side of the principal measurement line dependent on the terrain and habitat situation. Image reproduced from Paulie et al. (2015) with permission.

2.2 Summit area sections

At each site, the highest point was found using GPS coordinates and permanent markers established in 2006. From each highest point, rope was laid out in each intermediate direction (NW, NS, SW, SE) down to 10 m below the summit. At 5 m and 10 m below the summit, an intersecting rope was laid around the summit, passing through each intermediate direction. As a result, two sections per aspect were established for each site (i.e., at 5 m and 10 m below the summit). These sections are referred to as summit-area sections or SAS. Within each aspect section, the percent cover of five surface types: barren/rock, litter, lichen, bryophyte, and vascular cover plants was determined. Additionally, data was collected on the presence of each plant species and their relative abundance in five categories established by the GLORIA protocol: dominant, common, scattered, rare, and very rare. These categories were defined as follows. Dominant species were very abundant and made up more than 50% of the section. Common species were frequent and widespread throughout the section making up less than 50% of the section. Scattered species were not obvious at first glance; however, the species were widespread throughout the section, including individuals that were not evenly dispersed. Rare species were present at several locations and could not be overlooked with careful observation, and very rare were species with one or only a few individuals.

2.3 Permanent quadrats

In addition, four permanent 3 m × 3 m quadrats were established in each cardinal direction, 5 m downslope from the summit. Within these quadrats, the four corner plots were surveyed. Data was collected on the percent cover of plant species and surface cover types within these quadrats. To ensure consistency among surveys, a 1 m × 1 m quadrat with 100 cells was used to estimate percent covers. For percent cover estimates that were <1%, a transparent grid that provided a visual reference of surface area ranges below 1% was used to increase precision on cover estimates. Lastly, photographs were taken of each quadrat for visual comparison to past surveys and to help ensure that the permanent plots could be relocated in future surveys.

Species richness was quantified as the number of distinct species present within the defined sampling areas. To evaluate changes in community compositional turnover, the number of species gained and lost was calculated between two sequential surveys. Gained species were defined as species absent in preceding survey but present in the following survey. Lost species were defined as species present in the preceding survey but absent in the following survey. Kruskal-Wallis tests were used to determine significant differences for cover of plant species across the four quadrat surveys over the 20 year period. The program R version 4.4.3 (R Core Team, 2025) was used to perform all statistical analysis and to generate data plots. The following R packages were used: dplyr for data management (Wickham et al., 2024), and ggplot2 for data visualization (Wickham et al., 2024).

Results

3.1 Surface Cover in 2025

The two sites are characterized by a predominantly rocky composition that supports small patches of vegetation, with forbs widespread throughout. Across both sites and all aspects, the dominant surface type was rock, contributing between 65-95% to the summit area's surface cover (Figure 3. Within the SAS, vascular plant surface cover was low (< 20%), except in SHR E10, KRS E05, and KRS N05, where vascular plant cover was 40%, 60%, and 30%, respectively (Figure 3b, 3d). Bryophyte and lichen contributed the least to surface cover, remaining under 10% across the two sites and all aspects (Figure 3a, 3b, 3d, 3e). When examining the influence of aspect on rock and vascular plant surface cover, there was no consistency between the two sites. The section with the least vascular cover was the 10 m section at KRS, which was largely barren with vascular plant cover (< 8%), bryophyte cover (< 6%), and lichen cover (< 7%) being limited throughout the section (Figure 5e).

The quadrats placed within the 5 m sections indicated that the sites were largely barren with mean rock cover ranging between 70-90%, except on the north aspect of KRS, where mean rock cover was 33% (Figure 3c, 3f). At SHR, mean vascular plant cover was < 8% on all aspects, except in the south, where vascular plant cover was 40% (Figure 3c, 3f). The mean vascular plant cover was lower at KRS (< 3%), except in the north quadrats, where mean cover was 25%. The quadrats on the west and north aspects of KRS had high bryophyte cover (~20%), and similarly, the west aspect of SHR had high bryophyte cover (~20%) (Figure 3c, 3f). At both sites, the mean lichen cover was < 6% across all aspects. There was no consistency for surface cover of the quadrats between the two sites.

3.2 Common Plant Species in 2025

In 2025, no species were recorded as dominant, with common being the highest abundance category observed. At the lower elevation site, SHR, *Pinus contorta* was common on all aspects, *Penstemon davidsonii* was common on the north and west, *Danthonia intermedia* was common on the north, and *Arctostaphylos uva-ursi* was common exclusively on the west aspect. *Pinus contorta* was common on all aspects of KRS except for the south, where there were

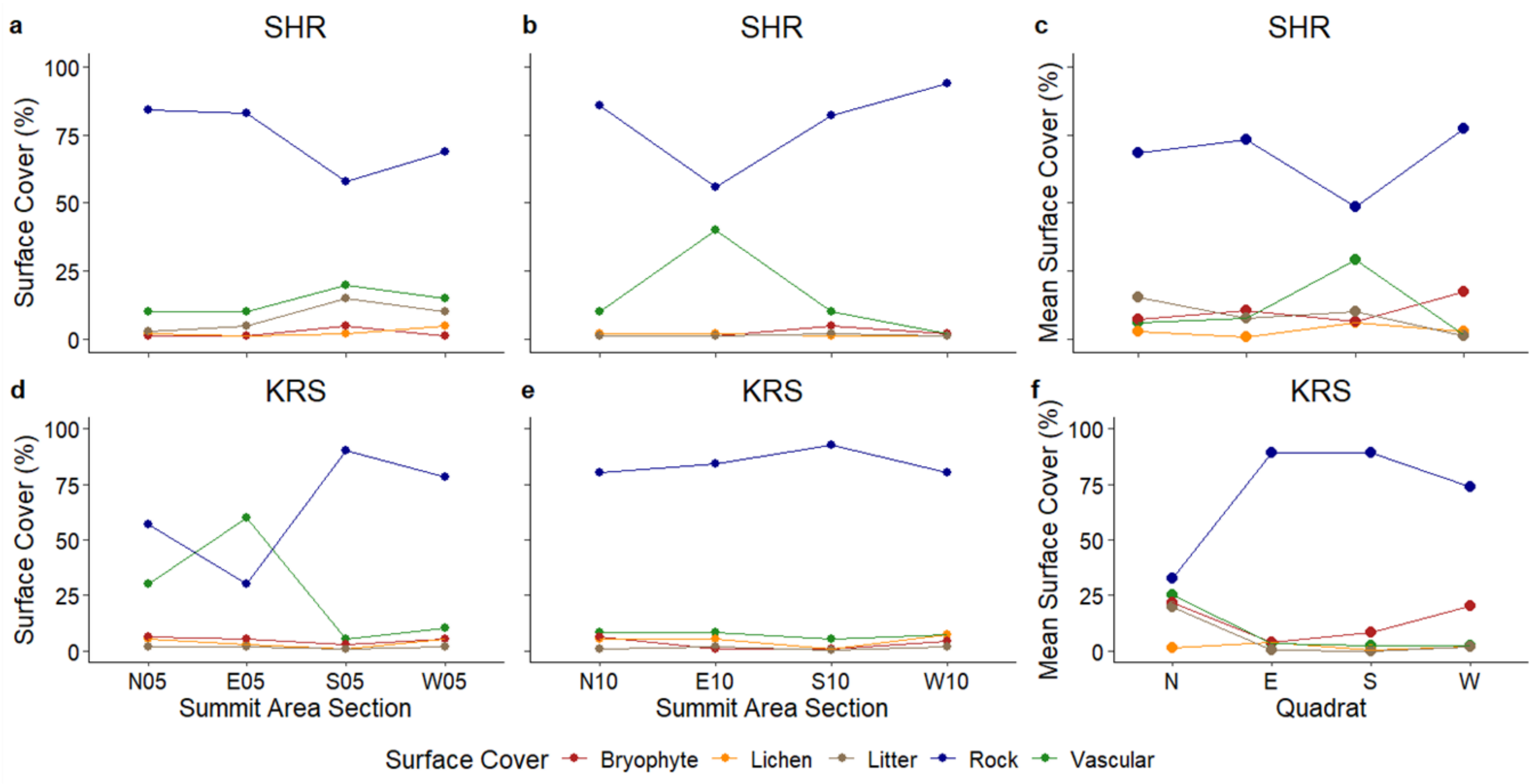

Figure 3. Surface cover of each aspect at SHR and KRS in 2025. Surface cover determined using SAS surveys: (a) SHR 5 m, (b) SHR 10 m, (d) KRS 5 m, (e) KRS 10 m. Mean surface cover of four quadrats placed within the 5 m section of (c) SHR and (f) KRS. Surface cover types include rock, vascular plant, bryophyte, lichen, and litter.

no common species. *Selaginella wallacei* and *Selaginella scopulorum* were common on the north, and *Phlox diffusa*, *Arctostaphylos uva-ursi*, and *Juniperus communis* common on the east.

3.3 Plant Species Richness in 2025

Summit Area Section Surveys

In total, 50 and 58 plant species were observed at SHR and KRS in 2025, respectively. At SHR, the north aspect had the greatest number of species (n=38), whereas the south and west aspects had the fewest number of species (both n=25) (Figure 4). At KRS, the greatest number of species were present in the west aspect (n=48), and the least were found in the south aspect (n=21) (Figure 4). At both sites, a greater number of species, by about 4 - 9 taxa, were present in the 5 m summit-area section compared to the 10 m section, except in the east at KRS where there were 10 more taxa in the 10 m section than the 5 m section. The species totals of SHR N10 and E10 may have been underestimated due to difficult and steep terrain resulting in the reduced survey efforts within the section.

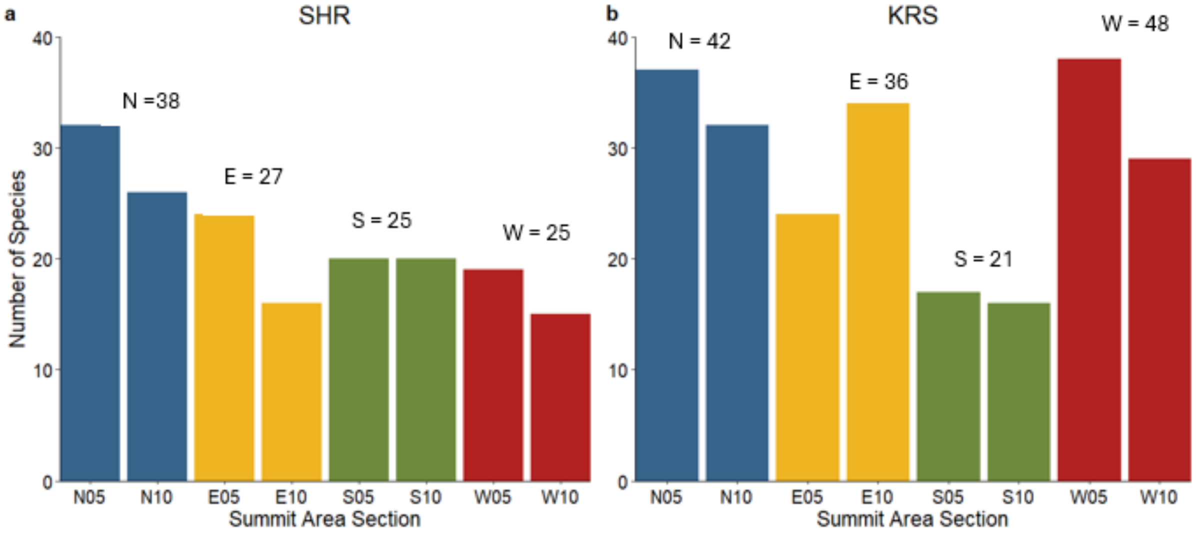

Figure 4. Number of species observed in each summit-area sections at the two Mt. Arrowsmith sites, (a) SHR and (b) KRS, in 2025. Annotations denote the total number of unique species observed on each aspect.

Quadrat Surveys

Across the two sites, the number of plant species observed in the quadrats ranged between 0 - 6 species (Figure 5). The mean number of species present in the quadrats were similar across all aspects, with SHR having an average of 3 species per quadrat (Figure 5). A higher number of species were observed at KRS, with an average of 4 species per quadrat across aspects, except in the south, where there was an average of 1 plant species per quadrat (Figure 5).

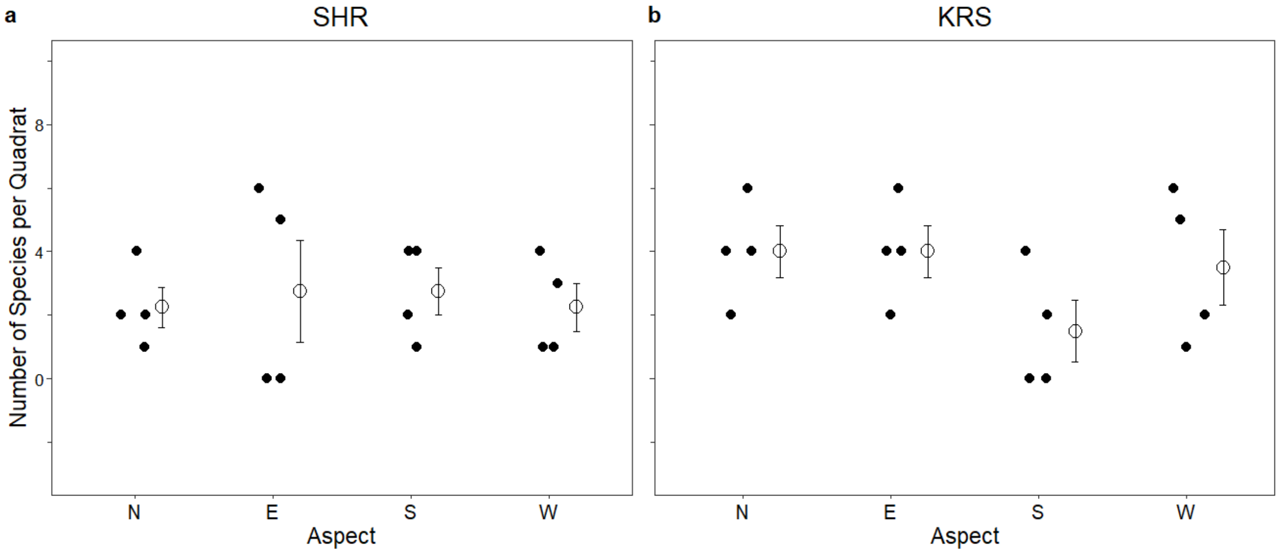

Figure 5. Mean and standard error for number of species observed in quadrats for each aspect of (a) SHR and (b) KRS. The number of species present in each quadrat are represented as black circles.

3.4 Surface Cover Over the Last 20 Years

Over the last 20 years, rock cover has remained the dominant surface cover type, contributing 60 - 90% to each section's surface cover (Figure 6b). Rock surface cover has declined slightly over time, except in the east where rock cover of the sections differs from each other, displaying inconsistent changes throughout the survey period. Similarly, vascular plant cover was variable between the sections in the east but remained constant through time in the other aspects, largely remaining under 30% of the surface cover (Figure 6a). Bryophytes showed a slight increase over time across all aspects. Previously, bryophyte cover remained under < 3% of surface cover across all aspects, but bryophyte cover was closer to 5% across all aspects in the 2025 surveys (Figure 6c). Lichen cover was 5 - 10 % higher at KRS than SHR in the east and west. Additionally, lichen cover on each respective site was similar between the north and south, and the east and the west.

Lichen cover was lower in the east and south, with KRS remaining greater than SHR; however, lichen cover remained less than 5% through time (Figure 6d). Rock and vascular plant cover in the east aspect is inconsistent among sites and plots.

3.5 Species Richness and Turnover Over the Last 20 Years

Species richness at SHR decreased slightly between 2006 – 2025 (Figure 7a). In 2006, the site supported 56 species, declining to 53 species in 2016, and undergoing no change in 2022 (Figure 7a). In 2025, the site declined again in species richness, with 50 species present (Figure 7a). While species richness only underwent minor change over the last 20 years, the site underwent turnover, indicating compositional changes between the surveys.

Between 2006 - 2016, SHR lost 9 species and gained 6 species (Figure 7b). The species present in 2006 and lost in subsequent surveys included *Antennaria racemosa*, *Carex pyrenaica*, *Arnica latifolia*, *Vaccinium parvifolium*, and *Vaccinium uliginosum. Poa stenantha* was gained in 2006 and continued to be present in all future surveys. In 2022, despite species richness remaining the same, 10 plant species were lost, and 10 species were gained (Figure 7b). The species not present in 2025 include *Tsuga heterophylla* and *Micranthes rufidula*. The greatest loss of species was at SHR, which occurred in 2025, with 11 species lost and 7 species gained (Figure 7b). Lost species included *Antennaria umbrinella* and *Erigeron compositus.* In 2025, the following species were found without any previous detection at the site: *Antennaria alpina*, *Antennaria microphylla*, and *Chamaenerion angustifolium.*

In contrast to SHR, species richness increased slightly at KRS between 2006 – 2025 (Figure 7a). In 2006, the site supported 55 species, which increased to 57 species in 2016, followed by a slight decrease to 56 species in 2022 (Figure 7a). In 2025, the site increased to 58 species present (Figure 7a). As seen with SHR, the little change in species richness does not account for the turnover occurring at the site, which indicates compositional changes.

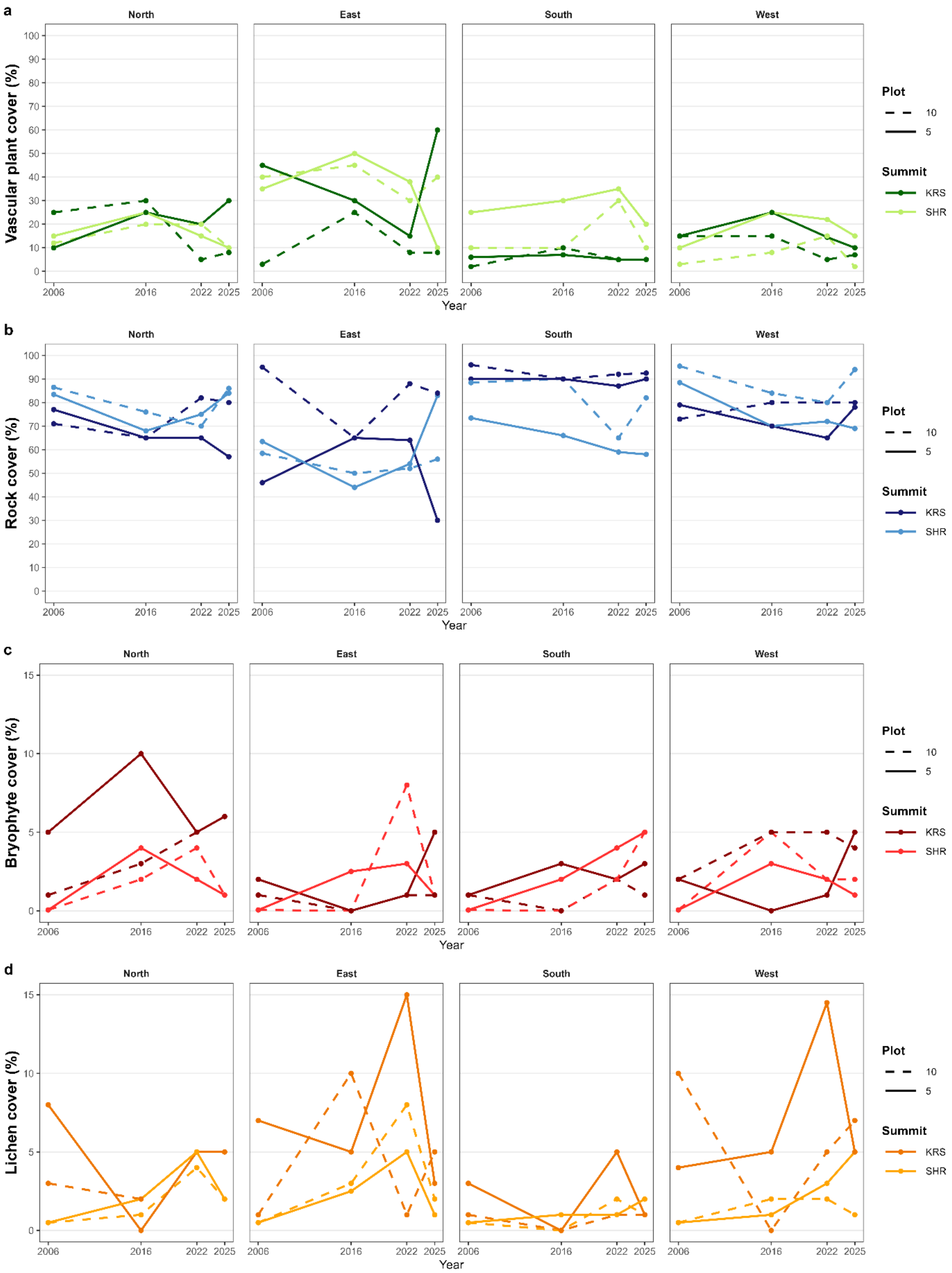

Figure 6. Changes in surface cover within summit-area sections at SHR and KRS, over the last 20 years. Four surface covers are plotted: (a) vascular plants, (b) rock, (c) bryophyte, and (d) lichen.

Between 2006 and 2016, KRS lost 6 species and gained 8 (Figure 7c). As seen in SHR, *Carex pyrenaica* was lost from the site and was not found in subsequent surveys. Between 2016 and 2022, the site lost 7 species and gained 6 (Figure 7c). *Pedicularis racemosa* was present in 2016 and not present in any subsequent surveys. *Rhododendron albiflorum* and *Elymus elymoides* were gained at the site in 2016. The greatest turnover at KRS occurred between 2022 and 2025, with 8 species lost and 10 species gained (Figure 7c). Lost species included *Streptopus amplexifolius* and *Antennaria umbrinella,* and gained species included *Chamaenerion angustifolium*, *Carex rossi*, *Agrostis mertensii*, and *Carex scirpoidea*. Notably, the non-native plant species *Hypochaeris radicata* was gained in the 2025 survey.

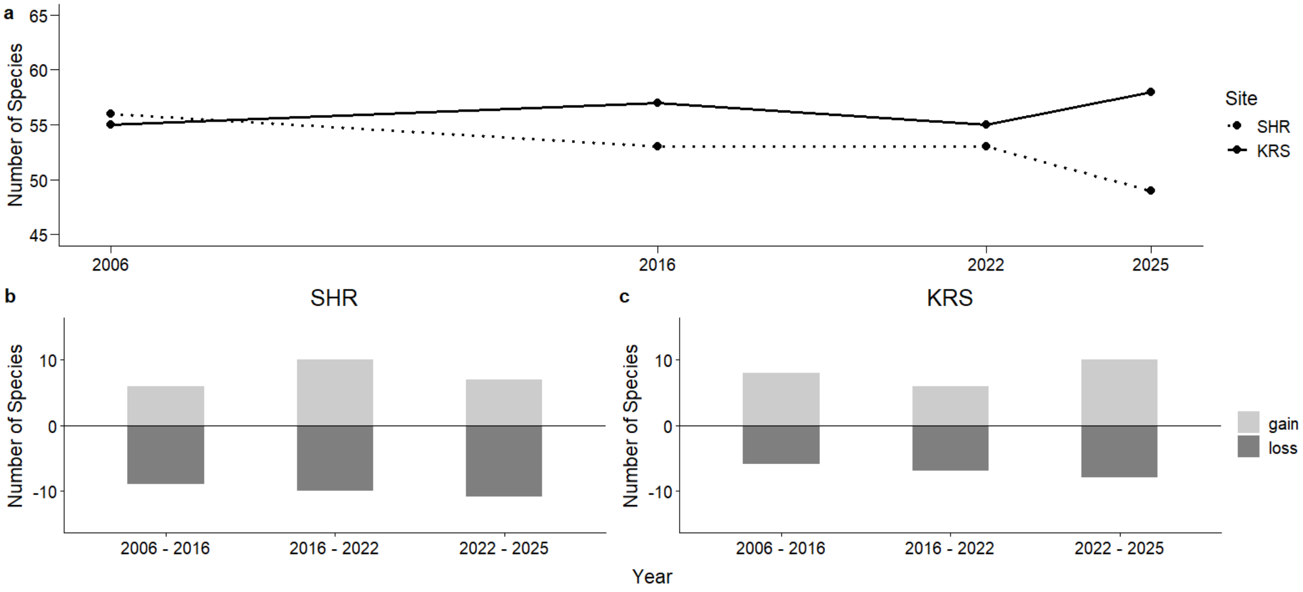

Figure 7. (a) Total number of species present for each survey year (2006-2025), at SHR and KRS. Community composition turnover between two sequential surveys is presented in plots (b) and (c). Light grey bars represent the number of species gained and the dark grey bars represent the number of species lost between two surveys. Gained species are present in survey but absent in the preceding survey and lost species are absent in the survey but present in the preceding survey.

Furthermore, the influence of aspect on species richness was examined at the two sites between 2006 – 2025. The declines in species richness occurred at SHR in the east, south, and west, with greatest declines in the south and east (Figure 8a). In 2006, the east aspect had 46 species present, declining to 40 species in 2016, and increasing to 43 species in 2022 (Figure 8a). In 2025, the east aspect lost 16 species resulting in only 27 species being present (Figure 8a). The south aspect displayed greater fluctuations in species richness between survey years. In 2006 the south aspect supported 36 species, declining to 30 species in 2016 and increasing to 42 species in 2022 (Figure 8a). In 2025, species richness on the south aspect declined to 26 species (Figure 8a). The greatest changes in species richness occurred in the south and east, however compositional changes are not accounted for.

Contrary to the aspects at SHR, species richness at KRS aspects remained stable and slightly increased between 2006 and 2022. Species richness in the south and west aspects of KRS remained constant through time, with species richness constant around 21 and 36 species, respectively (Figure 8b). Species richness varied more in the north and west aspects, with the north having 40 species in 2006, increasing to 42 species in 2016, and declining in 2022 to 37 species (Figure 8b). In 2025, the north aspect increased to 41 species (Figure 8b). The north aspect experienced variation in species richness over the survey years but not an overall change. In the east aspect, a slight increase occurred from 43 species to 46 species in 2025 (Figure 8b).

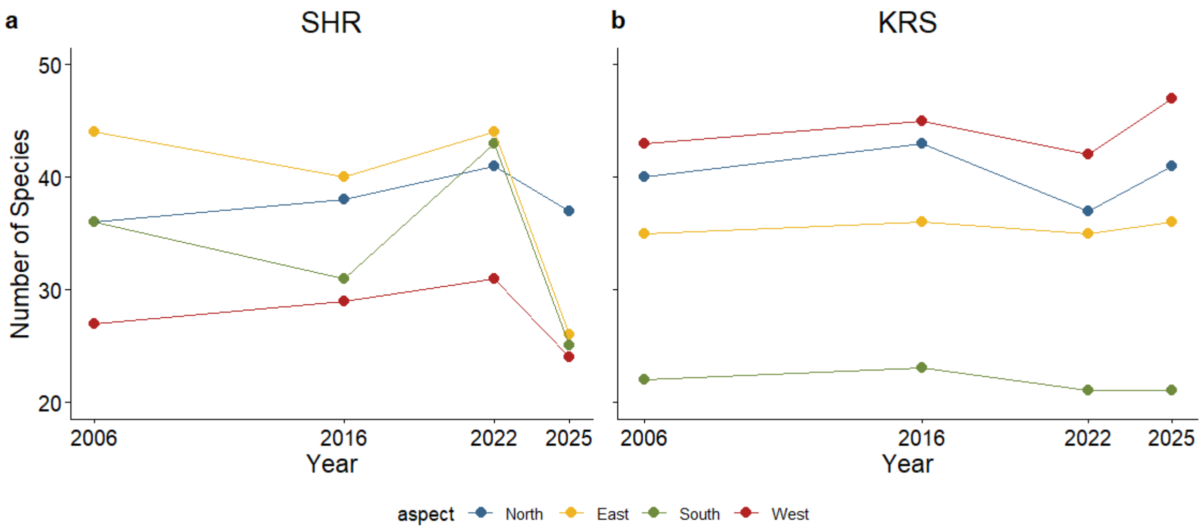

Figure 8. Total number of species present at each aspect for (a) SHR and (b) KRS, between 2006 and 2025.

3.6 Changes in Species Cover Over the Last 20 Years

Over the last 20 years, percent cover of the four most abundant species within the quadrats at SHR have remained stable, despite some variation between years. The cover of *Pinus contorta* and

Vaccinium membranaceum increased between 2006 and 2016, with a notable increase in 2022 followed by a decrease in 2025 (Figure 9). However, *Arctostaphylos uva-ursi* and *Empetrum nigrum* have undergone decreases in cover over the study period, with *Empetrum nigrum* contributing to 5% of the quadrat cover between 2006 and 2016 (Figure 9). In 2022, the cover reduced to 0%, where it has remained (Figure 9). While individual species showed short-term increases and decreases in cover, no consistent directional trends occurred. Kruskal-Wallis tests indicated no significant differences in cover among surveys for any of the four species (Table 1).

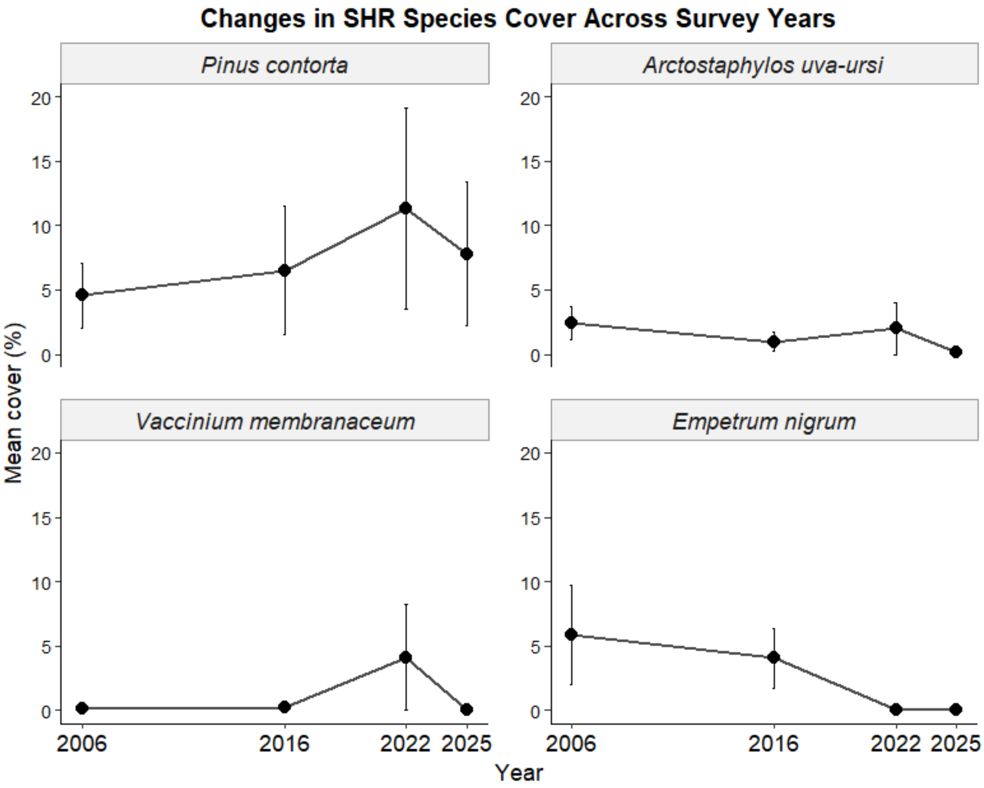

Figure 9. Mean cover and standard error of the four most abundant species within quadrats at SHR between 2006 – 2025.

Similarly, the cover of the four most abundant species at KRS have remained more or less stable. Little to no change occurred in the covers of *Vaccinium membranaceum* and *Penstemon davidsonii* between 2006 – 2025 (Figure 10). *Phyllodoce empetriformis* underwent a slight decrease in 2016 and an increase in 2022, but in 2025 the cover decreased to 0% (Figure 10). Similarly, *Cassiope mertensiana* has undergone fluctuations between surveys. Between 2006 – 2016, *Cassiope mertensiana* underwent a slight increase, then greatly decreased in 2022, before increasing again in 2025 (Figure 10). While individual species showed short-term increases and decreases in cover, no consistent directional trends occurred. Kruskal-Wallis tests indicated no significant differences in cover among surveys for any of the four species (Table 1).

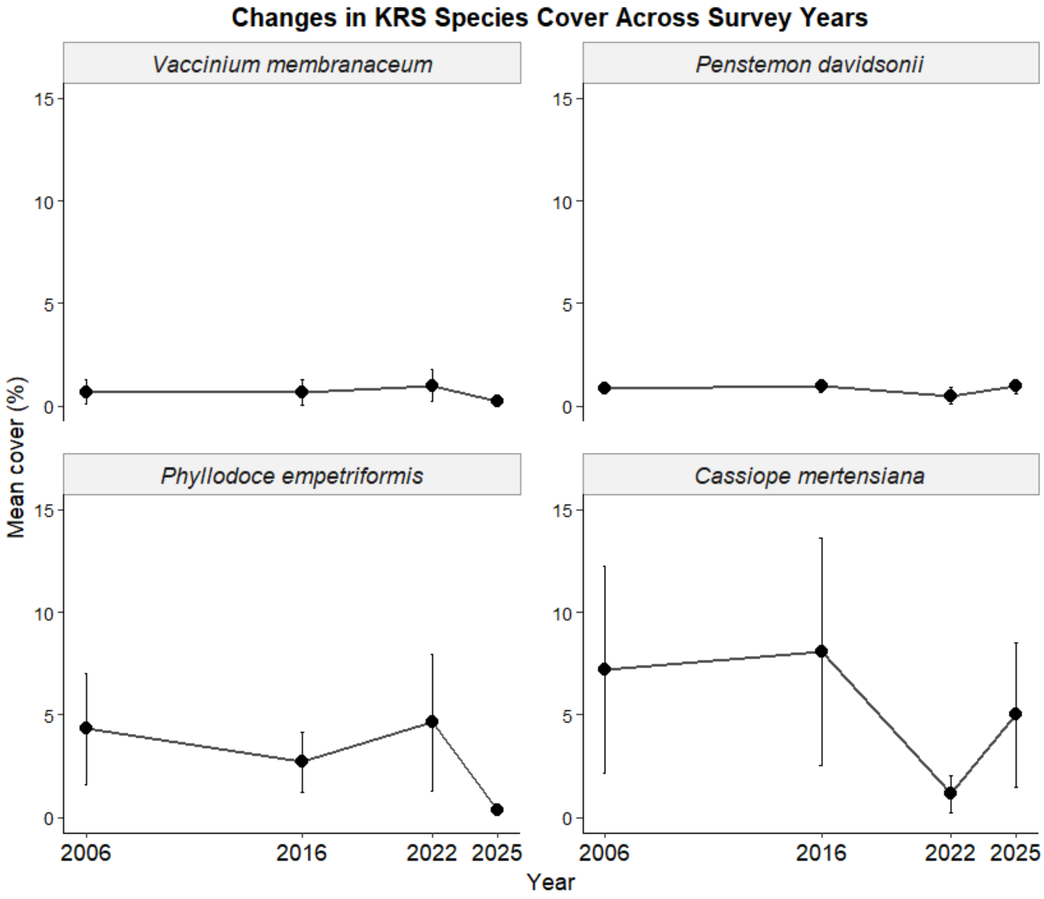

Figure 10. Mean and standard error of cover of the four most abundant species within quadrats at KRS between 2006 – 2025.

Table 1. Results of Kruskal-Wallis tests on changes in species cover at SHR and KRS between 2006 and 2025.

SHR				**KRS**			
Species	**df**	**χ^2**	***P***	**Species**	**df**	**χ^2**	***P***
Empetrum nigrum	3	4.492	0.213	*Vaccinium membranaceum*	3	0.016	0.999
Vaccinium membranaceum	3	0.006	0.999	*Penstemon davidsonii*	3	5.104	0.164
Pinus contorta	3	1.913	0.591	*Phyllodoce empetriformis*	3	0.200	0.978
Arctostaphylos uva-ursi	3	2.464	0.482	*Cassiope mertensiana*	3	0.036	0.998

Discussion

4.1 Plant Community Composition in the Alpine-Treeline Ecotone at Mount Arrowsmith

The plant community within the ATE at Mt. Arrowsmith transitions from the mountain hemlock forests at lower elevations into the alpine tundra at higher elevations. Across the study sites, trees occur primarily in krummholz form, with larger upright individuals occurring outside of the site in areas where soil is deeper and vegetation cover is greater. Of the tree species currently present in ATE, *Pinus contorta* is the most common. As for shrub species, nine species are currently present with the dominant species being *Arctostaphylos uva-ursi* and *Juniperis communis*. The site is composed largely of herbaceous plants spread across rocky substrate with approximately 64 plant species. Of those species, *Penstemon davidsonii* and *Phlox diffusa* are the most common. The vascular plants are adapted to exposed alpine conditions, including wind, shallow soils, and xeric stress. Surface cover is dominated by bedrock and scree.

The plant communities at Mt. Arrowsmith resemble the *Rhizocarpon geographicum* order described by Brett et al. (2001) in their study of high elevation plant communities in coastal British Columbia. This order is characterized by high bryophyte and lichen cover and vegetation rooted in < 10 cm of organic material accumulated between rocks. Brett et al. (2001) observed these communities in the southern British Columbia Coast Mountains, with sites primarily on northern Vancouver Island and in the Garibaldi Park region.

Of the four associations within the *Rhizocarpon geographicum* order described by Brett et al. (2001), two were present at Mt. Arrowsmith: *Penstemon davidsonii – Juniperus communis* on xeric microsites and *Phyllodoce empetriformis – Abies lasiocarpa* on deeper, more developed soils. Within the ecotone, *Arctostaphylos uva-ursi* and *Penstemon davidsonii* were dominant, consistent with the *Penstemon davidsonii – Juniperus communis* association that is typical of steep, very xeric, exposed sites where shrubs remain under 10 cm tall (Brett et al., 2001). In contrast, microsites supporting *Phyllodoce empetriformis – Abies lasiocarpa* communities were characterized by more developed soils and cooler microclimates, which increase moisture retention and allow for krummholz forms of *Abies lasiocarpa*, *Chamaecyparis nootkatensis*, and *Tsuga mertensiana* (Brett et al., 2001). The occurrence of dominant *Phlox diffusa* suggests a potential third order characterized by cushion and mat-forming forbs on shallow but developed soils (Brett et al., 2001).

4.2 Influence of Aspect on Plant Community Composition at Mt. Arrowsmith

No notable differences in plant community composition across aspects of the ATE at Mt. Arrowsmith were detected. At both SHR and KRS, species richness and surface cover did not show any similar trends regarding aspect. In the Mountain Hemlock zone, aspect influences plant community structures primarily through its control of snowpack. North-facing slopes retain deeper snow and sustain higher soil moisture, resulting in high-plant cover communities such as mountain-heather meadows and snowbed communities, supporting communities with species *Phyllodoce empetriformis*, *Cassiope mertensiana*, and *Sibbaldia procumbens* (Douglas & Bliss, 1977) Southern-facing aspects experience earlier snowmelt and greater moisture losses through the growing season, favouring drought-tolerant shrub and graminoid communities, with less continuous vegetation cover than north aspects (Douglas & Bliss, 1977). Similarly, the *Rhizocarpon geographicum* order typically exhibits greater lichen cover on south-facing aspects and greater moss cover on north-facing aspects due to different moisture stresses (Brett et al., 2001). With this in mind, one would expect greater plant cover on the northern aspects and higher rock cover on the southern aspects; however, no trends were observed between all the summit area sections. The lack of community composition differences across the aspects is likely a result of plant communities forming along local environmental gradients and the inability of the GLORIA protocol to separate them at the Mt. Arrowsmith sites (Douglas & Bliss, 1977). The protocol is conducted on a summit, where differences between aspects are relatively small. Moreover, the boundaries between summit area sections are adjacent, so the plant community characteristics of one aspect may transition into another, making it difficult to quantify potential differences. No changes related to aspect were found when comparing surface cover and species richness changes over the last 20 years, which contrasts with previous studies reporting increased treeline advancement on north facing aspects (Jackson et al., 2009; Trant et al., 2016). This may further be a result of sampling technique with other studies comparing aspects on much larger scales e.g., entire mountain sides.

4.3 Environmental Influences on Plant Community Composition

Snow cover is one of the most influential environmental factors driving plant community composition at the landscape level (Walker et al., 1993). Within the ATE at Mt. Arrowsmith, microtopography drives snow cover distribution at a finer scale, resulting in a mosaic of plant communities in a relatively small area. Across the sites, there are differences in slope, with the 10-meter section often being steeper than the 5-meter section, within these sites, ridges and depression also form in the rocks. Ridges on landforms cause wind scours and shallower snow depths, resulting in earlier snowmelt (Evans et al., 1989). Conversely, depressions within the ATE result in greater snow accumulation, which in turn causes later snowmelt and sustained moisture throughout the growing season (Evans et al., 1989). As a result, plants experience different growing season lengths and moisture regimes within the ATE. Areas with shallow snow depth and earlier snow melts result in a longer growing season and often support stress-tolerant plants. Within the Vancouver Island subalpine, the presence of a *Phlox* – moss community (similar to Brett et al.'s (2001) *Penstemon davidsonii – Juniperus communis* association) indicates shallow, undeveloped soils and xeric conditions, often associated with an early snow melt and well-drained soil (Milko & Bell, 1985). Conversely, the presence of plant communities similar to *Vaccinium - Carex* (similar to the *Phyllodoce empetriformis – Abies lasiocarpa* association) suggest areas with later snow melt and soils with more pronounced humus layers (Milko & Bell, 1985). The date of snowmelt directly influences the length of the growing season and creates moisture differences among communities. Within vegetation patches with woody plants, snow accumulates and insulates the soil, and moisture is retained later into the summer, resulting in reduced drought stress (Milko & Bell, 1985). Therefore, the presence of multiple plant communities within a small geographic range can be attributed to the complex microtopography of the Mt. Arrowsmith treeline and the microclimates it creates.

Furthermore, alpine plant communities are influenced by the stability of the soil. Surface cover at Mt. Arrowsmith is largely rock and scree, the amount of each varying throughout the sites. The 5-meter sections of the summit area sections tended to be flatter and have less scree whereas the 10-meter sections were steeper and often had more scree and loose substrate. The difference in soil and stability of substrates can play a role in plant community dynamics, with plant establishment becoming more difficult with increased soil slippage (Belsky & Moral, 1982). As a result, there can also be a differentiation of species despite being relatively close to each other, as flatter areas support the growth of plants that require stable substrates such as *Luzula spicata*, whereas *Allium crenalatum* can grow well within disturbed sites such as the 10-meter section of KRS (Belsky & Moral, 1982).

4.4 Surface Cover Changes in the ATE Over the Last 20 Years

No significant surface cover changes in the ATE were detected over the last 20 years, despite the global trends of woody expansion and infilling in arctic and alpine regions (Myers-Smith et al., 2011). Vascular plant cover did not increase within the site over the last 20 years. This contrasts with previous studies reporting recruitment of tree and shrubs into higher elevations of southern Vancouver Island (Laroque et al., 2000; Jackson et al., 2016). On Vancouver Island, episodic recruitment of mountain hemlock, amabilis fir and subalpine fir throughout the 20th century has led to gradual infilling of the treeline (Laroque et al., 2000). Similarly, it is expected that alpine tundra in the BC Coast Mountains will decline with subalpine meadows being replaced by encroaching species such as subalpine fir, yellow cedar, and shrubs such as mountain-heather and crowberry, with the most changes occurring in high elevation sites (Jackson et al., 2016). Despite these studies, no significant increases in shrub or tree cover were detected at Mt. Arrowsmith.

The lack of directional change within the quadrats suggests the plant community is stable and not undergoing substantial changes. However, the present study spanned only the last 20 years, which may be insufficient time to identify similar changes. Other treeline studies vary in the lengths of their study period; however, many compare the same community over a minimum 40-year period (Laroque et al., 2000; Harsch et al., 2009; Jackson et al., 2016; Trant et al., 2020). Moreover, when comparing the photographs from the 2006 survey to the 2025 survey, there is a loss of shrubs and tree individuals within a few quadrats. These differences in cover were not statistically significant; however, they could be an indicator of potential change for the community towards more drought conditions.

4.5 Compositional Changes in the ATE Over the Last 20 Years

Species richness remained more or less stable at Mt. Arrowsmith over the last 20 years, which differs from studies across the Northern Hemisphere documenting increases in species richness in alpine peaks and alpine-tundra plant communities as a response to climate warming (Danby et al., 2011; Pauli et al., 2012; Steinbauer et al., 2018). The lack of changes in species richness at Mt. Arrowsmith despite increasing annual temperatures could be explained by ecological lags that occur during colonization and extinction (Alexander et al., 2017). Colonization lag may occur through the dispersal and establishment process of the lower elevation species; these lags may be strong in alpine environments because of the extreme abiotic conditions (Alexander et al., 2017). While the temperature may allow for establishment of lower elevation species, they may be delayed by the complex topography making seed dispersal difficult as well as competition within the new community (Alexander et al. 2017). Extinction lags occur within the alpine as cold-adapted species persist longer than expected despite warming conditions, resulting in extinction lags and delaying community responses (Bektas et al., 2024). Together, these processes result in a lag of species response behind the changing climatic conditions of their ranges. The ATE plant community at Mt. Arrowsmith could be shifting directionally towards an increase or decrease in species richness; however, it is not currently evident, likely due to either an ecological lag in colonization of low-elevation plant species or an extinction lag of high-elevation plant species.

Variable responses in species richness to warming climates have been identified in the southern Mediterranean mountain regions, as a result of precipitation and snowpack changes (Pauli et al., 2012; Lamprecht et al. 2021). Previous GLORIA studies report precipitation to influence species richness in alpine plant communities, with species richness increasing in cooler wetter summits of northern Europe and decreasing in the Mediterranean region, where conditions were hotter and drier (Pauli et al., 2012). Within the Mediterranean region, when precipitation and snow cover increased, the studies reported increases in species richness, suggesting moisture plays an important role in creating ideal conditions for lower elevation species to colonize higher elevations (Lamprecht et al., 2021). Paulie et al. (2012) concluded that species richness is most likely to decline in mountain regions with predicted increases in temperature and decreases in precipitation. Given the interaction between precipitation and temperature in determining directional shifts in plant communities, the stable conditions at Mt. Arrowsmith could suggest that soil moisture changes have yet to exceed the tolerance of current species, despite increasing temperatures. Future studies could assess precipitation and snow cover at Mt. Arrowsmith to gauge directional change at the site.

While species richness has remained stable over the last 20 years, the plant community at Mt. Arrowsmith underwent turnover with plant species being gained and lost at each survey. Similarly, a GLORIA study conducted by Goff et al. (2025) at sites in the mountain regions of California and Nevada reported no significant changes in species richness over a 19-year period, despite species being gained and lost. They concluded that species richness may appear stable, but this obscures the amount of turnover occurring between surveys. Moreover, the study highlights the bias towards detecting gained species over lost species, as a gained species only requires one individual to be observed, whereas species loss requires all individuals to disappear (Goff et al., 2025). This could suggest that the stable species richness observed in this study and in Goff et al. (2025) is a result of a delay in complete species loss.

Over the last 20 years, the sites lost the following mesic species: *Carex pyrencaica*, *Vaccinium parvifolium*, *Vaccinium uliginosum*, and *Streptopus amplexifolius* (Milko & Bell, 1985). The loss of these species from the ATE plant community could suggest that drying is occurring at Mt. Arrowsmith (Milko & Bell, 1985). In 2025, two species not previously recorded at the site were *Chamaenerion angustifolium* and *Hypochaeris radicata*, both of which are notable as they often indicate a disturbed ecosystem. *Chamaenerion angustifolium* is an early-succession species, and one of the first species to establish in British Columbia montane forests after disturbance such as fire, flooding, or logging (Beese et al., 2022). On Vancouver Island, *Chamaenerion angustifolium* greatly increases as the dominant understory species after logging (Beese et al., 2022). Similarly, *Hypochaeris radicata* establishes easily on disturbed sites. This non-native species has naturalized across Canada, occurring on both the east and west coasts, and is particularly common on Vancouver Island (Aarssen, 1980). In North America, *H. radicata* is commonly found in lawns, pastures, along roadside, and in forest clearings (Aarssen, 1980). The occurrence of these two species at Mt. Arrowsmith is likely an indication of disturbance. Mount Arrowsmith Regional Park is bordered by privately-owned land with active logging including a cut block as close as 500 m away from the study sites that was logged around 2016 (based on Google Earth imagery). The recent introduction of an early successional species and an invasive species could suggest that the ATE plant community at Mt. Arrowsmith may undergo increases in early colonizing species in the years to come, as the lower elevation plant communities undergo successional stages. Moreover, Mt. Arrowsmith has popular hiking trails on the west and north aspects of the mountain that may further facilitate seed dispersal across the area and into the sub-alpine and alpine plant communities.

Conclusion

The plant community in the ATE at Mt. Arrowsmith closely resembles Brett et al.'s (2001) *Rhizocarpon geographicum* order with two vegetation associations being present: *Penstemon davidsonii – Juniperus communis* on xeric microsites and *Phyllodoce empetriformis – Abies lasiocarpa* on deeper, more developed soils. Trees within the study sites are in krummholz form and the site is largely rock, with low vascular plant cover. There are approximately 64 species of plants present. The plant community is comprised predominantly of *Pinus contorta* with dominant shrubs, *Arctostaphylos uva-ursi* and *Juniperus communis*. Herbaceous plants include *Penstemon davidsonii*, *Phlox diffusa*, and *Danthonia intermedia*.

The ATE plant community composition at Mt. Arrowsmith has undergone little change over the last 20 years, with species richness and surface cover remaining stable and only slight changes occurring in species presence. Ecological lags in responses to ongoing climate change might be making directional shifts in species richness undetectable. The ATE plant community may also require greater changes in climate, such as a substantial decrease in precipitation, for a more notable response to occur. Over the course of the study period, there was an introduction of lower elevation early successional species, suggesting the community may be influenced by the disturbed lower elevation plant communities. Overall, these results suggest that ATE plant communities in the southern Vancouver Island mountains are stable and are not exhibiting large responses to climate change.

This study provides a strong baseline for what the ATE plant community composition at Mt. Arrowsmith is in 2025 and provides insight into southern Vancouver Island Mountain plant community dynamics, suggesting that the community is currently stable. While this study succeeded in describing ATE plant communities at Mt. Arrowsmith, there are limitations to this study. The first limitation is the length of the study as alpine ecosystems are composed of long-lived species that take time to undergo shifts. Monitoring should be continued in order to detect longer-term responses. Furthermore, the study design also may have limited the results as the influence of aspect may not have been fully captured within the study summits. The aspects were close to each other resulting in little variation between them. Moreover, this study aimed to detect changes in the cover of dominant species; however, the positions of the permanent quadrats lack much plant cover, with an average of only 3 species per quadrat, underrepresenting the composition of the plant community in the ATE. Further studies should use more sites to gain a better idea of the community.

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Appendix

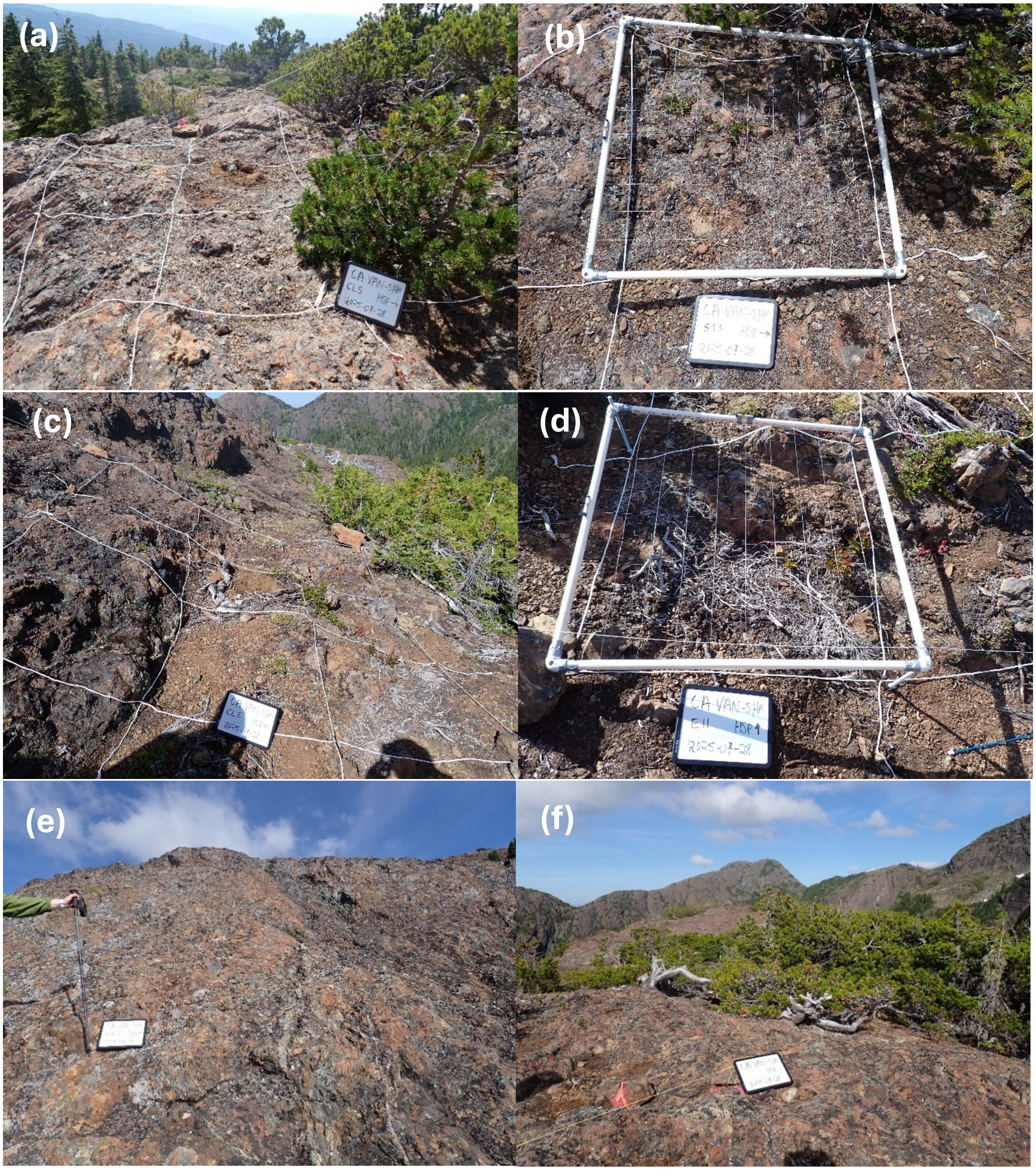

Figure A1. Photographs of the SHR site at Mt. Arrowsmith. (a) The 3 x 3-meter quadrats on the south aspect of SHR, with lodgepole pine. (b) The S13 quadrat within the 3 x 3-meter quadrat on the south aspect of SHR. (c) The 3 x 3-meter quadrats on the east aspect of SHR. (d) The E11 quadrat within the 3 x 3-meter quadrat on the east aspect of SHR with a dead shrub. (e) Intersection of the ropes of the summit area section, corner is 10 m contour line NW, facing towards the highest summit point. (f) Highest summit point at SHR. Present in the photograph is lodgepole pine.

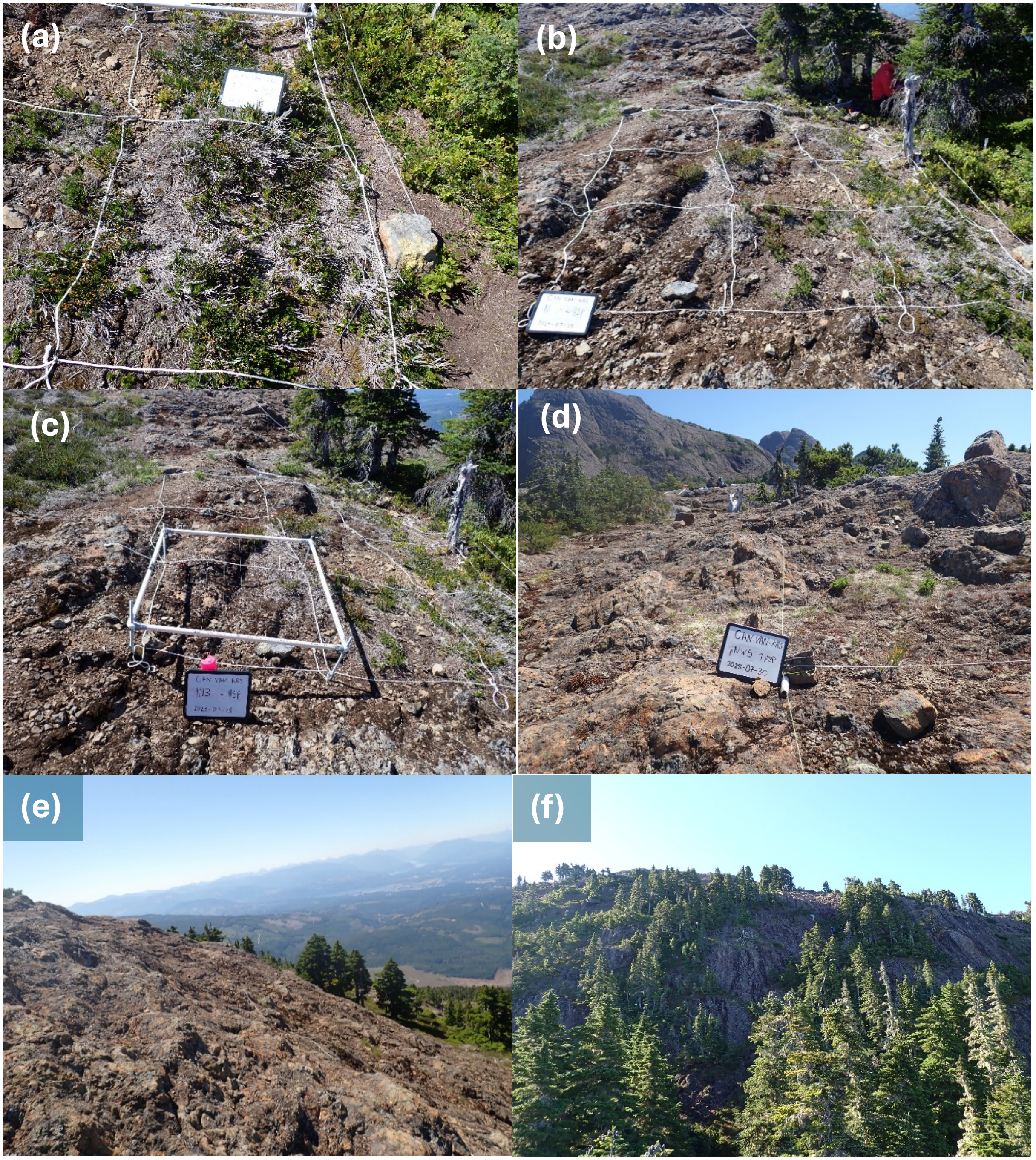

Figure A2. Photographs of the KRS site at Mt. Arrowsmith. (a) The N11 quadrat within the 3 x 3-meter quadrat on the north aspect of KRS. (b) The 3 x 3-meter quadrats on the north aspect of KRS, with *Phyllodoce empetriformis* and *Cassiope mertensiana*. (c) The N13 quadrat within the 3 x 3-meter quadrat on the north aspect of KRS.(e) Intersection of the ropes of the summit area section, corner is 5 m contour line NW, facing towards the highest summit point. (d) Image of the northwest slope of KRS, within the 10-meter summit area section. (f) Looking from SHR to KRS summit, featured is the north aspect.

Table A1. Vascular plant species presence/absence at the SHR and KRS sites at Mt. Arrowsmith, over the survey period (2006-2025). Present species are represented by a x symbol.

	SHR				**KRS**			
Species	**2006**	**2016**	**2022**	**2025**	**2006**	**2016**	**2022**	**2025**
Abies lasiocarpa (Hook.) Nutt.	x	x	x	x	x	x	x	x
Achillea millefolium L.	x	x	x	x	x	x	x	x
Agrostis mertensii Trin.		x						x
Agrostis scabra Willd.	x	x	x	x	x	x	x	x
Allium crenulatum Wieg.			x		x	x	x	x
Alnus alnobetula subsp. *crispa* (Aiton) Raus			x					
Antennaria alpina (L.) Gaertn.				x		x	x	
Antennaria microphylla Rydb.				x	x			x
Antennaria racemosa Hook.	x						x	
Antennaria rosea Greene			x			x		
Antennaria umbrinella Rydb.	x	x	x		x	x	x	
Arctostaphylos nevadensis Gray						x		
Arctostaphylos uva-ursi (L.) Spreng.	x	x	x	x	x	x	x	x
Arnica gracilis Rydb.			x			x		
Arnica latifolia Bong.	x				x			x
Campanula rotundifolia agg.[1]		x	x			x		x
Campanula rotundifolia L.	x	x		x	x	x	x	x
Carex phaeocephala Piper	x	x	x	x	x	x	x	x
Carex pyrenaica Wahlenb.	x				x			
Carex rossii Boott	x	x	x	x				x
Carex scirpoidea Michx.				x				x
Carex spectabilis Dewey	x	x	x	x	x	x	x	x
Cassiope mertensiana (Bong.) G.Don	x	x	x	x	x	x	x	x
Chamaecyparis nootkatensis (D. Don) Sudworth	x	x	x	x	x	x	x	x
Chamaenerion angustifolium subsp. *circumvagum* (Mosquin) Moldenke				x				x
Cryptogramma acrostichoides R. Br.	x	x	x	x	x	x	x	x
Danthonia intermedia Vasey	x	x	x	x	x	x	x	x
Elymus elymoides (Raf.) Swezey						x	x	x
Empetrum nigrum L.	x	x	x	x	x	x	x	x
Erigeron compositus Pursh	x	x	x					
Festuca brachyphylla Schult. & Schult.f.	x	x	x	x	x	x	x	x
Goodyera oblongifolia Raf.	x	x	x	x				
Heuchera glabra Willd. ex Roemer & J.A. Schultes		x		x			x	
Hieracium albiflorum Hook.	x		x	x	x	x	x	x
Hieracium gracile Hook.	x	x						

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[1] *Campanula rotundifolia* L. refers to the single defined taxon, whereas *Campanula rotundifolia* agg. denotes the broader species aggregate that includes this species and closely related taxa that were not identified to a finer taxonomic level.

Species	SHR				KRS			
	2006	2016	2022	2025	2006	2016	2022	2025
Hypochaeris radicata L.								x
Juniperus communis L.	x	x	x	x	x	x	x	x
Lewisia columbiana (T.J. Howell ex Gray) B.L. Robins. var. *columbiana*					x	x	x	x
Luetkea pectinata (Pursh) Kuntze	x	x	x	x	x	x	x	x
Luzula parviflora (Ehrh.) Desv.	x	x	x	x	x	x		
Luzula spicata (L.) DC.	x	x	x	x	x	x	x	x
Micranthes ferruginea (Graham) Brouillet & Gornall	x	x	x	x	x	x	x	x
Micranthes rufidula Small	x	x					x	
Minuartia sp.	x	x			x			x
Montia parvifolia (Moc. ex DC.) Greene subsp. *flagellaris* (Bong.) Ferris	x	x	x	x	x	x	x	x
Orthilia secunda (L.) House	x	x	x	x	x	x	x	x
Pedicularis racemosa Dougl. ex Benth.	x	x	x	x	x	x		
Penstemon davidsonii Greene var. *menziesii* (Keck) Cronq.	x	x	x	x	x	x	x	x
Penstemon eriantherus Nutt. ex Pursh							x	
Phlox diffusa Benth.	x	x	x	x	x	x	x	x
Phyllodoce empetriformis (Sw.) D. Don	x	x	x	x	x	x	x	x
Phyllodoce glanduliflora (Hook.) Coville					x		x	x
Pinus contorta Dougl. ex Loud. var. *contorta*	x	x	x	x	x	x	x	x
Poa secunda J. Presl	x	x						
Poa stenantha Trin.		x	x	x	x	x	x	x
Polygonum minimum S. Wats.	x	x	x	x	x	x	x	x
Polypodium amorphum Suksdorf					x	x	x	x
Potentilla villosa Pallas ex Pursh	x	x	x	x	x	x	x	x
Ribes lacustre (Pers.) Poir.			x					
Rhododendron albiflorum Hook.						x	x	x
Rubus pedatus J.E. Smith	x		x		x	x	x	x
Sabulina rubella (Wahlenb.) Dillenb. & Kadereit					x	x	x	x
Saxifraga austromontana Wiegand	x	x	x	x	x	x	x	x
Sedum divergens S. Wats.	x	x	x	x	x	x	x	x
Selaginella densa Rydb. var. *scopulorum* (Maxon) R. Tryon	x	x	x	x	x	x	x	x
Selaginella wallacei Hieron.	x	x	x	x	x	x	x	x
Sibbaldia procumbens L.	x	x	x	x	x	x	x	x
Silene douglasii Hook.			x					
Solidago multiradiata Ait. var. *scopulorum* Gray	x	x	x	x	x	x	x	x
Sorbus sitchensis M. Roemer	x	x	x	x	x	x	x	x
Streptopus amplexifolius (L.) DC.					x	x	x	
Trisetum spicatum (L.) K.Richt. subsp. *australiense* Hulten	x	x	x	x	x	x	x	x
Tsuga heterophylla (Raf.) Sarg.	x	x						

	SHR				KRS			
Species	**2006**	**2016**	**2022**	**2025**	**2006**	**2016**	**2022**	**2025**
Tsuga mertensiana (Bong.) Carr.	x	x	x	x	x	x	x	x
Vaccinium caespitosum Michx.	x	x	x	x	x	x	x	x
Vaccinium deliciosum Piper	x	x	x	x	x	x	x	x
Vaccinium membranaceum Dougl. ex Torr.	x	x	x	x	x	x	x	x
Vaccinium parvifolium Smith	x							
Vaccinium uliginosum L.	x							
Vahlodea atropurpurea (Wahlenb.) Fr. ex Hartm.					x	x	x	x
Viola orbiculata Geyer	x		x	x	x	x	x	x