

## **Establishing GLORIA Long-Term Alpine Monitoring in Southwestern British Columbia, Canada**

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## Establishing GLORIA Long-term Alpine Monitoring in Southwestern British Columbia, Canada

### Abstract

We established long-term alpine monitoring in southwestern British Columbia (BC) by following the protocol outlined in the Global Observation Research Initiative in Alpine environments (GLORIA). Monitoring sites were located on the Mount Arrowsmith Massif on Vancouver Island (Arrowsmith Biosphere Reserve) and in close proximity to Whistler Mountain (Garibaldi Provincial Park) in the summer of 2006. The aim of the GLORIA project is to develop a long-term, world-wide database of standardized observations of alpine biodiversity, vegetation patterns and mountain-top temperature. In both the Arrowsmith and Whistler target regions, the most dominant species in terms of cover were woody plants and included mountain hemlock (*Tsuga mertensiana*), white mountain-heather (*Cassiope mertensiana*) and subalpine fir (*Abies lasiocarpa*) in order of cover percentage. Thirty-nine vascular plant species were common to both target regions, 36 species were inventoried only in the Arrowsmith region and 28 species were only recorded in the Whistler region. No conclusive trends in species numbers were evident from baseline data. With plans to monitor and resurvey at five-year intervals, the sites established in this project document current plant species composition, and allow for a long-term assessment of changes in biodiversity attributable primarily to change in climate.

### Introduction

The environmental condition of our planet is rapidly being altered due to a combination of land-use changes, diminished air and water quality, and global climate change. The pace of these changes is raising concern about the ability of plant and animal life to adapt (Parmesan and Yohe 2003, Pearson and Dawson 2003, Thuiller et al. 2005). To help develop management strategies for maintaining global biodiversity and healthy ecosystems, researchers have begun to initiate ecological risk assessments that are designed to evaluate the consequence of expected impacts.

There is broad agreement that theoretical work on the stability of ecosystems over time has outpaced experimental work (Loreau et al. 2001, Folke et al. 2004, Midgley and Thuiller 2005). This recognition confirms the need for field observations to allow evaluation of hypotheses on the predicted ecological effects of climate change and other disturbances. High mountain

ecosystems are being predicted as one of the first ecosystems to be significantly altered by climate change. Montane plant biodiversity is expected to decline as a result of prolonged climate warming, with cold-adapted species likely being driven out of their distribution range by warm-adapted species (Grabherr et al. 1994, Theurillat and Guisan 2001 in Pauli et al. 2007).

The lack of standardized long-term ecological observations within high mountain biomes provided the impetus for developing a worldwide observation network designed to monitor the effect of changing climates on the vegetation of alpine peaks. Known as, "The Global Observation Research Initiative in Alpine Environments" (GLORIA), GLORIA consists of a global network of monitoring sites (known as target regions) coordinated by the University of Vienna Institute of Ecology and Conservation Biology. GLORIA focuses on monitoring changes in species richness (number of species), species composition (loss or gain of individual species), patterns of vegetation (changes in % cover), soil temperatures of microhabitats, and snow cover (indirectly through temperature measurements).

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A field manual was prepared by Pauli et al. (2004) with simple and cost effective protocols to encourage numerous researchers to establish and regularly monitor GLORIA target regions. Beyond monitoring the impact of changing climates on alpine peaks, GLORIA also aims to assess climate change-induced impacts on biodiversity and habitats and thereby contribute to international efforts mitigating biodiversity and habitat losses. Observations from target regions worldwide are being compiled by the GLORIA coordination office and are available for analyses by the scientific community. There are currently 28 countries participating in the program and 61 active GLORIA target regions ([www.gloria.ac.at](http://www.gloria.ac.at)), including the Canadian (British Columbia [BC]) sites described herein.

The aim of our project was to use GLORIA protocols to establish two long-term alpine vegetation target regions in southwestern BC on both sides (leeward and windward) of the Georgia Basin. With plans to monitor and resurvey our newly established GLORIA sites at five year intervals, the baseline data collected during the establishment of monitoring sites in target regions provides an opportunity for assessment of any changes in biodiversity that may be related to changes in climate.

## Methods

### Study Areas

Two target regions, each comprised of four summits, were established in the Arrowsmith and Whistler areas within the Georgia Basin region of southwestern BC (Figure 1). Weather systems in this region typically come from a westerly direction off the Pacific Ocean. The Basin is bordered on the west by the Vancouver Island mountain range and the Olympic mountain range, and on the east by the Coast and Cascade mountain ranges. The summits studied within the target regions occur in the Coastal Mountain-heather Alpine Zone (MacKenzie 2006) where the winter snowpack is deep and summers are moderated by maritime influences. The snowpacks are variable in extent and duration, being affected by both the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) (Burkett et al. 2005). The treeline can be as much as 900 m lower than at comparable latitudes in the dryer BC interior due

to heavy and prolonged snow cover (MacKenzie 2006). GLORIA focuses on the alpine life zone (or high mountain area), which is defined as the area above the low-temperature determined treeline and includes the treeline ecotone, the alpine, and nival elevation zones. The nival zone is a region with perennial snow cover and represents the upper limit of vascular plant life. The alpine life zone has been investigated throughout the Pacific Northwest by a number of workers (Ogilvie and Ceska 1984, Viereck et al. 1992, Klinka et al. 1997, Brett et al. 2001).

The Arrowsmith target region is located on Vancouver Island within the Mount Arrowsmith Biosphere Reserve east of Port Alberni (Figure 2). At 1,819 m asl (a local relief of 1,430 m), Mount Arrowsmith is the highest mountain on southern Vancouver Island. Summits in the Arrowsmith target region are composed entirely of Triassic Karmutsen formation basalt and pillow lava (Yorath 2005). Glaciers played a major role in shaping this target region during past ice ages, when only the tops of the highest peaks remained ice-free, explaining the sharp rugged peaks and deeply notched couloirs and cirques on the north and northwestern sides. All drainage from the region flows east to the Strait of Georgia.

The Whistler target region is situated within the Pacific Range of the southern BC Coast Mountains, just inside Garibaldi Provincial Park (Figure 3). This is a high mountain region with a local maximum elevation of 2,892 m asl, and a local relief of 2,252 m. The Whistler target region is 3 km east of the Resort Municipality of Whistler. Bedrock of summits studied here consists of 150 million year old granitic (granodiorite) rock (Souther 2005). Drainage from the area flows to the Green River and eventually into the Fraser River.

The Pacific Ranges contain the largest temperate-latitude icecaps in the world and there are numerous glaciers near the study area. Reconstructed glacier fluctuations in Garibaldi Provincial Park within the last 10,000 years show that the Little Ice Age began around 1000 AD and that glacial activity has not been uniform (Koch 2006). Between the 1930s and 1960s glaciers receded at average annual rates of about 30 m. Since then, recession has been 5-10 m per year. These records were found to be "broadly synchronous" with other glacial records around the world and suggest "a global forcing mechanism" (Koch 2006).



Figure 1. Maps showing GLORIA Arrowsmith and Whistler target regions, situated in the Georgia Basin/Puget Sound region of southwestern BC and northwest Washington State.

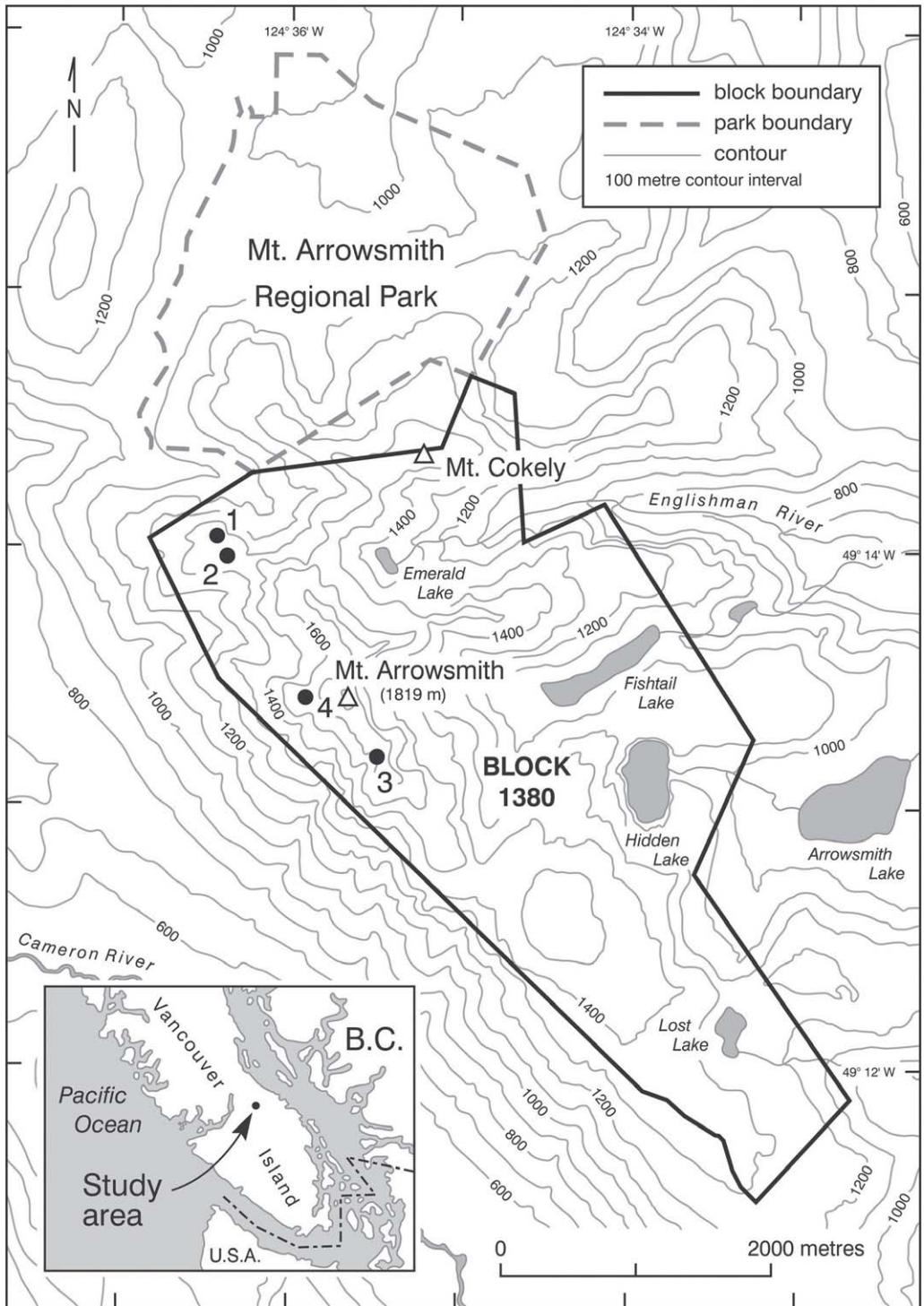


Figure 2. Maps indicating location of Arrowsmith target region and summits. 1 = Shari's Summit, 2 = Kristina's Crag, 3 = Amber's Alpine, and 4 = Peter's Peak.

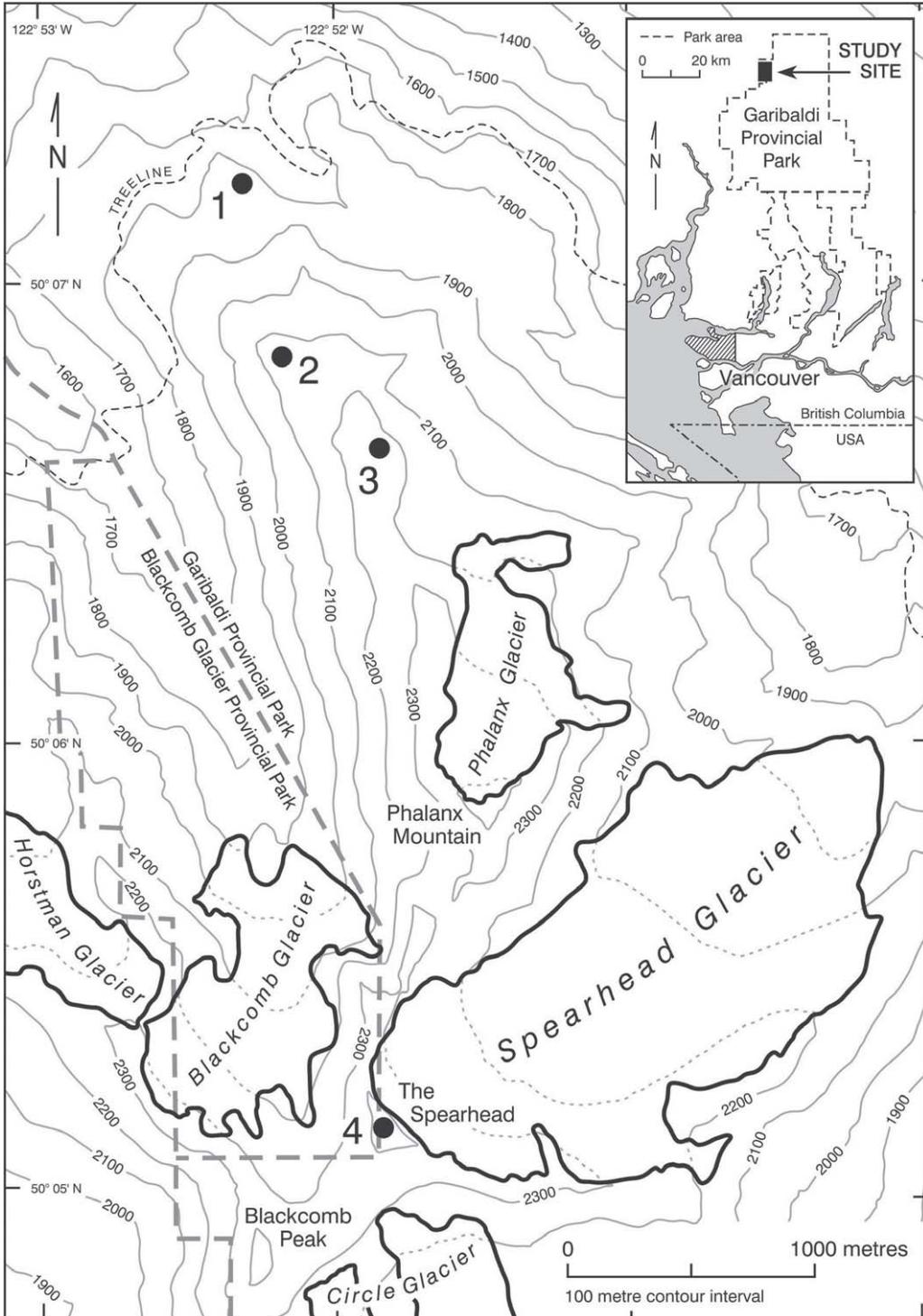


Figure 3. Maps indicating location of Whistler target region and summits. 1 = Lowest Summit, 2 = Medium Summit, 3 = High Summit, and 4 = The Spearhead.

## GLORIA Sampling

Four summits representing an altitudinal gradient of vegetation patterns characteristic for their respective mountain regions were selected to constitute each GLORIA target region (Figure 4).

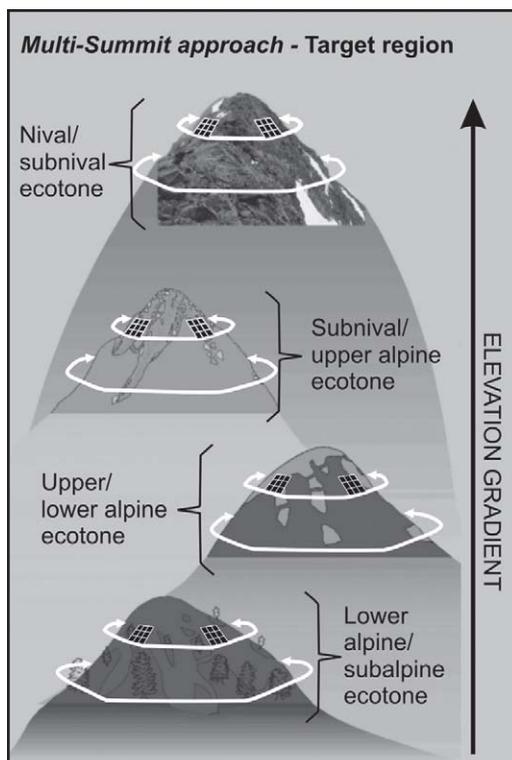


Figure 4. Four summits of different altitude represent a target region. White lines indicate lower boundaries of the 5 and 10 m vertical summit areas. From Pauli et al. (2004:9).

The study areas of each summit encompassed the top 10 vertical metres, and these areas satisfied the six criteria adapted from Pauli et al. (2004) for selection of GLORIA sites (Table 1).

On each summit, four permanent 3x3 m areas were established 5 vertical metres from the summit and in each cardinal direction (Figure 5). Boundary markers were permanently marked using white paint on rock or aluminum nails secured in soil, depending on the substrate. Within each 3x3 m area, the four corner 1x1m quadrats were sampled for a total of 16 quadrats per summit. Within each 1x1 m quadrat, the uppermost cover surface types were described and a complete vascular plant species inventory and percentage cover of each of the species was compiled. In addition, frequency counts of the vascular plants within each 1x1 m quadrat were recorded. This was done by laying a frequency frame (grid) over the quadrat with 100 cells and recording presence/absence of each species.

Each summit was additionally divided into eight permanent Summit Area Sections (SAS): four sections in the upper five vertical meters and four sections in the lower, each in a cardinal direction (Figure 5). Nomenclature follows Hitchcock and Cronquist (1973), BC Ministry of Environment (2006), and the Integrated Taxonomic Information System (2006).

Within each SAS a full species inventory and cover was collected as well as the cover of surface types, area, elevation, slope and aspect. Data loggers that measure soil temperature every hour were installed in the center of each 3x3 m area, 10 cm below the surface. Photos were also taken

TABLE 1. Criteria used for GLORIA summit selection within a target region. Adapted from Pauli et al. (2004).

Criteria	Description
Volcanism	The summit (or surrounding summits) is not an active or dormant volcano.
Consistent climate	All four summits are exposed to similar climate.
Geomorphologic summit shape	The slope of each aspect of the summit needs to be relatively consistent. It cannot be so steep that it cannot be accessed without climbing equipment or so gentle that the 10 m vertical boundary lies beyond 100 m of surface distance.
Habitat situation	The geomorphology of the slope must have potential to support plant growth.
Bedrock material	The bedrock of all summits must be the same.
Land use and land use history	Impact from land use must be low to moderate with no significant changes in the last 100 years.



TABLE 2. Overview of GLORIA summits in Arrowsmith (49° 13' N, 124° 35' W) and Whistler (50° 06' N, 122° 52' W) target regions.

Code	Summit Name	Elevation (m)	Zone or ecotone represented
<u>Arrowsmith</u>			
SHR	Shari's Summit	1,450	Treeline ecotone
KRS	Kristina's Crag	1,514	Treeline ecotone
AMB	Amber's Alpine	1,745	Ecotone between treeline and lower alpine zone
PTR	Peter's Peak	1,800	Lower alpine zone
<u>Whistler</u>			
LOW	Lowest Summit	1,844	Treeline ecotone
MED	Medium Summit	2,118	Lower alpine zone
HGH	High Summit	2,262	Alpine-nival ecotone
SPH	The Spearhead	2,457	Alpine-nival ecotone

in the area. The most dominant species overall in terms of cover were shore pine (*Pinus contorta* var. *latifolia*) at 6.1%, mountain hemlock (*Tsuga mertensiana*) at 2.8%, crowberry (*Empetrum nigrum*) at 2.1%, white mountain-heather (*Cassiope mertensiana*) at 2.0% and subalpine fir (*Abies lasiocarpa* var. *lasiocarpa*) at 1.2%. The most widespread species in terms of how many SASs they occurred in were Davidson's penstemon (*Penstemon davidsonii* var. *menziesii*) at 94%, and common juniper (*Juniperus communis*), spreading phlox (*Phlox diffusa*) and spotted saxifrage (*Saxifraga bronchialis* ssp. *austromontana*) all at 91%.

In the Whistler target region, the dominant species overall in terms of cover were white mountain-heather at 6.4%, yellow mountain-heather (*Phyllodoce glanduliflora*) at 2.9%, white-bark pine (*Pinus albicaulis*) at 2.6%, subalpine fir at 2.4% and mountain hemlock at 1.8%. The most widespread species in terms of presence in SASs not already mentioned as a dominant species were all common graminoid species with wide ecological ranges: dunhead sedge (*Carex phaeocephala*) at 84%, alpine fescue (*Festuca brachyphylla*) at 72%, and spiked wood-rush (*Luzula spicata*) at 69%. The range extension noted for Brewer's sedge (*Carex engelmannii*) was an item of botanical interest.

Thirty-nine vascular plant species were common to both target regions, 36 species were inventoried only in the Arrowsmith region and 28 species were only recorded in the Whistler target region. All of the 36 species inventoried only in the Arrowsmith target region also exist in the general Whistler region (Douglas et al. 1999, BC Ministry of Environment 2006). The likely reason they did not show up on the Whistler summits is presumed

to be because of chance, as the area sampled was relatively small. Also, nine of the species unique to the Arrowsmith target region have relatively low elevation ranges, and would be more likely found at lower elevations in the Whistler target region than at those sampled.

Of the 28 species recorded only in the Whistler target region, six do not occur on Vancouver Island. These include: tree species Engelmann spruce (*Picea engelmannii*) and whitebark pine; herbaceous species small-flowered penstemon (*Penstemon procerus*); and graminoid species capitate sedge (*Carex capitata*) and Letterman's bluegrass (*Poa lettermanii*) (Douglas et al. 1999, BC Ministry of Environment 2006). It is theorized that these species could exist on Vancouver Island but have never yet made it to the island, due either in part to geography, seed dispersal limitations, or relative abundance. Other species inventoried only in Whistler are found on Vancouver Island at higher elevations (e.g., Golden Hinde in Strathcona Provincial Park) than in the Arrowsmith target region (BC Ministry of Environment 2006).

#### Number of Species

A total of 104 individual vascular plant species were inventoried during establishment of BC's eight GLORIA summits. Relatively few identification problems were encountered, especially on Vancouver Island. Our botanist, Dr. Roemer, has 40 years of field experience in BC's forests and mountains. On Mt. Arrowsmith some specimens were collected during the day and confirmed in the evening, then mostly discarded. Only four collections needed to be retained and deposited in the Royal BC Museum herbarium. From the work in the Whistler area eleven voucher specimens were

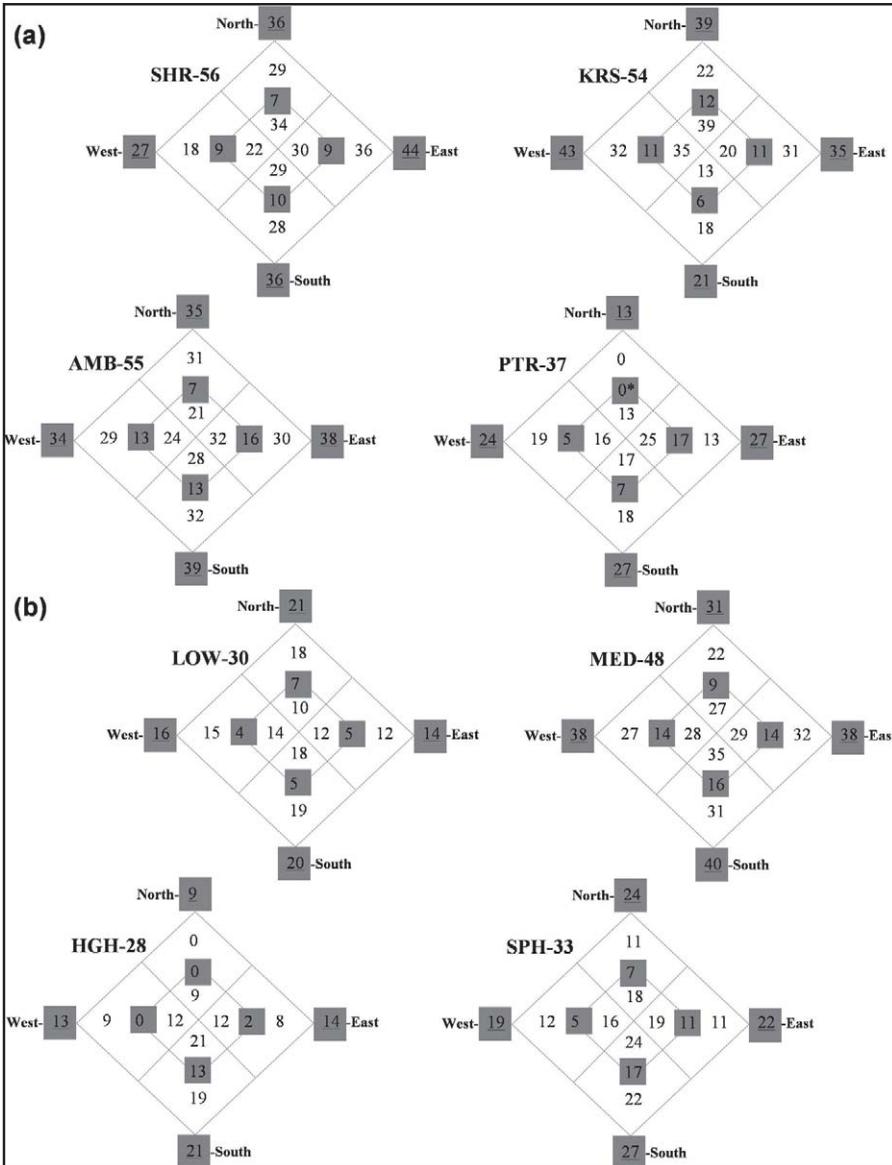


Figure 6. Summary of the vascular plant records collected in the A) Arrowsmith target region, and B) Whistler target region, labeled by summit code. Overall number of vascular plant species found on each summit is listed beside summit code. Additionally, number of species are given for the 5 m SASs (central group in diagrams), in the four 1x1 m quadrat clusters (inner grey boxes), and for the 10 m SASs (perimeter), on each of the four aspects. Underlined numbers in outer grey boxes indicate total species inventoried on each aspect. \*No 1x1 m quadrats were established due to extremely steep topography just north of the summit.

deposited in the RBCM herbarium. A summary and breakdown of the number of vascular plants inventoried within the top 10 vertical metres of each summit is shown in Figure 6.

In the Arrowsmith target region, 75 species of vascular plants were inventoried. In terms of

species numbers on each summit, they are similar for the three lower summits (56, 54 and 55 from lower to higher) and decrease to 37 species for the highest summit (PTR). The differences in species numbers can most likely be attributed to the fact that PTR was not only the highest summit, but it

also had a significant difference in summit shape (a vertical north side) compared with the other Arrowsmith summits.

In the Whistler target region, a total of 68 vascular plant species were inventoried. Species numbers were low for the HGH summit due to the fact that only this summit had perennial snow on it when visited (bottom edge of the north side), and it was almost entirely covered with scree (99%).

## Discussion

Our climate is changing in ways that researchers are only just beginning to comprehend making it impossible to predict with any certainty the eventual outcomes and impacts. If society is concerned about how climate change will affect biodiversity, the problem becomes even more complex since drivers of biodiversity—and the link between biodiversity and ecosystem stability—are also poorly understood. For these reasons, projects like GLORIA that aim to provide data to allow assessment of predictive distribution models for alpine flora are an important part of the puzzle.

The objective of the GLORIA project is to allow documentation of changes in species distribution and temperature over *time*, locally and for numerous locations around the globe, and to use these data toward an understanding of how alpine climate and biodiversity are interconnected. No conclusive trends in species numbers were evident from our baseline data. This was expected, as the GLORIA protocol is not designed to analyze baseline species numbers. The number of species found at each summit is influenced by local factors including aspect, rock outcrops, vegetation cover and slope/size of area surveyed. Not surprisingly, trends in species numbers reported by GLORIA researchers using baseline data have thus far not been consistent. In some target regions, the number of species were found to: decrease with altitude (Pauli et al. 2003, Coldea and Pop 2004); increase with altitude (Mark et al. 2006, Bertin et al. 2001); and not markedly differ between summits, even though they differed by as much as 450 m in elevation (Kanka et al. 2005).

### Biodiversity and Ecosystem Functioning

GLORIA's first goal is biodiversity monitoring. Changes in biodiversity can affect how ecosystems provide goods and services essential to humans

and, as such, biodiversity represents a central issue in ecological studies (Loreau et al. 2001, Balvanera 2006). Maintaining an adequate local biodiversity is the basis of the “insurance hypothesis” that states when multiple species exist together and have the same or similar functions within an ecosystem, the system will still be able to persist even with a few losses or changes (McNaughton 1977, Yachi and Loreau 1999). With respect to ecosystem functions being performed, many minor species may appear similar to dominant ones, but close study usually shows they have different responses to environmental stress and disturbance. Minor species therefore give added resilience to their community's ecosystem function (Walker 1999). Higher biodiversity thus acts as a buffer to maintain community productivity at a relatively constant level or as an enhancer to increase productivity (Yachi and Loreau 1999).

The levels of biodiversity required to sustain healthy ecosystems are presently unknown since ecosystems are such complex webs of interrelated and non-linear processes (Folke et al. 2004). Researchers agree, however, that ongoing monitoring is key to understanding the importance of species diversity to ecosystem functioning, and that such monitoring is an investment for future understanding (Loreau et al. 2001, Folke et al. 2004, Midgley and Thuiller 2005).

### Factors Affecting Species Richness

Information collected at GLORIA target regions can be used to assess and predict declines in species richness (number of species) in fragile alpine ecosystems. Theurillat et al. (2003) offer a hypothesis that the interactions of three factors can explain existing regional species richness along elevation gradients. The first factor is historical, and encompasses features like past glacier movement, land use (e.g., grazing and development) (Theurillat et al. 2003), geological history, geomorphological processes, and soils (Gordon et al. 2002).

The second factor is space limitation. Steep slopes, high gradients and rock outcrops that characterize alpine ecosystems cause microclimates to vary markedly over short distances, which can influence biodiversity. The GLORIA protocol addresses space limitations by documenting percentage cover of rock in each study area and slope. Our data from each summit showed that species richness is negatively correlated to the top cover of rock.

The third factor thought to influence biodiversity is ecological in nature, relating to climate and species interactions. Soil temperature data collected at the GLORIA summits can be used to establish whether a correlation exists between species richness and soil temperature. Although mountain climate systems involve complex interactions among precipitation, wind patterns, human disturbance and invasive plant species (Halloy and Mark 2003), the GLORIA protocol focuses on soil temperature data because this is relatively easy to collect and there are well-developed understandings of how soil temperature relates to plant ecology (Körner 2003).

Alpine environments have been substantially impacted by historical climate warmings (Grabherr et al. 1994, Lesica and McCune 2004, Huelber et al. 2006). Based on rising levels of greenhouse gases, the Intergovernmental Panel on Climate Change (IPCC) estimates that average global temperature will increase by 1.1-6.4 °C by 2090-2099 relative to 1980-1999 (IPCC 2007). In the Pacific Northwest, mean annual air temperatures are predicted to rise by approximately 1.5 to 3.0 °C by 2050 and winter precipitation is expected to increase by 5%. Changes in summer precipitation vary from model to model (Nakawatase 2006).

Vegetation altitudinal range responses to climate warming are anticipated to show a time lag, as alpine plant species are generally slow growing and long-lived (Pauli et al. 2003). It has been hypothesized that above a certain climatic threshold, the rates of upward range expansion of plant species may rapidly increase (Burkett et al. 2005, GLORIA 2006). Persistence of plant species already in alpine areas will be particularly vulnerable to local extirpation since they will have no upward area to further expand into once the summit is reached (Halloy and Mark 2003).

There are competing hypotheses as to what upward migration will mean to alpine species richness over the long term. Current research suggests a systematic decrease in alpine specialist species in response to warming temperatures (Guisan et al. 1998, Gottfried et al. 1999, Lesica and McCune 2004). However, over shorter time periods, some studies have found that alpine plant species were not always immediately replaced by species from lower altitudes, but instead an upward migration of species resulted in an overall increase in alpine richness (Grabherr et al. 1994, Walther et al. 2002, Bahn and Körner 2003).

Predicting how individual alpine species will respond to climate warming may involve consideration of the following:

- a) Rates of climate warming versus the rates of individual species to extend their geographical ranges (Jump and Peñuelas 2005), which incorporates species' longevities and dispersal mechanisms (Beniston 2003, Pauli et al. 2003);
- b) Differences in climatic tolerances by local species (includes genetic variation in tolerances within a species); and
- c) Species interactions

Air temperature change also directly affects snow cover and snow melt. Rising air temperature tends to result in an elevated snowline, i.e., an overall decrease in snowpack depth and duration at existing lower alpine levels. It is projected that the snowline will rise, on average, about 150 m for every 1 °C increase in the air temperature (Beniston 2003), with local snow patterns being heavily affected by wind and topography. Snowpack patterns affect length of the local growing season, soil moisture regime and soil temperature, and are key parameters that influence vegetation patterns in alpine areas (Heegaard and Vandvik 2004, Huelber et al. 2006).

The relative importance of biotic and abiotic factors on community dynamics in habitats of contrasting environmental severity and productivity are poorly understood (Klanderud 2005). For example, species interactions may play only a small role in community composition at alpine sites with high abiotic stress because growth is primarily limited by the harsh environmental conditions (Klanderud 2005, Stinson 2005) and these conditions result in more conservative resource use by species (Stinson 2005). In contrast, other research suggests that species interactions are important to consider when predicting plant community changes in response to climate warming, and may even be modified by climate warming (Klanderud 2005). Studies have reported that there is a significant difference in species interactions between low and sheltered sites where competition is dominant, and at high and exposed sites where facilitative effects between neighbours can occur (Choler et al. 2001, Kikvidze et al. 2005). Alternatively, other studies show that neighbouring plants at high and exposed sites compete because of a scarcity of resources (Stinson 2005).

The GLORIA protocol addresses the influence of species interactions by collecting data that allows species richness and plant top cover to be analyzed. A multiple regression of our data using all environmental factors (area, slope, aspect, elevation and top cover of: plants, rock, lichens, bryophytes and litter) on each Whistler summit shows that on the two highest summits only (HGH and SPH), significantly more species are found (at the 0.01 and 0.05 level respectively) when plant cover is higher. This finding would seem to support the theory that facilitative effects between neighbours can occur at high and exposed sites. Overall, the general trend shows that the maximum number of species occurs at intermediate plant cover (roughly 10-30% at Arrowsmith and 10-20% at Whistler).

## Conclusion

Long-term monitoring will make it possible for researchers to identify changes in biodiversity over time, to correlate them with factors such as climate change, and to assess how the nature of observed change may influence high mountain ecosystems over the long term. To make this assessment, suggested priority questions when monitoring GLORIA sites are: 1. Did species richness changes result from species immigration from lower elevations or from a filling in process from plants already established in the plots?; 2. What species are thriving and which are declining, and are there any obvious or suggested explanations?; and 3. How are temperature and snow cover data correlated with changes in species composition and richness?

Observations recorded at the species level during the baseline monitoring of GLORIA summits

are relevant since different individual species are expected to respond to climate change in different ways (Pauli et al. 2004). Establishment of the Arrowsmith and Whistler GLORIA target regions provides baseline observations that will be important to document and assess the long-term vulnerability of high mountain ecosystems in southwestern BC. In addition, the inclusion of this work into an international project allows Canadian alpine regions to be assessed relative to other mountain regions around the world. It is suggested that ongoing monitoring will confirm the higher vulnerability of cold-adapted species to climate warming, and their likely displacement out of their existing distribution range by warm-adapted species.

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APPENDIX 1. Vascular plant species found in Arrowsmith and Whistler target regions. An “x” marks the summit(s) where each species was found. Nomenclature follows Hitchcock and Cronquist (1973), except where indicated [BCSE] for BC Species and Ecosystems Explorer (2006) or [ITIS] for Integrated Taxonomic Information System (2006).

Target region Summit (code)	Arrowsmith				Whistler			
	[SHR	KRS	AMB	PTR]	[LOW	MED	HGH	SPH]
<b>TREE SPECIES</b>								
<i>Abies lasiocarpa</i> var. <i>lasiocarpa</i> <sup>[ITIS]</sup>		X	X	X	X	X	X	
<i>Chamaecyparis nootkatensis</i>	X	X	X					
<i>Picea engelmannii</i> var. <i>engelmannii</i> <sup>[BCSE]</sup>							X	
<i>Pinus albicaulis</i>					X	X		
<i>Pinus contorta</i> var. <i>latifolia</i>	X	X	X	X				
<i>Tsuga heterophylla</i>	X							
<i>Tsuga mertensiana</i>	X	X	X	X				
<b>SHRUB SPECIES</b>								
<i>Arctostaphylos uva-ursi</i>	X	X	X	X	X	X		
<i>Cassiope mertensiana</i>	X	X	X	X	X	X	X	
<i>Cassiope tetragona</i>							X	
<i>Empetrum nigrum</i>	X	X	X	X	X	X		
<i>Juniperus communis</i>								
<i>Phyllodoce empetriformis</i>	X	X	X					
<i>Phyllodoce glanduliflora</i>		X	X	X	X	X	X	X
<i>Rhododendron albiflorum</i> var. <i>albiflorum</i> <sup>[BCSE]</sup>							X	
<i>Rubus pedatus</i>	X	X	X					
<i>Salix nivalis</i>						X		X
<i>Sorbus sitchensis</i>	X	X	X					
<i>Vaccinium caespitosum</i>	X	X						
<i>Vaccinium deliciosum</i>	X	X	X					
<i>Vaccinium membranaceum</i> <sup>[BCSE]</sup>	X	X	X	X	X	X		
<i>Vaccinium parvifolium</i>	X							
<i>Vaccinium uliginosum</i>	X							
<b>HERBACEOUS SPECIES</b>								
<i>Achillea millefolium</i>	X	X		X				
<i>Allium crenulatum</i>		X	X					
<i>Antennaria microphylla</i>		X		X				
<i>Antennaria racemosa</i>	X		X					
<i>Antennaria umbrinella</i>	X	X	X	X		X	X	X
<i>Arnica gracilis</i> <sup>[ITIS]</sup>						X		
<i>Arnica latifolia</i>	X	X	X	X	X	X		
<i>Arnica rydbergii</i>			X	X				
<i>Campanula rotundifolia</i>	X	X	X	X				
<i>Cryptogramma acrostichoide</i> <sup>[ITIS]</sup>	X	X			X			
<i>Diphasiastrum sitchense</i> <sup>[ITIS]</sup>				X			X	
<i>Draba</i> cf. <i>incerta</i>						X	X	X
<i>Epilobium angustifolium</i>								X
<i>Erigeron compositus</i> var. <i>glabratus</i> <sup>[BCSE]</sup>	X							
<i>Erigeron peregrinus</i>			X			X		
<i>Goodyera oblongifolia</i>			X					
<i>Heuchera glabra</i> <sup>[BCSE]</sup>			X					
<i>Hieracium albiflorum</i>	X	X						
<i>Hieracium gracile</i>		X		X				
<i>Lewisia columbiana</i> var. <i>columbiana</i> <sup>[ITIS]</sup>	X							
<i>Lomatium martindalei</i> <sup>[BCSE]</sup>			X					
<i>Luetkea pectinata</i>	X	X	X	X	X	X		
<i>Luina hypoleuca</i>			X					
<i>Minuartia</i> sp. (aff. <i>rubella</i> ) <sup>[ITIS]</sup>	X	X	X	X				
<i>Montia parvifolia</i> subsp. <i>flagellaris</i> <sup>[ITIS]</sup>	X	X	X					
<i>Orthilia secunda</i> <sup>[ITIS]</sup>	X	X	X		X			

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APPENDIX 1, continued.

Target region Summit (code)	Arrowsmith				Whistler			
	[SHR	KRS	AMB	PTR]	[LOW	MED	HGH	SPH]
<i>Oxyria digyna</i>							X	X
<i>Pedicularis racemosa</i> <sup>[BCSE]</sup>		X	X	X	X		X	
<i>Penstemon davidsonii</i>	X	X	X	X	X			X
<i>Penstemon procerus</i>						X		X
<i>Phacelia sericea</i>								X
<i>Phlox diffusa</i>	X	X	X	X		X		
<i>Polygonum minimum</i>	X	X						
<i>Polypodium amorphum</i> <sup>[TTIS]</sup>		X						
<i>Potentilla diversifolia</i>			X	X		X	X	X
<i>Potentilla villosa</i> <sup>[BCSE]</sup>	X	X	X	X		X	X	X
<i>Saxifraga bronchialis</i>	X	X	X	X		X		X
<i>Saxifraga ferruginea</i>	X	X	X	X	X			X
<i>Saxifraga nelsoniana</i> subsp. <i>cascadensis</i> <sup>[BCSE]</sup>				X	X			
<i>Saxifraga rivularis</i> <sup>[BCSE]</sup>								X
<i>Saxifraga rufidula</i> <sup>[TTIS]</sup>	X		X					
<i>Saxifraga tolmiei</i>							X	X
<i>Sedum divergens</i>	X	X	X	X				
<i>Selaginella densa</i> var. <i>scopulorum</i> <sup>[TTIS]</sup>	X	X	X					
<i>Selaginella wallacei</i>	X	X		X	X	X		
<i>Sibbaldia procumbens</i>	X	X	X	X		X	X	X
<i>Silene acaulis</i> var. <i>exscapa</i> <sup>[TTIS]</sup>		X	X		X	X	X	
<i>Silene parryi</i>						X		
<i>Solidago multiradiata</i> var. <i>scopulorum</i> <sup>[BCSE]</sup>	X	X			X	X	X	
<i>Stellaria longipes</i> <sup>[TTIS]</sup>							X	X
<i>Streptopus amplexifolius</i>		X						
<i>Taraxacum ceratophorum</i>								X
<i>Tonestus lyallii</i> <sup>[TTIS]</sup>						X	X	X
<i>Viola orbiculata</i>	X	X						
<b>GRAMINOID SPECIES</b>								
<i>Agrostis scabra</i>	X	X	X		X			
<i>Calamagrostis purpurascens</i>						X	X	
<i>Carex albonigra</i>						X	X	X
<i>Carex capitata</i> <sup>[BCSE]</sup>						X	X	
<i>Carex engelmannii</i> <sup>[TTIS]</sup>								X
<i>Carex nardina</i> <sup>[BCSE]</sup>						X	X	X
<i>Carex nigricans</i>							X	X
<i>Carex phaeocephala</i>	X	X	X	X	X	X	X	X
<i>Carex pyrenaica</i>	X	X	X	X	X	X	X	X
<i>Carex rossii</i>				X		X	X	X
<i>Carex spectabilis</i>	X	X	X	X	X	X	X	
<i>Danthonia intermedia</i>	X	X	X					
<i>Festuca brachyphylla</i> <sup>[TTIS]</sup>	X	X	X	X	X	X	X	X
<i>Juncus drummondii</i> <sup>[BCSE]</sup>					X	X		
<i>Juncus parryi</i>			X			X		
<i>Luzula parviflora</i>	X	X		X				X
<i>Luzula piperi</i>					X	X	X	X
<i>Luzula spicata</i>	X	X	X	X	X	X	X	X
<i>Poa alpina</i>						X	X	X
<i>Poa cusickii</i>			X	X		X		
<i>Poa lettermanii</i>								X
<i>Poa rupicola</i>					X	X		
<i>Poa secunda</i> var. <i>secunda</i>	X							
<i>Poa stenantha</i>		X	X	X		X	X	X
<i>Trisetum spicatum</i>	X	X	X	X		X	X	X
<i>Vahlodea atropurpurea</i>		X			X			