Measuring Impacts to Rare Peripheral Arctic-Alpine Plants at the Edges of Permanent Snowfields/Glaciers that are Receding due to Climate Change in Glacier National Park

P12AC10557, MT-02

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September 14, 2012

Introduction:

Glacier National Park is situated in the Northern Rocky Mountains of Montana, a location that coincides with the southern boundaries of the arctic-alpine flora (Lesica 2002). Glaciers and snowfields are intrinsic parts of the alpine landscape at Glacier National Park, and are documented to be retreating and shrinking at a rapid rate (Watson et al. 2008, Fagre 2010). Plants are inextricably linked to their habitats. Because of this linkage, plants at the edges of snowfields and glaciers may be vulnerable to changes in these habitats. Plants growing near and/or along the edges of these important reservoirs of frozen water are positioned to be influenced by the predicted decline and likely disappearance of glaciers and formerly permanent snowfields. For example, growth near the edge of snowfields may currently be advantageous for plants as water is readily available in the form of melting snow during the summer, while if the current edge of a particular snowfield melts inward, or if a snowfield melts earlier in the summer or disappears altogether, plants at the former edges of the snowfield may experience water stress during the summer growing season, when water is needed for important processes such as emergence from the soil, leaf expansion, root growth, seed germination, seedling establishment, photosynthesis, and transpiration. This water stress may reduce the chances of survival for snowfield plants, lead to a reduction in abundance of species that are less tolerant of water stress, and contribute to an influx of water tolerant species. Even though seeds of *Ranunculus adoneus* are relatively abundant in the soil of snowbeds at 0.033 seeds/cm^3, *R. adoneus* seedlings still experience a higher risk of dessication in snowbeds than in meadows (Scherff et al. 1994). Phenological changes (Wipf and Rixen 2010) and the accompanying changes in pollinators and dispersal agents (Schoville and Roderick 2009, Todisco et al. 2010, Inouye 2012) in alpine environments may amplify the effects of changes in the snowfields, and along with geomorphology, (Malanson et al. 2012), interact to influence the physiology and other aspects of the snowfield plants. Range expansions and contractions are occurring in the high Alps (Pauli et al. 2006).

The peripheral arctic-alpine element of the flora at Glacier National Park may prove to be especially sensitive to these changes if they are directly or indirectly reliant on extensive snowfield edges, cold temperatures, and the availability of melting snow at precise times during the abbreviated summer growing season. Peripheral populations have a high likelihood of genetic and morphological divergence from central populations (Lesica and Allendorf 1995), and are thus valuable to conserve based on their potential contributions to evolutionary diversity. Importantly, rare plants are common where you find them (Lesica et al. 2006), so sites at Glacier National Park where rare plants are found may be especially important in terms of conservation and monitoring (Lesica and Steele 1996). Snowfield plants endure their own special set of environmental pressures, and form an important subset of plants to be conserved. For example, reproductive strategies of arctic-alpine species are strongly linked to phenology and the duration of snow cover, and early flowering species are more likely to be outcrossers, as compared to species inhabiting fellfields and late thawing snowbeds, which are more likely to be self-pollinated or propagated asexually (Molau 1994). This points to a likelihood of genetic and morphological divergence, as stressed by Lesica and Allendorf (1995).

We initiated a study of plants and their responses to changing snowfield habitats at Glacier National Park during the summer of 2012 and established quadrats and transects at snowfields on Siyeh Pass, Piegan Pass, at Preston Park, and at Mt. Clements near Logan Pass with the goals of setting up a baseline study of the current snowfield plants, and of revisiting the quadrats and transects at intervals in order to determine change in plant species presence over time with respect to changes in snowfields at Glacier National Park.

Materials and Methods:

In the initial phases of a study of rare arctic-alpine plants that grow along the edges of receding glaciers and semi-permanent snowfields at Glacier National Park, we established quadrats and transects along the environmental gradient of distance from the snow's edge at Logan Pass, Preston Park, Siyeh Pass, and Piegan Pass. The snowfields and the quadrats and transects were photographed for reference and for information on the surrounding plants and landforms.

Snow to Trees Transect:

A transect extending from the scree fields below the cliffs of Mt. Clements near Logan Pass runs from the center of a predominant rock that was positioned at the center of a snowfield on July 31st, 2012 southward but at the same elevation and over to the tree line towards the Hidden Lake Lookout. This linear transect covers terrain ranging from snowfield, to bare scree, to scree intermittently populated by to soil, to alpine meadow, and onward to the edge of a group of subalpine fir trees. At this transect, we measured the decrease of the snowfield's lateral extent into the transect as the snowfield melted during the warm, sunny, summer days in late July and early August, 2012.

Paired Transects:

Paired transects were established on Mt. Clements at Logan Pass, at Preston Park, at Siyeh Pass, and at Piegan Pass. These paired transects were established by placing one transect perpendicularly outward for 50 m from approximately halfway down the lateral edge of the snowfields while the other transect in the pair extended outward for 50 m from the approximate middle of the toe of the snowfields.

Transects were marked by building small cairns out of native rock placed on top of larger rocks at the snowfield's edge, or start of transect, and at the end of the transect. For likely detection with a metal detector, the cairns at the long transect on Mt. Clements, at the paired transects on Mt. Clements, and at Piegan Pass each contain metal carriage bolts (3 inch long X 3/8 inch wide), while the cairns at Siyeh Pass each contain two quarters. The cairns at Preston Park, (a timbered site with a lake and an alpine meadow) do not contain metal because of the strong winds, (which could have negated sounds intended to alert grizzly bears of our presence in their likely habitat) that were prevalent the day we revisited the Preston Park site to place metal in the cairns. The transects at Preston Park are marked with cairns, photographs, and GPS references. The beginning and endpoints of the transects were geospatially referenced with a Garmin *etrex* handheld GPS device and/or with the Trimble Outdoors Navigator Pro *i*phone application, which had the advantage of linking photographs with GPS data and Google Earth images. The beginning and endpoints of the transects were photographed, as were the views from these points in order to provide a visual context for relocating the cairns for future studies.

The 50 m paired transects were sampled every 5 m from the 0 m mark, or beginning, of the transects by placing a 1 m^2 quadrat first on the uphill side of the measuring tape, photographing the area within the quadrat along with the frame, and then flipping the frame to the downhill side of the tape and again photographing the area. This procedure resulted in documentation of a 2m^2 area at each 5 m interval along the transects. Smaller areas within the 1m^2 quadrat were photographed in order to document specific plants. The long, 118 m, transect was first sampled every 4 m when it was established on July 31st, August 1st, and August 3rd, but was resampled at 5 m intervals on August 22nd for consistency with the other sampling intervals.

During establishment of the long transect, we used a $1m^2$ quadrat constructed of measuring tape with strings intersecting to form squares with areas of $10cm^2$. This quadrat design is very portable but proved to be tricky to hold taut without the work of two people, so we constructed a 1 m^2 quadrat that consisted of wooden dowel rods marked at 10 cm intervals and connected at the ends by plastic tubing to make flexible corners. This quadrat could be folded compactly for ease of carrying and it was used for all 50 m transects and for the August 22nd resurvey of the long transect at Mt. Clements.

In addition, the point-step method was used at all transects. Starting at the 0 point, and at each meter, we recorded which plants and substrata were found at one meter intervals, beginning with the zero, or starting point, we determined what plants and/or substrata were found at that point in an approximately 0.25 m radius. Care was taken to avoid trampling plants, although in areas with dense cover, some trampling was unavoidable. When this happened, we attempted to right the plants that had been stepped on.

The area around each snowfield was observed to denote information on the extent of the snowfields, landforms, animals which may play a role in grazing, digging, pollination and/or seed dispersal, and the travel and activities of humans.

The overall percentage area covered by plants was estimated in each quadrat along with the percentage areas occupied by rocks, soil, cryptogamic crust, snow, water, feces, burrows, and sticks. The percentage of rocks covered by lichens was estimated, but tallied separately from the overall percentage areas of plants and categories denoting ground surfaces. The percentage class occupied by individual species was estimated according to the following classes: 0.5 = Trace, 1 – 1-5%, 2 = 5-25%, 3 = 25-50%, 4 = 50-75%, 5 = 75-95%, and 6 = 95-100%, according to a modification of the Daubenmire method of canopy-coverage estimation (Daubenmire 1959).

Plant Species: The vascular plants at each site were noted by presence in the general area, along the 5 m intervals used with the 1 m^2 quadrats of the transect, and along the 1 m intervals via the point-step method. Pants that grew uphill, downhill, and across the slope from the transects were recorded, and if identification through a taxonomic key was necessary, we collected only enough material for use in identification. Due to the sensitive nature of the areas, we did not attempt to identify every species if it meant excessive trampling or depredation of a particular species or fragile community, such as a wet alpine marsh. In addition, extensive sampling for identification or other purposes would have changed the dynamics of the snowfield communities and would therefore have introduced new variables into the environment with the possibility of changing the outcomes of future investigations.

Rare Peripheral Arctic-Alpine Plant Species. We searched for, and if found, noted the presence and locations of the following species of rare peripheral arctic-alpine plant species: Pygmy poppy (*Papaver pygmaeum*), Timberline buttercup (*Ranunculus verecundus*), Arctic pearlwort, (*Sagina nivalis*), Small tofieldia (*Tofieldia pusilla*), Lyall's phacelia (*Phacelia lyallii*), Jones columbine (*Aquilegia jonesii*), and others including *Draba macounii*, *Saxifraga cernua*, *Potentilla uniflora*, *Pinguicula vulgaris*, *Erigeron lanatus*, *Senecio megacephalus*, *Physaria saximontana*, *Festuca vivipara*, *Carex lenticularis* var. *dolia*, *Juncus albescens*, *Kobresia simpliciuscula*, and *Euphrasia arctica*.

Cushion Plants: We observed and photographed *Silene acaulis* and other plants with a cushion morphology that were inhabited by other vascular plant species in order to document the different extents of inhabitation with the size and viability of the cushion plant, with the idea of using these photographs as a reference towards the idea of a future study on cushion plants as hosts for other plants, which, having the nursery of the cushion plants, can then thrive in snowfield communities and contribute to changes in species composition in these communities that occur with snowmelt and climate change.

Results:

Transects are now established at snowfields in Glacier National Park and are intended as baseline transects that can serve as references and sites for future field research. These transects are located on Mt. Clements near Logan Pass, and at Preston Park, Siyeh Pass, and Piegan Pass. At all snowfields visited, plants existed above, below, and along the sides of the snowfields. Plants growing near snowfields are potential colonizers of terrain uncovered by retreating snowfields. Plant cover and species richness increased with distance from snowfields.

Mt. Clements: The long transects at Mt. Clements, abbreviated as MCLT1 and MCLT2, face eastward and extend from a prominent central green rock at 2213 m, 7260 ft, +48.688375° latitude and -113.739013° longitude. The MCLT was initiated in what was a snowfield on July 31st, 2012, but which subsequently melted. This snowfield had an upper lobe, inclusive of the prominent central green rock as of 7/31/12, and a lower lobe that extended along a gully in a scree slope above a small cliff band on Mt. Clements and parallel with the Hidden Lake Trail. The MCLT extends across a scree slope and onward to the tree line, which is populated by subalpine fir (*Abies lasiocarpa*), some with Krummholz morphology. The treeline, and the end of the transects are found at 2207 m, 7240 ft, +48.688141° latitude and -113.740569° longitude. Here the treeline extends along a vertical gradient and thus extends up the slopes of Mt. Clements. These transects are approximately parallel to, but higher in elevation, than the Hidden Lake Trail at Logan Pass. MCLT1 was established on 7/31/12, 8/1/12, 8/3/12, and 8/6/12 and revisited along a slightly different trajectory on 8/22/12. The 8/22/12 transect is called MCLT2, and followed a slightly different route along the same general terrain. However, due to the length of the transect, and the curvature of the terrain it did not line up exactly with MCLT1.

The MCLT1 was initiated on 7/31/12, when the central green rock designating the start of the transect was 14.8 m inward from the lateral edge (marked by a small, stone cairn) of a snowfield extending southward on the Mt. Clements scree slope towards Hidden Lake. The snow melted 4.2 m from the edge in one day, so by 8/1/12, the central rock was 10.6 m from the snowfield's edge, and by 8/3/12, the snow had melted an additional 2.4 m so that the snowfield's lateral edge was 8.2 m from the central green rock's cairn, and its diagonally southeastern edge was 4.8 m away, and its lower edge was 6.55 m away. Between 8/3/12 and 8/6/12, the snow melted an additional 11.1 m so that the snow's lateral edge was 2.9 m from the other, northern side, of the central green rock's cairn, and the central green rock was free of snow but within 0.5 m of snow on its lower, or eastern edge. As of 8/6/12, the upper lobe of the snowfield was 33.6 m wide (extending towards Hidden Lake), and 17.5 m long to the isthmus that divided the snowfield into its upper and lower lobes. The lower lobe had an additional isthmus that formed a subdivision of the lower lobe halfway to the Hidden Lake Trail, which the snowfield extended a few meters beyond as of 8/6/12. At the toe of the snowfield, there was a small, mossy-edged pond where *Tofieldia pusilla* grew and bloomed on the snowfield's edge of the pond. As of 8/6/12, there was another snowfield 22m to the north-northeast of the MCLT snowfield. The MCLT snowfield had completely melted by 8/13/12, although the other snowfield was still present but smaller. The weather from 7/31/12 to 8/13/12 was generally sunny, warm, and bright with the exception of the night of 8/2/12, which brought a thunderstorm and rain along with fresh snow high on Mt. Reynolds and other nearby peaks, and cool, cloudy weather on 8/3/12. Upon revisiting the area on 8/21/12 and 8/22/12, the snow had melted off sufficiently so we could climb to the top of the other snowfield, walk slightly to the north, and find the vast snowfield behind the moraine that ends shortly before the scree slope that holds the MCLT. We had noticed the moraine and snowfield in late July and early August, but had refrained from climbing the moraine so close to the trail and so close to the prominently placed revegetation signs and equipment.

The beginning, or 0 m mark of MCLT1 and MCLT2 is on the cairn of the central green rock, followed by snow and scree with only a few isolated *Oxyria digyna* plants for the first few meters. There were some apparently dead plants of *O. digyna* visible upon the establishment of the MCLT, some of which were in fact dead, but some of which were not dead at all but eventually produced leaves and flowers. Islands of *Carex* plants grow in the scree, albeit a little farther from the snow than the *Oxyria* plants. *Phacelia hastata* grows among the rocks of the scree slope, and these three angiosperms live closest to the snow. While step-point sampling does not reflect all plants in the area, and since many plants were still emerging and not readily identifiable on 8/3/12, results of the step-point sampling on 8/3/12 still reveal a cross-section of the general distribution of plants and substrata along the MCLT. The results showed rocks on snow or snow until 8 m, after which there were rocks or scree until 28 m, when the first green plants were detected via the step-point method. Scree with some plants continued until 64 m, when the plant cover became more continuous and more varied, and when soil was first recorded. Plants detected by step-pointing along the transect include *Oxyria digyna*, *Carex* sp., moss and *Phacelia hastata*, which were all found before reaching the 64 m mark. After 64 m, plants included *Sibbaldia procumbens*, *Carex* sp., moss, *Antennaria media*, *Potentilla diversifolia*, *Potentilla ovina, Selaginella sp.*, *Saxifraga occidentalis*, *Arabis lemmonnii*, *Achillea millefolium*, and *Arenaria capillaris*, *Gentiana calycosa*, *Zigadenus elegans*, *Pentaphylloides fruticosa*, *Parnassia fimbriata*, *Arnica alpina*, *Erigeron peregrinus*, *Carex scirpoidea* ssp. *scirpoidea*, *Carex paysonis*, *Carex stenophylla*, *Carex lenticularis*, *Hypericum formosum*, *Deschampsia caespitosa*, *Poa secunda*, *Poa arctica*, *Phleum alpinum*, *Hieracium triste*, *Sedum lanceolatum*, *Calocortus apiculatus*, *Ranunculus verecundus*, *Astragalus bourgovii*, *Senecio cymbalaria*, and *Aquilegia flavescens*. At 118 m, *Heracleum sphondyium* grew next to *Abies lasiocarpa*, where treeline marked the end of the transect. Cryptogamic crust was recorded at 67 m, 84 m, and at 85 m and lichens were first detected with step-point sampling at 95 m.

The substrate changed with distance along the MCLT. It began with snow, soon became scree (possibly with soil underneath the rocks of the scree), and became soil at approximately the 60-70 m range, which coincided with an increase in the abundance and diversity of the plants. This increase was visible as a green line of plants that coincided with soil development and extended upwards and parallel to the treeline.

Plant cover increased with distance from the snowfield. It was < 5% of the area from the central rock, (with the exceptions of islands of *Carex* sp. downhill from large rocks), to the ecotone marked by soil development at approximately 60 – 70 m from the central rock, when it increased from an approximate 20% of the area to 80 – 90% cover by the time the end of the transect was reached. Exceptions to this extensive cover were outcrops, large rocks, burrows and cliffs, where the cover was less extensive or absent. Small cliff bands were immediately above and below the MCLT. Downhill from the transect and on a ledge above one of the small cliff bands, there was a virtual lawn consisting of a mixture of *Carex* sp. interspersed with *Ranunculus verecundus* and *Phyllodoce empetriformis*. Rocks of the cliff bands supported lichens, while the downhill slope of the cliff bands held cryptogamic crust and supported the growth of *Selaginella densa*, *Potentilla* sp., *Silene acaulis*, *Pedicularis groenlandica*, *Carex* sp., *Phyllodoce empetriformis, Salix arctica*, *Saxifraga occidentalis*, *Erigeron peregrinus*, *Veronica wormskjoldii*, and *Dodecatheon pulchellum*.

Plants on the scree slope above the snowfield but below the cliffs of Mt. Clements, and thus above the MCLT and the other three transects of Mt. Clements on 8/3/12 included: *Penstemon ellipticus*, *Minuartia obtusiloba*, *Salix arctica*, *Carex* sp., *Arabis lemmonnii*. *Chamerion latifolium*, *Epilobium anagallidifolium*, *Senecio cymbalaria*, *Potentilla* sp., *Arnica alpina*, the ferns *Cystopteris fragilis* and *Cryptogramma acrostichoides*, *Phacelia hastata*, *Oxyria digyna*, seemingly dead cushions of *Silene acaulis* and *Oryzopsis exigua*, *Abies lasiocarpa*, *Pentaphylloides fruticosa*, and *Ribes* viscosissimum var. *viscosissimum* grew on the cliffs above the scree.

MCLT2 was surveyed on 8/22/12, a date that is relatively late in the alpine growing season. We resurveyed the general area of MCLT by setting up MCLT2. One goal of MCLT2 was to determine whether more plants had grown in the scree that falls between the edge of soil development and the edge of the now melted snowfield near the start of MCLT. The scree surveyed in MCLT2 was similar in plant cover to MCLT, and was only very sparsely covered by plants, with *Phacelia hastata*, *Epilobium anagallidifolium*, *Carex* sp., *Oxyria digyna*, and moss as the representative species, which were also found in the scree of MCLT. Seemingly dead plants, some of which were resprouting during the MCLT survey were still growing, but other seemingly dead plants were in fact dead or remained dormant. Thus, there was not a lot of new growth appearing on the scree as the season progressed.

In addition to the MCLT, three shorter transects were installed at Mt. Clements. Transect One, abbreviated as MCT1 which extends 50 m laterally from the middle of the southern edge of the snowfield, begins at 2200 m, 7217 ft, and +48.688665° latitude and -113.737619° longitude, and ends at 2200 m, 7217 ft, +48.688665° latitude and -113.739017° longitude, and faces southward. MCT1 extends 50m from the snow through a scree slope. Transect Two, or MCT2, starts at the approximate midpoint of the bottom of the snowfield at +48.688665° latitude and -113.737619° longitude, ends at +48.688343° latitude and -113.737619° longitude, and faces eastward. Because it traverses terrain that consists almost completely of large boulders which appear to have originated from the cliffs above, and few if any plants, we established Transect Three, or MCT3, which runs 50 m from the end of MCT2, (+48.688343° latitude and -113.737619° longitude) towards the Hidden Lake Trail's edge at +48.68817° latitude and -113.736497° longitude, in a southeastern direction to avoid travel through a small pond. The edges of this small pond support a community of *Carex* sp., moss, and other plants, including *Parnassia fimbriata*. These transects were established on 8/13/12.

MCT1 was established on the lateral, south-extending edge of the snowfield that was 22 m to the north-northeast of the MCLT snowfield on 8/6/12. A cairn was built on the rock at 0 m. Using the results of the step-point method, there was a large rock marking the initial, or 0 position, at 1 m, *Carex*. sp., but only rocks of the scree slope from 2 – 5 m. The rocks of the scree between 9 – 15 m held *Carex* sp., *Arnica alpina*, moss, *Arabis lemmonnii*, and *Penstemon ellipticus*. Rocks and scree, along with *P. ellipticus*, *Arnica alpina*, *Luzula piperi*, *Carex* sp., and moss were found between 15 – 29 m. *Achillea millefolium*, *Arabis lemmonii*, and *Phacelia hastata* joined the list between 30 m and 40 m. Step-pointing showed the last 10 m of the transect to have rocks of scree, *P. hastata*, and a neon green lichen.

MCT2 extended 50 m from the toe of the snowfield and across a boulder field which fell towards the pond near the Hidden Lake Trail. It consisted of rocks, usually boulder-sized, and there were no plants. Because there were no plants, we added an additional transect to the end of MCT2. This transect, known as MCT3 started 50 m from the toe of the snowfield and extended to the Hidden Lake Trail's edge. At MCT3, the step-point sampling technique landed on rocks for the first 11 m, then a rock with *Phacelia hastata* at 12 m, then rocks at 13 and 14 m, and rocks with *Arnica* *alpina* and *Epilobium anagallidifolium* at 15 m. The transect was continually rocky until 22 m, but after 15 m, plants became more continuous, with *Carex* sp, an unknown species of grass that had been grazed, *Oxyria digyna*, *Poa secunda*, *Arnica alpina*, and *Epilobium anagallidifolium,* and *Salix arctica* occurring between 15 and 22 m. The transect intersected the pond's edge at 23 and 24 m, where *Salix arctica* and *Carex* sp. were found. Proceeding onward, *Senecio fremontii*, *S. arctica*, *Carex* sp., moss, cryptogamic crust, *Antennaria media*, *Phyllodoce glanduliflora*, *Veronica wormskjoldii*, *Pedicularis groenlandica*, *Phleum alpinum*, *Potentilla diversifolia*, *Allium schoenoprasum*, and *Pentaphylloides fruticosa* were all found between 25 and 50 m. The transect ended in the compacted earth of the Hidden Lakes Trail. On the other side of the transect, the mossy banks of the aquatic community continued but we did not extend the transect further for fear of trampling and appearing to be establishing a trail in what was in fact a very fragile environment.

Mountain Goats, a Wolverine, Hoary Marmots, and Ground Squirrels were all present at Mt. Clements. The Mountain Goats frequented the transect area and were found upslope, downslope, and across the slope from the transects. The wolverine was only seen on 8/3/12, when it traveled along the interface of the scree and the cliffs of Mt. Clements. The Hoary Marmots and Ground Squirrels were generally downslope from the transects, although MCT2 and MCT3 run through an area frequented by both Hoary Marmots and Ground Squirrels. The Mt. Clements transects are within sight of but a short off-trail climb on scree from the Hidden Lake Trail, so, while many hikers were nearby, few were on or near the transects. In late July, there were still a few snowboarders on the nearby snowfields.

Preston Park: Two transects were established on 8/10/12 along a snowfield situated near treeline at Preston Park. Transect One, abbreviated as PPT1, extends laterally for 50 m from +48.76516° latitude and –113.639955° longitude, at the approximate midpoint of the lateral edge of the snowfield and extends to the treeline at 2216 m, 7260 ft, +48.716905° latitude and -113.640357° longitude. PPT1 runs to the south towards a creek and a pair of small lakes, (one of which contains icebergs) between the Siyeh Pass Trail and Mount Siyeh. The second transect at Preston Park, abbreviated as PPT2, extends 50 m in an eastward direction from +48.716334° latitude and -113.639607° longitude at the approximate midpoint of the toe of the snowfield to 2216 m, 7270 ft, +48.716644° latitude and -113.639178° longitude, where the transect ends.

Preston Park Transect 1, PPT1, traverses territory northward from the snowfield and across a subalpine meadow with *Gentiana calycosa*, *Castilleja rhexifolia*, *Xerophyllum tenax, Zygadenus elegans*, and *Pedicularis contorta.* It reaches treeline, which is populated by the subalpine fir tree, *Abies lasiocarpa*. The results of the step-point sampling show that the first five meters of the transect hold rock, snow, soil and *Carex* sp. (at 4 m). Between 6 m and 15 m, the transect crosses rock, soil, a type of greyish clay soil that we refer to as gley, *Carex* sp., *Oxyria digyna*, and *Arabis lemmonnii*. From 16 m to 30 m, the transect travels through *Carex* sp., *Ranunculus* sp., *Senecio fremontii*, *Arabis lemmonii*, grass, rocks, soil, and thatch formed by old leaves, and *Luzula hitchcockii*, *Anemone occidentalis*, *Euphrasia arctica*, grass, *Carex* sp., *Erigeron perigrinus*, *Antennaria media*, *S. fremontii*, *Cerastrium arvense*, and more thatch are found from 31 m to 40 m. The final 10 m of the transect hold *Pedicularis contorta*, *Erigeron perigrinus*, *Carex* sp., *Polygonum bistortoides*, grass, *L. piperi*, and a seedling of *A. lasiocarpa*.

Preston Park Transect 2, PPT2, extends across a fellfield that gently slopes uphill to some of the last, and krummholzed A. lasiocarpa trees before treeline and the windswept mountainside leading upwards to Siyeh Pass. Step-pointing of the transect gave the results of rock at 0 m, followed by a zone of rock, cryptogamic crust, *Sibbaldia procumbens*, *Carex* sp., and moss between meters 1 and 6. From 7 m to 15 m, the transect crosses rocky terrain populated by *Arabis lemmonnii*, *Salix arctica*, cryptogamic crust, *Potentilla diversifolia*, unidentified seedlings, black lichens on rocks, and *Carex* sp. At 16 m there was a seedling of *A. lasiocarpa*, and the rocky terrain between 17 m and 33m held *Carex* sp., *S. procumbens*, *Selaginella sp., Erigeron perigrinus*, *Potentilla diversifolia,* cryptogamic crust, fluorescent green lichens on a rock, *S. arctica*, and *Dryas octopetela*. At 34 m, there was a 1-2 feet tall and wide subalpine fir, *A. lasiocarpa*, Proceeding from 35 to 50 m, the continually rocky transect held *Smelowskia calycina*,(which is common farther upslope towards Siyeh Pass), one individual of a miniscule, unidentified plant with five white petals which we did not collect but did photograph, and which was possibly a *Sagina*, *S. procumbens*, *Antennaria media*, *Luzula piperi*, *Heracleum sphondylium*, *Erigeron perigrinus*, *Arnica alpina*, *Aster* sp., *Oxyria digyna*, *Arabis lemmonnii* and *Poa secunda*.

The Preston Park snowfield is relatively flat and sits in in a shallow basin containing *A. lasiocarpa* trees. The area is still in the subalpine zone but it is close to treeline. The lower edge, or toe, of the snowfield extends eastward. To the east of the snowfield, there is a rocky, relatively flat field populated by cushion and other plants. Trees begin to the south of the snowfield, and a walk of approximately 100 m southward and past the end of PPT2 leads to the outlet of a small lake, where water flows into Siyeh Creek. Numerous horseflies were present and biting on 8/10/12. Along the shores of the small lake, (but not within the transects), there is a wet marshy community with *Tofieldia pusilla* and *Pinguicula vulgaris*, both of which were in bloom on 8/10/12. The flowers of *P. vulgaris* at this site were white, but they were blue in a mossy seep adjacent to the northern side of the Going to the Sun Highway on the downhill side of Siyeh Bend where vehicles are often parked.

Siyeh Pass: Both transects at the Siyeh Pass snowfield are completely above treeline. Transect One, which is abbreviated as SPT1, extends westward and laterally for 52 m from 2415 m, 7923 ft, +48.718202° latitude and -113.627278° longitude at the approximate midpoint of the lateral edge of the snowfield to +48.718284° latitude and -113.627988° longitude, where it ends on a rocky, sparsely vegetated slope of Matahpi Peak that marks the division between the Preston Park and the Siyeh Pass areas. Siyeh Pass Transect Two, or SPT2, extends 50 m northward from +48.719139° latitude and -113.627179° longitude at the approximate midpoint of the toe of the snowfield to 2362 m, 7750 ft, +48.719629° latitude and -113.627404° longitude, where the transect ends in a relatively flat, stony, alpine fellfield. The largest non-human animal we saw near these two transects was a hummingbird, which flew past on 8/9/12.

The Siyeh Pass snowfield is steep, expansive, and lobed. The main vertical axis of this large snowfield follows the curvature of the cliffs and slopes leading from immediately below the top of Siyeh Pass downwards in a north-northeastern direction into the Boulder Creek Valley, which is between Mount Siyeh and the summits above the Otokomi Lake Area. The presence of snow is in marked contrast to the dry, rocky slopes to its east and the relatively flat alpine fell field to the south. A small pond existed at the terminus, or toe, of the snowfield in August 2012.

SPT1 traverses an area that is what some may refer to as an alpine desert, and this high, steep scree slope is home to xeromorphic plants, including *Draba oligosperma*, *Aquilegia jonesii, Draba macounii,* and others. *A. jonesii* and *D. macounii* had finished blooming by 8/9/12, except for one *A. jonesii* flower. Both species had begun to produce seed-bearing structures. The slope is sparsely vegetated, with what appears to be a clay-like soil. In the moist swales of the area, the plants are generally less xeromorphic in appearance and include *Arnica alpina*, among others. Downslope from the area traversed by SPT1 there is an extensive mosaic of patterned ground with *Dryas octopetela*.

Following the step-point transect, SPTI begins with scree, soil, rock, *Carex* sp., and *Oxyria digyna* from meters one through five. Meters 6 through 15 travel through rock, scree, soil, gravel, the greyish clay known informally as glay, species of grass, unidentified plants just beginning to emerge, *Oxyria digyna*, and *Epilobium anagallidifolium.* Substrata in meters 16 through 30 consisted of gravel, soil, rock, and gley, while the plants in this range were *Epilobium clavatum*, *Oxyria digyna*, *Carex* sp., *Saxifraga occidentalis*, *Salix arctica*, *Arnica alpina*, *Erigeron perigrinus*, and *Poa secunda*, The next 10 m, (31-40), had rock, gley, and scree for substrata and were populated by *A. alpina*, *Epilobium anagallidifolium*, *Carex* sp., *Arenaria capillaris*, and *Potentilla diversifolia*. The 40 m mark saw an increase in wind as the transect crested the ridge between the Preston Park and Siyeh Pass areas, and the substrata from 41 m to 52 m consisted of scree and rock. Plants in this windy area were *Aquilegia jonesii*, *Draba macounii*, *Poa secunda*, *Oxyria digyna*, *Dryas octopetala*, *Phacelia lyallii*, and *Sedum lanceolatum*, Lichens were found on the rocks in this range.

SPT2 begins at a rock on the northern edge of the snowfield's pond, and the cairn we built on this rock on 8/9/12 had been dismantled and there were footprints in the mud surrounding the pond and the cairn. We reassembled the cairn on 8/23/12 and hopefully the lateness of the season served to reduce the chances of other curious hikers disassembling the cairn.

SPT2 extends out from the snowfield onto a relatively flat fell field. This fell field is rocky with some gravel, but the rocks and gravel form an incomplete layer above moist soil which appears to have a high percentage of clay and which sinks down slightly to form slight compressions when walked upon. Cryptogamic crust, an important microbial community for nitrogen fixation and soil stabilization, is found discontinuously along the transect. *Oxyria digyna* grows closest to the snowfield and was emerging on 8/9/12, and *Carex* sp. appear within 10 m of the snowfield. Other plants along SPT2 include Willow Herb, (*Epilobium anagallidifolium*), Yarrow, (*Achillea milllefolium*), *Poa secunda*, *Arenaria capillaris*, *Penstemon ellipticus*, Milk-Vetch, (*Astragalus bourgovii*), *Silene acaulis*, *Potentilla diversifolia*, *Polygonum viviparum*, and *Erigeron lanatus*. The presence of *Astragalus* is important because it implies the capacity for symbiotic nitrogen fixation by rhizobial bacteria. The field is populated by *Silene acaulis*, which is host to many obther plants that grow within its cushion morphology. The Pygmy Poppy, *Papaver pygmaeum*, was in bloom at SPT2 on 8/9/2012 and had produced capsules by 8/23/12. *Sedum roseum*, often called *Rhodiola integrifolia*, was in bloom on 8/23/12.

The results of the step-point transect for SPT2 are water, rock, and scree at 0 m, with the addition of what looked to be recently submerged, decayed, plant material at 1 m. Meters 2 and 3 had mud and rock, while by meter 4 the substrate was rock and scree. Meters 5 – 10 had substrata of rock and soil, and the first plant detected with the point step method was *Oxyria digyna* at 5 m. Meters 6 – 15 had rock, soil, gravel and scree as substrata, with *O. digyna*, *Carex* sp., *Poa secunda*, and *Sibbaldia procumbens*. Meters 16 – 30 were rocky with soil, and plants in this range detected via the step-point method were *Epilobium anagallidifolium*, *Achillea millefolium*, *Poa secunda*, *Arenaria capillaris*, *Penstemon ellipticus*, *Antennaria media*, *Astragalus bourgovii*, *Silene acaulis*, *Carex* sp., and *Potentilla diversifolia*. The terrain between meters 31 and 40 was rocky with lichens on the rocks, cryptogamic crust, moss, *P. secunda*, *P. diversifolia*, *Carex* sp., *S. acaulis*, *A. bourgovii*, and *Phacelia lyallii*. The concluding 10 m of the transect were rocky with soil and *A. bourgovii*, *S. acaulis*, *Carex* sp., *Polygonum viviparum*, *P. secunda*, *P. diversifolia* and *Erigeron lanatus*,

A very high snowfield is situated above the summit of Siyeh Pass, at 2438 m, 8000 ft, +48.710369° latitude, and -113.629068 longitude. Plants at this very high snowfield, which is adjacent to and likely extends onto and covers the Siyeh Pass Trail early in the season, included *Myosotis alpestris*, *Silene acaulis*, *Penstemon elipticus, Oxyria digyna*, *Phacelia lyallii*, and likely *Potentilla uniflora*, although we did not collect this plant to key. *Penstemon ellipticus* grows above this snowfield near the boundary between the scree and the cliffs. The only non-human mammal we saw at this site was a chipmunk, who had learned to drink water from a Camelbak valve, possibly attesting to the frequency of human visitors.

Piegan Pass: Two transects were established on Piegan Pass on 8/14/12. Transect One, slightly above the summit of Piegan Pass (2307 m, 7570 ft.) and is abbreviated as PIET1. It extends 51 m westward from +48.72037° latitude, and -113.688049° longitude at the approximate midpoint of the lateral edge of a north-facing snowfield on Piegan Mountain, very slightly to the lee of the summit of Piegan Pass, which is essentially the saddle between Piegan Mountain and Cataract Mountain, to +48.716644° latitude, and -113.640357°longitude, where it ends on a rocky yet vegetated north-facing alpine slope on Piegan Mountain. Here the vegetation is low to the ground, which suggests exposure to frequently high winds. *Oxyria digyna* was abundant and emerging in the meters close to the snowfield and in bloom farther away from the snowfield's edge. Other plants along PIET1 include *Carex* sp., the willow-herb, (*Epilobium anagallidifolium*), *Senecio fremontii*, *Ranunculus verecundus*, *Poa secunda*, *Arenaria capillaris*, and

Salix arctica. Approximately 15 plants of what was very likely *Euphrasia arctica* grew at Piegan Pass along this transect, but due to the rarity of the plant we did not collect it.

The step-point results for PIET1 were as follows. At 0 meters, we built a cairn on a rock which was 0.5 m from the snowfield's lateral, western edge as of 8/14/12. At meters 0 through 5, the substrate consisted of rock with *Oxyria digyna* at 1 and 5 m. Meters 6 through 15 had a rocky substrate with *O. digyna* and moss. From 16 m to 30 m, the substrate consisted of rock and the plants were *O. digyna*, *Carex* sp., *Poa secunda, Arenaria capillaris*, *Sibbaldia procumbens*, and *Epilobium anagallidifolium*. The range from 31 m to 40 m had a rocky substrate with *Carex* sp., *Oxyria digyna*, *Ranunculus verecundus*, *E. clavatum*, *Senecio fremontii*, likely *Euphrasia* sp., and *P. secunda*. The substrate of the last eleven meters consisted of rocks, with cryptogamic crust at 50 m, and *P. secunda*, *Carex* sp., *Cerastrium arvense*, *Antennaria media*, and *Salix arctica*.

Transect Two, which crosses the summit of Piegan Pass, as well as the Piegan Pass Trail, is abbreviated as PIET2. It extends 51 m northward from the approximate midpoint of the toe of the snowfield to +48.72037° latitude and -113.68746° longitude to +48.720832° latitude, and -113.687211° longitude. As with PIET1, PIET2 is characterized by *Oxyria digyna* growing abundantly and close to the snowfield. Northward and beyond the trail, the vegetation became increasingly woody, with the pink blooms of *Spiraea densiflora* and krummholzed *Abies lasiocarpa* trees near the abandoned structure, presumable built for the bell that used to be at the top of the pass. PIET2 has an abundance of lichens, especially towards the distal end of the transect.

The step-point sampling of PIET2 resulted in a rock at 0 m (upon which we built a cairn), rocks for substrate from 0 m to 5 m. The plants in this range were *Oxyria digyna*, *Carex* sp., *Arabis lemmonnii*, *Ranunculus verecundus*, and moss from 0 m to 5 m. From 6 m to 15 m, the substrate was rocky and the plants were *A. lemmmonii*, *Carex* sp., *Sibbaldia procumbens*, *R. verecundus*, *Arnica alpina*, *Euphrasi*a sp., *Epilobium anagallidifolium*, and *Poa secunda*. Proceeding from 16 m to 30 m, the substrate continued to be rocky, although plants obscured the rocks at 20 and 21 m, and again at 24 m and 26 m. The transect crossed the approximately one meter wide trail at 28 m. Plants in this range included *A. lemmonii*, *S. procumbens*, *Carex* sp., *Silene acaulis*, *Arenaria capillaris*, *Antenari*a *media*, *Potentilla diversifolia*, *Achillea millefolium*, *P. secunda*, and *Phleum alpinum*. Continuing onward from 31 m to 40 m, the substrate consisted of soil and rocks, upon which grew the neon green and black lichens, and was inhabitated by *Carex* sp., *S. procumbens*, *A. media*, *P. alpinum*, *P. secunda*, *Potentilla diversifolia*, *Gentiana calycosa*, moss, *A. millefolium* and *Pedicularis contorta*. The interval inclusive of 41 m to 51 m had soil and rocks with lichens, and supported the growth of *P. contorta*, moss, *P. diversifolia*, *A. capallaris*, *Dryas octopetela*, *Carex* sp., *A. media*, krummholzed subalpine fir trees (*Abies lasiocarpa*) at 46 and 47 m, *P. secunda* and *Minuartia obtusiloba*.

At Piegan Pass, a hoary marmot approached the snowfield's edge from a pile of boulders and rocks, where it had established a type of citadel, and which was quite possibly its home. The hoary marmot traveled back and forth, and hither and yon while meandering in what appeared to be a semi-random pattern, on the exposed ground around the snowfield's edge, eating *Oxyria digyna* and *Epilobium anagallidifolium* leaves and possibly flowers and seeds as it went. The hoary marmot appeared to be habituated to human presence. We did not observe seeds in the fur of this animal, but we did notice that it is low to the ground, and it may be that it disperses seeds in its fur. A bighorn sheep, which also appeared to be habituated to humans, was in the summit area north of the trail, although it did not travel within the transects or cross to the southern side of the trail while we were there.

As of 8/14/12, the northern edge of the snowfield came within 28 - 30 m of the Piegan Pass trail, which is probably covered by the snowfield earlier in the season. Hikers sat at the edge of the trail, walked around on the summit of the pass, ate lunch, rested, and/or walked up to the top of Piegan Mountain. Thus, the Piegan Pass snowfield is not without human influence and at least its northern edge receives foot traffic.

Sexton Glacier: While we intend to establish at least one transect at or near Sexton Glacier, to date we have not done so. On August 4th, 2012, we hiked the Siyeh Pass trail and found the side-trail to Sexton Glacier. However, our access to the glacier was inhibited by the presence of angled snowfields and we did not have crampons, ice axes, etc., or knowledge of safe travel routes near the glacier. We decided to wait until later in the summer when the snowfields might have receded enough to allow a direct approach to the glacier's edge. We attempted to return on August 16th and 17th but had to cancel the expedition due to a family emergency, regrouped and tried again on August 21st, but retreated when a sudden thunderstorm materialized, and yet again on August 23rd, but decided to work lower down at the Siyeh Pass snowfield due to very strong winds that day.

While near the Sexton Glacier on August 4th, 2012, we observed plants growing between the Siyeh Pass summit and the side-trail to the glacier, near the side-trail to the Glacier, and along the Siyeh Pass Trail below the glacier and towards Baring Creek. *Myosotis alpestris*, *Silene acaulis*, *Penstemon elipticus, Oxyria digyna*, *Phacelia lyallii*, and a species of *Potentilla* which we did not collect due to scarceness, but which appeared to fit the description of *P. uniflora* were found between the Siyeh Pass summit and the side-trial to the glacier. The following plants were near the side trail: *Oxyria digyna*, *Carex* sp., *Phacelia hastata*, *Phacelia lyallii*, *Potentilla uniflora* (likely, although not collected), *Zigadenus elegans*, and *Solidago multiradiata*. These plants were found below the side-path to the glacier towards Baring Creek: *Parnassia fimbriata*, *Zigadenus elegans*, *Arnica alpina*, *Erigeron perigrinus*, what may have been *Potentilla uniflora*, *Pentaphylloides fruticosa*, *Carex* sp., and *Xerophyllum tenax*. This list of plants is by no means intended to represent the entire flora of the area.

Mt. Clements Moraine: On August 21st, we climbed up the Mt. Clements scree field to near the cliff/scree interface, and traversed across to the southern end of the Mt. Clements moraine to find a vast snowfield behind the moraine, where we could hear rocks falling down the hill. While the sides of the moraine were very steep and unstable, we easily walked along the ridgetop and noted the plants. *Oxyria digyna* was abundant throughout. Leaves of *Oxyria digyna*, *Phacelia hastata*, *Chamerion latifolium*, and *Epilobium anagallidifolium*, were just emerging and grew with moss close to the top of the scree field and the start of the moraine, where snow had most recently melted. Proceeding down the ridgeline, we saw *Senecio fremontii*, *Arnica alpina*, *Penstemon ellipticus*, *Poa arctica*, *Silene acaulis*, *Achillea millefolium*, *Eriogonum flavum*, *Minuartia obtusiloba*, *Heuchara* sp., and *Phacelia lyallii*. *Sedum* l*anceolatum* bloomed slightly off of the ridgetop towards the snowfield, and *Castilleja rhexifolia* was in bloom along with *P. ellipticus* and *E. clavatum* on the slopes of the moraine. Continuing onward, we came to a gnarled krummholzed *Abies lasiocarpa* tree grew on the ridgetop, near a krummholzed but not gnarled specimen. *Deschampsia caespitosa*, *Poa secunda*, *Arabis lemmonnii* grew just off the top of the ridge and towards the snow, and *Anemone occidentalis* and *P. ellipticus* were in fruit at the ridgeline. *Salix arctica* was present on the descent of the moraine towards the Hidden Lake Trail, and Ranunculus sp. grew in a snowmelt-fed mossy fen downhill from the moraine. Small, singular cushions of what were likely *Arabis* and *Draba* sp. grew downhill from the moraine. We did not observe any members of the nitrogen-fixing Fabaceae. Photographs of cushion plants taken at the moraine will be useful in determining which plants use the cushions as nursery plants.

Rare Peripheral Arctic-Alpine Plant Species: We found some, but not all, of the plants on the following list: Pygmy poppy (*Papaver pygmaeum*), Timberline buttercup (*Ranunculus verecundus*), Arctic pearlwort, (*Sagina nivalis*), Small tofieldia (*Tofieldia pusilla*), Lyall's phacelia (*Phacelia lyallii*), Jones columbine (*Aquilegia jonesii*), *Draba macounii*, *Saxifraga cernua*, *Potentilla uniflora*, *Pinguicula vulgaris*, *Erigeron lanatus*, *Senecio megacephalus*, *Physaria saximontana*, *Festuca vivipara*, *Carex lenticularis* var. *dolia*, *Juncus albescens*, *Kobresia simpliciuscula*, and *Euphrasia arctica*. We searched for, but did not find *Sagina nivalis*, *Saxifraga cernua*, *Physaria saximontana*, *Festuca vivipara*, *Juncus albescens*, and *Kobresia simpliciuscula*.

We found *Papaver pygmaeum* in bloom on the fell field at the toe of the Siyeh pass snowfield on 8/9/12 and in fruit on 8/23/12. Although the *P. pygmaeum* plants were very small, there were still enough plants to be noticed while walking on the fell field. *Phacelia lyallii* was abundant at the large snowfield at Siyeh Pass, the high (above trail) snowfield at Siyeh Pass, beneath the side-trail to Sexton Glacier, and at the Mt. Clements moraine. *Aquilegia jonesii* grew abundantly at Siyeh Pass, and particularly along the Siyeh Pass Trail where it leads above treeline from Preston Park up the rocky slope to Siyeh Pass itself. It was in fruit by 8/4/12, and we found one plant still in bloom on 8/9/12 when all others that we saw were already in fruit. *Draba macounii* grew along the above treeline climb of the Siyeh Pass trail and in the SPT1 area towards the large snowfield, along with *A. jonesii*. *D. macounii* was in fruit by 8/9/12. We may have found *Potentilla uniflora* on the Siyeh Pass Trail between the pass and the area just beneath the side trail to Sexton Glacier. However, we did not collect a sample for identification and unfortunately have not yet returned to the area due to weather and other constraints. The plants that may have been *P. uniflora* were growing along the embankment of the trail, and generally on the southeast facing, uphill slope of the switchbacks that the trail forms when descending from Siyeh Pass but long before it reaches the treeline on the Baring Creek side. *Erigeron lanatus* grew and was in bloom on the fell-field north of the terminus of the large snowfield at Siyeh Pass, and in the transect area of SPT2. It was also found in general in the area between Preston Park and Siyeh Pass. *Euphrasia arctica* was seen at Preston Park.

Ranunculus verecundus was found in bloom during the first week of August at the Mt. Clements long transect at approximately the point where scree begins to shift to soil, and on rockier terrain at Piegan Pass. We ascertained that *Carex lenticularis* var. *dolia* grew along the shores of ponds at Mt. Clements, but did not collect it for identification because of the fragile, boggy, mossy nature of its habitat. A very few individuals of *Senecio megacephalus* grew and were in bloom along the uphill, or northern, side of the Piegan Pass trail where it traverses gently uphill between treeline and the summit snowfields of Piegan Pass. S. megacephalus was found near *Festuca brachyphylla*. Several of what were likely *Euphrasia arctica* plants grew near the snowfield and in the transect areas of PIET1 and PIET2 at the summit of Piegan Pass.

Tofieldia pusilla was found in bloom on the edge of a pond, which at the time was at the terminus and fed by snowmelt from a snowfield that melted along the Hidden Lake Trail near the base of Mt. Clements, in a small, mossy fen off of the boardwalk of the Hidden Lake Trail at Logan Pass, and on the edge of a small lake near the Preston Park transects. *Pinguicula vulgaris* was found blooming, and with white flowers along the mossy, wet shore of the first of two small, consecutive lakes in Preston Park, where it grew with *Tofieldia pusilla*. *P*. *vulgaris* was also found on the mossy seep on the downhill and northern side of the Going-to-the-Sun-Highway at Siyeh Bend where cars are often parked uphill from the bus stop. Along the Going-to-the-Sun-Highway, *P*. *vulgaris* had blue flowers. *T*. *pusill*a and *P*. *vulgaris* were both found in very fragile marshy, mossy communities on the edges of lakes, small ponds, or ephemeral streams fed by meltwater from the snowfields above, but not directly on or near the edges of snowfields.

Trees and Shrubs: The subalpine fir, *Abies lasiocarpa*, was found near all snowfields except for those at Siyeh Pass.

At Mt. Clements, *A*. *lasiocarpa* grew on the top of the moraine and on the cliffs above the snowfields. It was also found at treeline, where treeline followed a vertical gradient at the end of the MCLT, albeit over 100 m from the snowfield. *Pentaphylloides fruticosa* was found near the treeline towards the end of the MCLT, near the distal end of MCT3, and *Pentaphylloides fruticosa* and *Ribes* viscosissimum var. *viscosissimum* were both found growing on the lower reaches of the cliffs just above the scree slope and above the snowfields on Mt. Clements. *Phyllodoce empetriformis* grew along the MCLT, while *Phyllodoce glanduliflora* grew in the MCT3 area. *Salix arctica* grew on the scree above the snowfields and on the Hidden Lake Trail side of the moraine’s slope at Mt. Clements, along the MCLT, and in the MCT3 area.

At the relatively flat snowfield in Preston Park, *A*. *lasiocarpa* lived within 20 m uphill from the top of the snowfield, towards the end of a subalpine meadow at PPT1, and small *A*. *lasiocarpa* trees were found along PPT2, above which there was another stand of *A*. *lasiocarpa* trees, albeit the last before treeline. *Salix arctica* and *Dryas octopetela* both grew at Preston Park in the PPT2 area

Near the summit of Piegan Pass, *A*. l*asiocarpa* and the shrub *Spiraea densiflora* were found near the northern end of PIET2, while *Salix arctica* grew in the PIET1 area.

Both *S*. *arctica* and *D*. *octopetela* grew at Siyeh Pass in the SPT1 area. *D*. *octopetala* grows on the Siyeh Pass trail above treeline, where it is colonized by other flowering plants. Extensive islands of *D*. *octopetala* grow to the northwest of the SPT1 and SPT2 areas in patterned ground. On the other side of the pass, *Pentaphylloides fruticosa* was also found along the Siyeh Pass Trail, downhill from the side-trail to Sexton Glacier.

Animals:

Here we list the animals found at or near the snowfields since they have the potential to act as pollinators and seed dispersal agents. They can also be herbivorous, and can trample plants, dig, make burrows, and compact the soil. Mountain goats, a wolverine, bighorn sheep, hoary marmots, ground squirrels, and chipmunks were all found at the snowfields. Humans were found on nearby trails and some ventured off-trail onto the snowfields, or crossed them early in the season when the snowfield covered parts of the trail. Grasshoppers, spiders, horse flies, butterflies, and bees frequented the snowfields. Birds were generally scarce, although there were some songbirds near the Hidden Lake Trail and we did see one hummingbird at the Siyeh Pass snowfield.

Discussion

Plants growing on the edges of snowfields and glaciers are critically situated since these reservoirs of frozen water are retreating at a rapid rate, and their retreat will change the habitat of snowfield plants, which are able to survive in the unique environment at the edge of alpine snowfields. Plants of snowfields, and the plants that depend on the water and nutrients derived from snowfields (but which do not actually live in the snowfield environment) may serve as important biological sentinels of climate change in alpine environments (Björk and Molau 2007). Snowfields provide an environment with low soil temperatures and snow cover that persists late into the growing season, two factors that are sensitive to climate change, and snowbed specialist plants are likely to lose their habitats and be replaced by avoiders of late-snowmelt sites (Schöb et al.

2009). Snowfield plants may succumb to frost damage if they no longer have their snow cover, and they may not be able to increase productivity with a longer growing season, as was found with experimental lengthening of the growing season (Baptist et al. 2009). *Oxyria digyna* and other snowfield-linked species decreased on an isolated island in the North Atlantic Ocean (Kapfer et al. 2012). The GNP study of snowfield plants is important in gaining an understanding of the current state of snowfield plants, and will serve as a baseline for future research on the responses of plants at Glacier National Park to changes in habitats that occur with climate change.

Some species of the rare, peripheral arctic-alpine plants at Glacier National Park inhabit areas adjacent to snowfields, such as the fell field near the terminus of the Siyeh Pass snowfield, while others live in areas downslope from the snowfields that appear to be at least partially reliant on snowmelt as a water source. Thus, while a rare, peripheral arctic-alpine plant may not actually live at a snowfield's edge, it may still live in a habitat that is closely attuned to the seasonal availability of water, which is in turn likely influenced by the timing of melting snow from snowfields in the vicinity. For example, *Tofieldia pusilla* grows on the edges of ponds, lakes, and small streams that are fed by water from the summer melting of snowfields. Were the snowfields to disappear, water availability might change for *T. pusilla* and other species that grow in similar habitats.

Some of the rare, peripheral arctic-alpine plants do not live on the edges of snowfields or near the edges of ponds fed by snowmelt. Instead, they live on rocky ridges near snowfields. One example is *Aquilegia jonesii*, which lives on the rocky, steep, windswept ridge that separates Preston Park from Siyeh Pass. However, *A. jonesii* may be influenced by the snowfield, since its outer edges may reach *A. jonesii* earlier in the season, and A. jonesii may then derive water from the melting snow in the late spring and early summer, or, water may melt from the snowfield and charge the nearby soil with water, which is then available for xeromorphic plants such as *A. jonesii*, which has an extensive root system.

Oxyria digyna, Epilobium anagallidifoliu, Phacelia hastata, and *Carex sp.* grew very close to the snowfields. *O. digyna*, the subject of intensive study by Mooney and Billings (1961), was consistently found near the edge of all snowfields, where it had green leaves signifying photosynthetic activity within a short time following the melting off of its cover of snow. This sometimes rhizomatous species has thin, leaves produced from a crown. *E. anagallidifolium* is also found emerging near the edges of snowfields within a short time following snowmelt. *E. anagallidifolium* is similar to *O.*

digyna in that both species have thin leaves that become green quickly. Thin leaves are less expensive to produce, and the aboveground parts of *E. anagallidifolium* originate from the root crowns. Both species have roots that can anchor themselves in scree, and that apparently can also absorb the layer of water that accumulates at the very edge of the melting snowfields. *P. hastata* is frequently found emerging quickly after snowmelt at the edges of snowfields edges and it is characterized by having relatively thick, xeromorphic leaves that emerge from a taproot or caudex. Leaves of *Carex* sp. appear to arise quickly from caespitose roots, or in some cases, from rhizomes. Although *O. digyna*, *E. anagallidifolium*, *P. hastata*, and *Carex* sp. are very different taxonomically, their leaves share the ability to become green quickly after snowmelt, they all have substantial roots, (although the monocotyledonous roots of *Carex* sp. are vastly different from the taproot and root crown structures of the other three dicotyledonous species), and, importantly, they all have the developmental and physiological traits that allow them to thrive near the edges of snowfields.

Knowledge of the functional traits of snowfield plants, and of which of these functional traits allow them to live in the harsh environment of the snowfield's edge, will likely prove important in predictions of which plants require the snowfield, (or are, in other words, obligate snowfield plants), and which may be able to live in non-snowfield environments if the snowfields recede (thus shrinking the snowfield's edge habitat, as it will decrease with the decreasing perimeter of the snowfield), or if the snowfields disappear altogether, in which case the snowfield's edge habitat would also disappear. However, if even after the disappearance of persistent snowfields, snowbanks still accumulate in winter at Glacier National Park, the snowbanks may be able to mimic the snowfield habitat. It seems that it will be a question of how late into the season the snowbanks last, the timing and duration of snowmelt, and how profoundly they influence their environment in terms of cooling the ground, providing cover for plants that may rely on them for shelter from grazing animals such as mountain goats and the smaller, insectivorous herbivores, and providing shelter from the intensive alpine sun when leaves are being formed and emerging, and without the snow may be subject to oxidative stress. Questions to ask include the following: What are the functional traits of plants along the edges of snowfields? What are some commonalities among these traits? Is there a pattern?

We chose our particular methodology of establishing quadrats and transects because they will serve as geospatially referenced semi-permanent plots from which we can derive baseline data on snowfield plants, and researchers can use the plots as research tools to investigate snowfield plants over time.   For example, researchers can compare baseline data from 2012 with that of future visits and conduct statistical analyses of possible changes in plant abundance, assemblages, percent ground covered, and species dominance. The sites may also be used as springboards for related investigations, such as studies of seedbeds, seed persistence, and seed longevity in snowfield communities. Repeat photography of the plots can be used to determine the rate of cushion plant growth and of spread of plants that spread clonally, as in the case of rhizomatous perennials. Because some of the peripheral arctic-alpine plants do not inhabit the snowfields but live in boggy areas along streams derived from melt water, separate plots that would not destroy the bogs could be established, perhaps by standing on solid ground away from the bogs and using binoculars and/or zoom lenses to obtain a record of the plants. If such photographs were geospatially referenced, it would be possible to return to the same place for repeat photography and subsequent analyses.   If future funding and logistics permit, it would be useful to place soil temperature and moisture sensors at the sites in order to gain information on climatic parameters. Measurement of the interval between release from snow cover and appearance of leaves and flowers would also provide valuable information. Importantly, information on the geophysics of these particular snowfields could be linked with studies of snowfield plants.

Greenhouse, growth chamber, and/or common garden experiments could be useful in determinations of whether species that are typical found very close to snowfields require that environment, or whether they can live in other habitats but live near the snowfields because they can, and because life near the snowfields may reduce competition from plant species that are not as well equipped developmentally and/or physiologically to withstand life at the edges of snowfields. In addition, physiological parameters of these plants could be measured to obtain a greater understanding of their ability to live in these environments. For example, growth experiments could be determined in order to ascertain the temperature, light, and moisture regimes necessary for such vital processes as seed germination, root growth, leaf production, photosynthesis, respiration, flower development and seed production.

Species that already exist at the edges of snowfields appear to emerge and become green very quickly with snowmelt and thus become established for the season. It would be very informative to place soil moisture sensors along the gradient beginning within the snowfield and moving to the scree/soil around the edges of snowfields and onward to the area beyond the snowfields. Temperature sensors could also be used to obtain species-specific determinations of the temperature of the soil when the roots begin to grow and when the leaves begin to emerge. Likewise, it would be informative to determine exactly when snowfield species produce their leaf primordial and their leaves, and to determine when the roots become metabolically active. It would also be valuable to measure the quantity and quality of light that reaches the scree-plant interface. For instance, *O. digyna* had green, mostly expanded leaves with anthocyanins within at most two days since it had been covered by snow in a snowfield that melted 4-5 m in one day along the lateral, south-facing edge of the snowfield. Sensors could be carefully placed near some of the more rare arctic-alpine plants in order to learn about their ecophysiological traits with minimal disturbance.

Two very important aspects of plant life are symbiotic. The first, nitrogen fixation, involves forming a symbiosis with nitrogen fixing bacteria, which inhabit root nodules or other structures of plants, often in the Fabaceae. There were few nitrogen-fixing plants at the GNP snowfields, although *Astragalus bourgovii* grew near the Mt. Clements and Siyeh Pass snowfields. *Dryas octopetela*, in the Rosaceae, has the capacity to form nitrogen fixing symbioses with *Frankia*, and it was found at Preston Park Transect Two, Siyeh Pass Transect One, the Siyeh Pass High Snowfield, and at Piegan Pass Transect Two. *D. octopetala* covers extensive areas on the slope between Preston Park and the Siyeh Pass snowfield.
The second of these two symbioses is mycorrhizae, in which roots form symbiotic relationships with soil fungi. The presence of mycorrhizae contributes to increased growth, nutrient uptake, and drought protection. Many of the plants at the GNP snowfields are mycorrhizal, including the nearby *Abies lasiocarpa*, which is ectomycorrhizal. Plants at or near the GNP snowfields that have been found to be arbuscular mycorrhizal (AM) at the Beartooth Plateau (Cripps and Eddington 2005) include *Achillea millefolium*, *Senecio cymbalarioides*, *Senecio fremontii*, *Solidago multiradiata*, *Campanula rotundifolia*, *Phacelia hastata*, *Poa alpinum*, *Potentilla diversifolia*, and *Sibbaldia procumbens*, while *Phyllodoce glandulifolia* had ericoid mycorrhizae and *Salix arctica*, *Polygonum viviparum* and *Dryas octopetela* were ectomycorrhizal. These symbioses may prove to be very important determinants of plant life in changing snowfield communities (Cazeres et al. 2005, Cripps and Eddington 2005).

These two symbiotic relationships involve roots, but it would also be very valuable to study root architecture in alpine plants in the context of water obtained from snowfields. For example, if an alpine plant species had extensive root systems that allowed it to inhabit a slope, such as the one separating the Preston Park and Siyeh Pass areas, it may be able to survive in that area if water supplies dwindled due to receding snows. It would also be useful to know if plants at the very edges of snowfields undergo a pulse of root growth and metabolism synchronous with the summer snowmelt at the edges of the snowfields.

Predictions of future distributions of plants can be based on current distributions of plants. For example, *Penstemon ellipticus* grows above the high Siyeh Pass and the Mt. Clements snowfields, along the Mt. Clements moraine, and below the Mt. Clements snowfields. If these snowfields vanish and more ground is exposed, *P. ellipticus* may expand its range downward, laterally, or upward into what is now the snowfield if the newly exposed land is suitable for *P. ellipticus*.

Quadrat sampling and the photographs of each quadrat from each transect, along with other snowfield photographs provide records of species presence, abundance, and percent cover, as well as information on functional traits of the different species. For example, if a hypothetical *Sedum sp*. is photographed 10 m away from a snowfield's edge, we know that that particular species with water storing leaves stores can grow in that particular location. Since the photographs were taken along a transect of distance away from the snowfields' edges, then important delineations in substrate, plant cover, species appearance with distance from the snowfield, phenology, plant communities, and so on, can be recorded. Some seed dispersal agents and pollinators may also appear in the photographs. If the transects are visited in future studies, then changes over time in these factors can be detected. Abrupt changes in species, functional types, and percent cover can also be detected, and these changes may prove, with more research, to be indicative of the seasonal and historical length of time without snow, distance from the snow pack, water availability, substrate composition, and thermal regimes. One possible scenario is that of a particular species assemblage which is usually only present in areas with a relatively long snow-free season. If this species assemblage begins to appear next to the edges of snowfields relatively early in the summer, it could indicate a shift in snowfield dynamics, and likely an increase in the duration of the snow-free season, that would support the particular species assemblage. The presence or absence of lichens in the photographs may be indicative of the length of time that a particular site is seasonally or historically free of snow, since slow-growing lichens would likely need time to establish themselves during the snow-free period of the year. For example, a site without lichens may indicate that is has previously been under snow cover. One caveat, though, is that lichens may not have become established on that particular site for reasons other than snow cover. The presence of cushion plants that require a snow-free period of time before establishment may also indicate the seasonal and historical duration of seasons without snow cover. However, it may be relatively involved to separate the current seasonal dynamics of the snow-free season from determinations of historical snow-free seasons, and, from usual snowfall that is not part of snowfields *per se*.

The influence of hikers on snowfield plants can be studied at snowfields adjacent to trails, at such places as Piegan and Siyeh Passes. The very high snowfield at Siyeh Pass is of interest because of its elevation, and because it is virtually adjacent to a trail. It may be useful to establish transects at this snowfield because information can be gained on the effects of hikers on snowfield plants, and possibly on the effects of hikers on the plants of retreating snowfields. Plants at this very high snowfield included *Myosotis alpestris*, *Silene acaulis*, *Penstemon elipticus, Oxyria digyna*, *Phacelia lyallii*, *Dryas octopetala*, *Salix arctica*, and *Potentilla uniflora*.

Seed dispersion and the establishment of a seed bank are two important facets of alpine plant life. If the seeds of alpine plant species have great longevity, then exposure of terrain previously covered by snow may expose some viable seeds that were previously under snow. If these seeds are of different species than are currently on the edge of snowfields, then the possibility exists for a change in species composition in the newly exposed terrain. It would be very interesting to determine how quickly seeds can be dispersed newly exposed localities and begin to establish a new seed bank, possibly before seed germination would actually happen. It is plausible that this could happen if seeds were to be imported into an area late in the season as winter was beginning. Of course, this would all depend on the edaphic conditions necessary for seed germination, since some species germinate best in colder temperatures. The establishment of seed banks could perhaps be investigated by establishing a number of pairs of quadrats at suitable sites, and by sampling the soil from one quadrat while monitoring any visible germination in the field from the other quadrat of each pair (Lundemo, pers com).

Hoary Marmots and other animals are likely instrumental in bringing seeds to the exposed sites. The Hoary Marmots at GNP live in rock piles near the edges of snowfields and travel inward to the snowfields, possibly transporting seeds in their fur. While walking between the rock piles and the snowfield, they eat the leaves of existing plants (mostly O. digyna and *E. anagallidifolium*), possibly dispersing the seeds of plants that have produced them. The hay-gathering activities of the Pika may also serve as a means of seed dispersal, as may the bulb-digging actions of the Grizzly Bear, and the grazing of alpine and subalpine plants by the Mountain Goats, which could conceivably transport seeds in their long, white fur.

It would be most valuable to investigate the dynamics of seedling establishment at the edges of snowfields and glaciers. The requirements for seedling establishment in these icy environments likely vary with species, seed dispersal, longevity and germination.

Silene acaulis is an abundant alpine plant with a cushion morphology that is often inhabited by other plants that do not form cushions. *S*. *acaulis* and other cushion forming plants may function as nursery plants for the other plants, and it may be that this aspect of S. acaulis is a mechanism of plant community change. Given the snowfield's edge scenario of other, inhabitor, plants becoming established in *S*. *acaulis* cushions when they may not otherwise be able to survive, and the eventual death of the *S*. *acaulis* cushions combined with growth of the inhabitor plants as well as possible shading of *S*. *acaulis* by the inhabitor plants, then the inhabitor plants may then survive and establish new species assemblages. This could be experimentally tested in greenhouse or growth chamber or field settings and could provide some useful knowledge of the dynamics, or mechanisms, of changes in species composition and abundance in snowfield communities.

It is very important to continue to monitor alpine plants as they respond to climate change (Kullman 2010). Long-term monitoring plots are valuable for repeated measures and for modeling, and thus predicting, responses of snowfield plants to climate change (Johnson et al. 2012), which have been used to predict a decrease in snowfield communities and an increase in shrub tundra at Niwot Ridge, Colorado (Johnson et al. 2012). One justification for continued monitoring is to increase human awareness of changes in the natural world, and increased awareness will be valuable in calibrating our responses to a changing world. Speaking botanically, monitoring is important because of species-specific responses of alpine plants to climate change which may lead to rapid changes in plant communities, and species at the edges of their ranges, such as the peripheral arctic-alpine species at Glacier National Park, are more likely to experience stress along these habitat edges (Abeli et al. 2012). Beyond monitoring, many questions remain. For example, characteristics of seed production and the seed bank are crucial to maintaining populations (Ninot et al. 2012), and more knowledge is needed of seed bank dynamics at Glacier National Park and its contiguous regions. Analyses of plant functional traits are another important means of predicting responses to environmental filters such as climate change (Venn et al. 2012). The above paragraphs represent thoughts and ideas on further research into the very compelling and timely topic of rare, peripheral arctic-alpine plants growing near the edges of retreating snowfields, or that grow closely enough to these snowfields so that changes in the snowfields may influence their abundance and distribution. It is my hope that this project can continue, possibly with at least one dedicated graduate student who would work with field botanists and others to further explore this important aspect of life at Glacier National Park.

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