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SITE CHARACTERISTICS FOR *SIBBALDIA PROCUMBENS* (ROSACEAE) ON THE UAPISHKA PLATEAU (MONTS GROULX), QUÉBEC, WITH NOTES ON THE ALPINE FLORA

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ABSTRACT. *Sibbaldia procumbens* occurs in arctic and alpine environments in widely disjunct locations in North America, Europe, and Asia. It is one of the rarest native plants in New England, with only a single station in New Hampshire. To inform conservation efforts for this species near the southeastern periphery of its North American range, we studied *S. procumbens* in alpine snowbeds on the Uapishka Plateau (Monts Groulx) in central Québec, a relatively poorly known mountain range in the Grenville geologic province where the species is abundant enough to evaluate associated site characteristics. *Sibbaldia procumbens* was positively correlated with slope, southern aspect, and elevation, with the highest abundances associated with 22–26° slopes, 100–230° aspect, and elevations of 1024–1039 m. At our site in Québec, *S. procumbens* was more abundant in association with bare rock, supporting the findings of previous authors that *S. procumbens* may benefit from some level of disturbance. We also quantified the dominant vascular plant species in both snowbed and summit communities on the Uapishka Plateau.

Key Words: *Sibbaldia procumbens*, Québec, Monts Groulx, Uapishka, arctic-alpine, snowbed, disturbance, Rosaceae

Sibbaldia procumbens L. is distributed throughout the circumpolar North, extending south to Arizona and New Mexico in alpine environments in the western USA (Coker 1966), and is especially common in areas of late-lying snow (Aiken et al. 2003; Billings and Bliss 1959; Brouillet et al. 1998; Holway and Ward 1963). In eastern North America, it reaches its southern extent on Mount Washington, New Hampshire, one of two general areas of known occurrence south of the Gulf of St. Lawrence (Harris et al. 1977). The New England population of *S. procumbens* was first reported by William Oakes in July 1846 (Oakes 1846, in Pease 1917). Today, *S. procumbens* is extremely rare on Mount Washington, and it is listed as "Endangered" under New Hampshire's Native Plant Protection Act of 1987 (NH RSA 217-A; New Hampshire Natural Heritage Bureau 2011) and as a priority species in the Flora Conservanda (Brumback et al. 1996). *Sibbaldia procumbens* produces fruits at this site (New Hampshire Natural Heritage Bureau, unpublished data; Sperduto 1997), and it is unclear why the Mount Washington population is so small and confined to a single glacial cirque. However, pressure from collection, climate change, or an absence of regular herbivore disturbance to reduce competing vegetation could be potential reasons for its decline. Recent studies of alpine snowbed vegetation in other regions suggest that *S. procumbens* is disturbance dependent (e.g., Virtanen et al. 1997) and in some cases responds to the reduction of taller competitors by herbivore grazing. In the Rocky Mountains, *S. procumbens* has been found more abundantly near trails (Dale and Weaver 1974), possibly responding to the increased sunlight. Between 2003 and 2008, the Mount Washington population appeared to have an extremely limited distribution (pers. obs.) unsuitable for landscape-scale analyses. We conducted a small field study on the Uapishka Plateau (also known as the Monts Groulx) in central Québec to determine site characteristics associated with *S. procumbens*. We report these results, as well as general observations on the alpine flora of the Uapishka Plateau.

METHODS

Our study area was located on and adjacent to the alpine summits of Mont Jauffret and Mont Tour Boissinot on the Uapishka Plateau (Monts Groulx), an alpine tableland in the Grenville geologic province of central Québec (51.6°, −68.1°), 850 km from the Mount Washington site. At least two cursory botanical surveys of the region have been published (Landry 1969; Lavoie 1984), but to our knowledge, much of the Plateau has not been surveyed. During six reconnaissance trips between 2008 and 2010, we conducted general surveys of the alpine flora of the western Uapishka Plateau with the purpose of identifying unique or rare alpine communities. We characterized the summit vegetation using two perpendicular 50 m transects on each of three massifs: Mont Jauffret-Boissinot, Mont Veyrier, and Mont Provencher. A 0.1 m × 0.4 m plot was placed every 2 m along each 50 m transect. This plot size has been shown to be effective for sampling alpine plant communities (Eddleman et al. 1964). The percent cover of each vascular plant species present in each plot was noted. The most common summit species were calculated by averaging across all three summit areas.

During these surveys, we also noted the location and extent of late-lying snow and corresponding snowbed vegetation. In August 2010, we placed 15 transects throughout snowbeds on the Jauffret-Boissinot massif. Each transect was near the center of a snowbed community, as evidenced by late-lying snow observed in previous visits and the presence of characteristic snowbed species (e.g., *Diphasiastrum alpinum* L. Holub, *Sibbaldia procumbens*, or *Salix herbacea* L.). The 20 m transects were situated along an area of generally consistent slope and aspect. Average slope, aspect, and elevation, as well as the overall area of the snowbed (in m^2), were recorded for each transect. Aspect was transformed using radians and scaled from 0 to 1 so that southern aspects received a value of 1 and northern aspects, a 0 (Beers et al. 1966).

A 0.1 m $\times$ 0.4 m rectangular sampling plot was placed every 2 m, for a total of 10 plots along each transect. Within each plot, the percent cover of each vascular plant species was noted. Nomenclature follows the Flora of North America (1993+). Total percent cover of bryophytes and lichens was also noted, though these groups were not identified to species. To obtain a total abundance of *Sibbaldia procumbens* and bare rock (as a surrogate for disturbance) across each transect, the abundance in each plot was summed across the entire transect.

Analyses were conducted at two scales: at the plot level and the snowbed (transect) level. At the plot level, the probability of presence of *Sibbaldia procumbens* within a plot was predicted using binary logistic regression analysis of the abundance of other species within the same plot. Five logistic regression models were created using each of the five vascular plant species occurring in 20% or more of the plots (at least 30 of 150 plots) as the predictor variable. A logistic regression model was also fit using the abundance of bryophytes in each plot as the predictor, as they occurred in 102 of the 150 plots. In all six models, transect was included as a fixed factor, as suggested by Legendre (1993) to account for differences between transects. The improvement of each of the six models over the simple logistic regression model (with the transect factor alone) was compared using ANOVA, with an alpha level adjusted using a sequential Bonferroni (Holm 1979) to reduce familywise Type 1 error.

At the transect level, environmental variables (i.e., slope, aspect, elevation, and snowbed size) were used to predict total abundance of *Sibbaldia procumbens* across each transect using linear regression. A sequential Bonferroni adjustment (Holm 1979) was used to control familywise Type 1 error.

RESULTS AND DISCUSSION

The Uapishka Plateau hosts extensive alpine snowbed communities and a summit flora typical of the potassic summit floras of eastern North America (Fernald 1907). The dominant summit flora of the Jauffret-Boissinot, Veyrier, and Provencher massifs consists of *Carex bigelowii* Torr. *ex* Schwein., *Anthoxanthum monticola* (Bigelow) Y. Schouten & Veldkamp, *Vaccinium uliginosum* L., *V. vitis-idaea* L., *Arctous alpina* (L.) Nied., *Rhododendron lapponicum* (L.) Wahlenb., and *Diapensia lapponica* L. Scattered patches of *Abies balsamea* (L.) Mill. and *Picea mariana* (Mill.) Britton, Sterns & Poggenb. form sheltered krummholz where *Trientalis borealis* Raf., *Maianthemum canadense* Desf., and *Clintonia borealis* (Aiton) Raf. commonly occur with other boreal species.

During summit and snowbed surveys, we recorded several species that had apparently not been reported by Landry (1969) or Lavoie (1984) during their earlier surveys, suggesting that the larger area has the potential to support additional species that have not yet been recorded there. These species include *Diphasiastrum sitchense* (Rupr.) Holub (near Mont Veyrier and on Massif Provencher); *Geocaulon lividum* (Richardson) Fernald (on the southern shoulder of Massif Provencher); *Sanguisorba canadensis* L. (multiple locations on Monts Jauffret and Boissinot, e.g., 51.627°, −68.118°); *Cardamine bellidifolia* L. (on wet cliffs near the summit of Mont Tour Boissinot; 51.611°, −68.085°); and *Salix vestita* Pursh (north of Lac Boissinot; 51.607°, −68.112°).

The most commonly occurring species in the snowbeds were those presented in Table 1. In addition, *Sibbaldia procumbens* was among the six most common, occurring in 33 of the 150 plots. At the plot level, *S. procumbens* was more likely to occur in plots with lower abundances of bryophytes, *Rubus chamaemorus* L., *Coptis trifolia* (L.) Salisb., *Solidago macrophylla* Pursh, and *Betula glandulosa* L., and with a greater abundance of *Salix herbacea* (Table 1). Of these, only *B. glandulosa* did not explain significantly

Table 1. Results from binary logistic regression models predicting presence on the Uapishka Plateau, QC, of *Sibbaldia procumbens* in each of 150 plots, with the inclusion of transect as a fixed factor. Each of the six models was compared with the simple transect model using ANOVA. The resulting p-values were tested against a sequential Bonferroni adjusted alpha (α; * = significance). Freq. = frequency of occurrence among the 150 plots; Parameter Est. = parameter estimate; AIC = Akaike's information criterion; Deviance Expl. = Deviance explained.

Explanatory Variable	Freq.	Parameter Est.	z-value	AIC	Deviance Expl.	p-value	α
Bryophytes	102	−0.05	−3.18	139.1	0.10	0.0001	0.0083*
Rubus chamaemorus	30	−0.25	−2.38	143.2	0.07	0.0009	0.01*
Coptis trifolia	59	−0.21	−2.04	145.2	0.06	0.0029	0.0125*
Salix herbacea	46	0.05	−2.47	146.8	0.05	0.0069	0.0167*
Solidago macrophylla	71	−0.03	−2.09	147.8	0.04	0.0116	0.025*
Betula glandulosa	30	−0.02	−0.87	153.2	0.01	0.3441	0.05

more variation than the transect factor alone, using a sequential Bonferroni adjustment.

At the transect level, the highest abundances of *Sibbaldia procumbens* (i.e., the three transects where the species was present in at least half of the plots) occurred at slopes of 22–26°, aspects of 100–230°, elevations of 1024–1039 m, and where bare rock comprised 5–8% of the transect. *Sibbaldia procumbens* abundance was positively correlated with slope, southern aspect, bare rock, and elevation, but only slope was significant at the Bonferroni corrected alpha level of 0.01 (Table 2). *Sibbaldia procumbens* was significantly more abundant in snowbeds that were steeper in slope, which accounted for 46% of the variation in the abundance of the

Table 2. Correlation between environmental variables and abundance of *Sibbaldia procumbens* at the transect level (n = 15) on the Uapishka Plateau, QC. * = significance of p-values tested against a sequential Bonferroni adjusted alpha (α).

Variable	Estimate	t	p	r^2	α
Slope	9.66	3.36	0.005	0.46	*
Aspect	159.30	6.63	0.021	0.35	
Bare rock	1.11	2.15	0.051	0.26	
Elevation	1.37	1.89	0.081	0.22	
Area	0.05	0.83	0.42	0.05	

species. Snowbed area had no relationship with abundance of *S. procumbens*.

Our results suggest that on the Uapishka Plateau, *Sibbaldia procumbens* occurs in greatest abundance in steep, south-facing snowbeds, at high elevation with a relatively high abundance of bare rock. At the plot level, *S. procumbens* was more likely to occur in plots with a high abundance of *Salix herbacea*, another common snowbed species. It was less likely to occur in plots with greater amounts of bryophytes, boreal species such as *Rubus chamaemorus* and *Coptis trifolia*, and *Solidago macrophylla*.

Our results corroborate, or do not refute, previous studies in other parts of the species' range that have shown *Sibbaldia procumbens* to be more abundant on south-facing slopes (Matthews 1978), to be associated with areas of moderate disturbance (e.g., Dale and Weaver 1974; Virtanen et al. 1997), and to apparently rely on herbivore disturbance to reduce tall competitors. Elsewhere, disturbance has been associated with grazing, trampling, or slumping soil associated with steeper slopes. Cole (1995) found the species to be moderately tolerant of trampling. Incidental observations by the authors on Mont Richardson and Mont Jacques Cartier in the McGerrigle Mountains of Québec, the closest known population to Mount Washington, revealed *S. procumbens* growing in local profusion along both human and caribou trails in areas of limited tall vegetation; but, with our limited observations, it is impossible to determine which combination of increased light, decreased competition, or disturbance itself might be the driving *S. procumbens* abundance.

Most evidence suggests that *Sibbaldia procumbens* is disturbance dependent, and herbivores or other processes that fill a similar role (e.g., avalanches or disturbance along human trails) may keep competitors at bay. Woodland caribou are associated with alpine tundra in eastern North America, and at some sites, caribou have been shown to alter vegetation composition and structure through grazing and trampling. Although it is unclear whether woodland caribou were present on Mount Washington during historic times, it is possible that the decline of *S. procumbens* could have been rapid following extirpation of caribou. Under this scenario, by the time the botanists arrived in the nineteenth century, *S. procumbens* was in decline. Reportedly, caribou occurred around the Connecticut Lakes in the early 1900s (e.g., Silver 1957), but they were not mentioned in Lucy Crawford's *History of the White Mountains*

(Crawford 1846). There is, however, strong evidence that they were native in Maine in the ninteenth century, and at least seasonally present on Katahdin (Palmer 1938), a similar mountain with a smaller area of alpine tundra than the Mount Washington massif (Kimball and Weihrauch 2000).

Although there are no large ungulates regularly present above treeline on Mount Washington today, the *Sibbaldia procumbens* population is located in a steep ravine, where avalanches may be an important alternative disturbance mechanism. But if the population is declining due to lack of disturbance, active management to remove competing vegetation may be necessary, near the current station of *S. procumbens* or other potential colonization sites, to enable the Mount Washington population to increase in size. The reasons for the population's decline and current limited extent are unknown, however, and rather than lack of disturbance, one could speculate that the Mount Washington population might have declined as a result of overcollection, changing climate conditions, or some combination of these. The limited distribution of *S. procumbens* could have resulted from the constraint of alpine vegetation during the hypsithermal, which may have caused the loss of several other alpine species (Miller and Spear 1999). Climate models project that regional temperatures and precipitation will increase over the coming century (Hayhoe et al. 2007), which could facilitate taller competitors, negatively influencing *S. procumbens* at its southern extent. Long-term climate data, however, suggest that warming and precipitation trends are less clear in northeastern alpine areas (Seidel et al. 2009), so it is difficult to assess how northeastern alpine plants might be influenced by climate in the future.

Because individuals from the New England population have been observed fruiting (New Hampshire Natural Heritage Bureau, unpublished data; Sperduto 1997), reestablishment through transplantation of laboratory-grown plants could eventually prove successful, given that transplant success for this species has been reported to be moderately successful elsewhere in its range (44%; May et al. 1982). In addition, recent transplantation of lab-grown *Potentilla robbinsiana* Oakes *ex* Rydb., a related Rosaceae species, has been proven successful on Mount Washington (Brumback et al. 2004). Our results, and those of previous studies, could be used to guide surveys, transplantation efforts, and other management decisions for this species in New England.

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