Using Distance Sampling to Estimate Density and Abundance of *Saussurea Weberi* Hultén (Weber's Saw-Wort)

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USING DISTANCE SAMPLING TO ESTIMATE DENSITY AND ABUNDANCE OF *SAUSSUREA WEBERI* HULTÉN (WEBER'S SAW-WORT)

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Abstract—*Saussurea weberi* Hultén (Weber's saw-wort) is a rare alpine calciphilic plant of the Rocky Mountains with disjunct populations in Colorado, Wyoming, and Montana. In Colorado, populations of *S. weberi* are scattered among <20 locations within the Mosquito Range and Hoosier Ridge regions. *Saussurea weberi* has specific habitat requirements, and its populations or populations of its pollinators may be susceptible to changing climatic conditions and use of off-road vehicles. It is scarce and discontinuous throughout its range, and there is no reliable estimate of density or abundance. Most estimates of abundance are based on cursory visits and unreplicated counts. To quantify size of the population at one of its centers, I used distance-sampling techniques to sample the population at Horseshoe Cirque, Park County, Colorado. I estimated density and abundance and examined variability of estimates to provide information for understanding the size of populations and for guidance in future protocols for sampling.

Resumen—*Saussurea weberi* Hultén es una planta alpina poco común de suelos de sales de calcio en las Rocky Mountains con poblaciones disyuntas en Colorado, Wyoming y Montana. En Colorado se dispersan poblaciones de *S. weberi* en <20 lugares dentro de las regiones del Mosquito Range y Hoosier Ridge. *Saussurea weberi* tiene requisitos particulares de hábitat, y sus poblaciones o las poblaciones de sus polinizadores pueden resultar susceptibles a condiciones cambiantes de clima y el uso de vehículos de todo terreno. Es una planta escasa y discontinua por toda su distribución geográfica y no existen estimaciones confiables de su densidad ni abundancia. La mayoría de las estimaciones de abundancia se basa en visitas superficiales y conteos no replicados. Para cuantificar el tamaño de la población en uno de sus centros, se usaron las técnicas de muestreo de distancia para muestrear la población en Horseshoe Cirque en el condado de Park del estado de Colorado. Hice estimaciones de la densidad y la abundancia y evalué la variabilidad de las estimaciones para proporcionar información que sirva para entender el tamaño de las poblaciones y para proveer orientación para los protocolos de muestreos futuros.

Saussurea weberi Hultén (Weber's saw-wort) is a rare alpine plant of the Rocky Mountains of Colorado, Wyoming, and Montana. It is a member of a monophyletic tribe of some of the earliest branches of the Asteraceae family (Bremer, 1994) and is a short (<25 cm), perennial herb with lanceolate leaves and tightly-clustered purple flowers (Keil, 2006). Populations of *S. weberi* are found at elevations >2,900 m on exposed subalpine and alpine slopes of gravelly scree, usually derived from limestone or dolomite (O'Kane, 1988; B. Glisson, in litt.). In Colorado, there are 17 known locations for *S. weberi*, and nearly all are on federal lands in the Mosquito Range or Hoosier Ridge areas of Park, Lake, and Summit counties. It has no special federal conservation status under the Endangered Species Act, but the United States Forest Service considers it a sensitive species in Wyoming and Montana, and the Bureau of Land Management considers it a sensitive species in Colorado (B. Glisson, in litt.). NatureServe (http://www.natureserve.org/explorer/) ranks *S. weberi* as a globally-imperiled species throughout its range. Estimates of populations vary widely from a few individuals to >10,000 in one locally-abundant population in Wyoming, and all locations are lacking rigorous estimates of the size of populations (B. Glisson, in litt.).

The threats to *S. weberi* are driven by its specific requirements for habitat, the limited availability of appropriate habitat, and the potential impacts of environmental stochasticity on populations of the plant and the pollinators (B. Glisson, in litt.). The elevations at which most populations of *S. weberi* are found minimize impacts from grazing, but some populations are in close proximity to heavy use of off-road vehicles. Of increasing interest is the impact climatic change may be having on this species. Given the harsh, cold climate to which these plants are adapted, alterations in growing season can adversely affect phenology or biology of pollinators (Guisan and Theurillat, 2000; Parmesan, 2006). *Saussurea weberi* is known to have specific flowering phenology and few pollinators (Abbott, 1998; Abbott, 2007; S. C. Spackman et al., in litt.), and climatic changes may adversely affect synchronization of visitation by pollinators and the timing of flowering. There is no active management in place for this plant, but, because of its patchy distribution, specific habitat requirements, limited geographic range, and small populations, conservation is warranted.

Effective management of *S. weberi*, as with other rare species of plants, requires knowledge of conditions of each population (Holsinger and Gottlieb, 1991; Schemske et al., 1994). For populations of rare plants, the consequences of not knowing size and structure of populations can have dire consequences for management (Morgan, 1999). Professional botanists have made preliminary estimates of populations of *S. weberi*, but no formal estimate has been made (B. Glisson, in litt.). The largest populations in Colorado may have as many as 4,500 individuals near Mount Bross, and >1,000 individuals near Mount Sheridan in the Mosquito Range (Colorado Natural Heritage Program Biodiversity Tracking and Conservation Systems database, BIOTICS, www.cnhp.colostate.edu). These estimates were made using nonrandom, unreplicated counts of individuals per area that were extrapolated to the presumed population extent. Unfortunately, such estimates are suspect at best. For the population at Mount Bross, estimates vary widely from 86–4,500 individuals (B. Glisson, in litt.). Improved techniques for estimating populations are available that would improve the precision of estimates of abundance, increase sampling efficiency, and provide an understanding of the uncertainty of estimates.

Distance sampling is a process of estimating abundance of organisms by modeling the detection function for observed organisms. Instead of estimating the number of individuals within a set geographic area, distance-sampling models the area from which organisms are detected (Buckland et al., 2001). This area is modeled using the probability of observing organisms as a function of the distance of those organisms from a point or transect. As the observer travels a transect, perpendicular distances to individuals are recorded. For sampling plants, the assumptions of the techniques of distance sampling are that all objects on the line are observed and distances to objects are measured accurately (Buckland et al., 2001). This methodology has been successfully applied to other populations of rare plants (Buckland et al., 2007), and *S. weberi* may be an ideal candidate for distance sampling because individuals are small and difficult to detect because they may be obscured by other alpine vegetation.

To provide reliable estimates of size and density for one of the largest populations of *S. weberi* in Colorado, I visited the population at Horseshoe Cirque on the east side of Horseshoe Mountain in 2006, sampling the population using distance-sampling techniques. The objectives of this work were to provide estimates of the size of the population of *S. weberi* that incorporate detection probability, use sampling methodology that can be replicated to assess changes in condition of the population of *S. weberi*, provide recommendations for improving distance-sampling techniques for estimation of populations of *S. weberi*, and initiate strategies for monitoring populations that are priorities for research by the United States Forest Service (B. Glisson, in litt.).

Horseshoe Cirque is located ca. 3 km southeast of Mount Sheridan in western Park County, Colorado, at the headwaters of Fourmile Creek. A population of *S. weberi* is located within the cirque at 3,750 m and adjacent to roads that lead to abandoned mining operations and an historic high-elevation pass. The population extends through ca. 141 ha of alpine meadow and willow shrublands, near scattered tarns and several glacier-melt lakes. Another population of similar extent occurs north of Horseshoe Cirque near the Peerless Mine. Most of the population is found in vegetated, stable tundra, instead of adjacent barren soils. Horseshoe Cirque and the surrounding area is managed by Pike and San Isabel National Forest, United States Forest Service, and is home to two globally imperiled plants, *Ipomopsis globularis* (Brand) W. A. Weber (Hoosier Pass ipomopsis) and *Draba grayana* (Rydb.) C. L. Hitchcock (Gray's draba), and home to two rare plants of Colorado, *Parnassia kotzebuei* Chamisso ex Sprengel (Kotzebue's grass-of-Parnassus) and *Kobresia simpliciuscula* (Wahlenberg) Mackenzie (simple bog sedge; J. A. R. Ladyman, in litt.; S. S. Panjabi and D. G. Anderson, in litt.; S. C. Spackman et al., in litt.).

The population was defined as the 141-ha mapped extent of the population of *S. weberi* at Horseshoe Cirque based on data in the Colorado Natural Heritage Program database (Colorado Natural Heritage Program BIOTICS, www.cnhp.colostate.edu). The spatially-mapped polygon was visualized in ArcView 3.3 (Environmental Systems Research Institute, Redlands, California), and 200 random points were drawn using the Minnesota Department of Natural Resources Sample Generation Extension version 2.6 (Minnesota Department of Natural Resources, St. Paul, Minnesota). These random points were the starting points for distance-sampling transects.

Sampling was conducted from 27–28 July 2006 using 200-m-long transects that were perpendicular to the slope of the area (i.e., traversed the slope). Having transects traverse the slope made observation of plants easier and allowed more transects to be sampled. Once the starting point for the transect was identified, I extended twine from this point to delineate the transect and traversed the area approximately perpendicular to the slope. After stretching the twine, I walked the transect again looking for *S. weberi* and recording perpendicular distances. Nine transects were sampled over 2 days. Inclement weather and lightning prevented sampling during midday, so most sampling was conducted between 0700 and 1100 h and between 1400 and 1700 h. To satisfy the assumptions of distance sampling, I scanned areas along the transect twice to ensure detection of plants on the line. Also, I measured perpendicular distances from the transect using a measuring tape. Because plant-specific attributes may make particular individuals easier to see, I recorded covariates of number of inflorescences and basal diameter of each plant observed (Marques and Buckland, 2003).

Distance data were analyzed using the multiple-covariate-distance-analysis engine in Program Distance 6.0 Release 2 (Research Unit for Wildlife Population Assessment, University of St. Andrews, United Kingdom). It is recommended that 5% of observations furthest from the transect be removed (truncation of data) because observations far from the transect provide little information for estimation of abundance (Thomas et al., 2010). I truncated data using the 5% rule but also generated another dataset using a truncation at 4 m because there was an obvious decrease in detections beyond this distance (Fig. 1). Truncation beyond 4 m removed 2.8% of the observations. Because number of inflorescences and basal diameter of plants were highly correlated ($\rho = 0.77$), no model was built using both covariates. Models of detection function were generated, and the most parsimonious models (explaining the most variability using the fewest terms) were assessed using Akaike's Information Criterion (AIC; Burnham and Anderson, 2002). Models within three values of AIC were considered tenable models (Burnham and Anderson, 2002).

Seventy-three individuals of *S. weberi* were detected on six of the nine transects, with an average of 8 ± 3 plants/transect (range of 0–21), meeting the sample size of 60–80 individuals suggested for distance-sampling analysis (Buckland et al., 2001). Most plants were detected within 4 m of a transect (Fig. 1). Number of inflorescences ranged from 1–7 (mean = 1.3 ± 0.1 *SE*), and basal diameter of plants ranged from 2.5–43.2 cm (mean = 8.4 ± 1.0 *SE*). There was an obvious spike in observations on the transect (0 m) and fewer observations between 0.5 and 2.0 m (Fig. 1). Program distance allows the flexibility of including multiple adjustment terms in the model to fit these peaks and troughs, but, usually, this is unnecessary and can over-fit detection-function models. I restricted analyses to those functions that are known to model detection function well (uniform, half-normal, and hazard rate) with cosine, hermite, or simple polynomial adjustments (Thomas et al., 2010).

For the dataset with 5% truncation, the most parsimonious models were the half-normal with cosine adjustment and the hazard rate with hermite adjustment, and neither model incorporated covariates of basal diameter or number of inflorescences (Table 1). Similarly, the most parsimonious models for the dataset with 4-m truncation were the same two models. A hazard-rate model that incorporated covariate of basal diameter was the next-best model (Table 1). For all models, there was some overall lack of fit in the data (Kolmogorov-Smirnov test, range of *P*-values 0.01–0.04; Fig. 2), but this may not be problematic because the fit of the model near zero is of greater priority (Buckland et al., 2001). Despite slight differences

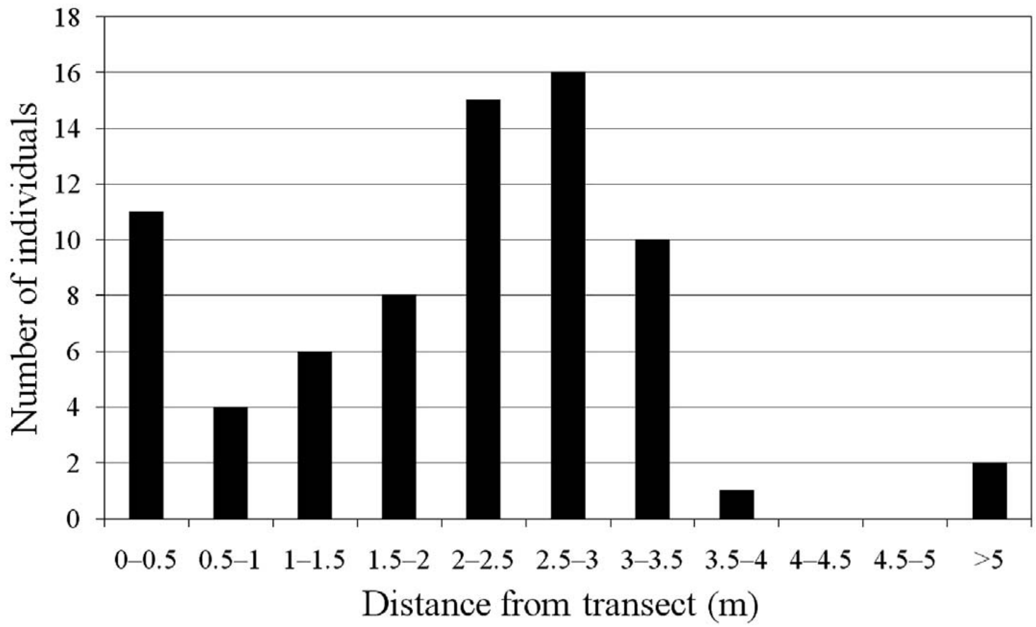

FIG. 1—Number of *Saussurea weberi* at Horseshoe Cirque, Park County, Colorado, by distance from the sampling transect.

in the two most parsimonious models in the 5%-truncation dataset, these models are essentially the same; the hermite function uses an additional parameter to fit the detection function, and this additional parameter penalizes the AIC value by 2 (ΔAIC = 2, Table 1).

Confidence intervals for density and size of the population were relatively large (mean *CV* = 36.4%, Table 1). The best model in the 4-m truncation dataset (half-normal with cosine) estimates the size of the population at Horseshoe Cirque at 8,002 individuals (95% CI of 3,597–17,805). However, using all of the best models to predict density, abundance, and variability ensures we incorporate model-uncertainty into estimates (Burnham and Anderson, 2002). Estimates of density were consistent among all of the most parsimonious models, with a model-averaged density of 57/ha (±21 *SE*; Burnham and Anderson, 2002). The model-averaged estimate of the size of the population at Horseshoe Cirque is 8,025 individuals (±3,547 *SE*).

Although the confidence interval of the size of the population is large, it provides a better understanding of the contribution the population at Horseshoe Cirque has to the size of the global population of *S. weberi* and provides a baseline estimate for abundance of *S. weberi* that can be used in temporal comparisons of this population or comparisons with other populations. Also, it provides a basis for refining the design of studies of this and similar species using distance sampling. For instance, there was a decrease in detection of *S. weberi* between 0.5 and 2.0 m from the line. It is possible that this plant is easier to detect when one is standing over it or is looking at the complete profile from 2–3 m away. At intermediate distances, this plant may be more difficult to detect and increased effort may be necessary in searches at these

TABLE 1—Most parsimonious models of probability-density-function, density, and abundance of *Saussurea weberi*. AIC = Akaike's Information Criterion, KS = Kolmogorov-Smirnov test, ESW = effective strip width, CI = confidence interval, *CV* = coefficient of variation.

Model	Covariates included	ΔAIC	KS *P*-value	ESW (m)	Density (95% CI; % *CV*)	Abundance (95% CI)
5% right truncation						
Half-normal with cosine adjustment	None	0.00	0.04	3.45	56.4 (25, 127; 38.0)	7,947 (3,521; 17,935)
Hazard rate with hermite adjustment	None	2.00	0.04	3.45	56.4 (25, 125; 35.6)	7,947 (3,584; 17,620)
Truncation at 4 m						
Half-normal with cosine adjustment	None	0.00	0.03	3.48	56.8 (25, 126; 35.9)	8,002 (3,597; 17,805)
Hazard rate with hermite adjustment	None	1.08	0.01	3.41	57.9 (25, 128; 36.0)	8,163 (3,667; 18,173)
Hazard rate with hermite adjustment	Diameter	1.58	0.03	3.46	57.0 (25, 126; 36.0)	8,027 (3,606; 17,866)

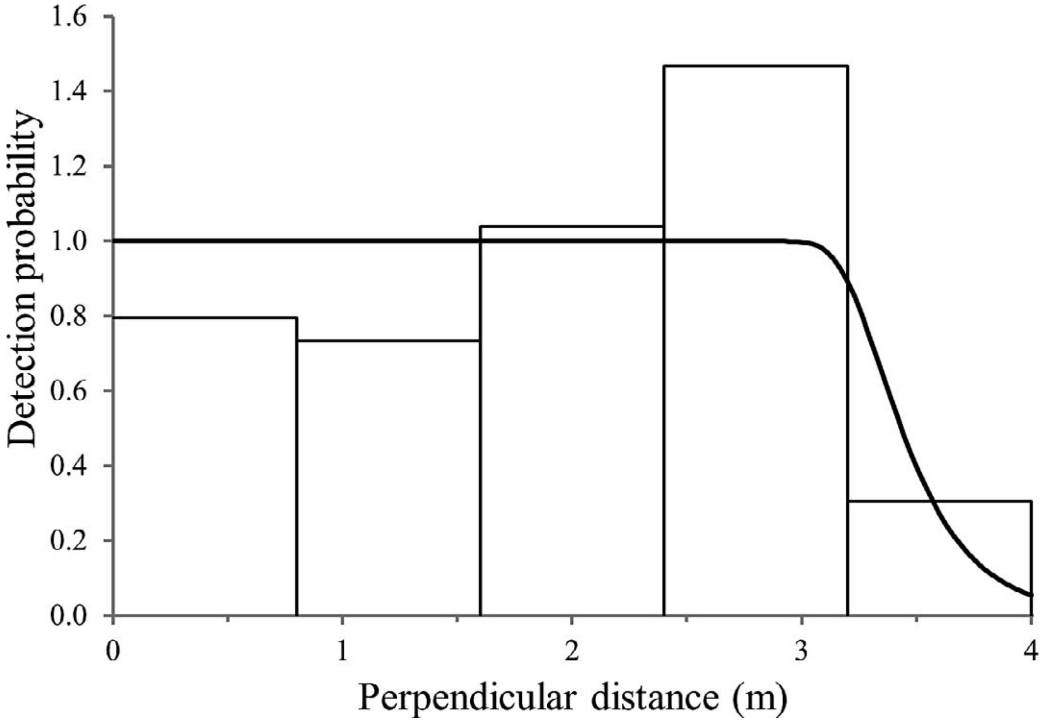

FIG. 2—Detection function of distance sampling of *Saussurea weberi* at Horseshoe Cirque, Park County, Colorado, based on the half-normal model with cosine adjustment.

intermediate distances. Based on the estimates of abundance provided in this study, the population at Horseshoe Cirque is the largest in Colorado and rivals the largest population within the range (B. Glisson, in litt.). However, more rigorous sampling of other populations likely would change current understanding of the contribution of the population at Horseshoe Cirque to the size of the global population.

Part of the motivation for this study was to understand how best to sample and estimate populations of *S. weberi*. The sampling strategy used at Horseshoe Cirque can be a template for designing sampling to achieve more precise estimates of density. Buckland et al. (2001) provide guidelines for using pilot data to improve the design of studies that use distance sampling. The total transect-length (L) needed to estimate abundance with a prescribed CV can be estimated using the following equation:

$$L = \left(b/(CV_D)^2\right)(L_0/n_0),$$

where CV_D is the desired coefficient of variation for the estimate of density, L_0 is the total line-length for the pilot study, n_0 is the number of individuals seen while sampling L_0, and b is an estimation of the variability of the number of individuals observed and the probability-density-function along the line (Buckland et al., 2001). Although difficult to estimate empirically, Burnham et al. (1980) recommend $b = 3$ for planning distance-sampling projects. Based on this pilot study, acquiring a 10% CV for the population at Horseshoe Cirque would require a total transect-length of ca. 7.4 km, which is 4.1 times longer than that for the pilot study. By extension, one would expect to encounter 300 individual *S. weberi*. Considering that the nine 200-m transects were surveyed by one person in approximately two 7-h sessions, sampling for a 10%-CV-density-estimate could be accomplished by two people in ca. 4 days. I would recommend using multiple 200-m transects to accomplish the total transect-length of 7.4 km because the topography at high elevations can make longer transects difficult to establish and sample. Also, it is advisable to establish transects using a visual marker, such as twine, to ensure the observer can accurately estimate the probability-density-function along the line and accurately estimate distances to individuals off the line (Buckland et al., 2001). Surveying in September or October, when the white pappus of plants provide a better contrast to the landscape, may increase detectabilty and increase sampling efficiency (B. A. Elliott, in litt.).

Besides being a simple sampling strategy, distance sampling provides some practical and theoretical advantages over traditional estimation of populations of plants. Compared to quadrat or strip-width sampling, distance sampling does not require the assumption that all individuals are observed. Eliminating this assumption means that less effort is needed to search an area. Additionally, probability of detection of individuals is modeled in distance sampling, whereas it is assumed to be 1 in surveys based on area. This assumption can be problematic for small or cryptic species (Buckland et al., 2001) and can necessitate greater effort to locate individuals. Lastly, the methodology of distance sampling is flexible to allow more intensive surveying when small populations are patchily distributed or individuals are extremely difficult to detect (Buckland et al., 2007).

There are many rare species of *Saussurea* that are declining due to overharvest (Butola and Samant, 2010). The sampling methodology outlined here can provide estimates of abundance and density that guide conservation effort and establish credible conservation priorities for these species. Additionally, being able to identify the largest and healthiest natural populations of *Saussurea* may provide guidance for establishing and maintaining *ex situ* populations for conservation or medicinal uses (Guerrant et al., 2004; Havens et al., 2006).

The estimate of abundance provided here establishes a baseline size of the population that is useful for framing the conservation value of the population of *S. weberi* at Horseshoe Cirque and for assessing future changes in the size of the population. Clearly, this estimate alone does not provide enough information for assessing the status of the species, but, with the distance-sampling strategy outlined, estimates of the size of other populations of *S. weberi* can be made efficiently. Although the estimated abundance at Horseshoe Cirque exceeds previous cursory estimates, it would be premature to suggest that abundance of *S. weberi* throughout its range was equally underestimated. Limited spatial extent, small and disparate populations, specific habitat requirements, and potential threats suggest *S. weberi* is a rare plant of the Rocky Mountains and warrants conservation attention.

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