

BASELINES TO DETECT POPULATION STABILITY OF THE THREATENED ALPINE PLANT *PACKERA FRANCISCANA* (ASTERACEAE)

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ABSTRACT.—Population size and density estimates have traditionally been acceptable ways to track species' response to changing environments; however, species' population centroid elevation has recently been an equally important metric. *Packera franciscana* (Greene) W.A. Weber and Á. Löve (Asteraceae; San Francisco Peaks ragwort) is a single mountain endemic plant found only in upper treeline and alpine talus habitats of the San Francisco Peaks in northern Arizona and is listed by the U.S. Fish and Wildlife Service as a Threatened species under the Endangered Species Act. We used 2 recreational trails, which pass through its elevational distribution in the Kachina Peaks Wilderness Area, as sampling transects to estimate population density and distribution because it was not possible to sample further from the trail due to loose volcanic talus and consequent disturbance of *P. franciscana* plants. Between-year comparisons of ramet density, population centroid elevations, and mid-September flowering or fruiting counts were not significantly different for the Humphrey's Peak Trail in 2010–2011 or the Weatherford Trail from 2009 to 2013. Use of a zero-inflated negative binomial response variable distribution allowed statistical inference for both sampling hits and misses, which gives ecologists and land managers an additional method to monitor changes in distribution and abundance. Population density and elevation of the population centroid estimates for *P. franciscana* appear to be stable; therefore, the 5-year Weatherford Trail data set may be used as a baseline to track future plant migration on a fine spatiotemporal scale, an approach that could apply to other threatened alpine species.

RESUMEN.—La estimación del tamaño y la densidad poblacional han sido, tradicionalmente, maneras aceptables de observar la respuesta de las especies a ambientes variables. Sin embargo, la elevación del centroide de la población de una especie se ha convertido recientemente en una medida igualmente importante. *Packera franciscana* (Greene) W. A. Weber y Á. Love (Asteraceae) una planta endémica sencilla de montaña que se encuentra sólo en los límites forestales y en los hábitats de astrágalo alpino de la Sierra de San Francisco, en el norte de Arizona, y está considerada una especie en peligro de extinción según la Ley de Especies en Peligro (ESA, por sus siglas en inglés) del Servicio de Pesca y Vida Silvestre de Estados Unidos. Utilizamos dos senderos recreativos que atraviesan la distribución altitudinal de esta especie en la Zona Virgen de los Kachina Peaks como muestras transversales, con el fin de estimar la densidad y distribución de la población, ya que no fue posible tomar muestras más alejadas del sendero debido al astrágalo volcánico en la zona y a la consecuente perturbación a *P. franciscana*. Las comparaciones de madurez de la densidad de rameto o individuo de la especie, las elevaciones centroides de la población y los recuentos de floración/fructificación de mediados de septiembre no fueron significativamente diferentes de los del sendero del Humphreys Peak, colectados entre 2010–2011, o a los del sendero Weatherford, colectados desde 2009 hasta 2013. El uso de una variable de respuesta de distribución binomial negativa cero inflada, permitió la inferencia estadística de los muestreos y errores de ambos accesos lo que ofrece a los administradores de las zonas un método adicional para el control de cambios en la distribución y abundancia. Dado que la densidad de la población y las estimaciones en la elevación del centroide de la población de *P. franciscana* parecen ser estables, los datos obtenidos durante cinco años y relativos al sendero Weatherford se podrían utilizar como punto de partida para rastrear la futura migración de la planta en una escala espacio-tiempo de calidad, un enfoque que podría aplicarse a otras especies alpinas amenazadas.

Population size and density estimates have traditionally been an acceptable way to track species' response to changing environments and land management treatments (Spellerberg 1991). In the altitudinal–plant-migration literature, species' population centroid elevation (the weighted average of elevational occurrence or abundance) has recently been an equally important metric (Ter Braak and Barendregt 1986, Kelly and Goulden 2008, Lenoir et

al. 2008, Fowler and Smith 2010, Crimmins et al. 2011, Felde et al. 2012, Pauli et al. 2012). Ter Braak and Barendregt (1986) first proposed weighted average as the indicator value of an environmental variable most preferred by individual species.

Many recent investigators have noted the correlation between changing climate and plant species migrations, upslope (Kelly and Goulden 2008, Lenoir et al. 2008, Felde et al. 2012) and

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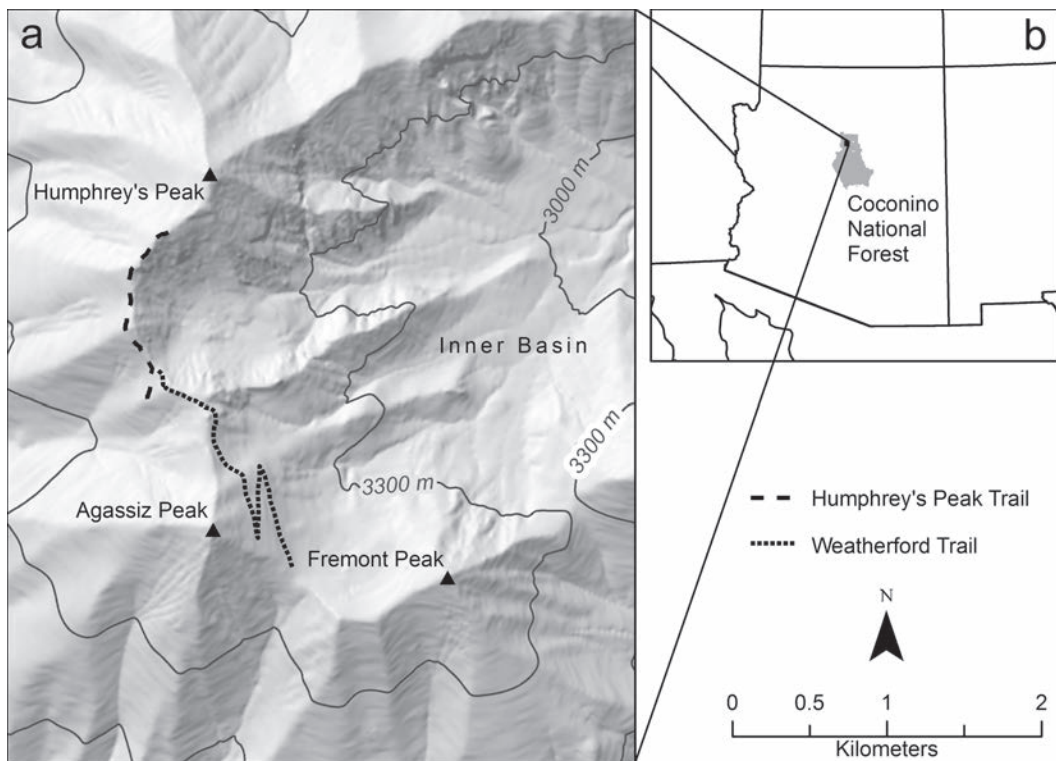


Fig. 1. Study area for *Packera franciscana* in northern Arizona, USA, showing the San Francisco Peaks volcanic slopes with the associated collapsed caldera to the northeast.

downslope (Crimmins et al. 2011). For alpine plant species with limited area for upslope migration, this could lead to local mountaintop extinctions (Root et al. 2003, Thuiller et al. 2005, Bravo et al. 2008, Colwell et al. 2008, Engler et al. 2011), especially for endemic species on mountains without nival zones (Theurillat and Guisan 2001). Doak and Morris (2010) suggested that climate-induced changes in population demographic rates such as growth and reproduction may also be a prelude to sudden range shifts or actual population crashes.

Single mountain endemics, those plant species found only on one mountain, have very limited distributions (e.g., Constantinidis et al. 2002, Constantinidis and Kalpoutzakis 2005) and may have only one local, interbreeding population. *Packera franciscana* (Greene) W.A. Weber and Á. Löve (Asteraceae; San Francisco Peaks ragwort) is a single mountain endemic found only in upper tree-line and alpine habitats of the San Francisco Peaks in northern Arizona (Greenman 1917,

Barkley 1988, Trock 2006; Fig. 1). The San Francisco Peaks are the collapsed caldera edge of a stratovolcano (Nations and Stump 1981) and lie within the Kachina Peaks Wilderness Area of the Coconino National Forest. *Packera franciscana*, as *Senecio franciscanus* Greene (Greene 1889), was listed by the U.S. Fish and Wildlife Service (1983) as a Threatened species under the Endangered Species Act because of its narrow geographic distribution, apparent volcanic talus habitat specificity, and concerns over recreational impacts. *Packera franciscana* habitats have not been subject to resource extraction activities. Previous research on *P. franciscana* has shown that mean density ranged from 2.89 to 5.62 plants $\cdot$ m⁻² with an elevational range of 3471–3722 m along trailside transects (Fowler and Sieg 2010), that the species has a reported range size of 85 ha (Dexter unpublished data), and that it flowers from mid-August to mid-October (Trock 2006). The purpose of this study is to determine whether *P. franciscana* population densities, population centroid elevations, and

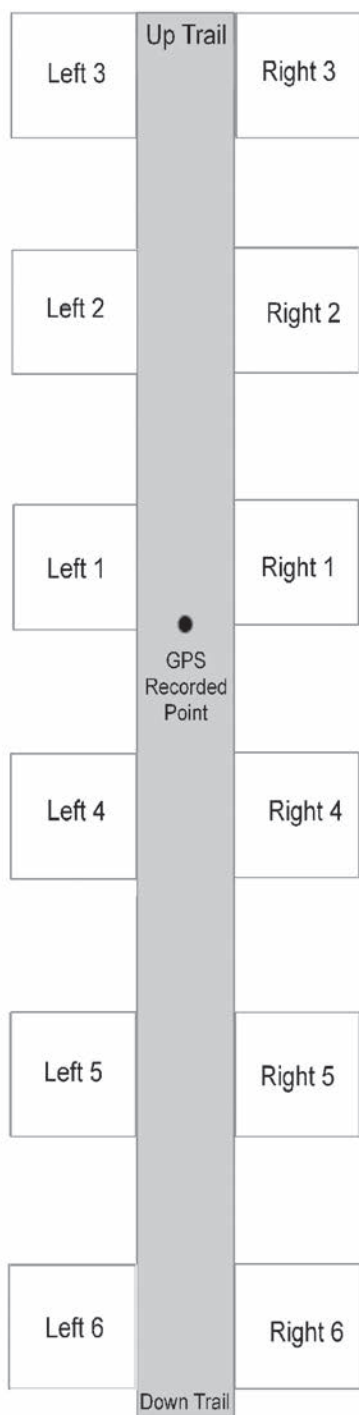


Fig. 2. Trailside sampling-frame layout within the 0–1-m zone. Sample points were spaced at 25-m intervals through the *Packera franciscana* elevational range of occurrence along each trail. Counts were made for vegetative, flowering, fruiting, and both flowering and fruiting ramets within each of the 12 sampling frames.

mid-September flowering or fruiting counts are stable and, if so, to establish a baseline for future detection of possible land-use or climate change effects on population size and distribution.

METHODS

We established elevational trailside transects through *P. franciscana* habitat along the Humphrey's Peak recreational trail on the outer volcanic slopes of San Francisco Peaks and along the Weatherford Trail, which runs mostly within the San Francisco Peaks caldera (locally known as the Inner Basin), in order to estimate the density of *P. franciscana* ramets, flower or fruit productivity, and the population centroid elevation where the population intersects each trail. Both trails go through Engelmann spruce (*Picea engelmannii*) forest and lead to alpine habitats above treeline and, after joining at 3573 m, to Humphrey's Peak (3854 m), the highest point in Arizona. We use the term centroid elevation because it is defined as a mean value for a geographical coordinate. We used trailside sampling because of probable disturbance of *P. franciscana* plants on broad volcanic talus slopes. Sample points were established systematically at 25-m intervals along each transect starting at the U.S. Forest Service 11,400-ft. (3474-m) signs, which are located approximately 300 m before the first trailside occurrences and extend 500 m beyond the last occurrence on the Humphrey's Peak Trail. The resulting sampling intensity of 48% of the 1-m trailside bands was necessary to ensure an adequate number of points with *P. franciscana* present. In mid-September of 2010 and 2011 on the Humphrey's Peak Trail and from 2009 to 2013 on the Weatherford Trail, we counted *P. franciscana* ramets (upright stems) within 12 individual 1-m² frames at each sample point arranged along the trail edge (Fig. 2). Ramet counts were chosen as an estimate of abundance because *P. franciscana* is a rhizomatous species (Barkley 1988, Trock 2006) and counts are easily converted to ramet density. Counts were separated into vegetative, flowering, fruiting, or both within each frame. Coordinates for latitude, longitude, and elevation were made for each sample point with submeter accuracy using a Trimble® Geo XH 2008 Series Global Positioning System (Trimble Navigation, Ltd., Sunnyvale, CA).

TABLE 1. Estimates for elevation of population centroids and density for *Packera franciscana* on the San Francisco Peaks in northern Arizona. Estimates for elevation of the population centroid are the mean of sample point elevations weighted by *P. franciscana* ramet counts, which follow a log-normal distribution with standard errors in parentheses. Arithmetic means of all sample points within *P. franciscana* range of occurrence for each trail are shown for ramet density along with the standardized Morista index of dispersion I_p for ramet counts. There was no significant difference between years within each trailside transect for centroid elevations or ramet counts. *Packera franciscana* frequency and elevational distribution are shown as number of occurrences with upper and lower elevations in parentheses.

Sample location	Centroid elevation (m)	Mean density (ramets · m ⁻²)	I_p	Occurrences
Humphreys 2010	3648.20 (4.63)	1.05	0.55	20 (3530–3700)
Humphreys 2011	3637.69 (3.89)	1.02	0.57	20 (3530–3700)
Weatherford 2009	3561.00 (3.33)	5.10	0.56	49 (3493–3632)
Weatherford 2010	3561.44 (2.85)	6.25	0.55	52 (3495–3627)
Weatherford 2011	3560.48 (2.93)	5.04	0.55	53 (3495–3627)
Weatherford 2012	3563.34 (3.24)	4.35	0.56	47 (3494–3630)
Weatherford 2013	3564.59 (3.05)	4.64	0.56	49 (3506–3630)

Descriptive and inferential statistics ($\alpha = 0.05$) were calculated with SAS/STAT 12.1® (SAS Institute, Cary, NC) using only sample points within the *P. franciscana* range of occurrence along each trail. Population centroids were calculated in Proc Univariate as the mean elevation of occurrence weighted by the number of ramets per sample point. Proc GENMOD with a zero-inflated negative binomial distribution function (ZINB) was used to test for Type III fixed-effects differences in ramet counts between years and trails. The ZINB models have 2 components: the negative binomial (nb) distribution for counts, and the zero inflation probability model (zero) for the extra zeros beyond the negative binomial distribution. Inferential statistics are reported for each part (nb and zero). Proc GLIMMIX with a log-normal distribution function was used to test for differences in elevation of *P. franciscana* occurrences between years. For all models, Pearson residuals were checked for means of 0 and a variance of 1. SAS/Graph 9.4® Proc Gplot (SAS Institute) was used to produce the figures. The standardized Morisita index of dispersion (I_p) was used to measure ramet count aggregation by sample point (Krebs 1989).

RESULTS

Population density and elevation of the population centroid estimates for *P. franciscana* in the San Francisco Peaks of northern Arizona appear to be stable (Table 1). Between-year comparisons of ramet counts were not significantly different for the Humphrey's Peak Trail 2010–2011 (nb $\chi^2_{0.05,1} = 0.01$, $P = 0.9396$; zero $\chi^2_{0.05,1} = 0.00$, $P = 0.9872$) or

the Weatherford Trail 2009–2013 (nb $\chi^2_{0.05,4} = 1.52$, $P = 0.8232$; zero $\chi^2_{0.05,4} = 0.66$, $P = 0.9559$). Similarly, between-year comparisons of the elevation of *P. franciscana* population centroids were not significantly different: Humphrey's 2010–2011 ($F_{0.05,1} = 1.37$, $P = 0.2488$) or Weatherford 2009–2013 ($F_{0.05,4} = 0.10$, $P = 0.9808$). Population stability is also suggested by minor year-to-year changes in altitudinal ranges, the lowest and highest occurrences at the sampling points (Table 1).

Although *P. franciscana* densities appear to be stable between years, *P. franciscana* was significantly denser along the Weatherford compared with the Humphrey's Peak Trail (nb $\chi^2_{0.05,1} = 28.83$, $P < 0.0001$) for count data in 2010–2011, the years we sampled both trails. The sample mean densities were approximately 5 times higher on the Weatherford Trail (Table 1). However, there was no significant difference between trails for the zero-inflated model (zero $\chi^2_{0.05,1} = 0.02$, $P = 0.9020$). Population centroid elevations are 73–88 m lower on the Weatherford Trail (Table 1), but the highest point on the Weatherford Trail (3634 m) is also well below the highest *P. franciscana* occurrence on the Humphrey's Peak Trail (3700 m).

Ramet counts per sampling point along both transects show a clumped numerical pattern as indicated by a standardized Morisita index of dispersion (I_p) of 0.55–0.56 for each of the 5 years on the Weatherford Trail and 0.55–0.57 for the 2 years on the Humphrey's Peak Trail (Table 1). I_p can range from -1 to $+1$, with values above 0 indicating a clumped pattern. This clumpiness is also reflected spatially by multiple modes on a smoothed *P.*

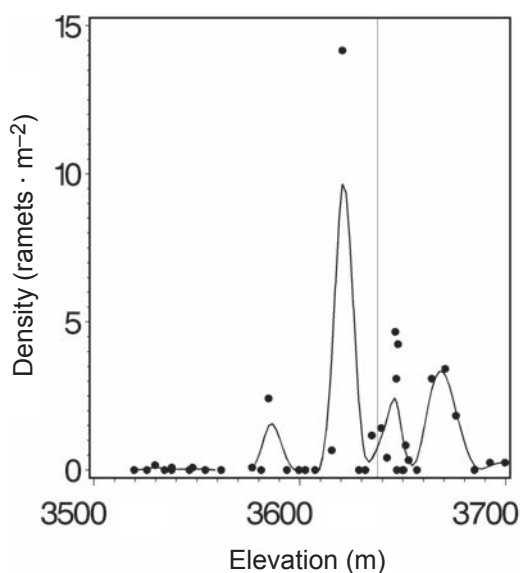


Fig. 3. Smoothed scatterplot of *Packera franciscana* ramet densities per sample point along the Humphrey's Peak Trail in 2011, starting below the first trailside occurrence and extending beyond the last occurrence. The density measurements show patches of occurrence and absence with a vertical reference line at the population centroid elevation point, 3638 m. Trail was broad and undefined between 3562 and 3576 m.

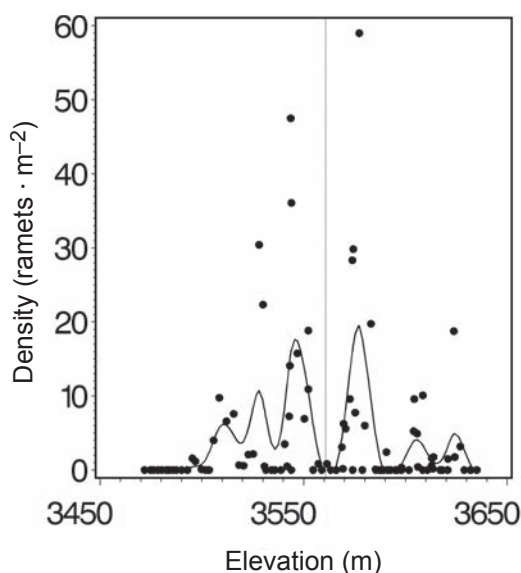


Fig. 4. Smoothed scatterplot of *Packera franciscana* ramet densities per sample point along the Weatherford Trail in 2011, starting before the first trailside occurrence and extending to the trail's junction with the Humphrey's Peak Trail. The density measurements show patches of occurrence and absence with a vertical reference line at the population centroid elevation point, 3560 m.

franciscana density-estimate plot for each trail (Figs. 3, 4). The population centroid elevations in Table 1 are weighted means, located between these multiple modes. The smoothed density plots also show a between-trail difference in number of sample points with ramet densities at and above the 5–15 ramets · m⁻² range.

Phenology counts for *P. franciscana* show that most ramets are not fertile and that the number of fruiting ramets was consistently higher than the number in flower in mid-September (Table 2). Flowering counts of *P. franciscana* from our samples show no significant difference between years for the Humphrey's Peak Trail in 2010–2011 (nb $\chi^2_{0.05,1} = 1.09$, $P = 0.2968$; zero $\chi^2_{0.05,1} = 0.59$, $P = 0.4023$) or the Weatherford Trail from 2009 to 2013 (nb $\chi^2_{0.05,4} = 6.71$, $P = 0.1517$; zero $\chi^2_{0.05,4} = 3.66$, $P = 0.4538$). The number of fruiting ramets was also not significantly different between years for the Humphrey's Peak Trail (nb $\chi^2_{0.05,1} = 0.02$, $P = 0.8751$; zero $\chi^2_{0.05,1} = 0.35$, $P = 0.5551$) or for the Weatherford Trail (nb $\chi^2_{0.05,4} = 9.46$, $P = 0.0506$; zero $\chi^2_{0.05,4} = 2.52$, $P = 0.6409$).

DISCUSSION

All between-year, within-trail ramet count comparisons for the Weatherford Trail 2009–2013 (Table 1), Humphrey's Peak Trail 2010–2011 (Table 1), and Humphrey's Peak Trail 2008–2009 (Fowler and Sieg 2010) show no significant difference. Separate analysis of the 2 Humphrey's Peak Trail data sets spans 4 years. With a consistent sampling method covering 48% of the accessible area and covering 5 years of interannual variability (Table 1), the Weatherford Trail data set is a more robust baseline than either the Humphrey's Peak Trail data or the 2009 Weatherford Trail data alone (Fowler and Sieg 2010). These results suggest that the size of the *P. franciscana* population on the San Francisco Peaks was stable for this time period and that the Weatherford Trail data set may now be used as baseline reference for future climatic- or anthropogenic-induced changes to population size. We recommend remeasurement at 10–20-year intervals to detect those possible changes.

TABLE 2. Summary phenology counts for *Packera franciscana* ramets on the San Francisco Peaks in northern Arizona. There was no significant difference between years for the flowering or fruiting sample point data.

Sample location	Vegetative	Flowering	Fruiting	Total ramets
Humphrey's Trail 2010	488	9	28	529
Humphrey's Trail 2011	441	29	34	512
Weatherford Trail 2009	5650	63	251	5993
Weatherford Trail 2010	6510	73	732	7355
Weatherford Trail 2011	5251	118	506	5932
Weatherford Trail 2012	4574	48	393	5016
Weatherford Trail 2013	5128	45	298	5471

Other studies on rare or endemic plant species have used baseline plant-density estimates to show population stability over time. Lesica and McCune (2004) used a 3-year baseline for 6 arctic-alpine species in Glacier National Park to show population stability for 3 species and population decline for 3 others. They also suggested that fixed-plot monitoring, similar to our *P. franciscana* sampling, may be better than annual random plot locations for detecting long-term change on account of reduced variance at fixed plots. Similarly, Dickinson et al. (2007) used plant density estimates to show population stability over 8 years for 2 rare species of *Myosotis* from the alpine areas of New Zealand, and Grant et al. (2012) concluded that 2 populations of *Penstemon harringtonii*, formerly a Category 2 candidate species under the Endangered Species Act, were stable over 13 years of annual monitoring. However, unlike in *P. franciscana*, Grant et al. (2012) did find significant interannual variation in *P. harringtonii* populations.

Pauli et al. (2012), Kelly and Goulden (2008), Lenoir et al. (2008), and Crimmins et al. (2011) have recently used centroid elevations (also known as species optima) to show average elevation shifts for multiple species: +2.7 m in 7 years, +64.7 m in 40 years, +29 m in 10 years, and -85.2 m in 80 years, respectively. We found no significant differences between years for the elevation of population centroids of *P. franciscana* in our 2010–2011 Humphrey's Peak Trail and 2009–2013 Weatherford Trail comparisons; therefore, the 5-year Weatherford Trail data set may be used as a baseline to track future plant migration on a fine spatiotemporal scale, which is a research approach that could apply to other threatened species in mountain environments. The spatial clumpiness of *P. franciscana* ramets (Figs. 3, 4) may allow a relatively quick numerical response of ramet density to changing climate. Changes in

mode densities should directly influence population centroid elevation. Rather than tracking the upper and lower elevational edges of the *P. franciscana* population, density-weighted population centroid elevations can reflect changing within-population densities (Felde et al. 2012: i.e., focus on the population center and density modes rather than the population edge). Breshears et al. (2008) have suggested the terms “march” or “lean” when the population centroid moves up- or downslope along with an elevational range shift or not, respectively. The Weatherford Trail baseline data should allow detection of both possibilities.

The use of a ZINB response variable distribution allowed statistical inference for both sampling hits and misses, especially important with systematic sampling of a highly rhizotomous species such as *P. franciscana*. In this study, between-trail comparisons showed that while there was a significant difference in the negative binomial (mostly hits) portion of the model, there was not a significant difference in the zero-inflation portion (mostly misses). We interpret this to mean that the number of ramets per patch is higher along the Weatherford Trail (Figs. 3, 4) but that the relative number of *P. franciscana* patches was not greater. This gives ecologists and land managers an additional method to monitor changes in distribution and abundance.

Density and centroid elevation differences between the 2 trails was consistent over the sampling period (Table 1), but more observational data on the abiotic and biotic niche of *P. franciscana* are needed to form viable hypotheses to explain these differences. Although the Weatherford Trail has a lower elevational position in the alpine zone, it appears to be slightly more mesic than the Humphrey's Peak Trail because of the volcanic geomorphology of the San Francisco Peaks. The Humphrey's Peak Trail is on outer slopes with southwestern

exposures, whereas the Weatherford Trail lies mostly within the collapsed caldera of the stratovolcano and has northeastern exposures. Both trails have similar substrate on open windswept alpine slopes. If ≥ 1 environmental factors associated with mesic conditions on the Weatherford Trail are responsible for its increased *P. franciscana* density, then *P. franciscana* would be just as likely to migrate downslope within, or become restricted to, the inner basin as it would be to migrate upslope on the mountain overall because of the predicted warmer, drier conditions of climate change.

Although there was no significant variation between years for flowering or fruiting ramet counts and no indication of changing sexual reproduction phenology (Table 2), the 2010–2011 fruiting ramet counts from the Weatherford Trail were higher than the 2009, 2012, and 2013 counts. The near significance of this difference ($P = 0.0502$, negative binomial part of the ZINB model) would suggest more variation in fruiting rate than in overall ramet density. Interannual variation in alpine weather may offer a possible explanation for year-to-year variation in fruiting ramet counts, but we detected no trend over 5 years.

Nothing is published about the reproductive biology of *P. franciscana* or its phenological plasticity. Bradley et al. (1999) note that for species that are photoperiod-regulated, flowering date would not be expected to change in response to temperature. Barkley (1988) generalized that aureoid *Senecio* species, which now comprise the genus *Packera* (Trock 2006), are obligate outbreeders with efficient dispersal abilities. Further research is needed to understand both the reproductive processes and population demographics for this species.

Plants are a vital component of biodiversity and functioning ecosystems but are facing a high rate of extinction worldwide. Within the United States, 57% of all listed species under the Endangered Species Act are plants. *Packera franciscana* may be threatened with extinction in the future if climate change results in the loss or constriction of alpine habitat on the San Francisco Peaks. The highest peak on the mountain is at 3850 m, so there is little potential habitat available for the plant to migrate upward in a warming climate scenario; and the U.S. Fish and Wildlife Service has speculated that the species may be vulnerable

to extinction because of climate change (USFWS 2010). Doak and Morris (2010) concluded that knowledge of current demographic processes is necessary to predict future population declines. Research, particularly for threatened and rare species, that allows managers to determine population stability and flowering or fruiting rates is critically important to the recovery and long-term management of these plant species.

Che-Castaldo and Neel (2012) noted that decreased numbers of individuals within populations is a primary threat to species persistence and that population density and size estimates over time are needed to develop defensible recovery criteria for threatened and endangered plants listed under the U.S. Endangered Species Act. *Packera franciscana* may have only one interbreeding population (Fowler and Sieg 2010) to monitor. Our focus on population density estimates along the centrally located trailside transects should allow future monitoring to determine whether the *P. franciscana* population remains stable or is migrating in response to environmental conditions.

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LITERATURE CITED

- BARKLEY, T.M. 1988. Variation among the Aureoid *Senecios* of North America: a geohistorical interpretation. *Botanical Review* 54:82–106.
- BRADLEY, N.L., A.C. LEOPOLD, J. ROSS, AND W. HUFFAKER. 1999. Phenological changes reflect climate change in Wisconsin. *Proceedings of the National Academy of Science* 96:9701–9704.
- BRAVO, D.N., M.B. ARAÚJO, T. LASANTA, AND J.I.L. MORENO. 2008. Climate change in Mediterranean mountains during the 21st century. *Ambio* 37:280–285.
- BRESHEARS, D.D., T.E. HUXMAN, H.D. ADAMS, C.B. ZOU, AND J.E. DAVISON. 2008. Vegetation synchronously leans upslope as climate warms. *Proceedings of the National Academy of Science* 105:11591–11592.

- CHE-CASTALDO, J.P., AND M.C. NEEL. 2012. Testing surrogacy assumptions: can threatened and endangered plants be grouped by biological similarity and abundances? PLOS ONE 7:e51659. <http://dx.doi.org/10.1371/journal.pone.0051659>.
- COLWELL, R.K., G. BREHM, C.L. CARDELÚS, A.C. GILMAN, AND J.T. LONGINO. 2008. Global warming, elevational range shifts, and lowland biotic attrition in the wet tropics. *Science* 322:258–261.
- CONSTANTINIDIS, T., E.-P. BAREKA, AND G. KAMARI. 2002. Karyotaxonomy of Greek serpentine angiosperms. *Botanical Journal of the Linnean Society* 139: 109–124.
- CONSTANTINIDIS, T., AND E. KALPOUTZAKIS. 2005. A new species of *Achillea* (Asteraceae: Anthemideae) from south-east Peloponnisos, Greece. *Botanical Journal of the Linnean Society* 147:249–256.
- CRIMMINS, S.M., S.Z. DOBROWSKI, J.A. GREENBERG, J.T. ABUTZOGLOU, AND A.R. MYNSBERGE. 2011. Changes in climatic water balance drive downhill shifts in plant species' optimum elevations. *Science* 331: 324–327.
- DICKINSON, K.J.M., D. KELLY, A.F. MARK, G. WELLS, AND R. CLAYTON. 2007. What limits a rare alpine plant species? Comparative demography of three endemic species of *Myosotis* (Boraginaceae). *Austral Ecology* 32:155–168.
- DOAK, D.F., AND W.F. MORRIS. 2010. Demographic compensation and tipping points in climate-induced range shifts. *Nature* 467:959–962.
- ENGLER, R., C.F. RANDIN, W. THUILLER, S. DULLINGER, N.E. ZIMMERMANN, M.B. ARAÚJO, P.B. PEARMAN, G. LE LAY, C. PIEDALLU, C.H. ALBERT, ET AL. 2011. 21st century climate change threatens mountain flora unequally across Europe. *Global Change Biology* 17:2330–2341.
- FELDE, V.A., J. KAFFER, AND J.-A. GRYNES. 2012. Upward shift in elevational plant species ranges in Sikkildalen, central Norway. *Ecography* 35:922–932.
- FOWLER, J.F., AND C.H. SIEG. 2010. Density and elevational distribution of the San Francisco Peaks ragwort, *Packera franciscana* (Asteraceae), a threatened single mountain endemic. *Madroño* 57:213–219.
- FOWLER, J.F., AND B. SMITH. 2010. *Erigeron mancus* (Asteraceae) density as a baseline to detect future climate change in La Sal mountain habitats. *Journal of the Botanical Research Institute of Texas* 4:747–753.
- GRANT, T.A., III, M.E. DEPRENGER-LEVIN, AND C. DAWSON. 2012. Long-term population demographics and plant community interactions of *Penstemon harringtonii*, an endemic species of Colorado's western slope. *Calochortiana* 1:115–119.
- GREENE, E.L. 1889. New or noteworthy species. *Pittonia* 2:13–24.
- GREENMAN, J.M. 1917. Monograph of the North and Central American species of the genus *Senecio*, part 2. *Annals of the Missouri Botanical Garden* 4:15–36.
- KELLY, A.E., AND M.L. GOULDEN. 2008. Rapid shifts in plant distribution with recent climate change. *Proceedings National Academy of Science* 105: 11823–11826.
- KREBS, C.J. 1989. *Ecological methodology*. Harper & Row, Publishers, New York, NY.
- LENOIR, J., J.C. GÉGOUT, P.A. MARQUET, P. DE RUFFRAY, AND H. BRISSE. 2008. A significant upward shift in plant species optimum elevation during the 20th century. *Science* 320:1768–1771.
- LESICA, P., AND B. MCCUNE. 2004. Decline of arctic-alpine plants at the southern edge of their range following a decade of climatic warming. *Journal of Vegetation Science* 15:679–690.
- NATIONS, D., AND E. STUMP. 1981. *Geology of Arizona*. Kendall/Hunt Pub. Co., Dubuque, IA.
- PAULI, H., M. GOTTFRIED, S. DULLINGER, O. ABDALADZE, M. AKHALKATSI, J.L.B. ALONSO, G. COLDEA, J. DICK, B. ERSCHBAMER, AND R.F. CALZADO, ET AL. 2012. Recent plant diversity changes on Europe's mountain summits. *Science* 336:353–355.
- ROOT, T.L., J.T. PRICE, K.R. HALL, S.H. SCHNEIDER, C. ROSENZWEIG, AND J.A. POUNDS. 2003. Fingerprints of global warming on wild animals and plants. *Nature* 421:57–60.
- SPELLERBERG, I.F. 1991. *Monitoring ecological change*. Cambridge University Press, Cambridge, England, United Kingdom.
- TER BRAAK, C.J.F., AND L.G. BARENDRECHT. 1986. Weighted averaging of species indicator values: its efficiency in environmental calibration. *Mathematical Biosciences* 78:57–72.
- THEURILLAT, J.-P., AND A. GUISAN. 2001. Potential impact of climate change on vegetation in the European Alps: a review. *Climatic Change* 50:77–109.
- THUILLER, W., S. LAVOREL, M.B. ARAÚJO, M.T. SYKES, AND I.C. PRENTICE. 2005. Climate change threats to plant diversity in Europe. *Proceedings of the National Academy of Science* 102:8245–8250.
- TROCK, D.K. 2006. *Packera*. Pages 570–602 in *Flora of North America* Editorial Committee, editors, *Flora of North America north of Mexico*, Volume 20: Magnoliophyta: Asteridae, Part 7: Asteraceae, part 2. Oxford University Press, New York, NY.
- [USFWS] U.S. FISH AND WILDLIFE SERVICE. 1983. Endangered and threatened wildlife and plants: final rule to determine *Senecio franciscanus* (San Francisco Peaks groundsel) to be a threatened species and determination of its critical habitat. *Federal Register* 48:52743–52747.
- _____. 2010. San Francisco Peaks ragwort (*Packera franciscana*), 5-year review: summary and evaluation. Arizona Ecological Services Field Office, Phoenix, AZ. 17 pp.

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