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DENSITY AND ELEVATIONAL DISTRIBUTION OF THE SAN FRANCISCO PEAKS RAGWORT, *PACKERA FRANCISCANA* (ASTERACEAE), A THREATENED SINGLE-MOUNTAIN ENDEMIC

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ABSTRACT

Packera franciscana (Greene) W. A. Weber and A. Löve is endemic to treeline and alpine habitats of the San Francisco Peaks, Arizona, USA and was listed as a threatened species under the Endangered Species Act in 1983. Species abundance data are limited in scope, yet are critical for recovery of the species, especially in light of predictions of its future extinction due to climate change. This study defined baseline population densities along two transects which will allow the detection of future population trends. *Packera franciscana* ranged from 3529 to 3722 m elevation along the outer slope transect and densities were 4.18 and 2.74 ramets m^{-2} in 2008 and 2009, respectively. The overall *P. franciscana* 2009 density estimate for both transects was 4.36 ramets m^{-2} within its elevational range of occurrence, 3471–3722 m. The inner basin density was higher, 5.62 ramets m^{-2}, than the estimate for outer slopes, 2.89 ramets m^{-2}. The elevation of the 2009 population centroid for both transects was at 3586 (±10 SE) m with the inner basin centroid significantly lower than the outer slopes centroid: 3547 (±7 SE) m vs. 3638 (±7 SE) m, respectively. In mid-September, 6–9% of the *P. franciscana* ramets were flowering and/or fruiting in 2008–2009. These results and our estimate of >36,000 *P. franciscana* ramets in <2% of its range would suggest that the species is locally abundant, persisting and reproducing.

Key Words: Alpine, narrow endemic, *Senecio franciscanus*, talus, trail transect.

Packera franciscana (Greene) W.A. Weber and A. Löve (Asteraceae), San Francisco Peaks ragwort, is endemic to treeline and alpine habitats of the San Francisco Peaks in Arizona (Greenman 1917; Barkley 1968; Trock 2006) (Fig. 1) where it has been reported to mostly occur between 3525 and 3605 m elevation (Dexter 2007) or, more generally, 3200–3800 m (Trock 2006). *Packera franciscana* predominately inhabits loose talus slopes (USFWS 1983) and has a reported range size of 85 ha (Dexter 2007). Since the elevation of the highest peak on the mountain is 3854 m, there is little habitat available for the plant to migrate upward in a warming climate scenario, and it has been widely speculated that the species is vulnerable to extinction due to climate change. In 1985, the distribution of *P. franciscana* on the San Francisco Peaks was mapped (Dexter 2007), but little published data is available on species abundance. *Packera franciscana*, as *Senecio franciscanus* Greene (Greene 1889), was listed as a threatened species under the Endangered Species Act by the U.S. Fish and Wildlife Service (1983) due to its narrow geographic distribution, apparent habitat specificity, and concerns over recreational impacts. Four other *Packera* taxa primarily grow in alpine-subalpine talus habitats in western America and two of those, *Packera musiniensis* (S. L. Welsh) Trock and *Packera malmstenii* (S. F. Blake ex Tidestrom) Kartesz, are also of conservation concern (FNA 1993+). The evolutionary relationships of *P. franciscana* within *Packera* are unknown.

Global mean temperature is predicted to rise 1–6°C in the next century due to increased concentration of greenhouse gases (Solomon et al. 2007) and has increased 0.4°C over the previous 150 yr (Trenberth et al. 2007). The predicted general response of species to this increased warmth is to migrate north in latitude or up in altitude (Grabherr et al. 1994; Theurillat and Guisan 2001; Walther 2002; Root et al. 2003; Kullman 2008; Lenoir et al. 2008). Alpine species population decline and extinction are also possible since there may be little available habitat for species' upward migration (Chapin and Körner 1994; Grabherr et al. 1994; Theurillat and Guisan 2001). These potential ecological changes indicate the need to establish baseline plant species' distributions and abundances at local scales to definitively detect changes (Post et al. 2009). Locally abundant, single mountain endemic species offer good opportunities to establish baseline studies for this purpose.

Kruckeberg and Rabinowitz (1985) note that narrow endemics can be locally abundant in specific habitats but geographically restricted. Biologists have long observed that *P. franciscana* is common to abundant in the alpine of the San Francisco Peaks (Greene 1889; Little 1941; Phillips and Peterson 1980; USFWS 1983; Phillips and Phillips 1987; Trock 2006), but peer-reviewed studies of *P. franciscana* abun-

FIG. 1. *Packera franciscana* study area showing the San Francisco Peaks in northern Arizona with the inner basin in an extended volcanic caldera to the northeast. Humphreys Peak is at 35°20′45.781″N; 111°40′40.102″W; and 3854 m elevation.

dance do not exist. Yet, such data are critical for recovery of the species under the Endangered Species Act from either recreational impacts or future climate change. Off trail use of above treeline habitats on the San Francisco Peaks is currently banned due to concerns about potential negative impacts on *P. franciscana.* Our study defines baseline population densities along permanent transects under current climate and recreational use conditions which therefore may allow the detection of future population trends. Specifically, our objectives are to: 1) establish a statistically robust sampling protocol for long-term population density trends; 2) determine the elevation of patch centroids along these transects to allow early detection of climate change driven altitudinal migration; and 3) provide data for species assessments, management responses, and revision of the 23-year old Species Recovery Plan (Phillips and Phillips 1987).

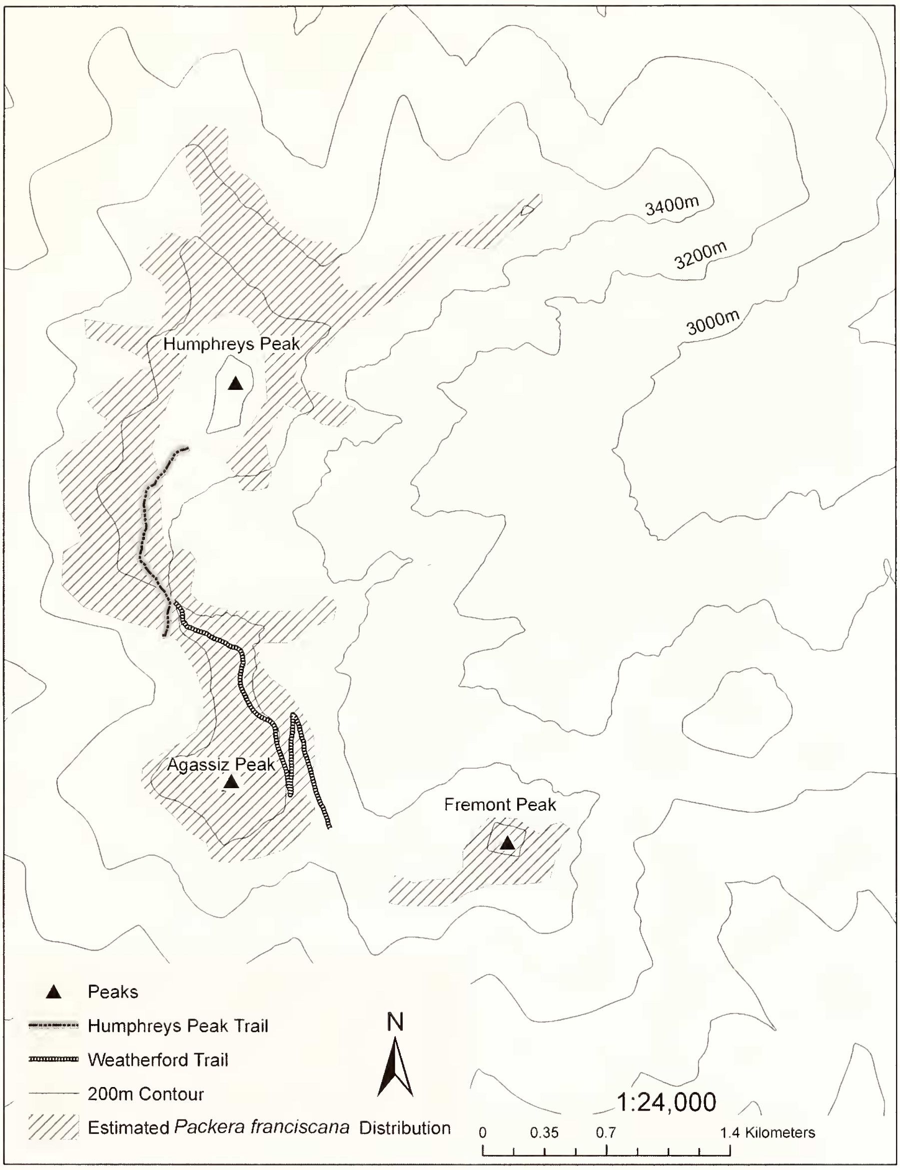

FIG. 2. Site map showing the approximate distribution of *Packera franciscana* and the location of sampling transects along recreational trails on the San Francisco Peaks. The Humphreys Peak Trail transect is on the outer volcanic slopes through and above treeline, and the Weatherford Trail transect is mostly within the inner caldera basin but crosses to the outer slopes near its junction with the Humphreys Peak Trail. Distribution map was modified from Dexter (2007) to group his polygons and include areas where we found *P. franciscana*. *Packera franciscana* was not found at the top of Humphreys or Agassiz Peaks but was found at the top of Fremont Peak.

METHODS

In 2008 we established an elevational transect along the Humphreys Peak Trail on outer slopes of the San Francisco Peaks through *P. franciscana* habitat to estimate the density of *P. franciscana* ramets, mid-September flowering/fruiting phenology, and the population centroid elevation as the population intersects the trail (Fig. 2). Fifty seven sample points were established at 25 m intervals along a transect starting at 3520 m elevation, below the first *P. franciscana* occurrence, and extending 1425 m along the trail to an elevation of 3798 m which is above the last trail-side occurrence. In mid-September 2008 and 2009 after the monsoon season, we counted *P. franciscana* ramets (upright stems) within 12 individual 1 m^2 frames at each sample point arranged along the trail edge to allow flexibility for trail curvature (Fig. 3). Ramet counts were chosen as an estimate of abundance since *P. franciscana* is a rhizomatous species (Barkley

FIG. 3. Sampling frame layout along the Humphreys Peak and Weatherford Trails transect showing the 0–1 m and 1–2 m bands. Both layouts had 12 sampling frames per sample point.

1968; Trock 2006). Sampling frames were omitted when they overlapped previously counted frames along trail switchbacks, covered recent trail maintenance areas, or covered vertical drop-offs >5 m. Counts of ramets with flower, fruit, or both were also made within each frame. In September 2009 we added an inner basin transect along the Weatherford Trail (Fig. 2) to increase sample size and habitat diversity. This hiking trail runs mostly within the San Francisco Peaks volcanic caldera and crosses a large talus slope. This transect began at 3449 m, below where the first *P. franciscana* plants were noted, and continued with 110 sample points at 25 m intervals along the trail to its junction with the first trail at 3569 m. Sampling intensity, 12 frames per sample point, was the same as that on the first trail but arrangement of the sampling frames was restricted to within one meter of the trail edge due to the large amounts of loose talus off trail (Fig. 3). Coordinates for latitude, longitude, and elevation were made for each sample point with a Trimble® Geo XT 2005 Series GPS (Trimble Navigation Ltd, Sunnyvale, CA) with sub-meter accuracy to allow relocation of each sample point in subsequent years.

Descriptive and inferential statistics were calculated with SAS/STAT 9.2 (SAS Institute Inc, Cary, NC). Population centroid elevations were calculated in Proc Means as the elevation of each sample point weighted by the number of ramets, so that each ramet received equal weight. Proc GLIMMIX with a negative binomial distribution function was used to test for type III fixed effects differences in ramet count between years and trail-side bands (distance from trail; 0–1 m vs. 1–2 m). Proc GLIMMIX with a normal distribution function was used to test for differences in elevation of *P. franciscana* occurrences between the inner basin and outer slopes. The Standardized Morisita index of dispersion was calculated to measure ramet count aggregation (Krebs 1989).

RESULTS

Packera franciscana occurred from 3529 to 3722 m elevation within two meters of the Humphreys Peak Trail transect. Within its range of occurrence along the trail, densities within the two-meter bands along each side for 2008 and 2009 were 4.18 and 2.74 ramets m^{-2}, respectively (Table 1). There was no significant difference in overall ramet density between years ($F_{1,\ 0.05} = 0.45$, $P = 0.502$). There was also no significant difference in ramet density between the 0–1 m bands and the 1–2 m bands ($F_{1,\ 0.05} = 2.43$, $P = 0.123$) for either year ($F_{1,\ 0.05} = 0.34$, $P = 0.561$).

The elevation of the *P. franciscana* population centroid along the Humphreys Peak Trail, weighted by ramet density at each sample point, was 3640 (±5 SE) m for 2008 and 3641 (±7 SE) m in 2009 (Table 1). The overlapping standard errors indicate no significant change in elevation between years.

In 2009, we added transect sampling points for *P. franciscana* along the Weatherford Trail, using only the 0–1 m band due to the large amount of loose volcanic talus just off the trail. *Packera franciscana* was found along this trail from 3471 m elevation to its junction with the Humphreys Peak Trail, both on the inner basin side and the outer volcanic slopes. In September 2009 we counted 1315 ramets of *Packera franciscana* at 163 sample points along the two transects. Ramet counts per sampling frame ranged from 0 to 180 and reflected the species' visual patchiness. The Standardized Morisita index of dispersion ($I_p = 0.54$) indicates a clumped pattern of ramet counts since it is between 0 (random) and +1 (maximum aggregation). The elevation of the 2009 population centroid for both transects combined was at 3586 (±10 SE) m (Table 1), but the inner basin centroid, 3547 m, was significantly lower than the outer slopes centroid, 3638 m ($F_{(0.05)\ 1,\ 28} = 14.92$, $P < 0.001$).

The overall *P. franciscana* 2009 trailside density estimate was 4.36 ramets m^{-2} within its

TABLE 1. ESTIMATES FOR DENSITY AND ELEVATION OF POPULATION CENTROIDS FOR *PACKERA FRANCISCANA* ON THE SAN FRANCISCO PEAKS IN NORTHERN ARIZONA. Density estimates follow a negative binomial distribution in which variance (var) is described by the negative binomial dispersion factor (k) and the square of the mean. The value of "k" given here was estimated by Proc GLIMMIX during statistical comparisons of the respective density estimates; variance in this table is the sample variance. Estimates for elevation of the population centroid are the mean of sample point elevations weighted by *P. franciscana* density which follow a normal distribution with standard errors (SE).

Sample location	Density ramets m^{-2}	var	n	k	Centroid elevation	SE
Humphreys Trail 2008	4.18	82.27	42	7.9	3640 m	±5 m
0–1 m	2.02	31.65	42	9.7		
1–2 m	6.41	294.13	42	9.7		
Humphreys Trail 2009	2.74	44.58	42	7.9	3641 m	±7 m
0–1 m	2.25	40.66	42	9.7		
1–2 m	3.31	71.82	42	9.7		
Inner basin 2009	5.62	143.86	77	9.6	3547 m	±7 m
Outer volcanic slopes 2009	2.89	48.57	63	9.6	3638 m	±7 m
Overall 2009	4.36	101.58	141	na	3586 m	±10 m

elevational range of occurrence, 3471–3722 m on the San Francisco Peaks. The 2009 inner basin density was higher, 5.62 ramets m^{-2}, than the estimate for the outer slopes, 2.89 ramets m^{-2} but not significantly so ($F_{(0.05,\ 1,113)} = 2.82$, $P = 0.096$). The number of *P. franciscana* ramets within two meters of the Humphreys Peak Trail and within one meter of the Weatherford Trail is over 36,000 (density estimate * sampled length).

Phenological measurements for *P. franciscana* during our mid-September sampling period were similar for 2008 and 2009, with 9% of the ramets either flowering and/or fruiting in 2008 versus 6% in 2009. There was less than 1% difference between inner basin and outer slopes flowering/fruiting rate in 2009.

DISCUSSION

The Recovery Plan (Phillips and Phillips 1987) offers an overall estimate of 100,000+ clones of *P. franciscana* on the San Francisco Peaks as a general estimate of population size. Phillips and Peterson (1980) reported a *P. franciscana* population density range of 50–370 plants 100 m^{-2} on Agassiz Peak near the Weatherford Trail but did not clearly define plants as ramets or genets (clumps or clones) or describe estimation techniques. However, later references to clump size would indicate that they were using the genet concept. On a per 100 m^2 basis, our density estimate (436) is somewhat larger than the upper end of their density range (50–370), which may reflect the different "plant" definitions. Given the difficulty of defining and counting clumps or clones in the field, ramets provide a more accurate way to assess population density. Even though ramet density may inflate the number of functional plants, it is an accurate reflection of photosynthetic and reproductive potential. Phillips and Peterson (1980) also reported that 13% of the *P. franciscana* plants were adult (sexually reproducing) which is comparable to the 6–9% of ramets we sampled which were flowering and/or fruiting in 2008–2009. Our results are consistent with the above data from the 1980's and give no indication of changing populations trends. Although these trail-side transects do not represent randomly selected population transects, they may be the only viable option since *P. franciscana* can inhabit large talus slopes which are very difficult to sample without uprooting plants near and within the sampling frame. These transects do sample the range of occupied habitats and observed densities in the center of its distribution in the San Francisco Peaks (Fig. 2). Our results and the estimate of >36,000 *P. franciscana* ramets in <2% of its range would indicate that the species is locally abundant, persisting, and reproducing.

We interpret the successful production of fruit, which we observed actively dispersing by upslope winds in mid-September 2008, as an indication that *P. franciscana* can sexually reproduce on the San Francisco Peaks. Seed viability studies may provide additional support for this interpretation. Examination of plant root systems would be necessary to determine if new ramets originate from seed or from existing perennial rhizomatous clones. The hypothesis that rhizomes produce large patches of ramets is supported by the clumped pattern of ramet counts ($I_p = 0.54$). Although this may be the primary method of reproduction (USFWS 1983), we also found single isolated ramets during our sampling which could be the result of seed dispersal or rhizome fragments moving downslope in the talus substrate that *P. franciscana* inhabits. Plants inhabiting the upper portions of talus slopes would seem to be the result of seed dispersal since avalanches and downslope creep of talus fields would carry existing *P. franciscana* plants down-

FIG. 4. Photo of *Packera franciscana* (Greene) W.A. Weber and A. Löve herbarium specimen showing ramets from an extensive rhizome and adventitious root system.

slope. We noted dead *P. franciscana* plants at the base of some avalanche chutes. Our observations during voucher specimen collection indicate a relatively large root system comprised of rhizomes and adventitious roots that may not be attached to a stable substrate (Fig. 4). This growth habit in an unstable talus sea may be an evolutionary adaptation for survival and reproduction in that fragmentation of the rhizome by talus creep processes may be common. Thus *P. franciscana* may be well adapted to this type of disturbance.

The overall population centroid of 3586 m we measured is within the 3525–3605 m elevation range for most *P. franciscana* noted by Dexter (2007) and the 3350–3750 m main occurrence range in earlier reports (Phillips and Peterson 1980; U.S. Fish and Wildlife Service 1983). However, the population centroid for the outslope samples located on a dry west-southwest slopes is 91 m higher in elevation than for the more east facing inner basin samples. The fact that southwest slopes have a higher *P. franciscana* patch centroid elevation lends credence to an upward migration hypothesis for this species in a future warmer drier climate.

We plan annual measurements of both transects to detect *P. franciscana* population trends. Sampling in subsequent years may indicate trends in population density, changes in September phenology, or elevational migration within its habitat. Changes in population density over time may allow detection of climate change effects, population cycles, or recreational impacts. Changes in the elevation of population centroids or September phenology will more likely be the result of climate change.

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