Western North American Naturalist 78(2), © 2018, pp. 184–194

# La Sal daisy, *Erigeron mancus*, density and associated species from treeline ecotone and alpine habitats

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Abstract.—The La Sal daisy, *Erigeron mancus*, is endemic to treeline ecotone and alpine meadow habitats of the La Sal Mountains in Utah, an insular, laccolithic mountain range on the Colorado Plateau in southeastern Utah. From 2009 to 2011 we established elevational transects through upper spruce-fir forest, treeline ecotone, and alpine meadow habitats on Laurel Ridge in the Middle Mountain group of the La Sal Mountains to measure (1) periodic changes in *E. mancus* population density, (2) changes in the elevation of the *E. mancus* population centroid, (3) changes in patch size occupied by *E. mancus*, and (4) changes in frequency of occurrence in herbaceous plant species associated with *E. mancus* along these transects. We measured both *E. mancus* density and vascular plant species composition within 1-m × 1-m square frames in mid-July, near peak alpine plant flowering time. The *E. mancus* population density on Mt. Laurel ridge did not significantly change from 2009 to 2015, but the species was most abundant in alpine meadow habitat for both years. Changes in patch width, centroid elevation, and frequency of occurrence of 30 associated plant species were also not statistically significant. Like *E. mancus*, most species show changes in frequency of occurrence between upper spruce-fir forest, treeline ecotone, and alpine meadow habitats. Individual plants of *E. mancus* are probably long-lived perennials, so changes in population density and distribution due to global warming are expected to be gradual and/or have an unknown lag time. Although there is no evidence of ongoing change in the Laurel Ridge population of *E. mancus*, having this information will provide a solid statistical basis for determining significant future changes.

Resumen.—La margarita de La Sal (*Erigeron mancus*) es endémica a los hábitats de ecotonos forestales y prados alpinos de las montañas La Sal en Utah (una cordillera laccolítica insular en la meseta de Colorado, al sureste de Utah). Desde 2009–2011 establecimos transectos ascendentes a lo largo de los hábitats de bosques de abetos, ecotonos forestales y prados alpinos de Mt Laurel Ridge en el Grupo Medio de La Sal para medir: (1) cambios periódicos en la densidad poblacional de las *E. mancus*; (2) cambios en la elevación de la población centroidal de *E. mancus;* (3) cambios en el tamaño del parche ocupado por *E. mancus;* y (4) cambios en la frecuencia de ocurrencia de especies de plantas herbáceas asociadas con *E. mancus* a lo largo de los transectos. Medimos la densidad de *E. mancus* y la composición de especies de plantas vasculares dentro de un transecto de 1 m × 1 m, a mediados de julio, durante la época de máxima floración de plantas alpinas. La densidad poblacional de *E. mancus* en Mt Laurel Ridge no presentó cambios significativos desde 2009–2015, aunque en ambos años, *E. mancus* fue más abundante en el hábitat de prado alpino. No hubo cambios estadísticamente significativos en la amplitud del parche ocupado por *E. mancus*, su elevación centroidal o en la frecuencia de ocurrencia de las 30 especies de plantas asociadas. Al igual que *E. mancus*, la mayoría de las especies muestran cambios en su frecuencia de ocurrencia en los diferentes hábitats de bosques de abetos, ecotonos forestales y praderas alpinas. Las plantas individuales de *E. mancus* son, probablemente, perennes de larga vida, por lo que se espera que los cambios en la densidad y en la distribución poblacional debido al calentamiento global, sean graduales y/o disminuyan en un tiempo desconocido. Aunque, no hay evidencia de cambios en la población de *E. mancus* en Laurel Ridge, poseer esta información proporcionará una base estadística sólida para determinar cambios futuros significativos.

The La Sal daisy, *Erigeron mancus,* is endemic to treeline ecotone and alpine habitats of the La Sal Mountains in Utah (Nesom 2006, Fowler et al. 2014), an insular, laccolithic mountain range on the Colorado Plateau in southeastern Utah. *Erigeron mancus* occurs in herbaceous plant assemblages from timberline to the crestline of the Middle Mountain group of the La Sal Mountains in and near the Mt. Peale Research Natural Area. It is also on the

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Forest Service R4 Sensitive Plant Species List. In 2009, we established a 1020-m elevational transect along Laurel Ridge to estimate *E. mancus* plant density and patch size. These data were collected to establish baseline population information in order to detect future climate change effects on this species (Fowler and Smith 2010). We also described vascular plant species composition within the area populated by *E. mancus*. The primary goal of the current work was to remeasure this transect to determine whether the 2009 population parameters have changed in the last 6 years. Specific objectives were to (1) measure change in *E. mancus* population density, patch width, and centroid elevation from 2009 to 2015; (2) determine changes in frequency of occurrence for herbaceous plant species associated with *E. mancus* along this transect; and (3) describe plant species composition for alpine, treeline ecotone, and forest habitats associated with this population of *E. mancus.*

Locally abundant, single-mountain endemic species like *E. mancus* (Fowler and Smith 2010) offer a good opportunity to establish baseline data sets to detect significant range, density, and population size shifts due to global warming. Global mean surface air temperature is predicted to rise 0.47 to 1 °C in the next 20 years due to increased concentration of greenhouse gases (Kirtman et al. 2013). Elevational gradient data for species occurrence may represent the ecological amplitude or range of tolerance (Good 1931) for correlated abiotic variables such as temperature, wind, and precipitation (Whittaker 1975). Fowler and Smith (2010) ranked centroid elevations for 36 species along the same baseline elevational transect used for the current report. Changes in environmental conditions along a gradient over time may lead to subsequent dynamic changes in population density along the gradient (Hengeveld 1990). Recent investigations have noted a correlation between changing climate and plant species migrations, upslope (Breshears et al. 2008, Kelly and Goulden 2008, Kullman 2008, Lenoir et al. 2008, Felde et al. 2012, Pauli et al. 2012) and downslope (Crimmins et al. 2011), although the predicted general response of plant species is to migrate upslope in mountain habitats (Grabherr et al. 1994, Theurillat and Guisan 2001, Walther et al. 2002, Root et al. 2003, Kullman 2008, Lenoir et al. 2008). In addition to elevation shifts, alpine species population loss is possible since there may be less available habitat as species migrate upward (Chapin and Körner 1994, Grabherr et al. 1994, Theurillat and Guisan 2001), which 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) or species extinction for endemic species on mountains without nival zones (Theurillat and Guisan 2001). Most ecologists expect species to respond individualistically to global warming (Franklin et al. 1991, Theurillat and Guisan 2001) based on Ramensky (1924) and Gleason's (1926) individualistic hypothesis: "each species is distributed in its own way . . . [and] no 2 species are alike in distribution." A species assemblage approach for examining species occurrence within the population range of *E. mancus* on Laurel Ridge will provide an additional test of these ideas.

## METHODS

The study area was in the Middle Mountain group of the La Sal Mountains in southeastern Utah on the Manti–La Sal National Forest, defined as the Mt. Peale Research Natural Area (RNA) and the ridge just west of a peak locally known as Mt. Laurel (Fig. 1). For the 2015 remeasure, we utilized the same methodology as Fowler and Smith (2010) to estimate plant density and the centroid elevation of a population of *E.mancus* along a 920-m ridgeline transect which runs along a narrow ridge from timberline up to the large talus field at the west base of Mt. Laurel plus a 100-m-long crestline transect in the saddle just south of Mt. Laurel (Appendix 1). These 2 transects include 4 vegetation patches with gaps to exclude large talus patches near the U.S. Forest Service Pre-Laurel Pk weather station and at the base of Mt. Laurel. It covers an elevational range from 3430 m to 3629 m through patches of treeline ecotone and alpine herbaceous vegetation. We measured both *E. mancus* density and vascular plant species composition within 1 m × 1 m square frames in mid-July, near peak flowering time. Vascular plant species composition was measured at 20-m intervals along these transects, with a random start sampling location within the first 20 m and systematic 20-m intervals thereafter. *Erigeron mancus* density was measured at

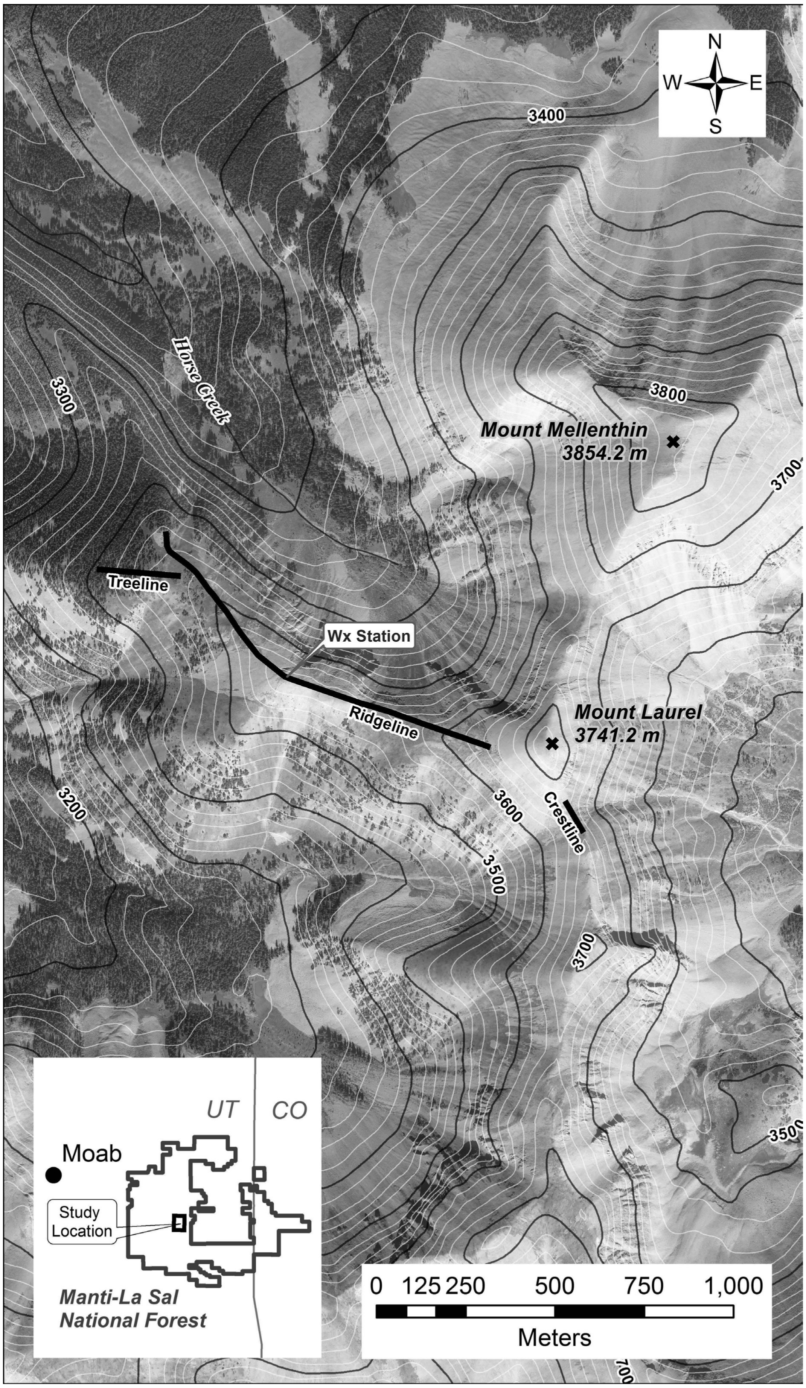

Fig. 1. *Erigeron mancus* study area map showing local topographic features and transect locations in the La Sal Mountains in southeastern Utah, USA. Wx Station indicates the U.S. Forest Service Pre-Laurel weather station location on the ridgeline transect. The upper part of the ridgeline and all of the crestline transect had alpine habitat, whereas the lower ridgeline and upper part of the treeline transects had treeline ecotone habitat. The lower part of the treeline transect was in spruce-fir forest.

randomly chosen points along patch-width cross transects perpendicular to the species composition sample points. We recorded latitude, longitude, and elevation at each sampling frame with a Trimble® Geo XT™ 2005 Series GPS at submeter accuracy using Trimble's differential correction software and North American Datum 1983.

In 2011 in order to better characterize the vegetation of timberline/treeline habitat, we added a 20-m × 250-m belt transect (Appendix 1) in a broad ridgetop location with more mesic vegetation near the *E. mancus* ridgeline transect. This forest-treeline ecotone transect ran along a line perpendicular to the topographic contour lines from treeline ecotone through timberline into the conifer forest based on visual timberline/treeline criteria from Körner (1998). These criteria define the timberline as the climate-driven upper limit of relatively closed forest and the treeline ecotone as starting at timberline where the closed forest begins to fragment into large patches and extending upslope to upper treeline, the general upper limit of small patches of a few arborescent trees (upright, and >3 m height). Krummholz trees—trees <3 m tall with a shrubby growth form (Arno and Hammerly 1984)—are located above the treeline ecotone. Thus the treeline ecotone is a mosaic of forest fragments and alpine meadow patches. Within this transect, we recorded height, diameter at breast height (dbh), and species for all conifer trees ≥1.4 m tall.

The centerline of the 20-m × 250-m transect was used to sample tree regeneration and herbaceous species composition. Spatial locations of all sampling points were recorded using a Trimble® Geo XH™ GPS®. Circular forest regeneration plots with a 5-m radius were located at 20-m intervals along the transect and counts were recorded for all regeneration trees (<1.4 m height) by species. Herbaceous plant species composition was recorded using a 1-m × 1-m sampling frame placed at 20-m intervals along the centerline transect. Voucher specimens of unknown plants were collected outside the frame and numbered for later identification in the herbarium. Vouchers were deposited in the U.S. Forest Service Herbarium (USFS) in Flagstaff, Arizona.

Descriptive and inferential statistics ($\alpha = 0.05$) for plant densities, patch width, and species centroid elevations were calculated with SAS/STAT© 13.1. Population centroids were calculated in Proc MEANS as the mean elevation of occurrence weighted by the number of plants per sample point. Proc GENMOD with a negative binomial distribution function (nb) was used to test for type-III fixed-effects differences in *E. mancus* plant counts between years where edge plot counts were given half weight rounded to the nearest integer. Proc GLIMMIX with a normal distribution function and random_residual_ option was used to test for differences in *E. mancus* population centroid elevation and patch width between years and habitats. For all models, Pearson residuals were checked for means near 0 and a variance near 1. Proc NPAR1WAY was used to test for centroid elevation shifts for plant species on the base ridgeline transect between years. Temperature and windspeed data from the Pre-Laurel Pk weather station (station name: LA SAL, station ID: LSL; 38.4566, −109.2455; 3568 m), which is directly on the ridgeline transect, were downloaded from the MesoWest web site (http://mesowest.utah.edu/cgi-bin/droman/meso_base.cgi?stn=lsl).

## RESULTS

An examination of the Pre-Laurel Pk weather station data showed interannual variation in both January and July mean temperatures but no clear trend in the amount of temperature change. The January mean was −7.3 °C in 2009 and −5.8 °C in 2015, but it was lower in the intervening years (−9.9 °C to −7.8 °C). The July mean temperatures ranged from 11.4 °C to 13.7 °C between 2009 and 2014 but was 9.7 °C in 2015. January wind speeds averaged 24.0 kph during the 2009–2014 interval with a maximum speed of 119.3 kph on 19 January 2009 when the air temperature was −0.2 °C.

### Density

The population of *Erigeron mancus* along the base ridgeline transect extended from treeline ecotone to alpine habitats in both 2009 and 2015. The estimated *E. mancus* population plant density increased in density during the 6-year interval from 2009 to 2015, but the increase was not statistically significant (Table 1). The change in density between

Table 1. Comparison of plant density, patch width, and patch centroid elevation for *Erigeron mancus,* the La Sal Daisy, near Mt. Laurel in the Middle Mountain group of the La Sal Mountains for 2009 and 2015. Sample means are given with standard errors in parentheses for the entire transect ($N = 52$) and by treeline ecotone ($n = 8$) and alpine habitats ($n = 44$). Inferential analysis indicated no significant differences between years for density (Proc GENMOD, negative binomial distribution), centroid elevation (Proc GLIMMIX, normal distribution), or patch width (Proc GLIMMIX, normal distribution) population parameters.

| Population parameter | 2009 | 2015 | Between-year inference |
|---|---|---|---|
| Density (plants/m$^2$) | 7.12 (1.29) | 10.21 (2.44) | $\chi^2_{0.05,1} = 1.43$, $P = 0.23$ |
| Treeline ecotone | 4.75 (2.36) | 0.87 (0.39) | $\chi^2_{0.05,1} = 3.02$, $P = 0.08$ |
| Alpine | 7.54 (1.47) | 11.91 (2.82) | $\chi^2_{0.05,1} = 2.20$, $P = 0.14$ |
| Centroid elevation (m asl) | 3538.05 (7.63) | 3537.46 (6.17) | $F_{0.05,1,75} = 0.00$, $P = 0.96$ |
| Treeline ecotone | 3440.66 (2.57) | 3449.74 (3.84) | $F_{0.05,1,6} = 1.18$, $P = 0.32$ |
| Alpine | 3549.20 (6.98) | 3538.63 (6.58) | $F_{0.05,1,67} = 0.91$, $P = 0.34$ |
| Patch width (m) | 27.99 (4.42) | 25.48 (3.95) | $F_{0.05,1,92} = 0.41$, $P = 0.52$ |
| Treeline | 0.75 (0.58) | 1.27 (0.90) | $F_{0.05,1,6} = 0.07$, $P = 0.80$ |
| Alpine | 32.95 (4.87) | 29.88 (4.35) | $F_{0.05,1,67} = 1.9,3$ $P = 0.17$ |

years was also not significant within either the treeline ecotone or alpine habitats. Two-way analysis also showed no difference between years ($\chi^2_{0.05,1} = 0.47$, $P = 0.49$) , but *E. mancus* was significantly more dense in the alpine habitat ($\chi^2_{0.05,1} = 5.66$, $P = 0.02$). Between-year changes in centroid elevation and width were not statistically significant overall or for either habitat (Table 1). However, *E. mancus* patch width was significantly narrower in the treeline habitat ($F_{0.05,1,101} = 15.63$, $P = 0.0001$). Although these parameters give an estimated overall population size increase from 203,275 plants in 2009 to 265,354 plants in 2015, this increase is not statistically significant since neither patch width nor density differences were significant.

### Associated Species

*Erigeron mancus* and 30 of the 73 species found along the 920-m ridgeline transect were also tested for shifts in centroid elevation between 2009 and 2015 using presence-absence data because they occurred at least 10 times in one of the 2 years. Like *E. mancus* count (density) data tests, none of these tests showed a significant difference from random sampling expectations, although the raw data showed a range of species changes between years: median elevation upshifts (9 species), no change (5 species), and downshifts (17 species), as well as elevation range expansions (5 species) and contractions (12 species).

Fifty-seven species co-occurred with *E. mancus* within the same 1-m$^2$ sampling frames, with *Eremogone fendleri* and *Festuca brachyphylla* being the most frequent co-occurring species (≥90%). In sampling frames with *E. mancus*, the average species richness was 17.1 species/m$^2$ (SE 0.50), while overall species richness was 16.7 species/m$^2$ (SE 0.40)

Frequencies of occurrence for plant species changed across the forest, treeline ecotone, and alpine meadow habitats moving up or downslope. Habitat affinities (Table 2) were assigned where the difference in species frequency of occurrence was ≥10% compared to the adjacent habitat or if a species occurred in only one habitat. Dual affinity was assigned for species occurrence differences <10% if the species occurred in 2 adjacent habitats. As expected for habitats defined by the abundance of trees (Table 2), *Abies bifolia* and *Picea engelmannii* most frequently occurred in the forest habitat, occurred less frequently in the treeline ecotone habitat (about half as frequent for both size classes), and were infrequent to absent in the alpine meadow. *Erigeron mancus* showed the opposite distribution pattern: frequent in the alpine, less frequent in the treeline ecotone, and absent from the forest habitat (Table 2). Other species also showed a change in frequency of occurrence between habitats. For example, forest species tended to gradually become less frequent upslope toward treeline ecotone and alpine meadow habitats. Of the 19 forest species in Table 2, 14 also extended into the treeline ecotone, and of the 30 alpine meadow species, 18 also occurred in the treeline ecotone. Treeline species occurred more frequently in that habitat than in either adjacent habitat. This group of species was split into some that extended upslope into alpine meadow (7), those that extended both up- and downslope into adjacent habitats (9), and a few that were

Table 2. Species composition across the upper spruce-fir forest, treeline ecotone, and alpine meadow habitats on Mt. Laurel in the Middle Mountain group of the La Sal Mountains. Habitat affinity was assigned when frequency of occurrence was >9% higher than adjacent habitats (if the species was present in both). The ecotone started at timberline where the closed forest began to fragment into large patches and extended upslope to upper treeline, the general upper limit of small patches of a few arborescent trees below alpine meadow. Tree species data are density (plants/ha) in the forest and treeline ecotone habitats; herbaceous plant data are frequency of occurrence (freq.) as a decimal fraction. Except for the 2 tree species, species are arranged alphabetically by family within habitat affinities. Forest, $n = 6$; treeline ecotone, $n = 15$; alpine, $n = 39$.

| Family | Species | Forest density/ freq. | Treeline density/ freq. | Alpine freq. | Habitat affinity |
|---|---|---|---|---|---|
| Pinaceae | *Abies bifolia* A. Murray bis <1.4 m | 2865 | 0 | 0.01 | forest |
| | *Abies bifolia* ≥1.4 m | 758 | 350 | 0.00 | forest |
| | *Picea engelmannii* Parry ex Engelm. var. *engelmannii* <1.4 m | 3374 | 254 | 0.00 | forest |
| | *Picea engelmannii* ≥1.4 m | 416 | 208 | 0.00 | forest |
| Asteraceae | *Arnica cordifolia* Hook. | 0.50 | 0.00 | 0.00 | forest |
| | *Senecio crassulus* A. Gray | 0.67 | 0.22 | 0.00 | forest |
| Boraginaceae | *Mertensia ciliata* (E. James ex Torr.) G. Don var. *ciliata* | 0.50 | 0.13 | 0.01 | forest |
| Cyperaceae | *Carex phaeocephala* Piper | 0.17 | 0.04 | 0.00 | forest |
| | *Carex rossii* Boott | 0.67 | 0.35 | 0.13 | forest |
| Fabaceae | *Thermopsis rhombifolia* (Nutt. ex Pursh) Richardson | 0.17 | 0.00 | 0.00 | forest |
| | *Trifolium parryi* A. Gray var. *parryi* | 0.33 | 0.13 | 0.04 | forest |
| Geraniaceae | *Geranium caespitosum* Fisch. & Trautv. | 0.17 | 0.00 | 0.00 | forest |
| Grossulariaceae | *Ribes montigenum* McClatchie | 0.33 | 0.04 | 0.00 | forest |
| Juncaceae | *Luzula parviflora* (Ehrh.) Desv. | 0.17 | 0.00 | 0.00 | forest |
| Poaceae | *Poa glauca* Vahl ssp. *glauca* | 0.50 | 0.17 | 0.19 | forest |
| | *Bromus lanatipes* | 0.17 | 0.04 | 0.00 | forest |
| | *Poa reflexa* Vasey & Scribn. | 0.50 | 0.26 | 0.03 | forest |
| | *Poa secunda* J. Presl ssp. *juncifolia* (Scribn.) Soreng | 0.33 | 0.00 | 0.00 | forest |
| Polemoniaceae | *Polemonium pulcherrimum* Hook. var. *delicatum* (Rydb.) Cronquist | 0.50 | 0.04 | 0.00 | forest |
| Rosaceae | *Fragaria virginiana* Mill. | 0.33 | 0.04 | 0.00 | forest |
| | *Sibbaldia procumbens* L. | 0.67 | 0.26 | 0.00 | forest |
| Asteraceae | *Hymenoxys hoopesii* (A. Gray) Bierner | 0.33 | 0.30 | 0.00 | forest-treeline |
| Brassicaceae | *Draba abajoensis* Windham & Al-Shehbaz | 0.67 | 0.70 | 0.04 | forest-treeline |
| Poaceae | *Bromus ciliatus* L. | 0.17 | 0.17 | 0.00 | forest-treeline |
| Apiaceae | *Cymopterus lemmonii* (J.M. Coult. & Rose) Dorn | 0.17 | 0.70 | 0.21 | treeline |
| | *Osmorhiza depauperata* Phil. | 0.00 | 0.09 | 0.00 | treeline |
| Asteraceae | *Achillea millefolium* L. | 0.50 | 0.91 | 0.37 | treeline |
| | *Antennaria rosea* Greene | 0.00 | 0.04 | 0.00 | treeline |
| | *Erigeron grandiflorus* Hook. | 0.17 | 0.61 | 0.01 | treeline |
| | *Solidago multiradiata* Aiton | 0.17 | 0.78 | 0.51 | treeline |
| | *Taraxacum officinale* Weber ex F.H. Wigg. | 0.00 | 0.13 | 0.03 | treeline |
| | *Tetraneuris acaulis* (Pursh) Greene | 0.00 | 0.09 | 0.00 | treeline |
| Cyperaceae | *Carex chalciolepis* T. Holm | 0.00 | 0.04 | 0.00 | treeline |
| | *Carex elynoides* T. Holm | 0.00 | 0.78 | 0.65 | treeline |
| | *Carex nova* L.H. Bailey | 0.00 | 0.04 | 0.00 | treeline |
| Fabaceae | *Trifolium dasyphyllum* Torr. & A. Gray | 0.17 | 0.83 | 0.59 | treeline |
| Gentianaceae | *Gentiana parryi* A. Gray | 0.17 | 0.43 | 0.06 | treeline |
| Liliaceae | *Zigadenus elegans* Pursh | 0.00 | 0.17 | 0.01 | treeline |
| Poaceae | *Calamagrostis purpurascens* R. Br.[a] | 0.00 | 0.26 | 0.14 | treeline |
| | *Elymus trachycaulus* (Link) Gould ex Shinners ssp. *trachycaulus* | 0.00 | 0.70 | 0.22 | treeline |
| | *Phleum alpinum* L. | 0.00 | 0.22 | 0.01 | treeline |
| Primulaceae | *Androsace septentrionalis* L. | 0.17 | 0.43 | 0.10 | treeline |
| Ranunculaceae | *Anemone multifida* Poir. var. *stylosa* (A. Nelson) B.E. Dutton & Keener | 0.00 | 0.09 | 0.00 | treeline |
| Rosaceae | *Potentilla glaucophylla* Lehmann var. *glaucophylla* | 0.33 | 0.52 | 0.19 | treeline |

TABLE 2. Continued.

| Family | Species | Forest density/ freq. | Treeline density/ freq. | Alpine freq. | Habitat affinity |
|---|---|---|---|---|---|
| | *Potentilla gracilis* Douglas ex Hook. var. *pulcherrima* (Lehm.) Fernald | 0.00 | 0.13 | 0.00 | treeline |
| | *Potentilla ovina* Macoun var. *decurrens* (S. Watson) S.L. Welsh & B.C. Johnst. | 0.00 | 0.35 | 0.19 | treeline |
| Saxifragaceae | *Veronica wormskjoldii* Roem. & Schult. | 0.00 | 0.09 | 0.00 | treeline |
| | *Saxifraga bronchialis* L. var. *austromontana* (Wiegand) Piper ex G.N. Jones | 0.00 | 0.17 | 0.00 | treeline |
| Scrophulariaceae | *Pedicularis racemosa* Douglas ex Benth. var. *alba* (Pennell) Cronquist | 0.00 | 0.04 | 0.00 | treeline |
| Asteraceae | *Antennaria umbrinella* Rydb. | 0.00 | 0.04 | 0.04 | treeline-alpine |
| | *Erigeron melanocephalus* (A. Nelson) A. Nelson | 0.00 | 0.09 | 0.05 | treeline-alpine |
| Boraginaceae | *Mertensia viridis* (A. Nelson) A. Nelson | 0.00 | 0.13 | 0.22 | treeline-alpine |
| Brassicaceae | *Noccaea fendleri* (A. Gray) Holub ssp. *glauca* (A. Nelson) Al-Shehbaz and M. Koch | 0.00 | 0.57 | 0.53 | treeline-alpine |
| | *Boechera stricta* (Graham) Al-Shehbaz | 0.00 | 0.13 | 0.04 | treeline-alpine |
| Caryophyllaceae | *Stellaria longipes* Goldie ssp. *longipes* | 0.00 | 0.04 | 0.01 | treeline-alpine |
| Crassulaceae | *Sedum lanceolatum* Torr. var. lanceolatum | 0.00 | 0.26 | 0.21 | treeline-alpine |
| Cyperaceae | *Carex scirpoidea* Michx. var. *pseudoscirpoidea* (Rydb.) Cronquist | 0.17 | 0.35 | 0.37 | treeline-alpine |
| Juncaceae | *Luzula spicata* (L.) DC. | 0.00 | 0.17 | 0.13 | treeline-alpine |
| Rosaceae | *Potentilla pensylvanica* L. | 0.00 | 0.04 | 0.01 | treeline-alpine |
| Apiaceae | *Cymopterus bakeri* (J.M. Coult. & Rose) M.E. Jones | 0.00 | 0.09 | 0.55 | alpine |
| Asteraceae | *Artemisia scopulorum* A. Gray[b] | 0.00 | 0.00 | 0.35 | alpine |
| | *Hymenoxys grandiflora* (Torr. & A. Gray ex A. Gray) K.L. Parker | 0.00 | 0.00 | 0.36 | alpine |
| | *Erigeron mancus* Rydb. | 0.00 | 0.13 | 0.71 | alpine |
| Brassicaceae | *Draba crassifolia* Graham | 0.00 | 0.00 | 0.01 | alpine |
| | *Draba aurea* Vahl ex Hornem. | 0.00 | 0.00 | 0.56 | alpine |
| Caryophyllaceae | *Cerastium arvense* L. ssp. *strictum* Gaudin | 0.00 | 0.52 | 0.67 | alpine |
| | *Eremogone fendleri* (A. Gray) Ikonn. | 0.17 | 0.65 | 0.86 | alpine |
| | *Minuartia obtusiloba* (Rydb.) House | 0.00 | 0.04 | 0.56 | alpine |
| | *Minuartia rubella* (Wahlenb.) Hiern | 0.00 | 0.00 | 0.08 | alpine |
| | *Silene acaulis* (L.) Jacq. | 0.00 | 0.00 | 0.23 | alpine |
| Cyperaceae | *Carex albonigra* Mack. | 0.00 | 0.09 | 0.19 | alpine |
| | *Carex arapahoensis* Clokey | 0.00 | 0.00 | 0.09 | alpine |
| Fabaceae | *Trifolium nanum* Torr. | 0.00 | 0.00 | 0.19 | alpine |
| Poaceae | *Elymus scribneri* (Vasey) M.E. Jones | 0.00 | 0.04 | 0.32 | alpine |
| | *Festuca brachyphylla* Schult. ex Schult. & Schult. ssp. *coloradensis* (Fred.) Dorn | 0.00 | 0.57 | 0.82 | alpine |
| | *Poa abbreviata* R. Br. ssp. *pattersonii* (Vasey) A. Love, D. Love, & B.M. Kapoor | 0.00 | 0.26 | 0.53 | alpine |
| | *Poa glauca* Vahl ssp. *rupicola* (Nash) W.A. Weber | 0.00 | 0.09 | 0.23 | alpine |
| Polemoniaceae | *Polemonium viscosum* Nutt. | 0.00 | 0.17 | 0.49 | alpine |
| Primulaceae | *Androsace chamaejasme* Wulfen ssp. *lehmanniana* (Spreng.) Hultén | 0.00 | 0.00 | 0.10 | alpine |
| Rosaceae | *Geum rossii* (R. Br.) Ser. var. *turbinatum* (Rydb.) C.L. Hitchc. | 0.17 | 0.61 | 0.78 | alpine |
| | *Potentilla hookeriana* Lehm. | 0.00 | 0.00 | 0.06 | alpine |
| | *Potentilla ovina* Macoun var. *ovina* | 0.00 | 0.13 | 0.62 | alpine |
| | *Potentilla paucijuga* Rydb. | 0.00 | 0.00 | 0.10 | alpine |
| Saxifragaceae | *Micranthes rhomboidea* (Greene) Small | 0.00 | 0.13 | 0.24 | alpine |
| | *Saxifraga cespitosa* L. | 0.00 | 0.00 | 0.01 | alpine |
| Scrophulariaceae | *Besseya alpina* (A. Gray) Rydb. | 0.00 | 0.00 | 0.04 | alpine |
| | *Castilleja sulphurea* Rydb. | 0.00 | 0.35 | 0.53 | alpine |
| Selaginellaceae | *Selaginella densa* Rydb. | 0.00 | 0.13 | 0.67 | alpine |

[a] Mislabelled as *C. purpurea* in Fowler and Smith (2010)

[b] Misidentified as *A. pattersonii* in Fowler and Smith (2010)

restricted to the treeline ecotone on these transects (Table 2). In addition, the 3 forest-treeline ecotone species and the 10 treeline ecotone-alpine species clearly showed that the treeline ecotone is transitional between upper spruce-fir forest at timberline and higher-elevation alpine meadow. Only *Achillea millefolium* was relatively abundant across all 3 habitats.

## DISCUSSION

The population of *E. mancus* near Mt. Laurel appears to have remained unchanged in plant density, patch width, and elevational position over the past 6 years. Moreover, we did not observe evidence of change in population structure such as dead mature plants or obvious changes in the environment due to trampling or grazing. The changes noted in Table 1 may be due to random sampling variation or to a fixed cause which has yet to have significant impacts on the population. Another low-growing single-mountain endemic plant, *Packera franciscana,* in the alpine of northern Arizona, similarly underwent no change in ramet density or centroid elevation over 5 years of annual sampling (Fowler et al. 2015). Individual plants of both *E. mancus* and *P. franciscana* are probably long-lived perennials, so short-term changes in population size and distribution due to predicted climate change (Kirtman et al. 2013) are expected to be gradual and/or have a delayed response (Pauli et al. 2007), but we expect climate-driven changes to first show up as shifts in centroid elevation as noted by Lenoir et al. (2008) and Walther et al. (2005). While both species reproduce sexually, the clonal growth of *P. franciscana* may make it more resistant to climate change effects than *E. mancus*. Since no clear trend of temperature change is evident from the Pre-Laurel Pk weather station data for this study period, whether *E. mancus* responds to temperature change remains to be seen. To facilitate faster detection of a response, future research on *E. mancus* populations should focus on population age and size structure changes and *E. mancus* distribution within other La Sal Mountain treeline ecotone sites. Research on the latter concept could be designed to measure the effect of forest tree densification (Batllori and Gutiérrez 2008, Fowler et al. 2012) on the lower elevational range of the species. More rapid shifts for both species could occur due to habitat destruction.

Statistical analysis of *E. mancus* presence-absence data on the base ridgeline transect produced the same nonsignificant result as the count (density) data sampled from broader patch widths. As noted above, neither were there significant elevational shifts with presence-absence data for 30 other species on the ridgeline transect. Species richness measurements were also similar: 17.1 species/m$^2$ in 2009 (Fowler and Smith 2010) and 16.3 species/m$^2$ in 2015. This short-term stability may reflect the absence of a temperature change trend on Laurel Ridge. In contrast, other longer-term studies report substantial upshifts due to increased regional temperatures: for example, 29 m/decade upshift for 171 forest plant species in Western Europe (Lenoir et al. 2008) and 28 m/decade in Swiss alpine species (Walther et al. 2005). Although there is no evidence of ongoing change in the vegetation of Laurel Ridge over 6 years, having this information will provide a solid statistical basis for determining longer-term climate change impacts as well as possible impacts from the newly introduced nonindigenous mountain goat or other unknown factors. The broad-scale sensitive plant monitoring program currently in place on the Moab District of the La Sal National Forest can provide the first indication of change.

*Erigeron mancus* is clearly less dense and occupies a narrower patch in the treeline ecotone habitat compared to the alpine meadow, an indication of alpine habitat affinity. This difference also correlates with different USDS Soil Series map units (NRCS 1997): Meredith stony loam soil in the alpine and Leighcan cobbly loam soil in the treeline ecotone. Meredith soils have larger rock fragments at the surface and shallower total depth, which suggests a more harsh growing environment. Both soil series occur only here within Utah. *Erigeron mancus* is most abundant in relatively species-rich (17 species/m$^2$) microhabitats on windswept narrow alpine ridges with other low-growing species like *Eremogone fendleri* and *Festuca brachyphylla* that can survive these conditions. January windspeeds indicate little if any snow accumulation. Most floras (Rydberg 1917, Cronquist et al. 1972, Welsh et al. 1987, Nesom, 2006) and systematic treatments (Cronquist 1947) indicate rocky slopes and/or alpine meadow as typical habitat for *E. mancus*, although Welsh and Chatterley (1985) specify "rocky igneous ridges in a spruce-fir community." The latter may be interpreted as treeline ecotone habitat. Our measurements show that even within the treeline ecotone, *E. mancus* is more abundant on rocky ridges than in less windswept, more mesic microsites with taller vegetation. The occurrence of a few *E. mancus* outlier plants in a dry ridgeline forest opening (Fowler and Smith 2010), off transect and well below timberline, is inversely similar to the infrequent occurrence of subalpine fir (*A. bifolia*) krummholz trees in the alpine meadow compared to upper spruce-fir forest (Table 2).

The species assemblage shown in Table 2 is not a complete list of all species closely spatially associated with *E. mancus* in these habitats. A few species—for example, *Cymopterus alpinus* A. Gray and *Draba fladnizensis* Wulf.—were collected within the area occupied by the sampled *E. mancus* population but did not occur in our systematic sampling. Several other alpine habitat species such as *Phacelia sericea* (Graham ex Hook) A. Gray and *Senecio amplectens* A. Gray also occurred within 50 m of the *E. mancus* population but outside the sampled area.

Most species in this assemblage exhibit spatial variation in frequency of occurrence via habitat affinities. Although similar assemblages may occur elsewhere in the La Sal Mountains, this assemblage and individual species occurrence frequencies are likely unique to these transects and ephemeral over longer timescales as noted by Hengeveld (1990) for all present day plant assemblages (cf. Gleason 1939). The 2009 and 2015 *E. mancus* density and associated species data sets will allow detection of significant population changes due to future habitat modification from global warming or land management activities.

## ACKNOWLEDGMENTS

Funding for this work was provided by the Forest and Woodland Ecosystem Program, and the BeSmart Grant Program, Rocky Mountain Research Station, U.S. Forest Service. Theresa Nallick prepared Fig. 1. We thank the Moab District, Manti–La Sal National Forest, for assistance from their summer field crew in 2015, and 2 anonymous reviewers for suggestions on how to improve the clarity of the manuscript.

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*Received 18 September 2017*
*Revised 23 April 2018*
*Accepted 30 April 2018*

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Appendix 1. Base transect locations in degrees latitude and longitude with elevation in meters above sea level for the ridgeline, crestline, and forest-treeline transects. The ridgeline transect follows the ridgetop from timberline to the talus base of Mt. Laurel and thus is not a straight line. The sample point coordinates and distance only cover the 3 vegetated sections of the ridgetop. The forest-treeline and crestline transects are straight. Forest-treeline transect coordinates were collected as Universal Transverse Mercator (UTM) Zone 13 easting/northing data as part of a tree spatial pattern study. After differential correction, horizontal and vertical precision generally ranged from 10 to 20 cm in the open but increased to 1 m within the forest. For future reference, random start locations for systematic sampling of *Erigeron mancus* counts were 17.7 m for the ridgeline transect and 15.7 m for the crestline transect.

| Latitude | Longitude | Distance (m) | Elevation (m asl) | Transect |
|---|---|---|---|---|
| 38.460682522 | −109.250356316 | 0[a] | 3429.599 | ridgeline |
| 38.460499711 | −109.250336075 | 20 | 3433.689 | ridgeline |
| 38.460325072 | −109.250327597 | 40 | 3438.136 | ridgeline |
| 38.460172916 | −109.250247728 | 60 | 3440.187 | ridgeline |
| 38.460066855 | −109.250072001 | 80 | 3444.634 | ridgeline |
| 38.459962331 | −109.249894354 | 100 | 3449.576 | ridgeline |
| 38.459855568 | −109.249722425 | 120 | 3454.519 | ridgeline |
| 38.45974535 | −109.249549942 | 140 | 3460.319 | ridgeline |
| 38.459618566 | −109.249393376 | 160 | 3465.635 | ridgeline |
| 38.459475784 | −109.249261452 | 180 | 3469.781 | ridgeline |
| 38.459336295 | −109.249135310 | 200 | 3475.533 | ridgeline |
| 38.459194302 | −109.249010127 | 220 | 3480.531 | ridgeline |
| 38.459058828 | −109.248872065 | 240 | 3482.907 | ridgeline |
| 38.458919852 | −109.248740006 | 260 | 3488.85 | ridgeline |
| 38.458782917 | −109.248610163 | 280 | 3493.977 | ridgeline |
| 38.458638552 | −109.248470589 | 300 | 3494.149 | ridgeline |
| 38.45849231 | −109.248347455 | 320 | 3498.466 | ridgeline |
| 38.458347145 | −109.248231632 | 340 | 3504.82 | ridgeline |
| 38.45820712 | −109.248118704 | 360 | 3512.168 | ridgeline |
| 38.458061214 | −109.247989617 | 380 | 3514.918 | ridgeline |
| 38.457919443 | −109.247854171 | 400 | 3516.708 | ridgeline |
| 38.45778232 | −109.247725500 | 420 | 3522.198 | ridgeline |
| 38.457648555 | −109.247595910 | 440 | 3529.92 | ridgeline |
| 38.457513016 | −109.247467638 | 460 | 3537.411 | ridgeline |
| 38.456964452 | −109.246626847 | 480 | 3556.947 | ridgeline |
| 38.456893029 | −109.246417955 | 500 | 3557.526 | ridgeline |
| 38.456264564 | −109.244231131 | 520 | 3547.735 | ridgeline |
| 38.45621193 | −109.244015126 | 540 | 3545.094 | ridgeline |
| 38.456156868 | −109.243799517 | 560 | 3543.844 | ridgeline |
| 38.456101147 | −109.243580522 | 580 | 3544.283 | ridgeline |
| 38.456046357 | −109.243365147 | 600 | 3543.862 | ridgeline |
| 38.455984809 | −109.243148982 | 620 | 3544.537 | ridgeline |
| 38.455921526 | −109.242935991 | 640 | 3546.627 | ridgeline |
| 38.455859313 | −109.242724798 | 660 | 3550.043 | ridgeline |
| 38.455797934 | −109.242516122 | 680 | 3554.347 | ridgeline |
| 38.45573572 | −109.242310957 | 700 | 3559.926 | ridgeline |
| 38.455440245 | −109.241292248 | 720 | 3590.595 | ridgeline |
| 38.455501083 | −109.241495205 | 740 | 3583.987 | ridgeline |
| 38.455561192 | −109.241699358 | 760 | 3578.032 | ridgeline |
| 38.455679383 | −109.242108335 | 780 | 3566.607 | ridgeline |
| 38.455620315 | −109.241904652 | 800 | 3572.869 | ridgeline |
| 38.455381512 | −109.241083689 | 820 | 3596.171 | ridgeline |
| 38.455321313 | −109.240880391 | 840 | 3602.648 | ridgeline |
| 38.45526006 | −109.240675697 | 860 | 3608.439 | ridgeline |
| 38.455202079 | −109.240464959 | 880 | 3615.469 | ridgeline |
| 38.4551428 | −109.240270603 | 900 | 3622.1 | ridgeline |
| 38.455081044 | −109.240073221 | 917 | 3628.891 | ridgeline |
| 38.453690771 | −109.237715328 | 0 | 3647 | crestline |
| 38.452884547 | −109.237134459 | 100 | 3638 | crestline |
| 38.459656 | −109.249895147 | 0 | 3456 | forest-treeline |
| 38.459869 | −109.252587776 | 250 | 3379 | forest-treeline |

[a] A benchmark nail marks the start point; other markers were lost due to frost action.