Influence of Weather on Low Larkspur (*Delphinium nuttallianum*) Density

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Abstract

Delphinium nuttallianum (low larkspur) causes serious cattle losses on mountain rangelands in western North America. Risk of cattle deaths is related to density of low larkspurs. Our hypothesis was that warmer winter/spring conditions, coupled with below average precipitation, would result in reduced low larkspur density (plants/m^2). We measured larkspur density using 4 transects at 4 sites: Collbran and Yampa, Colorado; Huntington, Utah; and Calf Creek (Teton Mountains), Wyoming over a 7-9 year period. Weather data was collected at nearby weather stations. Larkspur density was often related to previous winter and spring precipitation, with increased precipitation resulting in higher plant densities. Higher ambient temperatures during winter and spring were related to lower plant densities. Further, there was a relationship between weather during the previous growing season (May to July) and larkspur density the next year, with warmer temperatures and/or low precipitation related to reduce densities at 3 of 4 sites.

Keywords: Toxic plants, Plant populations, Climate

1. Introduction

Low larkspurs (*Delphinium nuttallianum* and other *Delphinium* species) are important toxic plants that often kill cattle on foothill and mountain rangelands in western North America (Pfister et al., 1999). Additionally the plants are an important early source of nectar for bees and hummingbirds (Inouye & McGuire, 1991). *Delphinium nuttallianum* is a long-lived perennial, and typically is one of the first plants to flower following snowmelt in late spring (Williams & Cronin, 1968; Waser & Price, 1991). Climate changes due to global warming are expected to alter temperature and precipitation patterns on many landscapes (IPCC, 2007). Such changes are likely to impact the timing of flowering (Saavedra et al., 2003) and the abundance of *D. nuttallianum*, thus potentially altering the risk of poisoning for grazing cattle. Saavedra et al. (2003) reported that abundance (i.e., density) of flowering *D. nuttallianum* individuals was sensitive to winter snowfall, and decreased in artificially warmed experimental plots.

Our investigations of poisoning episodes suggested that increased density of *D. nuttallianum* and related low growing *Delphinium* species results in higher cattle mortality ((Pfister & Gardner 1999; Pfister et al., 2003). Thus, the purpose of this study was to quantify the density of *D. nuttallianum* at four sites in the Rocky Mountains, and to determine if plant density was related to weather parameters. Our hypothesis was that low larkspur density would be related to winter or spring ambient temperatures and precipitation.

2. Materials and Methods

2.1 Life history of D. nuttallianum

Delphinium nuttallianum is a montane herbaceous perennial found in varied habitats across the western U.S. and Canada such as open subalpine meadows, rocky slopes, and shaded, forested areas like aspen woodlands. Typically these areas are slightly drier than those where tall larkspurs (e.g., *D. barbeyi*) are found, although at times *Delphinium* species overlap (Pfister, personal observations). Seed dispersal is passive in this species

(Williams & Waser, 1999), with most seed found at < 10 cm from the parent plant. Seed set in *D. nuttallianum* populations decline greatly in sparse populations relative to nearby dense populations (Bosch & Waser et al., 1999). Williams & Cronin (1968) found that the seed of *D. nuttallianum* either germinated or disintegrated during the first year under field conditions, and no viable seed existed during the second year. Williams & Waser (1999) reported that *Delphinium nuttallianum* does not reproduce vegetatively, and has essentially no seed bank in the soil. Plants begin flowering when 3–7 years old (Waser & Price, 1991). *Delphinium nuttallianum* plants overwinter as fibrous or rarely as small tuber-like roots, and sprout quickly when snow has melted in early spring (Williams & Waser, 1999). *Delphinium nuttallianum* preforms flower buds one year in advance, so it flowers quickly after snowmelt (Saavedra et al., 2003). *Delphinium nuttallianum*, unlike tall larkspurs like *D. barbeyi* (Inouye, 2008), does not appear to be sensitive to frost damage. Flowering occurs for about 3 to 4 weeks during spring or early summer (Pfister, personal observations). Once mature, the above ground portion of the plants senesce and die back before entering dormancy (Waser & Price, 1994), typically in mid-to-late June or early July, depending upon elevation and ambient temperatures (Pfister, personal observations). *Delphinium nuttallianum* has the capability of entering dormancy for one or more growing seasons during sub-optimal climatic conditions (Lewis & Epling, 1959; Beatty et al., 2004).

2.2 Study sites and methods

Four sites in the Rocky Mountains were selected for sampling based upon a history of periodic abundance of *D. nuttallianum*, reported cattle losses in these areas, and the proximity to weather stations. The sites selected were Collbran and Yampa, Colorado, Huntington, Utah, and Calf Creek (Teton Mountains), Wyoming (Table 1). Exact locations and elevations are given in Table 1. The Huntington, Utah site was sampled from 2000 to 2008; the Colorado sites were sampled from 2001 to 2008, and the Wyoming site was sampled from 2002-2008.

Measurement of various weather parameters was provided by the SNOTEL network operated and maintained by the National Resources Conservation Service (NCRS; Crook, 1977; NRCS, 1997). A central computer at NRCS's National Water and Climate Center (NWCC) in Portland, Oregon receives the daily data collected by the SNOTEL network. Each SNOTEL site measures daily snow-water equivalent (SWE), minimum, maximum and average temperatures, and precipitation. Daily water equivalent of snow is measured by the weight of the snow pack on a snow pillow, a fluid-filled flat pouch with hydraulic connections to a pressure measuring device. Manometer pressures are converted to precipitation values. Daily accumulated precipitation is measured by the weight of the accumulated precipitation in a rain gauge equipped, like the snow pillow, with hydraulic connections to a manometer. The rain gauges are emptied and recharged annually and contain antifreeze to prevent freezing, and oil to prevent evaporation of accumulated precipitation.

D. nuttallianum density (plants/m^2) was measured at each site once per year during May or June when the plants were flowering. A permanent center point was established at each site, and transects were established along the 4 cardinal directions. A 0.5 m^2 metal frame (1 m x 0.5 m) was used to determine density. The metal frame was placed every other meter along the transects for a total of 125 quadrats per cardinal direction, and the total number of low larkspur plants within each frame was counted and recorded. The dependent variable was the average plant density (plants/m^2) for each directional transect at each location each year.

SNOTEL records were accessed via the NRCS website (NRCS, 1997). Records were downloaded into SAS (2007), and analyzed for relationships with *D. nuttallianum* density. Weather records were analyzed using various time periods within the water year (October 1st to September 30th) in use in the USA. The periods examined for each water year were: 1) October 1 to Dec. 31; 2) October 1 to May 31; 3) January 1 to March 31; 4) January 1 to May 31; 5) March 1 to May 31; 6) April 1 to May 31; and 7) the previous summer's weather from July 1 to August 31. These periods were selected for their possible biological relevance to low larkspur emergence. Within these periods, various measured and calculated weather variables were determined. The most important of these were snow water equivalent (SWE) on April 1 and on May 1, mean and sum of SWE for the period in question, maximum, minimum, sum, and mean precipitation at various time points, maximum, minimum and mean temperature during various periods, maximum snow depth, Julian date of final snow melt in spring, and total growing degree days during March, April and May. Growing degree days were calculated for each day as the mean temperature minus the base temperature, and were accumulated by adding each day's contribution as the season progressed. For growing degree days, we used two base temperatures, 10 and 20 ^{0}C, and no high temperature cutoff was required. We used these base temperatures because *Delphinium nuttallianum* sprouts and begins active growth as soon as snow has melted in late winter (Williams & Cronin, 1968; Waser & Price, 1994).

2.3 Regression analysis

Correlation analysis and multiple regression with influence diagnostics (e.g., residuals, examining outliers, and leverage) were used in SAS (2007) to determine relationships. After this initial analysis, a stepwise multiple

regression was used in an exploratory analysis to screen independent variables, followed by hierarchical multiple regression with 1 or 2 variables introduced in a specific order for the final regression equations. Because of the small sample sizes (n = 32), and to overcome inherent problems with multi-collinearity, the number of weather regressors in each model was limited to a maximum of 2. Multi-collinearity is loosely defined as a regression model in which two or more predictor variables are highly correlated; this greatly inflates the R^2 value. Variance inflation factor (VIF) is a common method for detecting multi-collinearity; VIF (the reciprocal of tolerance) was examined for each model, and models with VIF > 4 were discarded (Belsley et al., 1980). A VIF of this magnitude indicates that the variance of the estimated coefficient is > 4 times larger than it would be if the predictors were not correlated. We also used the condition index as another indicator of collinearity; a condition index of > 30 suggests that some variables are highly correlated, and the model should be refit (Yu, 2000). We discarded variables with a condition index > 15. Additionally, collinearity was diagnosed by recognizing variables that had large proportions of variance (0.50 or more) that corresponded to large condition indices.

The best models were defined as those that had a high R^2, were significant at $p < 0.05$, and had a relatively small value of Mallow's *Cp* statistic, where *Cp* was approximately equal to the number of terms in the model. *Cp* tends to find the best subset of the model that includes only the important predictors of the dependent variable. We did not compare r^2 between periods and locations because the variances of some of the independent variables were not equal.

This approach generated numerous models; however, for simplicity only the best fitting models with 1 or 2 terms are given here for selected periods from each the 4 locations. Because the purpose of this study was to determine if there was a relationship between weather and low larkspur density, no cross validation was attempted in this study to forecast larkspur density in other populations of plants.

3. Results and Discussion

The majority of precipitation in the northern Rocky Mountains comes from winter storms originating in the Pacific Northwest as part of a strong annual cycle (Carson, 2007). Some years however, winter snowfall and spring precipitation vary substantially from long-term averages. In addition, temperatures may vary above and below seasonal averages, with occasionally warmer than normal winter and spring weather. In some years weather fluctuations are related to El Nino or La Nina conditions in the Pacific Ocean (Holmgren et al., 2001). Our hypothesis was that warmer winter/spring conditions, coupled with below average precipitation, would result in reduced low larkspur density at a number of mountain sites. The results of this study confirmed these observations, as temperature and precipitation, singly and together, were often highly related to low larkspur density.

Mean low larkspur density over years at the 4 study sites is shown in Figure 1. Low larkspur densities varied greatly from year-to-year, particularly at the Colorado and Utah sites. Plant densities ranged from 0-15 plants/m^2 at Huntington, UT, 2-17 plants/m^2 at Yampa, CO, and 1-11 plants/m^2 at Collbran, CO. On the other hand, larkspur densities and year-to-year variability were lower and less extreme at the Calf Creek, Wyoming site, ranging from 0-4 plants/m^2 (Fig. 1). These differences illustrate inherent site differences influencing long-term low larkspur populations.

At Yampa, CO the highest larkspur density during 2003 (16 plants/m^2) was related to colder and wetter weather conditions during that year (Table 2). The regression equations relating weather and density for Yampa, CO and the other 3 sites, are shown in Table 3. The most important weather variables were those related to temperature and precipitation (Table 3) as larkspur density often had a strong positive relationship with previous winter and spring precipitation, with increased precipitation resulting in higher plant densities. At Yampa, CO, low density occurred during 2005 (2 plants/m^2), and was related to lower precipitation during the previous winter (2005) and the previous summer (2004). At this and the other sites, temperature variables were important in the regression models, however the influence of precipitation was more visually apparent than temperature when examining weather and density (Table 2).

Larkspur densities were low at Collbran, CO during 2002, and this reduction was related to a decrease in snow water equivalent and precipitation (Tables 3 and 4). Conversely, the high larkspur densities during 2003-2005 were related to increases in snow water equivalent and precipitation, and a simultaneous decrease during 2003 in temperature.

Larkspur densities at Calf Creek, WY did not change as dramatically as did other sites, but there were differences over time. These differences were related to temperature and precipitation (Table 3), as the warmer winter and spring of 2004 (Table 5) resulted in a greatly reduced density. The peak plant density occurred during 2008, and apparently was related to cooler temperatures (Table 5), and to increased snow water equivalent.

There were dramatic yearly differences in densities at Huntington, UT (Figure 1). During 2000, larkspur densities were extremely low, and density was related (Table 3) to a significant decrease in precipitation (Table 6), and warmer temperatures. The large increase in density during 2005 was apparently related to the concomitant increase in precipitation that spring (Table 6).

Snow is a critical factor in plant growth in montane ecosystems, as the majority of precipitation comes from winter snowfall. Reduced snow cover lowers soil temperatures (Wipf et al., 2009), whereas advanced snowmelt increases the duration of the growing season. The records from the SNOTEL sites show that winter snowpack accumulation peaks with a maximum snow-water equivalent typically occurring between April 1 and May 1 of each year. Thus, the snow-water equivalent measured on April 1 and May 1 provides an indication of the water available to spring-growing plants. Snow-water equivalent (cm) on April 1 was an important predictor of low larkspur density at the Colorado and Wyoming sites. Supporting our observations, Saavedra et al. (2003) found that the number of flowering individuals of *D. nuttallianum* was closely related to previous winter snowfall in western Colorado, with more flowering individuals as snowfall increased.

Our findings are consistent with other observations of low larkspur life history in relation to previous winter snowfall and temperature (Saavedra et al., 2003). Saavedra et al. (2003) manipulated winter temperature in plots of low larkspur in Colorado, and warming had a negative effect on plant abundance. Further, de Valpine & Harte (2001) showed that abundance of low larkspur declined after experimental warming in study plots (4.6 vs. 1.3 plants/m^2 in control vs. heated plots, respectively). Low larkspur emergence in spring appears to be regulated primarily by soil moisture availability (de Valpine and Harte, 2001) in conjunction with temperature, and thus reduced snowfall or spring precipitation and warmer temperatures leads to a decline in the number of plants.

At the Colorado and Utah sites, an interesting relationship between larkspur density and the previous summer's precipitation and/or temperature was observed (Table 3). At Yampa, a combination of precipitation and temperature from the previous summer (May to July) was related (r^2=0.68) to the next year's density. At Calf Creek, the related (r^2=0.70) variables were minimum temperature and May precipitation of the previous year. At Huntington, the sum of May to July (i.e., growing season) precipitation was related (r^2=0.65) to the next summer's low larkspur density. Previous summer precipitation and temperature appear to be important factors influencing low larkspur dormancy, and subsequent emergence. Low larkspurs respond to spring and summer drought and high temperatures by reducing flowering (i.e., flowers abort) with a corresponding early entry in dormancy. During their spring and summer growth cycle, low larkspurs preform flowering buds for the next growing season, and it appears that environmental stress in the form of lower precipitation and/or higher ambient temperatures reduce the number of plants that break dormancy and grow the following year. Lewis and Epling (1959) and Koontz et al. (2001) noted that spring emergence of different species of low larkspur was related to sub-optimal weather conditions and stress from the previous growing season. Further, Beatty et al. (2004) reported that low larkspurs not only become dormant seasonally, but dormancy may persist after a large reproductive effort, such as might occur after an abnormally wet winter or spring (Saavedra et al., 2003). Given the variability in Rocky Mountain weather patterns, a favorable precipitation year may often be followed by a less favorable year, thus enhancing the dormancy effect and exacerbating the low density of some low larkspur populations.

As we have shown, low larkspur density can vary greatly among years; we have also noted that density can vary greatly at a single site within years (unpublished observations). This is congruent with other work near Gunnison, CO, showing that dense plots of *D. nuttallianum* in Colorado had 14 plants/m^2 vs. sparse plots with approximately 2 plants/m^2 (Bosch & Waser, 1999) during the same growing season. Bosch & Waser (1999) found that low larkspur density (high vs. low) did not have a major impact on pollination, but did negatively impact seed set in a Rocky Mountain population.

Winter snowfall may be one of the most impacted aspects of global climate change (IPCC, 2007). Some forecasts suggest that total mountain precipitation will increase, but the amount of moisture falling as snow may decrease with future warming trends (IPCC, 2007). Current projections also indicate that montane ecosystems may be more susceptible to prolonged drought (Bradley & Mustard, 2007). Future low larkspur populations may be impacted by climate change if rising temperatures and changes in precipitation reduce low larkspur population densities. Under conditions of rising temperatures and reduced winter precipitation, low larkspur populations may gradually become less dense (Inouye et al., 2002; Inouye, 2008), while existing populations may undergo more rapid maturation and desiccation in early summer. This hypothetical scenario would reduce the risk of cattle losses during spring and early summer grazing, as the mass of toxic plant material available for grazing would be reduced, in conjunction with a reduced window of exposure. However, such a scenario might also mean less desirable forage for livestock grazing, and more invasive plant problems on rangeland ecosystems (Bradley et al., 2009). For example, the best predictors of cheatgrass invasion on western U.S. rangelands under current warming trends are

summer precipitation followed by winter temperature (Bradley, 2009). Recent warming experiments suggest that in subalpine montane communities of which *D. nuttallianum* is a part, the abundance of forbs such as low larkspur will decrease with increasing temperatures, whereas shrubs such as sagebrush will increase (Shaver et al., 2000). For livestock producers, the risk of cattle losses from low larkspur may decrease, but forage quality and quantity may not be enhanced.

4. Conclusions

Population dynamics of montane flowering plants such as *D. nuttallianum* is a complex interaction of life history, abiotic factors, pollinating insects, and numerous other factors that vary greatly in time and space. Our work has shown that weather factors, primarily precipitation and temperature, are related to low larkspur densities at 4 subalpine montane sites in the northern Rocky Mountains. The purpose of our work was not to predict larkspur densities based on weather, as plant populations at landscape scales are not easily amenable to such prediction because of complex feedback patterns and contingencies. Instead, our work indicates that the relationship between weather and low larkspur plant densities can inform livestock producers about the existence of such patterns, and that these patterns may be important in animal and rangeland management to reduce livestock losses. Livestock producers grazing cattle on rangelands with low larkspur populations need to be able to identify low larkspur species, be aware of the abundance or scarcity of low larkspur populations on their ranges, and gain awareness that weather patterns can exacerbate or reduce toxic plant populations and alter the risk to grazing animals.

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Table 1. *Delphinium nuttallianum* sites where density was measured yearly, site features, and distance from nearest SNOTEL site. SNOTEL weather data available from Natural Resources Conservation Service. Online at: http://www.wcc.nrcs.usda.gov/snow/

Site	Years	Location	Elevation (m)	NRCS SNOTEL station name	SNOTEL distance from research site
Collbran, CO	2001-2008	N lat 39 14 49 W long –107 37 02	2681	Overland Reservoir	13 km
Yampa, CO	2001-2008	N lat 40 11 39 W long –107 04 50	2801	Crosho	3 km
Calf Creek, WY	2002-2008	N lat 44 07 37 W long –110 53 22	2216	Grassy Lake	4 km
Huntington, UT	2000-2008	N lat 39 27 43 W long –111 04 98	2915	Red Pine Ridge	14 km

Table 2. Summary of important weather statistics by period within each water year[a] for Yampa, CO. Weather variables shown below relate to regression equations shown in Table 3. Weather statistics were downloaded from NRCS SNOTEL records (accessed at http://www.wcc.nrcs.usda.gov/snotel/) for the SNOTEL station Crosho Lake.

	Year								
	2000	2001	2002	2003	2004	2005	2006	2007	2008
Mean daily snow water equivalent (SWE, cm) Oct. 1 to Dec. 31	-	4.6	3.0	6.4	5.6	1.7	5.6	3.8	3.1
Average daily minimum temperature (^{0} C) January 1 to May 31	-	-22.4	-23.4	-13.3	-22.2	-22.4	-21.6	-21.1	-22.9
Sum of precipitation (cm) January 1 to May 31	-	35.3	21.3	47.5	27.9	27.2	33.0	28.2	47.8
Sum of precipitation (cm) the previous growing season (May 1 to July 31)	13.7	12.9	11.4	15.8	7.1	17.8	12.7	10.2	-

[a] The water year goes from October 1 to September 31 of each year. The periods in this table were used to examine weather variables that relate to low larkspur density (see Table 3).

Table 3. Regression equations for weather variables related to low larkspur density (plants/m^2, $\hat{y}$). The water year (October 1 to September 31 of each year) at each location was divided into various periods and observed and calculated weather variables were used in multiple regression equations relating weather parameters to low larkspur densities. The best one or two variable regression equations are shown below (i.e., highest R^2, lowest value of Mallow's *Cp* statistic) from the specific period during the water year. The regression equations are not comparable between locations.

Location	Period	*Cp*[a]	Equation/variables[b]	R^2
Yampa, CO	Oct 1 to Dec 31	3.0	$\hat{y}$ = 4.8 + 4.1 MeanSWE – 0.94 MaxT	0.81
	January 1 to May 31	3.0	$\hat{y}$ = −35.0 + 0.78 SumPrecp − 1.18 MinT	0.74
	May 1 to July 31 (previous summer)	4.4	$\hat{y}$ = 4.9 + 0.02 SumPrecp − 0.67 MinT	0.68
Collbran, CO	Oct 1 to Dec 31	3.0	$\hat{y}$ = −3.6 + 0.4 SumSWE − 0.13 MinT	0.82
	April 1 to May 31	2.0	$\hat{y}$ = −3.3 + 2.3 SumPrecp	0.85
	April 1 to May 31	3.0	$\hat{y}$ = −7.6 – 0.81 MinT	0.90
Calf Creek, WY	Jan 1 to March 31	2.0	$\hat{y}$ = 7.6 – 0.46 MaxT	0.79
	March 1 to May 31	3.0	$\hat{y}$ = 9.9 + 0.14 SWEApril – 0.36 MaxT	0.69
	May 1 to July 31 (previous summer)	3.0	$\hat{y}$ = 6.4 − 0.3 MinT + 0.1 PrecMay	0.70
Huntington, UT	Oct 1 to May 31	3.0	$\hat{y}$ = 13.6 + 0.56 PrecAprilMay – 2.9 MeanT	0.57
	Oct 1 to May 31	2.0	$\hat{y}$ = 16.7 – 7.1 MeanT	0.54
	May 1 to July 31 (previous summer)	2.0	$\hat{y}$ = 16.7 + 2.53 SumPrecp	0.65

[a] *Cp* = Mallow's *Cp* statistic. Mallow's statistic is one criterion for selecting among many alternative regressions; the regression model may be a reasonable fit if Mallow's statistic does not deviate greatly from the number of terms in the model.

[b] All regressions were significant ($P < 0.05$). Abbreviations:

MeanSWE = average daily snow water equivalent (SWE, cm) during the time period indicated

SumPrecp = sum of daily precipitation (cm) during the time period indicated

SumSWE = sum of the snow water equivalent (SWE, cm) during the time period indicated

SWEApril = SWE (cm) on April 1

MaxT = maximum daily minimum temperature (^{0} C) during the time period indicated

MinT = minimum daily average temperature (^{0} C) during the time period indicated

MeanT = mean daily maximum temperature (^{0} C) during the time period indicated

PrecAprilMay = total precipitation (cm) received during April 1 to May 31

Table 4. Summary of important weather statistics by period within each water year[a] for Collbran, CO. Weather variables shown below relate to regression equations shown in Table 3. Weather statistics were downloaded from NRCS SNOTEL records (accessed at http://www.wcc.nrcs.usda.gov/snotel/) for the SNOTEL station Overland Reservoir.

	Years							
	2001	2002	2003	2004	2005	2006	2007	2008
Sum of snow water equivalent (SWE, cm) Oct. 1 to Dec. 31	444.5	345.4	731.5	660.4	619.6	330.2	556.2	441.9
Average Daily Minimum Temperature (^{0} C) Oct. 1 to Dec. 31	-23.8	-22.8	-23.9	-22.6	-21.8	-21.4	-21.3	-21.6
Sum of precipitation (cm) April 1 to May 31	11.6	5.08	13.2	15.54	9.6	7.6	10.4	8.6
Average Daily Minimum Temperature (^{0} C) April 1 to May 31	-19.8	-19.5	-20.5	-19.6	-19.7	-18.9	-19.0	-20.8

[a] The water year goes from October 1 to September 3 of each year. The periods in this table were used to examine weather variables that relate to low larkspur density (see Table 3).

Table 5. Summary of important weather statistics by period within each water year[a] for Calf Creek, Teton Mountains, WY. Weather variables shown below relate to regression equations shown in Table 3. Weather statistics were downloaded from NRCS SNOTEL records (accessed at http://www.wcc.nrcs.usda.gov/snotel/) for the SNOTEL station Grassy Lake.

	Year						
	2002	2003	2004	2005	2006	2007	2008
Average daily maximum temperature (^{0} C) from Jan. 1 to Mar. 31	-18.7	-17.3	-16.7	-17.0	-17.9	-16.9	-18.5
Snow water equivalent (SWE, cm) on April 1	71.8	80.0	87.1	62.7	97.2	65.5	95.0
Average daily maximum temperature (^{0} C) from Mar. 1 to May 31	-14.3	-13.0	-12.4	-13	-12.5	-11.6	-13.7

[a] The water year goes from October 1 to September 31 of each year. The periods in this table were used to examine weather variables that relate to low larkspur density (see Table 3).

Table 6. Summary of important weather statistics by period within each water year[a] for Huntington, UT. Weather variables shown below relate to regression equations shown in Table 3. Weather statistics were downloaded from NRCS SNOTEL records (accessed at http://www.wcc.nrcs.usda.gov/snotel/) for the SNOTEL station Red Pine Ridge.

	Year								
	2000	2001	2002	2003	2004	2005	2006	2007	2008
Sum of precipitation (cm) from April 1 to May 31	9.1	10.8	6.5	11.9	11.4	16.5	9.4	10.2	13.5
Minimum Daily Temperature (^{0} C) April 1 to May 31	-19.2	-19.7	-20.1	-20.8	-19.6	-19.9	-19.8	-19.5	-21.2

[a] The water year goes from October 1 to September 31, thus for example the 2001 water year goes from Oct. 1, 2000 to September 31, 2001. There is a similar pattern for all years. The periods in this table were used to examine weather variables that relate to low larkspur density (see Table 3).

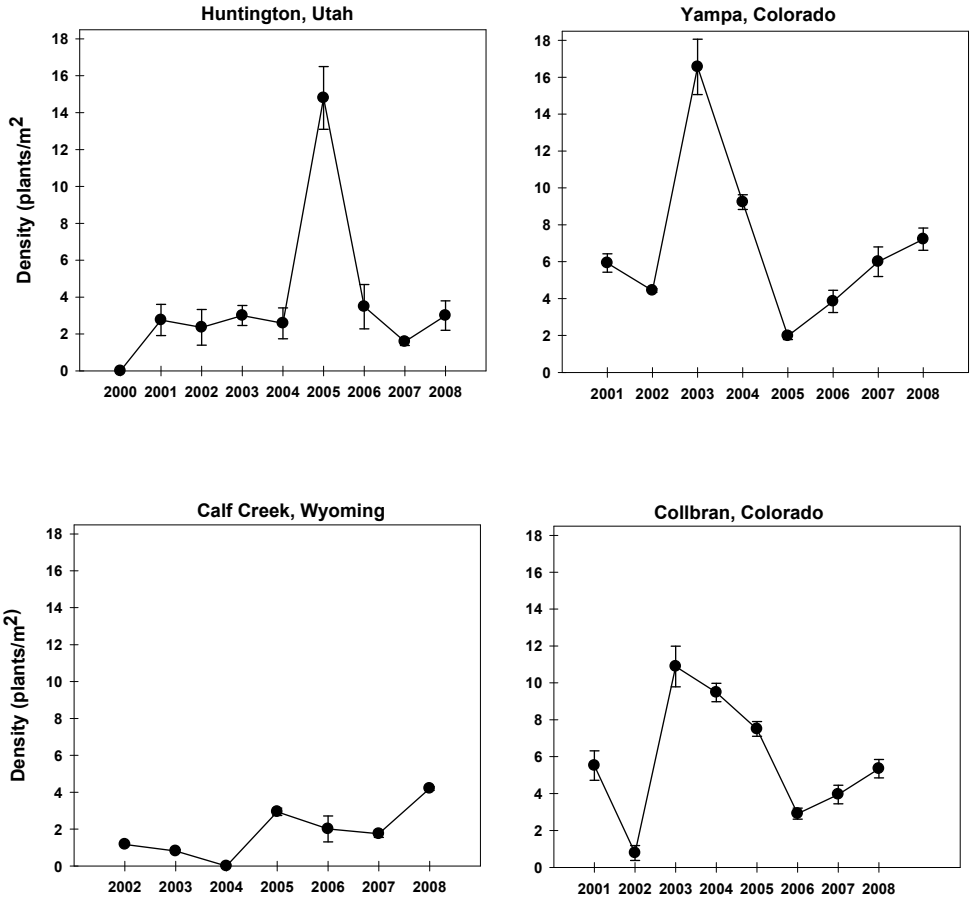

Figure 1. Density (plants/m^2 ± SE) of *Delphinium nuttallianum* at four sites in the Rocky Mountains. Densities are the mean of 4 transects taken at each site each year during flowering

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