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Comparison of Drought Response between Delphinium nuttallianum and Taraxacum officinale

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Delphinium nuttallianum **and** ***Taraxacum officinale***

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Abstract

As global warming raises average temperatures, increases evaporation rates, and brings earlier snowmelt, drought has become more frequent in the state of Colorado and the intermountain region in general. Native plant species are expected to adapt to these changes faster than non-native ones. The common dandelion (*T. officinale*) is a non-native plant in the Gunnison Basin, but as drought conditions increase in frequency, how are the plant's abundance levels rising or falling compared to Nuttall's larkspur (*D. nuttallianum*)? This question was investigated by comparing years with varying degrees of drought using a suite of GIS tools and high-resolution drone imagery. The year 2019 was just above average in precipitation levels, while 2020 was well below average. In 2021, an early snowmelt preceded another summer of significant drought. Dandelion abundance decreased in 2020 from 2019 abundance, while the Nuttall's larkspur abundance remained constant. However, the larkspurs experienced a large decline in 2021 and dandelions returned to the abundance level of 2019. The results of this study offer insights for the future about how droughts may impact the communities in which dandelions and larkspurs exist from the changes in abundance and spatial variance seen with these two flower species.

Introduction

Over the past 200 years, climate change has continued to cause rises in air temperatures, decreased amount of snow and ice in the winter, and more sporadic rains in the summers (IPCC, 2007). The gradual and steady increase in atmospheric temperatures has put all ecosystems in some amount of jeopardy, especially biological hotspots located near the equator (Liu, 2018). Rainfall becoming increasingly sporadic means that areas with traditionally heavy rainfall are beginning to experience drought and areas where drought previously occurred are seeing the levels and impacts exacerbated (Chiang, 2021). All ecosystems maintain some level of equilibrium between the species that coexist in them and droughts reduce all plants ability to grow to full potential and maintain such a balance (DeAngelis, 1987). Invasive species, ones that outcompete native species and cause damage to the environment, and exotic species, ones that are non-native but become assimilated overtime, have both become more frequently introduced into new environments around the world by humans (EPA, 2022). Drought can put non-native species at a disadvantage compared to species in their natural habitat or vice versa but, in general, drought negatively impacts all species and can also weaken native communities' ability to resist biological invasions (Diez, 2012). While non-native species do not normally affect the equilibrium of their community, climate change and droughts can lead to shifts in species abundance, changes in flora biodiversity and lead to interspecies competition (Fahey, 2018). Drought can lead to the competition for space, nutrients, and pollinators between species (Armstrong, 1993; Alexander, 2019). Shifts in ecological equilibriums and competition between native and non-native species will continue to increase as global warming does (Dobrowski, 2021), leading to changes in fitness for organisms across trophic levels (Rosenblatt, 2018).

THE STUDY SYSTEM

The study was conducted at the Rocky Mountain Biological Laboratory (RMBL) in Gothic, CO (figure 1a, see appendix). Colorado has seen rising temperatures, decreased snowpack, earlier snow melts, and fewer summer rains during the monsoon season (Gao, 2011). Predictions and models for the state's future water supply look grim (Christensen, 2004). Colorado is one of the few states in the US that has a topographic landscape that means that no water flows into the state (McKee, 2000) and, therefore, Colorado's water is exclusively from precipitation, mostly from the snow that falls in the winter and then melts into the streams, rivers, and lakes in the spring and summer (McKee, 2000). This past summer (2021) for the second year in a row, the Gunnison River Basin (fig.1b) experienced levels of decreased water in June, 2021 as the year moved into the peak heat conditions (NOAA, 2022), continuing a multi-year drying trend (Udall, 2017). The purpose of this project was to assess how species' abundances respond to the more frequent drought conditions in the Gunnison River Basin with drone and geospatial technologies. Dandelions are quick to grow in harsh environments with poor nutrient availability (Brock, 2005; Quiroz, 2011) which led to my hypothesis that *T. officinale* would be more robust to drought than *D. nuttallianum*. I predicted that *T. officinale* would be less impacted by drought than *D. nuttallianum* because of their success in colonizing harsh, alpine and disturbed habitats (Quiroz, 2011).

METHODS

To examine the response of native and exotic species to drought, I gathered abundance and spatial data on the Nuttall's larkspur, *Delphinium nuttallianum*, and the exotic common dandelion, *Taraxacum officinale*. *Delphinium nuttallianum* is a purple flower in the Ranunculaceae family, native to the Gunnison Basin, which typically blooms early to mid-summer and produces about 20 seeds per plant (Jones, 2004). *Taraxacum officinale*, a non-native flower, blooms at a similar time as the *D. nuttallianum* and can reproduce asexually through apomixis to produce hundreds of seeds, spreading very easily over vast distances (DeLorenzo, 1973). Dandelions thus avoid the pollen limitation (Jones, 2004) which can depress reproduction in larkspurs have to experience (Waser, 1991; DeLorenzo, 1973). *Taraxacum officinale* was originally introduced to the North American continent by English settlers in the 1600s as a food and medicinal source (Esser, 1993). Dandelions were brought with the European settlers as they pushed west on Native lands and probably established in Colorado sometime in the 19th century (Hourdajian, 2006). Although dandelions are now naturalized within the montane environment, the plant is still listed as exotic for the entire United States, including Gunnison County (fig.2) (NPS, 2018).

Throughout the state of Colorado, *T. officinale* and *D. nuttallianum* share similar elevational ranges and microclimates (Pyke, 2012). The two species also compete for soil resources according to data juxtaposing abundances, seed production, and water retention (Jones, 2004). *Taraxacum officinale* performs well in mesic environments due to a greater leaf surface area, increased carbon assimilation, and a higher capacity for water extraction (Brock, 2005). Drought conditions continuing to change the environment means that the alpine zone may be under threat of the continued biological invasion by *T. officinale* (Brock, 2005). The annual snowpack has been trending downwards since records were first kept in 1974 (barr, 2022). The snowfall for the winter of 2018-2019 was an average amount at 967 cm, followed by two years of well below average snowpack of 602 cm and 561 cm, respectively (Table 1) (barr, 2022). Early melting of the snowpack means earlier flowering for plants, shifting their phenology against the dryer summer conditions (Inouye, 2001). In addition to the reduced snowpack in 2020 and 2021, those two years also experienced moderate, severe, and extreme levels of drought according to the National Oceanic and Atmospheric Administration (NOAA) while

2019 did not (fig.3) (NOAA, 2022). Moderate drought is indicative of streams and lakes containing decreased levels of water and the potential for crop damage while drought is qualified as extreme when there are widespread water shortages and major damage to crops (NOAA, 2022).

Field Collection

A single site was surveyed using drone imagery taken over three years, 2019-2021. The site is a rocky southwest-facing slope with a gradient of about 30% at the top (northeast) of the plot leading down to two nearly flat mounds at the bottom of the site (southwest). The steep pitch of the slope may mean that less water is held by the soil before it flows down to the low elevation portion of the site (USU, 2009). The study site is located near the Copper Creek and a natural waterfall called Judd Falls (hereafter referred to as the "Judd Falls" site). Data were collected from drone flights at the Judd Falls site in 2019 on June 13th, 17th, 24th, and July 1st, 7th, 15th, in 2020 on May 21st, 27th and June 3rd, 11th, 17h, 24th and in 2021 on May 14th, 27th, June 3rd, 7th, 14th, and 24th. In 2019 the upper Gunnison Basin had a very high snowpack and also received rain throughout May and June. In contrast, 2020 and 2021 were very low in snowpack which melted out early and each June was a time of moderate to severe drought for the area around Gothic (fig.4). Yet the Gunnison Basin received a minor level of precipitation before and after the study season of 2021, in May and July, while 2020 had none at all (NOAA, 2022). In all three years, six weeks were sampled from the peak flowering season of both *D. nuttallianum* and *T. officinale*. The peaks were determined from presence-absence data taken from a 50m transect in the middle of the site (Breckheimer, UR). Larkspur and dandelions flower at approximately the same time and occur in the same locations (Jones, 2004), making them ideal for comparing the responses of a native and non-native to drought. The drone, a DJI Mavic 2, was flown at an average altitude of ~10m above the surface and at a speed of 1.3 m/s, capturing an image parallel to the ground every 2 seconds. To keep the imagery consistent, the flights were paused if the cloud cover changed significantly from sunny to cloudy or vice versa.

Image Processing

The program Agisoft Metashape was used to process, stitch, and combine raw images and create final orthomosaic maps, following the USGS workflow (USGS, 2017). After uploading the images to Metashape, a batch process was used to create a sparse point cloud (fig.5a) of the 18 weeks all at once, which evaluates matching high contrast points between the images and aligns them. Four white bucket lids were located around the Judd Falls site and are clearly visible from the imagery. These lids act as georeference points so that they can be found within the individual images, further helping to align the camera positions with their real locations in the NAD83 / UTM zone 13N coordinate system used for this project. After each week was georeferenced, another batch process was created to turn the point cloud into a dense cloud (fig.5b), filling in most of the missing pixels in the combined imagery, then optimizing the camera alignment. After this, a digital elevation model (DEM)(fig.5c) was made for each week, which can be overlaid on OpenStreetMap satellite imagery (fig.5d). The final step of the batch process was combining all of these steps to create a flat, orthomosaic image map (fig.6) of each of the 18 weeks. This final product has a resolution strong enough to view 2mm from the 10m flight height and can be used to count individual flowers within the plot.

Flower Data Collection

QGIS was used to count the individual flowers by importing the orthomosaics as raster layers and using a highlight tool to create vector outlines of flowers. A tile index was formed as a vector layer, which consisted of 150 4x4 meter tiles with an even overlap of 200 cm to the tiles surrounding it that encompassed the whole orthomosaic area. For each week's raster, another two vector layers were created for flower highlights, one for *D. nuttallianum* and one for *T. officinale*, totaling 36 flower vectors. Initially the full tile index consisted of 900 tiles but 150 were randomly selected to analyze. Starting with 6/13/19, one tile at a time would be scanned for the bright yellow circles of *T. officinale* or the deep purple clusters of *D. nuttallianum* and when one was found, a polygon was created around the flower. Twenty tiles were done at a time before moving onto the next week, to keep the level of completion consistent across the 18 weeks. By the end of the data collection, 150 tiles were examined for each of the 18 weeks, totaling 2,700 tiles and 36,302 flowers.

Analysis

To examine if there was any change in spatial variation at the flowering peak from year to year I created a geographic visualization in the form of a heatmap for both flower species. In order to determine if there were any significant changes in peak abundance of the flowers for each week, I ran statistical tests such as ANOVAs and regressions. The tiles were spatially joined with the flower vectors from that particular week, with each flower id given a number corresponding to the tile that enclosed it before running a zonal statistic output. This heatmap represented the number of flowers per tile and the changes within each tile from year to year. The flower vector layers and the clipped tile index were then exported for statistical analysis using R (R Core Team 2021). The abundance values, tile number, and geographic information were then grouped and summarized by species and year. Due to the large number of zeros, in which a layer did not contain any of the layer species within a tile, there was a pronounced right-skew, so I assumed a non-normal distribution of the data. The "st_join()" function from the "sf" library was used to spatially join the data (10.1, Pebesma, 2018) before an "anti join" was performed to re-include all of the tiles with zeros back into the dataset that were left out originally. The "dplyr" package was also used to form and summarize data frames (1.0.7, Wickham, 2021). I used a negative binomial regression to statistically analyze the datasets which were performed for each species to compare their 2020 and 2021 peak abundances to the peaks in 2019 (for *D. nuttallianum*: 7/1/19 and for *T. officinale*: 6/24/19). The null hypothesis is that *T. officinale* and *D. nuttallianum* remain at equal abundances in years of drought conditions compared to years with average precipitation. The alternative hypothesis is that *T. officinale* persists at higher abundances than *D. nuttallianum* in years of drought compared to average years. The R libraries "MASS" (7.3-54, Ripley, 2021) and "magrittr" (2.0.1, Milton Bache, 2020) were used, along with the glm.nb() function (package MASS) utilizing a log link function.

RESULTS

The *D. nuttallianum* peak in 2019 was July 1st with an abundance of 48.68 flowers per 4 m^2. The peak in 2020 was almost one month earlier, on June 3rd, with an abundance of 46.32 flowers per 4 m^2 and 2021 abundance decreased on its peak of June 7th to 18.22 flowers per 4 m^2 (fig.7). Table 2 contains the flowers per 4 m^2 (mean flower abundance per tile) of all weeks, in chronological order for *D. nuttallianum*, and Table 3 contains *T. officinale* mean flower abundances chronologically (95%

confidence intervals included). In 2019 the highest abundance per tile of *T.* officinale occurred on June 24th with a mean abundance per 4 m^2 tile of 8.00 flowers and 2020 peaked on June 11th which had a mean abundance of 0.12 flowers per 4 m^2 tile. The peak of 2021 was on June 3rd and the mean abundance per 4 m^2 tile was 9.28 (fig.7).

During the weeks of peak flowering, the abundance of *D. nuttallianum* was significantly lower in 2021 than in 2019 and 2020. The peak mean of 2020 was 0.32 standard deviations below the mean of 2019 while 2021 was 6.25 standard deviations below 2019 (Table 4). For *T. officinale*, the peak flowering abundance of 2020 was significantly lower than 2019 and 2021. The peak mean of 2020 was 13.33 standard deviations of 2019, but the peak mean of 2021 was actually 0.7 standard deviations above 2019 (Table 4). The mean abundance of larkspur was not significantly different between 2019 and 2020 (p-value = 0.751), but spatially, the flowers were uniformly distributed in 2019, and significantly skewed in 2020. Abundance increased in 2020 within the lower elevation area of the site, which tends to collect more moisture in the soil, along the bottom left edge of the map, highlighted by the dark purple boxes (USU, 2009) (fig.10). However, larkspur abundance decreased on the upper slope of the site, where it tends to be drier in contrast. In 2021, the larkspur abundance decreased the most where there had been increases the year before, and saw declines across the site. Dandelions uniformly decreased in 2020 across the site and then uniformly increased in 2021 in nearly every tile (fig. 10). The changes in flower abundance per 4x4 m^2 tile are displayed in the figure 11, with decreases shown as red tiles and increases as green. By performing a t-test between the change in flower abundance per tile and a baseline dataset of no change (0.00 for all tiles), the spatial variance for larkspurs was found to be insignificant from 2019 to 2020, but significant from 2020 into 2021 (Table

5; fig 12). Dandelion spatial variance, when compared to the baseline dataset, was significantly different both from 2019 to 2020 and from 202 to 2021 (Table 5; fig 12).

Discussion

As humans continue to increase the production of greenhouse gases and global warming accelerates, the Earth's climate will continue to change (IPCC, 2007). The impacts of our actions will be experienced in every ecosystem on the planet, with an increase in the severity and frequency of drought being one of the most serious dangers (Chiang, 2021). In Colorado, studies concerning drought and non-native species will become more crucial to understand how the ecology of communities change. Native plants may struggle to compete with new invaders that adapt themselves to their new environments or conditions quickly (Quiroz, 2011), therefore, I predicted that dandelions would be less impacted by drought than larkspurs. If this were the case, *D. nuttallianum* mean abundance would decrease, while there would be no decrease or one that was significantly smaller for *T. officinale*. However, there was no statistically significant difference between the mean abundance of *D. nuttallianum* between the peak weeks of 2019 and 2020. Conversely, the abundance of *T. officinale* declined precipitously and significantly from 1,200 plants in 2019 to just 18 in 2020. The next year, 2021, showed a change in mean abundance from 2019 that now followed my prediction, where dandelions increased in the second year of drought while the larkspur population decreased significantly.

Between 2019 and 2020, the increase in drought may not have impacted the native Nuttall's larkspur in terms of abundance, but did impact in terms of phenology and flowering. Dandelion flower abundance was potentially more negatively impacted by drought, and peak flowering time was shifted forward by a full month in 2020 compared to 2019. The summer of 2020 was severely dry after a very low snowpack (barr, 2022) and appeared to impact the abundance and spatial variance of both species. Dandelions disappeared from the site almost entirely while larkspurs maintained overall numbers, in large part within the flat, low elevation portion of the site where the soil holds more moisture (USU, 2009). However, this trend did not continue into the third year of study, where in 2021 there was a reversal of the trend in changes of abundance. Dandelion abundance returned in this second year of drought, higher than it had been in the wet year of 2019, possibly because dandelions exhibit delayed flowering when faced with drought but show an increased plasticity when rainfall is variable (Molina-Montenegro, 2010). The second consecutive dry summer led to a decrease in larkspur abundance across the site, especially in the wetter, low elevation portion that had held the highest number of flowers in 2020. The native *D. nuttallianum* may be better equipped to handle short-term variances in the environment in which they live, but *T. officinale* are so persistent with a high fitness in harsh living conditions, they may be able to respond more quickly to an ever-drying environment experiencing repeated drought.

Although sampling over 36,000 flowers provided statistical power to detect differences among years, the three year study period is not powerful enough to produce results capable of showing long-term trends. Future studies that account for seed production in each year could reveal the impacts of past and present conditions on plant fitness and be used to project future demographics. Flower abundances (and seed production) may be greater one year, but that does not necessarily indicate long-term growth in population size. It is possible that the *D. nuttallianum* produced a large number of flowers in 2020 with a reduced survival of seeds into a second consecutive year of drought in 2021. *Taraxacum officinale* may have successfully avoided the cost of a large seed set by delaying their flowering during a year that had stressful conditions only to have an abundant population in the following summer when the water availability was more variable (NOAA, 2022; Molina-Montenegro, 2010). *Delphinium nuttallianum*, the native flower with a longer lifespan, may have also delayed flowering a year later in 2021 (Saavedra, 2003). *Taraxacum officinale* could have adapted to this drought environment quickly after 2020 because it performs well in unwelcoming settings that have insufficient water, nutrients, and disturbed soils (Brock, 2005)(Quiroz, 2011). The results of this study have led to insights into how *D. nuttallianum* and *T. officinale* abundances respond to drought and the way that spatial variances change within the community.

ACKNOWLEDGMENTS

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Appendix

Figures

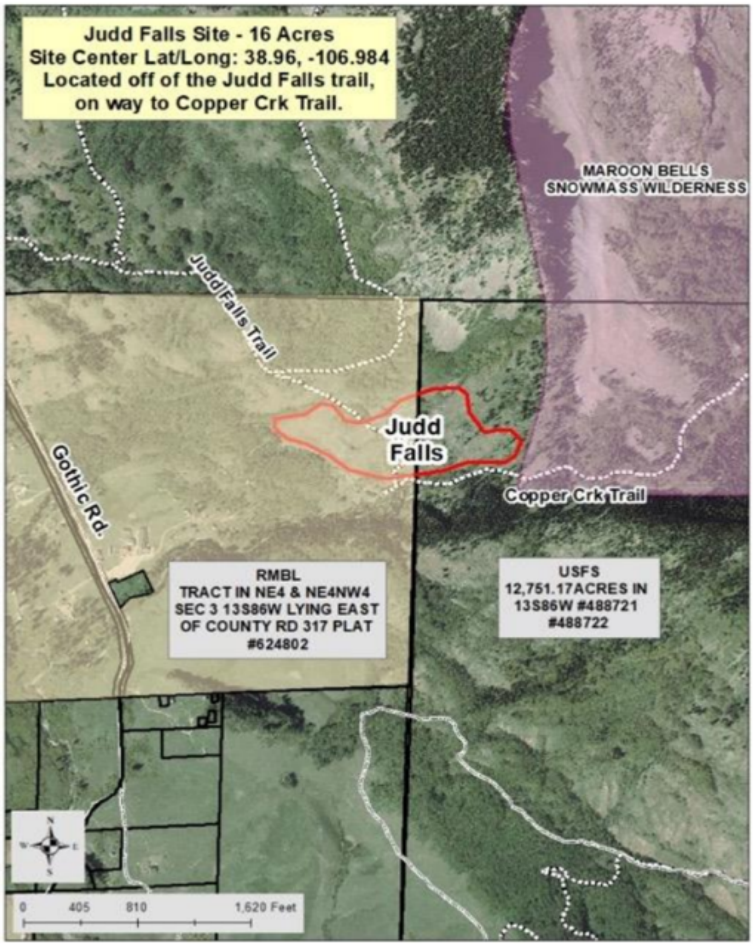


Figure 1a. Judd Falls site (38.96, -106.984). Unmanned Aircraft Systems - Filming Request. 2020. Dr. Ian Breckheimer, Uncompahgre and Gunnison National Forests.

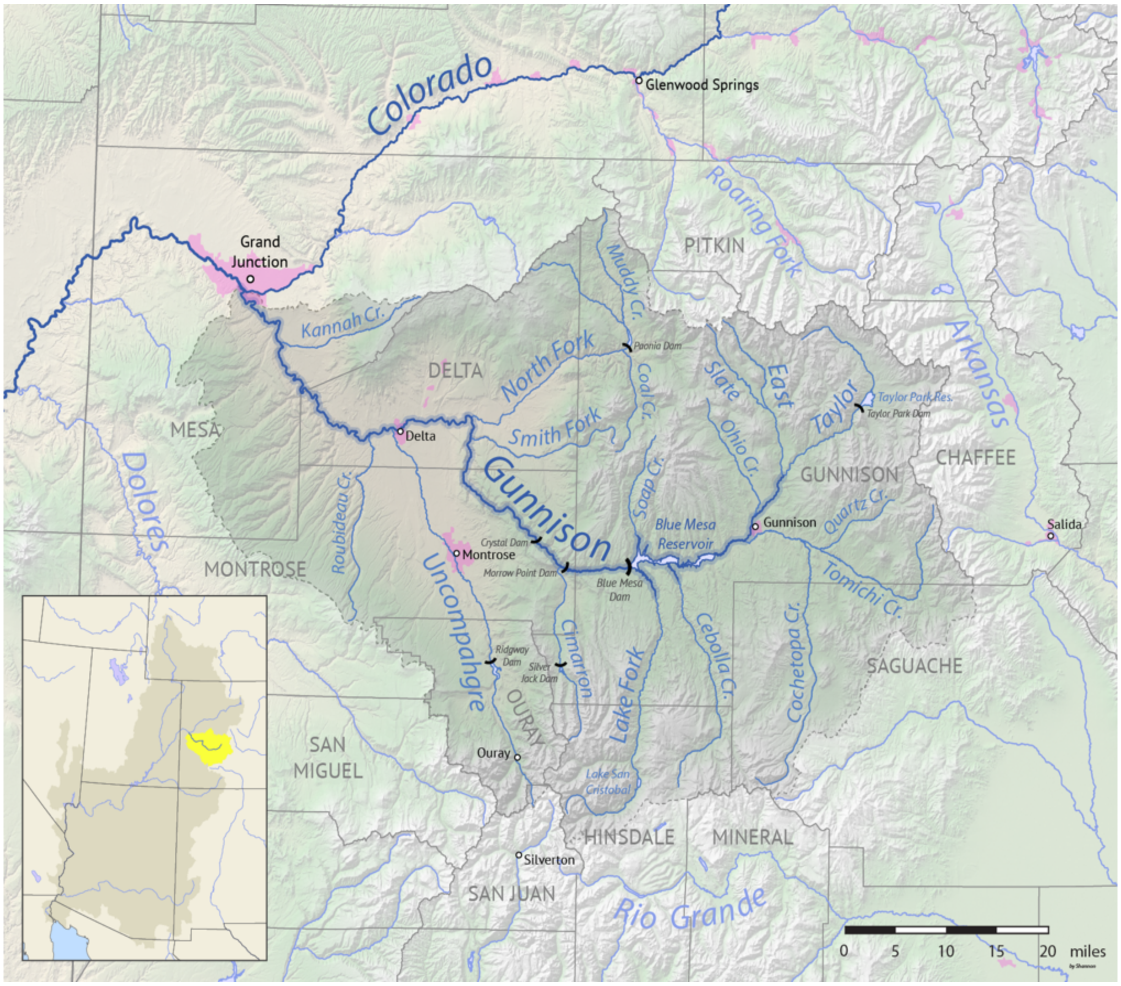


Figure 1b. By Shannon1 - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=69257550

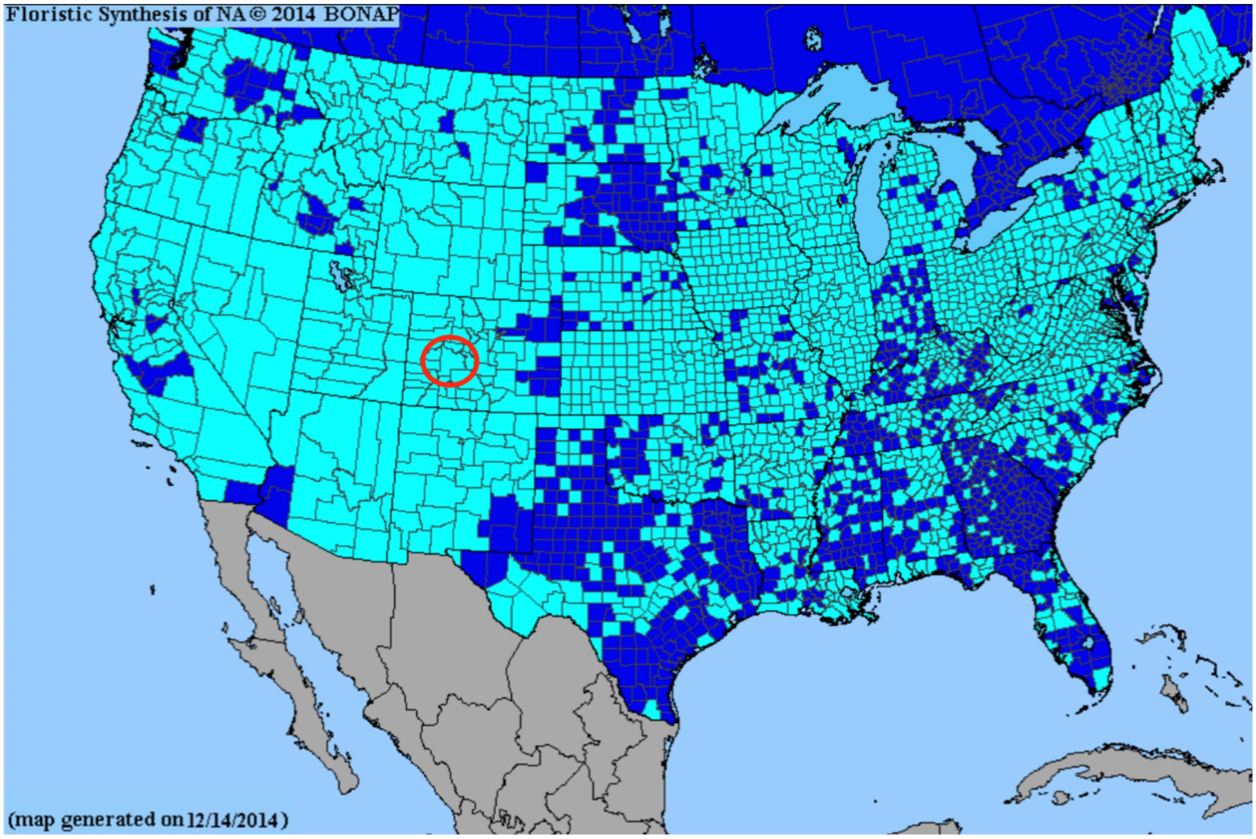


Figure 2. Species present in state and exotic. Species present in county and exotic.

O = Gunnison County

http://bonap.net/MapGallery/County/Taraxacum%20officinale.png

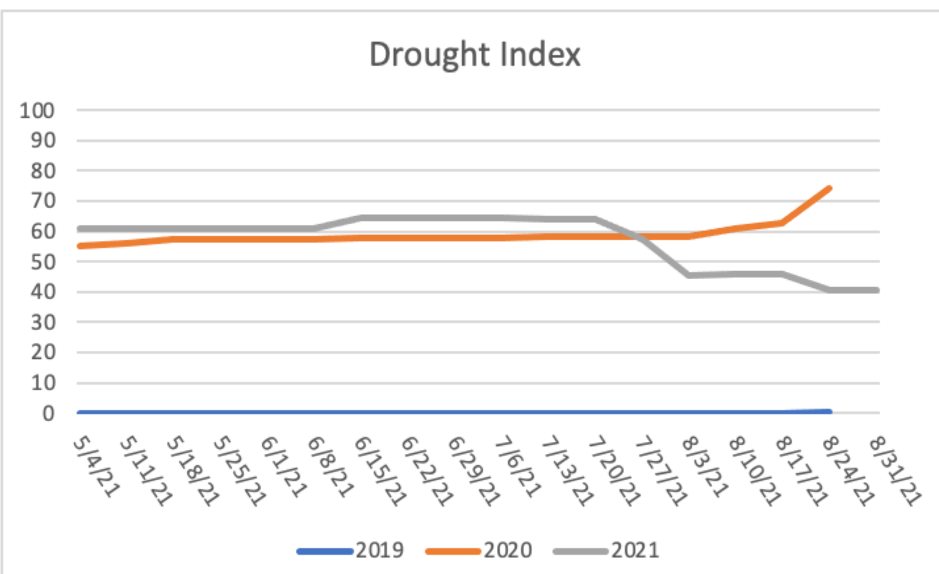


Figure 3. The drought index in Gunnison County during the summer of 2019-2021. An index of 0 indicates no drought, 0-20 is associated with abnormal levels, 21-40 is Moderate, 41-60 is Severe, 61-80 is Extreme, and 81-100 is Exceptional. (NOAA)

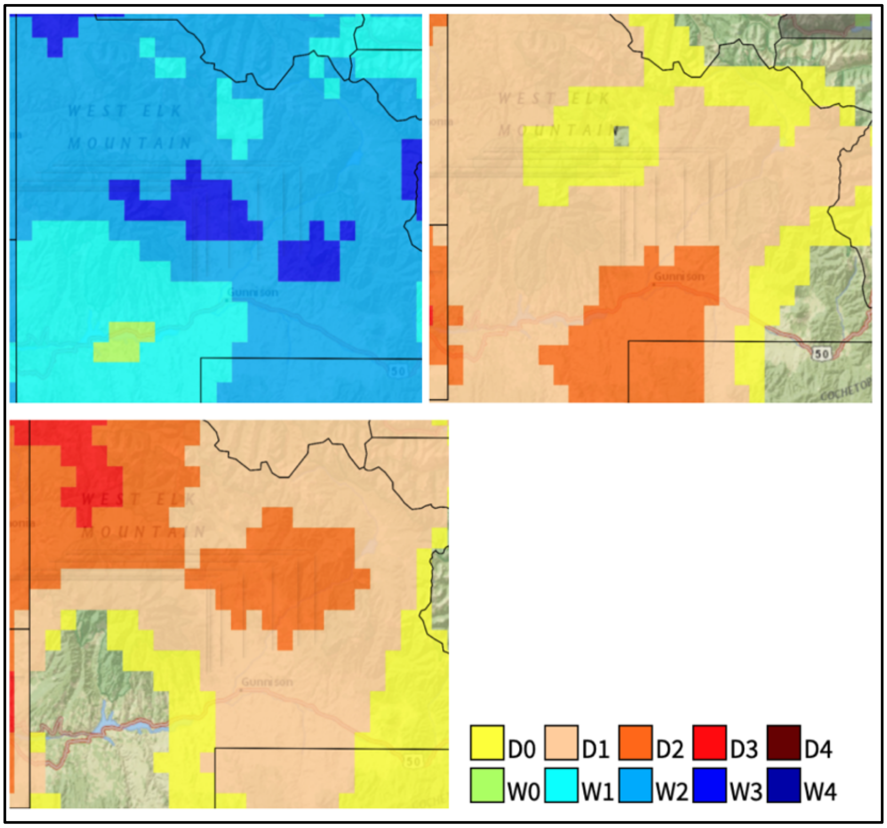


Figure 4. Gunnison County: June, 2019 top left, June, 2020 top right, June 2021 bottom. Drought/Wet levels: 0.Abnormal, 1.Moderate, 2.Severe, 3.Extreme, 4.Exceptional. (https://www.drought.gov/states/colorado)

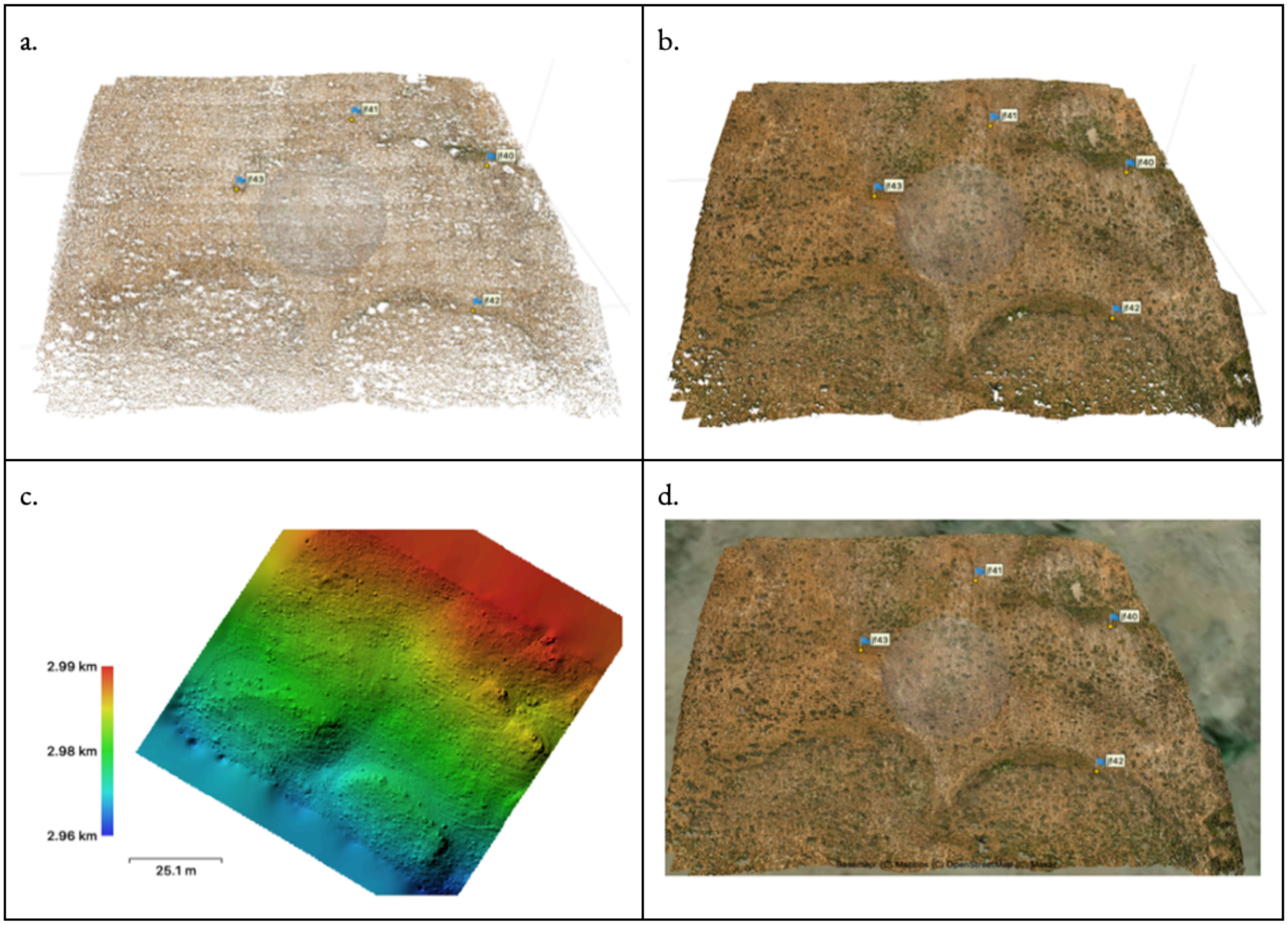


Figure 5.

a. Sparse point cloud of Judd Falls site, 6/13/19. Flags represent Ground Control Points.

b. Dense cloud of Judd Falls site, 6/13/19.

c. Colorized digital elevation model (DEM) of the Judd Falls site, 6/13/19.

d. DEM overlaid on OpenStreetMap satellite imagery, Judd Falls site, 6/13/19.

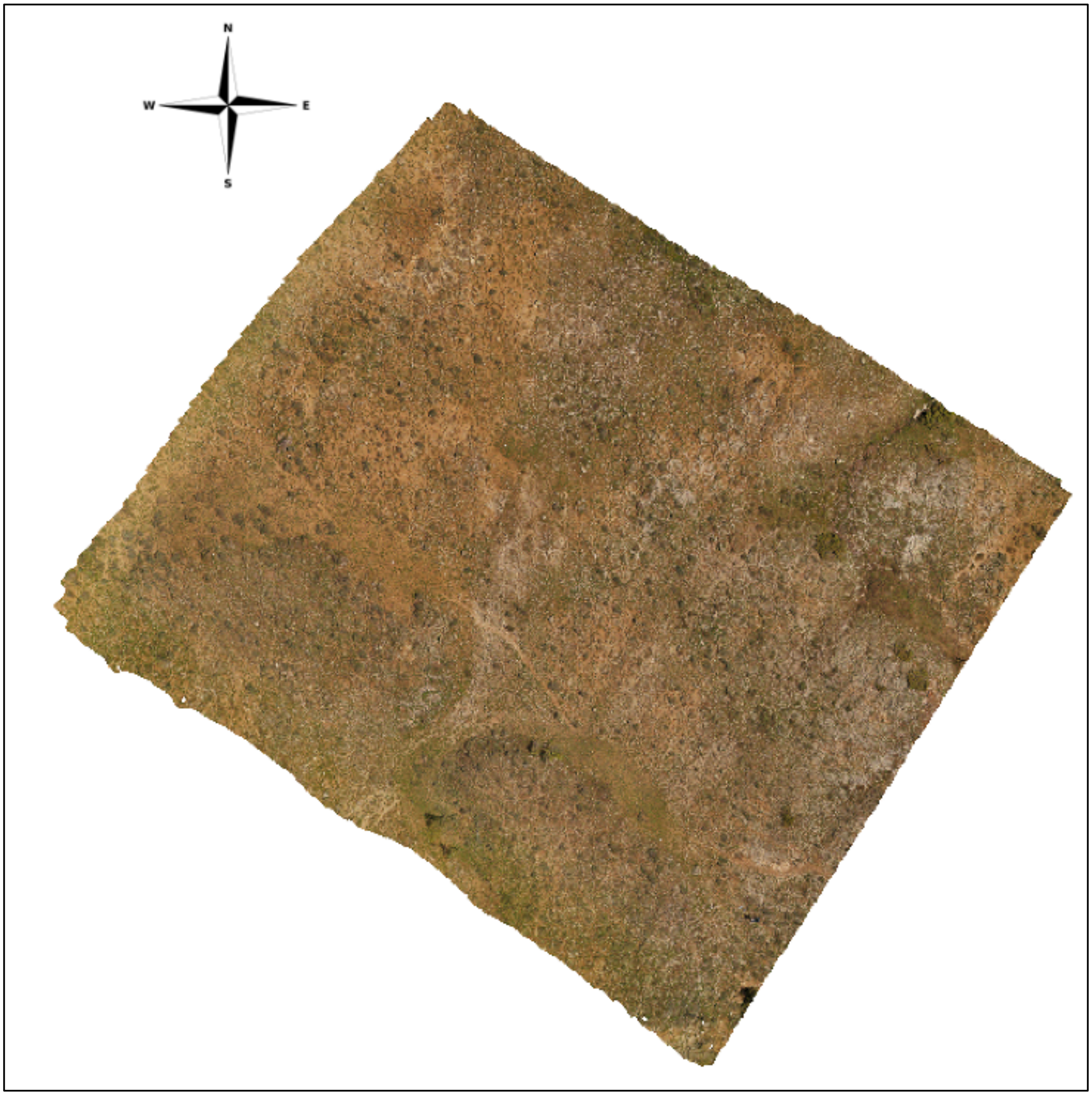


Figure 6. Final orthomosaic of Judd Falls site for 6/13/19.

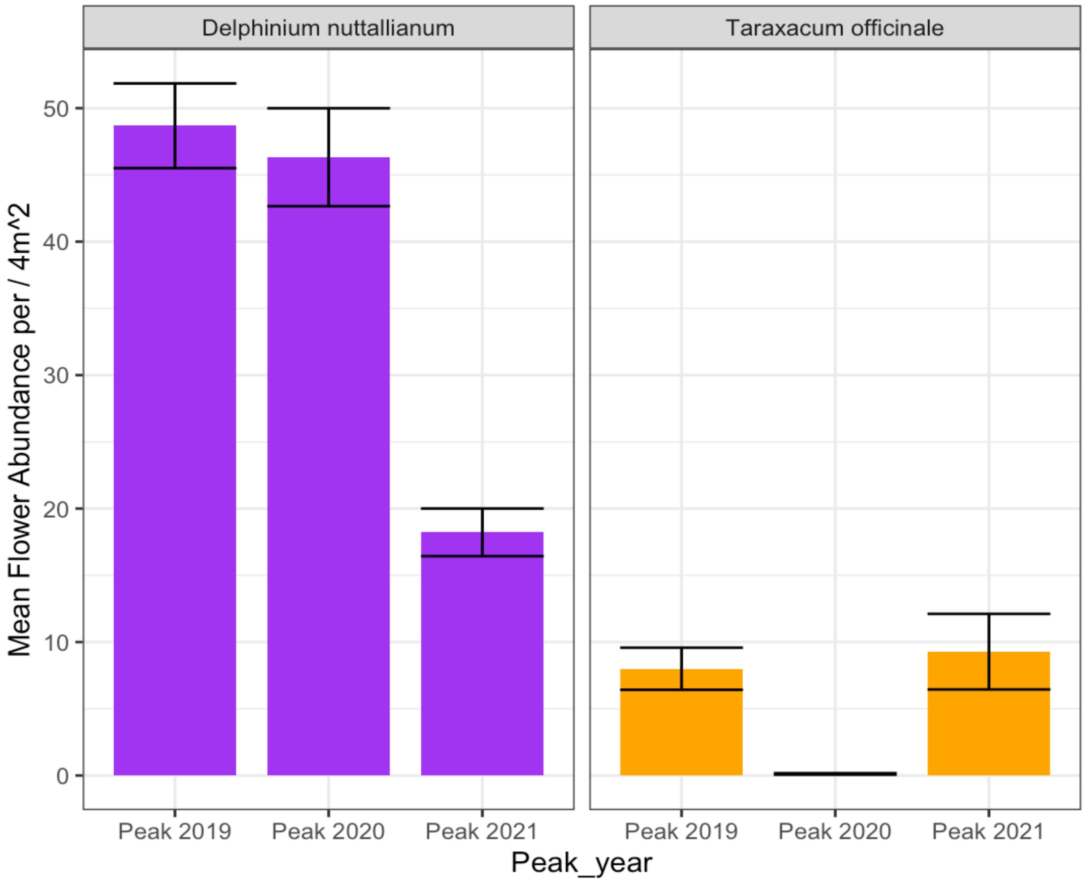


Figure 7. Dynamite plots showing the mean flower abundances per 4x4m tiles for the peak weeks 2019-2021 for *D. nuttallianum* and *T. officinale*.

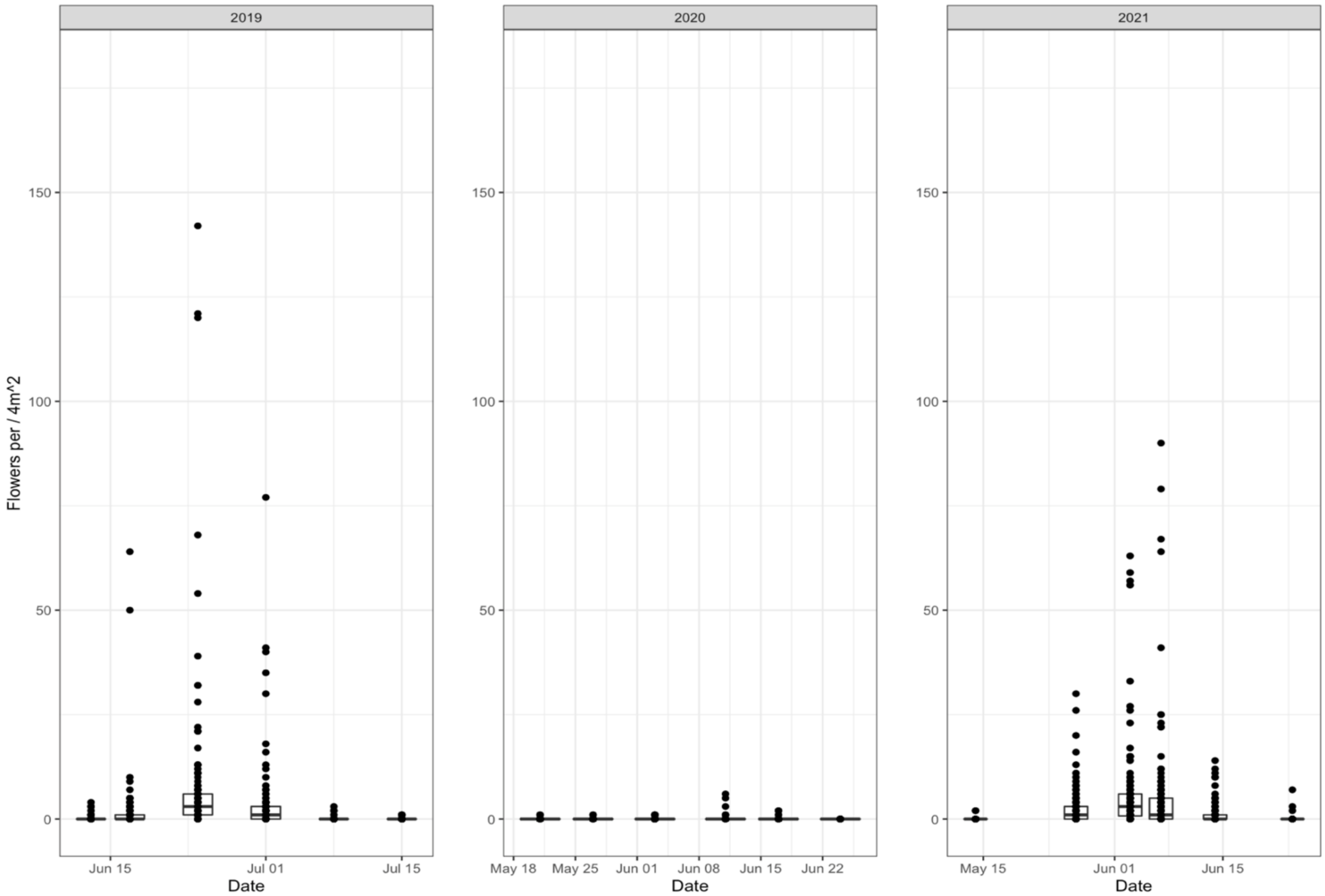


Figure 8. Taraxacum officinale abundance per $4m^2$ per date.

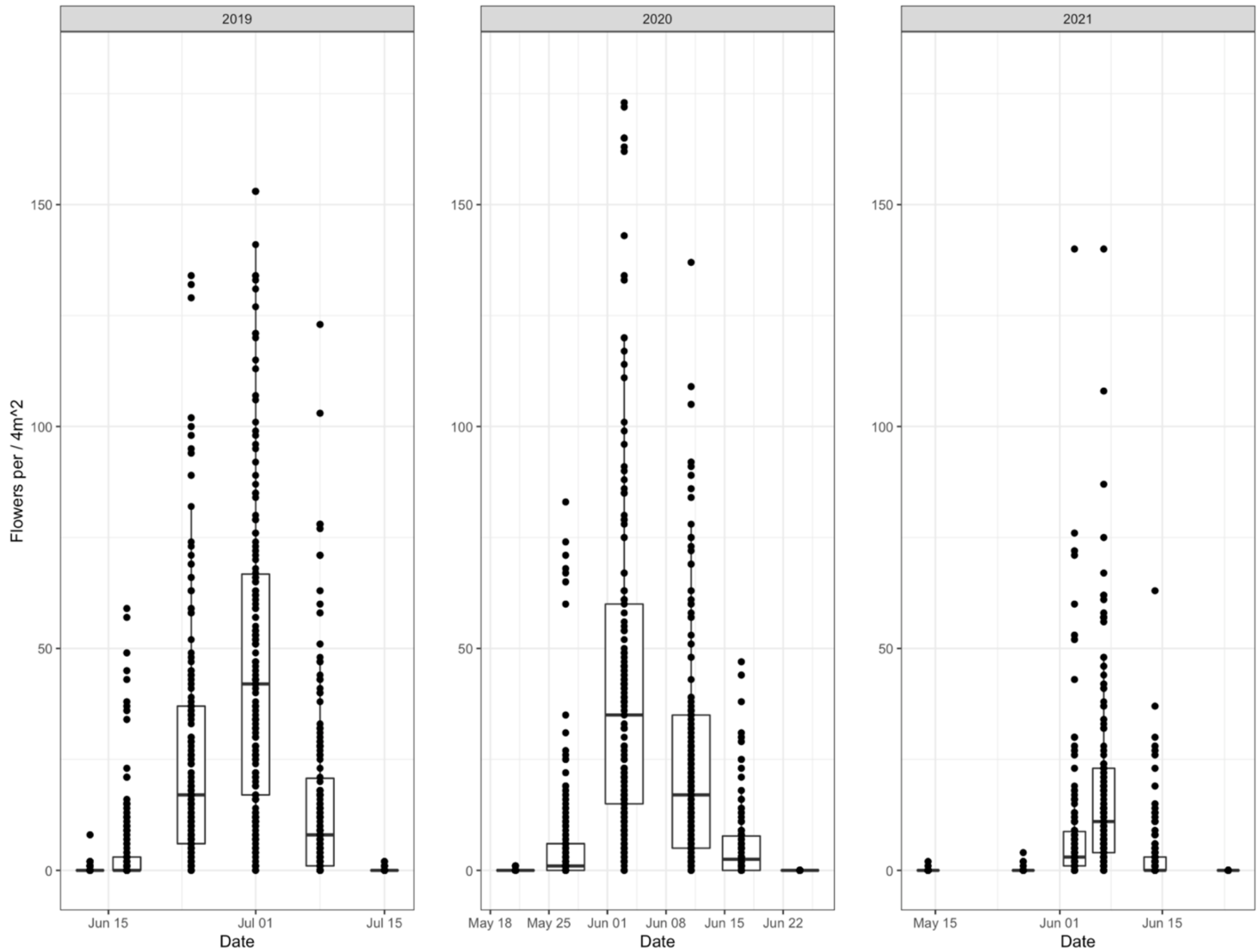


Figure 9. Delphinium nuttallianum abundance per $4m^2$ per date.

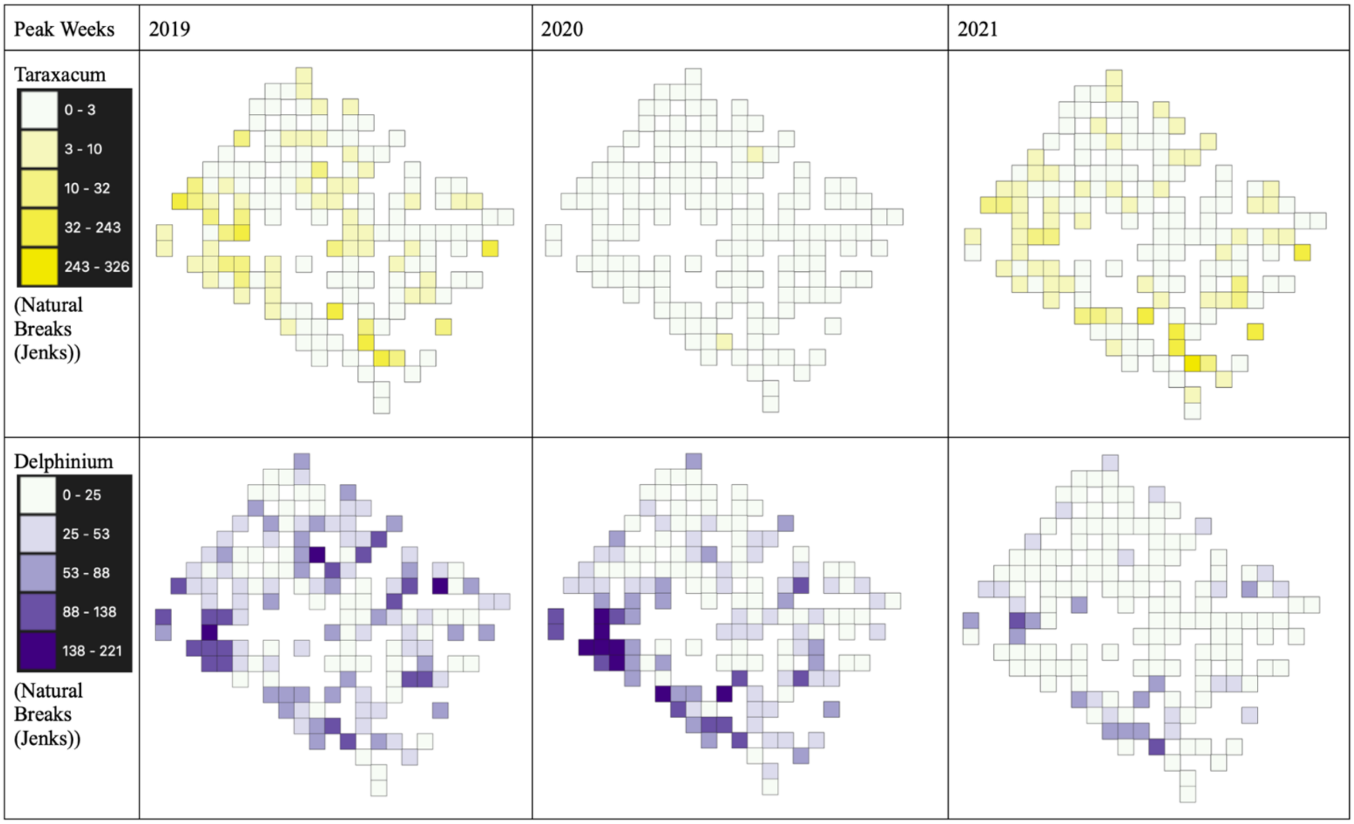


Figure 10. D. nuttallianum and *T. officinale* abundance per 4x4m tile for the peak weeks of 2019-2021.

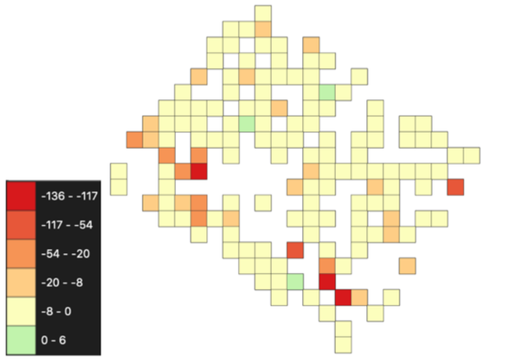
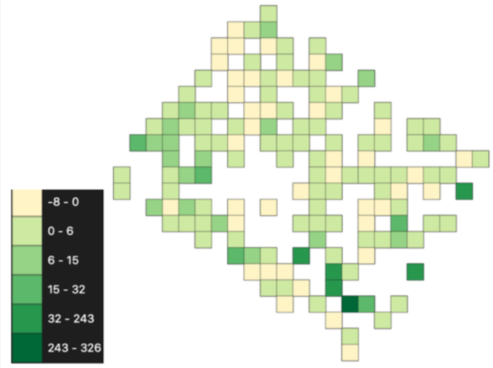
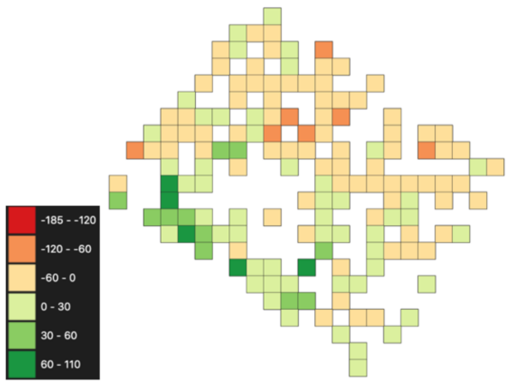
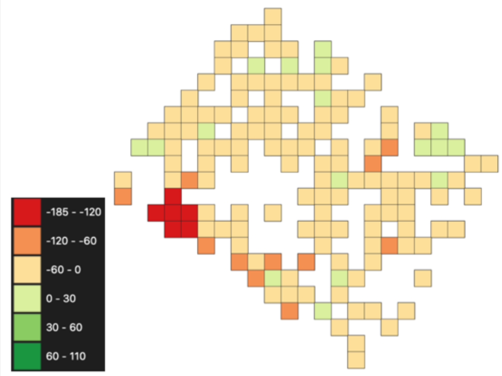
<table>
<tr><td>Change</td><td>2019-2020</td><td>2020-2021</td></tr>
<tr><td>Taraxacum</td><td>
</td><td>
</td></tr>
<tr><td>Delphinium</td><td>
</td><td>
</td></tr>
</table>

Figure 11. The change in abundance per tile between 2019-2020 and 2019-2021 for *D. nuttallianum* and *T. officinale.*

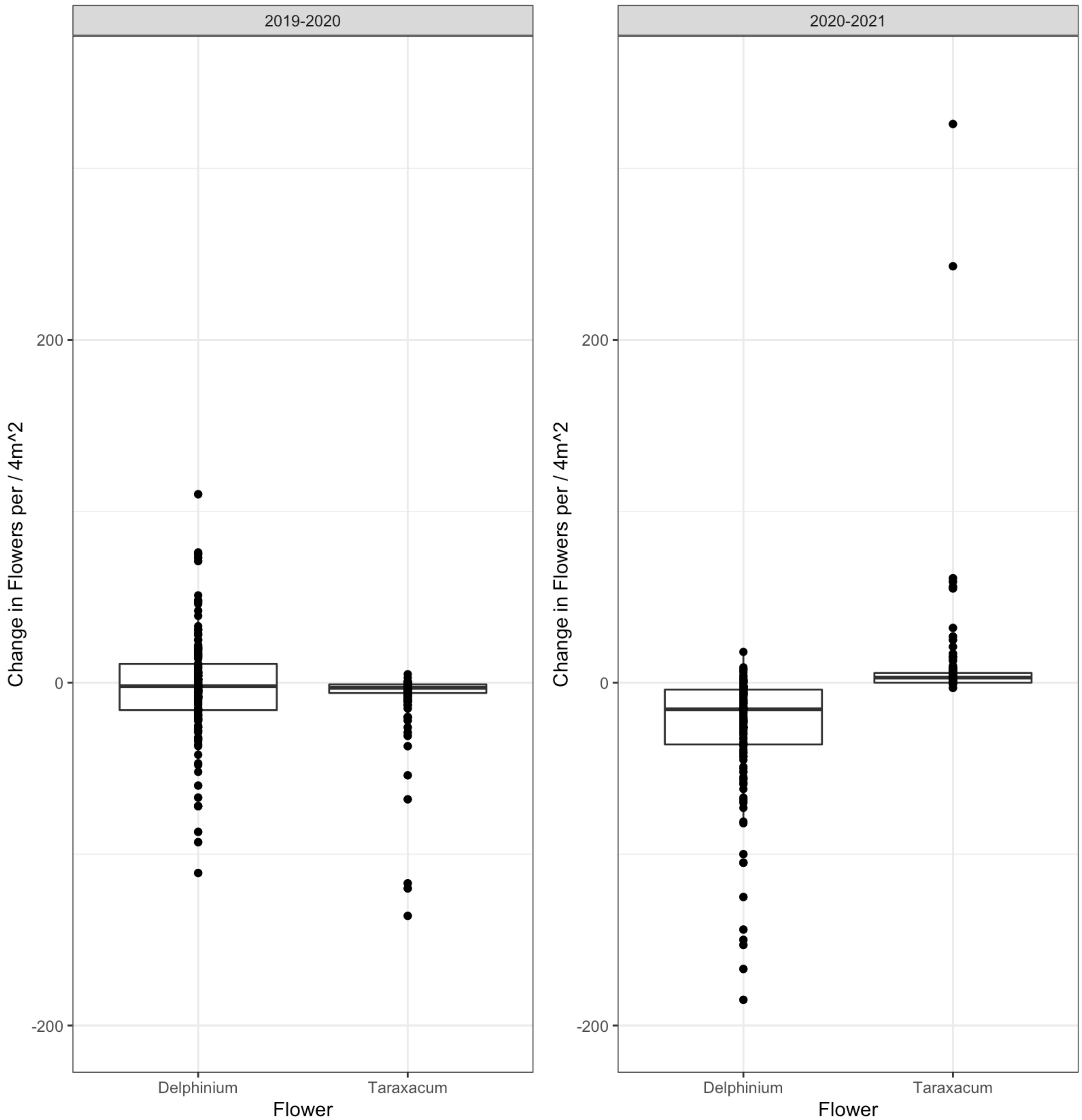


Figure 12. The change in abundance per tile between 2019-2020 and 2019-2021 for *D. nuttallianum* and *T. officinale.*

Tables

Table 1. Snow accumulations (cm) by month, 2018-2021 at the Gothic Weather Station. Gothic Weather, billy barr, https://www.gothicwx.org.

													on g.	on g.	date 0
Winter of	Sept.	Oct.	Nov.	Dec.	Jan	Feb	Mar	Apr	May	June	July	Total	Apr 01	May 01	on grnd.
2018-19	0	62	105	91	147	117	242	87	108	8	0	967	180	149	6/6
2019-20	0	50	46	115	76	82	146	63	10	14	0	602	114	43	5/8
2020-21	23	12	73	115	62	124	89	31	32	0	0	561	107	16	5/7

Table 2. Mean abundances per week and statistical test results for *D. nuttallianum*, 2019 - 2021. Compared to 7/1/19 (peak 2019). Peaks of 2020 and 2021 have dates underlined and p-values bolded.

		95% confidence			
Date	**Mean**	**Lower**	**Upper**	**z value**	**Pr(>|z|)**
6/13/19	0.17	0.27	0.10	-22.38	0.0000
6/17/19	4.80	6.57	3.51	-14.44	0.0000
6/24/19	26.77	36.38	19.69	-3.82	0.0001
7/1/19 (Intercept)	48.68	60.45	39.21	35.18	0.0000
7/8/19	15.93	21.68	11.70	-7.10	0.0000
7/15/19	0.05	0.11	0.03	-17.64	0.0000
5/21/20	0.03	0.08	0.01	-15.38	0.0000
5/27/20	7.47	10.20	5.47	-11.80	0.0000
6/3/20	46.32	62.92	34.11	-0.32	**0.7507**
6/11/20	25.59	34.81	18.82	-4.10	0.0000
6/17/20	5.67	7.75	4.14	-13.46	0.0000
6/24/20	0.00	0.00	0.00	0.00	1.0000
5/14/21	0.02	0.06	0.01	-13.04	0.0000
5/27/21	0.06	0.12	0.03	-18.20	0.0000
6/3/21	8.97	12.24	6.58	-10.68	0.0000
6/7/21	18.22	24.79	13.39	-6.25	**0.0000**
6/14/21	3.34	4.59	2.43	-16.51	0.0000
6/24/21	0.00	0.00	0.00	0.00	1.0000

Table 3. Mean abundances per week and statistical test results for *T. officinale*, 2019 - 2021. Compared to 6/24/19 (peak 2019). Peaks of 2020 and 2021 have dates underlined and p-values bolded.

		95% confidence			
Date	**Mean**	**Lower**	**Upper**	**z value**	**Pr(>|z|)**
6/13/19	0.11	0.20	0.06	-13.25	0.0000
6/17/19	1.67	2.57	1.09	-7.16	0.0000
6/24/19 (Intercept)	8.00	10.71	5.97	13.95	0.0000
7/1/19	3.23	4.91	2.13	-4.24	0.0000
7/8/19	0.05	0.12	0.02	-12.20	0.0000
7/15/19	0.05	0.12	0.02	-12.20	0.0000
5/21/20	0.02	0.07	0.01	-9.76	0.0000
5/27/20	0.02	0.07	0.01	-9.76	0.0000
6/3/20	0.05	0.12	0.02	-12.20	0.0000
6/11/20	0.12	0.22	0.06	-13.33	**0.0000**
6/17/20	0.03	0.09	0.01	-11.10	0.0000
6/24/20	0.00	0.00	0.00	0.00	1.0000
5/14/21	0.03	0.08	0.01	-10.52	0.0000
5/27/21	3.76	5.71	2.48	-3.54	0.0004
6/3/21	9.28	14.03	6.14	0.70	**0.4815**
6/7/21	9.08	13.73	6.01	0.60	0.5482
6/14/21	0.90	1.40	0.58	-9.66	0.0000
6/24/21	0.08	0.16	0.04	-12.92	0.0000

Table 4. Results of negative binomial regression for *D. nuttallianum* and *T. officinale* during the peak weeks of 2019-2021.

	Difference in z value	**Pr(>|z|)**
D. *nuttallianum*		
7/1/19 (Intercept)		
6/3/20	-0.32	0.7507
6/7/21	-6.25	0
T. *officinale*		
6/24/19 (Intercept)		
6/11/20	-13.33	0
6/3/21	0.7	0.4815

Table 5. Results of the t-test comparing the spatial changes from 2019 to 2020 and 2020 to 2021 for the two species. The data were compared to a baseline dataset of 0.00 for all tiles, assuming no changes in abundance were present for the null hypothesis.

Species	Year	Pr(>|z|)
D. nuttallianum	2019-2020	0.43467
	2020-2021	0.00000
T. officinale	2019-2020	0.00000
	2020-2021	0.00168