

Comparison of Drought Response between
Taraxacum officinale* and *Delphinium nuttallianum

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Abstract --- The state of Colorado continues to see more frequent drought conditions, from minor to exceptional levels. Global warming has been raising average temperatures with increasing evaporation rates, and earlier snowmelt. Climate change affects every species differently, but for many plant species it has the effects of reducing habitat, decreasing abundance or limiting seed production. At the same time, biological invasions continue to transform ecosystems through the effects of non-native species. So the question of how of native and non-native plants will respond to drought and climate change is key to working on conservation and protection into the future. The common dandelion (*T. officinale*) is a non-native plant in the Gunnison Basin, but as drought conditions increase in frequency, is it providing a more reliable and resilient resource for pollinators compared to the native Nuttall's larkspur (*D. nuttallianum*)? We investigated this by analyzing high resolution drone imagery, GIS, and statistical analysis. Flights were performed once a week at a site next to Judd Falls, outside Gothic, CO, where images were taken of the flowering landscape. Data processing will be performed to map and count the abundances of flowers in order to analyze statistically using negative binomial regressions. The result was that dandelion abundance decreased in drought conditions while Nuttall's Larkspur saw no change in years of drought.

Introduction

As climate change continues globally, the state of Colorado and the Gunnison Basin are not immune. Colorado has seen rising air temperatures, decreased snowpacks, earlier snow melts, and fewer summer rains during the monsoon season (Gao, 2011). The Gunnison Basin, typically a slight exception to Colorado's arid conditions, experienced the same levels of decreased water this past June (2021) as the year moved into the peak heat conditions (NOAA, 2021). Predictions and models for the state's future water supply look grim (Christensen, 2004), as Colorado is one of the few states in the US that has a topographic landscape that means that no water flows into the state. Any water that collects within Colorado's 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). Besides the anthropocentric concerns over the lack of future water, the question of how native species of plants, invertebrates and vertebrates will respond is at the forefront. The purpose of this project is to look into the response that species may already be taking towards the more frequent drought conditions using a variety of techniques.

The question of performance was assessed between a flower that is native to the Gunnison Basin, Nuttall's larkspur, *Delphinium nuttallianum* and the common dandelion, *Taraxacum officinale*, which is a non-native flower species. *D. nuttallianum* is a purple flower in the Ranunculaceae family which typically blooms early to mid season of the summer and will produce about 20 seeds per plant (Jones, 2004). *T. officinale* was originally introduced to the North American continent by English settlers in the 1600s as a food and medicinal source, but quickly spread out of the gardens and has since established itself from coast to coast, Canada to Mexico (Esser, 1993). This

flower blooms at a similar time as the *D. nuttallianum* and can reproduce asexually through apomixis to produce hundreds of seeds (DeLorenzo, 1973). The site of our study is located next to Judd Falls, just outside the Gothic townsite, north of Crested Butte, CO, which is home to the Rocky Mountain Biological Laboratory. The plot is on a southwest facing slope with a gradient of about 30%, it has full sun exposure and the rocky soil is derived from the igneous matter of the Copper Creek Sill, meaning the site is on the more arid side as far as the Breckheimer Lab sites go, which are spread throughout the upper Gunnison Basin.

Previous studies into *T. officinale* and *D. nuttallianum*, as well as *Taraxacum*'s response to drought have yielded varying results. 2004 at RMBL, Jones performed an experiment with the aim to determine whether or not *T. officinale* were influencing the seed set of *D. nuttallianum*. Jones cut off the flower heads of *T. officinale* in certain plots and not others before observing the frequency in pollinator visits to *D. nuttallianum*. They found that there was no such competition between the species as pollinator visits turned out to be independent, but added that the plants may have been competing for soil resources (Jones, 2004). Another study in 2005 comparing the drought response between native dandelion *Taraxacum ceratophorum* and *T. officinale* found that *T. officinale* performs better in mesic environments due to a greater leaf surface area, better carbon assimilation, and a higher capacity for water extraction (Brock, 2005). However, the study found that drought conditions favored *T. ceratophorum* (Brock, 2005). Molina-Montenegro et al. found in a study that *T. officinale* exhibited delayed flowering as well as a worse photosynthetic performance in drought while plants where rainfall varied more showed greater plasticity (Molina-Montenegro, 2010).

So, how does drought affect the abundance of these two flowering plants at Judd Falls? I hypothesized that *T. officinale* and *D. nuttallianum* had varied responses in abundance in drought conditions. It was predicted that if drought conditions exist then *T. officinale* will be less impacted than *D. nuttallianum* in the future. The primary question at hand was answered first and foremost with drone imagery and remote sensing technology. Using drones to photograph landscapes means that there is the potential to go back in time and reconstruct landscapes in order to visualize spatial patterns. Compared to counting flower abundances by hand, drones also help us to save time and we can view how the landscape may look to pollinators. GIS software was used to count the flowers from processed imagery and RStudio was used to analyze data.

Methods

I. Field Collection

Data was collected from drone flights at the Judd Falls site in 2019 and 2020. 2019 represents the wet year, where the upper Gunnison Basin had a very high snowpack and also received rain throughout May and June. On the other hand, 2020 saw a very low snowpack that melted out early and June was a time of abnormal to moderate drought for the area around Gothic (fig.1). In both years, four weeks were sampled from the peak season of both *D. nuttallianum* and *T. officinale* flowering abundance according to the Breckheimer Lab's transect data, which helped confirm the later data collection methods. The drones were 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 throughout if the cloud cover changed significantly from sunny to

cloudy or vice versa. After each flight was completed, the SD card was backed up to a computer and the next step was evaluating the raw imagery.

II. Image Processing

In order to go from hundreds of raw images per flight to eight finalized high-resolution images of all the photos stitched together, called orthomosaic maps, the program Agisoft Metashape was used to process, stitch, and combine all of the images. The workflow used for the project was based on a process from the USGS (USGS, 2017). After uploading the images to Metashape, a batch process was used to create a sparse point cloud (fig.2a) of the 8 weeks all at once, which evaluates matching high contrast points between the images and aligns them together. 4 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.2b), filling in most of the missing pixels in the combined imagery, then optimizing the camera alignment. After this, a digital elevation model (DEM)(fig.2c) was made for each week, which can be overlaid on OpenStreetMap satellite imagery (fig.2d). The final step of the batch process was

combining all of these steps to create a flat, orthomosaic image map (fig.3) of each of the 8 weeks. This final product was what would be used in the next step of the actual individual data collection.

III. 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,

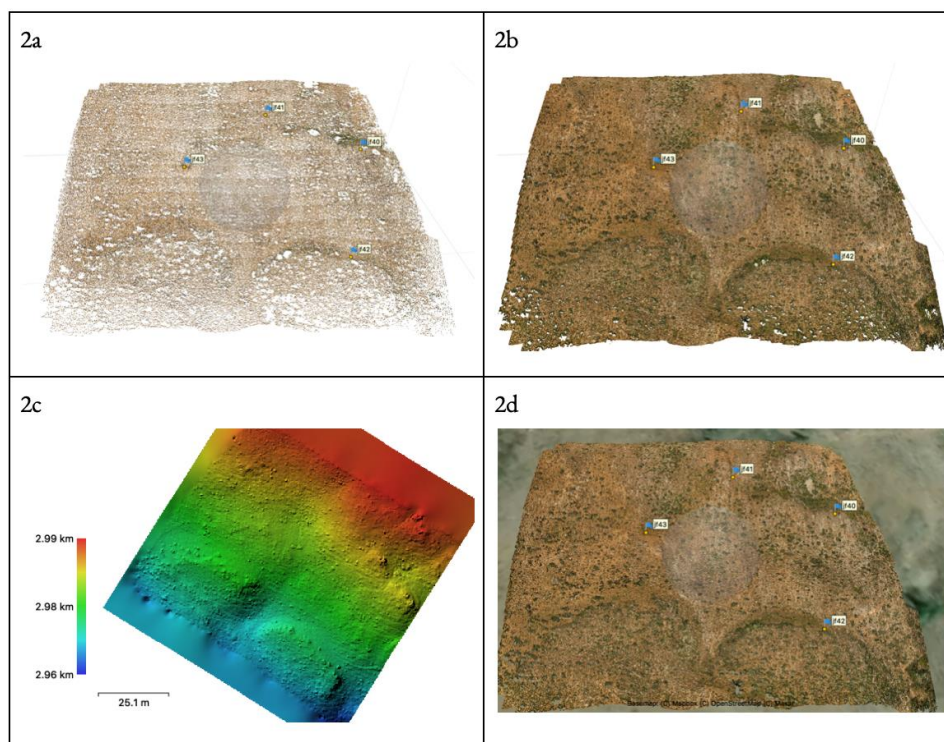


Figure 2.
2a. Sparse point cloud of Judd Falls site, 6/13/19. Flags represent Ground Control Points.
2b. Dense Cloud of Judd Falls site, 6/13/19.
2c. Colorized digital elevation model (DEM) of the Judd Falls site, 6/13/19.
2d. DEM overlaid on OpenStreetMap satellite imagery, Judd Falls site, 6/13/19.

which consisted of 80
 4 by 4 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*, totalling 16 flower vectors. Initially the full tile index consisted of 900 tiles but was randomly selected down to 80. A random number generator assigned a float value of 0 to 1 to each of the 80 tiles and the same order of data collection was used throughout all 8 weeks. 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. 20 tiles were done at a time before moving onto the next week, to keep the level of completion consistent across the 8 weeks. By the end of the data collection, 80 tiles were examined for each of the 8 weeks, totalling 640 tiles and 14,944 flowers.

IV. Analysis

The flower vector layers and the clipped tile index were then exported for statistical analysis using R (R Core Team 2021). A list was created for both *T. officinale* and *D. nuttallianum* which included new columns for data such as everything from the original files, the dates of the flights, and the species names. Everything from these lists were bound together and spatially joined with the tile index using the “st_join()” function from the “sf” library (10.1, Pebesma, 2018). These values were then grouped and summarised. Since the files initially only included the rows which contained at least one flower (and many tiles had none), 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). Once the datasets were full of all 80 rows per week, they were rejoined and then plots and regressions could be made. Due to the number of zeros present in the data and a pronounced right-skew, we assumed a non-normal distribution of the data.

Specifically, we used a negative binomial regression to statistically analyze the datasets. 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. Statistically speaking for this regression, 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.

Results

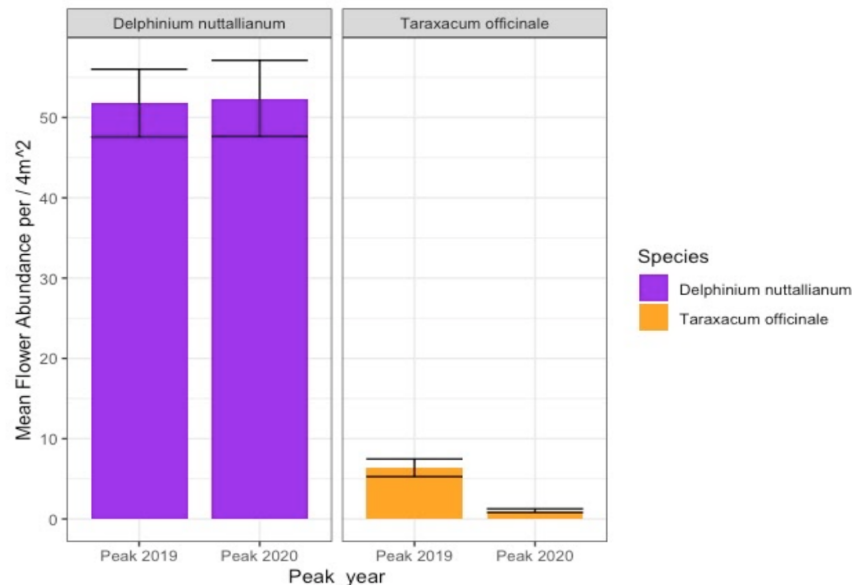
The four dates examined in 2019 were June 13th, 17th, 24th, and July 1st, while the four dates in 2020 were June 3rd, 11th, 17th, and 24th. For *D. nuttallianum*, the flowers per 4 m² (mean flower abundance per tile) in chronological order can be found in table 1. The *D. nuttallianum* peak in 2019 was July 1st with an abundance of 51.79 flowers per 4 m² and although we don't have abundance data for the weeks following to confirm this was the peak, we do have presence/absence transect data, as shown in figure 4, that shows that the number of sections of our 50m transect with the presence of *D. nuttallianum* drops off sharply in the following week, and this information shows correlation with the abundance data. The peak in 2020 was almost one month earlier, on June 3rd, with an abundance of 52.37 flowers per 4 m². This peak has been confirmed by looking at the raw images for the week prior and seeing a large difference in the number of *D. nuttallianum* when compared to number in the first date in June.

T. officinale displayed means that can be found in table 2 for the same chronological order across the two years of study (fig.5). This species' peak was one week earlier than *D. nuttallianum* in 2019, appearing at the highest abundance per tile on June 17th (fig.6) with a mean abundance per 4 m² tile of 6.37 flowers, but shared the peak on June 3rd, 2020, which had a mean abundance of 2.81

flowers per 4 m² tile (this peak was also confirmed from the raw drone imagery). 95% confidence intervals for both species can be found in Tables 1 and 2.

Negative binomial regressions were performed for each species to compare their 2020 peak abundances to the peaks in 2019 (for *D. nuttallianum*: 7/1/19 and for *T. officinale*: 6/24/19). For *D. nuttallianum*, the test statistic of the peak week was 30.66. All non-peak weeks showed a statistically significant difference in the mean abundance of flowers per tile compared to the peak. June 3rd, 2020

Figure 7.



Dynamite plot, showing the mean abundances per 4 m² at the peak weeks by species. Error bars included.

displayed a z-score of 0.06 and a p-value of 0.9516 and that date's confidence interval surrounds the entirety of the one from the 2019 peak (fig.7). June 24th, 2019 and June 11th, 2020 were the other two dates that were somewhat close to the peak, with p-values of 0.0004

and 0.0028, respectively. No other week had a p-value above 0.0000 (Table 1).

The 2019 peak for *T. officinale* was June 24th and the negative binomial regression was run against that week, as seen in Table 2. The test statistic of the intercept was 11.22, but unlike the regression run for *D. nuttallianum*, not a single week was similar, all differences were statistically significant, including the peak week of 2020. This value was the closest of all 7 other weeks, with a z-

score of -3.42 and a p-value of 0.0006, but still a very large difference (fig.7). Table 3 shows how the peak weeks between 2019 and 2020 for the mean of *D. nuttallianum* showed no statistically significant difference, while the same was not true for *T. officinale*, where the difference of mean

Table 3. Statistical demonstration of the difference in peak weeks of 2019 and 2020 for both species of flowers.

		Difference in z value Pr(> z)	
D. nuttallianum			
7/1/19 (Intercept)			
6/3/20	0.06		0.9512
T. officinale			
6/24/19 (Intercept)			
6/3/20	-3.42		0.0006

abundances per tile between the two peaks was statistically significant.

Discussion

The prediction of this study was that dandelions would be less negatively impacted by the year of drought than the larkspurs. If this were the case, we would see a drop in the *D. nuttallianum* mean abundance, while there would be no decrease or one that was significantly smaller for *T. officinale*. However, the results have shown the opposite. *D. nuttallianum* only had a difference in mean abundance of 0.06 standard deviations, and 2020 was actually slightly higher (though not significantly) during the peak week. The peak mean of *T. officinale* in the dry June of 2020 was 3.42 standard deviations below the peak mean of 2019. Our null hypothesis was stated that there would be no difference in both species' peak mean abundances between 2019 and 2020. Assuming this was true, the *D. nuttallianum* p-value means that this result would have been observed in 95% of trials had it been repeated. A p-value of 0.9512 indicates that there is no statistically significant difference between the mean abundance of *D. nuttallianum* between the peak weeks of 2019 and 2020. Conversely, when the null is assumed to be true for *T. officinale*, the result we found would be observed in less than 0.1% of repeated trials. This p-value of 0.0006 shows that there is a statistically significant

difference in mean abundance between the peak weeks of 2019 and 2020 and the null hypothesis should be rejected.

From this study, we can draw initial conclusions that drought is not impacting the native Nuttall's larkspur in terms of abundance, but is being impacted in terms of phenology and flowering timing. Dandelion flowering abundance was more negatively impacted by drought, and their peak flowering time was shifted forward by a full month in 2020 compared to 2019. However, we did not measure seed count during these two years of study. While the changes in abundances may show significance, it is possible that the *D. nuttallianum* in 2020 produced a high number of flowers with a reduced production of seeds. This would be a waste of reproductive effort from these flowers, so maybe *T. officinale* were actually avoiding the cost of energy in a year that had stressful conditions where they were less likely to be able to set seed. Without this or other additional information beyond abundance, we cannot know the “why” of the significant result we saw. This result of the non-native dandelion performing worse than its native neighbors falls in line with what previous studies have found (Jones, 2004, Brock, 2005). When looking at the two years in this study alone, with a sample size of almost 15,000 flowers, the results do show significance, but if you were to pose the question of long-term impacts, more work needs to be done. On a greater scale, my sample size was only the two years I focused on. In order to find more powerful results with long-term significance, many more years need to be studied.

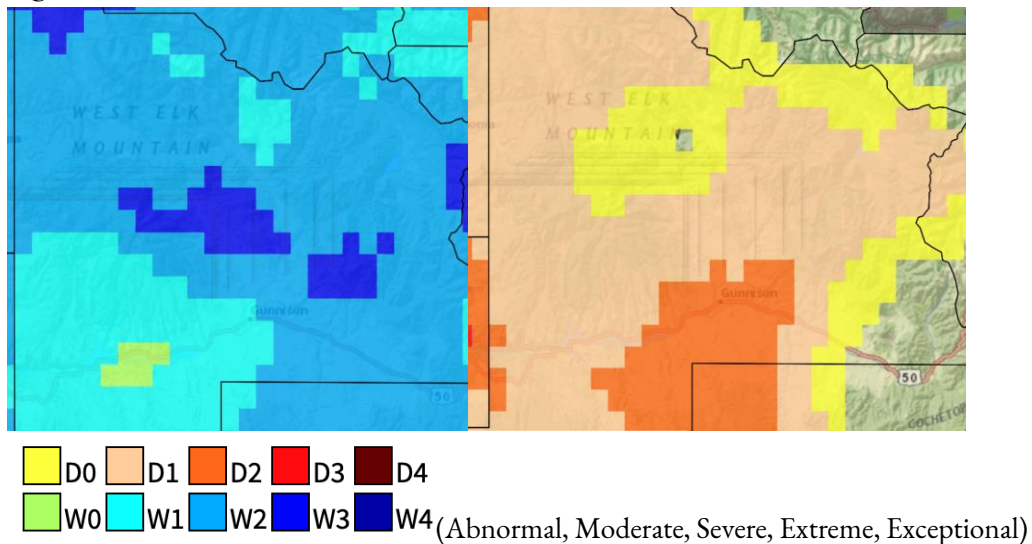
The next step of this project is to create and analyze orthomosaics for the two weeks after July 1st, 2019 (peak) and the two weeks before June 3rd, 2020 (peak) in order to confirm fully that these are the peaks. In addition to that, I will make another six orthomosaics from the drone flights taken in

2021, which was another year of drought earlier on, but as the summer progressed, it did not mirror 2020, as July was one of the wettest in recent memory. It will be interesting to find out how different kinds of drought patterns affect these two flower species. In addition to the abundance data that will be collected, I will also look into the question of how clumpiness, or spatial variation changes year to year. Drone imaging and pinpoint geographic locations of the individual flowers in QGIS allows us to be able to find means to answer complex questions such as that. Additional analyses might compare 2019-2021 changes in abundance to slope, topographic wetness, or other covariates. With another year analyzed as well as the question of spatial variation, we gain much more knowledge about the drought responses of *D. nuttallianum* and *T. officinale*.

Appendix

I. Figures

Figure 1.



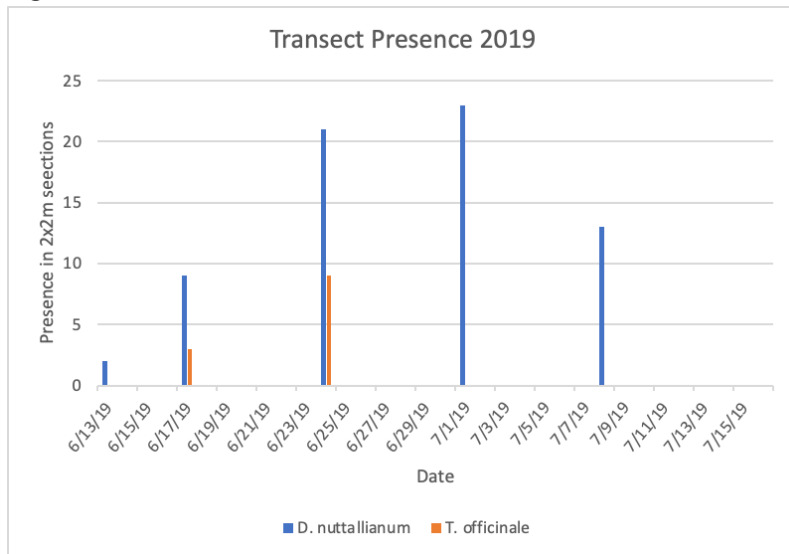
Gunnison County: June, 2019 on the left, June, 2020 on the right. (<https://www.drought.gov/states/colorado>)

Figure 3.



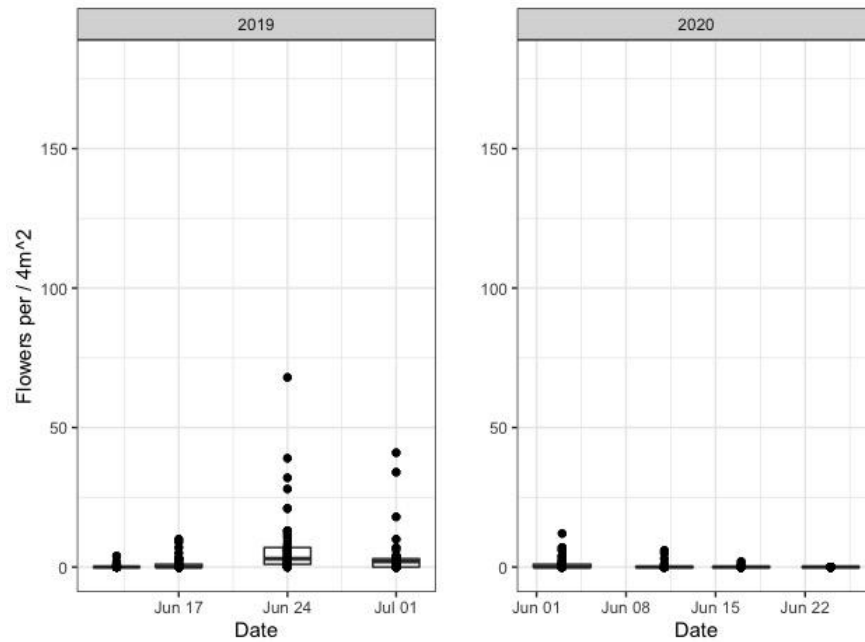
Location of the Judd Falls site and the final product: processed orthomosaic, 6/13/19.

Figure 4.



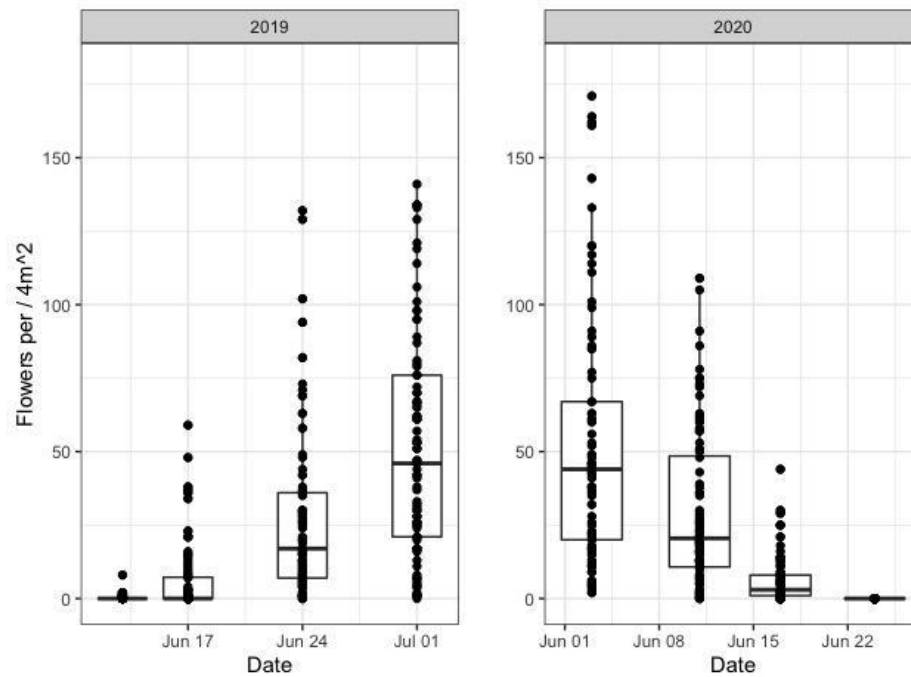
2019 presence of species within the 50m transect on the dates before, during and after the peak weeks of 6/24 and 7/1 to show that those weeks are indeed the peaks.

Figure 5.



Abundance per m² per day of Taraxacum officinale, with boxplots.

Figure 6.



Abundance per m² per day of the Delphinium nuttallianum, with boxplots.

II. Tables

Table 1. Mean abundances per week and statistical test results for *D. nuttallianum*, 2019 and 2020. Compared to 7/1/19 (peak 2019).

Date	Mean	95% confidence		z value	Pr(> z)
		Lower	Upper		
7/1/19 (Intercept)	51.79	40.24	66.66	30.66	0.0000
6/13/19	0.31	0.18	0.53	-18.90	0.0000
6/17/19	6.04	4.18	8.72	-11.46	0.0000
6/24/19	27.19	19.00	38.89	-3.53	0.0004
6/3/20	52.37	36.65	74.83	0.06	0.9512
6/11/20	29.96	20.93	42.90	-2.99	0.0028
6/17/20	6.08	4.21	8.77	-11.43	0.0000
6/24/20	0.00	0.00	0.00		0.0000

Table 2. Mean abundances per week and statistical test results for *T. officinale*, 2019 and 2020. Compared to 6/24/19 (peak 2019).

Date	Mean	95% confidence		z value	Pr(> z)
		Lower	Upper		
6/24/19 (Intercept)	6.37	8.80	4.61	11.22	0.0000
6/13/19	0.11	0.25	0.05	-9.97	0.0000
6/17/19	0.86	1.43	0.52	-7.71	0.0000
7/1/19	2.81	4.50	1.76	-3.42	0.0006
6/3/20	1.04	1.71	0.63	-7.13	0.0000
6/11/20	0.20	0.39	0.10	-10.19	0.0000
6/17/20	0.04	0.13	0.01	-8.26	0.0000
6/24/20	0.00	0.00	0.00		0.0000

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