

**Surveying historical patterns of vegetation change (1929-2019) in the upper
East
River Valley using RMBL's archival herbarium records**

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Abstract

One of the ongoing challenges in studying the effects of global change on biodiversity is finding credible baseline data of prior conditions. The Rocky Mountain Biological Laboratory in Gothic, Colorado is located in a valley with a wide range of plant species and communities due to its diversity of microclimates, and sharp gradients of precipitation and elevation (ca. 8000 – 14000 feet ASL). There have been a number of studies conducted near Gothic documenting changes in plant community composition, population distributions and flowering phenology, but the herbarium has been little used by researchers as a source of historical plant distribution and phenology data. Herbarium data provide a novel tool to assist biologists when conducting floristic studies to trace vegetation distribution patterns and studies of long-term phenological change. With the data available in the RMBL's online herbarium database, potential study sites can be located, and target species lists can be generated from a long list of historical specimens (dating back to 1929) to conduct modern surveys and make qualitative comparisons of species presence or absence. Here we test the adequacy of archival herbarium data as a baseline to study historical changes in species richness and abundance from three plant communities from montane to alpine habitats. We collected 380 new specimens from Kettle Ponds (montane meadow and riparian), 113 specimens from Lower Virginia Basin (subalpine meadow) and 125 new specimens from Upper Virginia Basin (alpine meadow). We added a total of 161 new species, unrepresented by historical records, for these sites; 76 at Kettle Ponds, 64 at Lower Virginia Basin and 21 at Upper Virginia Basin. In addition, we estimated the relative abundance of the dominant species at each site using quadrat samples of percent vegetation cover. We conclude that using RMBL's herbarium database is useful for finding potential study sites with a diversity of species, but these species lists are incomplete due to a variety of sampling biases. Species lists do not reflect relative species abundance; historical collections seldom included the common, dominant species identified from quadrat sampling. We concluded that blanket sampling is the most effective method to document species richness so long as every species, common or rare, are collected with the intention of building a complete species list. Finally, after compiling merged species lists of both historical and recent specimen data, we found that the rate of accumulation of new species declined asymptotically as we approached a complete species list for each site we sampled throughout the summer.

Introduction

The alpine is defined as the biotic zone on mountains above the natural limit of tree establishment dominated by herbaceous plants (Bowman and Seastedt, 2001). Global climate change is altering abiotic (temperature, precipitation), and biotic (competition, predation, mutualism) factors that determine plant species' distribution, abundance and community composition in the alpine (Zorio et al., 2016). Species diversity is rapidly decreasing, and extinctions of local plant species has become a serious threat to maintaining the health and overall balance of ecosystems on every scale (local, regional, and global). Observing, describing, and forecasting patterns of biodiversity under changing climate conditions are critical goals in the fields of biogeography, conservation, and ecology (Bloom et al., 2017).

In a recent publication of how vegetation community composition in the southern Rocky Mountains have changed in the last 65 years (Zorio et al., 2016), changes in species richness and

dominance were observed, and an upward migration of species distributions were detected. These changes may have been due to increasing temperatures and earlier snowmelt over this time period. As temperatures continue to increase, the primary response of alpine vegetation to environmental changes will be a change in composition and abundance of species which includes the possible establishment of subalpine species in alpine tundra (Bowman and Seastedt, 2001). These types of studies are limited by a lack of substantial historical baseline evidence to recognize these patterns and it will take more time and rigorous research to accept them (Zorio et al., 2016).

The use of historical ecological data for comparative studies is a valuable tool for assessing and predicting effects of climate change and other factors on species and communities. In a recent study (Zorio et al., 2016), sites were resurveyed in the Rocky Mountains and compared with Jean Langenheim's quantitative surveys of plant community composition from the late 1940s and early 1950's. (Zorio et al., 2016) found that many species from sagebrush to subalpine meadows shifted their distribution upwards into higher elevations and community types. In the same study they found that in sixty-five years there was a loss of species diversity, reduced species abundance, reduced vegetation cover, loss of forbs and an increase of grasses and shrubs across all community types (Zorio et al., 2016).

Another approach that may be useful for comparing long-term changes in vegetation is the use of archival herbarium specimens. Herbaria are libraries of pressed, dried plants used for teaching, studying phylogeny, taxonomy, ecology and the distribution of plants across the globe (Greve et al., 2016). Herbarium collections have the potential to provide baseline data to inform studies of changes in plant distributions, phenological stages, and other plant traits and interactions (Williams, 2019).

The RMBL Herbarium, with more than 8000 vouchers, has the largest collection of plant specimens from Gunnison County and the East River Valley of any herbarium worldwide (Williams, 2019). Historical vouchers go as far back as 1929, collected by Harriet G. Barclay, RMBL's earliest botanist and plant ecologist, as well as sites surveyed by Jean Langenheim between 1948 and 1951 (Williams, 2019). There is an increasing demand for long-term data to trace changes in biodiversity. Information regarding changes in species and community distributions can be a useful tool by conservation biologists studying the shifting patterns of plant communities and the altering of ecosystem dynamics due to climate change, anthropogenic influences, etc. (Shelley et al., 2018). To date, RMBL's herbarium data has not been used to study historical changes in plant distribution or phenology.

The purpose of this project was to use herbarium data as a baseline to track changes in plant communities between 1929 and 2019 along elevation gradients and across the unique topography surrounding RMBL. Our focus was to obtain herbarium data from older, well-collected sites, resurvey these sites, and record species richness to identify any changes in plant diversity. Historical herbarium collection data (pre 1965) was compared with recent (post 2008) collection and quadrat survey data to determine how completely and accurately the herbarium records describe community composition and if there was evidence of compositional changes. and results will be analyzed with a presence/absence-based approach. We hope that this study will lead to a long-term monitoring program and demonstrate the utility of herbarium collections as an important tool for providing reliable data for future research and field studies (Williams, 2019).

The primary research questions of this project were:

1. How adequate are herbarium records to document patterns of species diversity?
2. Can herbarium records provide long-term data to trace temporal changes in species distributions, particularly species loss?
3. How well do herbarium records reflect relative species abundance – rare vs. common species?

Methods

Choosing Study Sites

Study sites were chosen from locations with large numbers of historical herbarium collections, generated from the herbarium database. Georeferenced data were accessed through the digitized information in the online herbarium database, Intermountain Region Herbarium Network (intermountainbiota.org/portal/), to search the large specimen collection held in dozens of herbaria collected from the RMBL vicinity. The Rocky Mountain Biological Laboratory (RMBL) herbarium data were accessed from the Southern Rocky Mountain Herbaria Consortium (SoRo) within the Intermountain portal. The RMBL herbarium contains a record of 8,190 specimens made up of 150 families, 530 genera and 1,301 species. Additionally, 8,180 of the specimens are georeferenced, 8,071 are accessible through high definition images, and 8,053 of the specimens are identified to species.

A species list was generated for each site by searching the online map and creating a polygon over the area of each potential study site. To broaden our search, we also used the locality keyword search option and included the names of each site and variations of the name (e.g. Kettle Ponds, kettleponds, kettle pond, pond, etc.). With the assistance of the curator of the RMBL herbarium, Dr. R. Williams, several sites were selected to resurvey based on the history of the sites having an abundance of documented specimens. The lists generated for each site were downloaded into Excel spreadsheets and sorted by Family, Genus, Species and date of collection.

Study Sites

Study sites were located along the East River Valley at several elevations. A total of three sites were surveyed, including 1) Kettle Ponds (38.944707, -106.975198) at 9500 ft. in elevation 2) Lower Virginia Basin (38.97671, -106.97725) between 11000-11500 ft. in elevation, and 3) Upper Virginia Basin (38.98125, -106.97150) between 11500-12300 ft. in elevation (Figure 1). Voucher collections of plants in bloom were made at each site. Each site was visited approximately five times to record, collect and document as many plant species as possible until the end of the season.

At each site, collections were made using a blanket sampling approach and were brought back to the lab for identification. Plants were identified using the *Colorado Flora Western Slope* by Weber and Wittmann (2012), *Flora of Colorado* by Ackerfield (2015), and *Sedges of Colorado* by Wingate (2017).

Field Methods

To quantify relative species abundance, a stratified random plot-less sampling of vegetation method was done using a transect line (meter tape) for more rapid sampling. Relative abundance was estimated for each species for each sampling site. Relative abundance was measured by estimating the percent cover of species, that is, the area occupied by species, in each sample quadrat (Phillips, 1959). Sites were surveyed at a time when most of the species present could be identified from flowers and fruits. Each site was sampled multiple times from the middle of June to the beginning of August to include as many flowering plants as possible as some plants may flower earlier in the season, some in the middle of the season and some later in the season. Due to a high snowfall this year, some sites were not accessible until mid-late Summer.

To record plant succession in open-water and/or wetland sites we used a combination of methods previously mentioned along with the line-intercept method using transects, useful for indicating transitions in vegetation (Phillips, 1959). By using meter tape, a transect line was measured out, perpendicular starting at the water's edge, up to 30 m away. Two transects were used to sample at each site either perpendicular from the edge of the water or parallel to slopes. In drier meadows, a similar approach was used to lay out quadrats through the meadow, parallel to slopes. Along the 30 m transect we placed a $\frac{1}{4}$ m² quadrat for every 0, 2, 5, 10, 20, and 30-meter intercept. Flags were staked at each intercept along each transect mentioned. In the wetland site we gathered percent coverage, relative abundance and species richness of thirty $\frac{1}{4}$ m² quadrats. At each meadow site we gathered percent coverage, relative abundance and species richness out of a total of sixty-one quadrats.

Data Collection

Coordinates and elevation for the perimeter of each site was recorded using the online herbarium database at intermountainbiota.org. Coordinates and elevation for each transect location was obtained using a hand-held GPS (Garmin Vista GTX), recording each waypoint from the start of the transect to the end. Each transect was labeled (ex. Trans. 1, Trans 2, etc.) in a data sheet along with the coordinates and elevation at the start of a transect line (at 0 meters) and the end of a transect line (30 meters). Quadrats were numbered based on the intercept along the transect line (ex. in Trans. 1 at 0 meters Quadrat 1 at 0m: T10m/Q10m, in Trans. 1 at 5 meters Quadrat 3 at 10 m: T105m/Q310m). Species encountered within the sample quadrats were recorded in the order that they are encountered and added into a data sheet along with a description on the surrounding habitat. If species within the quadrats were unidentifiable, they were labeled as 'Unknowns', their approximate percent coverage was recorded in the data sheets and afterwards collected as a voucher specimen to identify in the lab.

Data Analysis

All data was input into Excel workbooks where sheets for each site were created for a master list, which contained the historical herbarium data downloaded from intermountainbiota.org. A list of collections was made to compare with the master list and to keep track of what species were present and absent at the sites being resurveyed. Meticulous records of dates and locations of sampling was recorded in Excel sheets as well. Data from

quadrat sampling was entered in Excel sheets, organized by species, transect number, transect distance, quadrat number, and quadrat distance. Percent coverage was estimated for each species and the total summed coverage was approximately 100 for each quadrat column. The average percent coverage was calculated for each species across all transects in each site and rearranged from highest percentage to lowest percentage. The top ten most abundant species from each site were selected to best represent most common and dominant species of each site or habitat.

Species richness, the total number of species found, was recorded from within the quadrats sampled. Duplicates specimens were given their own collection numbers, but each unique species was only counted once for the species richness data. Histograms were used to represent the composition of the ten most abundant species found within quadrats and their average percent coverage. Using a red star in our histograms (Fig. 4-6, 9 & 12), we especially labeled the species with historical herbarium records later found within our quadrat samples.

To compare historical collections, made from 1929 to 1965, to modern collections made since 2008, including this summer, we tallied the total number of unique species collected each year and compared it with the total number of specimens collected each year over the past 90 years. We analyzed the data by creating an accumulation curve to compare the number of specimens collected (collection efforts) vs. the number of new species found each year at each site (Fig. 3, 7 & 10).

Results

Kettle Ponds (KP)

The total number of collections made in 2019 was 380. Whereas, the total number of historical specimens (1929-2018) recorded in this site was 169 collections. In the past ninety years 149 unique species have been identified from a total of 549 collections. Recent collections (2008-2019) accounted for 76 out of the 149 species from this site, while 44 species documented from historical specimens (pre-1965) were not found in recent collections. Thirty-one species were found in both historical and recent collections (Fig. 13). Species richness for the three different habitat zones away from the pond edge were: Riparian zone/pond edge 30 species, willow zone 37 species, and meadow zone 27 species. Of the ten dominant species in the riparian zone only 4 (*Carex nebrascensis*, *Salix wolfii*, *Salix boothii*, and *Eleocharis palustris*) were documented by historical specimens. In the willow zone, only 3 (*Salix boothii*, *Hypericum scouleri*, and *Salix wolfii*) were documented by historical specimens. Lastly, the 10 dominant species in the meadow zone were *Festuca thurberi*, *Lupinus polyphyllus*, *Viola praemorsa*, *Bromus inermis*, *Poa pratensis*, *Achillea millefolium*, *Agoseris glauca*, *Artemisia dracunculus*, *Taraxacum officinale*, and *Delphinium nuttalianum*). None of these species were documented historically before 1965.

Lower Virginia Basin (LVB)

The total number of collections made in 2019 was 113. Whereas, the total number of historical specimens (1929-2018) recorded in this site was 127 collections. In the past ninety years 105 unique species have been identified from a total of 243 collections. Recent collections (2008-2019) accounted for 69 out of the 143 species from this site, while 64 species documented from historical specimens (pre-1965) were not found in recent collections. Fourteen species were

found in both historical and recent collections (Fig. 13). Species richness for subalpine meadows identified within our quadrats was 41 species. Of the ten dominant species in the riparian zone (*Fragaria virginiana*, *Ligusticum porteri*, *Vaccinium caespitosum*, *Helianthella quinquenervis*, *Lathyrus lanzwertii*, *Erigeron eliator*, *Distegia involucrate*, *Potentilla pulcherrima*, *Senecio crassulus* and *Carex spp.*) we found no historical record of them in the database.

Upper Virginia Basin (UVB)

The total number of collections made in 2019 was 125. Whereas, the total number of historical specimens (1929-2018) recorded in this site was 273 collections. In the past ninety years 143 unique species have been identified from a total of 400 collections. Recent collections (2008-2019) accounted for 126 out of the 143 species from this site, while 44 species documented from historical specimens (pre-1965) were not found in recent collections. 54 species were found in both historical and recent collections (Fig. 13). Species richness for the alpine meadow habitat identified within our quadrats was 35. Of the ten dominant species in the riparian zone only 4 (*Carex elanoides*, *Salix spp.*, *Oxytropis deflexa*, and *Poa spp.*) were documented by historical specimens (Fig. 12).

Discussion

We wanted to know whether historical herbarium data was adequate to provide the long-term data needed for tracing changes in vegetation over time in terms of diversity, species distributions, and possibly to record species loss. We were also interested in using historical data from the past ninety years as a baseline to compare with this year's data to detect whether or not these historical records reflect relative species abundance of rare and/or common species.

Some of the most interesting findings of my project were the large number of common species found in each site that were not previously collected and found in the historical (pre-1965) herbarium data. A common occurrence was that earlier, historical collections emphasized rare or uncommon species, while common species were apparently not collected. We also noted that collection efforts were highest between 1940 and 1965. Most of these collections appear to be from Dr. Harriet Barclay and Jean Langenheim's collections (refer to Fig. 2, 7 & 10). Very little collecting occurred in RMBL between 1965 and 2010, and due to a few projects by Stansberry (2008), Zorio (2012), and our efforts this year collecting has increased significantly in the past decade.

Of the two methods used, we found that blanket sampling was the best method to record species richness from each site as we saw a significant increase in the total number of unique species collected in recent collecting efforts (Fig. 13). As for quadrat sampling, we found that even though species richness was being underrepresented, the data told us more about the relative abundance of species including the most common species found in each habitat. We were able to find similar results in each site, that the most common species were often not collected in the past. We speculate that this may be due to collection biases, perhaps the common species are less desirable than the rare ones.

The most intensive herbarium specimen collections were done this year (2019), represented as the highest spike in each accumulation curve (Fig. 2, 7, and 10). But, we found

that there were diminishing returns on collection efforts, therefore the amount of new species found in each site would no longer increase as it will have reached the maximum regardless of an increase in collection efforts. Thus, we expressed visually that we would have come close to creating a complete species list for all three sites (Fig. 3, 8 and 11).

When analyzing the historical data collected prior to 1965, we saw numerous alpine species collected in the subalpine habitats of the Lower Virginia Basin. A number of these typically alpine species were absent from more recent collections. However, we found many of these species growing in higher elevations in alpine habitats in the Upper Virginia Basin. The list of plants included: *Arnica rydbergii*, *Packera dimorphophila*, *Mertensia lanceolata*, *Juncus drummondii*, *Pedicularis parryi*, *Bistorta bistortoides*, *Ivesia gordonii*, and *Sibaldia procumbens*. We cannot determine why these species were not relocated in the subalpine habitat of Lower Virginia Basin, but we do know that these species are typically found in higher elevations today. One possible explanation is the uncertainty of the locality descriptions may have placed these collections at the wrong site. It may also be possible that these species occurred at lower elevations in the past, but no longer are found at this low elevation site.

We expected to find a number of alpine species in the Upper Virginia Basin, based on the historical records (collections made prior to 1965). However, many of these previously documented species were not found in our recent collections from this site. Common alpine species such as *Erigeron compositus*, *E. simplex*, *Cerastium beeringianum*, *Towsendia leptotes*, *Claytonia megarhiza*, *Campanula rotundifolia*, and *Lonicera involucrata*, and rarer species like, *Draba incerta*, *D. lonchocarpa*, and *D. oligosperma*, were not found in our recent collections. Because of late snowmelt at high elevations this year, we were only able to collect species that typically bloom early in the season in the alpine. Continued collecting later in the season should reveal many of these “missing” species as they come into bloom. In fact, on a more recent collecting trip (August 12) we did find many of these species in bloom and they will be added to final species list. Timing of collecting trips to encounter species that bloom at different times during the season is another form of bias in herbarium collection data.

We began this project expecting to find patterns in occurrence of species, but instead were faced with a number of limitations in the historical data, including: sporadic collection efforts, common vs. rare species bias, spatial, temporal, trait, phylogenetic, and collector biases (Barnabas et al., 2017). We discovered that there are many species that are not being collected due to collection such collection biases. When using herbarium data for floristic studies such as ours we must account for sampling biases when measuring collection efforts. An example of collector bias may be based on accessibility such as collecting close to roads and herbaria or collecting specimens of threatened species less frequently (Barnabas, 2017). We too experienced our own taxonomic bias and realized that certain common species like *Taraxacum officinale* are less desirable to collectors because they are a nuisance or *Fragaria virginiana* and *Pseudocymopterus montanus* which have a widespread distribution that they're easy to ignore.

We came to the conclusion that there is a need for complete species lists in the herbarium database in order for them to be useful for studying species distribution or to track species loss. To avoid biases herbarium collecting efforts should attempt to include statistically unbiased samples of plant diversity across space and time (Barnabas, 2017). We encourage curators and collectors to continue their efforts, but to use mindful collection efforts to alleviate sampling biases for future studies.

Tables and Figures

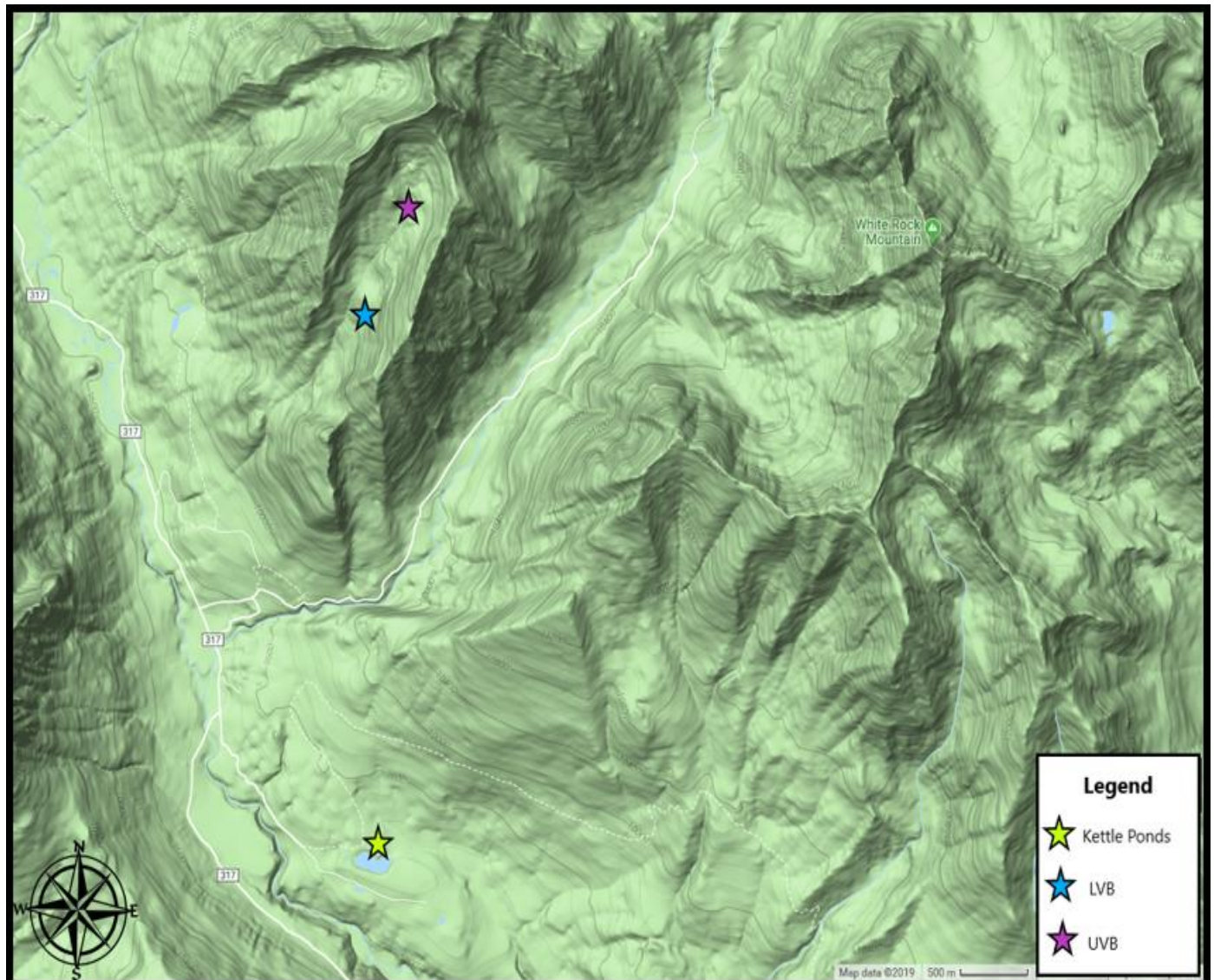


Figure 1. Map of 2019 sites: Green-Kettle Ponds, Blue-Lower Virginia Basin (LVB), Purple-Upper Virginia Basin (UVB)

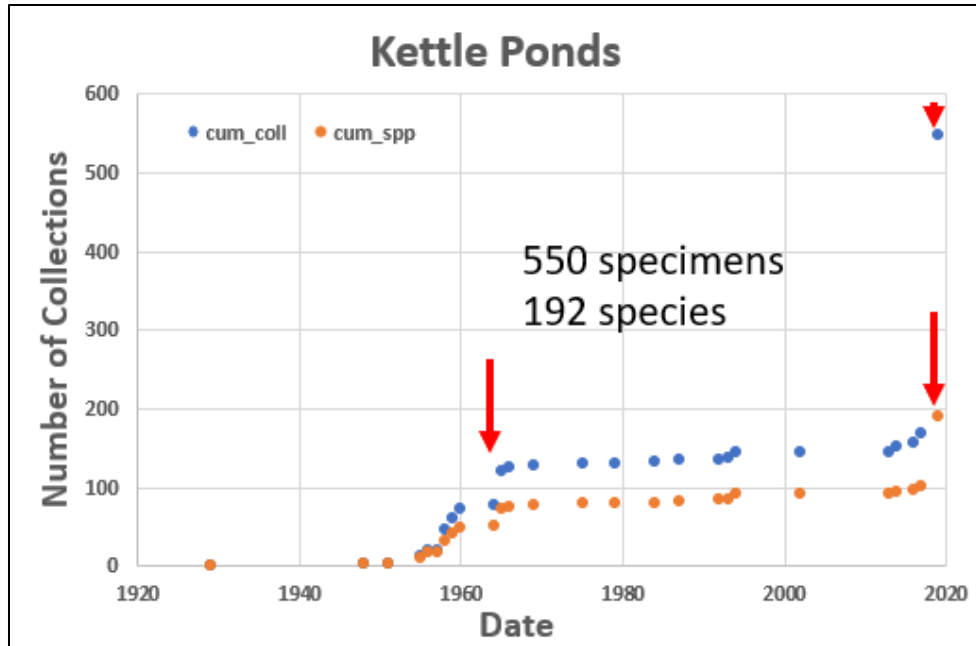


Figure 2. Accumulation curve representing number of herbarium collection efforts from 1929-2019; orange represents cumulative number of unique species and blue represents the number of collections made in a year; red arrows point at record of highest collection efforts and highest number of unique species.

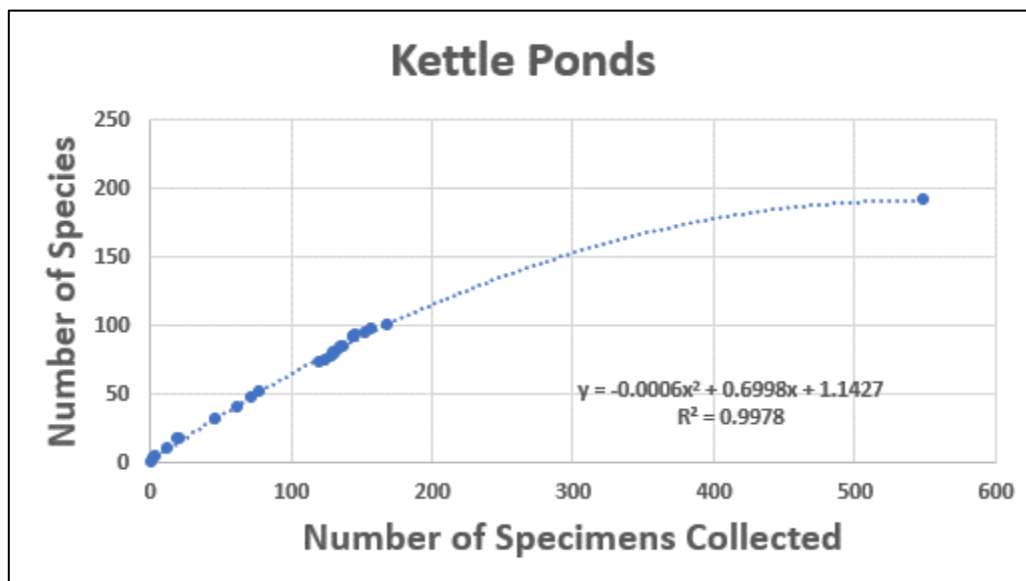


Figure 3 Accumulation curve representing the increase of number of unique species (191) vs. the number of specimens collected (549) at the Kettle Ponds.

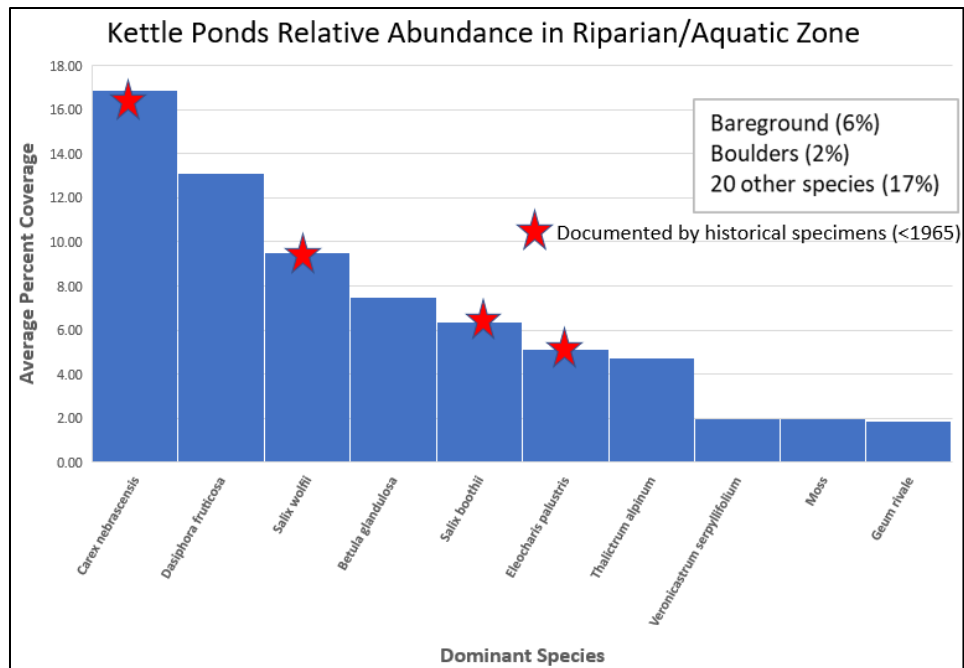


Figure 4 Kettle Ponds Relative Abundance in riparian/aquatic zone representing the top ten dominant species and the average percent coverage sampled within quadrats; red stars represent the species that are documented by historical specimens before 1965.

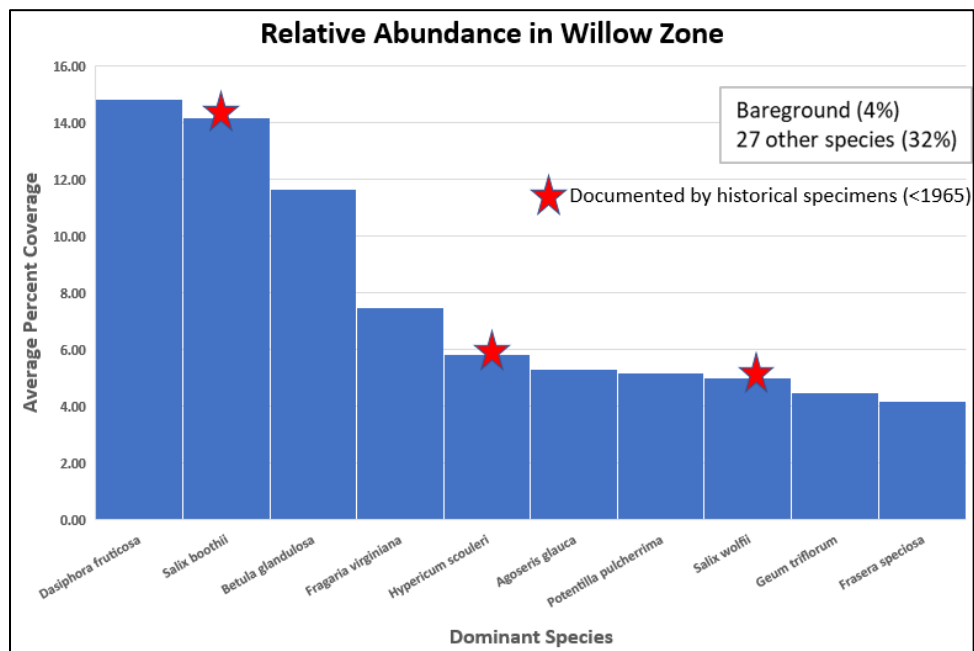


Figure 5 Kettle Ponds relative abundance in willow zone representing the top ten dominant species and the average percent coverage sampled within quadrats; red stars represent the species that are documented by historical specimens before 1965.

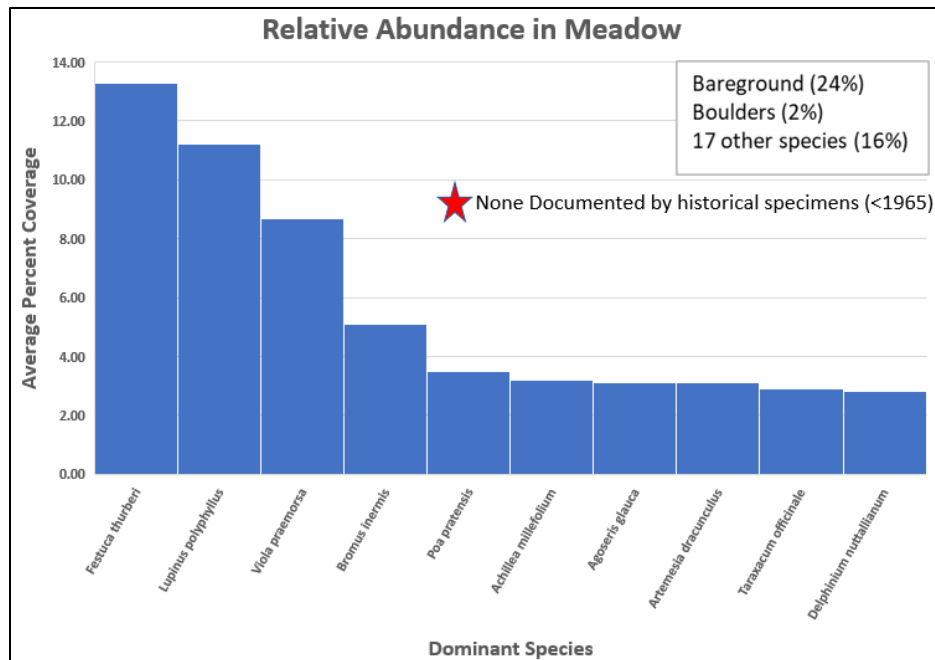


Figure 6 Kettle Ponds relative abundance in meadow zone representing the top ten dominant species and the average percent coverage sampled within quadrats; red stars represent the species that are documented by historical specimens before 1965.

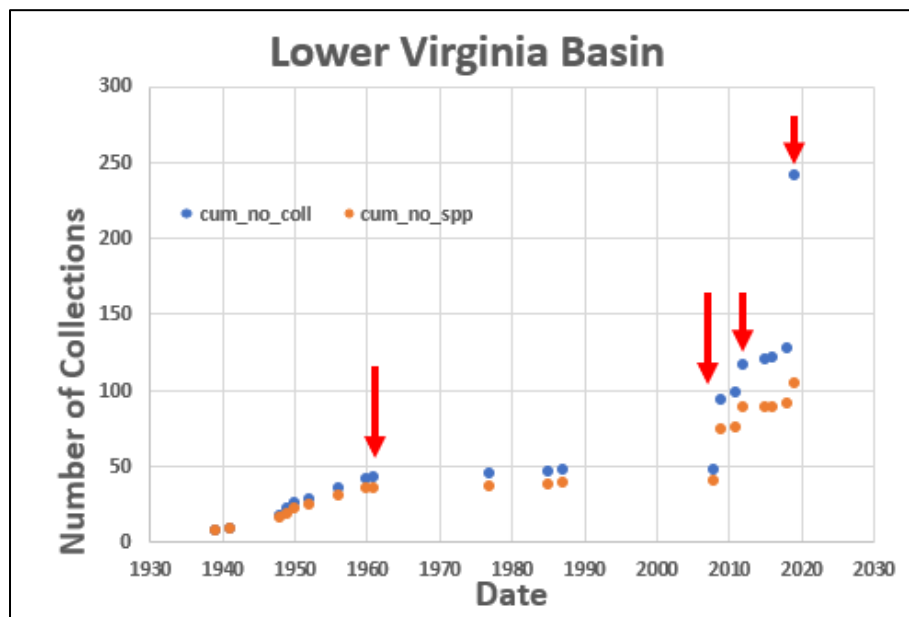


Figure 7 Accumulation curve representing number of herbarium collection efforts from 1929-2019; orange represents cumulative number of unique species and blue represents the number of collections made in a year; red arrows point at record of highest collection efforts and highest number of unique species.

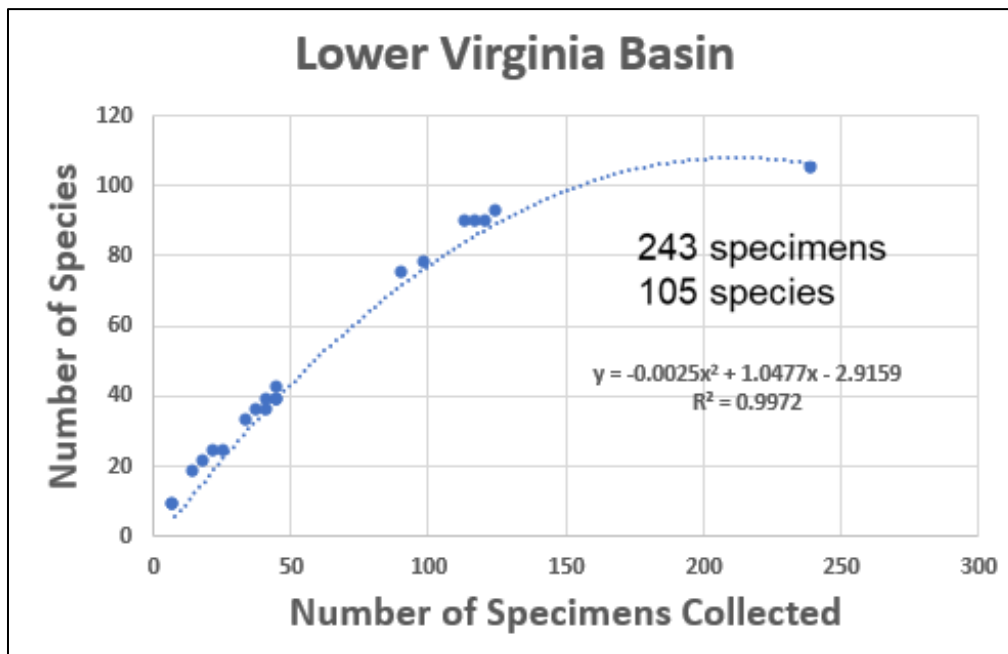


Figure 8 Accumulation curve representing the number of unique species (105) vs. the number of specimens collected (243) at the Lower Virginia Basin.

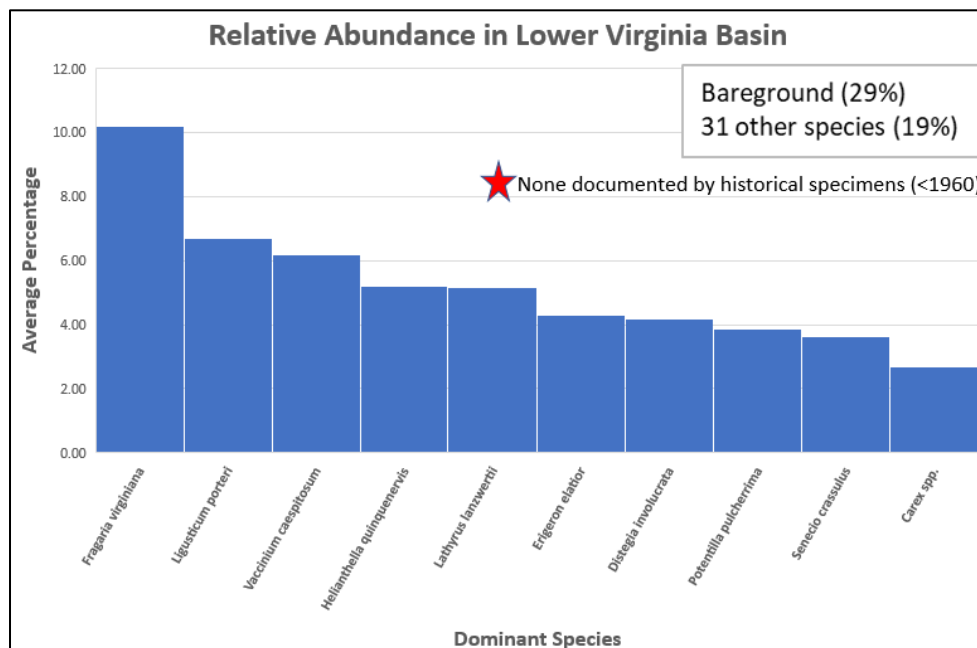


Figure 9 Lower Virginia Basin relative abundance in riparian/aquatic zone representing the top ten dominant species and the average percent coverage sampled within quadrats; red stars represent the species that are documented by historical specimens before 1960.

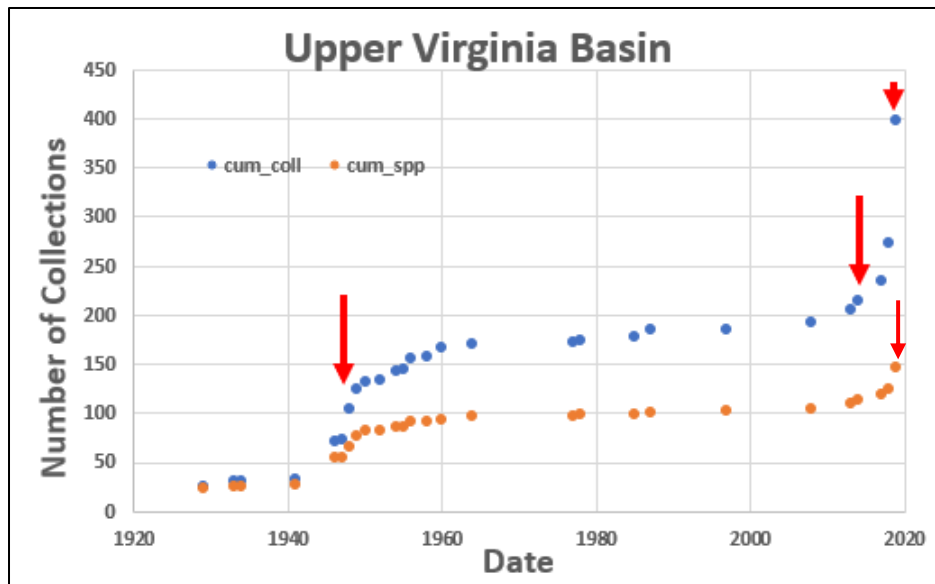


Figure 10 Accumulation curve representing number of herbarium collection efforts from 1929-2019; orange represents cumulative number of unique species and blue represents the number of collections made in a year; red arrows point at record of highest collection efforts and highest number of unique species.

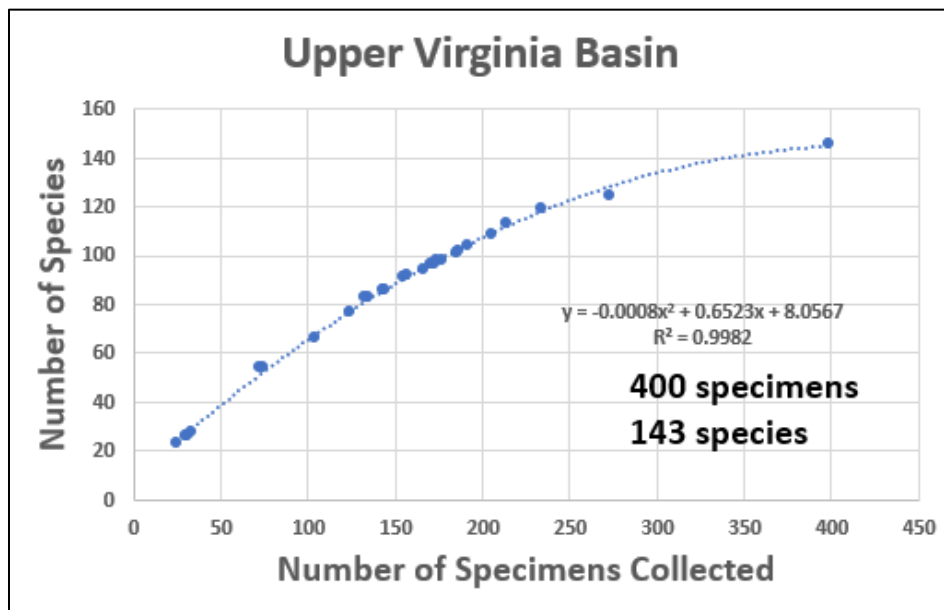


Figure 11 Accumulation curve representing the number of unique species (143) vs. the number of specimens collected (400) at the Upper Virginia Basin.

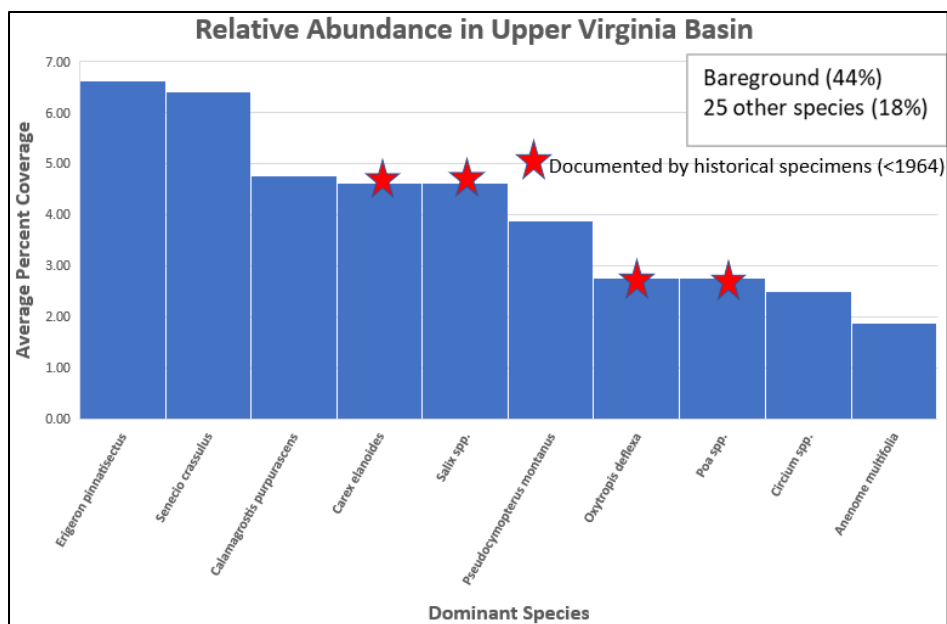


Figure 12 Upper Virginia Basin relative abundance in riparian/aquatic zone representing the top ten dominant species and the average percent coverage sampled within quadrats; red stars represent the species that are documented by historical specimens before 1964.

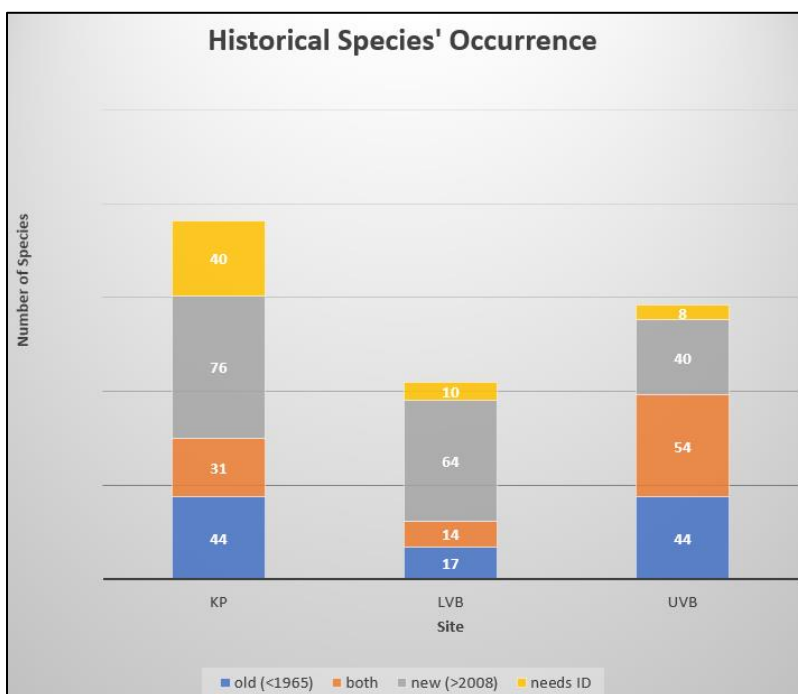


Figure 13 Histogram representing each site and number of species only collected in historical data (blue), species collected before 1965 and after 2008 (orange), new species only collected after 2008 (grey), and specimens collected in 2019 that still need to be identified (yellow).

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