Final Report:
Impacts and recovery status of wild bee communities following a catastrophic flood

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Abstract
Natural disturbances such as flooding, drought, and wildfire, can promote biodiversity by creating new opportunities for species colonization. However, disturbances that occur too frequently or too severely limit an ecosystem's ability to recover and may lead to a decline in species diversity. Current climate models project an increase in both the frequency and severity of disturbances in response to anthropogenic climate change. In 2013, a 500-year flood hit Colorado's Front Range, this disturbance event provided a rare opportunity to assess the impacts of a severe natural disturbance on a particularly important group of animals: wild bees. Wild bees are essential for plant recolonization following a disturbance event through the pollination services, yet little is known about their response to flooding. In 2012, one year before the flood, we conducted a comprehensive survey of the wild bees along the St. Vrain Greenway, an 8-mile long urban trail following an east-west riparian corridor in Colorado. We resampled in 2014 and to quantify flood impacts on wild bee diversity, and again in the field season of 2020 assess short- and long-term changes in diversity following the flood. Preliminary analysis shows a decline in diversity of bee genera and an improvement in 2020 seven years post-flood. This research provides crucial baseline data about changes in wild bee diversity in response to catastrophic storms and has implications for restoration efforts following large disturbance events.

Introduction
There is overwhelming evidence that Earth's climate is rapidly changing due to human activities, and these changes have initiated an unpredictable increase in the frequency of extreme weather events, such as flooding (IPCC, 2018; Pendergrass et al., 2017). Due to the difficulty in predicting catastrophic weather events, little is known about the impacts on biological communities, including wild bee communities. A recent extreme flooding event on Colorado's Front Range provides a unique opportunity to study its impacts on the diversity and abundance of an important group of organisms, wild bees. Bees are essential pollinators in wild, urban, and agricultural ecosystems and they also play a vital role in plant colonization and reestablishment through pollination, an essential process following large disturbance events such as a flood (Williams, 2011).

In September of 2013, an anomalous weather pattern brought The Great Colorado Flood to the state. There were five consecutive days of record-breaking rainfall, resulting in what some have argued could be considered a 500-year flood in Longmont (Figure 1). In some areas, over 400mm of rain fell over a week's time, which exceeds the entire annual precipitation for most of the arid state of Colorado (Gochis et al., 2015). This flood resulted in major rivers and their tributaries breaching, including the St. Vrain Creek and Left Hand Creek of the South Platt River which run through Longmont, CO. In addition to impacting city infrastructure, the flood devastated riparian areas, resulting in over 1,000 landslides, bank erosions, and deposition of soil and woody debris.

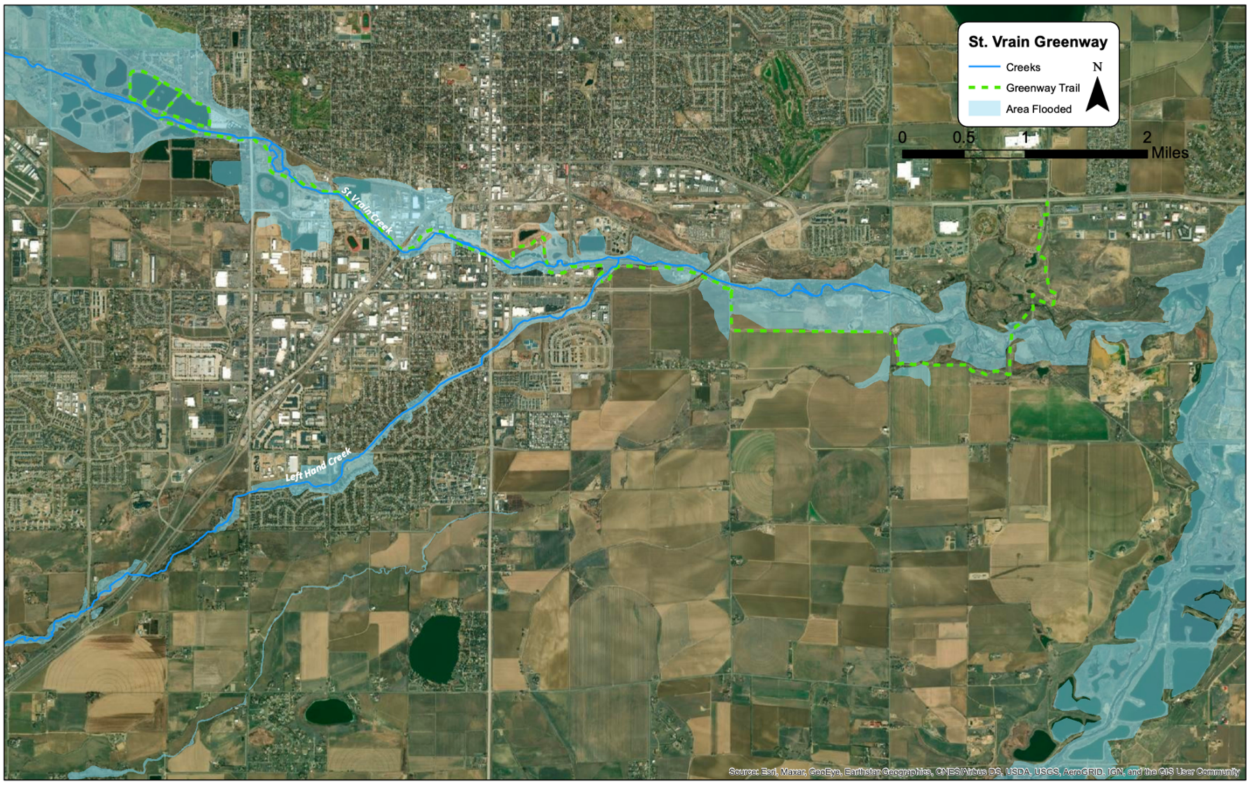

Figure 1 A map of Longmont, Colorado showing the extent of the September 2013 flood on the St. Vrain and Left Hand Creek.

In 2012, the University of Colorado Museum of Natural History (CUMNH) Entomology Section fortuitously established and sampled plots along the St. Vrain Greenway in Longmont, CO from March until early October. The sites were sampled in an identical manner in 2014 one year after the flood and again in 2020. Previous research on how bees respond to catastrophic weather or flooding events has focused on a single species at a time, some of which are special adapted to seasonally flooded areas (Cane, 1997; Fellendorf et al., 2004; Norden et al., 2003; Visscher et al., 1994). Wild bees have a wide variety of life history traits, many of which serve as predictors to recovery following disturbance (Williams et al., 2010). Long-term bee monitoring efforts are needed (Winfree, 2010), particularly to understand how wild bees respond to disturbance. This dataset provides the rare opportunity to quantify the impacts of a catastrophic flood on wild bee communities.

Riparian corridors like the St. Vrain Greenway are essential habitat for wild bees because they are rich in floral resources and diverse nesting sites for both ground and cavity nesting species. Understanding how wild bees respond to disturbance events such as catastrophic flooding can better help us develop restoration practices that will mitigate the negative impacts on wild bees and their food resources. **The objectives of our research include determining** (1) wild bee diversity and abundance pre-, one year post-, and seven years post-flood and (2) the bee life history traits of species that are particularly susceptible to or provide resilience to flooding.

Study area

This study took place along the entirety of the St. Vrain Greenway, an 8-mile long east-west urban trail running through a riparian corridor. The trail is parallel to the St. Vrain Creek, a tributary of the South Platt River, in Boulder and Weld Counties on the Front Range of Colorado (Figure 1). This trail runs through the City of Longmont passing through a variety of habitats including riparian areas, shortgrass prairie, busy roadways, shopping malls, parks with playground equipment, and agricultural fields. The trail is a popular recreation area, an important byway for non-motorized vehicles and is one of the most utilized trails in Longmont. It is managed by the City of Longmont and one portion of the trail (The Peschel property referred to as Quicksilver in our sampling) is co-managed with Boulder County Parks and Open Space. We obtained permits from both land managers to conduct our surveys. The cement trail was divided into 11 sampling sites that are roughly 1 km long and extend 10-25 meters out on either side of the trail into the surrounding vegetated area. Several of the sites have large, undeveloped areas of vegetation away from the trail that were also surveyed. Sites were delineated by major roads, bridges or stream crossings, and are thus not equal in size (Figure 2).

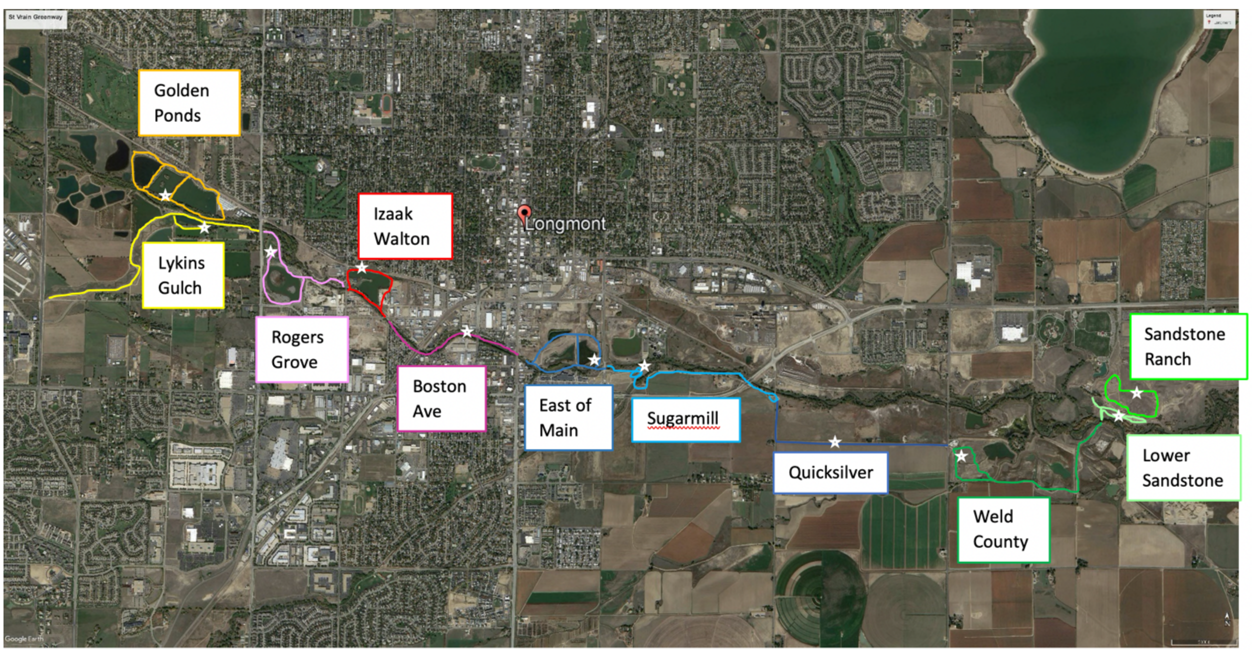

Figure 2 The St. Vrain Greenway Trail illustrating 11 sampling sites visited in 2012 (pre-flood), 2014 (post-flood) and 2020 (recovery).

The CUMNH Entomology Collection Manager fortuitously designated and sampled these plots as part of a pilot biodiversity survey in 2012, one year prior to the flood. This is an area containing prime bee habitat that had not been sampled for many decades. The flood came in 2013 and introduced a natural experiment and provided the opportunity to assess the bee community before and after a disturbance. The same sites were sampled again in 2014 to assess short-term impacts and the flood and again in 2020 to assess bee recovery.

In each of the three years, all 11 sites were sampled for 2 hours every 10-14 days beginning in March - just after first bloom and ending right before the first frost in October. We captured each bee encountered with a hand net and recorded the plant upon which it was found. We brought all samples back to CUMNH for pinning and labeling. After this, all bees were identified to genus using the Bee Genera of North and Central America. The first two years of data have been identified to species level by following multiple dichotomous keys for the region, consulting experts, and visiting other museum collections throughout the west to compare specimens. All specimens are vouchered in the CUMNH Entomology Collection. Over the three field seasons, we captured over 20,000 bee specimens of over 120 different species. We completed 9 sampling rounds in 2020, one round less than anticipated due to a late April snow delaying bee emergence (Table 1). Our final collection date was on October 8, 2020 and as of the submission of this report, all specimens have been pinned, labeled and identified to the generic level. Species-level identification is ongoing.

Table 1: Field season progress showing rounds, days sampled and number of bees processed.

Round	Dates Sampled	Collected	Pinned	Labeled	Identified*	Databased
1	Apr 27-May 5	1,208	1,208	1,208	1,208	1,208
2	May 12-21	534	534	534	534	534
3	May 28-Jun 5	672	672	672	672	672
4	Jun 15-18	676	676	676	676	676
5	Jul 6-9	400	400	400	400	400
6	Jul 23-29	568	568	568	568	568
7	Aug 17-24	943	943	943	943	943
8	Sep 3-7	611	611	611	611	611
9	Oct 4-7	179	179	179	179	179
Totals		5,791	5,791	5,791	5,791	5,791

**bees have been identified to genus; species identification is ongoing.*

Figure 3 Jessica Mullins (left – photo by Virginia Scott) and Virginia Scott (right- photo by Danielle Forte) sampling for bees on St. Vrain Greenway in 2020.

Results

Objective 1: Determine wild bee diversity and abundance pre-, one year post-, and seven years post- flood.

Our preliminary analyses show an increase in wild bee generic diversity from 2014 to 2012, with numbers approaching those seen in in 2012 prior to the flood. As identification to the species level requires more time and some groups will require consultation with experts, at this point our findings are based off of analysis of genus richness, or the total number of genera encountered, which is an indicator for species richness (van Rijn et al., 2015). As predicted, the genus richness declined from 2012 to 2014 and has improved in 2020 (Figure 4). We expect this to become statistically significant (P < 0.05) as we refine bee identifications to species level.

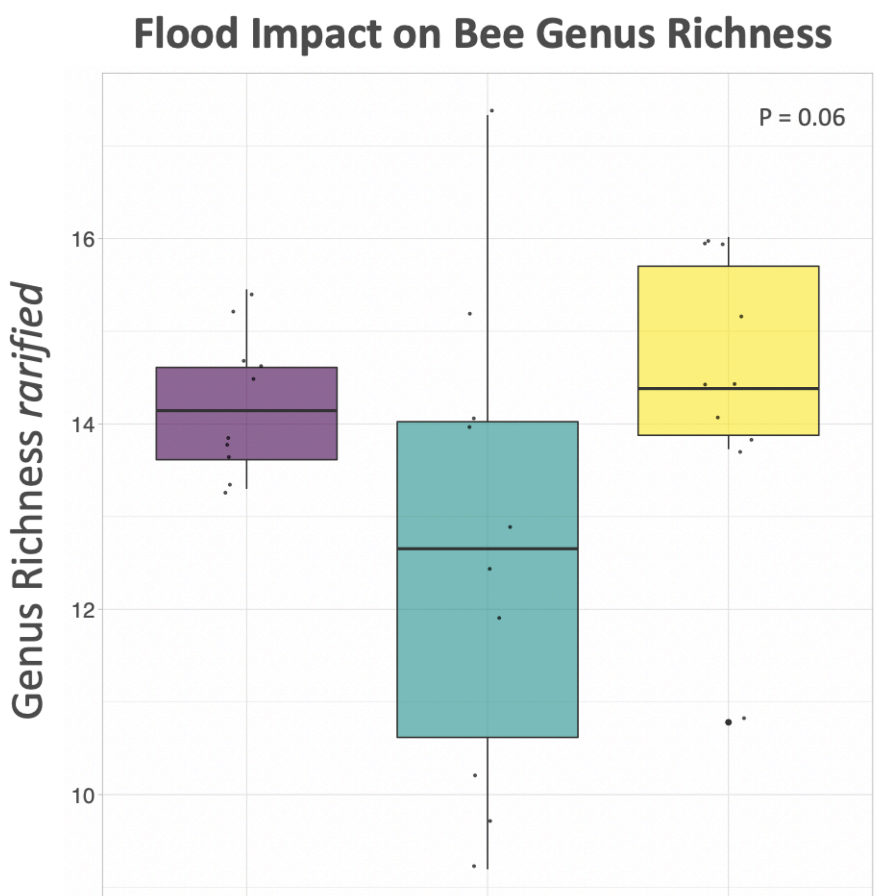

Figure 4 Changes in total number of bee genera observed pre-, post- and seven years post- flood with near significance (P = 0.06).

In our wild bee surveys, we found members from five of the six bee families found in North America: Mining Bees (Andrenidae), Apid Bees (Apidae), Cellophane Bees (Colletidae), Sweat Bees (Halictidae), and Leaf-cutting Bees (Megachilidae). The relative abundance of each family has varied between years (Figure 5), likely in response to the flood and restoration efforts undergone by the City of Longmont. In all three years of sampling, the Sweat Bee family was the most abundantly captured. The spike in abundance of this family one year following the flood (shown in light blue) may be explained by their preference to nest in bare ground and their generalist diet. Sweat Bees have been coined as disturbance-loving by experts (Eickwort, 1986), and disturbance caused by the flood could have created nesting habitat and limited competition for floral resources. Analysis of absolute abundance is still underway as we control for sampling effort at each site. Within the Cellophane bee family, we most commonly encounter the masked bee. These bees nest in pithy stems and twigs, which may have been broken and carried away by the storm. We expect their abundance has not recovered to pre-flood levels because their nests were broken and carried away in the storm and they may not have been able to recolonize from nearby areas. The response of each family to the flood and restoration varies vastly, showing "wild bee" response is more complex than it sounds. The diverse life history traits found within each family help explain their response to disturbance (Williams et al., 2010).

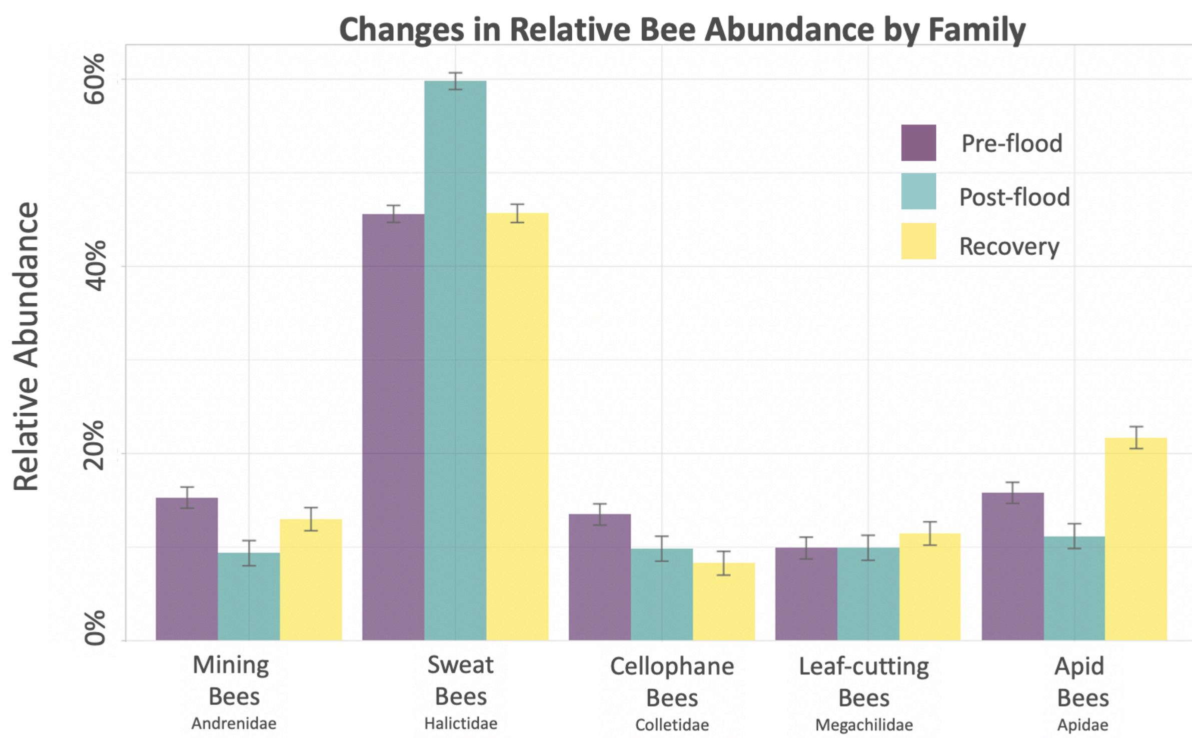

Figure 5 *Relative abundance by bee family for all three sampling years.*

Objective 2: Assess life history traits that are particularly susceptible to or provide resilience to flooding.

We broke the bee life history traits into four major categories: sociality, cocoon spinning, nest location, and nest architecture. We again looked at changes in abundance for bees who occupy these life history traits, with each bee family expressing one or more traits from these categories.

Sociality

Bees were assigned as parasitic, solitary or social at generic level, classifications that have been used in prior research (Wilson & Messinger Carril, 2015). As some bees express all three variations of sociality, they were not analyzed (i.e. the sweat bee in the genus *Lasioglossum*). Parasitic bees can be an indicator of a "healthy" bee community (Sheffield et al., 2013), and 2020 (recovery) resulted in the lowest abundance of parasitic bees. Parasitic bees are what is known as brood parasites, meaning the parasite lays their egg in the host's nest and they do not gather nutritional resources for their own young. For parasites to survive, they require a host and if the host is missing the parasite cannot survive. In the future we will aim to assess the changes in specific parasitic bees and their host (for example the Cuckoo bee *Nomada* and the Mining bee *Andrena*) over the three study years.

In the case of most parasitic bees, their hosts are solitary and 2020 (shown in yellow) marked the year with the lowest abundance of solitary bees. This low abundance of solitary bees in turn means fewer hosts for the parasites. In 2020 we captured the greatest abundance of social bees for all three sampling years, suggesting there are ample nesting and food sites available.

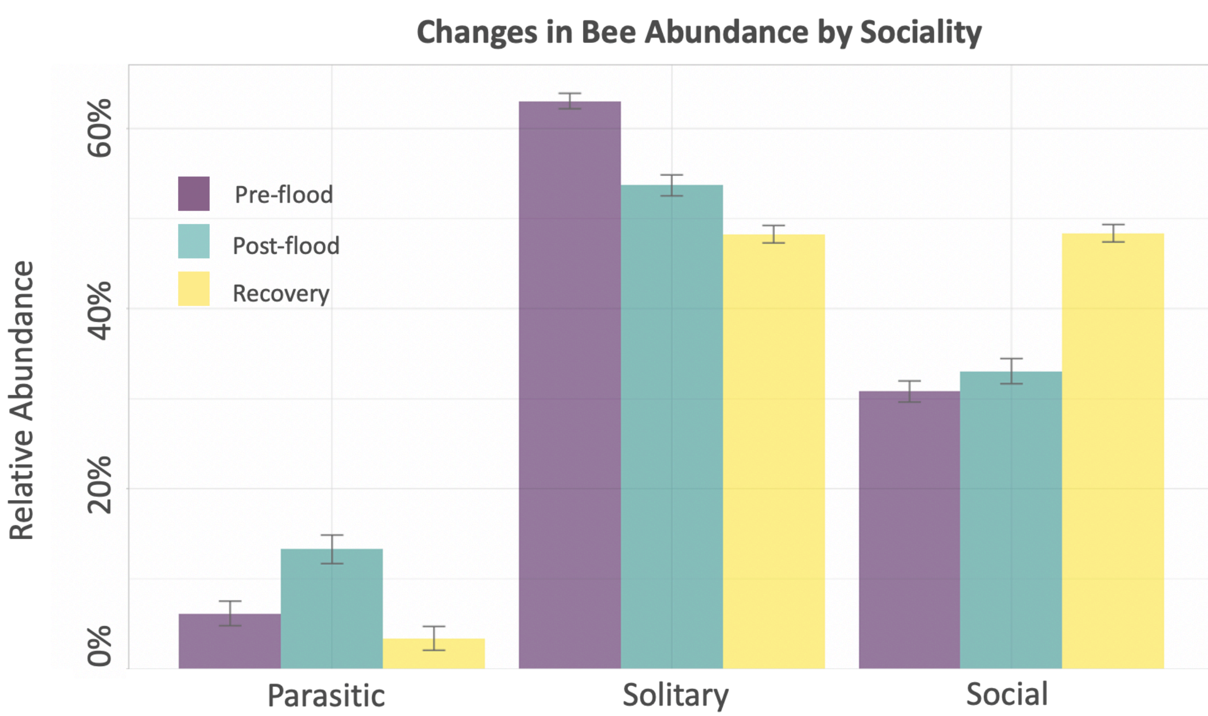

Figure 6 Changes in relative abundance of bees based on sociality. The abundance of parasitic bees is currently at its lowest.

Cocoon-spinning

The larvae (immature developmental stage) of some bees in the Leaf-cutting and Apid bee families spin cocoons during their development (Danforth et al., 2019). As the figure suggests, most bees do not spin larval cocoons. Examples of bees who do include digger bees in the apid family (*Anthophora* sp.), mason bees (*Osmia* sp.*),* wool-carding bees (*Anthidium* sp.*),* and leaf-cutting bees (*Megachile* sp.) all in the leaf-cutting bee family. We hypothesized these cocoons could provide protection from inundation by water, but we saw no significant changes in relative abundance based on this trait.

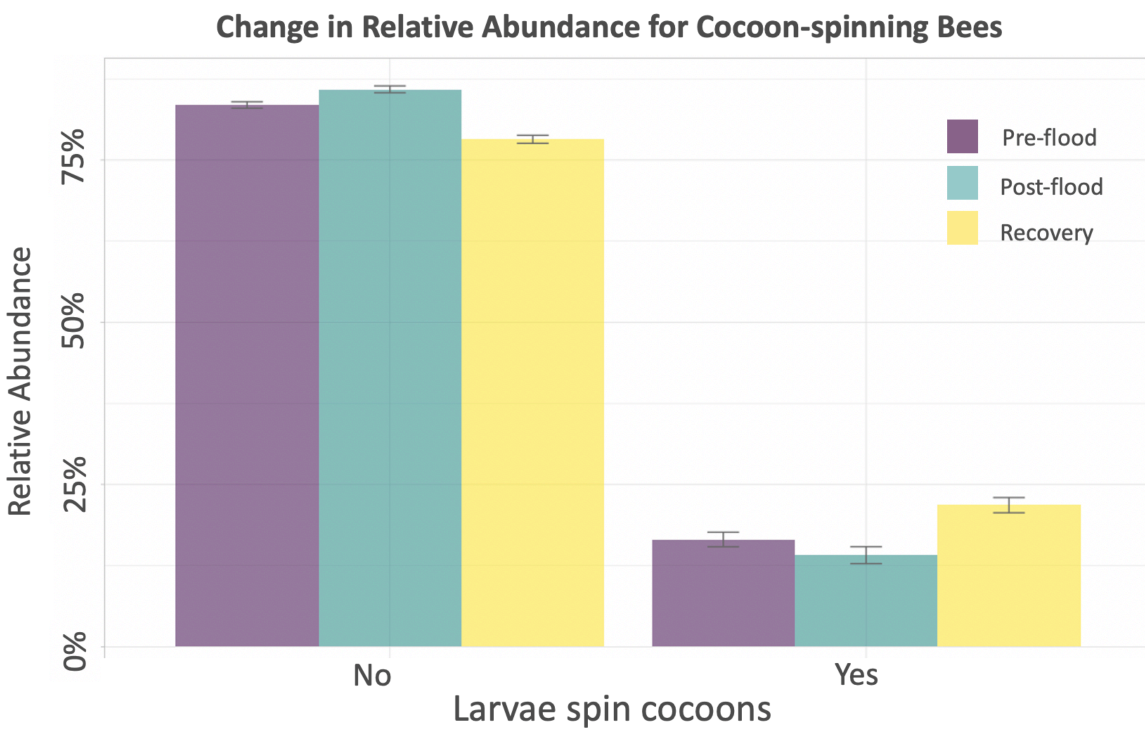

Figure 7 Changed in relative abundance of bees whose larvae spin cocoons vs. those who do not. There was no significant difference between years.

Nest Location

Most bees are ground-dwelling (Danforth et al., 2019), some constructing elaborate tunnels in soil others taking up residence in abandoned rodent holes, others nest both above and below ground. Most of our sampling area along the St. Vrain Greenway was completely inundated following the flood, and we expected to find a lower abundance of ground-nesting bees in both 2014 and a recovery in 2020. There were no significant changes to relative bee abundance based on nest location following the flood.

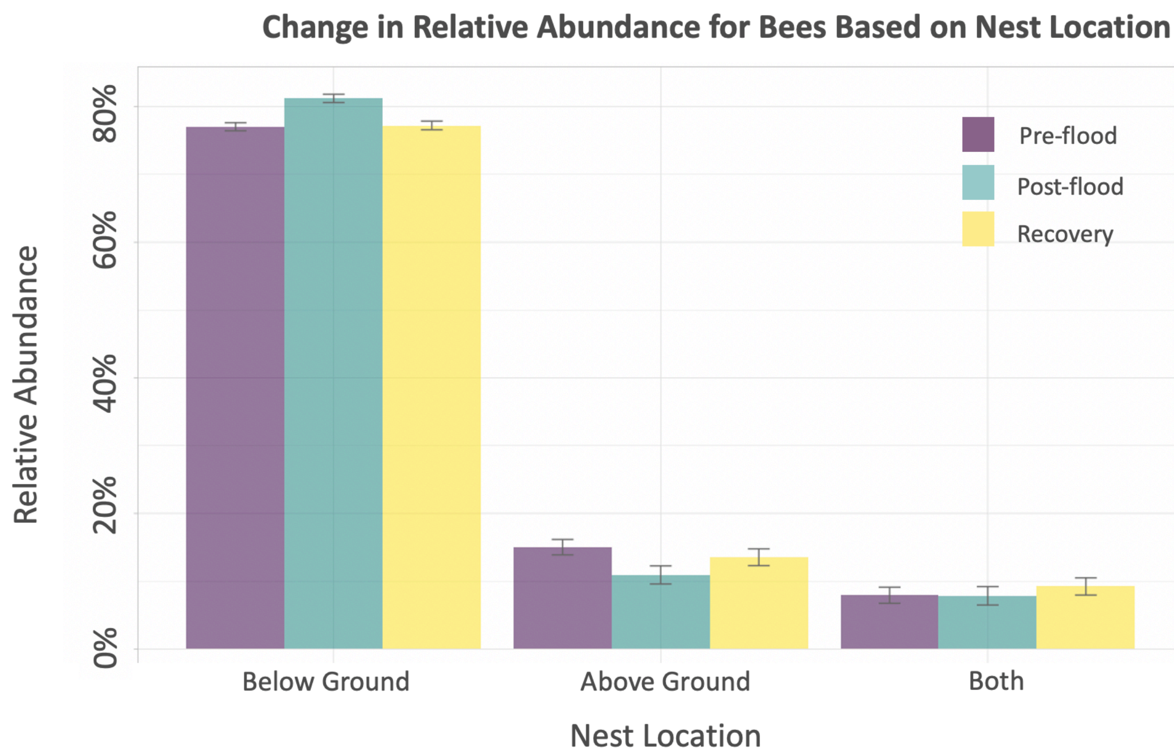

Figure 8 Changes in relative abundance of wild bees based on nest location.

Nest Architecture

The way a wild bee builds her nest, like nest location, varies. We assigned each bee into one of four categories (Dufour's gland, cellophane, plant material, none) based on Table 3-1 in the Danforth et al., 2019 book *The Solitary Bees.*

Bees have a special gland referred to as a "Dufour's gland," which is used to secrete a waxy often water-resistance substance to line the walls of the nest. This secretion maintains the humidity of the nest, which is necessary to maintain the quality of the larval food provision. Cellophane nest-linings, which are completely water-resistant, are constructed only by bees in the Cellophane bee family (Colletidae) (Almeida, 2008). Some bees, particularly from the Leaf-cutting bee family, collect plant material (resins, leaves, and/or petals) to contract their nests. Some bees, such as some Fairy Bees in Mining Bee family do not line their nests at all.

There were no significant changes to the relative abundance of wild bees categorized by their nest architecture life history trait. The decline in bees who lines their nests with cellophane may be better explained by nest location. As previously mentioned, masked bees nest in pithy stems which were likely carried away in the storm and have yet to grow back.

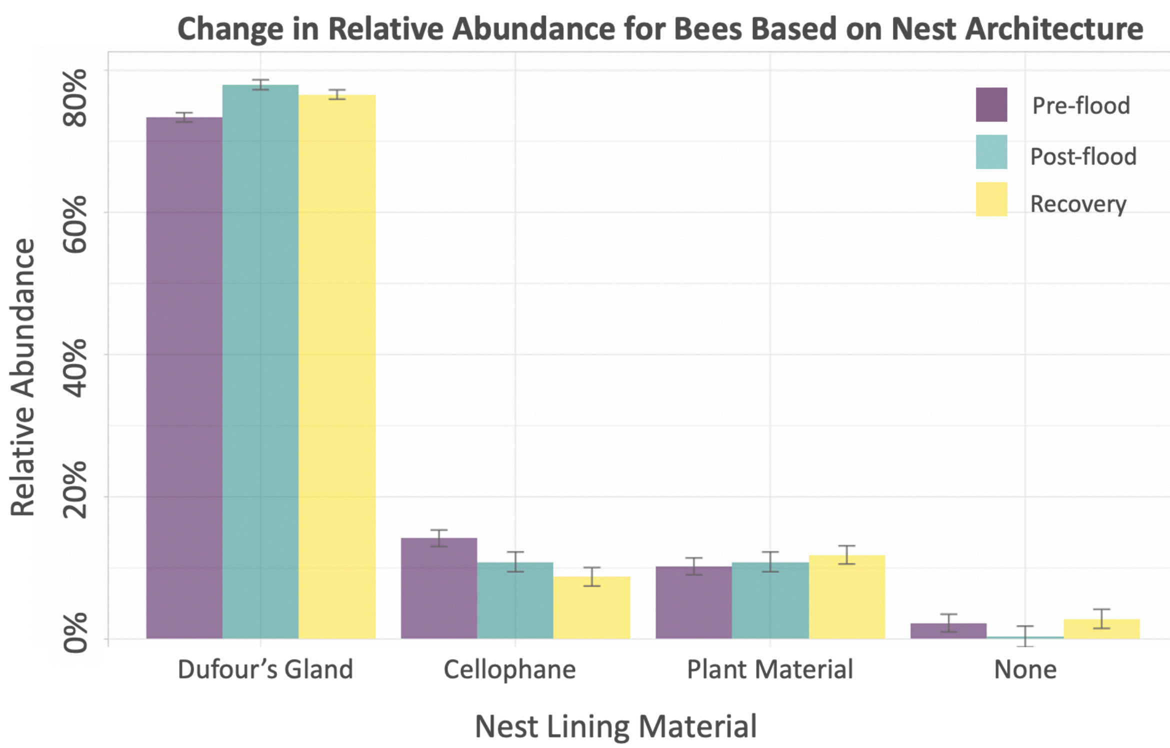

Figure 9 The changes in the abundance of bees depending on the materials they use (or do not) in nest construction.

Discussion

Disturbances, such as floods, wildfire, and drought are natural in biological systems. Disturbed ecosystems are often the most speciose, although the frequency and severity of these disturbances will impact an ecosystem's ability to recover. If the climate continues to change according to current projections, the frequency and severity of storms will advance – particularly in arid regions like Colorado (Pendergrass et al., 2017). Due to difficulty in predicting natural disturbances, baseline datasets such as ours are rare. Understanding how biological communities respond to natural disasters is key to facilitating restoration, which is particularly crucial for wild bees who are responsible for pollinating most flowering plants.

While analysis is ongoing, preliminary results show that wild bee diversity was impacted by the flood, and it has improved seven years post flood. At the current state of data resolution, we have not identified any life history traits associated with resilience following the flood. As we obtain species-level identifications, we expect this to change. Wild bees are incredibly diverse, and their life history traits are equally varied. This research confirms that not all bees will respond in the same way to disturbance at the family level, and likely complexifies as we work to obtain species identifications. Additionally, it is important to note the changes we observe can also be linked to natural variation in biological communities.

The City of Longmont launched the multi-year Resilient St. Vrain project, focusing on restoring the St. Vrain Greenway to improve the habitat for plants and wildlife and protect humans in the event of another natural disaster. This work involved extensive restoration efforts to the floral resources, and many of our field sites appeared to have been recently seeded with native wildflowers. Continuing to manage the land in a way that encourages native vegetation growth, and introduces nesting habitat (leaving pithy stems, exposed bare soil, and dead and standing trees) promote the wild bee community. Restoration work must not be left only to public land managers, but also to people with access to yards and community gardens. Planting wildflowers and providing bee nesting habitat will increase habitat availability and in turn increase the area of possibly unimpacted land following a disturbance. Bees from these unimpacted areas will survive to recolonize disturbed areas following disaster such as a flood.

Acknowledgements

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