

Floral Visitor Frequency to Different Colored Flowers  
and the Impact on Flora and Floral Visitors

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## Abstract

I monitored the frequency of visitation by floral visitors to plants with varying colors of flowers. The flower visitors described in this study include bees, spiders, beetles, butterflies, flies, ants, and wasps. The flower colors observed in the study were red, orange, yellow, blue, purple, pink, and white of various species. Previous studies have demonstrated a preference for flower visitation based on color and the resulting suppression of native flora through competition with invasive flora and the subsequent impacts on populations of flowering plants and floral visitors. My objective was to determine if there was a preference by floral visitors for flowers of a certain color and to evaluate the potential impacts of such a preference on flora populations and floral visitor populations. The main goal of this study is to understand how the color preference of floral visitors impacts visitation frequency, and how that impacts flowers and pollinators in Northern Colorado to better inform residents of Northern Colorado which plants they should plant that are more beneficial to maintaining healthy populations of native flora and floral visitors. This study also briefly examines how ecosystems that experience disturbances like invasives or warming areas can be more vulnerable to the impacts of color preference. Visitation frequency is important to understand because plants and floral visitors rely on each other for many natural processes, including reproduction and nutrition. Reduced visitation could decrease the overall health and populations of native plants by reducing their reproduction rates, in turn reducing populations of floral visitors that rely on these plants for protection and food. This study found a higher frequency of visitation of the blue flowers, with purple, yellow, and red flowers following in frequency of visitation respectively. The most frequent floral visitors across all colors of flowers tended to be bees, followed by wasps and then flies. These results show that planting blue or purple flowers that support bees is beneficial and conducive to healthy populations of flora and floral visitors in Northern Colorado.

## Introduction

Insects and plants have an important, interconnected, and co-evolutionary relationship with each other that has persisted for millions of years, two hundred twenty-five million years to be exact (Faheem et al., 2004). About 308,000 plants rely on floral visitors for pollination (Erickson & Pessoa, 2022), which is how they reproduce. Almost 300,000 species of animals are

responsible for pollination in nearly 87.5% of flowering plants (Howard & Symonds, 2023). Some of these 300,000 species include those included in this study: bees, spiders, beetles, butterflies, flies, ants, and wasps. Other species that aid in pollination that are not included in this study are moths, bats, birds, and hornets (Howard & Symonds, 2023). Pollination occurs through many means, including the wind and animals. On a basic level, pollination consists of pollen being transferred from the anther of one flower to the stigma of another for the purpose of producing seeds and reproducing (Faheem et al., 2004). Due to the reliance of many plants on pollinators for reproduction, flowers need to be appealing to them. This idea of plants adapting to appeal to floral visitors is supported by the examination of receptors of arthropod ancestors, which were likely adapted by insects before flowers even existed (Chittka, 1996). This means that flowers likely adapted to appear appealing to insects, rather than insect vision adapting to better see flowers (Chittka, 1996). The idea that flowers adapted to floral visitors instead of vice versa is important because it demonstrates how floral traits can impact floral visitation frequency and thus impact floral and floral visitor population health, which is the core focus of this study. This study focuses on color as a method of attracting floral visitors, but it is also important to acknowledge that other purposes for the coloration of flowers have been hypothesized. Some of these purposes include protection from ultraviolet radiation, protection from consumption by herbivores, and resistance to temperature, drought, and various toxins (Erickson & Pessoa, 2022).

Plants rely heavily on insects, but insects also rely heavily on plants. Insects rely on plants for food, for protection, as a place to find prey and mates, and as a place to lay eggs (which could be considered rewards for floral visitation in addition to pollen and nectar) (Kevan & Baker, 1983). Insects and plants rely on each other for various functions, and when events that impact the composition of flora and floral visitors in an ecosystem occur, it can affect the health of their populations. For example, if invasive plants enter an area, they can create competition for resources and floral visitors that are detrimental to native plants and floral visitors (Goodell & Parker, 2017). Resources that plants might compete for include water, light, shade, nutrients, and land to grow on (Brown et al., 2002). Competition for these resources can be detrimental to native species by preventing them from being able to sustain or grow their populations (Brown et al., 2002). In addition to the resources mentioned previously, pollinators and floral visitors can also become a resource that plants have to compete for. Plants rely heavily on insects for

reproduction, so sometimes this competition for pollinators can negatively impact populations of plants and their floral visitors. It is important to acknowledge that many things can impact the frequency of floral visitors and their attraction to certain flowers besides their coloring. Among these characteristics are shape, smell, and rewards like pollen and nectar (Kevan & Baker, 1983). Nectar is a mixture of complex sugars often used by pollinators as a source of nutrition and calories. Similarly to nectar, pollinators can also use pollen as a source of nutrition. Other rewards that a floral visitor might gain from plants could include the aforementioned benefits of protection and egg-laying sites (Faheem et al., 2004). Floral visitors' senses of taste, vision, smell, structure, and behavior also contribute to preferences and visitation frequency (Faheem et al., 2004). Environmental factors that influence floral visitor frequency include temperature, weather, altitude, light, precipitation, and wind (Faheem et al., 2004). Foraging behaviors contribute significantly to how floral visitors interact with flowers and the frequency with which they visit them. The range of pollinator foraging is about three to twelve kilometers (Faheem et al., 2004), and rates and speeds of foraging are often dependent on the species and kind of flower being foraged from. Different bee species forage at different rates, and insects like ants and beetles tend to have low rates of foraging (Faheem et al., 2004). Many species of bees, flies, butterflies, and moths have been observed moving only short distances in plots of flowers (Faheem et al., 2004).

Previous studies have compared floral visitor frequency in invasive and native plants such as purple loosestrife and winged loosestrife (Brown et al., 2002), but few have focused specifically on color preference by floral visitors. Previous research has also observed that there are trends in color preferences for flowers by different types of floral visitors. For example, bees have been shown to prefer flowers that are purple and blue, while flies tend to prefer white or yellow flowers (Lunau & Maier, 1995). Bees have also been observed to prefer flowers with radial symmetry (Gibson et al., 2012). Pipevine swallowtail butterflies (*Battus philenor*) have been observed to have a preference for flowers of purple, yellow, and blue varieties (Erickson & Pessoa, 2022). Pipevine swallowtail butterflies were observed as having more flexible preferences in colors, while another butterfly that was studied, skippers (family *Hesperiidae*), were much more rigid in their color preferences (Briggs et al., 2018). This is thought to be attributable to the fact that color might be the primary trait that skippers use to effectively forage (Briggs et al., 2018). Generally, pollinators follow their innate color preferences, but this can be

altered if they learn to expect better rewards (like pollen or nectar) from other flowers (Erickson & Pessoa, 2022). As such, floral visitation frequency can be dependent on the cognition of the floral visitor. Invasive species have not been observed influencing native plants' floral visitation frequency in previous research, but other studies have shown that many other invasive species can impact floral visitation frequency, and subsequently negatively impact populations of native flora and floral visitors (Goodell & Parker, 2017). Native plants that are most at risk of being impacted by invasive species tend to have similar flowers to the invasive species. This includes characteristics such as color, structure, and inflorescence (Goodell & Parker, 2017). Previous studies have observed that in many cases, native plant reproduction is affected by decreased floral visitation and pollination caused by invasive plants primarily by invasives causing a lack of quantity and quality of pollen necessary to produce healthy seed sets, which are collections of seeds produced by plants after pollination (Goodell & Parker, 2017). This can impact floral visitors by decreasing the number of plants they depend on for nutrition, shelter, and reproduction. Decreased frequency in visitation is a problem for native flora and floral visitors because it has the potential to reduce the efficacy of pollination, and the seed sets of native plants compared to invasive plants. One way that invasive plants can negatively impact the health of native species is by reducing the number of native flowers that exist, which in turn can make the native flowers less appealing to floral visitors (Goodell & Parker, 2017). Another potential way invasive plants can reduce the fitness of native species is by increasing overall flower abundance in the area with its population while the number of floral visitors remains the same, which can decrease the rate at which native flowers are visited by floral visitors (Goodell & Parker, 2017). A final way that invasive species can reduce the fitness of native species is by being the preferred species and increasing competition for pollinators in that way (Goodell & Parker, 2017). It is also relevant to note that floral visitors could also transfer pollen from invasive species to native species, impacting the amount and quality of pollen transferred between plants which can impact seed production.

It should be noted that bees are usually considered to be generalists (Gibson et al., 2012), which means they do not specialize in visiting certain plants, and instead are suited and able to visit many different species. This allows for some amount of variation and competition in the visitation of flowers without causing significant harm to the health of plants that depend on them to perform various functions. On the other hand, if a floral visitor or plant has more specific and

specialized relationships, variation and competition for floral visitors could have a much more severe impact (Gibson et al., 2012). For example, with more generalist floral visitors, plants can make up for lost floral visitors with visitation from other species, but if a plant is adapted to certain pollination from a specific species such as birds, competition for those floral visitors would have a much greater negative impact (Gibson et al., 2012).

While invasive plants can decrease native plant fitness through changing floral visitor interactions, it is important to recognize that invasive plants also have the potential to increase floral visitors to native plants in some scenarios, which is known as facilitation (Gibson et al., 2012). For example, if an invasive species is very popular with floral visitors, it could attract floral visitors to native plants in the area (Goodell & Parker, 2017). Another way it is possible for invasive plants to positively impact fitness and floral visitation for native plants is by increasing the number of flowers in an area. This can have a positive impact on floral visitors and increase their populations as a whole, which aids in floral visitation and reproduction of native species (Goodell & Parker, 2017).

In summary, the composition of flowers and floral visitors in an ecosystem is impacted by the presence of color preferences, especially in an area impacted by invasive species. Color preferences can increase competition and reduce visitation, and pollination, especially in the species that are not the preferred color and do not have the characteristics that make invasives thrive, including the rate of growth, seed size, and capability to resprout (Gibson et al., 2012). As a result, reproduction and seed sets of species that aren't preferred colors can be reduced, which diminishes the health of their populations and the health of any pollinators that rely on them. This is exacerbated in areas with invasive species because if an invasive species with certain preferred colors is better able to compete than native plants, they will be selected for and the original composition of native plants and floral visitors that rely on these plants will be affected (Goodell & Parker, 2017). With the innate color preferences of some pollinators in mind, I hypothesized that visitation of floral visitors to preferred colored flowers has the potential to negatively impact the frequency of visitation and pollination of certain plants, especially plant communities disturbed by events like invasions that already have a negative impact on the ecosystem due to decreased visitation reducing the health of native plants and floral visitor populations. This study aims to address the gap in knowledge about how the specific characteristic of flower color impacts the visitation frequency of various floral visitors, and why

decreased visitation could be detrimental to native flora and floral visitors, especially in an environment disturbed by invasive species.

## Materials and Methods

In this study, data were collected using three cameras with three intervalometers set up in front of varying flowers in the Annual Trial Garden of Colorado State University (Figure 1). One camera was a Canon Rebel t3i, and one intervalometer was an Enegon CSRC-10. The specifications of the other two cameras and intervalometers are not available but were similar. The Annual Trail Garden at Colorado State University is a garden on Remington Street in Fort Collins that is open from late May to October in which various annual plants are grown to see how they perform in the conditions in the area associated with the Rocky Mountains. The trial garden has been located on Remington Street since 2000 but was initially maintained at the W. D. Holley Plant Environmental Research Center when it began in 1971. Most of the plants in the trial garden are grown from cuttings and are studied to see how uniform they are, how many flowers they produce, their vitality, and their ability to tolerate stresses from the environmental and biological factors in the garden (Flower Trial Gardens, n.d.).

Figure 1. Image of the CSU Trial Garden in the summer of 2023.



The three cameras were set up for about thirty minutes in front of each flowering plant, using the intervalometers to take pictures in intervals of two seconds for a total of about nine hundred pictures per flower in an attempt to capture the frequency of visitations by floral visitors. It is important to note that the term “floral visitor” is used intentionally in this study as opposed to “pollinator” because it creates the necessary distinction between visitation and pollination of flowers. Not every occurrence of an insect at a flower involves pollination, and it is difficult to distinguish visitation from the specific process of pollination.

As mentioned previously, data was collected for seven different colors of flowers including red, orange, yellow, blue, purple, pink, and white. Each color had at least two different species photographed, except for yellow and red which had three kinds of flowers photographed.

Multiple different species with different structures were selected to prevent alternative floral traits such as structure from impacting the results of flower visitation frequency. For red, the flowers photographed were Virtuoso Classy Carmine (*Dahlia variabilis*), Vermillionaire (*Cuphea hybrid*), and Fire in the Sky (*Playlist Combination, Sakata*). For orange, the flowers photographed were Cresta Orange (*Tagetes patula*) and Gelato Passion (*Osteospermum hybrid*). For yellow, the flowers photographed were Alumia Yellow (*Tagetes patula*), Heartland Citrus 2025 (*Lantana camara*), and Rising Sun Chestnut Gold (*Rudbeckia hirta*). For pink, the flowers photographed were Dahlegria Magenta Bicolor (*Dahlia xhybrida*) and Empress Sun Pink 2025 (*Verbena xhydrida*). For purple, the flowers photographed were Scala Purple Bird 2025 (*Scaevola aemula*) and Primavera (*Lavansula stoechas*). For white, the flowers photographed were Grace White (*Pelargonium interspecific*) and Unplugged White (*Salvia hybrid*). For blue, the flowers photographed were Salgoon Lake Como (*Salvia laterspecific hybrid*) and Unplugged So Blue (*Salvia hybrid*). Data was collected on June 28th and June 29th of 2024 from about 1:30 pm to 5:30 pm. Temperature and weather were consistent on both days, ranging from about thirty to thirty-two degrees Celsius with clear skies and wind speeds of about seventeen to nineteen kilometers per hour. It is critical to keep environmental factors like temperature, altitude, light, precipitation, and wind relatively consistent in this study. This is because all of these factors impact foraging behaviors and general behaviors of floral visitors and could skew the results. Temperature impacts floral visitors by decreasing their foraging efficiency (Faheem et al., 2004). The cooler it is, the more energetically expensive it is to forage, and the more floral visits and higher-quality nutrition are necessary for foraging to be worth it (Faheem et al., 2004). Various species of floral visitors are more effective at various altitudes (Faheem et al., 2004). Light impacts the activity levels of floral visitors, as they are often more active at specific times of the day such as during the day (diurnal), at night (nocturnal), at dusk and dawn (crepuscular), and in the morning (matinal). Wind ranging from speeds of twenty-four to thirty-four kilometers per hour has been observed to impact the foraging of bees negatively (Faheem et al., 2004). Rain impacts pollinators by reducing foraging rates. Some bumble bees will keep foraging in light rain; however, it does reduce foraging rates, and many floral visitors take shelter when faced with precipitation (Faheem et al., 2004). Pollinators can adapt to windy conditions more easily if they have strong wings, or if plants have short and strong stems.

Initially, pictures were intended to be taken for forty-five minutes in intervals of fifteen seconds using the intervalometers, but after a test run under these parameters, the aforementioned method of data collection was used. It was necessary to adjust the method of data collection because taking photographs for forty-five minutes at intervals of fifteen seconds proved to be too long of a period with too long of an interval to capture any floral visitors effectively in photographs.

After data was collected, it was compiled into folders separating the different species and colors. We ran the photos through code that subtracted the content of a photograph from the content of the previous photograph in an attempt to emphasize any changes in the frame of the photograph and make it easier to see if a floral visitor was in the picture (Figure 2 and Figure 3). This proved to be quite helpful during data processing, which involved going through roughly fourteen thousand photographs to observe the type and frequency of floral visitors to different colored flowers.

Figure 2. Picture of Heartland Citrus 2025 *Lantana camara* with a bee next to the subtracted image to demonstrate how the bee appears from image to image. The bee is in the bottom left corner of the colored image and is a blue and yellow silhouette in the subtracted image. The yellow spot on the subtracted image is likely from changes in the lighting or wind that caused the flower to move between images.



Figure 3. Picture of Cresta Orange *Tagetes patula* with a bee and a wasp next to the subtracted image to demonstrate how floral visitors appear in the different images. When observed closely, the outlines of the bee and wasp are emphasized on the right in a blue color.



It is important to note that this method of highlighting floral visitors in the photographs had flaws. For instance, the floral visitors only showed up clearly in the subtracted image if there was not a gust of wind, change in lighting, or other forms of interference/changes in the frame of the photograph between the two images that were subtracted from each other.

Data processing consisted of going through every picture and pictures that were subtracted from each other (totaling about fourteen thousand images) and observing and recording each observation of a floral visitor in an Excel spreadsheet. The number of floral visitors in the categories of bees, spiders, beetles, butterflies, flies, ants, and wasps were all recorded in the spreadsheet and subsequently analyzed to determine if there were trends in the color preferences of flower visitors. Hornets and birds were also included in the sheet used for data collection, but none were observed throughout the data collection and data analysis processes and were not added to the analysis for the purpose of clarity.

After data collection and processing, it was analyzed through Excel graphs to find any trends in floral visitor type and color preference. The data was organized and analyzed using charts comparing the total type of floral visitors, the total number of visitors to each flower color, which floral visitors visited which colored flowers, and which colored flowers were visited by which species.

## Results

Through analysis of collected data through Excel about floral visitation frequency to certain colored flowers, I observed that overall, blue flowers tended to have the highest frequency of visitation of floral visitors with two hundred eighty-one visits, followed by purple flowers with one hundred fifty-five visits (Figure 4). Yellow flowers were the next most frequently visited with one hundred forty-nine visits, red following that with one hundred thirty visits, pink following red with one hundred seventeen visits, orange following pink with seventy-eight visits, and white flowers having the least number of floral visitors with thirty-eight visits (Figure 4). Bees were the most frequent pollinator observed with one thousand nine hundred fifteen total visits, with wasps being the next most frequent with one hundred three visits, and flies being the third most frequent floral visitors with seventy-seven visits (Figure 5). Unidentified visitors followed flies in terms of visit frequency with fifty-two visits, butterflies after flies had forty-two visits, spiders had seven visits, ants had six visits, and beetles had the least number of visits at two (Figure 5). It is important to note that these are not the standardized results to visitors per 1000 images. The same number of pictures were not taken for each flower and flower color due to issues with SD cards storage, overheating, and batteries dying. To ensure that the results seen were not due to there being fewer or greater pictures of certain flower colors, I standardized the results to show visitors per one thousand images. After these calculations, I found that blue flowers had 171.55 visitors per one thousand images, purple flowers had 76.09 visitors per one thousand images, pink had 67.47 visitors per one thousand images, red had 58.3 visitors per one thousand images, yellow had 53.87 visitors per one thousand images, orange has 43.24 visitors per one thousand images, and white has 26.06 visitors per one thousand images (Figure 8). This shows that the main findings, that blue and purple flowers were the most visited and that orange and white flowers were the least visited, as well as that red flowers were the fourth most visited were not biased, but it did show that the results for pink and yellow flowers were biased. Pink flowers were actually the third most visited, while yellow flowers were the fifth most visited.

Bees tended to prefer blue flowers and visited them two hundred eighty times, with one hundred forty-four visits to purple flowers, one hundred twelve visits to pink flowers, seventy-two visits to red flowers, twenty-five visits to yellow flowers, sixteen visits to white flowers, and ten visits to orange flowers (Figure 6). Spiders were most commonly seen visiting purple flowers

(five visits), with pink flowers following (two visits) (Figure 6). Spiders were not observed visiting any other color of flower (Figure 6). Beetles were only observed once each on purple and red flowers and not on any other flowers (Figure 6). Butterflies most commonly visited yellow flowers with thirty-nine visits, with white being the next most frequently visited with two visits, and blue flowers being visited once (Figure 6). Butterflies were not observed visiting any other flower colors (Figure 6). Flies were observed visiting yellow flowers twenty-five times, red flowers twenty times, white flowers fifteen times, orange flowers fourteen times, purple flowers two times, and pink flowers one time (Figure 6). Flies were not observed visiting blue flowers (Figure 6). Ants were observed visiting red flowers four times and orange flowers two times, with no other visits recorded (Figure 6). Wasps visited orange flowers fifty-one times, red flowers twenty-six times, yellow flowers twenty-two times, white flowers three times, and pink flowers one time (Figure 6). Unidentifiable/unknown floral visitors visited yellow flowers thirty-eight times, red flowers seven times, purple flowers three times, white flowers two times, and orange and pink flowers one time each with no visits to blue flowers recorded (Figure 6). This could be attributed to framing and focus differences between the photographs of varying flower colors. The yellow flower pictures were blurrier and far away at times than the rest of the flower color pictures.

Bees were the primary visitors of red, pink, purple, blue, and white flowers with seventy-two visits to red flowers, one hundred twelve visits to pink flowers, one hundred forty-four visits to purple flowers, two hundred eighty visits to blue flowers, and sixteen visits to white flowers (Figure 7). Wasps were the primary visitors to orange flowers with fifty-one visits (Figure 7). Butterflies were the primary visitors of yellow flowers with thirty-nine visits (Figure 7). After bees, wasps were the most frequent floral visitors for red flowers with twenty-six visits, flies were next with twenty visits, unknown visitors with seven visits, ants with four visits, and beetles with one visit (Figure 7). After wasps, the most common floral visitors for orange flowers were flies with fourteen visits, and bees with ten visits (Figure 7). After butterflies, the most common floral visitors for yellow flowers were bees and flies with twenty-five visits each, then wasps with twenty-two visits, and thirty-eight unknown visitors (Figure 7). After bees, the most frequent floral visitors of pink flowers were spiders with two visits and flies, ants, and unknown visitors visiting one time each (Figure 7). After bees, purple flowers were most frequently visited by spiders with five visits, three unknown floral visitors, two fly visitors, and one beetle visitor

(Figure 7). After bees, the most common visitors to white flowers were flies with fifteen visits, wasps with three visits, and butterflies and unknown visitors with two visits each (Figure 7). For blue flowers, only one butterfly visit was observed alongside the bee visits (Figure 7).

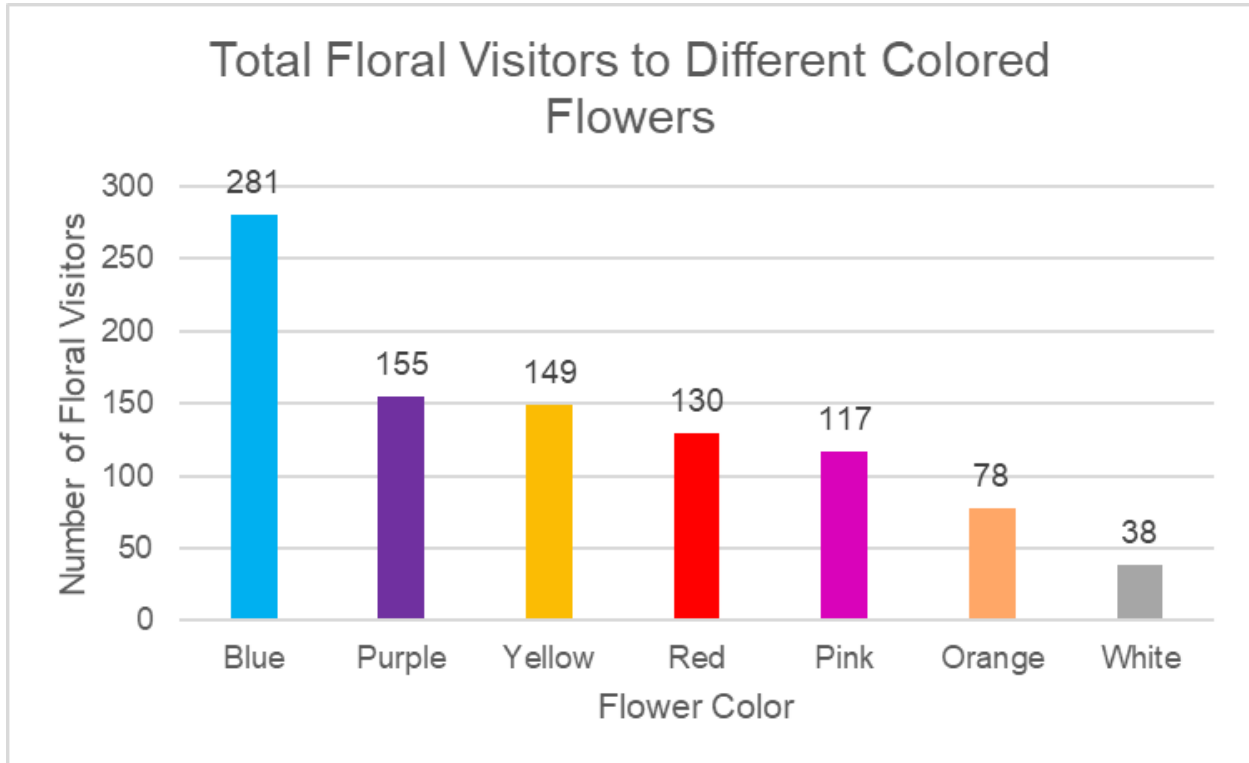


Figure 4. Number of floral visitors visiting red, orange, yellow, pink, purple, white, and blue flowers. Blue flowers were the most frequently visited, with purple flowers next, and yellow following purple. Red flowers were the next most frequently visited, followed by pink, then orange, with white flowers having the least number of floral visitors.

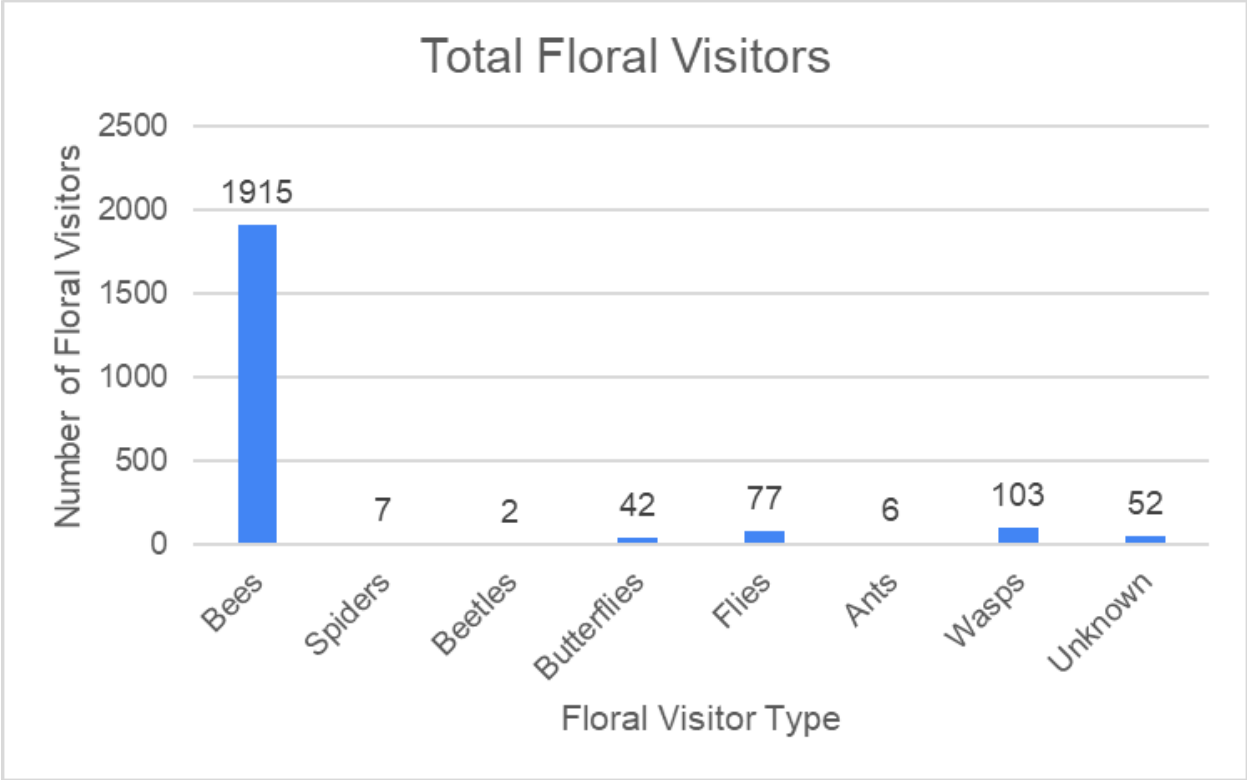


Figure 5. The total number of visits by different floral visitors, including bees, spiders, beetles, butterflies, flies, ants, wasps, and unknown floral visitors that were unable to be identified due to the image being blurry. Bees were the most common species of floral visitor by far, followed by wasps, flies, unknown visitors, butterflies, spiders, and ants, with beetles as the least common species of floral visitor.

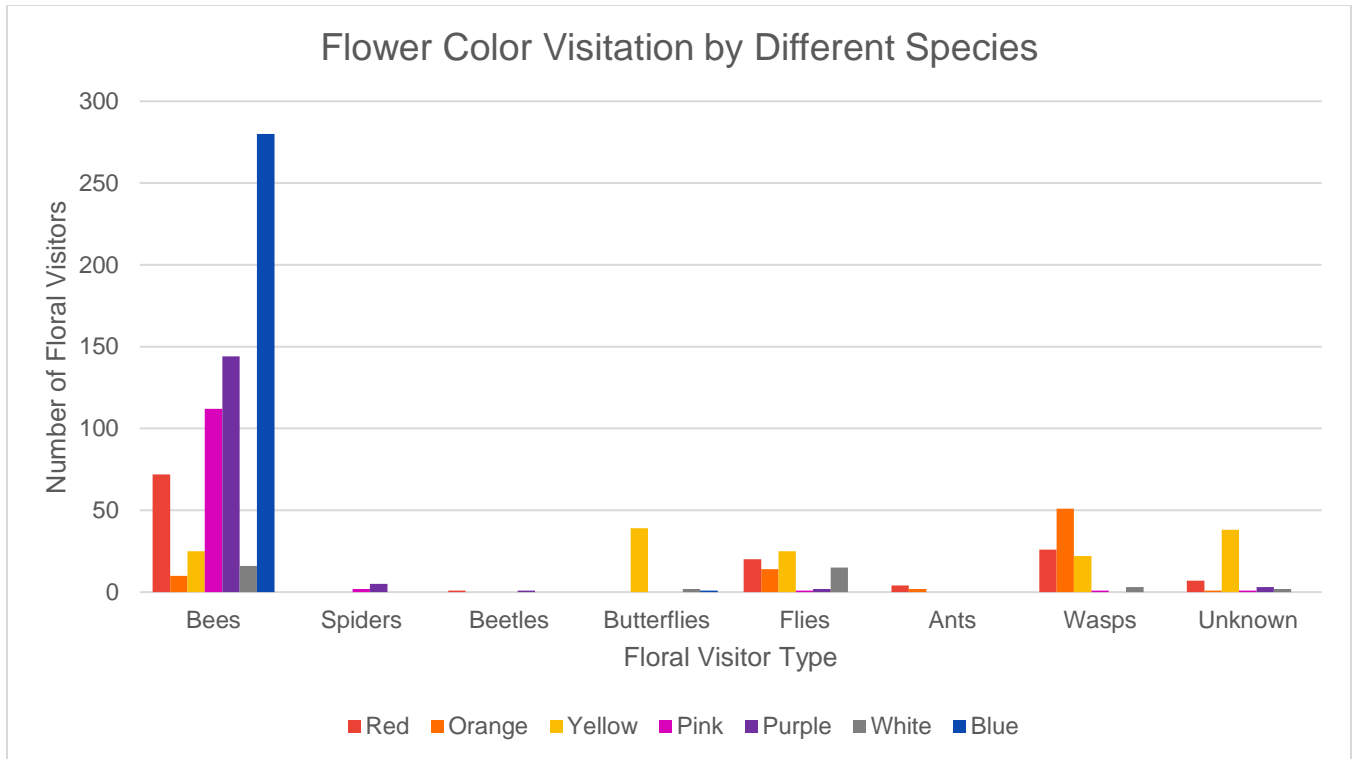


Figure 6. Flower colors most frequently visited by each type of floral visitor. Bees primarily visited blue flowers, with purples, pink, red, yellow, orange, and white following respectively. Spiders tended to visit purple flowers, but that could be explained by the structure and form of the plant being more appealing as opposed to the color. Beetles and ants didn't have many visits. Butterflies preferred yellow flowers with very few visits to white flowers and no visits to other flowers. Flies preferred yellow, red, white, and orange flowers with a few visits to purple flowers and none to pink or blue flowers. Ants were observed visiting only red and orange flowers. Wasps preferred orange, red, then yellow flowers with few visits to pink and white flowers and no visits to blue or purple flowers. Unknown visitors were primarily seen at yellow flowers and some red, purple, white, and orange flowers but not at blue flowers.

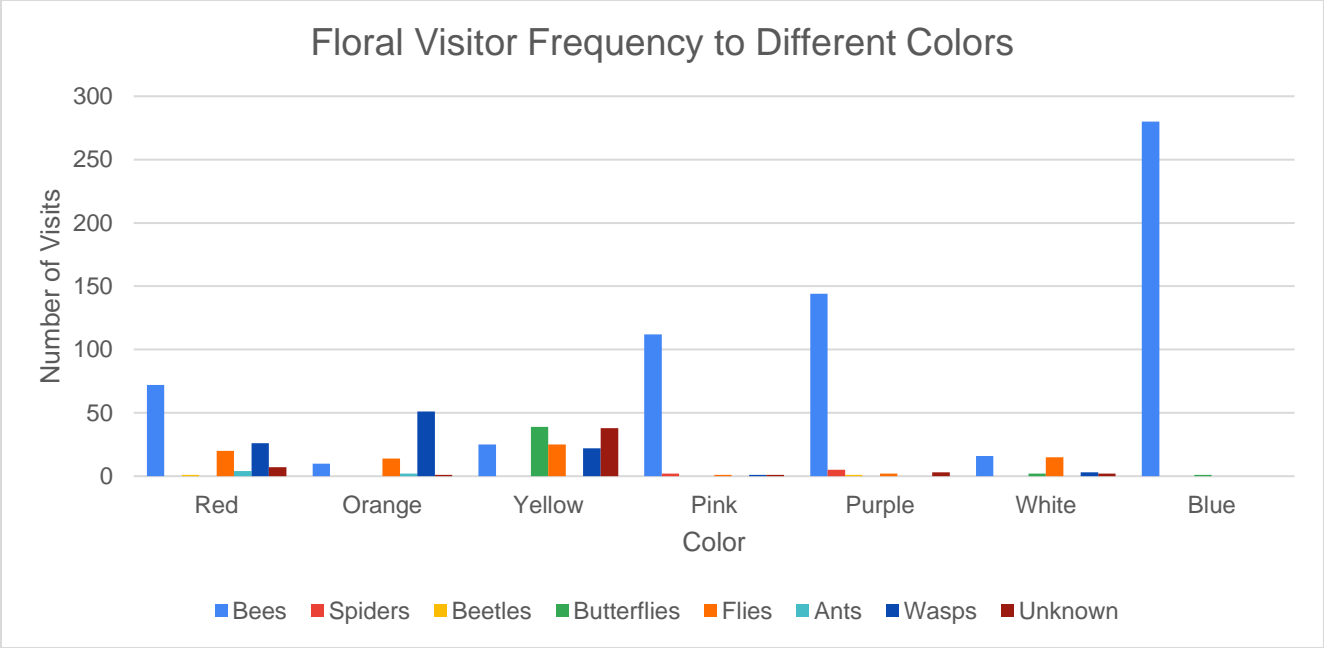


Figure 7. Type of floral visitor visiting red, orange, yellow, pink, purple, white, and blue flowers. Bees were the primary visitors of blue, purple, white, pink, and red flowers. Wasps were the primary visitors to orange flowers. Butterflies were the primary visitors to yellow flowers.

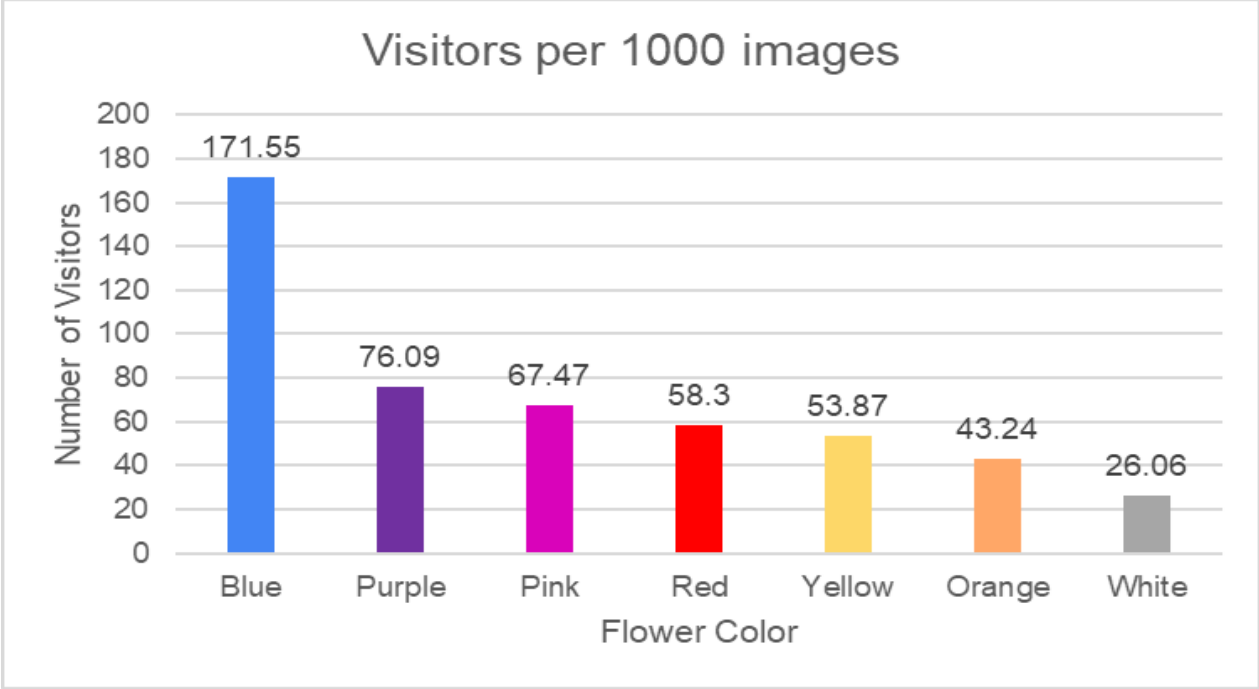


Figure 8. Visitors per one thousand photographs for blue, purple, pink, red, yellow, orange, and white flowers.

## Discussion

The results demonstrated that bees were the most common floral visitors of most flower colors, with the exception of wasps being the most common floral visitors of orange flowers and butterflies being the most common floral visitors of yellow flowers. Overall, blue flowers received the most visitors, followed by purple, then yellow, then red flowers. The least frequently visited flower color was white, then orange, then pink. Previous research has suggested that invasive plants with similar floral traits to native species have a more significant impact on native species than other invasive species (Gibson et al., 2012). This information coupled with the results of this study suggests that floral visitation and competition for pollinators would have a greater impact on native flowers that are blue and pollinated by bees, at least in the specific area of Northern Colorado. This also suggests that if homeowners want to support pollinators in their own gardens, they should plant flowers that are blue, purple, and pink since they are more popular among pollinators and thus more likely for floral visitors to depend on them. This study does show that bees are a significant part of floral visitation, but it is important to recognize the importance of other floral visitors as well as they make up a large part of floral visitation and support plants in pollination. Between one quarter and one half of flower visitation in the world is carried out by insects that are not bees, and about 39% of floral visitation to crops are insects that are not bees (Howard & Symonds, 2023).

While the results suggest some trends in color and floral visitation frequency, it is important to acknowledge potential issues and limitations within the study, as well as additional previous research and context, and future direction. The study was capable of observing slight trends in color preference in floral visitors, but there are ways methods could be improved to achieve more accurate results if more time, technology, and money were able to be put into a subsequent study. One of the primary issues with this study was the amount of data collected. Ideally, more data being collected would have allowed for thorough statistical analysis as opposed to simple comparisons in visitation frequency, and thus more concrete and informative results. Unfortunately, the significant amount of data collection required for this would require more time and money than I have access to. Improved technology to isolate color as a trait impacting floral visitors would be helpful, as in the natural environment I carried the study out there are multiple factors that might have had an impact on the frequency of floral visitation in

addition to color. The benefit of the method used to carry out this study is that it observed the frequency of floral visitors in a more natural environment. With this study specifically, issues of time, technology, and money were significant limitations. Time was a limitation for this study because there was only about a year between the planning, data collection, and execution. There was not enough time to resample over multiple years or even over multiple days, let alone to analyze the sheer quantity of data that would result from expanded data collections. Technology was a limitation of this study because while there are ways to isolate color as a trait and observe floral visitors' reactions to that specific trait, creating models or genetically and physically altering plants is more time-consuming and expensive than this study has the scope for. Finally, finances were a significant constraint in this study. Cameras and intervalometers were able to be procured and used for data collection, but the technology needed to take more reliable measurements and data, as well as alter flowers in a way to isolate color as a trait would be extremely expensive, far more expensive than the scope of this study could encompass.

One potential issue with the results of this study is that floral visitors may visit more flowers in less time when there are plants with high flower density, which could cause an overestimation of the impact of color on floral visitation. Other previous studies have observed that invasive plants become integrated into the ecosystem, which means that total flower abundance overall, including natives and invasives, has an impact on overall visitation to flowers, not just native flowers (Goodell & Parker, 2017).

There are some limitations that are important to discuss in this study in addition to the issues with the process of subtracting an image from the previous one to distinguish floral visitors more easily. These include issues with data collection, data processing, and data analysis. Issues with the cameras and data collection that I ran into include issues with the camera batteries, SD card storage, overheating, and photograph quality inconsistency. The camera batteries were all different and lasted different amounts of time, so it was difficult to manage all of the batteries, and they did occasionally die and stop data collection temporarily before all pictures in the thirty minutes of two-second intervals could be captured. This raises some concerns regarding the consistency and reliability of data. Similar to camera battery issues, it was difficult to manage SD cards of varying degrees of storage availability and ensure that data collection did not stop temporarily due to SD cards being at capacity and no more pictures being able to be taken. This causes similar issues of reliability and consistency to the issues with

camera batteries. Another technical issue that I ran into with the cameras was their overheating. I had umbrella attachments for two of the cameras in an attempt to keep them from overheating, but taking pictures for several hours in a row in two-second intervals in the summer sun caused some of the cameras to overheat, which also paused data collection and could have caused reliability and consistency issues. Camera setup and framing might also be a cause of consistency and reliability issues with the data as it is difficult to set the camera up to capture a similar frame for different sizes of plants. If a camera was set up further away, more floral visitors might have been hard to distinguish and classified as “unknown” or more floral visitors would have been recorded in a larger area. A camera set up closer, however, might have fewer floral visitors categorized as “unknown” if the closeness caused them to appear more clearly and might have fewer floral visitors recorded in a smaller area.

Potential issues regarding data processing are primarily human error and lack of standardization. Human error could exist in this study in the form of missed data points, fatigue, bias, and inconsistent evaluation/variation in judgment. Manually going through large amounts of data in the form of identification from pictures is a difficult task. It is possible that when going through images some floral visitors were missed or misidentified, and it is important to acknowledge the possibility of fatigue and bias when discussing the limitations of manual data processing by humans.

While this study focuses on color as a method of attracting floral visitors, there are many other characteristics such as floral density, shape, and symmetry that could have an impact on the frequency of visitation (Gibson et al., 2012). As such, one of the primary issues to acknowledge about this study is the challenging nature of determining whether floral visitors are responding to flower color or if they are responding to the other previously mentioned floral traits of floral density, shape, symmetry, smell, length, and rewards. In previous studies, this has been done by creating model flowers, genetically altering flowers, and physically altering flowers (Campbell et al., 2010). These methods have pros and cons, the most notable being that all of these methods do not emulate a natural environment, making the result difficult to directly compare to the frequency of floral visitation and behavior of visitors in a natural environment. This study focused exclusively on visitation in a natural environment with the interest of not overcomplicating the study by trying to identify when pollination was occurring or going outside the scope of my technological, temporal, and financial capabilities.

Color is also not always a consistent trait to measure, as it can appear differently to different species and under varying lighting conditions and different amounts of background contrast. Lighting can vary based on the time of day, the season, the year, and the surrounding environment. It is an incredibly variable factor in how color is perceived. An example of this is a flower looking pink from a pink flower being under a white light or a white flower being under pink lighting (Chittka et al., 2014). An adaptation to this issue with lighting variation is called color constancy, which is where colors tend to look the same under varying lighting (Chittka et al., 2014). Another type of constancy that pollinators demonstrate, flower constancy, is the tendency to limit visits to a handful of flower types and colors, which also could have an impact on results. Despite the potential of this flower constancy to reduce visitor frequency, it is important to flowers because it can reduce the amount of pollen wasted (Erickson & Pessoa, 2022).

Overall, flower color impact on floral visitation frequency is an understudied topic with limited and varying results. Previous research has found that significant evidence of pollinator-mediated selection of flowers based on traits like color is extremely limited (Trunschke et al., 2021). Study results have also varied based on the geographic locations studied and the species studied. One study showed a positive relationship between the color of snapdragons and floral visitor frequency (Erickson & Pessoa, 2022) and another showed color preferences of syrphid flies in alpine New Zealand (Campbell et al., 2010), but another study in a Malaysian forest found that characteristics like pollen and nectar, shape, and flowering had an impact but color did not (Erickson & Pessoa, 2022). The lack of consistency in previous research could be attributed to the fact that the analysis of colors is done through human vision, not pollinator or insect vision, which could lead to inconsistencies in how flower colors are differentiated in flower coloration research that is focusing on how other organisms see flowers and color. Another reason why results might be limited and varying is that flower color might only impact floral visitor frequency in specific scenarios (Erickson & Pessoa, 2022). Emphasis on pollinator impact and color preferences on plants could also be attributed to the fact that pollination studies are more frequent and popular among literature about flower colors than studies on the contrary, which could be skewing the perceived influence that pollinators have on flower coloration overall (Erickson & Pessoa, 2022).

While this study focuses on color as a means of attracting floral visitors, it is important to acknowledge that there are scenarios in which color is potentially used as a way of reducing floral visitors of certain species. For example, bird-pollinated red and yellow flowers have been observed reflecting longer wavelengths than bees are capable of seeing, making them difficult to see and preventing them from collecting the nectar and pollen the plant is using primarily to attract birds (Erickson & Pessoa, 2022).

All in all, with varying results and limitations regarding studies examining floral color preferences and the subsequent effect on floral visitation frequency, more extensive research is necessary. More research is necessary to understand the relationship between the trait of flower color and floral visitors and the impacts that it has on the health of their populations. This is important research to develop and continue because potential impacts of floral visitation frequency changes due to flower color include issues with pollination and evolution, especially in an environment that is becoming increasingly disturbed by human activity. Humans depend on plants and insects to perform many functions in the environment including supporting the environment for cultural and agricultural use, and to protect that use the interactions between flowers and floral visitors need to be understood effectively.

In conclusion, the study faced many issues in terms of consistency, reliability, and replicability. However, it emphasizes the importance of further research into color preference as an impact on the health of flora and floral visitor populations in Colorado to better understand the outcomes and consequences of native flora and floral visitors that are becoming increasingly disturbed by invasive species. With a better understanding of this, residents of Colorado can make educated decisions about what to plant to support the flowers and floral visitors in the ecosystems that they know and love.

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