

Climate Change Causing a Decline in *Bombus occidentalis* by Reducing
Floral Resources

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Independent Study

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Abstract

Concerns of the decline of pollinators and their services have recently been raised. While several hypothesis have been studied, such as the shift of flowering phenology so it no longer overlaps with pollinators and habitat fragmentation, this study investigated the decline of the nectar robbing bumblebee species *Bombus occidentalis* and the flower that it robs, *Ipomopsis aggregata*. *B. occidentalis* depends on *I. aggregata* because it is out-competed by other bumblebee species, of which none visit *I. aggregata*. This study tested the hypothesis that *B. occidentalis* has declined using data that Graham Pyke collected in 1974. I also tested the hypothesis that using the proportion of robbed *I. aggregata* is a strong predictor of the abundance of *B. occidentalis*. I then investigated whether *B. occidentalis* is dependent on both *I. aggregata* and a patch of mixed flowers. Lastly, I investigated whether there is more nectar robbing occurring later in the bloom of *I. aggregata* than early in the bloom. I found that *B. occidentalis* has declined since 1974. Proportion robbed is a strong estimator of bee abundance. In the early part of *I. aggregata*'s bloom the number of flower species in the nearest patch of mixed flowers significantly explained the proportion robbed. Later in the season the distance to the nearest patch of mixed flowers explained the most variation of proportion robbed. *B. occidentalis* is dependent on patches of *I. aggregata* that are close to or mixed with other species of flowers. There was more robbing later in the season and this is most likely because of increased competition for nectar by other species of bees as more workers are produced.

Introduction

The current decline in pollinators and pollinator services have raised alarm. Kearns et al. (1998) have coined the term “pollination crisis,” as reduction in future crop yields are expected. Climate change can disrupt plant-pollinator interactions by shifting the temporal overlap (Memmott et al. 2007). Warmer spring temperatures are predicted to melt the winter’s snow-pack earlier, which will shift the flowering phenology of plants that use melted snow-pack as a cue to flower (Price and Waser 1998). This change in flowering phenology has shown to elongate the growing season and cause increased drought later in the summer season (Miller-Rushing, unpublished data). Miller-Rushing (unpublished data) found that these changes in flowering phenology and soil temperature reduce the total number of flowering plants and will cause gaps in the blooms of sequentially flowering plant species. These changes will have an affect on plant-pollinator interactions and may cause extinctions (Memmott et al. 2007), reducing 17-50% of floral resources for pollinators. Other studies have shown that habitat fragmentation has caused a decline in pollination services (Pauk 2007). In this study I will investigate the effects of climate change on the novel plant-animal interaction between *Ipomopsis aggregata* (Polemoniaceae) and the bumblebee species *Bombus occidentalis*.

I. aggregata is a monocarpic perennial that is pollinated by hummingbirds. *I. aggregata* has declined in the Colorado Rocky Mountains in the last 34 years (Fig 1). Graham Pyke (personal communications) suggests that the decline of *I. aggregata* has been caused by the decline of pollinators. *I. aggregata* is pollinator limited (Caruso 1999, 2000a), and competes with *Castilleja linariaefolia* for pollen (Caruso 2000a, 2000b). If

climate change is causing a decline in pollinators then *I. aggregata* will become increasingly pollinator limited and competition will exacerbate the limitation. It is also been shown that small populations of *I. aggregata* may suffer from inbreeding depression, which will increase susceptibility to environmental stress (Heschel and Paige 1995). Another factor affecting the fitness of *I. aggregata* is nectar robbing by *B. occidentalis*. *B. occidentalis* uses its sharp mandibles to chew a hole in the base of the flower's tubular corolla and then inserts its proboscis to feed on the nectar (Inouye 1980). By doing this *B. occidentalis* avoids the reproductive organs and does not pollinate the flower. The holes are often conspicuous and hummingbirds avoid robbed flowers, which can decrease the flower's fitness by 50% (Irwin and Brody 1998, Irwin and Maloof 2002).

Bombus occidentalis is a bumblebee species that has experienced decline in numbers throughout its ranges and has gone locally extinct in California and parts of the Pacific Northwest (Pyke personal communications, Rao 2007). One hypothesis explaining the widespread decline and local extinction is that pathogens have been introduced from using *B. occidentalis* as an agricultural pollinator (Rao 2007). However, there is no evidence yet to support this hypothesis. This study will investigate another hypothesis that the decline in *B. occidentalis* is related to how its distribution is closely correlated with *I. aggregata* (Pyke 1982).

This alternative explanation is supported by the decline of *I. aggregata* during the last 34-years (Pyke, unpublished data). Graham Pyke (1982) surveyed bumblebee abundances as well as flower phenology and abundances around Rocky Mountain Biological Laboratory in 1974 and 1975 (1982). Reexamining these data in 2007, Miller

and Pyke (unpublished data) found that both *I. aggregata* and *B. occidentalis* have declined since 1974 (Fig. 1 and 2). Surveying in 2008 will make a stronger case that *I. aggregata* has declined in numbers because of climate change and is not merely experiencing annual variation. Pyke (1982) suggests that, although *B. occidentalis* is the most catholic of all the bumblebees in the region, its distribution is limited to *I. aggregata* because it is out-competed by the other non-nectar robbing species of bumblebees. *Bombus occidentalis* depends largely on the flower *I. aggregata* because this flower is not pollinated by bumblebees but rather by hummingbirds. No other bumblebee species visit it (Pyke 1982). Therefore, if *I. aggregata* is experiencing a decline due to warming of the climate then it is likely that *B. occidentalis* will also experience a decline.

Theory has predicted (Gilbert 1978, Cox 1983) that the decline in generalist pollinators will have cascading negative effects on plant specialists that rely on the generalist pollinators. Pauw (2007) has presented empirical evidence supporting the theory. *B. occidentalis* is an ideal species to study specific effects of climate change on plant-pollinator interactions because it has a novel foraging behavior in Western Colorado. While *B. occidentalis* is capable of being the most general in number of flowers it feeds on (Pyke 1982), since it is out competed by other bumblebee species it has a dependent relationship on *I. aggregata*. It is a generalist forced into a specialist situation.

Several hypotheses will be investigated in this study: 1.) *B. occidentalis* is declining regionally in the upper Gunnison Basin because of the decline in the distribution and abundance of *I. aggregata*. 2.) Using the proportion of robbed *I.*

aggregata flowers to estimate the abundance of bees is accurate. 3.) The regional distribution and abundance of *B. occidentalis* is the same as *I. aggregata*, as long as there is a mixture of other flowers to support the bee throughout the season and enable it to reproduce. It is important that there is a mixture of other species because *I. aggregata* will not last through the entire bumblebee season. 4.) That there will be more nectar robbing later in *I. aggregata*'s bloom because there will be increased competition for nectar at that point. If these hypotheses are supported then it would provide evidence that climate change is negatively effecting this plant-pollinator interaction. If they are not then *B. occidentalis* may be experiencing disease and/or parasitism or there is another factor causing its decline.

Methods

This study was done around RMBL in the East River Valley and in the vicinity of Crested Butte, Colorado, USA. In the East River Valley the same plots that Pyke surveyed in 1974 and 1975 were resurveyed. These were along County Road 317 and contained a center point with a ~50m radius. The center point was marked with a GPS unit. The sampling techniques used in this study were the same techniques used to survey in 1974, 1975 and 2007. Bumblebee populations will be estimated from bees per person hour. Flowers were noted and their abundance was estimated on 1-4 scale, with one being sparse and four being widespread and dominant. Phenological level was measured on a 1-5 scale, with 1 being few flowers and almost all buds and 5 being few flowers and almost all fruits. I surveyed the upper sections of the East River transect, while Hannah Beane and Graham Pyke surveyed the lower sections. This data was used to examine the null

hypothesis that the population of *B. occidentalis* has not declined between 1974 and 2008.

In addition to this transect I found patches of *I. aggregata* that were both close to and far away from a patch of mixed flowers. A hundred meter transect north and south of the patch was walked and every other patch of *I. aggregata* was used as a site. The sites were done once a week from the end of June to the beginning of August. These sites were located around RMBL in the East River Valley as well as Washington Gulch, Slate River Valley, Kebler Pass, and Brush Creek. The distance to the nearest patch of mixed flowers was measured, and the area of each patch of *I. aggregata* was found. The density of *I. aggregata* was measured by counting the number of individuals within the patch and dividing it by the area. To obtain a proportion of flowers that have been robbed I counted the holes in every other odd flower in the plot and divided the number of robbed flowers by the total number of flowers observed. The number of flowers in the mixed patch was counted. At most sites the area was observed once later in the season for 30 minutes and any *B. occidentalis* was recorded and bees per person hour was calculated. A linear regression was run with the proportion of robbed flowers being the independent variable and the abundance of bumblebees (bees per person hour) as the dependent variable. If a strong relationship exists between proportion robbed and abundance of bees then I will be justified in using proportion of robbed flowers to estimate bumblebee abundance.

I used paired sample t-test to evaluate bees per person hour between 1974 and 2008. In this test, year was the independent variable and bee abundance was the dependent variable. Another paired samples t-test was run between 2007 and 2008 to test for annual variation. A multi-variant stepwise regression will be run with proportion of

robbed flowers as the dependent variable and distance from a mixed patch of flowers, number of flower species in mixed patch, elevation and density of the patch of *I. aggregata* as independent variables. I predicted that a negative relationship would be generated by the regression. The proportion of robbed flowers would decrease with an increased distance from a mixed patch of flowers. This will reveal that *B. occidentalis* is both dependent on *I. aggregata* to enable it to coexist with other bumblebees in the region that out-compete *B. occidentalis* for other floral resources, and on a mixed flower set that will last through the season so the colony can reproduce. Possible explanations for lack of a relationship include increased competition between bumblebees that could cause *B. occidentalis* to becoming increasingly dependent upon *I. aggregata* or that the distances between *I. aggregata* and the mixed patches of flowers was not great enough to reveal a trend. An ANOVA to test for differences in the proportion of robbing early and late in *I. aggregata*'s bloom. Proportion of robbed flowers will be the dependent variable and time of flowering will be the independent variable.

Results

There is a significant difference in bumblebees per hour between 1974 and 2008 ($t_{72} = 7.654, p < 0.001$). In 1974 122 *B. occidentalis* were captured in the same time frame that bees were captured in 2008. In 2008 only 5 were observed. The mean bees per person hour in 1974 was 5.78, while in 2008 it was 0.1412. Many sites that had *B. occidentalis* in 1974 did not have them in 2008.

Bees per person hour is a strong predictor of the proportion of robbed *I. aggregata* ($R^2 = 0.635, F_{1,13} = 22.57, p < 0.0001$, fig. 3). The y variable is proportion of

robbed flowers and the x variable is bees per person hour. A proportional relationship was generated, $y = 0.797x + 0.064$. Bees per person hour can be found with a known proportion robbed: $x = y/0.797 - 0.08$. The site that had nine bees per person hour had a 0.28 proportion of robbed flowers. Most sites had 3.5-4.5 bees per person hour and ranged from 0.125 to 0.25 in proportion of robbed flowers. Two sites had no bees per person hour and no nectar robbing.

In the first two weeks of the flowering period of *I. aggregata* the number of flowering species in the nearest mixed patch of flowers was found to be marginally significant ($R^2 = 0.069$, $F_{1,56} = 4.091$, $p = 0.048$, fig. 4). As the number of flower species increased in the nearest patch of mixed flowers the proportion of robbed *I. aggregata* increased. In the last three weeks of the flowering period, the only strong predictor was the log of distance (m) to the nearest patch of mixed flowers ($R^2 = 0.436$, $F_{1,56} = 43.312$, $p < 0.001$, fig. 5). A negative relationship was produced between proportion of robbed flowers and distance to nearest patch of mixed flowers. Patches of *I. aggregata* that were close to patches of mixed flowers had a higher proportion of robbing. As the distance to nearest patch of mixed flowers increased, the proportion of robbed *I. aggregata* decreased. In most patches of *I. aggregata* that were further than a Log_{10} (distance (m)) of 1.2 had a 0.0 proportion of robbed flowers. The second two weeks experienced significantly more robbing than the first two weeks ($R^2 = 0.223$, $F_{1,114} = 32.8$, $p < 0.001$, fig. 6). There was no robbing the first week and only a little in the second week. During the third week the amount of nectar robbing quickly rose to 0.20 through 0.50 during the third and fourth weeks.

Discussion

I reject the null hypothesis that there is no difference in the abundance of *B. occidentalis* between 1974 and 2008. Few *B. occidentalis* were found in 2008 and were found only at three sites. The mean of 2008 is much smaller than the mean of 1974. This evidence supports the hypothesis that the population *B. occidentalis* in the Colorado Rocky Mountains is declining (Miller and Pyke, unpublished data) and it is not merely annual variation. Miller (unpublished data) uses *Bombus* as an indicator of climate change near RMBL and found that the elevation of transition between *B. appositus* and *B. kirbyellus* moved up from 0 to over 200 meters and for *B. flavifrons* and *B. sylvicola* the transition zone moved up from 200 to over 400 meters. This is strong evidence that *Bombus* spp. are reacting to the changes in climate. Other factors, such as landscape fragmentation, do not appear to be affecting the population of *B. occidentalis* in the central Colorado Rocky Mountains. This study did not investigate whether pathogens were present and possibly responsible for the decline.

Using the proportion of robbed flowers to estimate the abundance of *B. occidentalis* is supported by my study. The proportion of robbed flowers is proportional to the bees per person hour (Fig. 3). It is often hard to find *B. occidentalis* amongst all the other bumblebee species. Over the years they have become quite rare and require a better method of estimating their population. This method allows a time efficient, strong estimation of abundance. Future studies can utilize this method in the central Colorado Rocky Mountains.

I rejected the null hypothesis that there is no difference in the proportion of robbed flowers between the first half of *I. aggregata*'s bloom and the second. There is

significantly more robbing that is happening in the second half of the bloom (Fig. 6). This is mostly likely caused by competition. The snow melted late this year and the bumblebees were behind in their usually schedule: queens emerged later in the season and therefore produced workers later. Early in *I. aggregata*'s bloom there was a higher ratio of flowers to bees. The workers did not start emerging in force until the second half of *I. aggregata*'s bloom. At this point the ratio of flowers to bees decreased and put additional pressure on *B. occidentalis* to rob flowers. *B. occidentalis* appears to only rob flowers when forced to and pollinates legitimately when it is not. Robbing of *I. aggregata* is likely more energetically costly than legitimate pollination.

The data supports my hypothesis that *B. occidentalis* is dependent on both a wide variety of flower species as well as in *I. aggregata*. During the early part of the bloom only the number of flower species in the nearest mixed patch of flowers significantly explains the proportion of robbed flowers (Fig. 4). This shows that *B. occidentalis* is found where floral diversity is high and is capable of being a generalist. However, as competition increased as more workers appeared, only the distance to the nearest patch of mixed flowers significantly explained the proportion of robbed flowers (Fig 5). Robbing by *B. occidentalis* was much more common in patches of *I. aggregata* that were close to mixes of other flower species. *B. occidentalis* uses both mixed flowers and *I. aggregata* but does not venture far from the mixed flowers in order to find *I. aggregata*. Future studies should monitor whether this is only annual variation or whether it is a pattern that may increase in competition for floral resources increase due to the decline of flowers (Miller-Rushing, unpublished data). There was no way to test if competition had increased between 1974 and 2008.

If competition is increasing since 1974 then increased robbing of *I. aggregata* is probably occurring. Since the robbing can affect the fitness of *I. aggregata* by up to 50%, *B. occidentalis* is creating a positive feedback that is aiding its own decline in the region. By robbing *I. aggregata* it is reducing the future abundance of it. As *B. occidentalis* becomes more dependent on *I. aggregata* if competition between bumblebees occurs then this positive feedback will increase in intensity and reduce the abundance of both species. Future studies should investigate whether competition for nectar by bumblebees has increased over the last decade and whether it continues to increase. Future studies should also investigate the spatial scale at which *I. aggregata* is robbed and to what degree it is causing the decline of *I. aggregata*.

Management for *B. occidentalis* should include management for all types of wildflowers as well as *I. aggregata*. Research should inquire as to the exact nature of the decline of *I. aggregata*, if it is caused by pollen limitation, nectar robbing, other climatic variable, or a combination of these factors.

Figure 1: The Proportion of *Ipomopsis aggregata* in 1974 and 2007 (Graham Pyke)

Distribution of scarlet gilia (*Ipomopsis aggregata*)

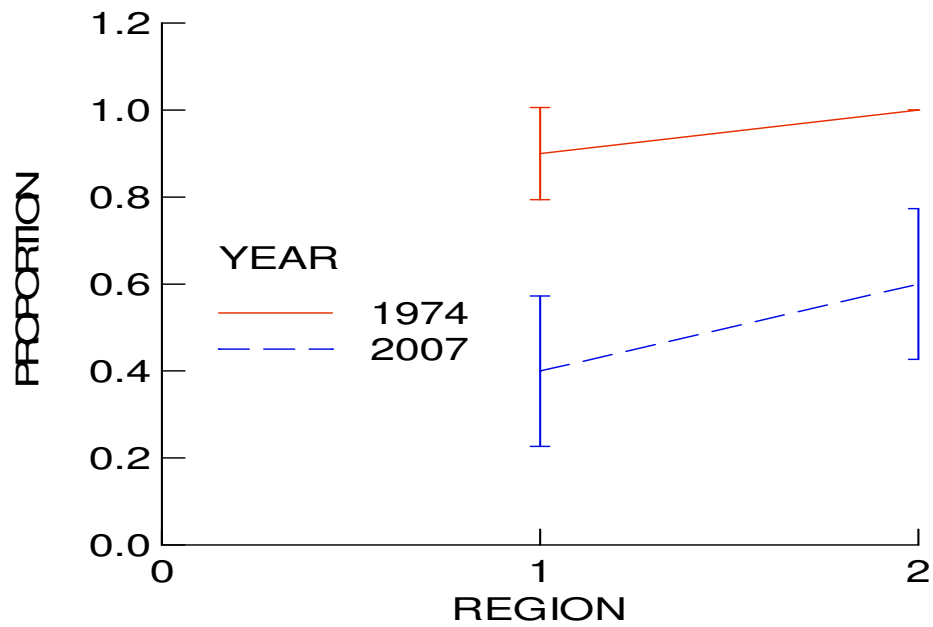


Figure 2: Proportion of *Bombus occidentalis* in 1974 and 2008 (Graham Pyke).

Nectar robber (*B. occidentalis*): Observations

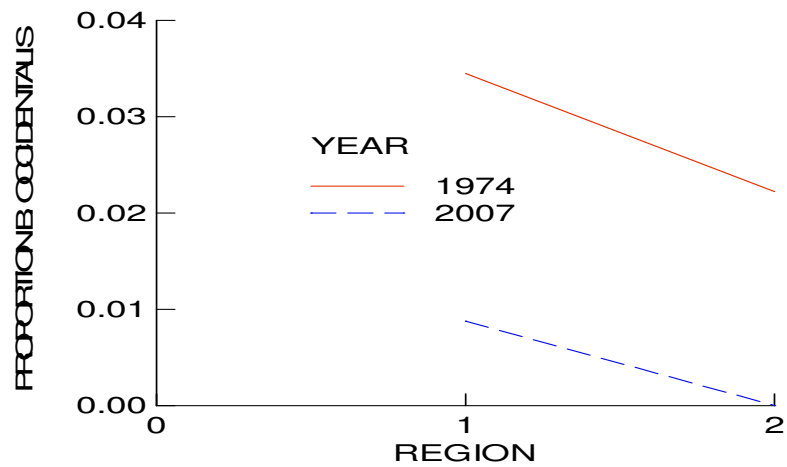


Figure 3: Proportion of Robbed Flowers to Bees per Person Hour

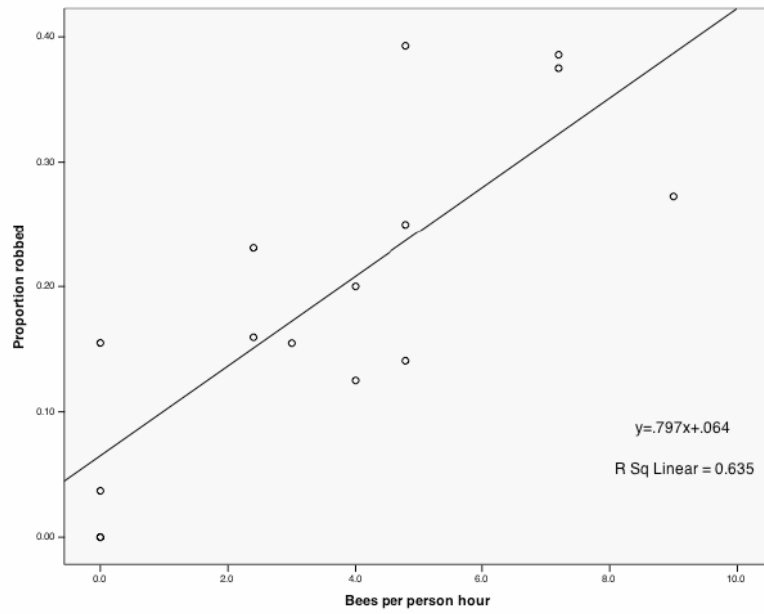


Figure 4: Proportion Robbed Early in *Ipomopsis aggregata*'s bloom vs. the Number of Flower Species in the Nearby Mixed Patch of Flowers

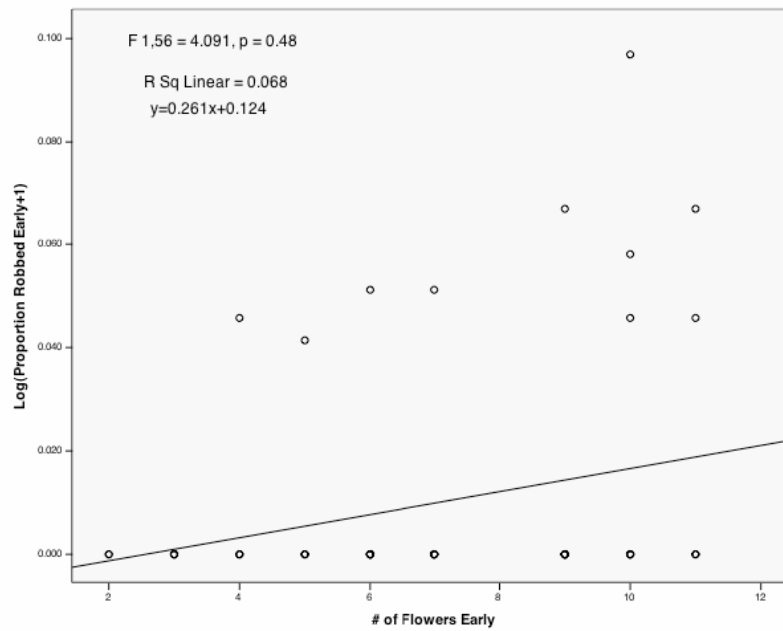


Figure 5: Proportion of Bees Late in *Ipomopsis aggregata*'s Bloom vs. the Distance (m) to the Nearest Patch of Mixed Flowers

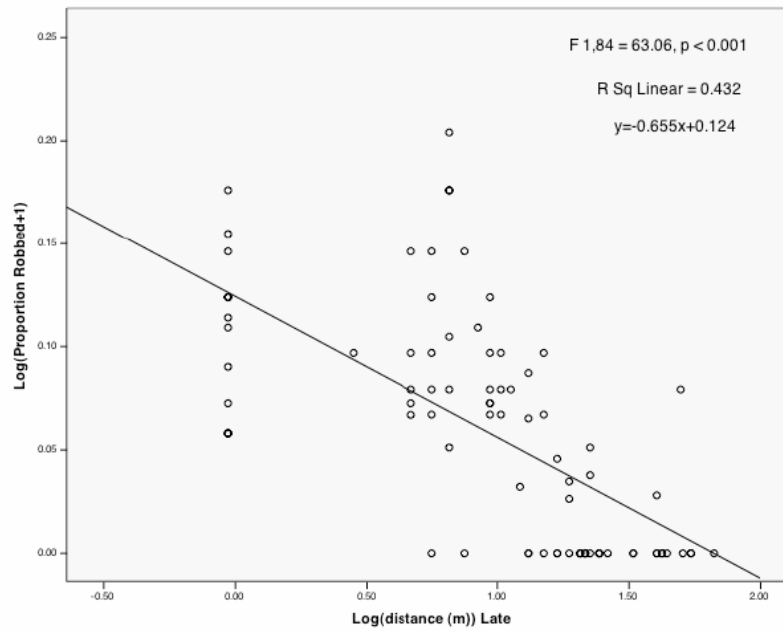
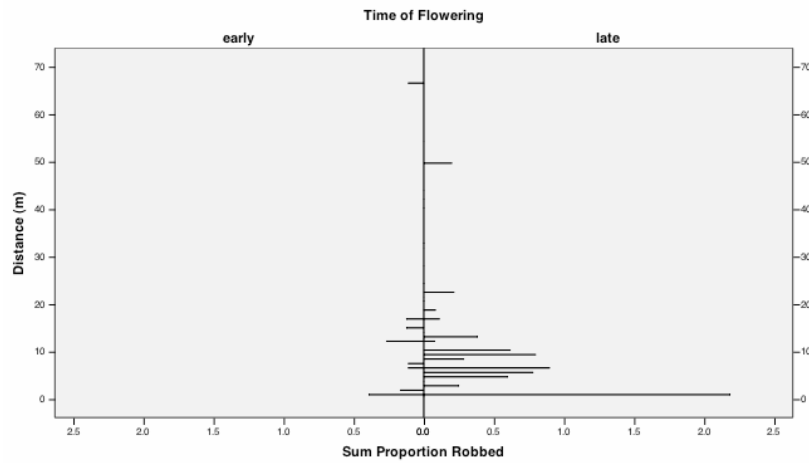


Figure 6: Population Pyramid of the Summed Proportion of Robbed Flowers vs. Distance (m) in both the Early and Late Part of the Flower's Bloom



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