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ABSTRACT

Heliconia monteverdensis is a species of Heliconiaceae that is endemic to the Monteverde cloud forest of Costa Rica. A limited amount of research has been conducted concerning *H. monteverdensis,* therefore, little is known about its life history. In this study, simple observations are reported with regards to its distribution, physical characteristics and interactions with its community. The effect of location and elevation on the fitness, (the ability of the plant to survive and reproduce), of *H. monteverdensis* was also studied. The three locations compared were the Atlantic slope, the Pacific slope and the Ridge in between the two slopes. Five parameters were then used to measure fitness; leaf size and number of flowers, bracts, leaves, and fruits. Elevation and location are found to have significant effects on fitness levels of *H. monteverdensis,* with the plants on the Ridge and at higher elevations sustaining greater fitness. The climate change in Monteverde and its possible effect on *H. monteverdensis* fitness was also studied. It was hypothesized that the increase in temperature and dryness due to climate change would decrease *H, monteverdensis* fitness levels. However, this study suggests that changes in moisture and temperature will not significantly decrease fitness levels of *H. monteverdensis.* However, other indirect effects that climate change might have on *H. monteverdensis* are discussed. The purposes of this study were to develop an understanding of the life history of *H. monteverdensis* and to study the effect of elevation and location on its fitness levels. With this knowledge, the possible affects that the changing climate of Monteverde will have on the future of *H. monteverdensis could* then be suggested.

RESUMEN

Heliconia monteverdensis es una especie de Heliconiaceae que es endémico del bosque nuboso de Monteverde, en Costa Rica. Hay un conocimiento limitado de *H. monteverdensis,* por eso, no se sabe mucho sobre su historia natural. En esta investigación nuestra observaciones simples sobre su distribución, las características físicas y las interacciones con la comunidad. Se estudio también el efecto de su localización y elevación en su adaptabilidad, (la habilidad de la planta para sobrevivir y reproducir). Las tres localizaciones comparadas fueron parte Atlántico, la parte Pacífica y la división entre los dos. Cinco parámetros fueron usados para medir su adaptabilidad; el tamaño de las hojas y el número de flores, frutos, hojas y brácteas. La elevación y localización se identificaron por tener efectos significados en las adaptabilidades de la planta, con las plantas que esta en la división y a las elevaciones mas altas teniendo mejores adaptabilidades.

El cambio climático en Monteverde y los efectos posibles sobre su adaptabilidad de *H, monteverdensis* también fue estudiado. La hipótesis fue que la alta temperatura y la falta de humedad por el cambio climático decrecerá la adaptabilidad de *H. monteverdensis.* Sin embargo, en esta investigación se insinúa que los cambios de humedad y temperatura no decrecerá significativamente la adaptabilidad de *H. monteverdensis.* Pero, hay otras efectos posibles que el cambio climático tiene y fueron discutidos. La intención de esta investigación fue empezar un entendimiento de la historia natural de *H. monteverdensis y* para estudiar los efectos de elevación y localizaciones en su adaptabilidad. Lo mas difícil es predecir el efectos que el cambio climático tendrá en el futuro de *H. monteverdensis.*

INTRODUCTION

Tropical forests are a host to many endemic species and certain habitats are more prone to harboring endemics, such as mountain tops and ridges (Gentry 1986, Lewis 1971). Endemics are described as any species that has a localized distribution (Gentry 1986). Often little is known about endemic species due to their smaller distribution patterns, or obscure locations. This study focuses on *Heliconia monteverdensis*, a species of herbaceous plant that it is endemic to the ridges of the Monteverde cloud forest and of which little is known (K. Masters, personal communication).

The Monteverde cloud forest is a tropical montane forest located in the province of Puntarenas, Costa Rica (Nadkarni et al. 2000). The forest has a relatively narrow altitudinal zone with frequent cloud cover during most of the year. It contains a particularly high number of endemic species and, like *H. monteverdensis*, most occur in the highlands of the Cordillera de Tilarán (Wheelwright 2000). *Heliconia monteverdensis* grow only on the Pacific montane slopes above 1200m, as well as above 700m on the Atlantic montane slopes (Haber 2000). These locations tend to be wetter, cooler, and windier than lower elevations (Cavelier 1989).

Heliconia monteverdensis is one of ten species from the family Heliconiaceae found in the Monteverde forests (Haber 2000). However, only one other species of Heliconiaceae, *Heliconia tortuosa*, grows above 1200m in the montane forests of Monteverde. It is unknown how these two species interact, but both species grow in light gaps and interactions most likely occur. According to Berry & Kress (1991), *H. monteverdensis* are found in light gaps with 20% to 70% shade and *H. tortuosa* grow in gaps with full sun to 70% shade. Therefore, there is an overlap of habitat, but through personal observation it was noted that *H. monteverdensis* often grow in areas with limited amount of sun, more towards the minimum levels of its shade tolerance. *Heliconia tortuosa* inhabited the larger gaps and some shady areas, but seemed to occur in a broader range of light gaps. *Heliconia tortuosa* also were noted to grow in larger patch sizes, consisting at times of over 30 plants at one location, while *H. monteverdensis* was never found to have a patch size of over 10 plants. These two observations, plus the observation that there was a noticeably higher number of *H. tortuosa* plants, reflects that H. tortuosa is most likely the stronger competitor of the two species. However, competition between the two species has never been studied and therefore, it is unknown the effect of one upon the other.

Berry and Kress (1991) report in their book, Heliconiaceae, that *H. monteverdensis* range three to six feet in height and usually have five to nine bracts on their inflorescence. The vegetation is similar in structure to the family Musaceae, due to the vertical orientation of the leaves and long petioles. *Heliconia monteverdensis* bloom from March to July, however, through personal observation it was noted that they do not necessarily flower synchronously. It was noticed that plants on the Atlantic slope seemed to flower before plants on the Pacific slope. The flowers of *H. monteverdensis* are suspected to be pollinated by non-hermit hummingbirds and the fruits dispersed by birds (Stiles 1993). However, the species of hummingbirds and birds are unknown.

Life history traits were used to measure the fitness, (the ability to grow and reproduce), of *H. monteverdensis*. Five different life history parameters dealing with physical characteristics of the plant were analyzed. The parameters all deal with the health of the plant and therefore, the probability of it surviving and reproducing successfully. A possible factor that could affect the fitness of H. monteverdensis is the changing climate in Monteverde. Climatic change is especially harsh on species that occupy restricted habitats or have a narrow habitat requirement, since they are generally more specialized in habitat characteristics (Gentry 1986). A study conducted by Pounds et al. (1999) identifies the changing climate of Monteverde and attributes changes in animal population numbers and ranges to a change in the number of dry days per year. Atmospheric warming is argued to be the presumed reason for the increase in dry days. The temperature increase from global warming would be even greater at higher elevations, such as Monteverde. In Monteverde, trade winds from the Pacific meet the Caribbean slope of the Cordillera de Tilarán and flow upward, cool and form the stratus-stratocumulus cloud base. The increase in temperature results in a higher cloud base and, therefore, is decreasing the amounts of mist and cloud water where the clouds once covered.

In Monteverde, certain animal species that are endemic to the area have presumably become locally extinct due to the change in moisture, such as Monteverde's famous golden toad (*Bufo periglenes*) (Pounds & Crump 1994, Pounds et al. 1999). Climate is often times an important factor in determining the geographic range of species. It is feared that other species endemic to Monteverde are also going to become extinct, or change distribution patterns, as the climate continues to change in the cloud forest (McCarty 2001, Pounds et al. 1999). A limited amount of research has been done on plant species and their possible reaction to a change in climate in the cloud forest. Since a determinant of vegetation types is water stress, it is highly possible that plant species would also be affected in the Monteverde cloud forest due to climate change (McCarty 2001).

One purpose of this study was to focus on *H. monteverdensis* and the possible effect of the changing climate, because it is unknown how the plant will respond to atmospheric warming and the rising cloud layer. Due to the current distribution of *H. monteverdensis*, it was proposed that they would have higher levels of fitness in regions with cooler temperatures and more moisture. Therefore, it was hypothesized that *H. monteverdensis* would be negatively affected by climate change. These moisture level and temperature preferences also support a hypothesis that fitness levels would increase with elevation, as well as, be higher on the Ridge and Atlantic slope. Lastly, purpose of this study was simply to acquire more knowledge on a plant about which very little is known.

METHODS

This study was conducted on the Pacific and Atlantic slopes of the Monteverde cloud forest at an elevation of 1465 m and higher. The methods consisted of collecting information on the location, elevation and fitness of individual *H. monteverdensis* plants. In total, 92 plants were studied; 51 from the Pacific slope, 27 from the Atlantic slope and 13 from the Ridge in between the Pacific and Atlantic slopes. The exact elevation of each individual was recorded using an altimeter. The fitness of the individual was then estimated by counting the number of bracts, flowers, fruits, leaves and the length of the longest leaf. A tape measure was used to measure the length of the leaf to the nearest millimeter. The data were analyzed using a one-way ANOVA test to find if fitness levels were significantly different between the three different sites; Atlantic, Pacific and Ridge. Five different tests were conducted; one for each fitness variable, and a Fisher's PLSD tested pairs of sites for fitness differences. Regression tests were then used for the Pacific slope, to establish if there was a correlation between elevation and any of the five fitness parameters.

RESULTS

Due to lack of documented life history data, this study reports the means, maximums and minimums of the five parameters observed at the three different locations (Table 1). One-way ANOVA tests showed that the effect of location significantly affected three of five fitness characteristics; number of bracts ($p = 0.0068$), flowers ($p = 0.0159$) and leaf size ($p = 0.0005$) (Table 1). In order to establish which of the three locations varied significantly in fitness levels, a Fisher's PLSD test was used. The results showed that fitness levels on the Pacific and Atlantic locations varied significantly from the Ridge for all five parameters. However, the Atlantic and Pacific were not significantly different from each other (Figures 1-3). Therefore, the fitness means were the highest for the Ridge and statistically similar on the Pacific and Atlantic slopes.

The regression analysis used with the Pacific slope showed a significant gradient in fitness for two of the five fitness of parameters (Figure 4,5). The number of flowers ($R^2 = 0.154$) and number of leaves ($R^2 = 0.25$) both increased significantly as elevation increased.

DISCUSSION

Very little is reported about the basic growth history of *H. monteverdensis*. Table 1 reports the results found is this study. However, the numbers of bracts reported in this study disagree with the general number of bracts per plant cited by Berry and Kress (1999). They reported the *H. monteverdensis* usually have 5-9 bracts per plant, but this study found the means of the three locations to be 4-6. An estimate of 5-9 bracts may be true for the Ridge, but it is high for an estimate on the Pacific and Atlantic slopes, and therefore, is high for a general estimate.

A life history trait not mentioned in the literature is the asynchronous flower pattern that was observed. *Heliconia monteverdensis* has both flowers and fruits on the plant simultaneously. Each flower, if pollinated, turns into a fruit. The Atlantic slope tended to have more plants that had finished flowering and turned to fruit. This could cause a discrepancy in the data. Both the Pacific and the Atlantic slopes were reported to have equal fruit means. However, the Pacific had a mean average of two more flowers. If the Pacific plants were still flowering and turning to fruit, they might, therefore, produce more fruit for the entire season then the plants on the Atlantic coast. The asynchrony may have caused the Pacific and Atlantic to have similar fitness levels at this static moment of time, but when in reality, the Pacific would have had higher fitness when the season finished.

Elevation was demonstrated to have a significant effect on two of the five life history traits studied. The regression analysis gives a positive correlation between elevation and the number of flowers and fruits produced. This translates, as elevation increases, so does the fitness of the *H. monteverdensis*. Since higher elevations tend to have wetter, cooler conditions, this would suggest that *H. monteverdensis* prefer these conditions. However, the results from the study concerning the effect of location on fitness do not support this suggestion.

Location was demonstrated to affect the fitness levels and fitness was significantly higher for the Ridge, while the Pacific and Atlantic were lower. However, in order to fully support the hypothesis that moisture and temperature effect fitness levels, H. monteverdensis would need to have similar fitness levels at locations with these conditions. Both the Atlantic slope and the Ridge have similar cool and wet conditions and should, therefore, have similar fitness levels to support the hypothesis. However, this did not occur. Heliconia monteverdensis had significantly different fitness levels for all five fitness parameters between the Ridge and the Atlantic slope. Therefore, moisture and temperature alone cannot be attributed to the differences in the fitness levels. However, this does not mean they do not contribute at all. This study is by no means an exhaustive study of abiotic parameters effecting fitness. The relationship of moisture and temperature could be involved in a more complex relationship then what is identified in this study.

Various other abiotic or biotic conditions could create differences in elevational and locational fitness levels. One abiotic factor that could have an effect is nutrient availability. It could be that the nutrients required for the health of *H. monteverdensis* are present in the Ridge, but lower at the Pacific and Atlantic slopes, especially at lower elevations. Support for this hypothesis is demonstrated in the regression analysis of the Pacific slope. As elevation increased, fitness levels increased as well, perhaps due to higher nutrient availability at higher elevations.

This elevational gradient of fitness could also be due to biotic conditions, such as herbivory. A previous study performed in the Monteverde region focused on herbivory rates at different elevations (Love 1999). If focused on *H. tortuosa* and showed that with an increase in elevation, herbivory rates on H. tortuosa decreased. This could be the true for H. monteverdensis as well, which would be a reason for higher fitness levels at higher elevations.

The observations made concerning moisture and temperature effects on fitness of *H. monteverdensis* do not support the hypothesis that climate change would negatively affect *H.*

monteverdensis. Climate change in Monteverde consists of an increase in temperature and dryness. Neither of these climatic factors was demonstrated to affect the fitness of *H. monteverdensis.* Therefore, it is possible that the change in climate in Monteverde may not affect the ability of *H. monteverdensis* to grow and reproduce.

This data set is limited, however. It does not take into account the lowest elevations of its previously reported range (Haber 2000). These plants may be more susceptible to climate change, since they are at the edge of their range and possibly at the minimum of their abiotic requirements. A slight change in climate could change their abiotic conditions enough that it would decrease fitness.

It also does not take into account the effect moisture levels and temperature may have on the plants life cycle. For example, it is possible the climate change would not affect flower numbers; however, it would affect germination success. Perhaps the plant needs a specific moisture level for successful germination that would not be met with an increase in dryness.

Another possibility is that climate change could affect the plants and animals that interact with *H. monteverdensis.* For example, as discussed previously, *H. tortuosa* are most likely competitors of *H. monteverdensis. Heliconia tortuosa* are found at lower elevations that have less moisture and higher temperatures and are also able to deal with more direct sun. These characteristics could equate to an ability to cope with higher temperatures and less moisture. The more cosmopolitan range of H. *tortuosa* suggests that it would be less effected by with a change in climate than *H. monteverdensis.* This could give *H. tortuosa* enough of a competitive edge to outcompete *H. monteverdensis* for similar habitats. McCarty (2001) supports this idea in his report on climate change by pointing out that there have been previous studies where climate change is linked to altering of interactions, including out competition, between species.

Other interactions that may be affected by climate change are the plant-animal interactions by *H. monteverdensis.* A study by Adam Lynn (2001) documents that there has been a change in distribution of a hummingbird species in the cloud forest of Monteverde. He identifies one species as moving upward in elevational range and attributes the movement to climate change. Other studies have also documented elevational changes in bird distribution and attributed them to climate change (Pounds et al. 1999). Since the pollinators of *H. monteverdensis* are hummingbirds and the dispersers are birds as well, an elevational change in range could have detrimental effects on the success of H. *monteverdensis.*

Another possibility is that climate change could lead to an asynchrony between the *H. monteverdensis and* its pollinators and dispersers (McCarty 2001). Plant and animal interactions depend on appearance of specific foods at critical times. Variations in temperature have been demonstrated to cause changes in flowering and fruiting times. If this were to occur with *H. monteverdensis,* it could also have detrimental effects.

The identification of possible futures for *H. monteverdensis* is important for its preservation. Since *H. monteverdensis* is an endemic species, found nowhere else, if climate change in Monteverde were to affect its ability to survive and reproduce, it could have drastic effects on its future. The life history of *H. monteverdensis* has only begun to be studied and much is still unknown about its interactions within the community. This study offers a beginning for understanding the life history of *H. monteverdensis* and will hopefully allow more studies to stem from it, which in turn will help in its preservation.

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Table 1. *Summary of the five fitness parameters at the three different locations*

Location	Fitness	N	max	min	x	s.d.	F-value	P-value
Pacific	leaf size	51	92	42.5	60.3	11.58		
Atlantic	leaf size	27	78.7	32.5	56.5	10.14	8.333	0.0005
Ridge	leaf size	14	98.2	52.3	71.8	13.1		
Pacific	# bracts	51	9	2	5.2	1.47		
Atlantic	#bracts	27	7	1	4.6	1.15	5.286	0.0068
Ridge	#bracts	14	10	3	6.2	2.01		
Pacific	#flowers	51	23	0	9.1	6.33		
Atlantic	#flowers	27	25	0	7.2	6.71	4.342	0.0159
Ridge	#flowers	14	35	0	13.7	8.19		
Pacific	#leaves	51	6	1	4	1.03		
Atlantic	#leaves	27	5.5	1.5	4.2	0.85	1.109	0.3342
Ridge	#leaves	14	5.5	2	3.7	1.01		
Pacific	# fruit	51	57	0	18.8	13.97		
Atlantic	# fruit	27	49	0	18.7	13.26	0.001	0.9988
Ridge	# fruit	14	55	2	18.9	14.71		

N = total number of plants counted; max = maximum fitness observed; min = minimum fitness observed; x = calculated mean; s.d. = standard deviation

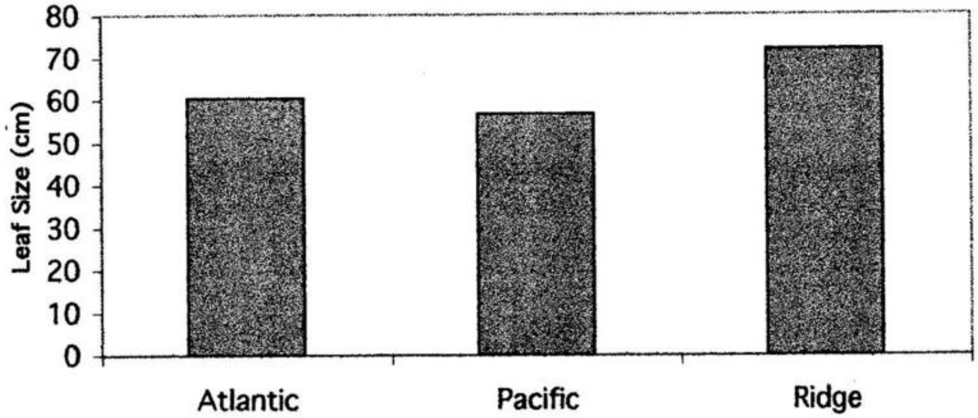

Figure 1. Mean values of leaf size compared against all three sites. Atlantic and Pacific do not vary significantly ($p > 0.05$) however, both have significant differences from the Ridge ($p < 0.05$)

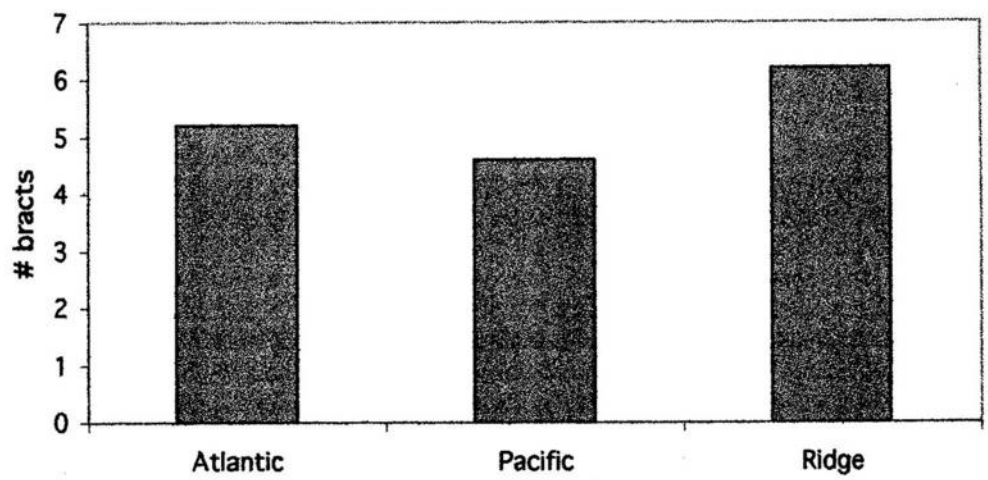

Figure 2. Mean values of number of bracts compared against all three sites. Atlantic and Pacific do not vary significantly ($p > 0.05$) however, both have significant differences from the Ridge ($p < 0.05$)

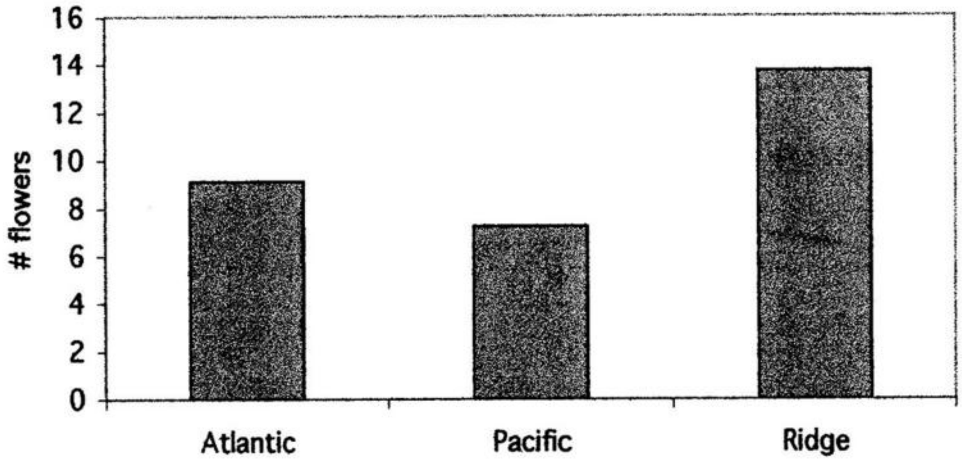

Figure 3. Mean values of number of flowers compared against all three sites. Atlantic and Pacific do not vary significantly ($p > 0.05$), however, both have significant differences form the Ridge ($p < 0.05$)

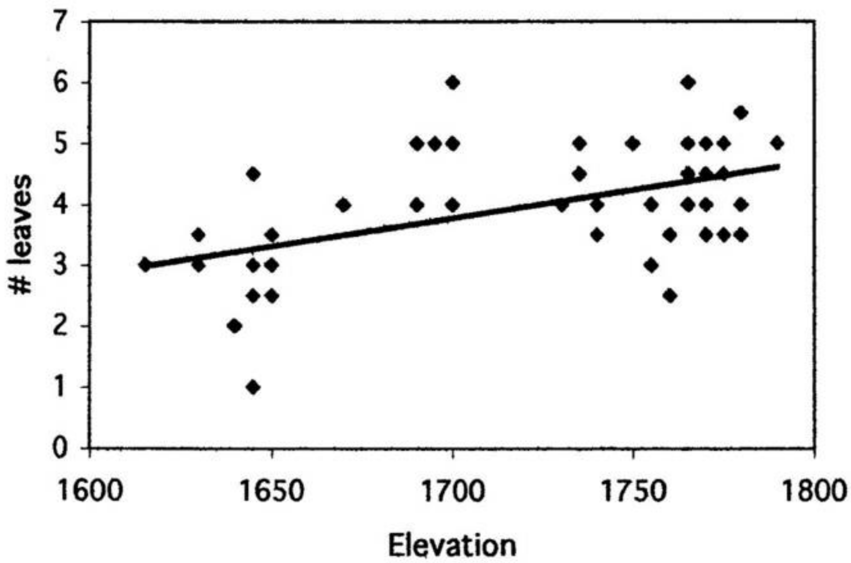

Figure 4. Relation between elevation and number of leaves on the Pacific Slope. (R = .25)

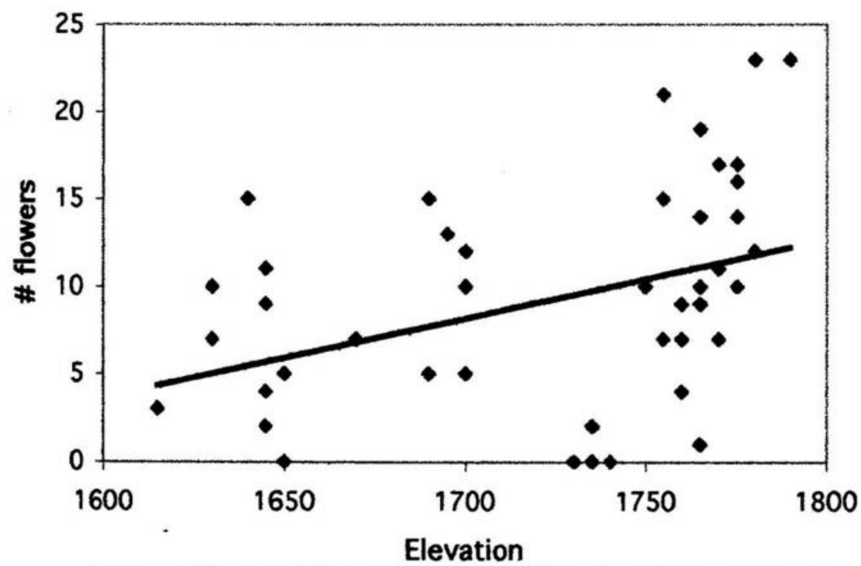

Figure 5. Relation between elevation and number of flowers on the Pacific slope (R = .154)