May 2007

Precipitation variation and its effects on the reproductive success and survival of Lepanthes jimenezii (Orchidaceae)

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Department of Environmental Science, University of Tennessee at Chattanooga

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ABSTRACT

Tropical cloud forests like that found in Monteverde, Costa Rica rely heavily on daily precipitation in the form of mist during the misty-windy and dry seasons. Studies have shown that this mist is occurring less frequently due to climate change (Pounds et al. 1999). This field study examines the effects of increased precipitation frequency, to mimic that found in the 1970s, on a specific member of the Orchidaceae family, *Lepanthes jimenezii* (Pounds et al. 1999). Additionally it compares such effects with those that *L. jimenezii* experiences in current conditions and those that may occur in the future. I divided a group of 83 orchids into three different sample groups. The first was exposed to ambient (and contemporary) conditions, the second to supplemented mist (1970s conditions) and the third to conditions that decreased the frequency of current precipitation (potential future conditions), although not volume. An ANCOVA test of covariance determined that average leaf change was positive only in the supplemented orchids showing that higher reproductive success is more common in orchids with more frequent precipitation ($F = 56.59$, $p < 0.0001$). With 82% mortality in the orchid group with restricted precipitation frequency, 64 % mortality in the ambient orchids, and only 10% mortality in the group of orchids given supplemented mist, results suggest that *L. jimenezii* is negatively impacted by current and future conditions with more variable precipitation, and that the mistier 1970s conditions provide an adequate habitat for the orchids.

RESUMEN

Los bosques tropicales nubosos como los que se encuentran en Monteverde, Costa Rica estos bosques dependen de la precipitación diaria en forma de niebla durante las estación de niebla y viento. Los estudios han demostrado que esta niebla menos ocurre con frecuencia debido al cambio del clima (Pounds et al. 1999). Este estudio examina los efectos de la frecuencia creciente de la precipitación, al imitar lo encontró en los años 70, en un miembro específico de la familia de Orchidaceae, *Lepanthes jimenezii* (Pounds et al. 1999). Compara además tales efectos con los que el *L. jimenezii* experimenta en condiciones actuales y los que puedan ocurrir en el futuro. Dividí un grupo de 83 orquídeas en tres grupos de muestra. El primero fue expuesto a las condiciones ambientales (y contemporáneas), al segundo a la niebla suplida (condiciones de los años 70) y al tercero a las condiciones que disminuyeron la frecuencia de la precipitación actual (condiciones futuras potenciales), aunque no volumen. Una prueba de ANCOVA determinó que el cambio medio de la hoja era positivo solamente en las orquídeas suplidas, el éxito reproductivo es más alto fue en orquídeas con una precipitación más frecuente ($F = 56.59$, $p < 0.0001$). Fue la mortalidad del 82% en el grupo de la orquídea con frecuencia restringida de la precipitación, 64 % la mortalidad en las orquídeas ambiente, y la mortalidad fue solamente 10% en el grupo de orquídeas con niebla, los resultados sugieren que *L. jimenezii* es afectado negativamente por condiciones actuales y futuras con una precipitación más variable, y que las condiciones con más cantidad de niebla de los años 70 proporcionan un hábitat adecuado para las orquídeas.

INTRODUCTION

Since the 1970s, worldwide climate change has been a suspected culprit in the demise of many organisms (Root et al. 2003). Climate studies suggest that the past decade has experienced the hottest temperatures recorded in the past one thousand years (Alley et al. 2007). With rising temperatures come other effects as well, such as changes in precipitation patterns (Pounds et al. 1999). For instance, in Monteverde, Costa Rica, climate change has not affected the amount of dry season precipitation but rather its variability. Days without precipitation are now more common than in the 1970s (before the rapid upswing in global temperatures) and periods with little or no precipitation are longer (Pounds et al. 1999; Masters et. al 2005). This horizontal precipitation affects many of the characteristics in tropical montane cloud forests, and so without regular precipitation, organisms in cloud forests may face endangerment or extinction (Still et al. 1999).

Changes in climate are only expected to worsen in the next two decades. It is predicted that sea surface temperatures will increase 1.4 to 5.8 °C by 2100 (Alley et al. 2007). Because scientists now know that this climate change is at least partially a result of anthropogenic modifications to the environment, it is important to fully understand the consequences that climate change may implicate so that steps can be taken in order to lessen its negative outcomes.

Global climate changes have additionally been shown to affect plant life, often in a negative way (Nadkarni and Solano 2002). A study done by Knapp and colleagues shows that the net photosynthesis of grassland plants decreased by approximately 20% when precipitation variability was increased by 50%, suggesting that present precipitation variability may also be negatively affecting other plant life (Knapp et al. 2002). Certain plants such as epiphytes may be more vulnerable than others to changes in precipitation frequency because they rely heavily on mist as sources of water and nutrients (Walter 1983).

The family Orchidaceae has many epiphytic members that greatly depend on mist as a source of nutrients and water (Chicurel 2000; Masters et al. 2005). In 2001 a study by Lara in Monteverde, shows that even though they have water conservation mechanisms like water storing pseudobulbs, orchids are very sensitive to mist frequency (Lara 2001). They may be important indicators of the state of microclimatic conditions because they are so dependent on specific environmental surroundings (Benzing 1998). Particularly, orchids of the pleurothallid tribe may be vulnerable because these 4,000 species of orchid are miniature and more susceptible to desiccation from extreme conditions. They additionally do not have the water storing pseudobulbs that many orchid species have, also making them more prone to water loss (Dressler 1993). Within this subtribe, the genus *Lepanthes* is additionally valuable for study because species within this genus are extremely small and lack water-storing leaf succulent leaves (Dressler 1993). Monteverde orchids are of particular interest because Monteverde is home to approximately 500 orchid species, which is equal to one third of all orchid species extant in Costa Rica many of which are endemic to the area (Atwood 2000).

This study therefore focuses on a species of *Lepanthes* that is found only in mountainous regions from Mexico to Panama (Dressler 1993). Generally if *Lepanthes jimenezii* is found at lower elevations it is only found in very wet forests. This endemism signifies that it is an important subject of study because if climate changes affect this orchid, it will have a smaller range of habitats in which it can still survive.

Lepanthes jimenezii was studied at 1550 m in elevation on the Pacific slope of Monteverde in order to determine whether or not mist frequency variation significantly affects its reproductive success. From studies mentioned above, I expected that reproductive fitness of the orchids would differ between those exposed to increased and decreased precipitation variability in relation to ambient conditions. Further, I predicted that increasing precipitation variability would negatively affect the reproductive success of the orchids, while decreasing precipitation variability (decreasing dry periods) would positively affect their reproductive success.

MATERIALS AND METHODS

The study was conducted in Monteverde, Costa Rica near the Estación Biológica de Monteverde at an elevation of approximately 1550 m from April 16, 2007 to May 4, 2007. I removed ninety individuals of *L. jimenezii* from atop the continental divide ridge (1800 m) and transplanted these orchids into a small clearing near the Estación Biológica. The study site was chosen because it faced the northeast trade winds ensuring that the orchids were exposed to sufficient precipitation and mist. Orchids were left on their natural substrates in order to avoid putting them under unnecessary stress.

The samples were then divided into three groups. The first group of orchids was hung uncovered and exposed to ambient conditions of precipitation. The second group of orchids was covered with a tent made of clear plastic to prevent moisture from hitting them, and was oriented in the direction of the incoming trade winds and precipitation. This tent structure had openings on both ends, which allowed airflow but restricted precipitation reception. Precipitation falling onto the tent flowed down the walls and into PVC pipes that funneled the water into collection containers. Each day, collected precipitation was measured. After leaving these orchids covered for five days at one time, all water collected during the five-day period was applied at once using a misting bottle. This method ensured that these orchids received the ambient *amount* (within 2 %) of precipitation, and the only variable experiencing change was the *frequency* of this precipitation. After collected water was applied, the orchids were covered for another dry period. The third group of orchids was exposed to ambient conditions of precipitation, but also received supplemented misting, which likened their precipitation input to the precipitation variability occurring before climate change.

Precipitation frequency during the 1970s, before climate change was known to affect mist and rainfall patterns, was more regular, and approximately 85% of days in Monteverde received some form of precipitation (Pounds et al. 1999). Therefore, of the 18 total days of data collection, the orchids received supplemented misting on 15 (85%) of these days. Each individual in this supplemented group received five ml of water daily (with the exception of the three ‘dry days’). In order to account for the small, but additional water that the supplemented orchids received, I applied the same amount to both ambient and tent orchids when natural precipitation occurred. This accounts for the additional 2 % of precipitation that the orchids received.

Each day, precipitation and the minimum and maximum temperatures for the past 24-hour period were recorded. Additionally, the number of new leaves, new flowers, and new fruits was recorded every day, as was number of lost leaves, and whether or not the plant was still alive.

RESULTS

Results of the reproductive success of *L. jimenezii* under different experimental treatments were significant (ANOVA, F = 69.87, p = < 0.0001). No group experience leaf growth except supplementally misted orchids. Also the supplemented orchids experienced only 10% mortality as compared with the ambient and tent orchids which experienced 64% and 82% mortality respectively (Appendix 1).

Average leaf growth and average leaf change were used as parameters for the reproductive success of *L. jimenezii*. Significant differences among treatment type were found to influence leaf change (ANCOVA test of covariance, F = 56.59, p = < 0.0001; Figure 1). Supplemented leaves experienced 0.1 average leaf growth, ambient orchids experienced 0.2 average leaf loss and tent orchids experienced 0.6 average leaf loss.

Additionally, significant results were found relating the starting number of leaves per individual with the change in leaf number. In general the smaller the starting size of the individual (starting number of leaves), the smaller the change in leaf number as well (ANCOVA test of covariance, F = 88.07, p = < 0.0001; Figure 2).

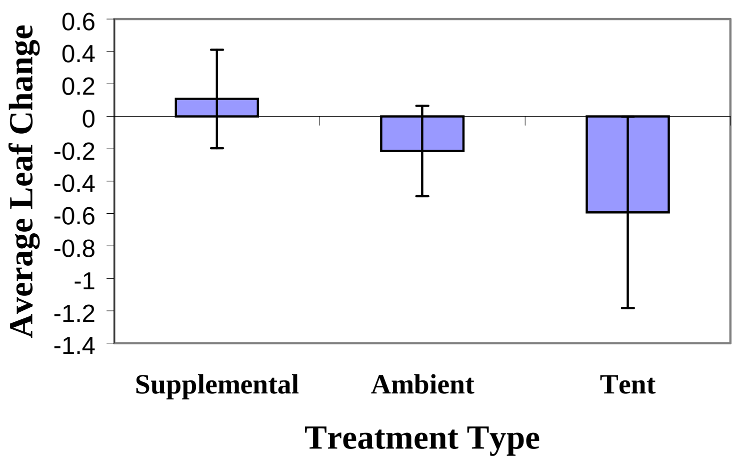

FIGURE 1. Average leaf change in *L. jimenezii* based on treatment type. Averages were taken for each treatment group. The only group experiencing positive leaf change was the supplementally misted group. Std. Err. Bars included.

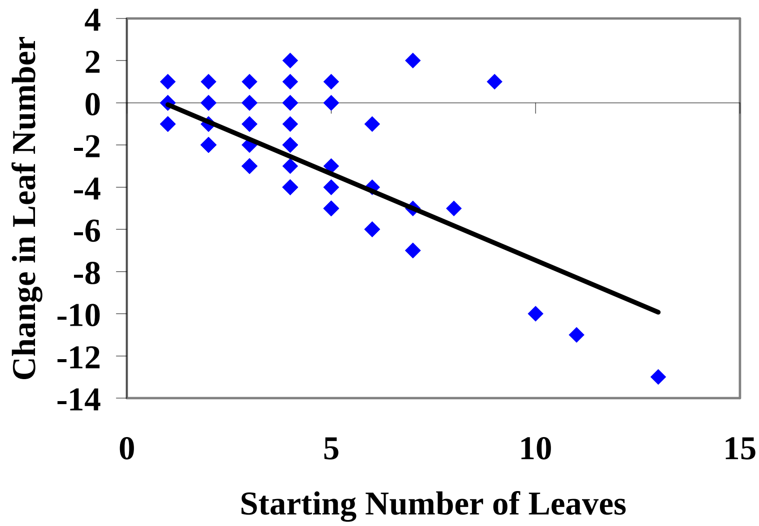

FIGURE 2. Change in leaf number of *L. jimenezii* based on starting leaf number (n = 83 individuals) across three treatment types. The trend here is that leaves with greater starting size will experience greater leaf loss.

The average was taken of the starting leaf number and leaf change for each treatment type (ANCOVA test of covariance, $F = 25.49$, $p = < 0.0001$; Figure 3). Here similar results were found, however, it was found that tent orchids and ambient orchids were most likely to experience leaf change if they were larger in the beginning than the supplemented orchids.

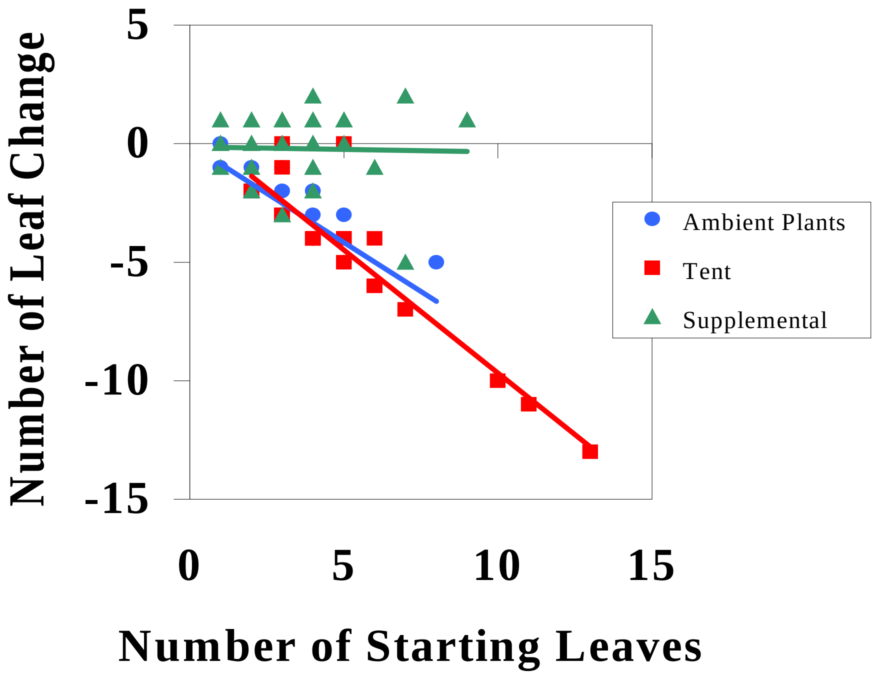

FIGURE 3. Change in leaf number of *L. jimenezii* based on starting leaf number for each treatment type. Blue indicates ambient plants, red indicates plants in tent, green indicates supplemented plants. The trend is that for both ambient and tent plants starting size does affect the amount of leaf change. For supplemented orchids, starting size is not a considerable factor in the amount of leaf change.

Only the supplementally misted group of orchids experienced any new leaf growth. Taking averages for new leaf growth, data was found to be significant (ANCOVA test of covariance, $F = 13.12$, $p = < 0.0001$; Figure 4).

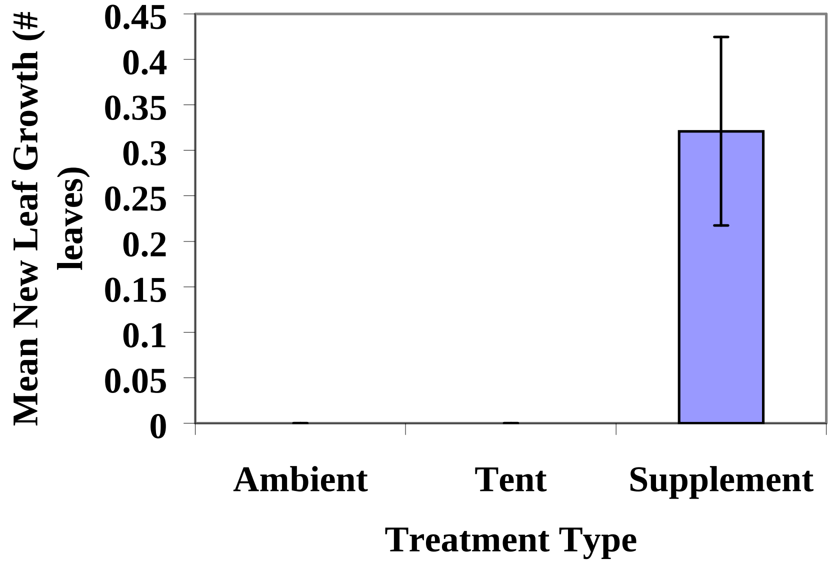

FIGURE 4. New average leaf growth of *L. jimenezii* based on treatment type. The only group to experience leaf growth was supplemented. Std. err. bar included.

Data relating the starting size of all individuals to their new leaf growth were found to have a clear trend but were not significant. (ANCOVA test of covariance, $F = 3.913$, $p = 0.0515$; Figure 5).

Examining the interaction between starting size and treatment type and how this cross action might affect new leaf growth, significant differences were again discovered (ANCOVA test of covariance, $F = 4.235$, $p = 0 .018$; Figure 6.)

Mortality was significantly higher in the tent group of orchids (those experiencing increased dry periods) and in the ambient group of orchids than in the group that received supplemented misting (χ^2 goodness of fit test = 27.89; $\chi^2 = 5.991$, DF = 1).

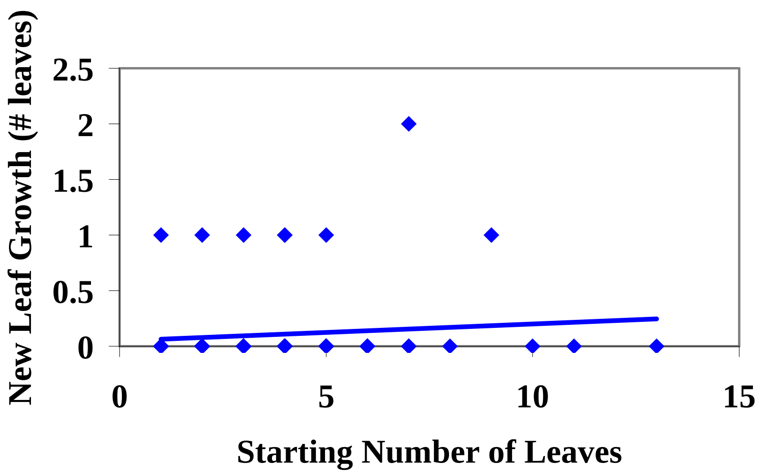

FIGURE 5. Starting size of all 83 *L. jimenezii* individuals compared to their experienced leaf growth. Again some points repeat thus 83 data points are not present. This trend is not significant, but shows a tendency that the higher the starting number of leaves the higher the leaf growth will be.

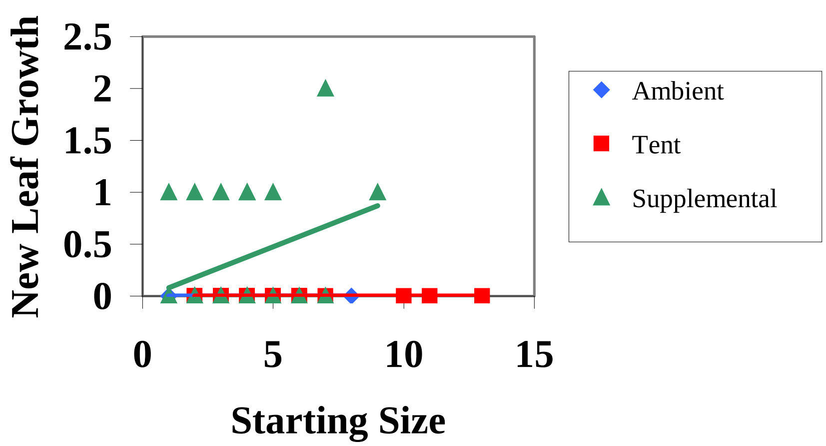

FIGURE 6. Starting size of each treatment type of *L. jimenezii* compared to each treatment type's average experienced leaf growth. Blue indicates ambient plants, green indicates supplemented, red indicates tent. Supplemented orchids experienced only growth.

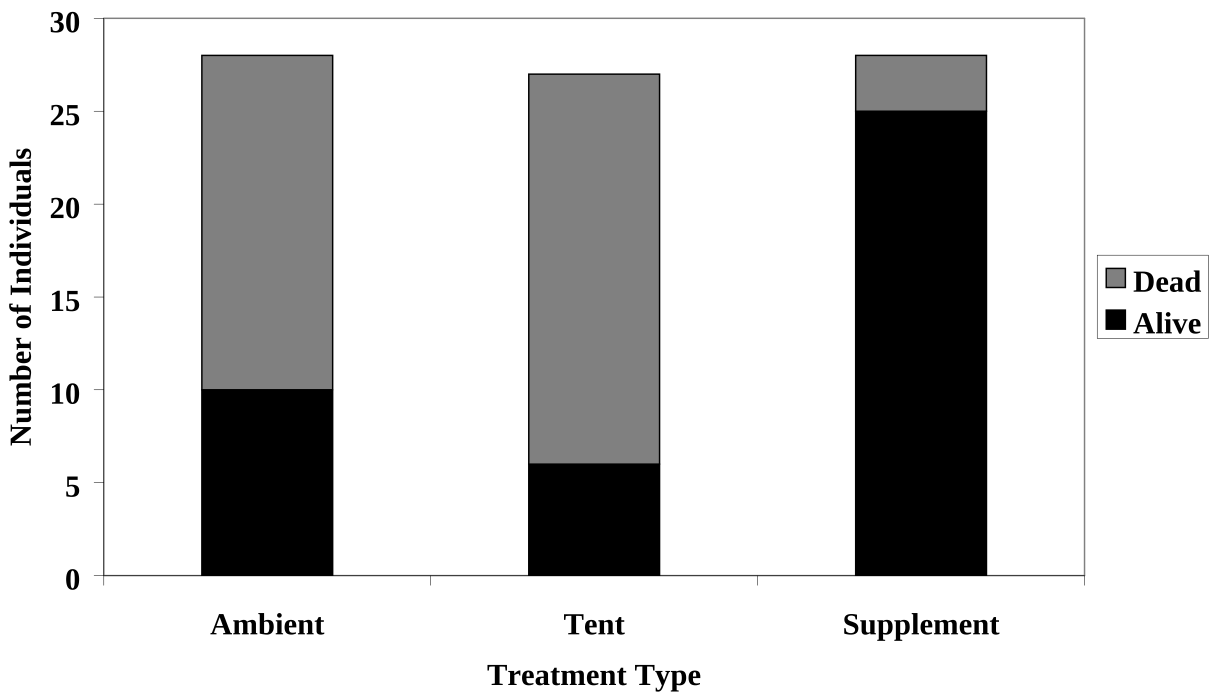

FIGURE 7. Mortality of *L. jimenezii* under three experimental treatments. Each bar in entirety represents the total sample size of each treatment type. Grey color indicates the number of individuals dead at the end of the testing period, black indicates the number of individuals alive after the testing period. The ambient group had 28 individuals with 18 that died, the tent group had 27 individuals with 21 that died, and supplemented had 28 individuals with 3 that died.

Temperature was taken daily with an average minimum temperature of 15.2 ± 1.4 degrees C and an average maximum temperature of 22.3 ± 1.6 degrees C. Precipitation was also recorded during the study. The first ten days of data collection were completely dry, supporting the hypothesis that dry periods in Monteverde are increasing (Pounds et al. 1999).

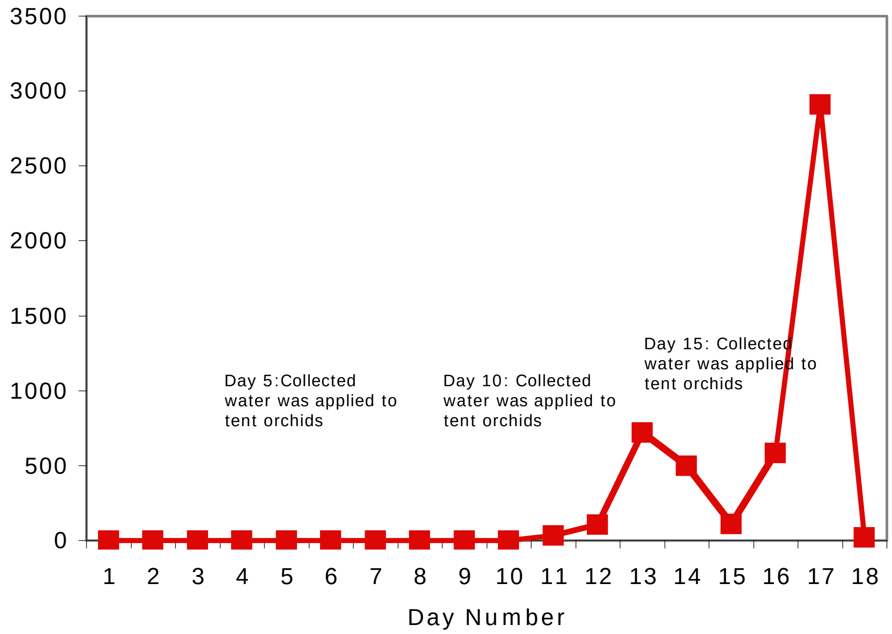

FIGURE 8. Daily precipitation that fell over the orchids under the tent treatment A dry period with no recorded precipitation existed for the first 10 days of the study, after which there were no more dry days. Precipitation was recorded in ml.

DISCUSSION

This study investigated the relationship between mist variability and reproductive success and mortality in *L. jimenezii*. I predicted that increased precipitation variability (increased dry periods) would negatively affect *L. jimenezii*, and that decreased precipitation variability (decreased dry periods) would have a positive effect on the orchids. If this prediction was supported, it would indicate that *L. jimenezii* was vulnerable to the recent changes in climate that cause these modifications in precipitation frequency, and that contemporary and possibly future precipitation conditions in Monteverde do not provide a satisfactory habitat for *L. jimenezii* . If data conflicted with this prediction it would indicate that orchids may not be susceptible to these changes in precipitation.

Results of this study indicate that increased precipitation variability did harm *L. jimenezii* and that decreased precipitation variability enhanced its reproductive success. Specifically, leaf change was negative among both ambient and tent orchids, but positive among supplemented orchids. This suggests that orchids exposed to contemporary ambient and potential future conditions were more likely to lose leaves than those exposed to conditions similar to those of the 1970s. The results also show that individuals of the current and future conditions were more likely to experience leaf loss if they had a larger starting size, but that orchids of the 1970s conditions gained leaves without regard to starting size. This is probably due to the fact that these orchids were so continually satiated with water and nutrients, while the ambient and tent orchids experienced more periods of extreme stress. Thus, those individuals with more leaves had to stop allocating energy for each leaf's preservation.

Orchid mortality was significantly higher in both ambient and tent orchids, and highest in tent orchids. Tent orchids experienced the most precipitation variation among the orchids, and ambient orchids experienced the next greatest precipitation variation, so it is logical, according to my hypothesis, that both of these groups would experience higher mortality. Twenty-one out of 27 orchids died in the tent sample, 18 out of 28 died in the ambient sample, and three out of 28 died in the supplementally misted orchid sample. It was expected that tent orchids would experience much greater mortality than either ambient or supplemented orchids, but this was not the case. The surprising result might be explained by the fact that tent orchids were protected from the strong winds of the misty season, and thus their rates of desiccation were lower than those of the orchids in ambient conditions.

My results indicate that as predicted, *L. jimenezii* is significantly affected by changes in precipitation frequency. Because the orchids were most successful when in an environment like that of the 1970s and least successful when exposed to potential future conditions, the effects of climate change on *L. jimenezii* and other members of the family Orchidaceae clearly play a significant role in their success, and should be examined at length. Future studies could improve these results by collecting data for a longer period and perhaps additionally incorporating other delicate epiphytes. From this study, it is reasonable to state that climate change may be a large problem for plants that depend heavily on regular precipitation, particularly epiphytes.

It is difficult to predict the future for cloud forest orchids or others. Worldwide temperatures are expected to increase 0.2 degrees Celsius in the next decade, which seems to indicate that the problem of climate change will only worsen in future years (Alley et al. 2001). My data along with data predicting the intensification of climate change indicate that increased current and future environmental temperatures should be considered an environmental problem of noteworthy significance.

ACKNOWLEDGEMENTS

Thank you first and foremost to Karen Masters, whose passion for orchids and nature in general is thoroughly contagious. Thank you also to Tom Mcfarland for being ever so talented with a hammer and nails and thanks to Cam Pennington for answering my relentless questions. Thank you to the Perez-Picados in San Luis for being so understanding about my long days. Thanks to Kerry for always being just one step ahead of me with these orchids and thanks to my roommates, without whom I would have had an entirely too serious three months. As always thanks to those people at home who no matter the distance are always closest to my heart.

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Appendix 1. Mortality of *L. jimenezii* upon termination of the study based on treatment types.

Treatment Type	Starting Number of Individuals	Ending Number of individuals
Ambient	28	10
Supplemented	28	25
Tent	27	6