Nocturnal Thermal Stratification in Selected Valleys at Pierce Cedar Creek Institute and Conklin, Michigan

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Abstract

Temperature data is usually generalized, yet the existence of unique thermal difference has been significant in many realms of human experience. Examples may include the location of fruit orchards on hill tops and near bodies of water, hospitals on hills and the urban heat island effect. At night when the turbulence caused by solar heating subsides and wind speeds diminish or cease, cold air with a high density sinks into low lying areas. Yet, little study has been done on specific night-time thermal stratification. This study investigated the stratification of evening valley temperatures with regard to relative elevation, progression of evening hours, wind speed, land cover, and finally the repetition of the study at a similar site. Three wooded locations and three grassland locations at Pierce Cedar Creek Institute south of Hastings, Michigan, were selected. During the evening hours data from each location at high, middle and low sites were gathered. A second location with similar relief in Conklin, Michigan, north of Grand Rapids, was chosen to determine if similar results would be obtained. The study determined that relative elevation produced striking evening temperature differences. The low elevations had significantly lower evening temperatures than the higher elevations. It was ascertained that the greater temperature differences usually occurred early to mid evening on calm nights. On nights with higher wind speeds, the temperatures were more uniform. Wooded areas consistently produced less dramatic evening temperature differences than grassland areas.

Introduction

Throughout the Pierce Cedar Creek Institute property, significant differences in elevation occur. The glacial landforms which dominate the area were deposited by the Saginaw lobe near the end of the Pleistocene approximately 12,500 years ago (Dorr and Eschman, 1978). The landforms are typical of those classified as being deposited as end moraines or by dead ice (Slaughter and Skean, 2005). The resulting landforms have valleys with enough local relief to experience air drainage and associated evening temperature stratifications. In 2005, both Slaughter and Skean, and Keys and Walker investigated unique habitats at Pierce Cedar Creek Institute that were at least partially related to temperature variations.

Typically, in the evening when turbulence caused by solar heating declines and wind speeds diminish or cease entirely, cold air which is more dense settles into lower elevations like those found at Pierce Cedar Creek and Conklin, Michigan. As a result, valley bottoms have lower evening temperatures than adjacent hillsides and divides (Ahrens, 1998, 2000). This project investigated the stratifications of evening valley temperatures and selected variables that influence those variations at Pierce Cedar Creek Institute and Conklin, Michigan. The variables included the following:

1. There is a relationship between elevation differences and evening temperature stratification at selected valley locations at Pierce Cedar Creek Institute and Conklin, Michigan. The assumption is that greater changes in elevation will result in greater differences in evening temperature values (Aguado & Burt, 2007).
2. Thermal stratification layers will develop throughout the evening at selected valley locations at Pierce Cedar Creek Institute and Conklin, Michigan. The assumption is that temperature differences between divides and valley bottoms will increase throughout the evening hours (Davey, 2005).
3. There is a relationship between the development of the evening thermal stratification layers and wind speed at selected locations at Pierce Cedar Creek Institute and Conklin, Michigan. The assumption is that as wind speed and associated forced turbulence increases, evening temperature stratifications will be less likely to develop (Runnalls, 2006).
4. There are similar evening temperature stratifications in valleys at Pierce Cedar Creek Institute and valleys near Conklin, Michigan. The assumption is that similar landform conditions will produce similar evening temperature results (Geiger 1965).

Hypotheses Proposed

A number of hypotheses were proposed. The first dealt with the relationship between elevation changes and evening temperature stratification. The amplitude of the evening temperature variations in the valleys should be strongly affected by the elevation changes in those valleys. Colder, denser layers of air near the surface will drain into the valleys (Ahrens 2000). As elevation differences between divides and valley bottoms increase, air drainage and associated evening temperature differences will increase in amplitude (Aguado & Burt 2007).

Expectations are that there is a positive relationship between elevation differences and stratification in valleys both at Pierce Cedar Creek and Conklin, Michigan.

With regard to wind speed and evening temperature stratification we expect that as wind speeds increase, air drainage and associated temperature differences between divides and valley bottoms will decrease. As wind speeds increase, greater friction with the surface will cause increased turbulence, mixing, and more unified temperatures. Turbulence displaces those parcels in contact with the surface preventing heat loss by conduction and associated air drainage (Aguado & Burt, 2007). On still evenings that lack of forced convection will result in a thin layer of air near the surface being cooled. That cool air will then settle into lower elevations. The expectation is that, as wind speeds increase, temperatures across the valley and onto the hilltop will be more uniform.

The third hypothesis to be considered is the development of the stratification features during the evening hours. As the evening progresses, greater temperature differences should develop between the valley bottoms and the adjacent divides. Following sunset the surface and the air above it lose energy by the effects of radiation cooling. The ground is a better radiator and cools more quickly than the air above it. The air near the surface transfers its energy to the ground by conduction. That energy is eventually re-radiated back to space. As time passes, the surface and the air near it continue to cool at a more rapid rate than the air a few meters higher. The cooler, denser air on the slopes continues to settle into low lying areas resulting in increased evening temperature differences between valley bottoms and adjacent divides. (Ahrens, 2000) Temperature differences between valley bottoms and divides should continue to increase as temperatures continue to fall during the evening hours (Aguado & Burt 2007). Therefore, expectations are that as the night progresses, temperature differences will increase.

Hypotheses

In the analysis of the data the following hypotheses will be tested:

H_0 Elevation changes in selected valleys at Pierce Cedar Creek Institute and Conklin, Michigan, do not affect evening temperature differences in the valley.

H_1 There is a positive relationship between elevation in selected valleys at Pierce Cedar Creek Institute and Conklin, Michigan, and evening temperature.

H_2 There is a negative relationship between elevation in selected valleys at Pierce Cedar Creek Institute and Conklin, Michigan, and evening temperature.

H_0 There is no relationship between wind speed and evening temperature stratification in selected valleys at Pierce Cedar Creek Institute and Conklin, Michigan.

H_1 There is a positive relationship between wind speed and evening temperature stratification in selected valleys at Pierce Cedar Creek Institute and Conklin, Michigan.

H_2 There is a negative relationship between wind speed and evening temperature stratification in selected valleys at Pierce Cedar Creek Institute and Conklin, Michigan.

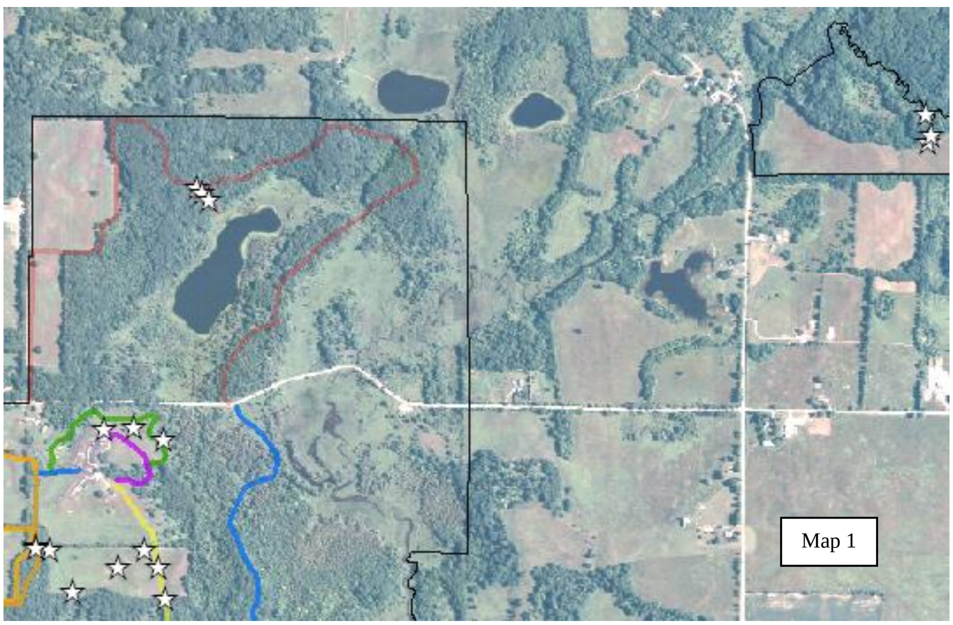
H_0 There is no relationship between the amount of time following sunset and evening temperature stratification in selected valleys at Pierce Cedar Creek Institute and Conklin, Michigan.

H_1 There is a positive relationship between the amount of time following sunset and evening temperature stratification in selected valleys at Pierce Cedar Creek Institute and Conklin, Michigan.

H_2 There is a negative relationship between the amount of time following sunset and evening temperature stratification in selected valleys at Pierce Cedar Creek Institute and Conklin, Michigan.

Data Gathering

Six locations were selected at Pierce Cedar Creek Institute and two in Conklin, Michigan. At each location a GPS was used to determine three measuring sites based on elevation (i.e. valley bottom, side of the valley, and drainage divide). Oakton TempLogs were placed at 1.5 meters above the surface at each measuring site. This is the height used by the National Weather Service to determine ambient temperature (Geiger, 1965). Each of the TempLogs was housed in a wooden structure similar to that of a bird house to protect the TempLogs from the elements



The six locations at Pierce Cedar Creek included a site at "The Little Grand Canyon," near the Visitor's Center between the Purple and Green Trail, along the Red Trail near Brewster Lake, two sites near the Yellow Trail and one site along the Orange Trail near the bee tree (See Map1). The two locations near Conklin, Michigan, included a wooded site and an open, grassy field.

During the evening hours (9:30 p.m. to 6:30 a.m.) from late May to early August temperature was recorded at the bottom of the hour at each site. The wind data was obtained from the weather station on site at Pierce Cedar Creek and via the Weather Underground for the Conklin study.

Data collected from Conklin, Michigan, a small community about 18 miles northwest of Grand Rapids, was compared to that from Pierce Cedar Creek Institute to determine if similar temperature stratification occurs in comparable landform locations.

Results and Analysis

During our research we collected over 2,160 readings of temperature and wind speed data. Our first hypothesis dealt with the relationship between elevation in selected valleys at Pierce Cedar Creek Institute and Conklin, Michigan, and evening temperature. The highest elevations demonstrated a significantly higher evening temperature reading throughout the study. We applied a paired t-test to determine the statistical significance of the evening temperature differences between the divides and valley bottoms in the data. We obtained overwhelmingly strong support with a t-value of 28.090 and a p-value of 0.000 for the research sites at Pierce Cedar Creek and Conklin, Michigan. An example of the relationship between elevation and temperatures is indicted by the data collected at the Visitor's Center (Figure 1-a). Relationships for other research sites are included in Appendix A. As a result of the analysis we rejected the null hypothesis and accepted:

> *H_1: There is a positive relationship between elevation in selected valleys at Pierce Cedar Creek Institute and Conklin, Michigan, and evening temperature ranges in the valley.*

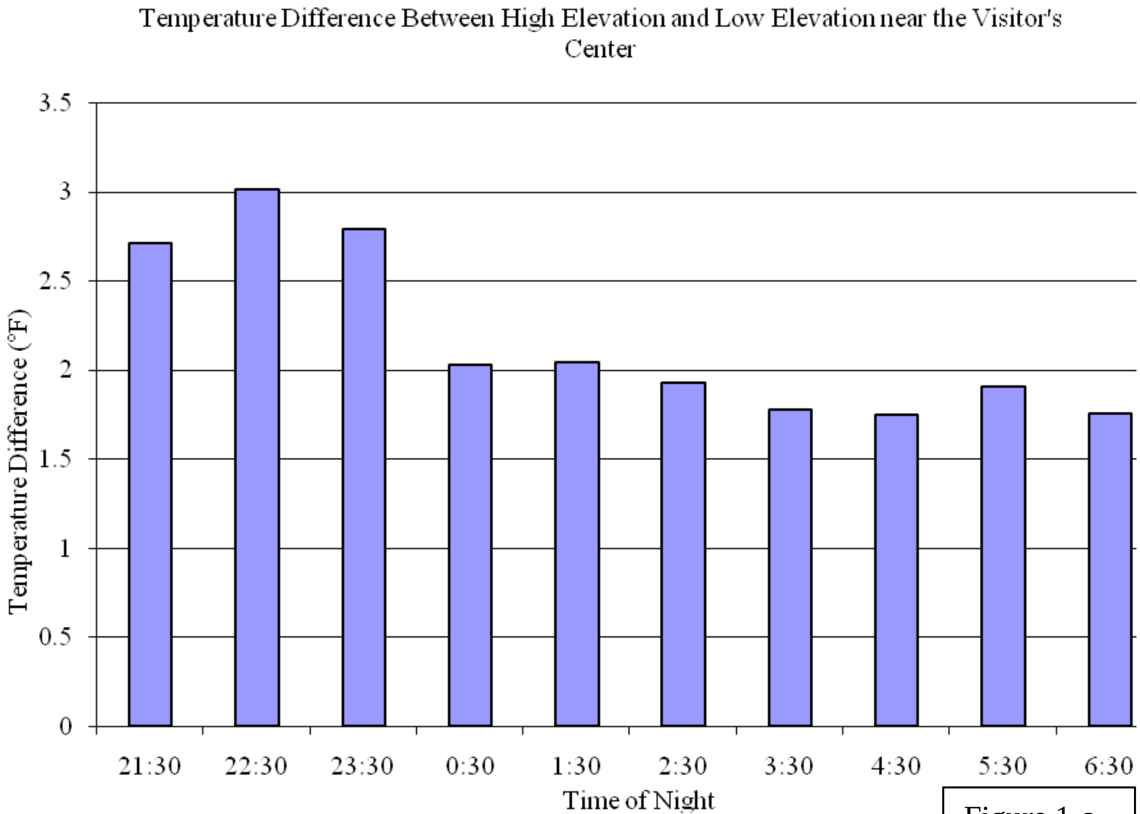


Figure 1-a

The second hypothesis addressed the relationship between wind speed and evening temperature stratification in selected valleys. We assumed that the greater the wind speed the more likely the temperatures are to be uniform. As can be seen in Figure 2-a, greater wind speeds are associated with more uniform evening temperatures, while lower wind speeds are associated with greater evening temperature differences. Figure 2-a depicts data collected at the Visitor's Center site. Relationships for other research sites are included in Appendix B. Based upon the analysis of the data we rejected the null hypothesis and accepted the:

> *H_2 There is a negative relationship between wind speed and evening temperature stratifications in selected valleys at Pierce Cedar Creek Institute and Conklin, Michigan.*

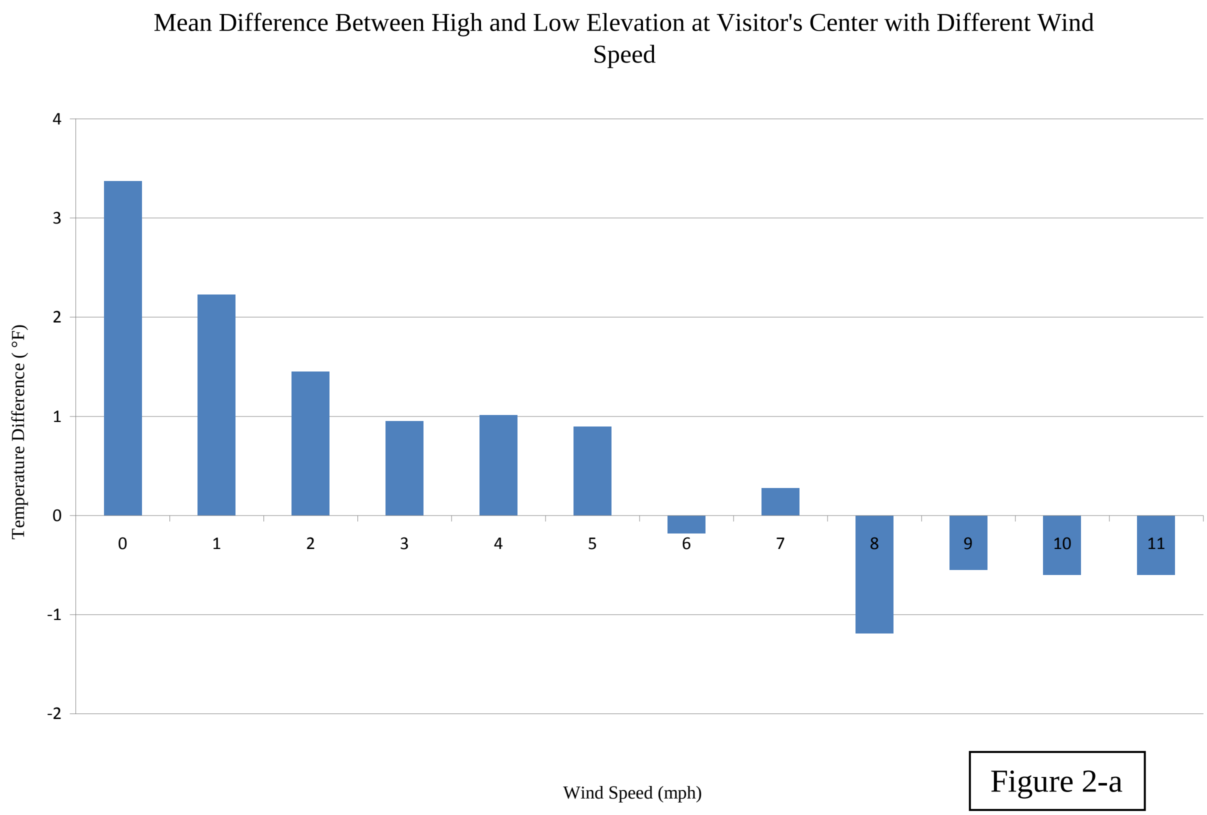


Figure 2-a

The third hypothesis dealt with the relationship between the amount of time following sunset and evening temperature stratification. In order to verify the results we performed a One-Way ANOVA test. This showed that as the evening progressed more stratification was present in the grassy valleys. The development was most rapid in the early hours of the evening. In mid evening a slight decline in temperature difference was experienced, while the later evening hours experienced little change. Charts 1 and 2 show the mean evening temperature difference and the standard deviation throughout the evening. Wooded area differences tended to be greatest in the early evening hours and decreased as evening progressed. Figure 3-a is a graphic representation of evening temperature differences for the wooded area in the Little Grand Canyon and the grassy surface near the Visitor's Center. Relationships for other research sites are included in

Appendix C. Based upon the analysis of the data, we rejected the null hypothesis and accepted the:

> *H_1: There is a positive relationship between the amount of time following sunset and evening temperature stratification in selected valleys at Pierce Cedar Creek Institute and Conklin, Michigan.*

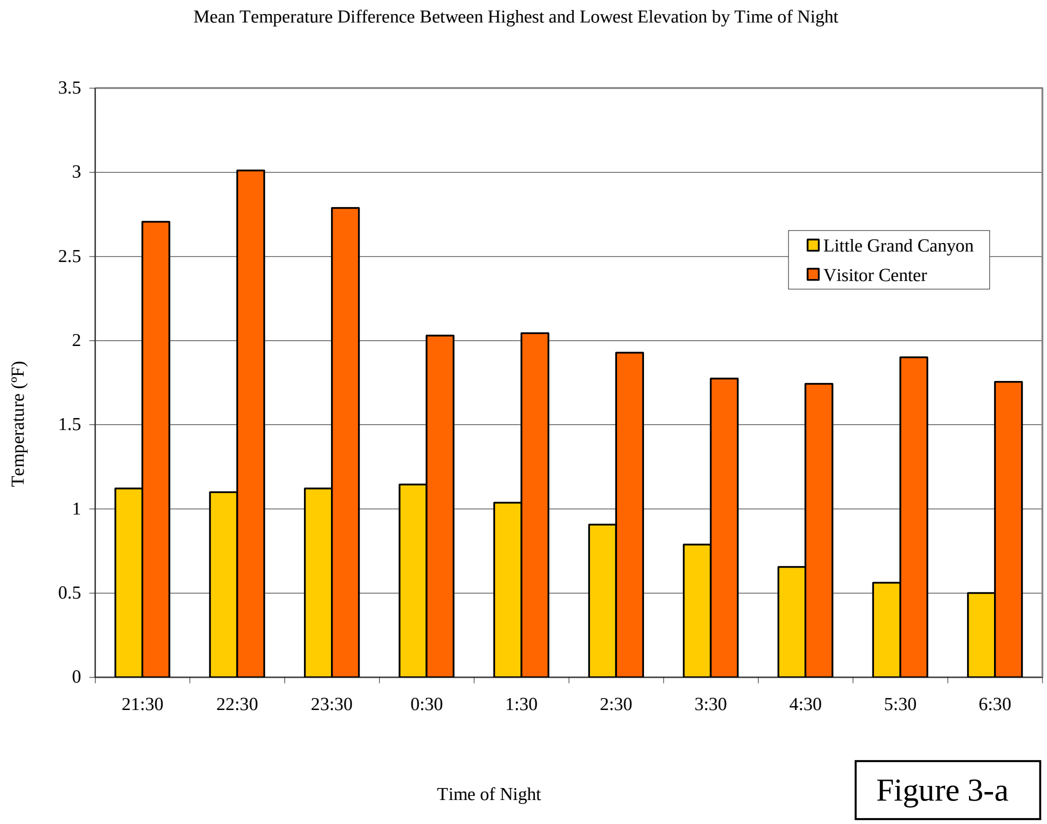


Figure 3-a

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Chart-1
Grass Land Areas
Source          DF      SS      MS     F      P
Time (hh:mm:ss)  9   141.64  15.74  3.11  0.001
Error          790  3999.96   5.06
Total          799  4141.60

S = 2.250   R-Sq = 3.42%   R-Sq(adj) = 2.32%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level     N  Mean  StDev  ------+---------+---------+---------+---
21:30:00  80  1.342  2.708  (-------*--------)
22:30:00  80  1.619  3.105      (-------*-------)
23:30:00  80  2.157  2.469             (-------*-------)
00:30:00  80  2.462  2.134                 (-------*-------)
01:30:00  80  2.640  2.068                   (-------*-------)
02:30:00  80  2.648  1.918                   (-------*-------)
03:30:00  80  2.595  1.921                  (-------*-------)
04:30:00  80  2.465  1.991                 (-------*-------)
05:30:00  80  2.376  1.879               (--------*-------)
06:30:00  80  2.313  1.967              (--------*-------)
                          ------+---------+---------+---------+---
                             1.20      1.80      2.40      3.00

Pooled StDev = 2.250
```

```
Chart 2
Wooded Areas
Source          DF      SS     MS     F      P
Time (hh:mm:ss)  9     3.95   0.44  0.12  0.999
Error          790  2811.31   3.56
Total          799  2815.26

S = 1.886   R-Sq = 0.14%   R-Sq(adj) = 0.00%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level     N  Mean  StDev  -------+---------+---------+---------+--
21:30:00  80  1.115  1.939  (-------------*-------------)
22:30:00  80  1.157  2.002   (-------------*------------)
23:30:00  80  1.320  2.036       (-------------*-------------)
00:30:00  80  1.277  2.031      (-------------*------------)
01:30:00  80  1.347  1.853       (-------------*-------------)
02:30:00  80  1.272  1.740      (------------*-------------)
03:30:00  80  1.242  1.794     (------------*-------------)
04:30:00  80  1.159  1.892   (-------------*------------)
05:30:00  80  1.237  1.795    (-------------*-------------)
06:30:00  80  1.238  1.754    (-------------*-------------)
                          -------+---------+---------+---------+--
                               0.90      1.20      1.50      1.80

Pooled StDev = 1.886
```

Conclusions

The research project results reaffirmed a number of the hypotheses considered, but also produced some surprises. The hypothesis that elevation changes from valley bottoms to drainage divides would be associated with different evening temperatures was confirmed. Paired t-tests indicated that at a 99% confidence level the evening temperatures were statistically different from those at the other elevations in the valley. Throughout the study the valley bottom evening temperatures were 1.238 ºF (.687 ºC) cooler in wooded areas and 2.263ºF (1.257 ºC) cooler in grassland areas than the mean temperatures at the divides. When wind speeds were lower the difference was considerably greater.

The second variable considered was the relationship that existed between the evening temperature in the valley bottoms and drainage divides and wind speed. The results of the research determined that, even though valley depths were not the same from site to site, evening temperature differences decreased as wind speeds increased. For all valleys, both wooded and grassland, mean temperature differences were 2.72 ºF (1.51ºC) under calm wind conditions. At three miles per hour (4.828 kilometers per hour) the differences dropped to 2.17ºF (1.21º C). At six miles per hour (9.656 kilometers per hour) the differences further decreased to 1.06ºF (.59ºC). At wind speeds greater than eight miles per hour stratification ceased.

The third variable investigated the progression of evening temperature stratification. The assumption was that differences would increase throughout the evening hours. The data indicates that rapid re-radiation cooling and temperature stratification develop immediately after sunset, reaching a maximum difference of 2.648ºF (1.47ºC) about 2:30 a.m., and declining slightly to 2.313 ºF (1.29 º C) just prior to dawn.

While conducting the research it was quite apparent that evening temperature stratification characteristics differed between wooded sites and open grassy fields. Wooded sites consistently had lower ranges of temperature differences between valley bottoms and divides as the evening progressed. Apparently the biomass at the wooded sites retained enough heat to alter the temperature variation. The density of the vegetation may have caused enough friction to reduce the movement of colder air to lower elevations and the development of associated stratification. As a result, in densely wooded areas increased wind speed had a limited effect on stratification features.

The research project investigated the role of a number of environmental variables on evening thermal stratification in selected valleys at Pierce Cedar Creek Institute and Conklin, Michigan. The result of the research determined that all variables considered played a statistically significant role in temperature stratification features. Analysis of the data indicated that the role of the variables in influencing stratification was similar at both Pierce Cedar Creek Institute south of Hastings, Michigan, and at the research site in Conklin, Michigan.

Acknowledgements

We would like to thank the staff at Pierce Cedar Creek Institute for their hospitality and for the use of their property and weather station. We would also like to thank Kurt Thompson of the Grand Valley State Annis Water Resource Center for his assistance in GIS support.

Appendix A

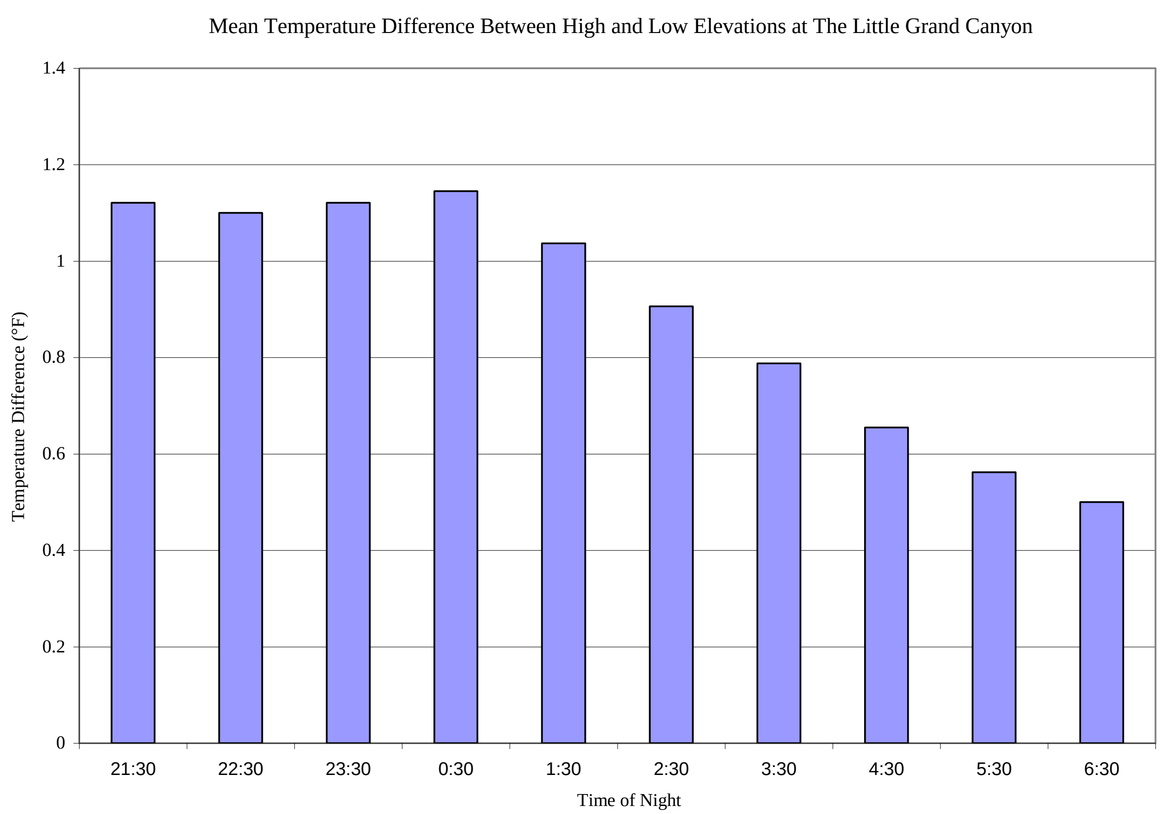
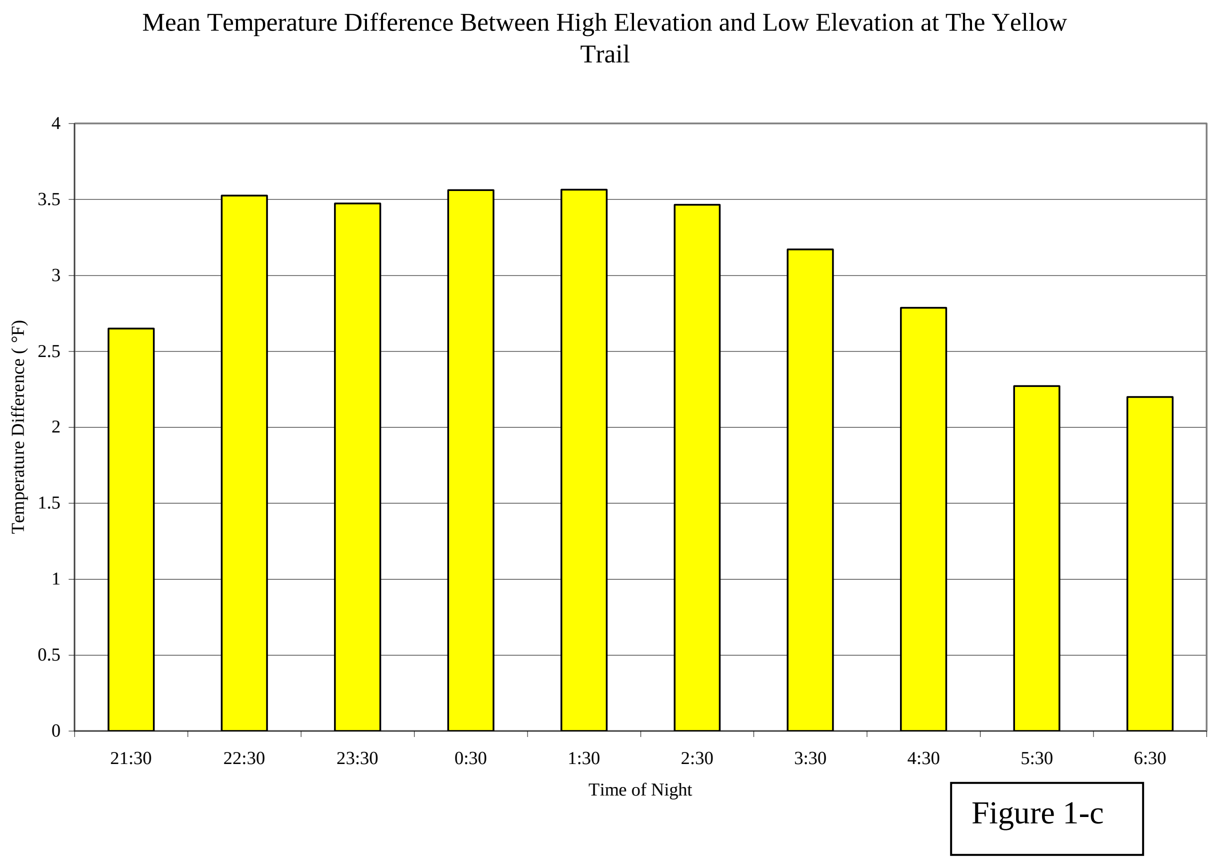
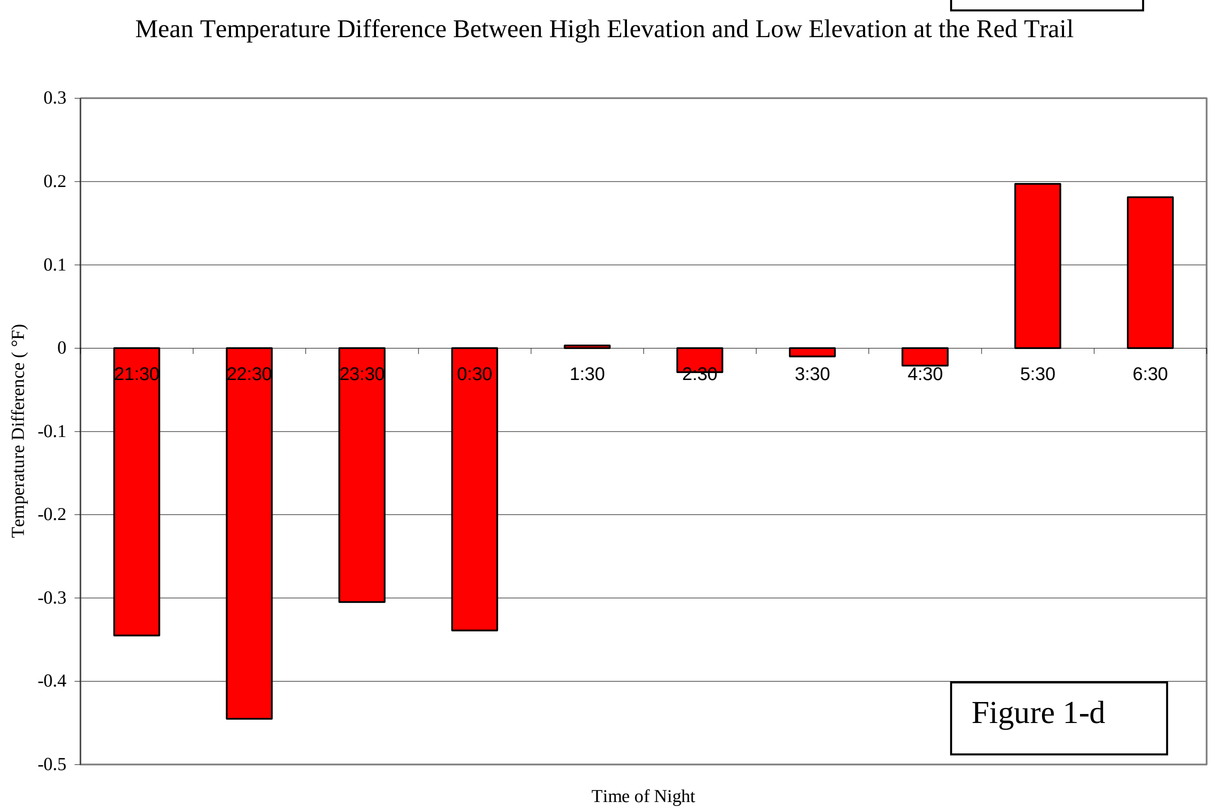


Figure 1-b


Mean Temperature Difference Between High Elevation and Low Elevation at The Yellow Trail
Temperature Difference (°F)
4
3.5
3
2.5
2
1.5
1
0.5
0
21:30
22:30
23:30
0:30
1:30
2:30
3:30
4:30
5:30
6:30
Time of Night
Figure 1-c


Mean Temperature Difference Between High Elevation and Low Elevation at the Red Trail
Temperature Difference (°F)
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
21:30
22:30
23:30
0:30
1:30
2:30
3:30
4:30
5:30
6:30
Time of Night
Figure 1-d

Mean Temperature Difference between High Elevation and Low Elevation at the Orange Trail

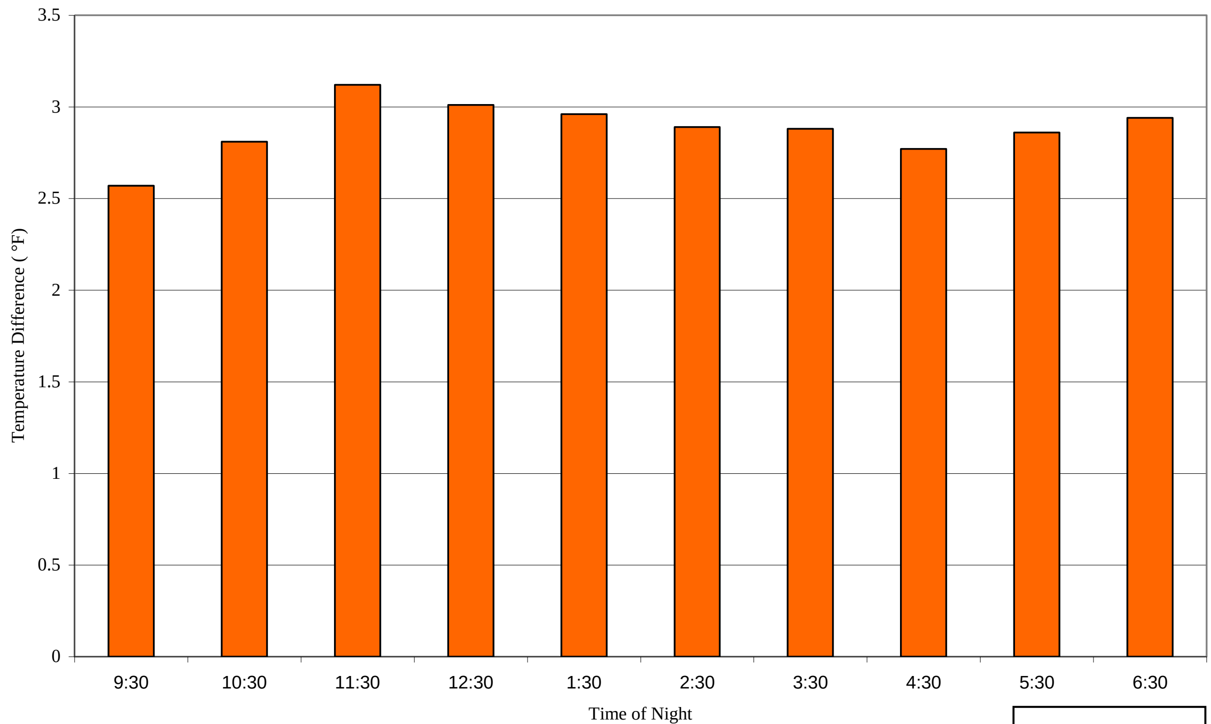


Figure 1-e

Mean Temperature Difference Between High Elevation and Low Elevation at Second Yellow Trail Site

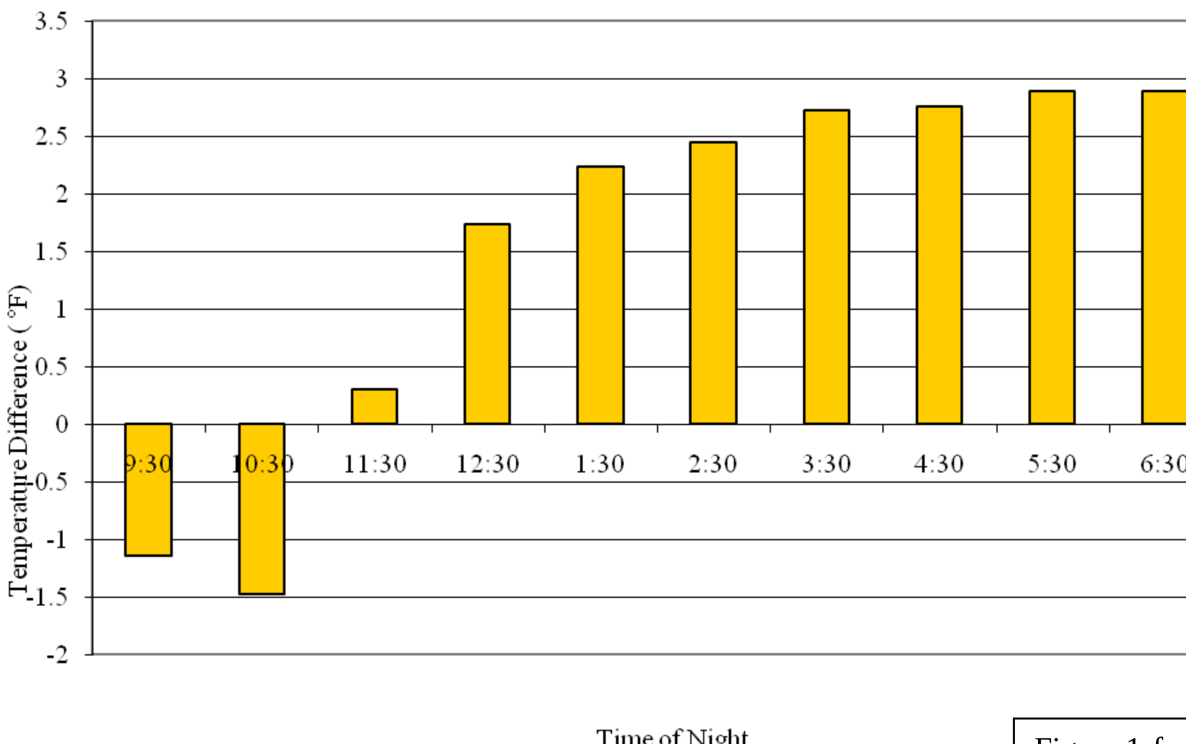


Figure 1-f

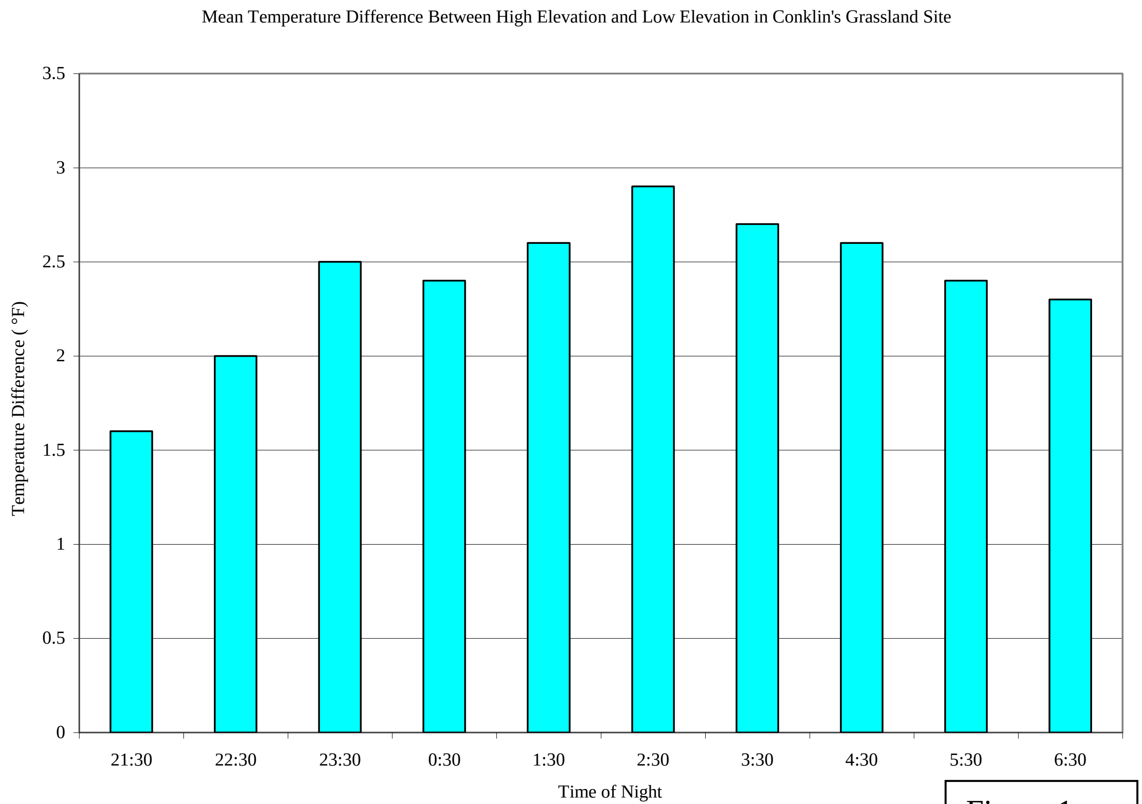


Figure 1-g

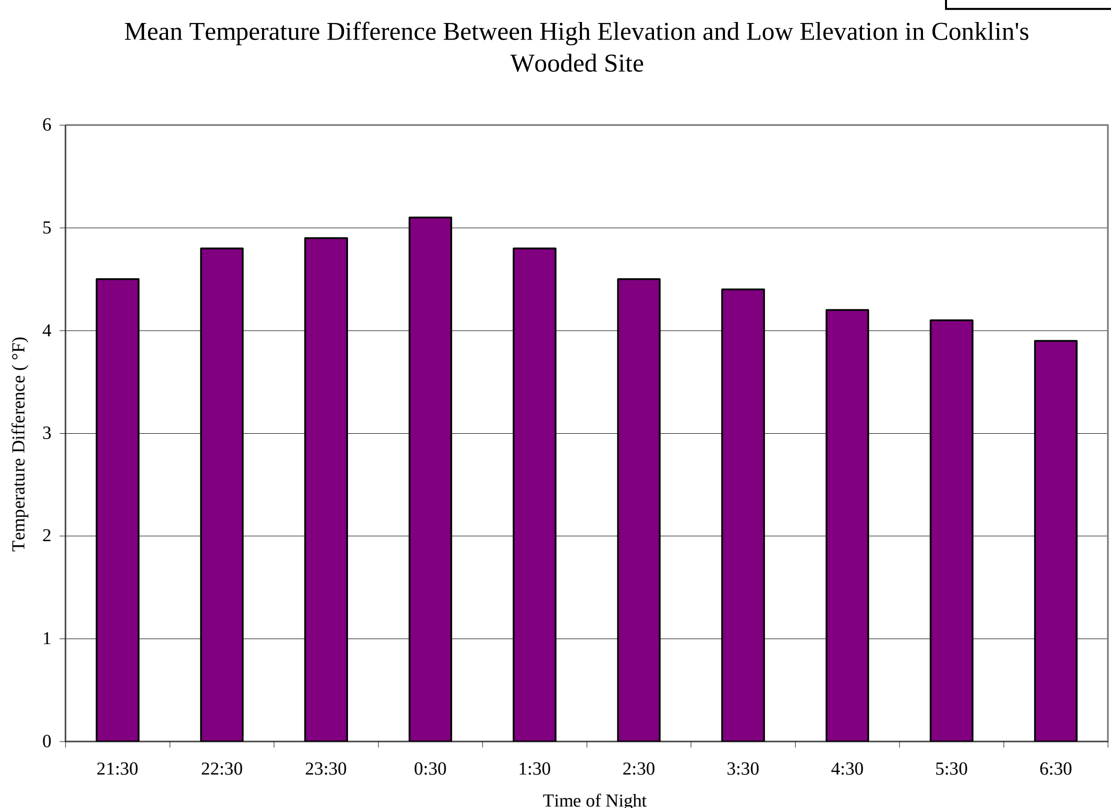


Figure 1-h

Appendix B

Mean Temperature Difference Between High and Low Elevations with Different Wind Speed
at The Little Grand Canyon Site

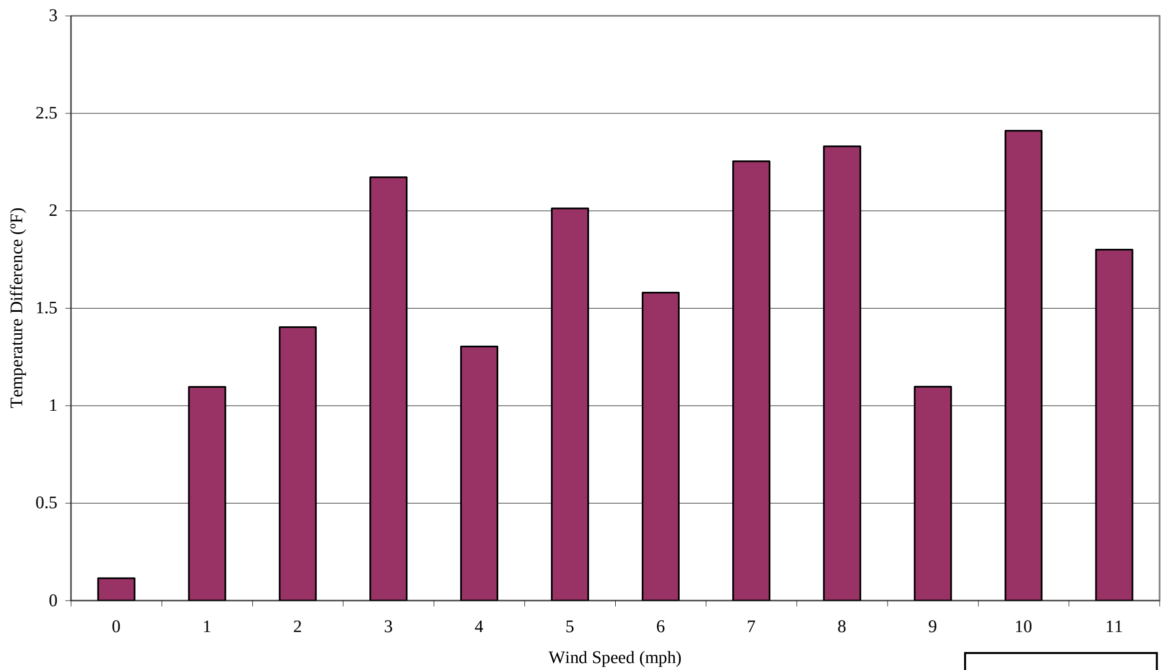


Figure 2-b

Mean Temperature Difference between High and Low Elevation at the Yellow Trail with
Different Wind Speed

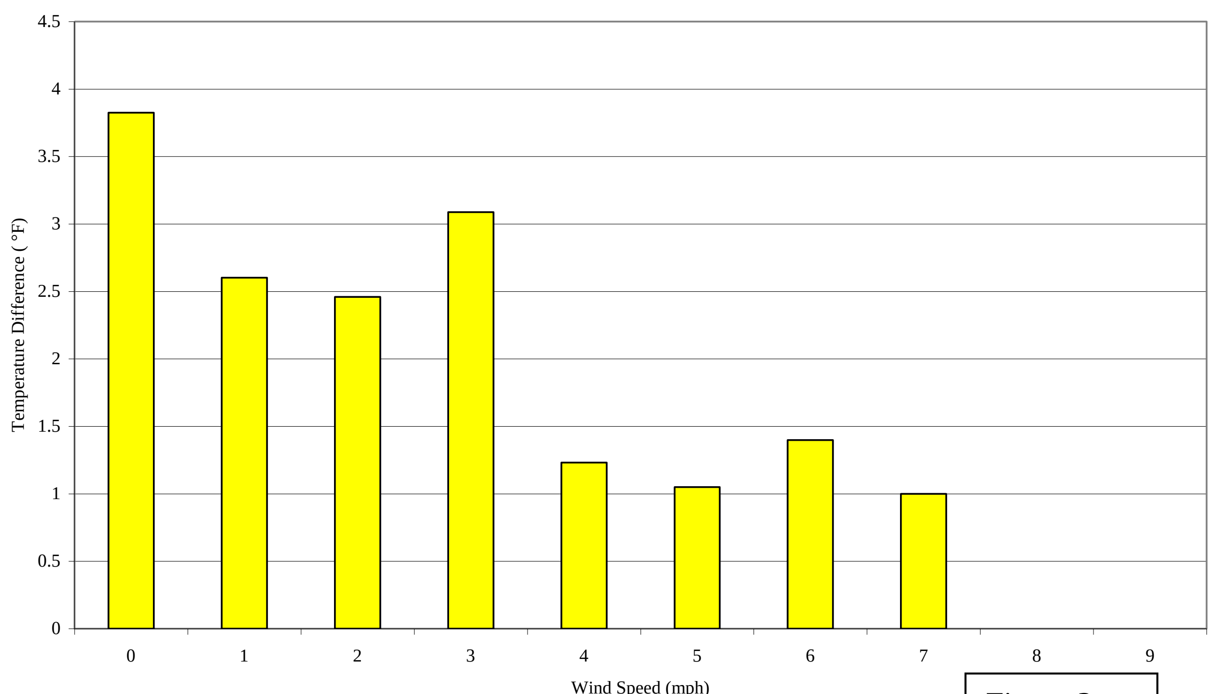


Figure 2-c

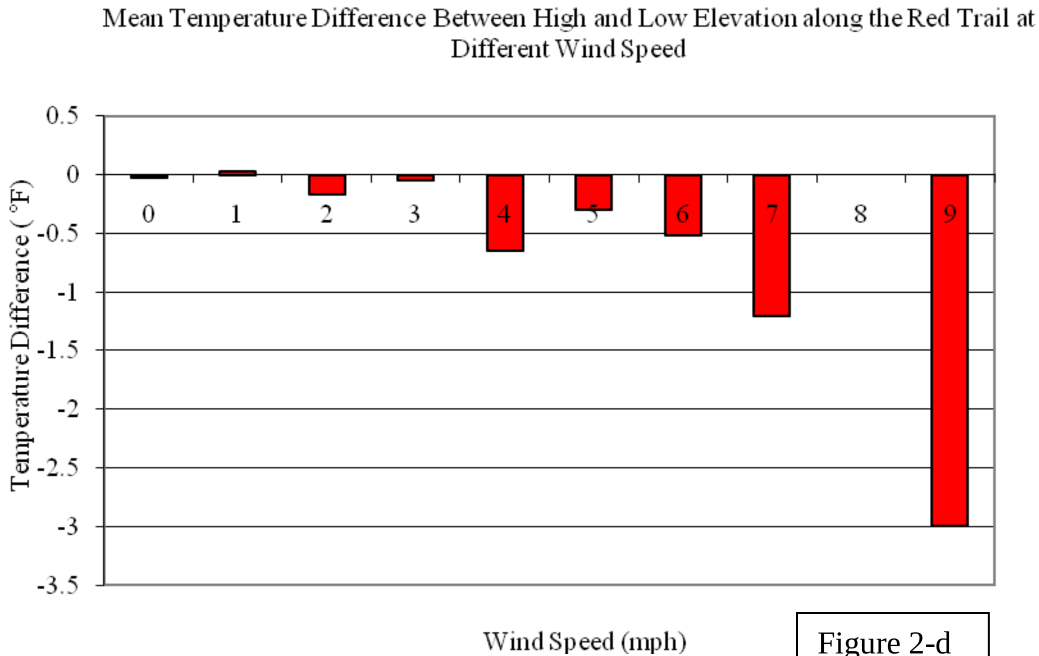


Figure 2-d

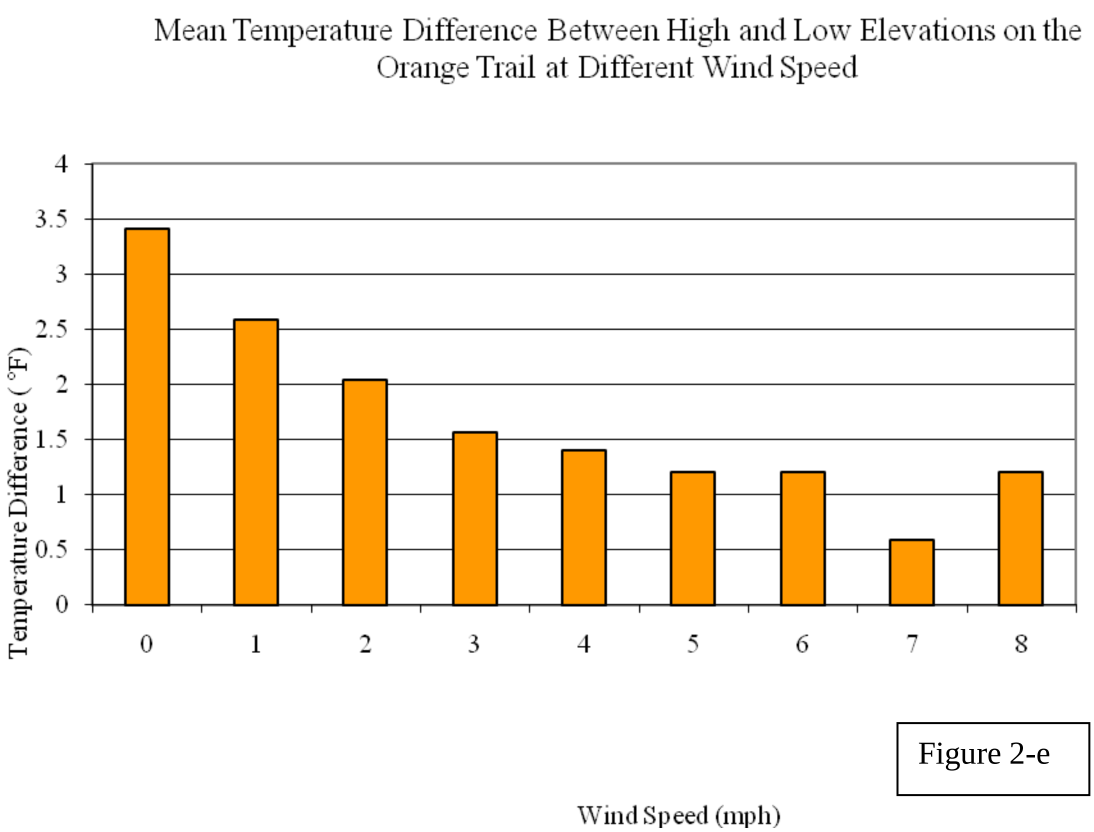


Figure 2-e

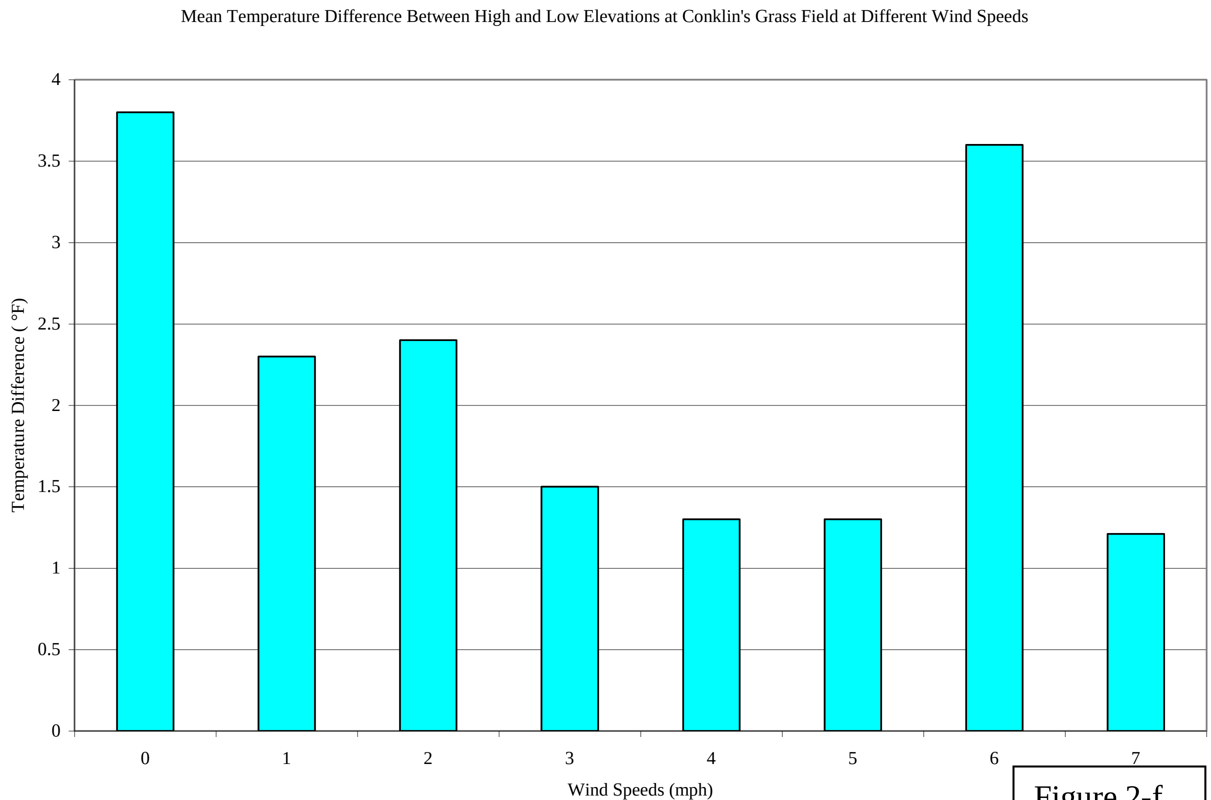


Figure 2-f

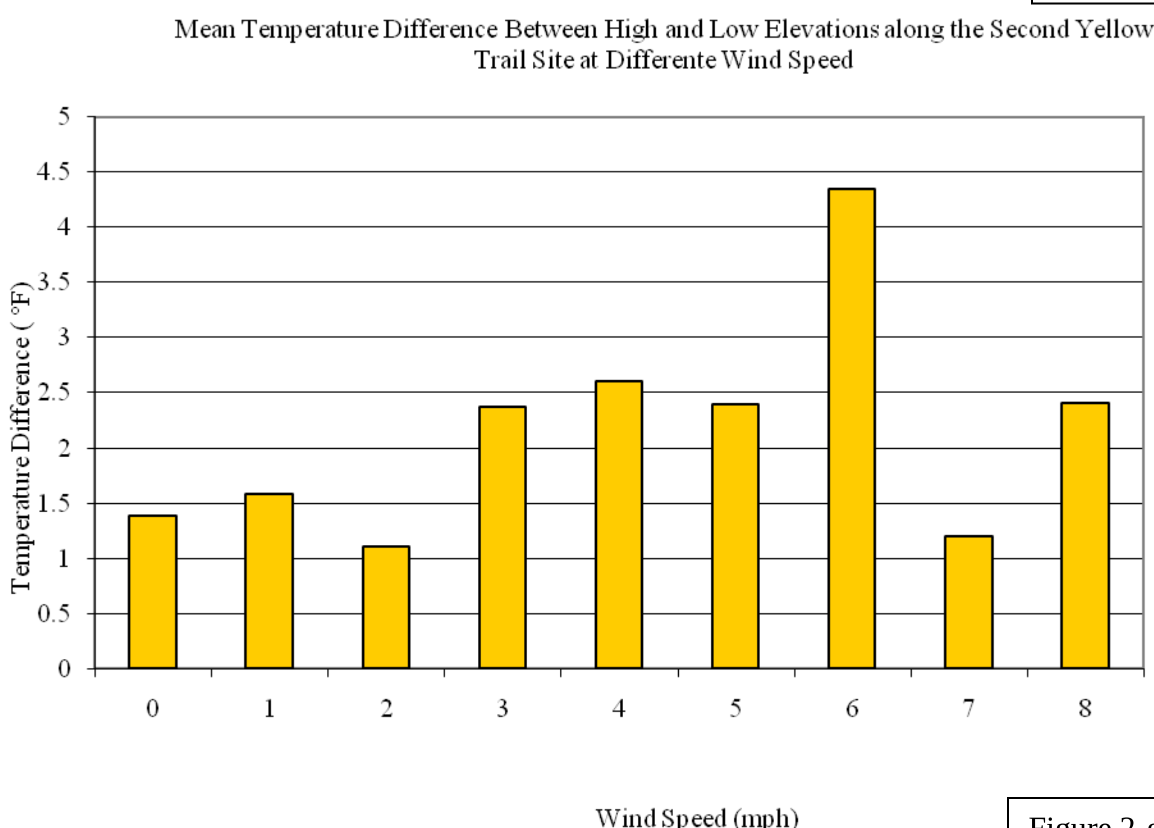


Figure 2-g

Mean Temperature Difference Between High and Low Elevations at Conklin's Wooded Site at Different Wind Speed

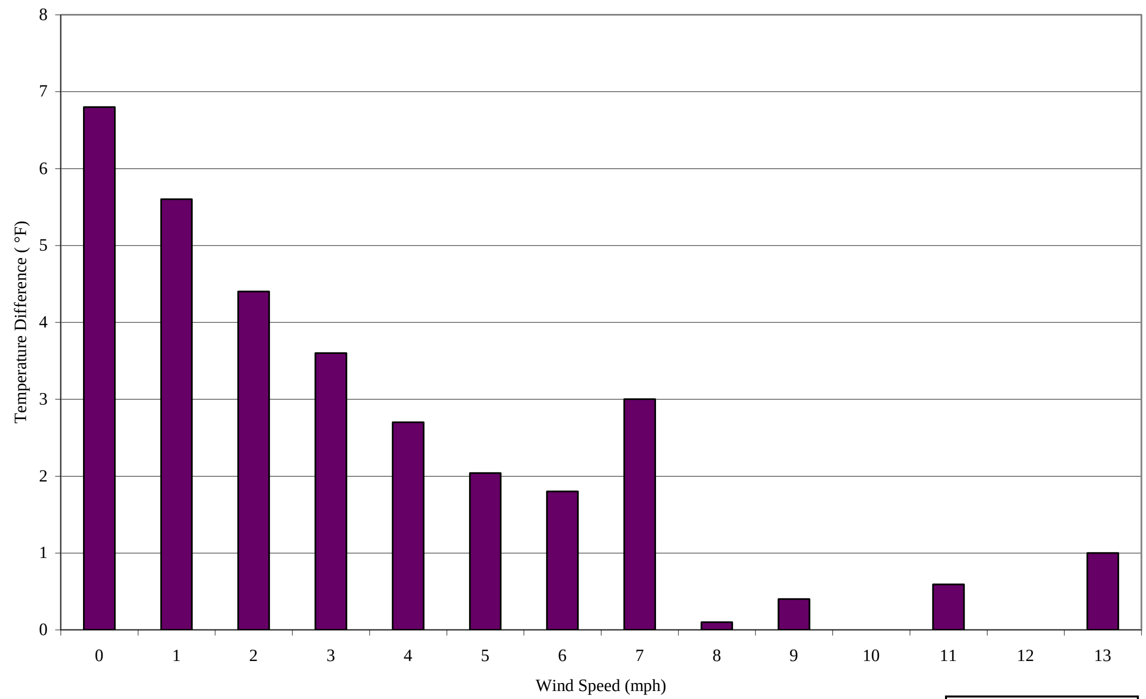


Figure 2-h

Appendix C

Mean Temperature Difference by Time of Night

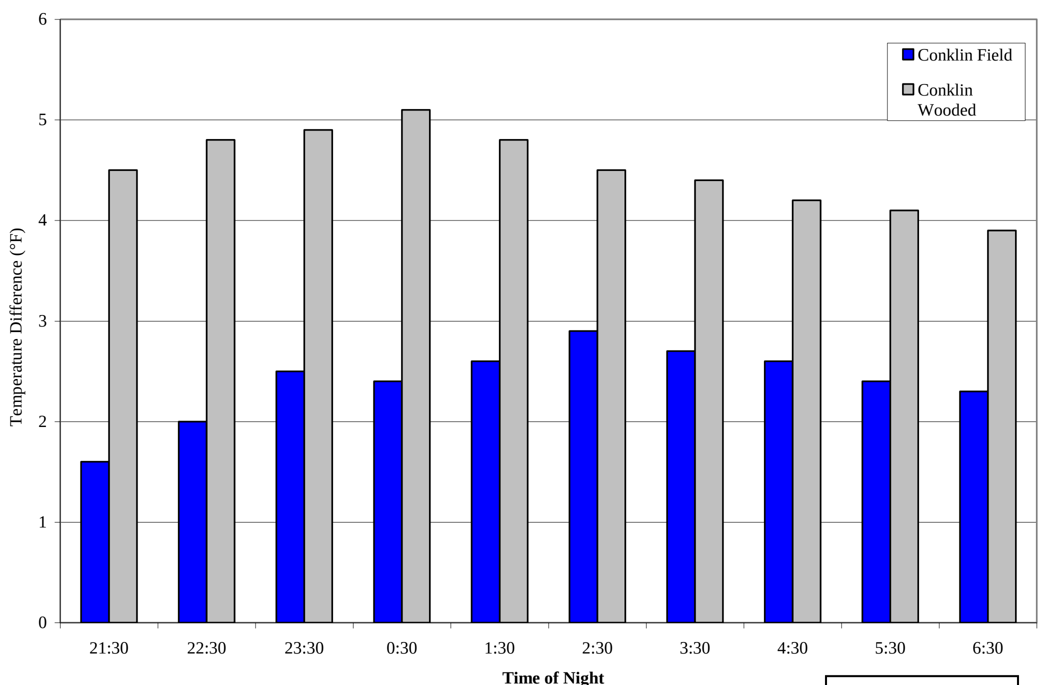
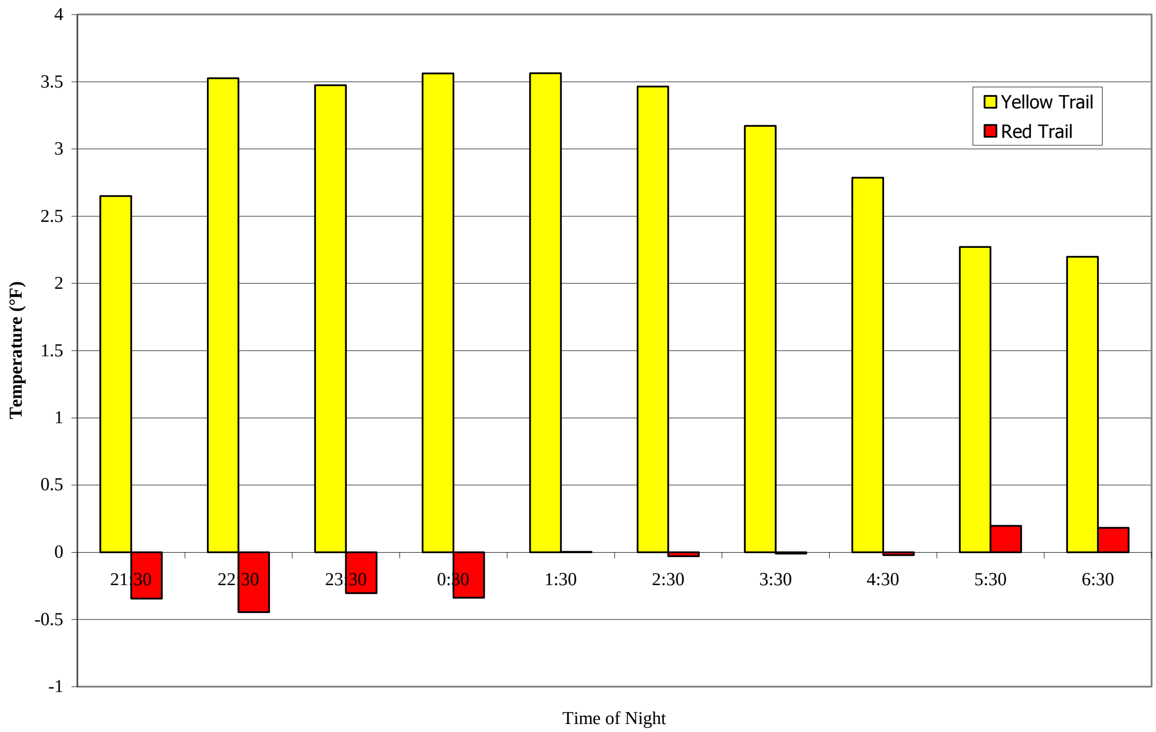


Figure 3-h

Mean Temperature Difference Between Highest and Lowest Elevation by Time of Night



Paired T-test Results for Elevation Variable

	t-value	p-value		t-value	p-value		t-value	p-value		t-value	p-value
Little Grand Canyon			Yellow Trail			Orange Trail			Conklin Grassy		
High vs. Mid	14.86	0.000	High vs. Mid	8.28	0.000	High vs. Mid	12.51	0.000	High vs. Mid	1.01	0.314
Mid vs. Low	13.34	0.000	Mid vs. Low	6.95	0.000	Mid vs. Low	3.42	0.001	Mid vs. Low	25.5	0.000
High vs. Low	17.58	0.000	High vs. Low	10.23	0.000	High vs. Low	8.73	0.000	High vs. Low	27.77	0.000
Visitor's Center			Red Trail			Yellow Trail 2			Conklin Woody		
High vs. Mid	8.28	0.000	High vs. Mid	-13.65	0.000	High vs. Mid	17.91	0.000	High vs. Mid	-1.47	0.000
Mid vs. Low	6.95	0.000	Mid vs. Low	2.82	0.005	Mid vs. Low	17.44	0.000	Mid vs. Low	29.15	0.143
High vs. Low	10.23	0.000	High vs. Low	5.26	0.000	High vs. Low	21.09	0.000	High vs. Low	1.11	.268

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