THE MICROENVIRONMENT OF *CLIMACIUM AMERICANUM*

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ABSTRACT.—Maximum and minimum temperatures and relative humidity of the air at one cm above the soil surface, soil temperature, potential evaporation rate, soil moisture and organic matter present in the soil were measured for five plots that appeared to be very similar habitat types. The plots on which *C. americanum* occur were found to have relatively low maximum and minimum temperatures, high relative humidity of the air layer directly over the plots, relatively low rates of potential evaporation, relatively low soil temperatures, and soils that are moderately acidic. Each of the plots on which *C. americanum* does not occur was found to be notably different in terms of one or more of the environmental factors measured than the plots where *C. americanum* is present.

Climacium americanum Brid. is a distinctive yellow to green pleurocarpic moss with prostrate underground stems. The plants are approximately 3 to 5 cm tall with many erect stems, each bearing numerous spreading branches at the tips.

The purpose of this study is to determine the environmental factors that limit the distribution of the bryophyte *C. americanum.*

This particular moss was chosen for the study because it was found to occur only on soil in dense mats, in very moist, well-shaded and litter-free areas; at or slightly below the crests of northfacing slopes. This restrictive habitat suggested to the investigators that the occurrence of this bryophyte depends on some very exacting environmental requirements. Due to their small size, bryophytes are ideal subjects for microclimatic studies. Most ecological studies on the bryophytes have emphasized the role of moisture in determining suitable habitats. Billings and Anderson (1966), and Potzoer (1939) found that the presence of certain bryophytes in a given habitat is a reliable indicator of the availability of moisture in that habitat. Moisture gradients have been found in vegetative continuums of bryophyte species (Foote, 1966). Moisture in the form of atmospheric humidity and rainfall was found to be a very important factor in governing the geographic distribution of many species of bryophytes (Tallis, 1958). The importance of substrata and soil conditions in governing the distribution of many bryophyte species was shown by Glenn and Welch (1931). Miyata and Hosokawa (1961) found that light interacts with atmospheric humidity in limiting the distribution of certain mosses that occur on tree trunks.

MATERIALS AND METHODS

The study area, Lake Argyle State Park, is located approximately five miles west of Macomb, Illinois in McDonough county. It occupies the following portions of three townships: Colchester township; the northeast one fourth of section 1, R4W, T5N, and the northwest one fourth of section 6, R3W, T5N; Emmet township; the southwest one third of section 31, R3W, T6N; and Hire township; the southeast one third of section 36, R4W, T6N.

The study area consists of 1056 acres, of which 95.1 acres are occupied by an artificial lake (Dunn, 1968). Prior to its acquisition for a state park, the area had been disturbed by heavy pasturing, and the timber areas cut over (Myers and Wright, 1948). The use of the park for public recreational purposes has caused a great deal of disturbance in certain areas.

The topography of the area is generally rough, being dissected by numerous ravines. The soil of the area is a Clinton Silt Loam (Fehrenbacker et al, 1967).

The temperate climate of the area has a very wide temperature range from minus 36° C to over 38° C. January is usually the coldest month, and July is normally the hottest month. The average annual precipitation is about 90 cm, and approximately 66 percent of this falls during the average growing season of 174 days. The summer season frequently has periods of high humidity (Dunn, 1968).

Microclimatic studies on *Climacium americanum* were initiated April 9, 1969, shortly after the soil on the north-facing slopes had thawed. The study was originally intended to be terminated after the onset of frost in the fall, but the advent of open hunting in the study area made it too risky to leave equipment out overnight, so the investigation was terminated on September 30, 1969.

Five plots for collecting data were selected in this study. Plots number 1 and 4 were chosen because *C. americanum* was abundant on these sites. Plots 2, 3, and 5 were chosen because their habitats appeared to be ecologically similar to plots 1 and 4; however, *C. americanum* was absent in these latter habitats.

Plot 1 is located on the crest of a north-facing slope. Red oak (*Quercus rubra* L.) and black oak (*Quercus velutina* lam.) trees, and many Americanum elm (*Ulmus americanum* L.) saplings provide shade. *Climacium americanum* grows on the crest of the north-facing slope in such a position that the upper portion of the mat begins where the slope has an angle of 16½ degrees. The lower portion of the mat is located where the slope has an angle of 34½ degrees, and below the mat the angle of slope is 42 degrees. The *C. americanum* mat covers an area of approximately two by four meters; however, it is also present in numerous other places along the same slope. The mat is growing upon a mineral soil approximately three cm in thickness that overlies a layer of sandstone. Very little litter is present on this portion of the slope, and there is negligible invasion of the mat by herbaceous species during any part of the growing season. *Thuidium recognitum* (Hedw.) Lindb. and *Bartramia pomiformis* Hedw. are two species of mosses that occur on this slope in abundance. They frequently grow adjacent to the mats of *C. americanum* but rarely seem to invade them.

Plot 2 is located about 10 meters above the crest of the same north-facing slope where plot 1 is located. The angle of slope at this point is 14 degrees. *Climacium americanum* does not grow this far above the crest of the slope. This plot is not as well shaded as plot 1, but it has a fairly closed canopy of black oak and shagbark hickory (*Carya ovata* (Mill.) K. Kock) trees. It receives additional shade from the numerous small American elm trees and saplings, and from several black oak saplings. The mineral soil on plot 2 is much thicker than it is on plot 1, and a sparse litter layer is also present. A relatively abundant growth of grasses does occur on plot 2, but mosses are not present on the soil in this region.

Plot 3 is located at the base of the same north-facing slope on which plots 1 and 2 are located. *Climacium* *americanum* does not grow at the base of this slope. The angle of slope where plot 3 is located is two and one half degrees while above plot 3, the slope is 39 degrees. Dense shade is afforded plot 3 by the north-facing slope above it, several large black oak trees, several large hickory trees (*Carya cordiformis* (Wang.) K. Koch); and American elm saplings. The mineral soil varies from complete absence to several cm of thickness and is covered by a thin litter layer. Vascular plants and mosses are absent from plot 3.

Plot 4 is located just below the crest of a north-northeast facing slope. *Climacium americanum* is present on plot 4 in a mat of about four by four meters, and the angle of slope at this point is 28 degrees. Shade is afforded the mat by several black oak and sugar maple (*Acer saccharum* Marsh.) trees, and saplings of these species. There is almost no litter present on this portion of the slope, and the mineral soil is at least 15 cm thick. Another moss, *Thuidium recognitum,* is common on this portion of the slope. There is no apparent invasion of the *C. americanum* mat by herbaceous plant species, or *Thuidium recognitum.*

Plot 5 is located just above the crest of a north-northwest facing cliff. The slope in the region of plot 5 is 26 degrees. Shade is afforded the site by black oak trees and several species of oak (*Q. velutina, Q. palustria* Muench., and *Q. imbricaria* Michx.) and American elm saplings. This is the least shaded of the 5 plots studied. Although *C. americanum* is not present on this slope, the mosses *Thuidium recognitum* and *Bartramia pomiformis* form large mats on the soil in this habitat, and small herbaceous plants are present. There is almost no litter layer on plot 5, and the mineral soil is over 15 cm thick.

Maximum-minimum temperature, relative humidity of the air at one cm above the mat surface, soil temperature, potential evaporation, soil pH, soil moisture, and organic matter present in the soil were recorded for each of the five plots.

Microclimatic data were collected four days each week, Monday through Thursday. Care was taken to collect data at approximately the same time each day. Data were recorded on each of the five plots from the initiation of the study on April 19, 1969 until May 8, 1969. On May 9, the equipment on plots 1 and 2 disappeared, so the collection of data from these two sites had to be abandoned. On May 17, 1969 the maximum-minimum thermometer on plot 3 was found to be broken and could not be replaced. From May 17, 1969 through the termination of the study, all categories of data were taken on plots 4 and 5, and all data excepting maximum-minimum temperature were taken on plot 3.

From April 9, 1969, until April 30, 1969, maximum-minimum thermometers were placed on each plot on Mondays, the first day of each week for collecting data. On the next day, the maximum-minimum temperatures were recorded, and the thermometers were taken back to the lab. On Wednesdays, they were reset and placed on the plots to be read again the following day. This allowed two readings for maximum-minimum temperature per week. From April 30, until the termination of the study, the maximum-minimum thermometers were placed on the plots on Mondays, and readings were taken on Tuesdays, Wednesdays, and Thursdays. This allowed three readings per week.

Soil temperatures were recorded at each plot with an Atkins Thermister, model number 3fo1A-F. Readings were obtained with a soil probe that was inserted into the soil, to a depth of one half cm; therefore the soil temperature readings were composite temperatures of the first one half cm of the soil. Four readings per week for each plot visited were obtained with this instrument.

Relative humidity readings were obtained with an aspirated psychrometer. Air for the measurement was taken at about one cm. above the soil surface. Four readings a week for each plot were obtained.

Potential evaporation, or the drying power of the atmosphere, was measured with standardized Bellani plates. On the first day for collecting data of each week, the Bellani plates were placed in holes deep enough to allow the evaporation surfaces to be nearly level and parallel with the soil surface. The volume of water lost from each apparatus was recorded on the following day. They were then taken back to the lab, stored in a container of deionized water, refilled, and placed on the plots again on Wednesday, the third day for collecting data of each week. On the fourth day, the final weekly reading was recorded. This allowed two readings for potential evaporation per week. Care was taken not to leave the plates out for more than one day at a time. This precaution was taken in order to keep the evaporation surfaces as clean as possible. The plates were checked twice during the study to see if restandardization was necessary. The Bellani plates were not put out on rainy days, because exposure to this type of weather can result in a growth of algae on the evaporation surfaces.

The soils of each site were tested as to pH, soil moisture, and the amount of organic matter present. The pH was determined with the use of a soil testing kit. The soil moisture was computed by drying the samples in an oven at approximately 120° C, and organic matter present was determined by ashing the samples.

The data from each plot were statistically analysed. The data in each category (relative humidity, soil temperature, etc.) were sorted as to the type of weather that prevailed on the day each reading was taken. An F test was made on each data grouping. For groups showing a significant F value, Duncans new multiple range test was run. This is a comparison of each treatment mean (mean for one plot) with each other treatment mean.

RESULTS AND DISCUSSION

Data collected in this investigation were separated into several groups before they could be analysed. These groupings are as follows: (1) that recorded from plots 1 through 5, (2) that recorded from plots 3 through 5 only, and (3) that recorded from plots 4 and 5 only (maximum and minimum temperature values only). Each of these groups was broken down into categories corresponding to the type of weather present on the date that each reading was recorded.

Significant differences or statistical separations mentioned in the following discussion refer to the 95 percent level of significance.

Maximum temperature. Maximum temperature data collected from plots 1 through 5, 3 through 5, and plots 4 and 5 were analysed in the following categories: (1) all days, (2) all sunny days, (3) all cloudy days, and (4) all partly cloudy days on which data were recorded.

Plots 1 and 4 (on which *C. americanum* occur) have significantly lower mean values for maximum temperature than plots 5 and 2 on data in the all days grouping. Plots 1, 3, and 4 have significantly lower mean values than plot 5, and plots 3 and 4 have significantly lower mean values than plot 2 for maximum temperature data collected on sunny days. Data collected on cloudy days shows plots 1 and 5 (with the lower mean values) separating statistically from plot 2.

Differences among maximum temperatures for plots 3 through 5 were found only for cloudy days. Plot 4 has a significantly lower mean temperature than plots 3 and 5.

When plot 4 (*C. americanum* present) is compared with plot 5 for the entire study period, a significantly lower mean maximum temperature is found for plot 4 for the all days and all sunny days categories.

The results of the maximum temperature study show that plots 1 and 4 (where *C. americanum* occurs) generally have significantly lower maximum temperatures than plots 2 and 5 where the moss does not occur. Plot 3 generally has a maximum temperature near that of the cooler plots 1 and 4.

Minimum temperature. Minimum temperature data for plots 1 through 5, 3 through 5, and 4 and 5 only were separated into the following weather categories: (1) all days on which data were recorded, (2) all sunny days, (3) all cloudy days, and (4) all partly cloudy days.

Plot 2 (*C. americanum* absent) is significantly warmer than plots 1, 3, and 5 on cloudy days, while plot 5 is significantly warmer than all other plots on sunny days. On all days that minimum temperatures were recorded for plots 1 through 5, plot 5 is significantly warmer than plots 1, 3, and 4; while plot 2 is significantly warmer than plots 1, and 3.

Statistical analysis of the minimum temperatures recorded for plots 3 through 5 indicates a difference for data recorded only on sunny days. In this category plot 5 is found to be significantly warmer than plot 3.

No significant differences are found for data concerning plots 4 and 5 only.

The results of the studies on minimum temperature indicate that the plots on which *C. americanum* occur (1 and 4) have significantly lower minimum temperatures than plots 5 and 2. Plot 3, on which *C. americanum* is not present, generally has minimum temperature values near those of the cooler plots (1 and 4).

Relative humidity. Relative humidity data from plots 1 through 5, and plots 3 through 5 only were separated into the following weather categories: (1) all days on which data were recorded, (2) all sunny days, (3) all cloudy days, (4) all partly cloudy days, (5) all rainy days, and (6) all nonrainy days.

A significant difference among plots 1 through 5 is found for all days, all nonrainy days, and all sunny days on which this data were collected. Plot 5, with consistently lower mean values for relative humidity, separates statistically from plots 1, 2, and 4.

A statistical separation among plots 3 through 5 is found for all days, all nonrainy days, all partly cloudy days, and all sunny days on which relative humidity data were collected. Plot 5, with consistently lower mean values for relative humidity is significantly different than plots 3 and 4 in each of the above mentioned weather categores.

Plot 5 is a different type of habitat than plots 1 through 4 in terms of relative humidity. Plots 1 and 4, on which *C. americanum* occurs, do not separate statistically from plots 2 and 3 where this moss is absent; but it is evident that the plots on which *C. americanum* occur have comparatively high relative humidity values

Potential evaporation. Potential evaporation data from plots 1 through 5, and from plots 3 through 5 were separated into the same six weather categories as the relative humidity data.

Plot 1 is found to have a significantly lower potential evaporation rate than plots 2, 3, and 5 for the data collected on all days, and plot 1 is also found to have a significantly lower rate of potential evaporation than plots 2 and 5 for data collected on nonrainy days.

A statistical separation of plot 4 from plots 3 and 5 is found for data collected from plots 3 through 5 only on partly cloudy, sunny, nonrainy, and all days on which this data were collected. In each above mentioned category, plot 4 has a significantly lower potential evaporation rate than plots 3 and 5.

The results show that the plots where *C. americanum* occurs (1 and 4), are more protected or have lower rates of potential evaporation than the plots where it does not occur.

Soil temperature. The soil temperature data for plots 1 through 5 and plots 3 through 5 were separated into the same six weather categories as the relative humidity data.

No significant differences are found for soil temperatures recorded from plots 1 through 5. This is unexpected when compared to the data for plots 3 through 5, where plot 5 has significantly higher soil temperatures than plots 3 and 4 in the cloudy weather category, and each plot is significantly different in terms of soil temperature than the other plots for sunny, nonrainy, and all days on which this data were taken. In the last three weather categories mentioned, plot 4 has the lowest mean values for soil temperature while plot 5 consistently has the highest mean values.

Plot 1 has mean values for soil temperature that are approximately as low as those found for plot 4 in the data from plots 3 through 5, but significant differences are not found in data concerning plots 1 through 5. The reason for this may be that there are fewer samples of data to work with for plots 1 through 5 than for plots 3 through 5. It may be seen, however, that plots 1 and 4, on which *C. americanum* occur, have relatively low soil temperatures when compared to plots 2, 3, and 5.

Soil pH. A statistical analysis of the soil pH for plots 1 through 5 was not possible since only one sample was taken. A statistical analysis was made on data collected from plots 3 through 5, and each plot is found to be significantly different than each other plot. The soils on plots 1 (pH of 5.75) and 4 (pH of 5.40, a mean value) on which *C. americanum* occur, are more acid than that of plots 2 and 3 (each with a pH value of 6.50). Plot 5, with a mean pH value of 4.88, has the most acidic soil of any plot studied.

Soil moisture. No significant differences among the plots were found for soil moisture data. Some of the soil samples were taken when the soil moisture was near field capacity, and others were taken when the soil was relatively dry. It is expected that the similar habitats would have proportionate values for soil moisture in dry times as well as moist times, but no reliable trends toward grouping the plots on the basis of soil moisture are found.

Organic matter. The results of the studies on the organic matter present in the soil of the plots show no significant differences among the plots.

Stability of mats. Observations during the study indicated to the investigators that the mats of *C. americanum* on plots 1 and 4 were expanding rather than being invaded by adjacent moss mats or by vascular plants.

CONCLUSIONS

The results of the microclimatic studies on *C. americanum* are summarized in Table I.

Plots 1 and 4, where *C. americanum* occur, are found to be similar for all types of data recorded. Both plots have relatively low maximum and minimum temperatures, high relative humidity of the air layer directly over the plots, relatively low rates of potential evaporation, relatively low soil temperatures, and soils that are moderately acidic. The apparently expanding nature of the *C. americanum* mats on plots 1 and 4, and the lack of invasion of these mats by adjacent moss species and vascular plants indicates that these habitats are well suited for the growth of *C. americanum.*

Plot 5 is a different type of habitat than plots 1 and 4 in that it has notably higher maximum and minimum air temperatures, higher soil temperatures, lower relative humidity, a higher rate of potential evaporation, and a more acidic soil.

Plot 3 is found to be a different type of habitat than plots 1 and 4 only in its higher rate of potential evaporation, somewhat higher soil temperatures, and almost neutral soil pH.

Plot 2 is found to be different than plots 1 and 4 in its higher maximum and minimum air temperatures, higher soil temperatures, higher potential evaporation rates, and almost neutral soil pH.

A set of environmental factors that limit the distribution of *C. americanum* are not positively found in this study. Therefore, the results of this investigation are not definitive. However, the high levels of significance found for potential evaporation, soil pH, maximum and minimum temperature, and soil temperature are strong indications that these could be limiting environmental factors concerning the distribution of this bryophyte. More data is necessary before the actual limits imposed on the distribution of *C. americanum* by these environmental factors can be determined.

TABLE I. Summary of Microclimatic Data.

Plot	Maximum temp.[1]	Minimum temp.	Relative humidity	Potential evaporation	Soil temp	pH
*1	Low	Low	High	Low	Low	Acid
2	High	High	High	High	High	Neut.[2]
3	Low	Low	High	High	Inter.[3]	Neut.
*4	Low	Low	High	Low	Low	Acid
5	High	High	Low	High	High	Very acid

* plots where *C. americanum* is present.
1 temperature
2 neutral
3 intermediate

Two other variables that may be of significance in limiting the distribution of *C. americanum* are the amount of shading afforded a particular habitat, and the relative amount of litter present. Both plots on which *C. americanum* occurred were well shaded and almost completely devoid of any litter layer.

The results of this investigation also indicate that unsuitable habitats may fail to meet environmental requirements for a particular species during certain types of weather only, or during certain portions only of the growing season.

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