SOME ASPECTS OF THE ECOLOGY OF TILIANDSIA RECURVATA L.
IN SOUTHERN ARIZONA

by
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STATEMENT BY AUTHOR

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ABSTRACT

The distribution of ballmoss, Tillandsia recurvata L., in southern Arizona is described. Its restricted canyon occurrence is interpreted to be the response of a highly specialized tropical xerophyte to generally severe environmental demands occurring on a border of its geographical range. The results of a vegetational and climatological study made from October 1966 to October 1967 in Flux Canyon, Patagonia Mts., are presented.

It is suggested that water needs are met by trichome absorption of the microrunoff from evergreen oak leaves and bark. Also suggested is periodic metabolic quiescence during unfavorable seasons. Information from an observed heavy frost, and circumstantial evidence from spatial considerations lead to the expressed belief that the effects of winter cold are largely modified by host tree canopies and the peculiar closeness of the canyon walls where ballmoss is found. These provide, respectively, shields against heat loss and reradiative, "heater," effects.

A review of the specialized adaptations in the species is presented. Speculations concerning the "prehistory" of the species in Arizona in view of its modern plant associations is also included.
INTRODUCTION

When the educated observer happens upon one of the isolated pockets of Tillandsia recurvata L., the ballmoss, in southern Arizona, his typical response is puzzlement. He is likely to regard the spidery grey epiphyte with wonder and ask something like, "What is a jungle-dwelling plant like you doing here in the desert?"

It was the original purpose of this study to answer this single question, but the question proved polycephalic. Two are readily apparent within the original: one is historical, "How did it get here?"; the other is broadly ecological, "How can it survive here?" For the first of these implicit queries there can be, at present, no definitive answer. However reasonable the educated guesses, the facts might be unpredictably otherwise. It could be that some wandering central Texas cowman who liked the plant, spotted a few seeds in likely places, partly to please himself and partly as a practical joke on whoever came after.

The second question is easier to approach, and answers obtained from its investigation may illuminate the shadowy problem of origins and travels. Resultantly, a large part of this study concerns an attempt to describe the ecological factors affecting the growth and reproduction of ballmoss.

1. The names used for Arizona plants in this manuscript are those given by Kearney and Peebles in *Arizona Flora* (1951).
Figure 1. Tillandsia recurvata and Phorodendron sp. on Juniperus monosperma Deer Canyon, Rincon Mts., Ariz. Approximate height of the juniper is 30 ft. (10 m.)
CHAPTER 2

THE BIOLOGY OF TILLANDSIA RECURVATA L.

Taxonomic Affinities

*Tillandsia recurvata* L., the ballmoss, is not a moss but an angiosperm. Within the monocotyledonous plants it is of the order Liliales and family Bromeliaceae. The *Tillandsia* genus is large and confined entirely to the New World.

The species type locality is Jamaica. Early systematic studies were done by Mez (1896, 1904). Recent taxonomic contributions have been those of Lyman B. Smith who has placed the species in subfamily Tillandsioideae and subgenus Diaphoranthema (1938: 61).

Morphology and Anatomy

Seeds

The plumed seeds of ballmoss are borne in a capsule, fruit of a spicate inflorescence, and are dispersed by the wind when the capsule splits into three valves from the tip. It is often seen in Arizona that the plumes tangle in such a way that the wind cannot separate them nor dislodge the seeds from the capsule, in which case one can find them germinating within the open fruit after the monsoonal summer rains begin. Birge (1911) claims vivipary for the species in more humid regions. This seems very likely. The small (6 x 0.4 mm), linear seeds have little
food reserve for long life outside the fruit, and germinate at once when exposed to mild temperatures and adequate water.

Within the Liliales, only *Tillandsia* has plumed seeds (Ridley, 1930). There are about 50 of these per capsule. The hairs of the coma are colorless like the seed coat. The seeds cling tenaciously to any roughened surface, a very useful characteristic for an epiphyte. The external morphology of a mature seed is shown in Figure 2 as are diagrams of portions of the seed.

In using propiocarmine stain to observe cell contents, the hair shown in Figure 3 was observed to absorb stain from the broken end with a violent pulsing action from cell to cell along its length, until fluid filled the large inner space of the hair. The cells that make up this inner space appear to have cell contents, and their walls do not coincide with the "joints" of the barbed hair. The possibility is suggested that the coma itself may aid in water absorption. This would be especially convenient in early germination since the special absorbing scales of the epidermis are as yet undeveloped.

**Germination**

It is easy for a temperate zone investigator, unused to working with wild, tropical monocots, to misunderstand germination in the *Tillandsia*. Possibly this is why Billings (1904) observed no germination for *Tillandsia usneoides*, Spanish moss, in his studies. Willie Dirge, whose 1911 publication is the only good, detailed reference in English on *T. recurvata*, records no difficulty with germination of Texas ballmoss, and in my work with Arizona plants, germination was quick and
Figure 2. Seed of ballmoss
   a. a capsule with seeds
   b. one seed with coma
   c. one seed without coma
   d. seed embryo without seed coat
   e. internal detail of embryo, 1 epicotyl
   f. germinating embryo, 1 epicotyl

Figure 3. Seed hair of ballmoss
Figure 2. Seed of ballmoss

Figure 3. Seed hair of ballmoss
in high (+ 80%) percentage. There is an observational prejudice to be overcome. One must not expect radicle emergence. The roots are rudimentary; their function is as holdfasts. In fact, until three months had gone by, I did not observe even cotyledon emergence. Instead, resumption of embryo growth after capsule ripening (what we may call germination) can be observed macroscopically by the fact that the seed imbibes water, swells, and turns green. Evidently the transparent seed coat allows passage of the wave lengths of light essential for photosynthesis, and for adequate gas exchange. Microscopic examination shows cell division beginning at once on addition of water.

According to Birge (1911), the seedling will discard the seed coat at the end of the second year when the roots can take over the anchoring function from the coma. Whether this process takes more or less time in Arizona, I cannot answer. In Figure 10 young plants are shown.

Germination does not occur in Arizona until the summer rains come in July even though capsule opening takes place over several months. Seedlings within the seed coat can be observed soon after the monsoon begins.

During the middle of December 1967 I collected capsules from Deer Canyon which opened 5-6 weeks later, after being stored in a dry, gas-heated home. In the field, capsules in Flux Canyon began opening the first of March and continued through the spring and early summer, probably the most arid time of year in southern Arizona. I submit that here the essentially viviparous seeds are maintained in a dormant spring condition by drought alone. It also seems indicated that capsule matur-

ity can be hastened by especially dry, warm conditions.
Seedlings

Examples of the tiny seedlings may be seen in Figure 4. From field observation, I would guess that mortality is quite high among plants dependent on the coma for anchoring. During August of 1967, a cluster of new seedlings on an oak stump in Flux Canyon was apparently doing well, but by midwinter had disappeared, blown away or eaten by some animal.

Birge (1911) describes the "ball" formation and gives some relative growth rates for the Gulf Coast plants. There is no comparable information from Arizona although since the effective growing season is only 2½-3 months long at most--this being the summer rainy season--one expects slower growth in Arizona.

Mature Plants

The mature plants are grey in color, tufted and epiphytic in life form and resemble clumps of grey grass roosting in a tree. A clump measures 10-20 cm. across (Biebl, 1964). Single individuals are hard to spot in the tree canopies, but where abundant, ballmoss is startling in its luxuriance, as seen in Figure 1 and Figure 15.

This Tillandsia is not of the "tank" type. That is, it does not collect and hold a reservoir of water in the cupped leaf bases against drought (Foster, 1945). The cylindrical leaves during wet weather are turgid, even succulent, yet during dry months they shrink, become longitudinally grooved, and may shrivel at the tips.

Stomata in Tillandsia are thought to be nonfunctional, usually being found closed; Billings (1904: 117-119) recounts unsuccessful
Figure 4. Seedlings of ballmoss with coma and seed coats still attached (To the left of the 2 cm. rule marking, on the dead Rhus choroiphylla branch)
attempts to open them and also describes thickened projections from subadjacent parenchyma which he thinks might actually serve to prevent stomatal opening. No sectioning of Arizona plants was done, but on an occasion in working with young seedlings, one open stomate was observed; all others were closed.

Scales

The most unique anatomical feature which has yet been studied in the genus is the absorbing scales which entirely cover the epidermis. The function of water absorption has been transferred from the roots to these special organs which are variously called scales, trichomes, peltate scales, suck-scales, trichompomps, and water absorbing epidermal hairs.

According to Billings (1904: 115), Schimper, in his publications of 1884 and 1888 (See references for full citation) was the first to call attention to the water absorption function of the scales, and his experiments along this line were "...so complete as to leave little else to be done." Schimper (1884, 1888) believed that the cells of the head (see Figure 5) were air-filled when dry and that water entry through them was by osmosis. Once water had entered, the head cells became turgid, raising the wings of the scales above the epidermis and permitting gaseous exchange. The stalk and basal cells allow water passage freely and serve as intermediaries between the head cells and the water storage cells dispersed throughout the chlorophyllous parenchyma. (All these observations were for Tillandsia usneoides scales.) Birge (1911) found that the scales of T. recurvata originate in much the same way
Figure 5. Peltate scales of the genus Tillandsia
a. stem of Tillandsia usneoides showing covering of scales
b. top view of one scale
c. side view of a scale; 1 head cells, 2 stalk cells, 3 basal cell, 4 epidermis, 5 aqueous tissue
Figure 5. Peltate scales of the genus *Tillandsia*.
as Billings describes for _T. usneoides_. Drawings of bryum moss scales are found in Figure 5.

Billings thought that the water storage cells would lose water to keep the food-producing chlorenchyma turgid. "Even after a plant has lost one fourth of its weight by transpiration, and the leaves have become grooved by contraction, the chlorophyll-bearing parenchyma is unhurt" (1904: 116).

Birge (1911), Billings (1904) and Haberlandt (1914: 725) quote Mez, writing in 1904 after Schimper's investigations (see references for full citation), as correcting Schimper's detail of the absorptive process. Rather than being air-filled, the head cells collapse when the plant is dry. The thickened part of the scale swells on wetting, raising it and causing the lumen to reappear in the collapsed cells. A partial vacuum is then created. The cells, in this view, then "suck" water in from the exterior capillary spaces. Once the head cells are filled, water movement proceeds osmotically as visualized by Schimper.

As indicated by Haberlandt (1914), Mez's suction theory was assailed by Steinbrinck in 1905 (see references for full citation) with various objections to the suction idea being raised, and with absorption being held due only to the natural cohesiveness of water.

This controversy over active suction versus passive absorption is not settled, but in the BASIC abstracts of a 1964 paper by Dolzmann (complete citation in references) there is some indication that Mez may have been right. The head cells were studied by electron microscopy. The micrographs showed several morphological peculiarities. Prominent
among these was "an intermediate substance," capable of swelling, but not yet properly identifiable, present between the cell protoplasm and the external cell wall and differentiable from the protoplasts proper by a doubly contoured plasmalemma. Dolzmann thinks that water uptake is an energy-demanding process involving changes in membrane permeability.

Analogous Water Absorbers

It is interesting that in New Zealand, *Astelia solandri*, of the Liliaceae, a tussock plant, epiphytic on the trunks and branches of trees, has special organs which conduct water from the outer cellulose layers (composed of coalesced hairs) of the lower epidermis, through the very thick cuticle to the mesophyll (see Figure 6 diagrams of this analogous water absorption mechanism). A further point of comparison is that the stalk cells of *Tillandsia* and the body cells of *Astelia* both possess dense protoplasm and large nuclei.

Certainly it is easy to agree with Haberlandt (1914) that the water absorbing scales of the Bromeliads are very highly specialized, but one is tempted to think that *Astelia* is on the same evolutionary path that *Tillandsia* has taken.

Cytological Details

Two other remarkable cytologic features deserve mention in *T. recurvata*. Birge (1911) and Billings (1904: 113-114) describe mega- and microchloroplasts, the former apparently being aggregations of the latter, the clumping taking place in response to increase in light intensity. With Arizona material, ordinary round chloroplasts 5μ in
Figure 6. Absorbing structures of the genus Astelia
a. cross section of lower epidermis;
   1 cellulose layer composed of coalesced hairs, 2 cuticle,
   3 epidermis, 4 aqueous tissue,
   5 water absorbing organ
b. surface view of lower epidermis of leaf, seen through cuticle;
   1 stoma, 2 water absorbing organ, 3 epidermis
Figure 6. Absorbing structures of the genus *Astelia*. 
diameter were seen in 7-day old seedlings; the microchloroplasts were about 1μ in diameter and undergoing constant agitation like that of Brownian movement.

In 41-day old Arizona seedlings, large numbers of cells from the growing shoot possessed sickle or leaf-shaped nuclei. Younger material did not have this character.

Cell walls stain reddish with Sudan III, indicating lipoid substances, and have a shining blue flourescence under the flourescent microscope according to Biebl's 1964 publication (see full citation in references) as translated in BASIC Abstracts.

Flowers

In the vicinity of Austin, Texas, ballmoss flowers in mid-June (Birge, 1911). In Florida, the blossoms open in August or September (Craighead, 1963). In Arizona, flowering awaits the rains, and in 1967, after a severely dry winter, began in the last week of July, and was over by the end of the first week in August. Although Foster (1945) used ethylene gas to initiate early flowering with some bromeliads, he does not report using it on ballmoss.

To the casual eye, the blossoms are pale lilac in color and inconspicuous. The perfect, regular flowers are borne in a spike and possess three stigmas, six stamens, six perianth segments, the inner three of which are colored (Kearney and Peebles, 1951). No concrete information on pollination mechanisms is available.
Water Relations

The omnipresent peltate scales absorb any liquid water on the plant surface. They also restrict transpiration by closing when conditions are dry. It has been found by Biebl (1964) and Garth (1964) that ball moss cannot utilize atmospheric moisture. Water must be in liquid form to enter the plant. This is in opposition to the assertion of Penfound and Deiler (1947). Two observations from Arizona seem to bear out Biebl and Garth. In Deer Canyon (Figure 8) where ball moss is abundant, plants were observed growing out of the bare rock on an intermittent waterfall (Figure 7), but this was only where the plant actually received runoff, as shown by the water stains on the rock. Also, a clump of *T. recurvata* hung in a humid University of Arizona greenhouse for several years, and which was sporadically watered, managed to survive but did not flower (Mineral deficiency may figure in this.). Biebl (1964) found that a one-hour rain (intensity unknown) did not completely compensate for a water saturation deficit of 60 percent, and that shoots laid in water require 4-5 hours to become fully saturated.

The osmotic concentration of leaf fluids has been determined. Harris (1918), using cryoscopic methods, found *T. recurvata* to average 5.8 atm. in subtropical Florida. He found this to be far lower than the values for terrestrial flora in the same area. We must extrapolate for the Arizona values. He found the osmotic values for the vegetation of rocky slopes, canyons and arroyos here to average between 13 and 16
Figure 7. Ballmoss in Deer Canyon, Rincon Mts., Ariz., growing on a dry, intermittent waterfall. Note the coincidence with water stains. Waterfall is about 35 ft. (10.6 m.) high.
atm. If the local ballmoss values are anything close to those in Florida, support is lent to his thesis. But actual measurement of osmotic concentrations of ballmoss has yet to be done.

Biebl's value (1964) from limit plasmolysis on plants from Puerto Rico was 6.3 to 8.5 atm. He utilized leaf parenchyma cells.

Several authors, among them Birge (1911), Schimper et al (1903: 199), and Haberlandt (1914), credit the extension of *T. recurvata* into dry areas to the ability of the plant to absorb dew.

Foster (1945) asserts the plants will die if exposed to too much moisture. Birge (1911) was also of this opinion and pointed to the lack of ballmoss in swampy areas along the Texas coast.

**Mineral Nutrition**

Bromeliads in general prefer an acid substrate. According to Foster (1953) they will not grow in anything above 8 pH. He, and Wherry and Capen (1928), support the contention that minerals enter the plant in solution through the scales.

Biebl (1964), from personal observation, gives greater mineral availability as a possible major reason for the abundant growth of ballmoss on utility wires in urban Puerto Rico. He claims that overland wires, passing through rural areas, support no such colonies.

The Arizona localities are contact zones between granitic and volcanic rocks. One wonders how this combination of dusts might meet the mineral nutrient demands of the plants.
Figure 8. Map of ballmoss sites in Arizona
Gas Exchange

Presumably, carbon dioxide exchange is through the scales and therefore is restricted to those times when water availability is high. This could be a reason for the slow growth and maturation of the plant.

Parasitism

I have found no scientific investigator who seriously entertains the idea that *Tillandsia recurvata* is either parasitic or saprophytic on its hosts. The clearest evidence for its independence comes from its ability to thrive on wires and bare rocks (Figure 9). However, Birge (1911) is of the opinion that dense colonies may shade out the support tree. This seems a possibility on considering a heavily laden host like the juniper in Figure 1. I was once told, by a Texas cattleman in Real County, that he thought some of his trees had been killed by ballmoss in this fashion.

The word "host" is a poor one, implying saprophytism or parasitism as it does, but it is in the literature. No better alternative is in use than "substrate" which implies non-living material.

**Genetics**

The chromosomes of ballmoss were studied with the intention of obtaining a karyotype. The following method was used:

1. Germinating seeds were immersed in Carnoy's Solution for 24 hrs.
2. The seeds were removed and placed in 70 percent ethyl alcohol until ready for use.
Figure 9. Ballmoss growing on rock, Deer Canyon, Rincon Mts., Ariz.

Figure 10. Young ballmoss plants in Flux Canyon, Patagonia Mts., Ariz. Ruler shown is 6 in. (15 cm.) long
3. The seeds were dissected in propiocarmine, squashed and subjected to mild heat and repeated propiocarmine.

Unfortunately the euchromatin was not visible using this squashing and staining procedure. Karyotyping was therefore impossible. However, rather consistent and very prominent heterochromatic regions were observed, and from these a 16 chromosome somatic number is postulated. The base number for the genus is 4 (Pittendrigh, 1948).

Birge (1911) covers the cytological developments involved in fertilization and embryo development.

Ecology and Geography

Factors Influencing Range

Within Arizona, Tillandsia recurvata is restricted to a few canyons in the southeast corner of the state. It is the only bromeliad in Arizona. It is probably no accident that the plant resides within the portion of Arizona which is considered part of the Mexican biotic province, since it is found extensively in northern Mexico. The international boundary is no phytogeographical border.

Ballmoss does not occur in California nor is it known from New Mexico or west Texas. The lack of it in New Mexico we may tentatively ascribe to the coldness and aridity of the southern portion which lies closest to the Mexican source of supply for seeds. The absence in California may be due to two things. Along the coast, the best rainy season is in the winter, quite the reverse of northern Mexico and southern Arizona. On the southeast of the Sierra Nevada is an extensive
very dry region where there is probably not enough moisture at any time to support it. With regard to the timing of rainfall, it was noted by Dr. Raymond Turner (personal communication, 1966) that the Baja Californias are a meeting ground for the summer and winter precipitation patterns. According to him, Baja California proper, to the north, does not get the summer rains, or ballmoss, whereas the territory Baja California Sur does.

Its extent in Texas appears bounded by aridity on the west and too much moisture on the east since ballmoss follows the 20-30 in. rainfall line, and in the north it stops not far from Austin where cold may be the deciding factor (Birge, 1911).

The species is also known in Florida and in many places along the rest of the Gulf Coast where it is associated with *Tillandsia usneoides* L., the Spanish moss. Lawrence (1951) gives Virginia as the northern boundary of the *Tillandsia* genus, Argentina as the southern.

**Hosts**

As Birge found in Texas, so I have found in Arizona, ballmoss grows on nearly any tree or other suitably wet substrate in the areas where it occurs abundantly, but it prefers rough bark and non-coniferous foliage. Although it grows on saguaro and ocotillo it does not appear on sycamore. It is rarely found on pine. Geiger (1965) remarks that 20 percent of the rainfall runs down a deciduous tree's trunk whereas 5 percent or less does on spruce. Therefore if the rainfall is marginal, an oak trunk would be a less xeric site than a pine or smooth-barked sycamore.
In Arizona the chief substrates are the evergreen oaks, the hackberries and junipers. In the western Sierra Madre region it inhabits the open pine forest and scrub oaks; in the Chihuahuan desert, the chaparral Zizyphus, Condalia, Koeberlinia, Opuntia, Parkinsonia, and Acacia; in the Antilles, St. Croix and Virgin Islands a spiny grey chaparral formation (Harshberger, 1911).

Light

Birge (1911), Craighead (1963), Foster (1953), Pittendrigh (1948), all claim that T. recurvata is strongly light-demanding. In the multiple stories of a jungle, it belongs to the highest stratum. Foster (1945) says it grows in the fourth stratum of the Brazilian Mato Grosso forests. In Texas it is found on upper branches rather than lower ones.

Wind

Craighead (1963) claims good storm resistance for it. Certainly there must be some wind if there is to be seed dispersal.

Temperature

Craighead (1963) and Foster (1953) cite prolonged freezing temperatures as important in restricting the occurrence of ballmoss.

Dew

Several authors attribute the survival of ballmoss in xeric regions to its ability to absorb dew that condenses on its surface (See Haberlandt 1914: 236-243).
Under heat and dryness transpiration is indeed much greater, but
the absorption of water is not hindered and the nightly dew is
of direct advantage to the superficial roots of the epiphytes,
whereas under temperate conditions there is no supply of water
to be set against its loss by epiphytes, for the frozen or at
any rate very cold exposed roots transpire, but absorb nothing.
they (the epiphytes) colonized regions with markedly dry
seasons, especially monsoon-forests, savannahs, and savannah-
forests. A limit was set to their success only where the
drought lasted several months without being interrupted regu­
larly by heavy falls of dew; yet there they were able to settle
permanently on the banks of rivers and lakes. The winter cold
more completely arrested the emigration of tropical epiphytes

From the foregoing it might be expected, that in sunny, dry
Arizona, a sub-temperate fringe of ballmoss range, cold would be the
first consideration for survival. Next would be moisture. To offset
high transpiration losses dew must subsidize the scanty rainfall.

Xerophytism

Biebl (1964) cites ballmoss as being the most xerophytic of the
tropical and sub-tropical epiphytes. He quotes Stocker's classification
of T. usneoides and T. recurvata as "Xerophytes with active drought
resistance." Also, Biebl forms a comparison with succulents, to say that
the two groups share a low osmotic value and a certain water storage
capacity. The Tillandsia differ from them, however, besides their outer
form, in reaching and enduring higher water saturation deficits and the
ease with which rainwater is immediately utilized through direct intake
through the scales on their leaves and shoots.

Foster (1945: 14) says of T. recurvata, "This tillandsia has
probably the greatest adaptability of any plant in the Western Hemis­
phere."
CHAPTER 3

ARIZONA SETTINGS

The Arizona ballmoss thus far discovered and reported is restricted to certain canyons of four southern Arizona mountain ranges: the Rincon, the Patagonia, the Atascosa, and the Galiuro. The list of pockets of occurrence that follows should not be taken as definitive. Two of the entries were discovered since I began working on the species in 1966. The most spectacular site thus far located, the one which precipitated this study, was found by Jack McGee that year, and other colonies may well be in existence but unreported.

Areas of Occurrence

Deer and Paige Canyons

Deer Canyon (USGS Happy Valley, Arizona, Quadrangle, 1958. T 14S, R 18E, Secs. 19, 20, Rincon Mts.) from its western entry near Barney's Ranch (elevation 4150 ft. or 1076 m.) to its junction with Paige Canyon (elevation 3550 ft. or 1758 m.) has the best community of ballmoss I have seen in the state. The rock substrate is granite, a little limestone, latite, and andesite with tuff and agglomerate. The sides are steep, averaging 500 ft. or 154 m. high. The ridges on either side support Sonoran desert vegetation including Carnegiea gigantea (saguaro). Tillandsia recurvata grows on all the riparian trees except Platanus.
wrightii (sycamore), even *Populus* sp. (cottonwood), *Vauquelinia californica* (Arizona-rosewood), *Fouquieria splendens* (ocotillo), *Ferocactus* sp. (barrel cactus), saguaro and rocks (Figure 9). *Celtis reticulata* (hackberry), *Juniperus* spp. (juniper), *Fraxinus* sp. (ash), and *Quercus* spp. (oaks) are the preferred hosts.

Here also it is found growing on the mistletoe, *Phorodendron*, which infests *Juniperus* in the canyon (See Figure 1). The discovery of this last host well shows the inconspicuous nature of ballmoss. A young couple of my acquaintance picked a bunch of Deer Canyon mistletoe for their new apartment at Christmastime 1966. One and one-half years later I idly noticed that the cobwebby, dust-dry sprig still hung from their kitchen light. After several moments of peering at it, I realized that there were familiar shapes on its stems. Closer inspection showed many plants of ballmoss. There were even young seedlings, under two years, persistent. Expectably, all of the plants were dead and pale beige in color.

Not until late April of 1969 did I find ballmoss on juniper and ash growing for some distance above Hell's Gate in Paige Canyon (Happy Valley, Arizona, Quadrangle T 14S, R 18E, Secs. 29 and 32). This was most chastening since I had often traveled that part of Paige for pleasure and study. It also occurs between Deer and Bear Canyons in steep gullies of the eastern wall.

It is a matter of considerable interest that Bear Canyon, literally just over the hill to the south of Deer, and also flowing into Paige,
has no ballmoss at all that I can find in spite of several searches.

In both Deer and Paige Canyons, the ballmoss population is superimposed on a typical gallery forest community existing along the more or less permanent waterway within the interdigitation of upper Sonoran and encinal (oak woodland) vegetation zones. It is the case that three usually differentiable life zones are here mixed, providing an exceedingly varied, composite plant community. Within it, Equisetum laevigatum, another rare species, is to be found. (Warning: It should be noted for posterity that Rhus radicans (poison ivy), on the increase throughout southern Arizona, is especially luxuriant in the Hell's Gate ballmoss site.)

Flux Canyon

Flux Canyon (USGS Nogales, Arizona Quadrangle, 1958, T 22S, R 15E and 16E, Secs 25 and 30, Patagonia Mts.) from the 4200 ft. (1273 m.) level to the 4560 ft. (1382 m.) contour has an abundant colony of ballmoss. The steep canyon walls are a maximum of 900 ft. (270 m.) high and the streambed is both narrow and tortuous. The rock substrate is mineralized, decomposing rhyolite, very dangerous to clamber upon. A contrast between this and granite and related crystalline intrusions occurs in the canyon. Many old mines and prospects are found in Flux Canyon, and as future needs for metal grow acute, may well bring about the end of the colony. One glumly envisions a giant, open pit mine where once the wily ballmoss grew among the oaks.

The sheer numbers of T. recurvata plants may well be greater in Flux than in Deer Canyon. Inhabited trees extend for long distances up
the canyon sides, but the density along the canyon bottom is less than in Deer. The number of species utilized as hosts is fewer than in Deer Canyon because hackberry, saguaro, ash, sycamore and cottonwood are absent. Ballmoss was observed to grow on the following species (This should not be considered an exhaustive account.):

- *Quercus emoryi*, emory oak
- *Q. tuomeyi*, toumey oak
- *Q. arizonica*, Arizona white oak
- *Q. grisea*, gray oak
- *Q. hypoleuroides*, silverleaf oak
- *Rhus choriophylla*,
- *Fouquieria splendens*, ocotillo
- *Juniperus deppeana*, alligator-bark juniper

Although some plants typical of the gallery forest are found in Flux, e.g., a lone cottonwood sapling and a small grove of *Sapindus drummondii*, soapberry, it is strongly of the encinal. In and around Flux, oaks cling to the north slopes and ravines. Desert grassland with encroaching mesquite claims the ridgetops and southern exposures.

However, four seldom-encountered gallery forest species occur in Flux whose association is more typical of Mexico than Arizona. (See Gentry, 1942, and White, 1948). These are *Woodwardia fimbriata* J. E. Smith, a large fern represented by two plants (Figure 20); *Juncus xiphoides* and *J. effusus* which fill the streambed over the length where ballmoss occurs; and *Rubus arizonicus* (Arizona dewberry), found at one site only.

Careful observations from the road which follows the high east wall of Flux reveal occasional, isolated tufts of ballmoss on the oaks and junipers.
Sycamore, Peñasco and Atascosa Canyons

Sycamore Canyon (USGS Ruby, Arizona Quadrangle, 1957, T 22S and 23S, R 11E, Secs. 14 and 23, Atascosa Mts.) flows toward the international boundary west of Nogales, Arizona. Two and one-quarter airline miles north of the line it is joined by Peñasco Canyon. Ballmoss has, in the past, been found sporadically in narrow, rocky places along Sycamore from the road end in the north, elevation 4000 ft. (1200 m.) to 1.5 mi. (2.4 k.) south of the Peñasco junction, elevation 3500 ft. (1050 m.). It is scarcer now because tourists in the canyon, which is a preserved biological area, have collected it so often. The most plentiful supply is now in Peñasco Canyon close to the Sycamore junction and in Atascosa Canyon, joining Peñasco from the north about three-quarters of a mile (1.2 k.) from the Sycamore junction.

All three of these canyons have water in pools most of the year, are within the encinal life zone, but exhibit typical gallery forest populations along the bottoms. Geologically, they are rhyolite with the west wall of Sycamore granitic. The ballmoss grows on the same collection of trees and shrubs as in Deer Canyon.

Other Sites Known Only From Herbarium Material

Redfield Canyon, the northernmost of the known locations, is in the southern end of the Galiuro Mts. and is rumored to possess a ballmoss community in the oak zone.

Specimens in the University of Arizona Herbarium also include collections from the Peña Blanca Mts.; a side canyon of Sonoita Creek,
30

\[ \frac{3}{4} \text{ mi. below the Sanford section house in Santa Cruz County, and} \]

"near Sonoita."

None of these areas was personally visited.

In common, ballmoss sites are beautiful, isolated, clifffy little canyons with hidden pools. Typically, the plants are not near the water level, even when the host grows directly in the streambed. They begin about five ft. (1.5 m.) above the streambed and range up to 100+ ft. (30 m.) above it, depending on the site.

Although samples from unreported areas would be of benefit to biologists and other interested parties, these should be placed in public, not private, herbaria for maximum use, and collecting of plants for casual curiosity's sake is inadvisable. This is a rare plant and a unique one in Arizona, and existing here at one of the limits of its range.
CHAPTER 4

THE FLUX CANYON STUDY AREA

Vegetation Survey

Transects

During 1968 a survey was conducted in Flux Canyon with the intention of learning something about the distribution of *T. recurvata* there. Accordingly, 13 line transects were run, 600 ft. (183 m.) apart, taped along the stream course (Figure 11). The exact starting point for #1 Transect was selected by chance but the general starting area was deliberately selected downstream from the known ballmoss (Figure 17). Each transect was at right angles to the streambed although the natural crookedness of the canyon made this criterion farcical at times. The "R" and "L" affixed to a transect number in the text and illustrations refer to the right and left canyon walls respectively as one looks downstream. There is no uniformity of length among the transects. Shrubs and trees were recorded if they intercepted the line (as drawn by a compass bearing) and the line was continued until no more ballmoss could be found along it, or until a ridgetop (arbitrarily equivalent to the canyon boundary) was reached. The length of the transects is in fact unknown; however their vertical extent was recorded in 5 ft. (15 m.) increments by means of an Abney level.
Figure 11. Flux Canyon map showing location of transects and instruments
Number 13 was the last transect because there was no ballmoss on either side of the line at that point, and no obvious bunches farther upstream. The first transect was at about 4160 ft. (1261 m.), the last at 4560 ft. (1382 m.), representing a 400 ft. (121 m.) elevational range for the main population at this locale. The horizontal distance was 1.46 miles (2.34 k.).

Topographically, the canyon at either extremity of the sample line is more open and the walls are less high and steep than in the middle where the ballmoss is found. The high ground on the northeast eventually goes up to 5239 ft. (1587 m.). The northeast bank is only 80 ft. per quarter mile (24 m. per .4 k.) less steep than the southwest bank, but in spite of this, travel on the "L" sides was harder most of the time.

Substrate Species

Vegetationally, Flux Canyon is oak-savannah or oak woodland or encinal. Even on very steep slopes the park-like openness is usually preserved. The understory is mostly warm-season perennial grasses (unanalyzed for this study). The forest is short trees, mostly evergreen oaks.

Emory oak is the dominant. It occurred in all transects except 7L, 7R, and 9L; in these, silverleaf oak and grey oak replaced it. Out of 79 trees supporting ballmoss which were encountered in transects, 72 percent were emory oaks, 14 percent were grey oaks, 9 percent were silverleaf oaks, and the remaining 5 percent were toumey oaks and Arizona white oaks.
Silverleaf oak occurs here some 600 ft. lower than the general range given for it in Kearney and Peebles (1951). It is first encountered about Transect 7, and favors the canyon bottom.

Arizona white oak only occurs in the upper end of the sample line. Grey oak is at lower elevations. It should be mentioned that white oak and grey oak intergrade so that this bifurcation may be illusory.

It is significant that evergreen species house the ballmoss. \textit{Rhus choriophylla}, an evergreen, is an acceptable host; \textit{Rhus trilobata}, although woody is deciduous and ballmoss does not utilize it. Either as shelter or as dew-catchers, the leaves seem important.

Other Canyon Vegetation

As mentioned earlier, cottonwood and soapberry occur close to the stream. Other streamside woody perennials are \textit{Garrya wrightii} (Wright's silktassel), \textit{Rhus trilobata} and \textit{Rhus choriophylla}. On the drier slopes above the waterway were found:

- \textit{Prosopis juliflora}, common mesquite
- \textit{Pinus cembroides}, Mexican pinyon
- \textit{Dodonaea viscosa}, switch sorrel
- \textit{Mimosa biuncifera}, wait-a-minute
- \textit{Erythrina flabelliformis}, coral-bean
- \textit{Fouquieria splendens}, ocotilla
- \textit{Cassia wrightii}, partridge pea
- \textit{Brickellia californica}, pachaba
- \textit{Agave spp.}
- \textit{Selaginella spp.} (in large quantity)
- \textit{Echinocactus spp.}
- \textit{Mammillaria spp.}
- \textit{Lobelia cardinalis}, cardinal flower
- and many other herbs
The waterfall just upstream from Transect 4 and the streambed rock directly athwart the line were covered in all but the driest season with a vivid green mat of leafy liverworts whose exact identities remain unknown. They never produced a sexual stage in either laboratory culture or field. According to Richard Hilton (personal communication) they are close morphologically to the genus Scarpania.

Topographically, the ballmoss site excludes cattle. The 12 ft. (3.6 m.) waterfall just upstream from Transect 4 positively prevents entry from lower Flux. A series of smaller but difficult drops largely closes off the upper end, and although the steep sidewalls are not cow-proof, they discourage all but the occasional determined individuals. As a result, the carpet of grasses and selaginella is essentially unbroken. The small watershed around the site is quite stable (See p. 58).

**Ballmoss Abundance and Extent**

Since it was impossible to count each plant of ballmoss encountered on the transects, five classes of abundance were set up, and each tree, bearing T. recurvata, was classified according to how many plants were judged to grow in it. It is certain that seedlings under two years would have been overlooked. The classes were:

- 1 - 10
- 11 - 50
- 51 - 100
- 101 - 500
- over 500

In all, approximately 4000 ballmoss individuals were sampled (if the midpoint of each class is used in the calculation). Figure 13 indicates the abundance relative to transect number. Contrary to its
Figure 12. Effect of exposure on ball moss height above water along the length of Flux Canyon.
alleged position in humid areas, ballmoss in Flux Canyon is found in greatest abundance in the undercanopy and on trunks (Figures 18 and 19). Vertical height above the stream does not appear to affect this preference.

The ranking of transects with the greatest number of ballmoss plants is 4L > 7R > 6L > 6R > 5L > 10L. Transect sequence versus ballmoss numbers is shown in Figure 13. Where ballmoss extends for long distances uphill, the 1-10 and 11-50 classes are the ones best represented. Thicker stands are only found below 130 vertical feet from the stream itself.

On the other hand, the greatest uphill extent of *T. recurvata* occurs in Transects 4L, 5L and 10L, all of which are NNE-facing slopes. To these should be added 9L, NNW-facing. Here the ballmoss continued strongly over the ridge and into a subsidiary drainage. The transect was stopped because of the arbitrary restriction on studying only Flux itself. Those lines with the next greatest uphill extent are 6L, 7L, 8L, NNE, ENE, and NE-facing, respectively (See Figure 12). Thus, uphill extent and abundance per transect do not coincide.

Transects 1L, 2L, and 3L, also N or NE-facing, have no ballmoss at all; they are below its elevational range in the canyon. 1R, 2R and 3R, SW, SW, and SSW-facing slopes, respectively, have none for the same apparent reason. 13L and R, N and S-facing slopes, respectively, have no *T. recurvata*; they are above its elevational range in the canyon.
Figure 13. Abundance of ballmoss plants per half-transect in Flux Canyon
Figure 14. The hygrothermograph shelter at 4250 ft. (1288 m.) in Flux Canyon, Patagonia Mts., Ariz. Ballmoss is visible in the lower canopy of the *Quercus emoryi* tree.
Although it is not easily seen in the figures, in Transects 10, 11, and 12 the ballmoss shifts slope preference toward the southwest. This may be tied up with increasing elevation and correlated cooler temperatures. Lack of suitable substrates on the right hand transects clouds this general trend, but it is judged a valid observation nonetheless.

**Microclimatic Measurements**

**Instrumentation**

Because of its year-round accessibility and its large sample of ballmoss, Flux Canyon was selected for a year-long microclimatic study. A Forest Service Special Use Permit was obtained in order to build a small platform between two emory oaks whose canopies supported ballmoss. On the platform a standard U.S. Weather Bureau housing was placed (Figures 14 and 16) and within it a Bendix hygrothermograph. It recorded temperature and humidity continuously from October 25, 1966, in October 24, 1967, except for two breaks of four days apiece.

Three maximum-minimum thermometers were installed in the canyon. It was intended that they should detect any marked differences in temperature extremes from the hygrothermograph location. Accordingly, one was hung on an oak in the streambed at road's end well below any known individuals of ballmoss, another about halfway from it to the hygrothermograph, and another at the top of the waterfall upstream from the station (See the canyon diagram for locations). These thermometers were nailed to the north sides of trees and were not protected in any way.
Figure 15. Ballmoss on Celtis reticulata in Deer Canyon, Rincon Mts., Ariz.
No instruments for recording either rainfall or dewfall were used. It was thought that this information could be inferred from the hygrothermograph humidity records. This assumption proved the most serious of several errors regarding the weather instrumentation.

The temperature data obtained from the hygrothermograph is accurate throughout the instrument's range. Readings were tested against several thermometers, a psychrometer, and a thermistor, with perfect (+ 1°F.) agreement.

Temperatures obtained from the max-min thermometers must be considered only suggestive for the following reasons:

1. The instruments were not calibrated before use.
2. They were exposed rather than sheltered.
3. They were not at exactly the same height above the stream.
4. They are not known for their accuracy anyway.

Of these, the third is the least critical. From calculations made on natural changes in temperature with height from Geiger (1965: 84 and 432), and from information in Hayes (1941: 2) it appears that the height differences in question, 5 ft. (1.5 m.) to 15 ft. (4.57 m.) will not vary over a degree, normally. The other reasons are valid.

After its year in the field, the hygrothermograph's humidity sensor was calibrated by Dr. R. E. Hastings and Douglas Warren. Their results confirmed suspicions of long standing. The 50+ year-old sensor was acceptably accurate for only 13 units of its range, between 37 and 50 percent relative humidity. Clearly, neither dewfall nor rainfall was faithfully recorded.
Figure 16. Site of the hygrothermograph shelter in Flux Canyon, Patagonia Mts., Ariz. The inconspicuous nature of the ballmoss community is evident.

Figure 17. Facing upstream in Flux Canyon, Patagonia Mts., Ariz., just downstream from the lowest occurring ballmoss
Figure 16. Site of hygrothermograph shelter in Flux Canyon

Figure 17. Facing upstream in Flux Canyon, Patagonia Mts., Ariz., just downstream from the lowest occurring ballmoss
Slope and Insolation

The preference of ballmoss for NNE-facing slopes in transects 4, 5, 6, and 10 was taken to be a response to some optimum amount of solar radiation sufficient for photosynthesis but not great enough to put insuperable evapotranspiration demands on the plants. An approximation of the magnitude of this incident radiation was obtained by determining the slope of each half-transect and its exposure in the field, then applying formulae as described in Fons, Bruce, and McMasters (1960). Several factors contribute to inaccuracy in these figures. The actual latitude of the site is 31°30' N. The tables used for the calculations provided 30°N. as the nearest approximation. Slope determination was made with a Brunton compass from the stream bottom so that the natural irregularity and change of slope above is not accounted for. Slopes were taken to the nearest 10°. It was necessary to choose a figure for transparency of the atmosphere. On a scale of 0.1 to 1.0, 0.8 was selected, signifying a clear atmosphere, unusually free of smog, dust and cloud, but at only 4500 ft., where there is still half the atmosphere between ground and the sun.

Four L, 5L and 10L, where the greatest uphill extent of ballmoss occurs, receive no or little direct sun around the time of the winter solstice, precisely, December 3 through January 10.

The opposite slopes, 4R, 5R, and 10R receive the greatest calories per centimeter per minute on December 3 and January 10 of any exposures. There is never a day when the southern exposure cannot receive insolation.
Figure 18. Ballmoss seen from under a *Quercus hypoleucoides* tree, Flux Canyon, Patagonia Mts., Ariz.

Figure 19. Horizontally oriented limbs of *Quercus hypoleucoides* with ballmoss on the downhill side, Flux Canyon, Patagonia Mts., Ariz.
Figure 20. The larger of the two Woodwardia fimbriata fern clumps in Flux Canyon. The surrounding stems are those of Juncus effusus.
In addition there is the factor of the deep, narrow canyon. The figures obtained are too high since they are for a tilted surface, but not one shaded by any obstacles such as the opposite canyon wall. Computing the amount of incident insolation actually received by a plant in these circumstances is thus a complex geometric problem. A cleaner approach would be direct measurement.

From Table 1 a general notion of how direct insolation might compare, transect to transect, can be gained. The hours given are those times when it was thought the sun might actually rise high enough in the sky to illuminate the inner canyon slopes.

The comparative "daily" totals do not represent the total direct radiation. They are merely the total calories cm$^{-2}$ min$^{-1}$ for three representative minutes of the day, 10 a.m., 12 noon and 2 p.m. added together to get an idea of how insolation varies with slope and exposure. The table is included because it is an available approximation to the needed data. A similar compilation for 34°N. latitude is included in Table 2. The ballmoss sites in Arizona all fall between these two approximations.

What light and heat the northern exposures experience then must be mostly counterradiation and reflection from the opposite wall of the canyon. The vegetation is of light colored dry grass and oaks, the leaves of most of which are shiny. Some previously mentioned factors may now be considered in this light (or lack of it).

Ballmoss shows a preference for canyons which run along a WNW-ESE line, possessing slopes which are shaded on midwinter days, but whose opposite walls receive more insolation than other exposures.
### TABLE 1

**DIRECT INSOLATION ESTIMATES FOR 30° N. LATITUDE**

<table>
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<th>Transect</th>
<th>%Slope</th>
<th>Exposure</th>
<th>10 a.m.</th>
<th>12 noon</th>
<th>2 p.m.</th>
<th>10 a.m.</th>
<th>12 noon</th>
<th>2 p.m.</th>
<th>&quot;Daily Total&quot;</th>
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<td>NE</td>
<td>.4029</td>
<td>.3647</td>
<td>.1594</td>
<td>.50</td>
<td>.49</td>
<td>.20</td>
<td>1.19</td>
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<tr>
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<td>SW</td>
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<td>.8293</td>
<td>.4904</td>
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<tr>
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<td>.4904</td>
<td>1.19</td>
<td>1.12</td>
<td>.61</td>
<td>1.19</td>
</tr>
<tr>
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<td>.3647</td>
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Formula: \[ \sin \theta \times p^{1/sin A} \times 1.946 \text{ cal. cm.}^{-2} \text{ min.}^{-1} \]

10 a.m.: 1.25
12 noon: 1.35
2 p.m.: 1.25

p = 0.8 = transparency coefficient; slopes to nearest 10°; latitude 30°N.
For: December 3, January 10 only; solar declination 22°

*Slope greater than tables include.
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Formula: \[
\sin \theta \times p \times 1.946 \text{ cal. cm.}^{-2}\text{min.}^{-1}
\]

10 a.m.: 1.20
12 noon: 1.31
2 p.m.: 1.20

p = 0.8 = transparency coefficient; slopes to nearest 10°; latitude 34°N
For: December 3, January 10; solar declination 22°

*Slope greater than tables include.
Ballmoss has no large food reserves nor does it shed leaves in order to survive the winter, therefore it must go on producing food. It may possess, in its dispersable chloroplasts (p. 12) the ability to utilize low intensity light, as from reflection. Its position on the undercanopy would minimize screening of light that comes from the side rather than from above.

The long-wave radiation coming to the shaded slopes from the sunlit ones may serve as a buffer against the cold. The steepness of opposite walls is such that their distance apart is not great for many feet upward.

One postulates a subsistence level of metabolism during the winter, photosynthesis occurring at a slow rate under low light intensity and using small amounts of water. This would also be compatible with increased cold resistance.

Temperature Amelioration

It was suspected that Flux Canyon might experience lower temperatures in the critically dry months of May and June, and might be warmer during the potential times of freezing, December through April, than other places of the same elevation. Accordingly, the maximum and minimum temperatures for 14 weather stations were calculated from USD Climatological Data for Arizona (1966-67), and compared with the hygrothermograph values from Flux. In Table 3 the stations and their elevations are shown. In Appendix A critical data are shown graphically. Table 4 gives the maximums and minimums for Flux itself.
TABLE 3

SOUTHEASTERN ARIZONA WEATHER STATIONS COMPARABLE TO FLUX CANYON

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TABLE 4

FLUX CANYON AVERAGE TEMPERATURE EXTREMES OCT.'66-OCT.'67

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</tbody>
</table>
It can be seen that a somewhat ameliorated climate did exist in Flux during the study period. The station most nearly comparable, vegetationally and elevationally, to Flux is Santa Rita Experimental Range #12. It is 3-4°F cooler in the winter and 1.5°F warmer in the early summer. It is also suggested, from the winter minimums recorded by the maximum-minimum thermometers (See p. 42) that the hygrothermograph station was 3°F warmer than the Halfway Station and this, in turn, was 3°F warmer than the Road End Station. It would seem possible that the lower reaches of the canyon are more of a cold air sink than the stretches colonized by ballmoss.

In a climate as generally sunny as that of southern Arizona there is great opportunity for rocks to store heat during the day. As this energy counter-radiates at night, the narrow defile will stay warmer than a flat field would. The fact that most plants are under the tree canopy will slow their own radiation to the clear night skies.

An interesting frost occurred during the week prior to April 20, 1968, in Flux and in Alum Canyon whose tributary it is. On virtually every oak in Alum and lower Flux, the tender new leaves and blossoms were destroyed, not only along the wide streambottoms but up the walls to 200 ft. (60.6 m.), as far as there were trees. No other blossoms developed. There were no acorns in the autumn. The dead tissue was still largely in place nearly a year later. The lower end of the ballmoss site was also stricken. Many clumps exhibited brown and crumbling leaf tips, but the farther upstream one went, the less damage was evident, one more evidence that minimum temperatures are less severe there.
Ice on the pools in lower Flux was observed once, but on this occasion a thorough investigation of the upper canyon was not made so no comparison is available. Snow fell several times even though the winter was dry. The hygrothermograph recorded freezing temperatures 36 times with the duration of freezing from 1 to 18 hours. The temperature never dropped below 20°F. As might be expected, the hours of freezing tended to occur between midnight and dawn.

In all, 43.5 hours of 32-30°F. cold were recorded; 144 hours of 29-20°F. cold, yielding 187.5 total freezing hours. This represents 35 days on which one or more frosts occurred, from early December to early May. Table 5 shows the freezing periods as recorded by the hygrothermograph.

The only cold weather observed to harm the ballmoss was the extraordinary frost mentioned above which occurred after the time of the hygrothermograph study.

It is supposed that the lack of ballmoss in Transects 1, 2, and 3, irrespective of slope exposure, is attributable in large part to the lower temperatures there. It is guessed that low temperatures also control the upper limit, accounting for the paucity of ballmoss in Transect 13.

Rainfall

The usual pattern of rainfall in southern Arizona calls for a drought in May, June and October (Sellers, 1960). The summer rains, whose source is in the southeast from the Gulf of Mexico, begin about the 4th of July. They are generally of the thunderstorm type and hence
### TABLE 5

**PERIODS OF FREEZING RECORDED BY BENDIX HYGROTERMOMETER #594 IN FLUX CANYON**

<table>
<thead>
<tr>
<th>Date</th>
<th>Duration # hrs.</th>
<th>Temperature °F.</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/9/66</td>
<td>3</td>
<td>32-30</td>
</tr>
<tr>
<td>12/13</td>
<td>0</td>
<td>32-30</td>
</tr>
<tr>
<td>12/15</td>
<td>2</td>
<td>32-30</td>
</tr>
<tr>
<td>12/19</td>
<td>0</td>
<td>32-30</td>
</tr>
<tr>
<td>12/21</td>
<td>.5</td>
<td>32-30</td>
</tr>
<tr>
<td>12/28-12/29</td>
<td>12</td>
<td>29-20</td>
</tr>
<tr>
<td>12/29-12/30</td>
<td>16</td>
<td>29-20</td>
</tr>
<tr>
<td>12/30-12/31</td>
<td>18</td>
<td>29-20</td>
</tr>
<tr>
<td>12/31-1/1</td>
<td>11</td>
<td>29-20</td>
</tr>
<tr>
<td>1/1-1/2</td>
<td>8</td>
<td>29-20</td>
</tr>
<tr>
<td>1/3/67</td>
<td>.5</td>
<td>32-30</td>
</tr>
<tr>
<td>1/4</td>
<td>7</td>
<td>32-30</td>
</tr>
<tr>
<td>1/5</td>
<td>4</td>
<td>32-30</td>
</tr>
<tr>
<td>1/6-1/7</td>
<td>14</td>
<td>29-20</td>
</tr>
<tr>
<td>1/8</td>
<td>8</td>
<td>29-20</td>
</tr>
<tr>
<td>1/8</td>
<td>3</td>
<td>32-30</td>
</tr>
<tr>
<td>1/13</td>
<td>3</td>
<td>32-30</td>
</tr>
<tr>
<td>1/14</td>
<td>4</td>
<td>32-30</td>
</tr>
<tr>
<td>1/17</td>
<td>0</td>
<td>32-30</td>
</tr>
<tr>
<td>1/18</td>
<td>5</td>
<td>32-30</td>
</tr>
<tr>
<td>1/20</td>
<td>2</td>
<td>32-30</td>
</tr>
<tr>
<td>1/21</td>
<td>0</td>
<td>32-30</td>
</tr>
<tr>
<td>1/23</td>
<td>0</td>
<td>32-30</td>
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<tr>
<td>2/6-2/7</td>
<td>8</td>
<td>29-20</td>
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<tr>
<td>2/8-2/9</td>
<td>7</td>
<td>29-20</td>
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<tr>
<td>2/10</td>
<td>4</td>
<td>32-30</td>
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<tr>
<td>2/11</td>
<td>1</td>
<td>32-30</td>
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<tr>
<td>2/18</td>
<td>0</td>
<td>32-30</td>
</tr>
<tr>
<td>2/21</td>
<td>1</td>
<td>32-30</td>
</tr>
<tr>
<td>2/22</td>
<td>3</td>
<td>32-30</td>
</tr>
<tr>
<td>3/6</td>
<td>7</td>
<td>29-20</td>
</tr>
<tr>
<td>3/7</td>
<td>5</td>
<td>29-20</td>
</tr>
<tr>
<td>3/8</td>
<td>1</td>
<td>32-30</td>
</tr>
<tr>
<td>4/12</td>
<td>0</td>
<td>32-30</td>
</tr>
<tr>
<td>4/30</td>
<td>.5</td>
<td>32-30</td>
</tr>
<tr>
<td>5/2</td>
<td>0</td>
<td>32-30</td>
</tr>
</tbody>
</table>
erratic in amount received from station to station. A recent trend is for heavy rains in August and September from tropical storms off Mexico's Pacific Coast.

Winter precipitation is more variable in amount from year to year than is summer precipitation. However, winter precipitation is more uniform from station to station than that of summer. Weekly storms come out of the northwest along the Pacific coast and produce general rains and snowfalls.

Since no rain gauge was placed in Flux Canyon, a reasonable estimate is tendered from the Patagonia, Arizona, weather station, 5.25 mi. (8.4 k.) northeast and 193 ft. (58.5 m.) lower in elevation. The long-term (40 yr.) record for Patagonia is 17 in. per annum. The year of the study, October 25, 1966 – October 24, 1967, was 14.31 in.

It has already been mentioned that 1966-67 was a severely dry winter. The following spring was abnormally arid, too. In Tables 6-7, rainfall information for six weather stations surrounding Flux Canyon are shown. The long-term seasonal precipitation of each was divided into that for the year of the study and the resulting percentages are recorded. The winter season averaged 18 percent of normal precipitation for these stations. The spring was 69 percent of normal, and was followed by a wet summer, 124 percent of normal.

Although Flux is shown as an intermittent stream, it is usually a flowing one at the hygrothermograph station, and can be boisterous during the summer. The stream was silent from the week of April 20, 1967, to the week of June 14, 1967, about eight weeks of drought.
### TABLE 6

**FORTY-YEAR AVERAGE OF SEASONAL PRECIPITATION IN SIX SOUTHEASTERN ARIZONA STATIONS**

<table>
<thead>
<tr>
<th>Station</th>
<th>40-year precipitation mean by season in inches</th>
<th>DJF</th>
<th>MAM</th>
<th>JJA</th>
<th>SON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fort Huachuca</td>
<td></td>
<td>3.86</td>
<td>1.28</td>
<td>8.33</td>
<td>2.98</td>
</tr>
<tr>
<td>Nogales</td>
<td></td>
<td>3.00</td>
<td>1.21</td>
<td>8.44</td>
<td>2.95</td>
</tr>
<tr>
<td>Patagonia</td>
<td></td>
<td>3.33</td>
<td>1.52</td>
<td>9.03</td>
<td>3.13</td>
</tr>
<tr>
<td>San Rafael Ranch</td>
<td></td>
<td>3.25</td>
<td>1.49</td>
<td>9.55</td>
<td>3.10</td>
</tr>
<tr>
<td>Santa Rita Exp. Range</td>
<td></td>
<td>4.66</td>
<td>2.09</td>
<td>9.07</td>
<td>3.75</td>
</tr>
<tr>
<td>Y-Lightning Ranch</td>
<td></td>
<td>2.08</td>
<td>.96</td>
<td>6.61</td>
<td>1.82</td>
</tr>
</tbody>
</table>

### TABLE 7

**SEASONAL PRECIPITATION IN THE YEAR 1966-67 FOR SIX SOUTHEASTERN ARIZONA STATIONS**

<table>
<thead>
<tr>
<th>Station</th>
<th>Precipitation in 1966-67</th>
<th>%Normal Precipitation received in 1966-67</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DJF '66- JF '67</td>
<td>NAM '67</td>
</tr>
<tr>
<td>1</td>
<td>.34</td>
<td>.87</td>
</tr>
<tr>
<td>2</td>
<td>.49</td>
<td>.61</td>
</tr>
<tr>
<td>3</td>
<td>1.20</td>
<td>1.23</td>
</tr>
<tr>
<td>4</td>
<td>.71</td>
<td>.90</td>
</tr>
<tr>
<td>5</td>
<td>.90</td>
<td>2.32</td>
</tr>
<tr>
<td>6</td>
<td>.20</td>
<td>.42</td>
</tr>
</tbody>
</table>
Although I have seen it in flood, I have never seen it muddy. Certainly there must be times when it does not run clear during intense downpours, but the heavy growths of Juncus that fill the streambottom, and the trees and herbs that clothe the sidewalls are proof against most runoff erosion.

Dewfall

The question naturally arises, if Willie Birge's Texas ballmoss follows the 20-30 in. rainfall belt in a region of greater humidity, hence less evapotranspiration, how do the Flux Canyon plants manage on 17 in. in the extremely dry Arizona atmosphere?

It would be pleasant if we could simply say "dewfall" and let it go at that, however, in view of the inaccuracy in the hygrothermograph data, the importance of dew as a water subsidy cannot be accurately assessed. Schimper's hypothesis (see quotations, p. 24) remains interesting but unverified for southern Arizona ballmoss. Such evidence as was gleaned is as follows:

The canyon bottom where it coincides with the ballmoss extent, retains water in pools during even the driest months of very dry years. One therefore supposes a sufficient source for condensation does exist;

From the hygrothermograph data, 13 instances were noticed in which the humidity had risen so steeply, and remained above "100%" for such a time that it might reasonably be postulated that 100 percent RH actually had been achieved with resulting dew or rain. In the absence of rain records from Flux, nearby stations of similar elevation were compared for the days in question to see if rain was the likely result.
For those days when rain did not appear to have fallen, sky cover and dew point in Tucson, 48 mi. (180 k.) north and 1800 ft. (545 m.) lower, were checked to see if the temperatures in Flux were within the range for dewfall. This information is itemized in Table 8. Six possible dewfalls emerge, all within the cold season.

These results are not what one could wish for an easy answer. For instance, one would imagine that dewfall would be needed most in May and June, not December and January.

However, condensation is really to be thought of in terms of individual surfaces and their ability to cool rapidly and to such a degree as to wring out what moisture is available in the surrounding air. No one has tested a ballmoss leaf to see of what it is capable in this regard. Perhaps more importantly, no one has tried out an oak leaf. If dew condenses on them in quantity to drip, the ballmoss under the canopy could certainly absorb this micro-runoff.

The dense stands of ballmoss along the streambottom are likely to be the result of more abundant dew, although the possibility of reduced evaporative loss may not be ignored.
TABLE 8
POSSIBLE DEWFALLS IN FLUX CANYON

<table>
<thead>
<tr>
<th>Hygrothermograph Sheet No.</th>
<th>Date</th>
<th>Time</th>
<th>Nogales</th>
<th>Patagonia</th>
<th>San Rafael</th>
<th>Sky Cover</th>
<th>Av. Dew Pt °F</th>
<th>Assoc. Op. in Flux</th>
<th>Rain</th>
<th>Possible Dew</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>11/30/66</td>
<td>a.m.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>.0</td>
<td>37</td>
<td>41-43</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>7</td>
<td>12/6</td>
<td>a.m.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>.3</td>
<td>46</td>
<td>44-48</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>7</td>
<td>12/7</td>
<td>p.m.</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>.0</td>
<td>34</td>
<td>44-47</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>7</td>
<td>12/8</td>
<td>a.m.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>.6</td>
<td>28</td>
<td>21-37</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>9</td>
<td>12/21</td>
<td>a.m.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>.0</td>
<td>34</td>
<td>44-47</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>9</td>
<td>12/25</td>
<td>a.m.</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>.6</td>
<td>28</td>
<td>21-37</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>10</td>
<td>12/26</td>
<td>p.m.</td>
<td>Known rain in Flux Canyon</td>
<td>Known rain in Flux Canyon</td>
<td>+</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>12/30</td>
<td>a.m., p.m.</td>
<td>+1</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>12/31</td>
<td>p.m.</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>.1</td>
<td>25</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>1/1/67</td>
<td>p.m.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>.9</td>
<td>32</td>
<td>27-34</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>14</td>
<td>1/23</td>
<td>p.m.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>.9</td>
<td>32</td>
<td>27-34</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>37</td>
<td>7/27</td>
<td>a.m.</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>.9</td>
<td>32</td>
<td>27-34</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>43</td>
<td>9/12</td>
<td>a.m.</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>.6</td>
<td>28</td>
<td>21-37</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>
CHAPTER 5

ORIGINS AND TRAVELS

There is an intriguing controversy in the literature which revolves about the ancestral way of life in the Tillansiodcae. As an example of one point of view, Schimper et al (1903: 199) says,

Xerophilous sun-loving epiphytes of the summits of trees, although they represent the descendants of hygrophilous shade-bearing plants, are able to desert the rain-forest. Thanks to their changed characters they are able to inhabit quite open country. Thus they emigrated from the rain-forests and colonized regions with markedly dry seasons, especially monsoon-forests, savannahs, and savannah-forests.

In opposition, we have reasoning like that of Pittendrigh (1948: 54) who sees the Tillandsia positioning in forests as a reflection of

...the evolutionary history of the Bromeliaceae as originally a desert group that has subsequently become highly successful in the upper levels in rain-forest. Their success in xeric epiphytic habitats is due essentially to preadaptations developed as desert saxicoles.

If the desert origin view were correct, ballmoss should be an inhabitant of the Sonoran desert in Arizona. If Shreve and Wiggins' definition of that province be accepted, ballmoss is not within it; it is a part of Sonoran desert vegetation in Mexico, for example, Imuris, Sonora. Within Arizona ballmoss is an oak woodland, not a desert dweller. If the Arizona populations are regarded as typical, this distributional evidence argues for a moist condition to drier environ evolution rather than vice versa. Argument from this base, however, is
futile. We do not know how typical the Arizona population is. It could well be genetically unique thanks to isolation. The distance from Flux Canyon to the nearest Mexican population is less than from Flux to the Rincon Mts. colonies, yet it is well known that linear distance is not the only, nor even the most significant, factor in isolation. Perhaps each mountain range possesses a genetically unique population dating from the rise of the desert which has now made biological islands of the southern Arizona ranges.

It would be worthwhile to take a closer look at the vegetation zone in which the Arizona ballmoss is found. It is properly a Mexican province. The oak woodland of Mexico is areally extensive and economically important. A. Starker Leopold (1950: 516) has commented that the pine-oak forest "...with its temperate, healthy climate, suitable for cultivation of corn, has always been the most important zone as regards human populations."

In eastern Mexico between 3300 (1000 m.) and 6600 ft. (2000 m.), there occur two kinds of oak woodland: that called "pure oak forest" by Miranda and Sharp (1950) which is parklike with trees about 35 ft. (10.6 m.) high, nearly no shrubs, but abundant herbs all year; and that called "mixed oak" which contains cloud forest elements like Liquidambar (sweet gum), Nyssa (sour gum), Carpinus (hornbeam), Carya (hickory), bromeliads and orchids. The cloud forest species point to connections with Tertiary and contemporary eastern United States flora and remind one that Tertiary southern Arizona may have possessed some of these plants. Carya (hickory) pollen is suspected from prehistoric Arizona
(Dr. Vorsila Bohrer, University of Massachusetts: personal communication) and in a very few encinal canyons in southern Arizona the bromeliad Tillandsia recurvata occurs abundantly today.

Since ballmoss is now a common component of the Mexican pine-oak woodland, itself of Madro-Tertiary origin, the genus is probably at least as old as the evergreen oaks. In warmer, wetter times it came with the oak association into southern Arizona. When the climate changed it retreated to the damper, sheltered ravines, and as the desert filled the lowlands the different canyons perpetuated their own strains of ballmoss. Thus we have relict populations.

If we pin our history of ballmoss in Arizona to that of the Mexican oaks, a picture of their history is in order.

During the Cretaceous Period, the area of southwestern deserts today was covered with subtropical and warm temperate forests. The woodland as a distinct entity began with the Tertiary. From Paleocene through Miocene a gradual drying process continued so that grassland prevailed in the incipient desert. Then during Lower Pliocene, the true desert emerged, still with its borders of grass and woodland. Decreased rain in Mid-Pliocene caused the woodland to move uphill, the grasslands interposing in the lowland next to the desert; in short, a composition rather like today's encinal and neighboring zones. With cooler temperatures in the Upper Pliocene the woodland regained lost ground and flourished.

Axelrod (1950), upon whose fossil studies this historical geological reconstruction depends, sees all present-day desert region
flora as evolving from the Tertiary floras of the same region. From southern Arizona to southwestern Texas and south into the mountains of northern Mexico he has defined an Arizona Component of the Sierra Madrean Woodland Element of the Woodland Complex of the Madro-Tertiary Floral Unit. The Arizona Component had: *Quercus emoryi*, *Q. grisea*, *Q. oblongifolia*, *Arbutus arizonica*, *Juniperus*, *Pinus cembroides*, *Robinia neomexicana*, *Sapindus drummondii*, *Celtis*, *Fraxinus velutina*, *Juglans major*, *Platanus*, *Populus*. Essentially, these are all present-day encinal tree species.

There were other components of the woodland in neighboring areas, e.g., Texas, California, Nevada, Colorado, Oklahoma. The species may have varied, but the community aspect was similar. The Madro-Tertiary Floral Unit was doing very well over Mexico and the western United States. Then came the Pleistocene. Here this version of the history is helped along by the pollen data interpretations of Martin (1963). The glacio-pluvial was in this region wet and cool. The northern territory of the oaks was resettled by Arcto-Tertiary species. The southern territory gained a few of the same, and its Madro-Tertiary species shrunk farther southward away from the cold winter. For southern Arizona, Martin (1963) postulates that the present-day northern elements were in the area by 11,000 B.P., late glacial and pluvial end.

Exactly when the demise of the oaks from northern regions began can be argued. The drying, cooling trend of Mid- and Upper Pliocene could have started what the ice age finished. At present there are two major controlling factors of the encinal's areal distribution. One is
the cold winters, which cannot be tolerated. These account for the absence of oaks from the great basin, Colorado and the high plains, for instance. The other is the problem of a summer-wet, winter-dry rain cycle. The Mexican, Arizonan, New Mexican and west Texan encinal species seem to prefer most of their 10-20 in. of precipitation in the summer.

The weather has been getting warmer since the Pleistocene, and the oaks reclaimed much of the mild-winter region. At 4000-8000 B.P. (the so-called Altithermal),

Southern Arizona probably resembled the belt of grassland and encinal found today in Mexico east of the Sierra Madre. During the altithermal species of animals and plants in the Mexican encinal and grassland penetrated southern Arizona and central New Mexico. At this time, the early Cochise gatherers began cultivating corn under the favorable wet summer climate (Martin 1963: 67).

It should be noted that Martin's version of the Altithermal as warm and wet is in apposition to the earlier Bryan-Anteves idea that it was warm and dry.

It is seen, around A.D. 1900, that arid southern Arizona is a meeting ground for two different biotas: one of Cordilleran, boreal derivation which came during the cool, wet Pleistocene and depends on winter rains for its seasonal activity; the second of Mexican origin, liking the summer monsoons and arriving here during some warm, wet period, the most recent of which was the Altithermal. There is a spring-blossoming flora vs. a summer-blossoming flora, and ballmoss is of the latter.

A drier, cooler regime should push this northern extension of the bromeliads into oblivion, if the picture of environmental demands
presented in this paper are truly those of ballmoss. As described by
Hastings and Turner (1965) the oaks themselves are moving uphill as
the regional climate grows drier and warmer. Whether this change will
adversely affect ballmoss is not evident.
CHAPTER 6

CONCLUSIONS

Ballmoss is a tropical and subtropical epiphyte which absorbs water through special scales that cover the entire surface of the shoot. Whereas tropical specimens are found in the outer canopy of forest trees, the Arizona plants are found on the trunks and undercanopies of evergreen, oak woodland trees and shrubs. These positions provide rough surfaces for secure anchoring of the plants. They also probably provide shelter against the drying capacity of the direct sun, a roof against heat loss to the clear night sky, and a vantage point from which to catch moisture dropping from the leaves or running down the bark.

The Arizona plants favor narrow, twisting, precipitous canyons which are oriented in a NW-SE direction. The orientation is probably important because it provides NE-facing slopes which receive little or no direct sunlight during the winter solstice, thereby reducing transpiration losses during a supposed period of metabolic quiescence. The constricted canyons may also afford counterradiation which moderates cold air drainage effects, very important to a frost-sensitive species, and perhaps most important during the mid-winter when the NE-facing slopes are in shadow but the SW-facing slopes receive the maximum available insolation.

Snow, ice and freezing temperatures of as low as 20°F. for as long as 18 hrs. were recorded during 1966-67 in the main study area.
Since the temperature-sensing device was in a tree beside several ballmoss plants, it is reasonable to assume that the adult plants are not seriously damaged by cold in this magnitude and duration. If one factor must be selected as most important to the ecology of the Arizona populations, it would be freezing temperatures.

In the main canyon studied, permanent water exists in pools the year around, and it is thought that from this moisture source dew supplements the 17 in. of average yearly precipitation available at this location. The largest number of plants per tree are found close to the streambed (under 150 vertical feet or 45 m.). Extension of colonies above that level is dependent on exposure. The NE-facing slopes have the greatest vertical extent, up to 390 ft. (118 m.). The SW-facing walls exhibit little or no ballmoss above the stream.

On geographical evidence it is probable that ballmoss in the Arizona, Sonora, and the Baja Californias area is keyed to the summer monsoonal rains which last from July through mid-September. Flowering and seed-set are precipitated by their arrival following the hot and severely dry spring and early summer. A secondary drought follows in the fall. Since no large water reservoirs exist in the plant body, and the first frosts begin in November, the true growing season probably terminates in September or October.

It is likely that the scattered, canyon-dwelling populations of ballmoss in Arizona are relict stands, separated by the rise of the Sonoran desert since Pliocene times. It is also likely that the fate of these communities is tied up with the areal expansions and contractions of the oak woodland, the zone in which the species is presently
found. It is hypothesized that the oak-ballmoss association is of ancient origin and not fortuitous.
CHAPTER 7

FUTURE LINES OF RESEARCH

Permanent stakes, consisting of lengths of iron pipe, were placed on each half-transect so that the transects could be relocated in the future. Aluminum tags were set on them for identification. Photographs of each half-transect were taken from the streambed to aid in relocation.

If dewfall is measured, it is suggested that No. 4 transect not be the site for a gauge, or if used, that it not be the only one. Its particular exposure may account for the extensive population of ball-moss there. Certainly, the stream and pools were more easily dried up there than farther upstream in the canyon, hence there may be fewer dewfalls at No. 4.

A few nights should be spent in the canyon to see whether oak or ballmoss leaves obviously exhibit condensed moisture. A dew-recording device could then be constructed similar in surface to the leaf doing the condensing.

It is thought that the scales largely prevent transpiration. How much water loss really occurs in the different seasons?

Why should a steep-sided, narrow canyon be less of a cold air sink than a broader, lower-walled drainage? Is this, in fact, a good generalization?
The critical points of the life cycle should be defined. How do adults and seedlings differ in their cold resistance? Are the winter freezes more important than the heat of May and June as has been assumed here?

By means of direct measurement, incident solar radiation could be determined, and counterradiation measured as well, for contrasting exposures and at different levels in the canyon.

How low can the light intensity be before photosynthesis stops? What is the actual length of the growing season? What magnitude of energy use exists in the winter? Is this really a dormant period?

Comparative studies of physiological ecology of the desert populations in Mexico and the encinal populations in Arizona.

Arid-zone specialists might well be interested in ballmoss, although its slow growth and rarity are not attractive features for short-term experimentation. Field work is expensive by virtue of the isolation of the canyons (requiring 4-wheel drive and winch for assurance of year-round access), and the need for costly recording, measuring devices. Worse, the species is economically neutral. This does not bode well for the acquisition of grants to study it.
APPENDIX A

MONTHLY MAXIMUMS AND MINIMUMS FOR
15 SOUTHEASTERN ARIZONA WEATHER STATIONS,
OCTOBER 25, 1966 - OCTOBER 24, 1967
Figure A-1. Average maximum temperatures for Oct. 25 - Oct. 31, 1966 in southeastern Arizona
Figure A-2. Average minimum temperature for Oct. 25 – Oct. 31, 1966 in southeastern Arizona
Figure A-3. Average maximum temperatures for November 1966 in southeastern Arizona.
Figure A-4. Average minimum temperatures for November 1966 in southeastern Arizona
Average maximum temperature, °F

Figure A-5. Average maximum temperatures for December 1966 in southeastern Arizona
Figure A-6. Average minimum temperatures for December 1966 in southeastern Arizona
Figure A-7. Average maximum temperatures for January 1967 in southeastern Arizona.
Figure A-8. Average minimum temperatures for January 1967 in southeastern Arizona
Figure A-9. Average maximum temperatures for February 1967 in southeastern Arizona.
Figure A-10. Average minimum temperatures for February 1967 in southeastern Arizona
Figure A-11. Average maximum temperatures for March 1967 in southeastern Arizona.
Figure A-12. Average minimum temperatures for March 1967 in southeastern Arizona
Figure A-13. Average maximum temperatures for April 1967 in southeastern Arizona
Figure A-14. Average minimum temperatures for April 1967 in southeastern Arizona.
Figure A-15. Average maximum temperatures for May 1967 in southeastern Arizona
Figure A-16. Average minimum temperatures for May 1967 in southeastern Arizona
Figure A-17. Average maximum temperatures for June 1967 in southeastern Arizona.
Figure A-18. Average temperatures for June 1967 in southeastern Arizona.
Figure A-19. Average maximum temperatures for July 1967 in southeastern Arizona.
Figure A-20. Average minimum temperatures for July 1967 in southeastern Arizona
Figure A-21. Average maximum temperatures for August 1967 in southeastern Arizona
Figure A-22. Average minimum temperatures for August 1967 in southeastern Arizona
Figure A-23. Average maximum temperatures for September 1967 in southeastern Arizona
Figure A-24. Average minimum temperatures for September 1967 in southeastern Arizona.
Figure A-26. Average minimum temperatures for Oct. 1 - Oct. 24, 1967, in southeastern Arizona
REFERENCES


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