# EVAPORATION AND PLANT SUCCESSION ON THE SAND DUNES OF LAKE MICHIGAN.

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The porous cup atmometer as used today was devised by Dr. B. E. Livingston in 1906. It consists of a hollow cup of porous clay 12.5 cm. high, with an internal diameter of 2.5 cm. and a thickness of wall of about 3 mm. It is filled with pure water and connected by means of glass tubing to a reservoir usually consisting of a wide mouthed glass bottle of one-half liter capacity. The water, passing through the porous walls, evaporates from the surface, the loss being constantly replaced from the supply within the reservoir. Readings are made by refilling the reservoir from a graduated burette to a certain mark scratched upon its neck. For convenience in handling a portion of the base of the cup is coated with some impervious substance and before being used in the field the instrument is standardized by comparing its loss of water with that from a free water surface of 45 sq. cm., exposed under uniform conditions. As a further check against error this standardization is repeated at intervals of six to eight weeks throughout the season.

The instrument thus briefly described is designed to be used by ecologists in measuring the evaporating power of the air in plant habitats. This power varies with changes in temperature, humidity, and rate of motion of the atmosphere, and with the intensity of the illumination. The readings of the atmometer, therefore, express a summation of the various atmospheric factors which combine in making demands upon the water contained in the aerial portion of plants. By careful experiments it has been found that there is a close relationship between transpiration and this evaporating power of the air. The atmometer, therefore, gives a convenient and accurate means for the quantitative determination of those atmospheric factors which affect the water supply of plants, or in other words, it affords a means of exactly measuring the comparative xerophytism of plant habitats in so far as it is determined by atmospheric conditions. The importance of such measurements may be imagined when it is recalled that ecologists are agreed that water is by far the most important factor in determining the character and extent of the various plant associations.

During the spring and summer of 1910, an attempt was made to obtain such a quantitative determination of the atmospheric conditions within the vegetation upon the sand dunes of Lake Michigan, in order to discover any existing causal connection between such conditions and the plainly marked succession of plant associations within these areas. The region selected for study was about twenty miles south and east of Chicago, near the little village of Millers, Ind. Here typical localities in each of the several plant associations were carefuly chosen for the evaporation stations which were maintained from May 6 to October 31, readings being made weekly.

On the moving dunes the pioneer tree association is one of the cottonwood, *Populus deltoides,* with a scanty undergrowth of two species of willow, the sand cherry and various xerophytic grasses. In this association three stations were established about 100 meters apart, nearly 200 meters south of Lake Michigan and 12 meters above the level of its waters. At each the instruments were somewhat shaded during a few hours of the day; one possessing some shelter from the northwest wind and another from the southwest. The mean of the standardized readings were plotted with the daily average evaporation in cubic centimeters as ordinates and the intervals between the weekly readings as abscissae. The graphs for the cottonwood stations were found to agree in their general direction and in the time of their maxima and minima, the minor differences being probably due to the differences in the direction of the winds to which the stations were unequally exposed. The mean of the readings of these stations is used in comparing the cottonwood dune with the other plant associations. (Fig. 2.)

The maximum average evaporation for any week is just above 35 cc. per day and the minimum less than 10 cc., while the average for the 178 days is 21.1 cc. per day.

As the dunes become fixed, a pine association succeeds the cottonwood. Here it is composed principally of *Pinus Banksiana, Juniperus virginiana,* and *J. communis* with an undergrowth of *Arctestaphylos Uva-ursi, Rhus canadensis,* seedlings of black oak, and various other shrubs and xerophytic herbs. Within it station No. 4 was located about 50 meters south of stations Nos. 2 and 3. The instruments were shaded for about two-thirds of the day. The resulting graph is much lower than that of the cottonwood dune, the maxima are smaller but occur at the same time. The minima are also synchronos but smaller, especially

during October. (Fig. 2.) The maximum rate never reaches 20 cc. per day, the minimum falls below 4cc. while the average for the season is 11.3 cc. daily.

Following the pines upon the fixed dunes comes *Quercus*

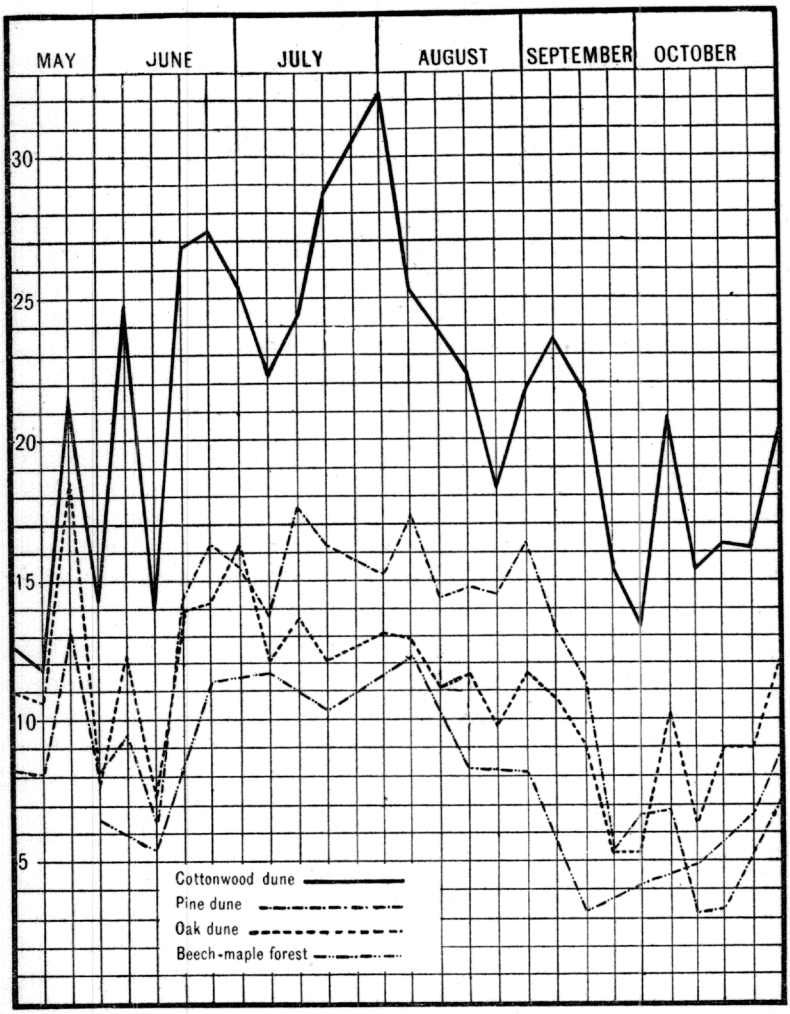


Figure 2. Mean daily evaporation rates in the sand dune plant associations and in the beech-maple forest.

*velutina,* finally forming at a distance of some 600 meters from the last station an almost pure stand of black oak, here referred to as the "oak dune." In the undergrowth are *Viburnum acerifo-*

*lium, Prunus virginiana, Vaccinium pennsylvanicum, Quercus alba* (seedlings), *Ceanothus americanus, Asclepias tuberosa* and other characteristic shrubs and herbs. Three stations were placed here about 50 meters apart, No. 6 on a fixed dune 12 meters high, No. 7 on a slope 5 meters above the general level and No. 8 on the floor of the forest. All were about equally exposed and shaded. The resulting graphs show differences corresponding closely to the elevation of their respective stations. The comparatively great elevation of the curve during the months of May and October when the oaks were not in full foliage is worthy of notice. The maximum for the summer months is 16 cc. per day and the average for the three stations for the 178 days is 10.3 cc. per day.

At Millers the vegetation exhibits no successional stages beyond the oak dune, but 15 miles farther east, near the village of Otis, Ind., there is a comparatively undisturbed tract of the climax deciduous forest here dominated by the beech, *Fagus grandifolia.* In parts of the forest sugar maple is fairly abundant, with occasional trees of *Tilia americana, Ostrya virginiana* and *Prunus serotina.* The undergrowth is principally seedlings of the trees mentioned, *Viburnum pubescens, Asimina triloba,* together with the usual mesophytic herbs. Here three stations were established, but on account of the poor train service, readings were made only every second week from May 30 to November 1. Station 11 was well surrounded by maple seedlings and largely shaded by maple trees, station 12 was near a large beech tree on a slope covered with a growth of Impatiens, and station 13 was in the midst of beech seedlings between two large beech trees. Together they seemed to well represent the average conditions of the beech forest. The resulting graphs were very similar and their mean is used in comparison with those from the other associations.

The maxima are in July and August, and amount to little more than 12 cc. daily, the minimum occurs in September and is scarcely 3 cc. per day, while the average for the 155 days is 8.1 cc. per day.

Several methods may be employed in comparing the data obtained from the various evaporation stations. Perhaps the best is to plot upon the same chart graphs representing the mean daily evaporation by weeks from the several stations in the different associations (Fig. 2). It will be seen that the graphs show several similarities, but more differences. The maxima and minima are generally coincident in time and proportionate in amount. All

show great irregularity during spring and autumn and a comparatively high rate during July and August. The general height of the different graphs probably expresses the most instructive and intresting differences in the different habitats. That of the cottonwood dune is farthest removed from those of the other associations and shows a habitat not only with great evaporating power, but one of great extremes, the difference in rate between two consecutive weeks being nearly or quite 10 cc. per day during May and the first part of June, and on two occasions amounting to an increase of 100 per cent in one week as compared with the preceding. This occurring early during the growing period would doubtless be very unfavorable for the development of any seedlings, especially as it was followed by the very high rates of the succeeding months. The high maximum occurring at midsummer would probably prove the excluding factor for all mesophytic plants even if not combined with such other factors as the deficiency of soil water at the same time. Such a graph seems to depict rather well a habitat of atmospheric extremes, making large demands upon all available water, and naturally and necessarily resulting in a xerophytic plant association, with a very limited undergrowth and an almost entire absence of herbaceous plants and seedlings. Perhaps nowhere could an association be found so entirely dependent upon vegetative reproduction for its maintenance, as almost without exception any increase in vegetation is the result of development from subterranean branches.

The graph for the pine dunes is decidedly lower and more regular in its contour than that of the association which it succeeds. Its four nearly equal maxima would indicate that within its limits there was throughout the summer season a continuous stress rather than a series of violent extremes. On the whole it shows a water demand of little more than half of that occurring in the cottonwood dunes. Its greatest divergence is plainly due to the evergreen character of its vegetation and is seen on its low range in May and the first part of June, and again in October when it falls below that of the oak dunes and is even less than that of the beech-maple forest. This would give good reasons for expecting to find within this association truly mesophytic plants whose activities are limited to the early spring.

The graph from the oak dune stations shows two surprisingly high points; one during May that may be partially explained by the absence of foliage; and the other near the end of June which

seems to coincide with maxima in the other associations. On the whole, it is more moderate during the summer months than that of the pine dune, but the difference is not so great as to make it surprising that its undergrowth differs but little from that found in the pine dune association.

The graph from the beech-maple forest stations is one of moderate height and great regularity. At no point does it reach to half the height of that from the cottonwood dune but surpasses that of the pine dune in October.

The data of these observations relate only to the stratum of vegetation immediately above the surface of the soil and would be quite different at a height of one or two meters. This lower stratum is, however, the critical one for a forest association for the development of tree seedlings occurs within its limits and it

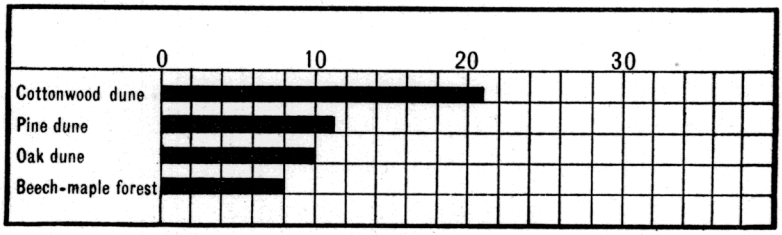


Figure 3. Diagram showing the comparative evaporation rates in different associations on the basis of the average daily amount from May 6 to October 31, 1910.

is therefore the portion of the habitat which determines the forest succession and hence the most important ecologically.

The rates of evaporation in the different plant associations may be compared in other ways. If the average amount of water lost by the standard atmometer daily throughout the season be taken as a basis represented in a diagram giving the loss in cubic centimeters (Fig. 3), a graphic representation results which, however, tells little more than what has been shown differently in the graphs. Likewise, the maximum daily rates for the week of greatest evaporation during the season gives a similar representation of the conditions in the several plant associations (Fig. 4). Upon a percentage basis, with the average rate per day throughout the season in the beech-maple forest as a unit, the comparative evaporation rate in the oak dune is 127 per cent; in the pine dune, 140 per cent, and in the cottonwood dune, 260 per cent. As the months of July and August probably represent

the critical portion of the growing season with reference to its water supplies, a comparison like the preceding might be made for those months only, when it would be found that the comparative evaporation in the oak dune would be *113* per cent, in the pine dune *146* per cent, and in the cottonwood dune *230* per cent.

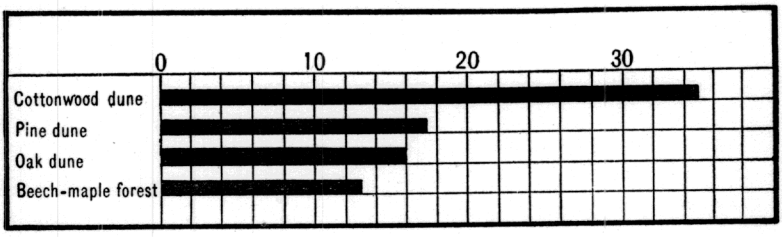


Figure 4. Diagram showing the comparative evaporation rates in different plant associations on the basis of the maximum average amount per day for any week between May 6 and October 31, 1910.

## SUMMARY.

1. These data represent the evaporation rates in the lower but critical stratum of the plant associations.

2. Evaporation at different stations in the same plant association exhibits variations similar in character and degree.

3. The rate of evaporation in the cottonwood dune association both by its great amount and by its excessive variation seems a quite sufficient cause for the xerophytic character of the vegetation and for the absence of undergrowth.

4. Evaporation in the pine dune association exceeds that in the oak and beech associations except when the latter are devoid of foliage.

5. The vernal vegetation of the pine dune is quite as mesophytic as that of the succeeding association, thus agreeing with its lower evaporation rate during that portion of the year.

6. Evaporation in the various association varies directly with the order of their occurrence in the succession.

7. The differences in the rate of evaporation in the various plant associations studied are sufficient to indicate that the atmospheric conditions are most efficient factors in causing succession.