

THE DIURNAL VARIATION OF AIR-BORNE RAGWEED POLLEN AS DETERMINED BY A CONTINUOUS RECORDING PARTICLE SAMPLER AND IMPLICATIONS OF THE STUDY

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DURHAM¹ appears to have been the first to report a study on the hourly variation of ragweed pollen. In his study which was made during the height of the season, the conclusion was drawn that most of the day's yield of pollen was thrown into the air early in the morning at the usual time of the daily ripening of the male ragweed flowers and that by midnight the bulk of this load has been precipitated.

Wilmer and Marshall² concluded after exposure of slides for a two-hour period and with these slides collected over a twenty-four hour period that the atmospheric pollen content is less as the earth cools. The lowest counts were reported between 5:30 and 9:30 P.M.

The distribution of ragweed pollen in the upper atmosphere was studied by Heise and Heise³ by exposing slides in the slip stream of a plane. "The data indicate that the level of maximum concentration rose from early afternoon until about 8:00 P.M. when the particles slowly fell until dawn, at which time there was ground fog. An analysis of these findings seems to indicate that the convection currents during the day and early evening are responsible for the lifting of the particles to high altitudes, and that the particles then sink as the ground cools off. . . . The importance of these observations is that they help explain the well-known fact that pollenosis is usually at its worst in the early morning hours."³

In a study by Barnes and Rooks⁴ conducted for seven days on the diurnal pattern of pollen fall, slides were exposed on the standard gravity sampler⁵ and were changed at intervals of six hours. The results showed that of the total pollen collected over twenty-four hour periods, 53 per cent was deposited on the slides between 6:00 A.M. and noon, 23 per cent from noon to 6:00 P.M., 14 per cent from 6:00 P.M. to midnight, and 10 per cent from midnight to 6:00 A.M. It was concluded that despite the fact that approximately three-fourths of the pollen is thrown into the air by the weeds in the daylight hours, the night air may contain large doses of pollen.

Jones⁶ exposed four microscope slides coated with a thin film of petroleum jelly on a weather vane at about the height of the plant and concluded that the giant ragweed released 88 per cent of the average daily total between 8:00 and 11:30 A.M. during August 24 and 25 at Lincoln, Neb. Additional readings were taken at Stillwater, Okla., for four days during September, at which time it was found that about 95 per cent of the average daily total of giant ragweed was shed between 7:00 and 10:30 A.M.

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Readings taken with the same sampler by Jones⁶ in terms of Western ragweed at Stillwater for three days during September showed that maximum shedding occurred at 8:30 A.M. and that approximately 90 per cent of the average daily pollen supply was shed between 7:00 and 10:00 A.M.

In none of these reported studies was a volumetric device used, that is, sampling a known amount of air with some method for the removal of pollen as the air passes through the instrument. In all of the reported studies an adhesive, usually petroleum jelly was used to coat an ordinary microscope slide and this slide was then exposed to the air in the standard sampler or some slight modification thereof.

Durham⁷ concluded that "in strong winds there are upward as well as downward currents and that wind impingement can, under such conditions be responsible for most of the 'gravity' catch."

Fletcher and Velz⁸ state that "probably because of high degree of turbulence associated with variation in air movement, pollen grains actually land on an exposed slide more in accordance with the laws of chance than with laws of gravity."

Although certain volumetric devices have been reported, they have not been widely used in the study of aerial transmission pollen problems. Hawes, Small, and Miller⁹ in 1942 reported a volumetric sampler by which the pollen was drawn through a fine slit opening and the pollen was impinged onto an adhesive coated slide which was moved lengthwise by an electric clock mechanism. Fletcher and Velz⁸ described a volumetric sampler developed by Hawes, Lang, and others by which the pollen is impinged onto a moving strip of adhesive tape. A similar device is described by Hall¹⁰ and by Stenburg.¹¹ The sampler described by Stenburg¹¹ was selected for this problem because of its simplicity in operation, permanency of records, and the fact that long-time readings could be taken without any attention by the operator.

STATEMENT OF PROBLEM

This report is concerned with a study conducted on the diurnal variation of air-borne ragweed pollen as determined by a continuous recording particle sampler. Because of the sampling errors that do arise in connection with the exposure of a slide even in the standard sampler and due to the scarcity of reports and the small number of readings taken on the diurnal variation of ragweed pollen, it was believed further study of this problem would be of value, preferably by a volumetric sampler.

By the use of a suitable volumetric sampler during the entire ragweed season, it was hoped further information aside from the diurnal variation might be added to our present knowledge as to the general aerial dispersion of ragweed pollen.

PROCEDURE

The Ragweed Pollen Sampling Efficiency of the Continuous Recording Volumetric Sampler.—Although a few readings were taken by Stenburg¹¹ with the "continuous recording particle sampler" to determine the efficiency of this

instrument in sampling for pollen, no exact statement as to its efficiency was made. The conclusion was drawn, however, that "the efficiency of the instrument is high."

In the study here reported preliminary efficiency readings were taken with commercially collected ragweed pollen (*Ambrosia trifida*). This pollen was released from a flask by compressed air directly into the air intake of the sampler during its operation by the use of a suitable rubber tube connection. Petroleum-jellied slides attached to the sides and placed at the bottom within the sampler indicated that not all of the pollen was being collected on the tape but rather some was undergoing impingement within the instrument. Slide counts indicated that although there was no impingement of the pollen on the sides, the pollen was collecting at the bottom of the sampler.

Additional readings indicated that if a small dosage of pollen was placed within and on the floor of the instrument and air was passed through the sampler which was known to contain no ragweed pollen, some of this pollen within the instrument was impinged on the recording tape. For this reason, during actual use of this sampler during the ragweed season, the bottom of the instrument was thoroughly cleansed daily. The top portion of the instrument which was difficult to cleanse was sealed such that no pollen could collect in this area.

In all efficiency tests and during actual operation of the sampler during the ragweed season, the distance between the impinger and tape was set at one-sixteenth of an inch. With a suitable opening for cooling of the motor and with this distance of one-sixteenth of an inch between the impinger and the tape, the air flow through the instrument was calibrated at 0.5 cu. ft. per minute. This rate of air flow was maintained in all preliminary readings as well as during operation of the sampler through the ragweed season.

In additional experiments on efficiency the pollen was released in a similar manner to the above procedure directly into the intake of the instrument while the continuous recording particle sampler was in operation. The air which passed through this instrument under test was led directly by a suitable connection into another sampler.¹² This connection was kept as short as possible (6 inches in length) to minimize impingement within this tube. That very little if any impingement did occur within this connection was indicated by the fact that there was no gradual increase in pollen counts by the second sampler with an increase in the number of readings. The rate of air flow through both samplers was maintained by a vacuum pump at 0.5 cu. ft. per minute and 1 cu. ft. air samples were taken on all efficiency readings.

In all readings on efficiency, petroleum-jellied slides were placed on the floor of the instrument to determine impingement within the sampler. One square centimeter slide area was counted for each reading and these readings were taken into consideration in computation of the efficiency.

The efficiency of the continuous recording particle sampler under the above sampling conditions was found to be 76 per cent. This, because of the high pollen dosage used on each test (300 to 1,000 pollen granules per cubic yard of air), undoubtedly represents the minimum efficiency of this sampler. This

figure compares favorably with a previous report¹² when under similar sampling conditions for ragweed pollen the efficiency was reported as 69 per cent when impingement to petroleum-jellied slides was compared with electrostatic precipitation. The somewhat higher efficiency when impingement occurs to tape may very well be due to the better adhesive qualities of tape* as compared with petroleum jelly.

Location and Operation of the Volumetric Sampler During the Ragweed Season.—The sampler was located on the topmost ledge of a tower on the Medical Laboratories Building, approximately 75 feet above the ground. This site placed the sampler well above any near-by trees with no obstructions to lateral air currents from any direction. The sampling site is also quite distant from any known ragweed source.

The sampler was kept in continuous operation, except for the small amount of time occasionally necessary to change the roll of tape and for the daily removal of that tape representing a twenty-four hour reading. Air samples were collected from Aug. 7 through Sept. 20, 1952. This represents the usual ragweed season in this area.

On three days the rainfall was so heavy as to destroy entirely the twenty-four hour reading. Although the intake into this sampler is protected, during a heavy rain, moisture of sufficient quantity is drawn into the instrument to destroy entirely the adhesive qualities of the tape.

DISCUSSION AND RESULTS

Hourly Variation in the Aerial Transmission of Ragweed Pollen on a Seasonal Basis.—Fig. 1 indicates that on a seasonal basis the peak incidence of ragweed pollen is reached from 11 to 12 A.M. This peak incidence amounting to 22.8 per cent of all the pollen collected for a twenty-four hour period is 57 times the dosage encountered by the individual during exposure for any single early morning hour from 3 to 6 A.M.

The hours from 10:00 A.M. to 1:00 P.M. account for 56 per cent of the pollen collected for the twenty-four hour period. This pollen dosage represents 23 times the exposure of the patient for the same time interval but from 6:00 to 9:00 A.M. Similarly, the pollen dosage from 10 A.M. to 1:00 P.M. accounts for 25 times the exposure of the individual during the hours from 9 to 12 midnight.

Hourly Variation in the Aerial Transmission of Ragweed Pollen During the Month of August.—Eighty-six per cent of the pollen collected on a seasonal basis from August 7 through September 20 was collected during the month of August.

Fig. 2 indicates that 21 per cent of the pollen obtained during this month was collected from 10:00 to 11:00 A.M. and 67 per cent was collected from 9:00 A.M. to 1:00 P.M.

*Scotch cellophane tape, $\frac{3}{4}$ inch by 300 inches (Minnesota Mining & Mfg. Co., Saint Paul 6, Minn.).

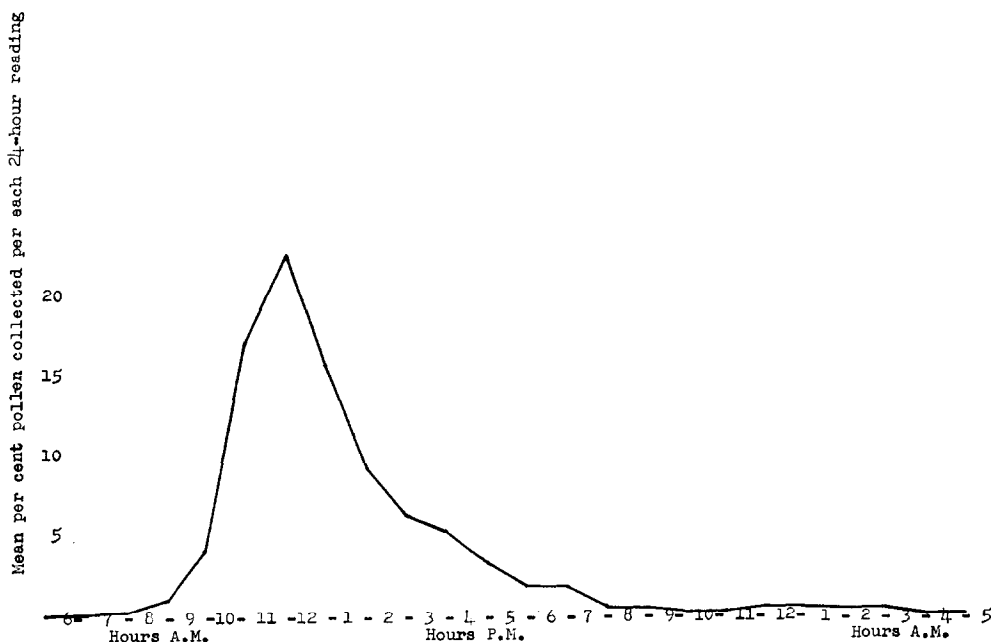


Fig. 1.—Hourly variation in air-borne ragweed pollen August 7 through September 20, Iowa City, Iowa, 1952. Each hourly reading indicates on a seasonal basis the mean per cent pollen collected per each twenty-four hour readings.

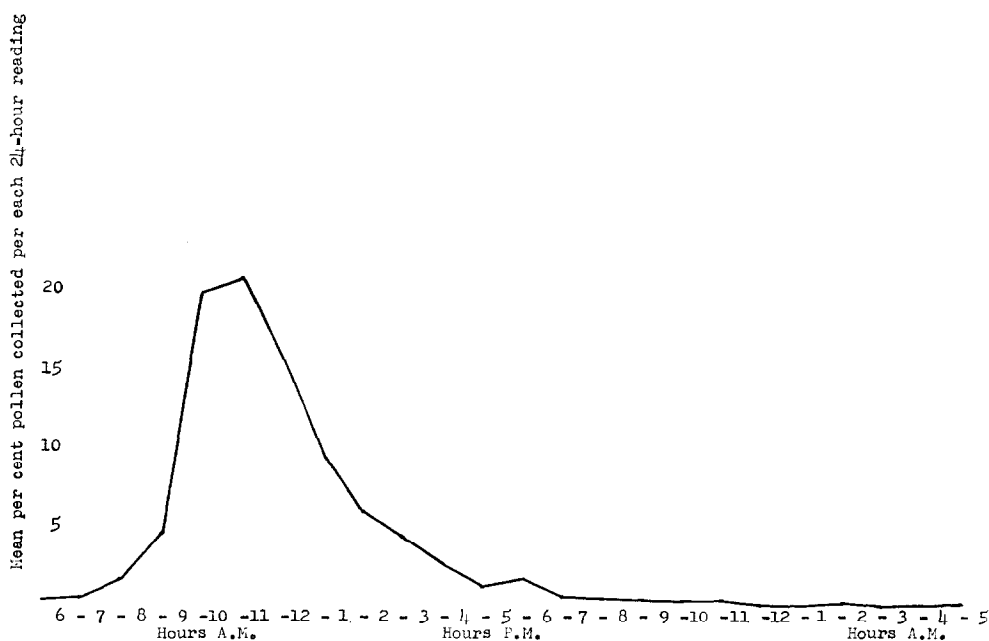


Fig. 2.—Hourly variation in air-borne ragweed pollen August 7 through August 31, Iowa City, Iowa, 1952. Each hourly reading indicates the mean per cent pollen collected per each twenty-four hour reading during the month of August.

The fall in the afternoon again occurs very rapidly and the incidence from 6:00 in the evening until 6:00 in the morning is practically the same during the month of August as compared with the incidence on a seasonal basis.

Hourly Variation in the Aerial Transmission of Ragweed Pollen During the Month of September.—September accounted for 14 per cent of the seasonal pollen collected. One might infer because of the low total for this month that hourly recordings would show marked changes as compared with the month of August.

Fig. 3, however, again indicates a sharp increase in the ragweed pollen incidence during the morning hours with 50 per cent collected between the hours of 9:00 A.M. and 1:00 P.M.

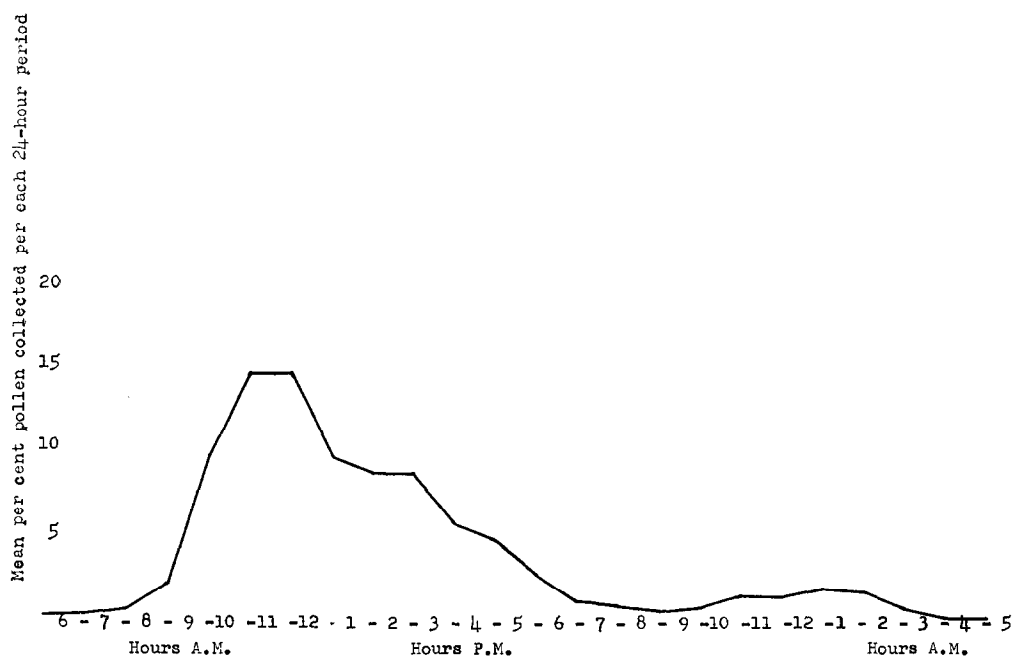


Fig. 3.—Hourly variation in air-borne ragweed pollen September 1 through September 20, Iowa City, Iowa, 1952. Each hourly reading indicates the mean per cent pollen collected per each twenty-four hour reading during the month of September.

Although the reported rainfall for the month of September was only 0.94 inch, the pollen incidence was again extremely low from 6:00 P.M. to 6:00 A.M.

It has been reported previously⁴ that in this area (Iowa City, Iowa) during seven pollen seasons, the apex date or peak daily incidence varied from August 21 to September 1. This, together with the fact that 86 per cent of the pollen is released during August, suggests that if pollen undergoes a marked redistribution after it has once settled upon trees, shrubs, and buildings, it should certainly occur during the month of September and especially when the month is characterized by a lack of rainfall. If such a redistribution does occur, it does not happen at night.

Daily Variation in the Aerial Transmission of Ragweed Pollen on a Seasonal Basis.—Volumetric air samples during the pollen season of 1952 when compared with pollen counts of slides exposed in a standard gravity sampler located at the same sampling site showed the same type curve when comparisons were made on a daily basis. Beginning with August 7 and with each additional day there was the usual marked increase in the pollen concentration of the air, but the peak incidence was reached with the standard sampler on August 26. The apex date using the volumetric sampler was August 28. After August 28 there was the usual irregular fall in incidence so characteristic of the ragweed problem.

There was close agreement in the first detection of air-borne ragweed pollen by the usual slide method as compared with the volumetric samples. Similarly, the close of the season was practically the same, at which time few or no pollen grains were sampled by either method. These comparisons indicate that volumetric air samples do not have any particular advantages over the standard gravity sampler in indicating the beginning, the end, and the apex date of the pollen season.

Meteorological Factors in Ragweed Distribution and Prevalence.—It has been previously reported¹³ that under experimental conditions the settling rate of ragweed pollen is increased with an increase in humidity. Duke¹⁴ reports that "pollen settles out of the air in the same way that mud settles out of water, so that air which has been still for a time is practically free from pollen." It is difficult to determine by means of the standard gravity sampler if the reported low pollen counts (1, 2, and 4) in the evening and night are due to the natural increase in the humidity or to the natural decrease in wind velocity or both. A sampling error does arise in the use of the standard sampler in that the pollen catch would be proportionately less in the evening and night. This is due to the fact that the pollen count in terms of this sampler is dependent in large part upon the passage of lateral air currents over the exposed slide.⁷

A comparison of the pollen incidence in terms of volumetric air samples shows that 47.0 per cent of the pollen collected on a seasonal basis was collected from 6:00 A.M. to 12 noon, 43.6 per cent from 12 noon to 6:00 P.M., 5.8 per cent from 6:00 P.M. to 12:00 midnight, and 3.6 per cent from 12 midnight until 6 in the morning. It is believed these readings reflect in part the importance of humidity in determining the settling rate of pollen. The mean relative humidity in percentage at 6:00 A.M. on a seasonal basis was 94 per cent while at 12:00 midnight it was 88 per cent. The lowest relative humidity reading was 51 per cent at 12:00 noon when the pollen counts are highest and by 6 in the evening the relative humidity had increased to 68 per cent.

That this marked variation throughout the day and night in pollen incidence is largely due to a change in the humidity rather than to a change in wind velocity is shown by these additional comparisons. It has been shown by Crawford¹⁵ that a horizontal air flow of 1.58 cm. per second (0.035 miles per hour) would be sufficient to overcome the force of gravity and produce air-borne pollen. The mean wind velocity for August and September at 12 noon in the study here reported was 11 miles per hour. The mean wind velocity

for the other six-hour intervals was from 5 to 6 miles per hour. This comparatively low wind velocity at night would be ample to overcome the force of gravity and produce air-borne pollen according to the experimental results of Crawford.

This discussion has so far neglected still another factor in the aerial transmission of ragweed pollen. As the earth's surface is warmed, rising convection air currents are formed. With a cooling of the earth's surface, downward air currents are produced and with an unequal warming of the earth's surface marked air turbulence results.

The mean dry bulb reading during the months of August and September was 78 at noon. By evening at 6:00 the mean dry bulb reading was 71. Meanwhile the proportion of pollen collected during the season (Fig. 1) had dropped from a peak of 22.8 per cent from 11 to 12 noon to only 2.2 per cent from 5:00 to 6:00 P.M. The slight difference in temperature at noon as compared with 6:00 in the evening, a difference of 7°, could hardly account for any large part of this rapid drop in the incidence of ragweed pollen.

It has been pointed out by Durham¹ that most of the day's yield in pollen is "thrown into the air early in the morning at the usual time of the daily ripening of the male ragweed flowers," with the bulk of this pollen released from the individual plants by 12:00 noon as shown by these results. Although with a sudden gust of wind the entire day's production of pollen by the individual plant may be released in just a few minutes,⁸ the gradual increase as shown in the figures suggests our sampler was sufficiently distant from any ragweed source to minimize this factor.

A comparison of these volumetric counts with wind direction revealed no differences. It would have been of interest to have determined volumetrically the exact percentage of pollen removed from the air by a given amount of rain. This, as has been previously mentioned, was impossible due to the moisture accumulation within the instrument during rain which destroyed the adhesive qualities of the collecting tape.

IMPLICATIONS OF THE STUDY

Maintaining a Low Pollen Refuge.—It has been reported by Barnes and Rooks¹⁶ that "the total daily pollen exposure even during the worst ragweed seasons and in the worst ragweed areas can be kept at a low and oftentimes even subclinical level." This was accomplished by the use of suitable window type pollen filtering units along with certain precautions against entrance of pollen into this refuge by air-dried laundry, outer clothing worn by members of the family, family pets, bouquets from the flower garden, etc.

In maintaining such a pollen refuge the most critical period during the day for entrance of pollen from the outdoors through open doors and windows would be from 9:00 A.M. to 1:00 P.M. during both the months of August and September. The second period of greatest danger would be the period from 1:00 P.M. to 6:00 P.M. From 6:00 P.M. until 6:00 A.M. the pollen dosage of outdoor air is so low as to be of much less significance if the home or pollen refuge is opened to outdoor air.

For those not able to afford the purchase of a commercial window type filtering unit, a pollen refuge could be established which would be effective and much less costly than would be the purchase of these units. An exhaust fan could be installed, either in the attic or in a window, and all outdoor air could then be filtered by installation of suitable air filters in certain windows in the home with all other windows and all doors kept tightly closed at all times. Volumetric air samples taken in a home during the ragweed pollen season in 1952 indicated that it was possible by this method to reduce the number of pollen granules to 5 or less per cubic yard of air. With this method of pollen control the air will enter the home at the place of lowest resistance so that full cooperation of other members of the family is essential from the standpoint of open doors, especially from 6:00 A.M. to 6:00 P.M.

The refuge should first undergo a thorough cleansing prior to the pollen season to prevent a carry-over of pollen from previous summers. A circular fan could be safely used at any time indoors to add to comfort provided the cleansing prior to the season has been thorough.

A person during the evening and early morning hours might take advantage of the outdoors for a time, provided the activity of the individual did not again create a pollen exposure problem. Mowing the lawn, working in the garden, a ride in the family car even in the evening could significantly increase the pollen exposure of the individual. Volumetric air samples taken within a car after brushing the upholstering have shown readings sufficient to produce clinical symptoms long after the pollen season.

Both of these methods can be used successfully with definite benefit to the individual patient in that the pollen exposure is significantly lessened. It is obvious that both of these methods would make more beneficial the treatment methods utilized by the physician.

In Desensitization.—The wide diurnal variation of ragweed pollen is also of some importance in attempts at desensitization. As has been previously reported,¹⁶ “the number of pollen granules inspired by an individual is not a direct multiple of the number reported per cubic yard of air.” In terms of the standard sampler it was calculated in this previous report¹⁶ that the pollen catch on a seasonal basis during the period from 6:00 P.M. to 6:00 in the morning was 25 per cent. Actually the pollen incidence as shown by volumetric readings is much lower, more nearly 10 per cent, while the pollen incidence is higher during the hours from 6:00 A.M. to 6:00 in the evening (90.6 per cent) than the incidence in terms of the standard sampler which was reported as approximately 50 per cent. The number of pollen granules inspired during a twenty-four hour period is actually much higher than would otherwise be expected unless this marked fluctuation in ragweed pollen incidence is recognized. This high incidence of ragweed pollen between the hours from 9:00 A.M. to 1:00 P.M., especially during the month of August, may make especially difficult attempts at desensitization or other treatment procedures.

SUMMARY

A continuous recording volumetric sampler was placed in operation during the entire ragweed season after the efficiency of this sampler was determined in terms of *Ambrosia trifida*.

An analysis of these twenty-four hour volumetric air samples revealed:

1. The most critical period in exposure of the patient to ragweed pollen is during the hours from 9:00 A.M. to 1:00 P.M. Sixty-seven per cent of the pollen collected during the month of August was collected from 9:00 A.M. to 1:00 P.M. Fifty per cent of the pollen collected during the month of September was collected during this same time period.

2. Only 10 per cent of the pollen collected for the twenty-four hour periods was collected from 6:00 P.M. to 6:00 A.M. during the months of August and September.

3. A comparison of volumetric air samples with ragweed pollen counts made with a standard sampler located at the same sampling site shows no particular advantages in the use of a volumetric sampler in indicating the beginning, the end, and the apex date of ragweed pollen.

4. Certain meteorological factors in determining the ragweed pollen incidence are mentioned and the implications of this study are discussed.

REFERENCES

1. Durham, Oren C.: Cooperative Studies in Ragweed Pollen Incidence, Atmospheric Data From Twenty-two Cities, *J. ALLERGY* 1: 12, 1929.
2. Wilmer, Harry B., and Marshall, Herbert: A Note on the Quantitative Survey of Pollen, *J. ALLERGY* 3: 63, 1931.
3. Heise, Herman A., and Heise, Eugenia R.: The Distribution of Ragweed Pollen and *Alternaria* Spores in the Upper Atmosphere, *J. ALLERGY* 19: 403, 1948.
4. Barnes, Milford E., and Rooks, Roland: Ragweed Pollinosis; Some Practical Considerations, *J. Iowa State Med. Soc.* 40: 287, 1950.
5. Durham, Oren C.: The Volumetric Incidence of Atmospheric Allergens. IV. A Proposed Standard Method of Gravity Sampling, *J. ALLERGY* 17: 79, 1946.
6. Jones, Melvin D.: Time of Day of Pollen Shedding of Some Hay Fever Plants, *J. ALLERGY* 23: 247, 1952.
7. Durham, Oren C.: Aerobiology: Development and Technic, chap. 42, p. 457, in Vaughn, Warren T., and Black, J. Harvey: Practice of Allergy, St. Louis, 1948, The C. V. Mosby Company.
8. Fletcher, Alfred H., and Velz, C. J.: Pollens-Sampling and Control, *Indust. Med.* 19: 129, 1950.
9. Hawes, Roland C., Small, Willard S., and Miller, Hyman: An Apparatus for Determining the Pollen Content of Air and Notes on Pollen Survey Methods, *J. ALLERGY* 13: 474, 1942.
10. Hall, Lawrence B.: The Equipment Development Section of the Technical Development Services, *CDC Bulletin* 9: 22, 1950.
11. Stenborg, R. L., and Hall, Lawrence B.: A Continuous Recording Particle Sampler, Mimeographed Notes, CDC Center, Technical Development Services, Public Health Service, Federal Security Agency, Atlanta 5, Ga.
12. Rooks, Roland: A Device for the Electrostatic Precipitation of Pollen and Fungus Spores Upon a Counting Slide, *J. ALLERGY* 19: 206, 1948.
13. Shapiro, Richard S., and Rooks, Roland: The Accuracy of the Reported Ragweed Pollen Count as a Measure of the Actual Pollen Exposure of Individuals in That Community, *J. ALLERGY* 22: 450, 1951.
14. Duke, W. W.: The Pollen Content of Still Air, *J. A. M. A.* 91: 1709, 1928.
15. Crawford, James H.: Determination of the Specific Gravity of Ragweed Pollen (*Ambrosia elatior*) and Conversion of Gravity Sample Counts to Volumetric Incidence, *Pub. Health Rep.* 64: 1195, 1949.
16. Barnes, M. E., and Rooks, Roland: Pollen Refuge at Home, *J. Iowa Med. Soc.* 36: 190, 1946.