EPA-650/3-75-003

TRAVELS OF AIRBORNE POLLEN

by

Eugene C. Ogden, Gilbert S. Raynor, and Janet V. Hayes

University of the State of New York
Albany, New York

Grant No. 800677
ROAP No. 21ADO
Program Element No. 1AA009

EPA Project Officer: George W. Griffing

Meteorology Laboratory
National Environmental Research Center
Research Triangle Park, North Carolina 27711

Prepared for

OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

January 1975

EPA REVIEW NOTICE

This report has been reviewed by the National Environmental Research Center - Research Triangle Park, Office of Research and Development, EPA, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U. S. Environmental Protection Agency, have been grouped into series. These broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and maximum interface in related fields. These series are:

1. ENVIRONMENTAL HEALTH EFFECTS RESEARCH
2. ENVIRONMENTAL PROTECTION TECHNOLOGY
3. ECOLOGICAL RESEARCH
4. ENVIRONMENTAL MONITORING
5. SOCIOECONOMIC ENVIRONMENTAL STUDIES
6. SCIENTIFIC AND TECHNICAL ASSESSMENT REPORTS
9. MISCELLANEOUS

This report has been assigned to the ECOLOGICAL RESEARCH series. This series describes research on the effects of pollution on humans, plant and animal species, and materials. Problems are assessed for their long- and short-term influences. Investigations include formation, transport, and pathway studies to determine the fate of pollutants and their effects. This work provides the technical basis for setting standards to minimize undesirable changes in living organisms in the aquatic, terrestrial and atmospheric environments.

This document is available to the public for sale through the National Technical Information Service, Springfield, Virginia 22161.

ABSTRACT

From 1957 to 1973, studies were conducted on the transport and dispersion of airborne pollen. The major areas of research were: (a) development and evaluation of sampling devices for particles in the pollen size range, (b) development and evaluation of techniques for tagging pollen in living plants with dyes and radioisotopes, (c) dispersion and deposition of pollen from known sources of several configurations, (d) study of the effects of forested areas in removing pollen from the atmosphere, (e) study of the variation in concentrations of pollen from natural sources with distance, height, time, and other variables, (f) study of the feasibility of predicting concentrations of ragweed pollen from unknown sources, (g) study of the occurrence and concentrations of ragweed pollen in a large source-free area, and (h) comparison of the concentrations of ragweed pollen before and after ragweed eradication efforts.

This report was submitted in fulfillment of Grant Number R-800677 by the University of the State of New York under the (partial) sponsorship of the Environmental Protection Agency. Work was completed as of December, 1974.

CONTENTS

FIGURES

ACKNOWLEDGMENTS

Many persons and institutions were of valued service in the conduct of these studies. We appreciate the assistance of staff members of the New York State Museum and Science Service and others in the New York State Education Department. We are grateful for help from many at Brookhaven National Laboratory, especially in the Biology Department and in the Meteorology Group. Several of the staff of the Division of Air Resources, New York State Department of Environmental Conservation, helped during critical periods. We express our appreciation for permission to install extensive sampling assemblages at: Brookhaven National Laboratory; Sagamore Conference Center of Syracuse University, Raquette Lake; Minnowbrook Conference Center of Syracuse University, Blue Mountain Lake; Adirondack Museum, Blue Mountain Lake; State University of New York Atmospheric Sciences Research Center, Wilmington; Whiteface Mountain Authority, Wilmington; New York State Department of Environmental Conservation Saratoga Nursery at Saratoga Springs; Lake Eaton Campsite, and Fish Creek Pond Campsite; the city of Saratoga Springs; and the property of Dr. Donald J. Dean, Guilderland.

Several persons should receive special mention. Of the staff of the New York State Museum and Science Service: Nancy Farr prepared materials for sampling and supervised identification and counting for the up-State locations; Eileen Coulston served as our bibliographer; Donald Lewis advised on pollen identification and lab techniques; Kenneth Dean processed many of the samples; these four also operated samplers in the field as needed.

Of the staff of Brookhaven National Laboratory: Maynard Smith authorized use of meteorological facilities and gave valued advice; Irving Singer advised on mathematical matters and helped program for computer analysis;

James Stangby supplied services of the Biology Department; Frank German and his staff cared for our plants in the greenhouse and fields; Charles Meinhold advised on radiation safety and supplied radiation counting machinery; Charles Flood taught us how to handle radioisotopes and assisted during critical times.

Among our full-time and part-time employees: Fay Hyland directed the studies with vital dyes; Benjamin Graham planned the initial studies with radioisotopes; Herbert Mapes helped design, construct, and operate sampling equipment at BNL and in the Adirondacks; Philip Walker directed the studies on pine pollen and operated samplers in the Adirondacks; Clifford Lloyd operated samplers on Whiteface Mountain; William Glider operated samplers at Blue Mountain Lake and Raquette Lake. At Brookhaven National Laboratory: Lester Cohen, Thomas Dowlearn, John McNeil, Anna Kokinelis, Paul Michael, Joyce Tichler, and Joan Glasmann assisted in many ways.

Among many who offered assistance that was gratefully received: Bruce Darling, caretaker of the Sagamore Conference Center; Patrick Collins, caretaker of the Minnowbrook Conference Center; Jerry Swinney, Director of the Adirondack Museum; Ray Falconer, Director of the Atmospheric Sciences Research Center on Whiteface Mountain; Harvey Prins, Stanley House, Jean Hoffman, and Carl Kundell of the Division of Air Resources, New York State Department of Environmental Conservation.

SECTION I

CONCLUSIONS

These studies on the occurrence, transport, and dispersion of atmospheric pollen include the data from several separate, but related, projects. Conclusions reached from each study are given in the pertinent Sections of this report. However, a few summarizing remarks may be in order here.

Samplers relying on gravity or impingement do not yield data which reliably indicate concentrations per unit volume of air. Rotating impactors are usually satisfactory for general use. Filter samplers are highly variable in efficiency for particles in the pollen size range unless isokinetic sampling is attained.

Concentrations of pollens from area and point sources normalized to 100% at 1 m from the source indicate that at 60 m from the source in the downwind direction, over open terrain, ragweed pollen averages ±9%, timothy ±6%, and corn ±1%. Extrapolation suggests that ±99% of ragweed pollen deposits within a km.

Dispersion into a forest from upwind sources is similar to that over open terrain. Concentrations within the forest decrease at a faster rate than in the open. Loss of material takes place by impaction near the forest edge and in the treetops and by deposition to the ground. Most loss is to the foliage rather than the ground.

Distant from local sources, vertical pollen profiles up to 100 m show variability from day to day but, when averaged over one or more pollen seasons, little change with height is found.

Narrow strips of vegetation markedly alter the low-level pollen concentration patterns. A pronounced concentration maximum is found in the area immediately downwind of a hedge (wake region). Similar behavior downwind of other obstacles may be inferred. Allergic individuals should avoid wake regions when aeroallergens are present.

Large quantities of pollen are transported in orderly fashion from their source regions, but pollen often travels in large, discrete clouds.

Ragweed pollen concentrations in a source-free forested area several hundred km from the sources of this pollen are mostly low, but they may reach high concentrations for short periods, especially in openings in the forest.

Ragweed eradication over a small area surrounded by a large area with many ragweed plants is unlikely to result in a significant reduction in pollen concentrations. However, eradication of abundant ragweed in an area surrounded by an extensive ragweed-free area should cause a marked reduction in local ragweed pollen concentrations.

The pollens of most flowering plants are not found in the atmosphere far from their sources. They are generally ignored when searching for possible causes of pollinosis. However, some of these entomophilous species at times emit pollen that becomes airborne in appreciable amounts close to the source plants. In some situations, a person allergic to such pollen might be exposed to concentrations sufficiently high to cause pronounced discomfort.

SECTION II

RECOMMENDATIONS

OPERATING PROCEDURES

Until an isokinetic sampler is developed for use under atmospheric conditions, rotating impaction samplers should be used for sampling airborne pollens, large spores, and other particles above about six microns in diameter. Smaller particles should be sampled with suction type samplers.

Sampling surfaces of impaction samplers should be shielded during nonoperating periods to avoid wind impaction.

In pollen surveys, species should be reported by their scientific names.

A volumetric measurement should be used for pollen counts reported to the public and the time period during which the count was taken should be specified.

FURTHER RESEARCH

Collection efficiencies of commonly used samplers should be determined for at least the more common airborne pollens and other spores as a function of particle characteristics, wind speed, and other pertinent variables.

Research to improve sampling techniques should continue with emphasis on developing instruments that minimize variation in efficiency with particle characteristics (size, shape, density) or with meteorological conditions (wind speed, turbulence, humidity, precipitation).

Development, evaluation, and calibration of the isokinetic sampler for use in the free atmosphere, which was designed and built under this program, should be completed.

Development, evaluation, and calibration of the automatic grab sampler, which was designed and built under this program should be completed.

Samplers should be designed whose efficiency is not significantly changed by precipitation.

Studies should be conducted to find methods of separating morphologically similar pollens such as: *Camptonia* from *Betula* and *Chenopodium* from *Amaranthus*.

Studies should be conducted to improve methods of separating freshly emitted from older airborne pollens.

The effectiveness of local ragweed eradication should be adequately tested with sufficiently long before and after sampling in areas of low, medium, and high concentrations.

Methods for predicting ragweed pollen concentrations should be developed further and tested in several geographical areas which differ with regard to pollen concentrations, location of sources, and meteorological conditions.

Temporal and spatial variability in airborne pollen concentrations should be studied at representative locations in a number of cities in diverse geographical areas.

The occurrence, concentration, and behavior of common aeroallergens in and around inhabited structures should be studied as functions of building size, shape, and function; ventilation and air cleaning devices; and of particle characteristics and meteorological parameters.

Long distance pollen transport should be studied by means of a systematic sampling program to determine the kinds and concentrations of pollen in the upper air, their temporal and spatial variability, trajectories, and their relationship to meteorological variables.

Medium-range transport and dispersion of aeroallergens should be further studied by use of aircraft-mounted isokinetic samplers to determine relationships with source areas, meteorological conditions, and other variables with emphasis on transport into source-free areas.

Studies should be conducted to determine if pollen grains equipped with air bladders are transported through the air with the bladders inflated or deflated and whether this varies with ambient conditions such as humidity. Similar information should be obtained on thin-walled pollen grains which could travel either in spherical form or partially collapsed.

Studies should be conducted to determine pollen washout efficiency as a function of particle characteristics, rainfall rate, and drop size distribution.

Studies should be conducted to determine impaction efficiency of various vegetative elements as a function of pollen characteristics and meteorological conditions.

Studies should be conducted to determine removal efficiencies of pollen from vegetative and other surfaces as a function of pollen characteristics, wind speed, and other variables.

Studies should be conducted to determine more precisely the relationships between airborne pollen concentrations and pollinosis in susceptible individuals.

Possible synergistic effects between aeroallergens and other air pollutants should be explored.

The possibilities of biological control of ragweeds should be explored.

SECTION III

INTRODUCTION

This research was conducted cooperatively by staff members of the New York State Museum and Science Service and Brookhaven National Laboratory. It was supported in large part by Research Grants from the National Institute of Allergy and Infectious Diseases (E-1958) and the Environmental Protection Agency (R-800677).

The study areas were all in New York State: primarily at Brookhaven National Laboratory on Long Island, at Albany, at Saratoga Springs, and in the Adirondack Mountains.

The results of these investigations appear in thirteen Progress Reports, numerous journal articles, books, and special printed or multilith documents. These may be obtained, while the supply lasts, from Botany Office, New York State Museum and Science Service, Albany, New York 12234, except those having Raynor the senior author which are from Meteorology 051, Brookhaven National Laboratory, Upton, New York 11973. For topics described in detail in these publications, only summaries appear here. References to pertinent research by others that appear in these publications are not repeated. Research not reported elsewhere, except for preliminary data in one or more Progress Reports, is presented in greater detail, including references to other authors.

These studies, which are not being duplicated by any other research group, have resulted in a wealth of experimental data, an increased understanding of many phases of pollen dispersion, and the development of useful techniques for predicting pollen concentrations. The results have practical value to allergists and public health officials concerned with pollinosis and weed control programs and to all concerned with dispersion of airborne particulate matter. The condensed versions appear in suitable serial publications, the supporting data in Progress Reports or in BNL Publications, as indicated in the bibliographic references for each section.

Research on the occurrence, transport, and dispersion of pollen in the atmosphere has required extensive studies on the sampling techniques best suited for the various phases of the work.[1] Also, we have had to be concerned with the whole field of aerobiology.[2]

REFERENCES

1. Ogden, E. C., G. S. Raynor, J. V. Hayes, D. M. Lewis, and J. H. Haines. Manual for Sampling Airborne Pollen. New York, Hafner Press, 1974. 182 pp.

2. Raynor, G. S., E. C. Ogden, D. M. Lewis, and J. V. Hayes. Aerobiology. Submitted for M. B. Rhyne, ed. Childhood Hay Fever, to be published by C. C. Thomas, Springfield, Illinois.

SECTION IV

INSTRUMENT DEVELOPMENT, TESTING, AND COMPARISON

IMPINGEMENT SAMPLERS

Durham Sampler

This sampler, also known as the gravity slide sampler, consists of a mount for positioning a glass microscope slide between two horizontal 9-inch circular disks. Pollen collection is by gravitational settling and by turbulent impingement to the adhesive surface of the slide. It was adopted as the standard pollen sampler by the American Academy of Allergy in 1946. It is still in widespread use. Nearly all of the "pollen counts" reported by news media are obtained by its use.

Studies conducted at eight levels on a 420-foot meteorology tower indicated that pollen capture is determined by several factors in addition to the concentration of pollen in the air.[1]

The amount of pollen captured is influenced by the amount of air passing over the slide and also by the orientation of the slide with respect to wind direction.

A comparison of Durham samplers with an intermittent rotoslide sampler indicated that variations between the counts from the two sampling methods were not orderly nor predictable.[2] No single factor would convert the counts from the Durham sampler to the concentrations measured with the rotoslide.

Modified Durham Samplers

Several modifications of the Durham sampler were designed and tested.[3,4] A standard orientation with wind direction was obtained with a wind vane. However, the slide holder is aerodynamically poor and variations in catch caused by wind speed and turbulence were still present. A streamlined circular holder accepting a square glass slide offered two improvements: equal orientation with any air flow and less modification of approaching air currents. It retains the other disadvantages. Durham samplers and modified Durham samplers were compared at several different locations. Four sets of modified Durham samplers, each containing four units mounted one above the other, were exposed at four heights on the Brookhaven meteorology tower. Because of wide differences between adjacent samplers, unknown variations in catch with wind speed and turbulence, and impossibility of determining the volume of air sampled, this sampler appears to be unsuitable for sampling airborne particles.

Deposition Samplers

For most of the sampling arrays, deposition was measured by one or two microscope slides placed on a small board at the base of each sampling station. The upper side of the slides was given a thin coating of silicone stopcock grease. This adhesive is suitable for dry weather. During long exposures when rain might occur, AEC fallout paper proved to be better, as the particles are not as easily dislodged by water.[5]

WIND IMPACTION SAMPLERS

Slide-edge-cylinder Sampler

This vane-mounted impaction sampler was designed, tested, and perfected by several modifications. It combines the principle of wind impaction on the side of a cylinder with the ease of reading a microscope slide and was used in quantity during several seasons.[6,7,8] It consists of a glass slide mounted vertically between two aluminum bars on the front of a vane (Fig. 4-1). The leading edge of the slide serves as the sampling surface. The bars present a 1/4-inch-diameter cylindrical surface to the wind. As efficiency varies with wind speed, an anemometer must be used with it. For open areas (nonforested), one or a few anemometers can serve many samplers. This sampler is inexpensive and easy to use.

Wind tunnel tests[9] with a slide-edge-cylinder sampler mounted beside a filter sampling isokinetically showed excellent agreement after applying a calculated efficiency correction.

The theoretical efficiencies for impaction of ragweed pollen (±20μ) on the 1-mm slide in the 1/4-inch holder is approximately as follows:

Air speed (mps)	1	2	3	4	5	6	7	8	10	15
Efficiency in percent	43	63	73	79	84	86	88	90	90	95

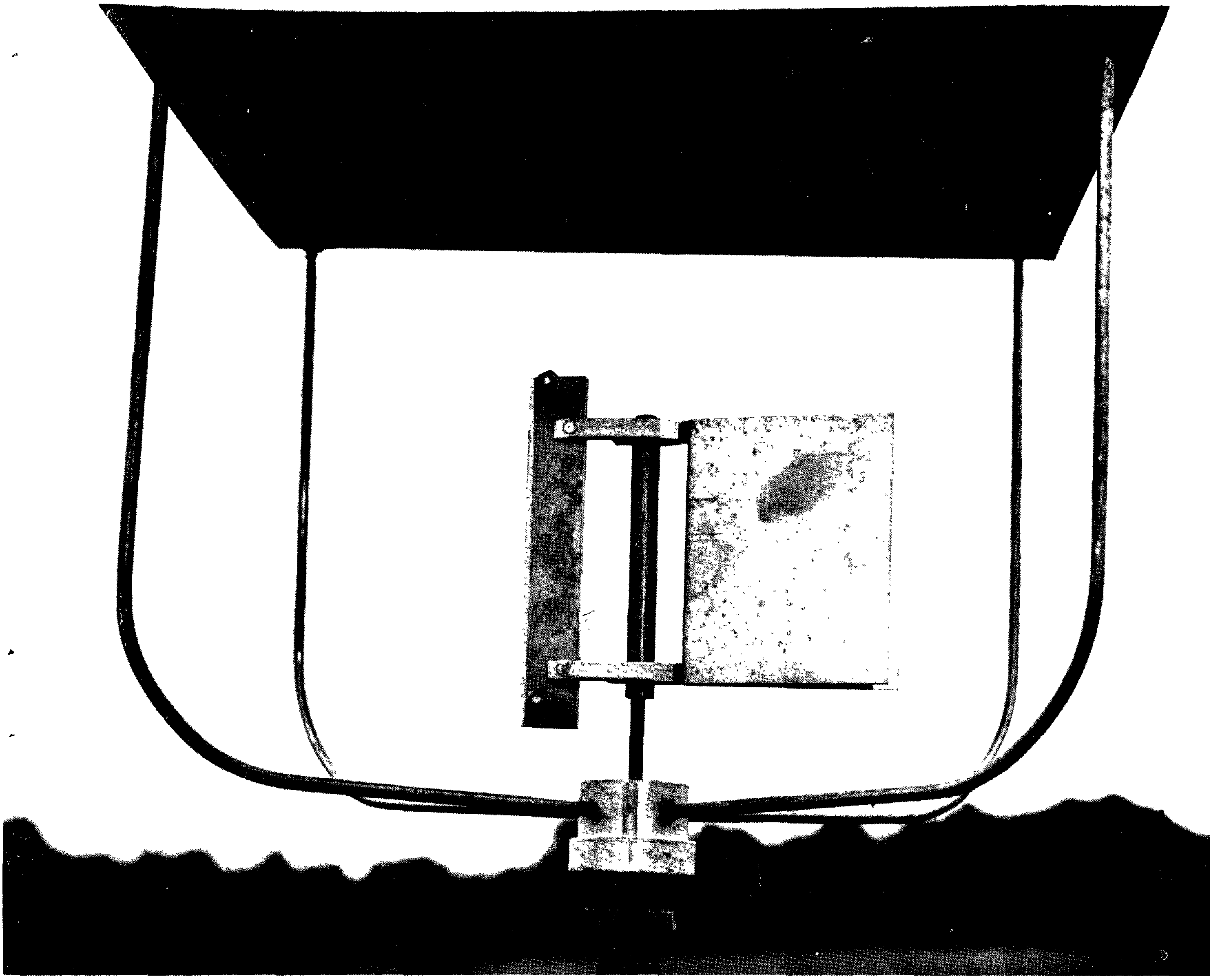


Fig. 4-1 Slide-edge-cylinder sampler.

ROTATING IMPACTION SAMPLERS

Because the efficiency of stationary impaction samplers is low and highly variable over the range of wind speeds most commonly encountered in low-level sampling, the rotating impactor has come into general use. Moving the collector through the air is equivalent to allowing the air to move past the collector. Sampling at a constant rotational rate with a fixed radius of rotation gives a constant average linear speed to the collecting surface which therefore samples a known volume per unit time.[10]

Rotoslide Sampler

After many experiments with the rotorod sampler, originally designed by personnel at the Stanford University Aerosol Laboratory, the rotoslide sampler[11] operating on the same principle but taking the samples on the edge of standard microscope slides was designed, tested in the wind tunnel and in the field, and used extensively. It consists of two upright slide holders at the ends of a horizontal crossarm mounted on the upright shaft of an AC motor. The rotational speed is about 1600 rpm with a linear speed about 10 mps. The volume sampled is about 3.5 m^3/hour. This sampler is essentially independent of wind speed and direction. The theoretical impaction efficiency of a 1 mm-diameter cylinder traveling at 10 mps is ±96% for ragweed pollen. However, the slide edge is not a true cylinder, turbulence is caused by the rotary action, and the retention of impacted particles is less than 100%. Wind tunnel tests indicated an impaction-retention efficiency of ±68% at 0 speed and 49% at 10 mps for ragweed pollen. This is a straight line ratio. For the usual outdoor average wind speeds during the ragweed season (±2 mps), we suggest using an efficiency of 64% when wind speeds are not known.

Intermittent Rotoslide Sampler

If the rotoslide is operated continuously for more than two or three hours, overloading occurs in most situations. The intermittent rotoslide

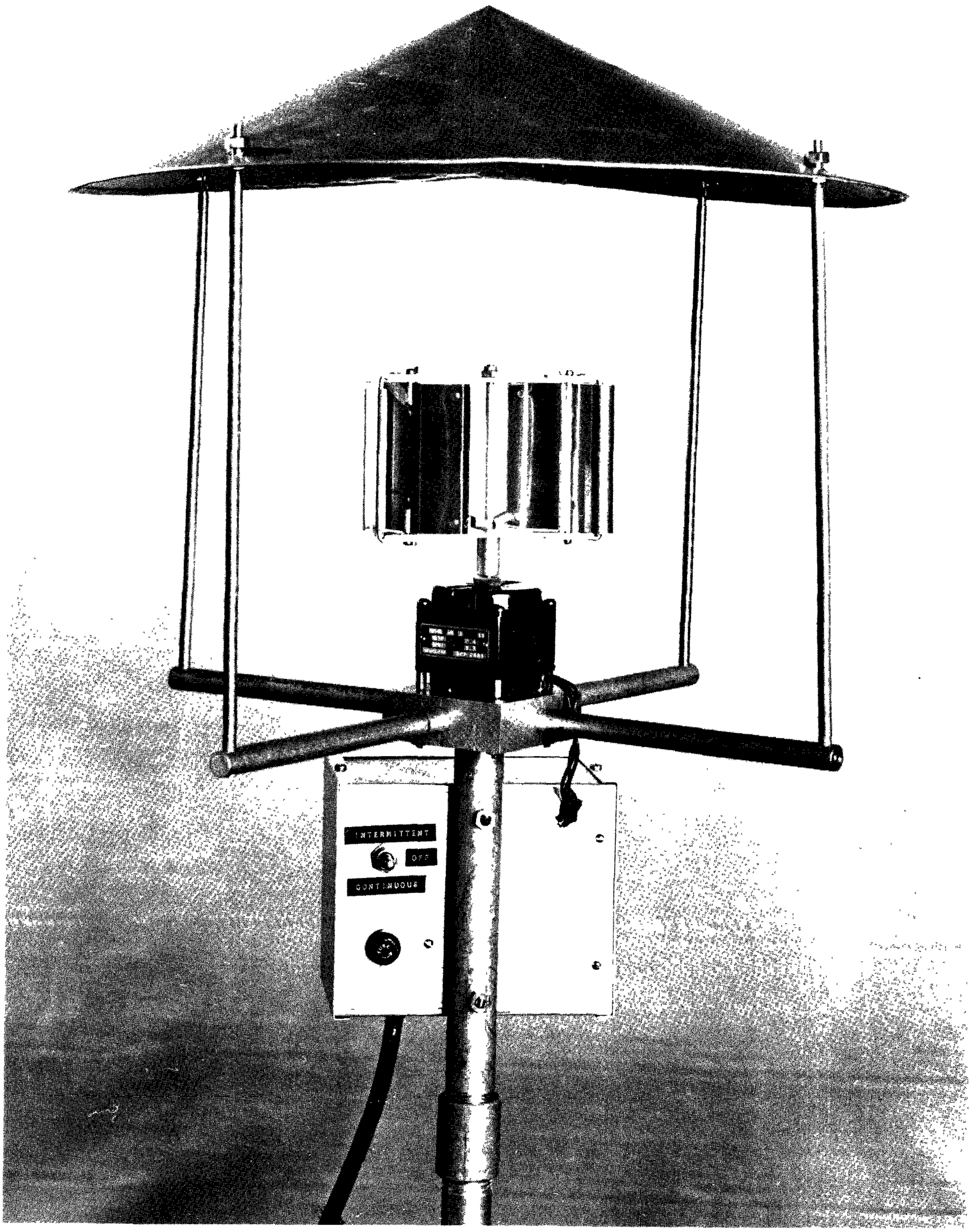


Fig. 4-2 Intermittent swing-shield rotoslide sampler.

is designed to take pollen samples representative of the average concentration over a 24-hour period by automatically operating periodically for short periods. A timing device energizes the motor for one minute in each twelve, giving a total sampling time of two hours each day. As the slide edge is an efficient impactor of pollen even when not rotating if it happens to stop facing the airflow, it is necessary to shield it from the wind when not rotating. The original model,[11] still in widespread use, employs a cylindrical shield, activated by a reversible motor and timer. During rotation, the shield is pulled down to expose the slides to normal airflow. When rotation ceases, the shield rises to shelter them from the wind.

Since mechanical difficulty was occasionally experienced with the shield-raising mechanism, a more reliable device, the swing-shield[12] was designed to eliminate this problem (Fig. 4-2). The shielding plates are pivoted on pins through the top and bottom of the slide-holder frame; the curved ends of the plates are held in front of the slide edges by spring tension. Upon rotation, the curved ends are drawn away from the slide edge by a combination of centrifugal force and air pressure against the tail section of the plate. Rotoslides using this shield are particularly well adapted for sequential sampling when used with an appropriate timing device.

Sequential Rotoslide Samplers

Several versions of a sampler employing rotating impactors operating sequentially were designed, tested, and used in experiments requiring sequential data.[6] To shield the idle units from wind impaction, all were housed in a box, with one at a time protruding for operation. Drive mechanisms tested included: air jet, magnet, and direct drive. In most of the studies, a direct flexible drive was used with a delay relay and a resistance allowing the drive motor to reach half speed before the full power comes on.

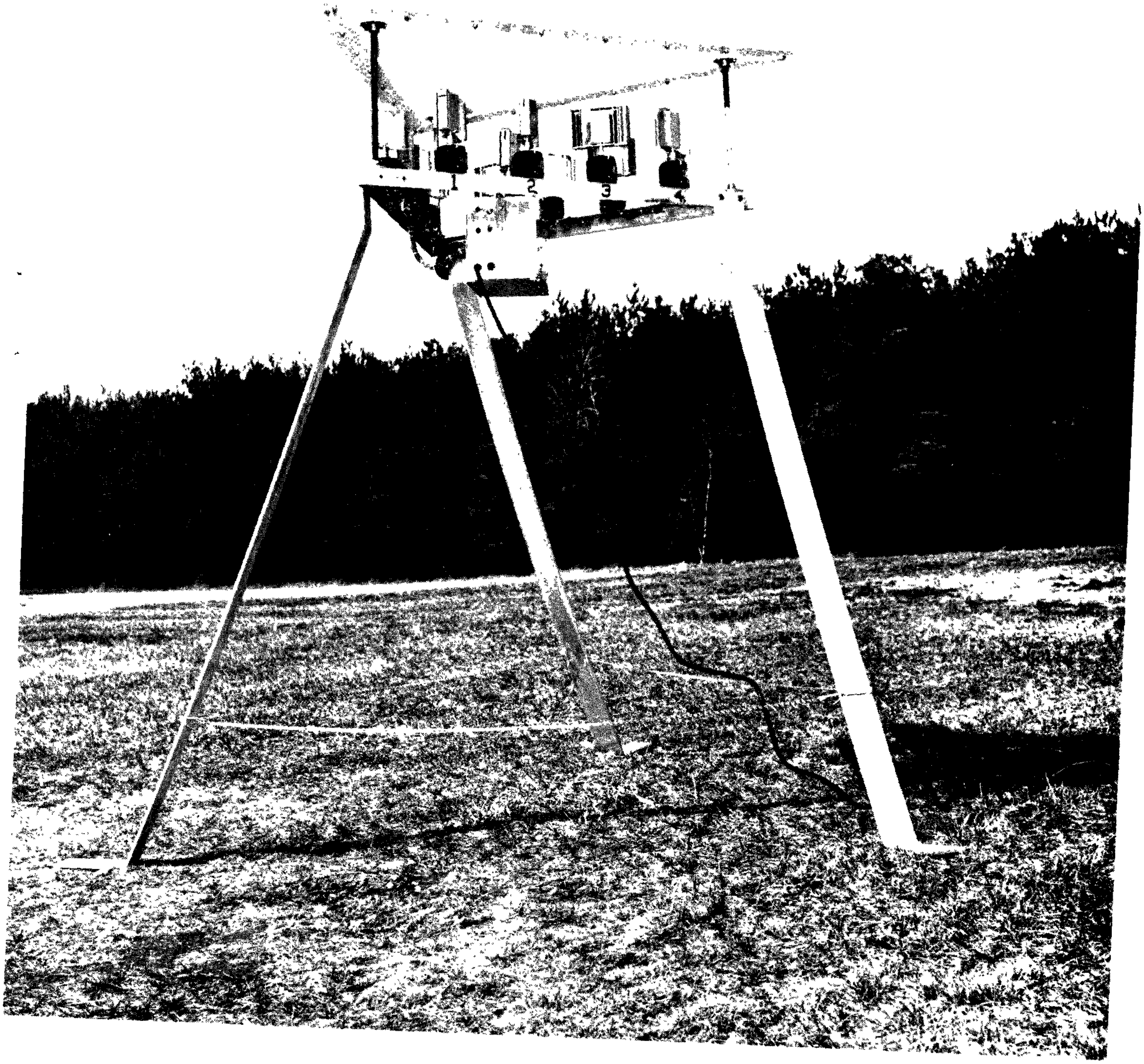


Fig. 4-3 Sequential swing-shield rotoslide sampler.

Development of the swing-shield slide holder for the rotoslide sampler[12] allowed the construction of rotoslide samplers for sequential operation with several advantages over existing machines. A six-unit, lightweight (30 lbs), portable sequential swing-shield rotoslide sampler was designed. Two such samplers were used independently or in tandem.[13] Four 13-unit sequential swing-shield rotoslide samplers were constructed for use in a study of variation in pollen concentrations with time. They consist of twelve motors with swing-shield slide holders mounted on a triangular frame of angle aluminum supported by three legs. A thirteenth motor is mounted in the center and a control box containing the timing mechanism below the center of the frame. The whole assemblage is protected by a rain shield (Fig. 4-3). Two samplers were timed so that the twelve motors operated sequentially for five minutes each while the central one sampled continuously for an hour. In the other two samplers, the twelve units sampled sequentially for two hours each. The central unit sampled intermittently

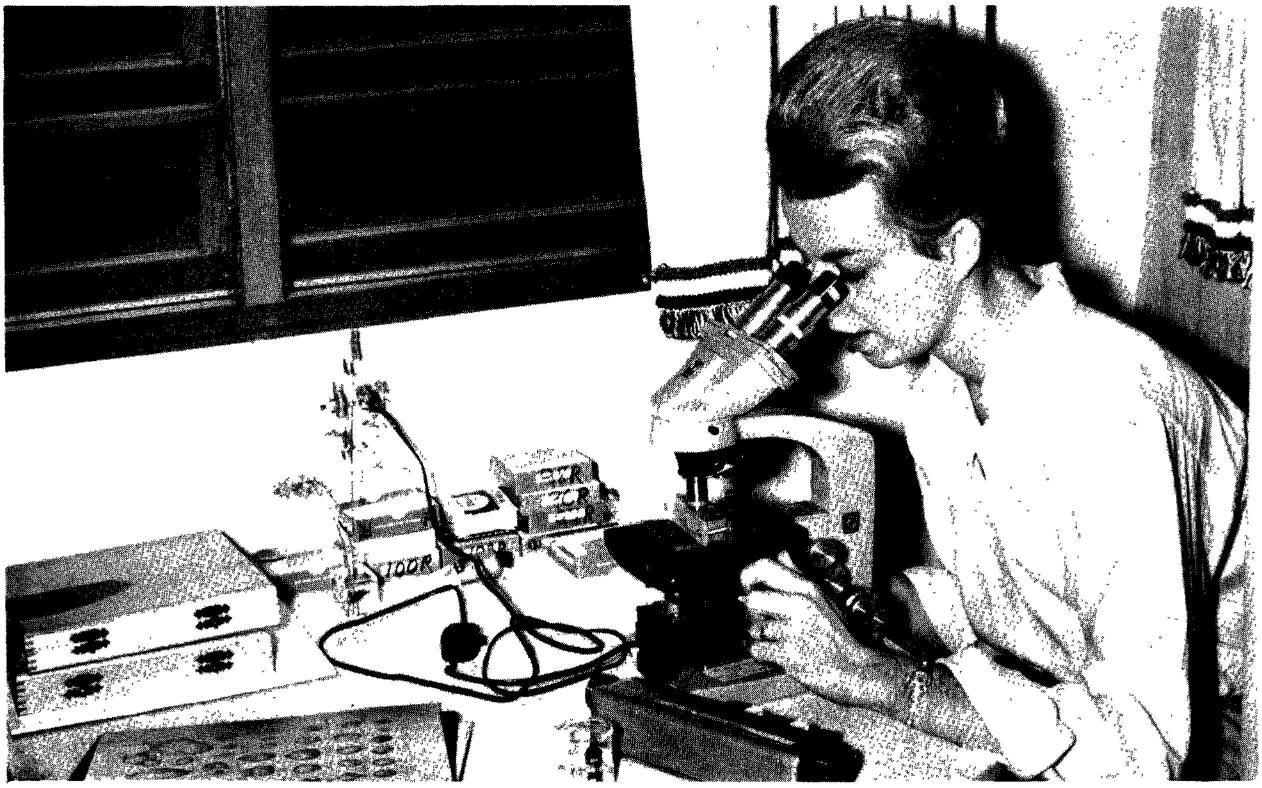


Fig. 4-4 Examination of a slide edge sample.

for twenty-four hours on a cycle of one in each twelve minutes. For another study, two of the samplers were operated in tandem, taking consecutive 30-minute samples. They were re-set by the operator twice in each 24-hour day.

Pollen samples on the edges of microscope slides proved to be easy to handle and prepare for study.[11] A slide positioner was designed and used for holding the slides on edge under the microscope. Identification and counting of pollen grains on more than 100,000 slide-edge samples presented no unusual difficulties (Fig. 4-4).

SUCTION SAMPLERS

Hirst Spore Trap

Samplers in which air, containing material to be sampled, is drawn into an entrance by suction are used for many air sampling purposes. Techniques for collecting and counting particles drawn into suction samplers have been subjects of extensive research and experimentation, but little attention has been given to the problem of getting a representative sample into the entrance. This is partially due to the fact that suction samplers are mostly used for submicron-sized particles whose entrance efficiency is normally high and uniform. Larger particles, such as pollen, tend to deviate from the air stream entering the sampler if the air is forced to change direction or speed.

Among the available suction samplers capable of yielding sequential data, the Hirst spore trap[14] appeared to be the best. It was used extensively by us for obtaining diurnal patterns of emission in our dispersion fields[15] and for patterns of occurrence elsewhere. It compared favorably with the sequential rotoslide samplers, although its time discrimination was not as precise.

The efficiencies for sampling ragweed pollen (∿20μ) at different ambient wind speeds were determined to be approximately as follows:

Air speed (mps)	1	2	4	6	8	10
Efficiency in percent	89	68	58	65	100	124

Filter Samplers

Filter samplers, as commonly used for sampling particles less than five microns in diameter, are not suitable for the larger pollen grains unless isokinetic sampling can be attained or at least approximated. Filter samplers were used extensively in our wind tunnel tests under isokinetic sampling conditions.

The effect on the entrance efficiency of a filter holder caused by variations in air speed, flow rate, angle between the air flow and the filter holder, and particle size was studied in the wind tunnel.[16] The efficiency varied with all parameters from less than 1% at the highest wind speed (7 mps) and lowest flow rate (6.4 liters/min) to more than 100% at forward angles where impaction aided suction. An empirical formula was developed to model the pertinent parameters.

From this formula, it was predicted that the entrance efficiency of an orifice at a 45-degree angle to the air stream should be unity and should not vary with wind speed, particle size, or flow rate. Tests were made with 6- and 20-micron diameter particles at wind speeds from 0.75 to 7.0 m/sec and at flow rates of 12.7 and 25.4 liters/min using both fixed and vane-mounted filter holders as test orifices. Early results confirmed that entrance efficiency at the 45-degree angle is relatively constant over the range of experimental conditions in contrast to results at other angles. A vane-mounted filter sampler with the entrance at a 45-degree angle was constructed.[17] Later tests, however, gave more variable results and more testing is needed before the sampler can be recommended.

ISOKINETIC SAMPLERS

Several existing volumetric samplers have a high efficiency in retaining pollen that enters the sampling intake. However, a significant percent of the pollen originally in the air drawn through the intake may deviate from this air due to its momentum in its original direction. This error can be overcome only by sampling isokinetically.

Variable Air Flow Isokinetic Sampler

A sampler was designed and constructed (Fig. 4-5) which will change its flow rate rapidly and automatically to conform to changes in the wind speed while the sampling intake is oriented into the wind by a vane. In both field and wind tunnel tests, the sampler indicated lower concentrations than comparison samplers. Reasons for the discrepancy have not yet been determined but further tests are planned.

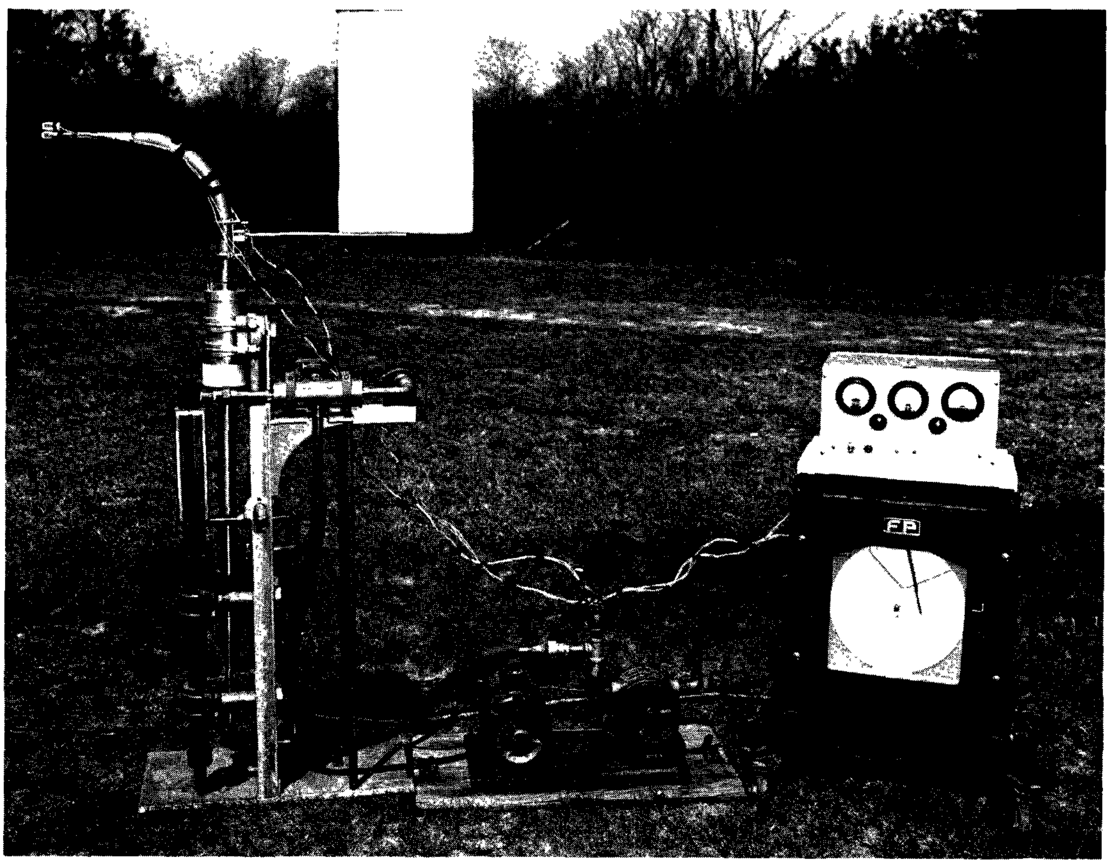


Fig. 4-5 Variable air flow isokinetic sampler.

Aircraft Isokinetic Sampler

A light-aircraft-mounted isokinetic sampler was designed for obtaining accurate samples of particulate matter in the lower atmosphere.[18] The sampler head is operated in undisturbed air under the wing and is drawn into the cabin along a track for changing filters. A battery-powered high volume sampler in the cabin serves as the air moving device. The sampler can draw as much as 0.72 m^3/min and match aircraft air speeds to 38 m/sec at standard temperature and pressure. The sampler was used two seasons for measuring the vertical and mesoscale distribution of airborne pollens.[19]

AUTOMATIC GRAB SAMPLER

Grab sampling consists of capturing a known volume of air in a way that all particles and gases in the volume are taken with it. A grab sampler was designed and built (Fig. 4-6) which periodically encloses a known volume of air, immediately removes the contaminants of interest, and repeats the cycle for as long as desired.[21] This sampler is easy to operate and is believed to trap atmospheric contaminants of any size with equal efficiency. Further tests are necessary to confirm its efficiency and utility.

WIND TUNNEL TESTS

A wind tunnel was constructed (Fig. 4-7) to study the air flow patterns over the various samplers. Wind speeds may be varied from zero to 45 mph. Oil fog smoke is produced by a small generator and introduced into the tunnel to allow visual observation and photography of the air flow past the objects under test. The true pollen concentration in the tunnel is measured by a filter sampler sampling isokinetically. Pollen is emitted into the closed wind tunnel room and mixed by four floor fans (one in each corner) and the wind tunnel fan. The extent of the mixing can be checked by an array of seventeen filter samplers in the form of a cross operated in the working section of the tunnel. Once the air enters the honeycomb air straighteners just inside the entrance, no further mixing is possible.

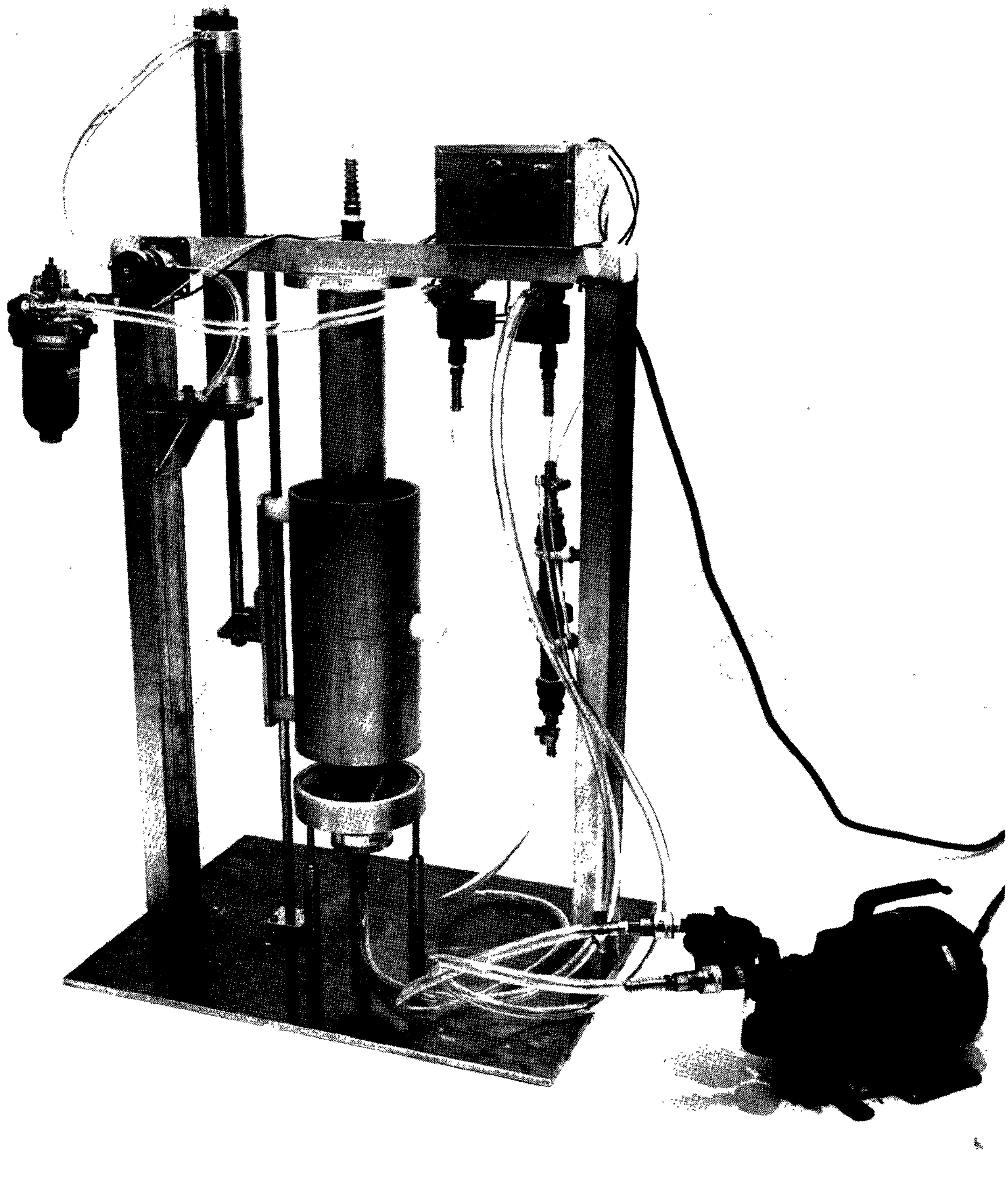


Fig. 4-6 Automatic grab sampler.

Wind tunnel studies confirmed our theories regarding the causes of errors in the samples from the Durham sampler. Tunnel tests indicated that the actual impaction efficiency of the slide-edge-cylinder sampler is essentially the same as the theoretical efficiency. Numerous wind tunnel tests were made to determine the sampling (impaction-retention) efficiency of the slide-edge-cylinder sampler,[9] the rotorod sampler,[21] the rotoslide sampler,[11] the Hirst spore trap,[21] and several other sampling devices.

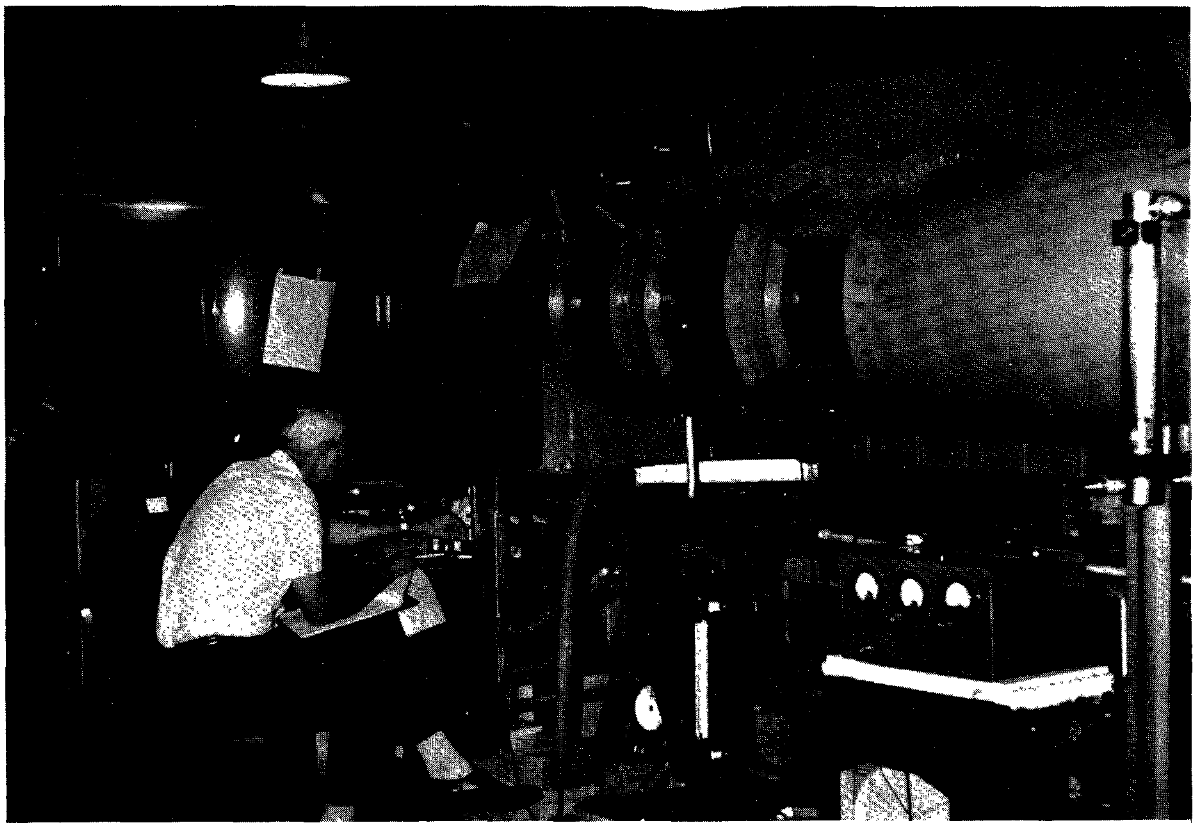


Fig. 4-7 Wind tunnel at Brookhaven National Laboratory.

CONCLUSIONS

Methods for determining concentrations of particulates in the atmosphere include impaction, filtration, liquid impingement, electrostatic attraction, and thermal precipitation. However, methods of removing particles from the free air and getting them onto a sampling surface or into a sampler entrance are limited to deposition, impaction, and suction. Impaction is the preferred method for large particles such as pollen.

Because the efficiency of stationary impactor samplers is low and highly variable over the range of wind speeds commonly encountered, the rotating impactor has come into general use.

Data from samplers relying on gravity or impingement (such as the Durham sampler and modifications of it) may not be converted to grains per unit volume of air.

None of the samplers in current use is dependable during wet weather (rain and fog).

REFERENCES

1. Ogden, E. C., and G. S. Raynor. Field Evaluation of Ragweed Pollen Samplers. J Allergy 31(4):307-316, July-August 1960.

2. Hayes, J. V. Comparison of the Rotoslide and Durham Samplers in a Survey of Airborne Pollen. Ann Allergy 27:575-584, November 1969.

3. Ogden, E. C. Tagging and Sampling Ragweed Pollen. Progress Report 1. New York State Museum and Science Service, Albany, N.Y. May 1960. 32 p.

4. Ogden, E. C., G. S. Raynor, and J. M. Vormevik. Travels of Airborne Pollen. Progress Report 5. New York State Museum and Science Service, Albany, N.Y. May 1964. 30 p.

5. Lewis, D. M., and E. C. Ogden. Trapping Methods for Modern Pollen Rain Studies. In: Handbook of Paleontological Techniques, B. Kummel and D. Raup (eds.). San Francisco, W. H. Freeman & Co., 1965. p. 613-626.

6. Raynor, G. S., M. E. Smith, I. A. Singer, and E. C. Ogden. Pollen Sampling and Dispersion Studies at Brookhaven National Laboratory. Air Pollut Contr Ass J 11:557-561 & 584, December 1961.

7. Raynor, G. S., J. V. Hayes, and E. C. Ogden. Experimental Data on Ragweed Pollen Dispersion and Deposition From Point and Area Sources. Brookhaven National Laboratory, Upton, N.Y. Publication Number BNL 50224 (T-564). February 1970. 33 p.

8. Ogden, E. C., and G. S. Raynor. Travels of Airborne Pollen. Progress Report 3. New York State Museum and Science Service, Albany, N.Y. July 1962. 8 p.

9. Ogden, E. C., G. S. Raynor, and J. M. Vormevik. Travels of Airborne Pollen. Progress Report 4. New York State Museum and Science Service, Albany, N.Y. June 1963. 12 p.

10. Raynor, G. S. Sampling Particulates With Rotating Arm Impaction Samplers. Brookhaven National Laboratory. (Presented at Proc. Workshop/Conference I. Ecological Systems Approaches to Aerobiology. Kansas State University, Manhattan. January 6-9, 1972.) US/IBP Aerobiology Program Handbook 2:82-105. University of Michigan, Ann Arbor.

11. Ogden, E. C., and G. S. Raynor. A New Sampler for Airborne Pollen: The Rotoslide. J Allergy 40(1):1-11, July 1967.

12. Raynor, G. S., and E. C. Ogden. The Swing-shield: An Improved Shielding Device for the Intermittent Rotoslide Sampler. J Allergy 45:329-332, June 1970.

13. Ogden, E. C., G. S. Raynor, and J. V. Hayes. Travels of Airborne Pollen. Progress Report 11. New York State Museum and Science Service, Albany, N.Y. February 1971. 25 p.

14. Hirst, J. M. An Automatic Volumetric Spore Trap. Ann Appl Biol 39(2):257-265, June 1952.

15. Ogden, E. C., J. V. Hayes, and G. S. Raynor. Diurnal Patterns of Pollen Emission in *Ambrosia, Phleum, Zea,* and *Ricinus*. Amer J Bot 56:16-21, January 1969.

16. Raynor, G. S. Variation in Entrance Efficiency of a Filter Sampler With Air Speed, Flow Rate, Angle and Particle Size. Amer Ind Hyg Ass J 31:294-304, May-June 1970.

17. Raynor, G. S. Entrance Efficiency of a Vane-mounted Filter Sampler at a 45-Degree Angle to the Wind. Brookhaven National Laboratory, Upton, N.Y. Publication Number BNL 15909. 1971. 10 p.

18. Raynor, G. S. An Isokinetic Sampler for Use on Light Aircraft. Atmos Environ (Great Britain). 6:191-196, 1972.

19. Raynor, G. S., J. V. Hayes, and E. C. Ogden. Mesoscale Transport and Dispersion of Airborne Pollens. J Appl Meteorol 13(1):87-95, February 1974.

20. Ogden, E. C., G. S. Raynor, and J. V. Hayes. Travels of Airborne Pollen. Progress Report 8. New York State Museum and Science Service, Albany, N.Y. February 1968. 36 p.

21. Ogden, E. C., G. S. Raynor, and J. V. Hayes. Travels of Airborne Pollen. Progress Report 9. New York State Museum and Science Service, Albany, N.Y. March 1969. 27 p.

SECTION V

TAGGING EXPERIMENTS

This phase of the project was concerned with several methods of marking pollen grains so that studies could be made on the travels of the pollen from a known source, including simultaneous emissions from different positions.

DYES

Experiments were conducted on the preparation of dyed pollen grains, *Lycopodium* spores, and fungus spores for dispersion and deposition studies.[1] The particles are added to a saturated aqueous solution of a suitable dye with a small quantity of wetting agent and stirred until the grains are colored and the clumps are separated. The staining solution containing the particles is released into the atmosphere by compressed air-operated atomizing nozzels.[2] The liquid quickly evaporates, leaving the dry particles subject only to atmospheric motions and their normal settling velocity. When two or more colors are to be released from the same container, they are removed from the staining solution and mixed in a liquid in which the dyes are not soluble. Dyed pollens were used extensively as tracers in our experiments designed to study the behavior of particles in a forested region. Dyed pollens also were useful in other point source experiments and in wind tunnel tests.

Many experiments were performed to determine whether ragweed pollen could be labeled by vital dyes in the living plants.[3] These studies were conducted with two species of *Ambrosia* in the greenhouse and in the field. Six nonfluorescent and six fluorescent dyes were used. Methods of application included: saturating the soil; adding dyes to aerated, buffered, nutrient solutions; introduction directly into the conducting system; and immersing inflorescences in the dye solutions. It was found that dyes in an aqueous solution of 1000 parts per million could be introduced directly into the xylem with but slight injury to the living plant. These dyes moved rapidly to the flower area. Among the dyes, rhodamine B was most easily detected because of its bright red color under white light and its bright red glow under ultraviolet light. Also, there was less chance of confusion between the red rays of the fluorochrome and the yellow-green rays due to autofluorescence of the pollen. Although the dye moved rapidly to the flowers, it did not enter the anthers. Experiments with immersion of flowers in alcohol and xylene to break the resistance of the cell membranes to the dye indicated that a strong xylene mixture or a long immersion period resulted in deeply dyed pollen but, in all such cases, the flowers drooped and no pollen was shed. As it appeared that vital dyes offered little promise for labeling ragweed pollen in the anthers in such a way that normal pollen shed is not modified, these studies were abandoned in favor of other more promising techniques.

RADIOISOTOPES

Two isotopes were chosen for these experiments with the two ragweed species: radiophosphorus (^{32}P) with a half-life of 14.3 days and radiosulfur (^{35}S) with a half-line of 87.1 days. They were not toxic to the plants in the amounts used, were no hazard to trained personnel, and they traveled to the pollen without excessive loss. The labeled pollen created no hazard in and around the area. The half-life was long enough to permit processing the samples and short enough so a contaminated area or expensive equipment need not be abandoned for an unreasonable length of time, and there was sufficient radiation from small amounts to allow detection with available methods.

The experiments[3] were mostly conducted with ^{32}P, using *Ambrosia artemisiifolia* in the greenhouse in hydroponic solution to which the isotope was added and using both species in the field with the isotope introduced into the main stem (Fig. 5-1). The relative amounts of radiation from different parts of the plants were determined by Geiger counters and

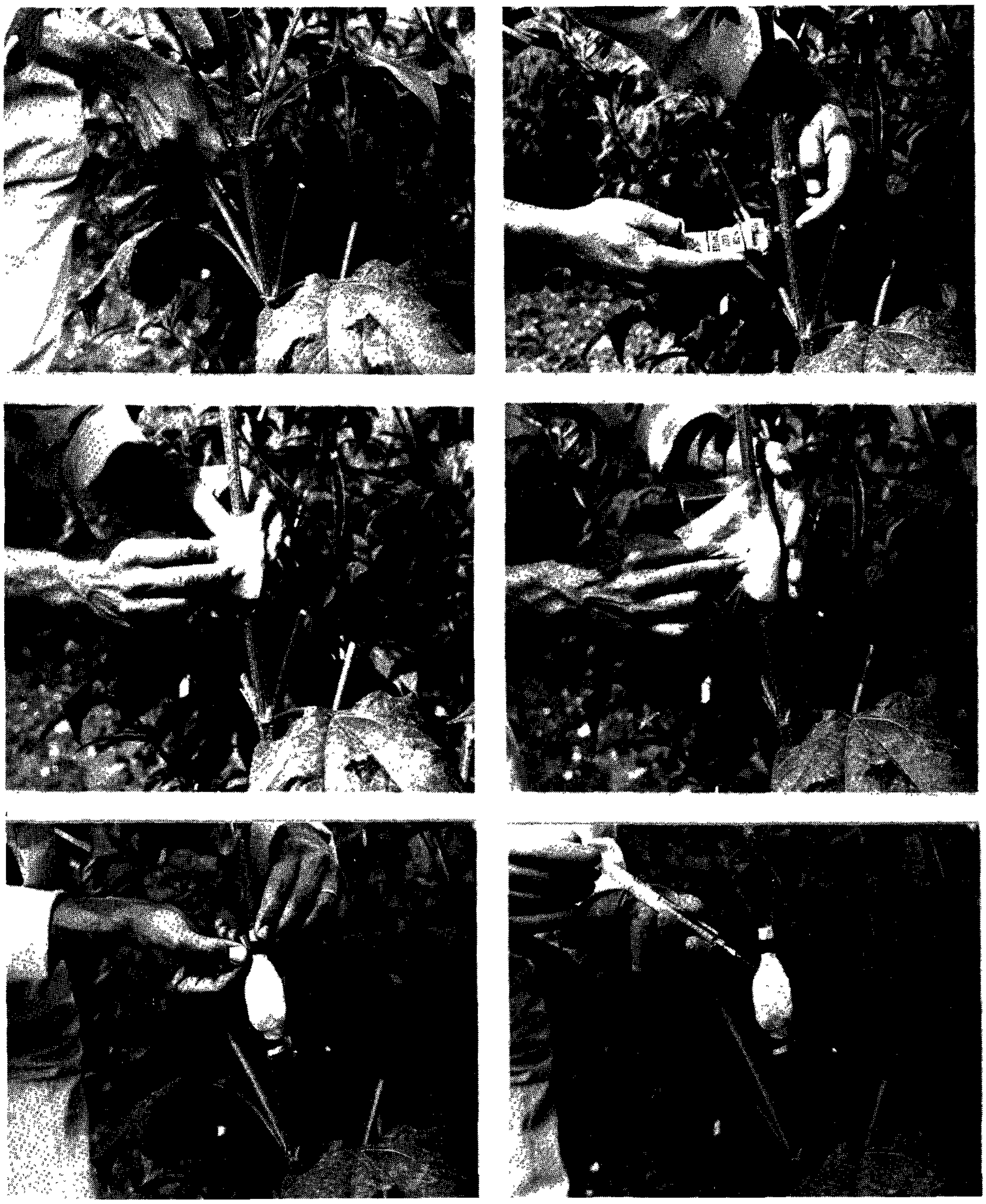


Fig. 5-1 Cotton wrap technique for introduction of a radioisotope into a ragweed plant.

radiation scalers. However, the amounts of radiation among individual pollen grains varied so greatly that autoradiographs were required for recognition of tagged grains (Fig. 5-2). These are easily prepared.[3] Radiosulfur acted much like radiophosphorus, going as readily to the pollen.[4] Its half-life, which is over six times as long, allowed longer exposures and less haste in taking and processing samples. Also, the traces from ^{35}S are shorter than those from ^{32}P, an advantage when counting crowded grains.

Although radioisotope tagging offered a tracer technique, it was not necessary for our dispersion studies as the production of preseason ragweed proved to be easy and satisfactory.

PRESEASON RAGWEED POLLEN

As giant ragweed (*A. trifida*) normally reaches anthesis one or two weeks earlier than common ragweed (*A. artemisiifolia*), the former was used for the production of preseason pollen.[4] Greenhouse and field experiments indicated that increasing the periods of darkness for five or more days would initiate flower bud formation. About 300 light-tight black cloth bags were used for covering the individual plants for the preseason pollen dispersion field. However, after it was noticed that allowing the plants to remain in small (4-inch) pots until they are rootbound will initiate early production of flowers, this technique was used during succeeding seasons. The short-day (actually long-night) technique was an alternate method and used again one year when animals got into the fenced field and destroyed the rootbound planting (Fig. 5-3).

CONCLUSIONS

Vital dyes offer little promise for tagging pollen. Radioisotopes may be used for special studies. However, pollen emitted naturally out-of-season or in quantities far exceeding background pollen and prestained artificially emitted pollen are more satisfactory for most dispersion studies.

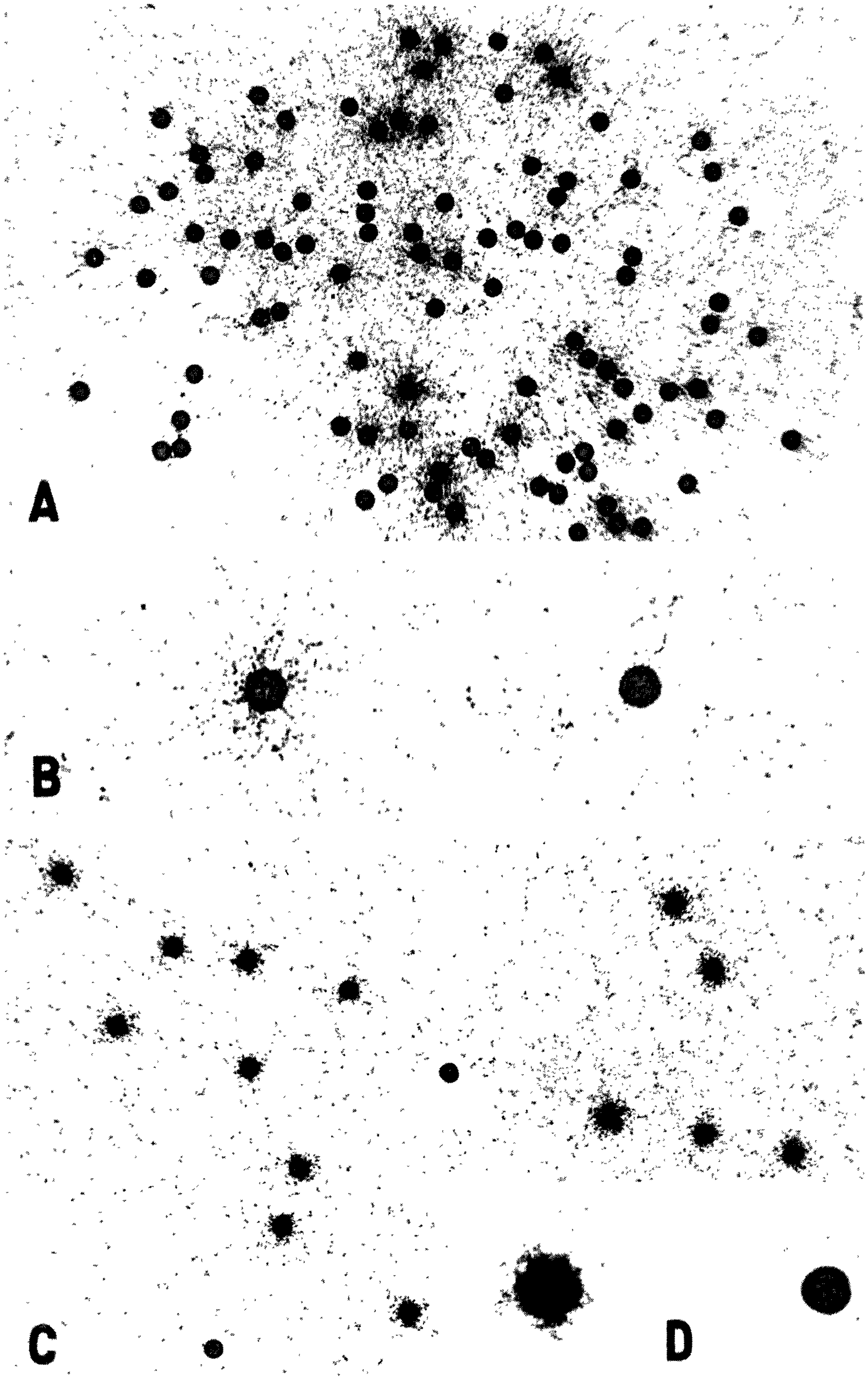


Fig. 5-2 Autoradiographs of ragweed pollen. (A and B) Pollen from plant injected with ^{32}P. (C and D) Pollen from plant injected with ^{35}S. (B and D) Grains on left show nuclear tracks, grains on right are not recognizably tagged.

Fig. 5-3 Ragweed field for preseason pollen.

REFERENCES

1. Raynor, G. S., L. A. Cohen, J. V. Hayes, and E. C. Ogden. Dyed Pollen Grains and Spores as Tracers in Dispersion and Deposition Studies. J Appl Meteor 5(5):728-729, October 1966.

2. Raynor, G. S., and M. E. Smith. A Diffusion-deposition Tracer System. Brookhaven National Laboratory, Upton, N.Y. Publication Number BNL 859(T-343). April 1964. 17 p.

3. Ogden, E. C. Tagging and Sampling Ragweed Pollen. Progress Report 1. New York State Museum and Science Service, Albany, N.Y. May 1960. 32 p.

4. Ogden, E. C., and G. S. Raynor. Tagging and Sampling Ragweed Pollen. Progress Report 2. New York State Museum and Science Service, Albany, N.Y. December 1961. 14 p.

SECTION VI

DISPERSION AND DEPOSITION STUDIES OVER OPEN TERRAIN

AREA AND POINT SOURCES

Ragweed Pollen

Dispersion of ragweed (*Ambrosia*) pollen emitted naturally from cultivated plants in 10 circular area sources (Figs. 6-1 and 6-2) of four sizes and artificially from point sources was studied over a four-year period.[1-3] Concentrations were measured by slide-edge-cylinder samplers mounted on 20° radii at four heights (0.5-4.6 m) and four or five distances from the sources to a maximum of 69 m. An anemometer was mounted at each height. Deposition was measured by greased

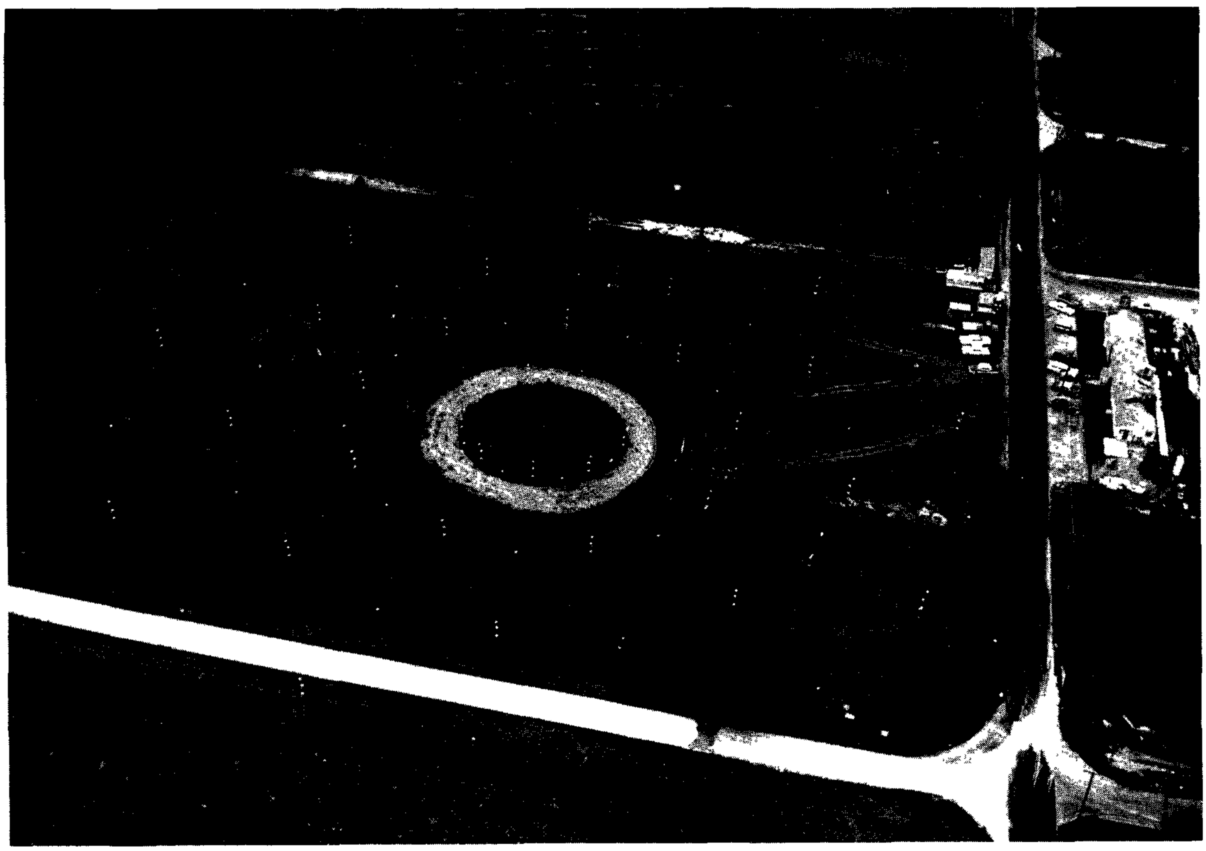


Fig. 6-1 Aerial view of area source of ragweed pollen.

microscope slides on the ground. A Hirst spore trap was mounted above the center of each source to measure the variation of pollen emission with time. Differences in dispersion patterns between point and area sources were analyzed. Dispersion patterns, normalized centerline concentrations, cross-wind integrated concentrations, plume widths, plume heights, mass flux, and deposition were presented as functions of distance and related to source size and meteorological variables.[3] During the normal ragweed pollination season, the contribution of pollen from other sources was determined from measurements on the upwind side of the plot and this quantity subtracted from all downwind measurements before further analysis.

Point sources (Fig. 6-3) consisted of compressed-air-operated atomizing nozzles[4] which sprayed a known amount of prestained ragweed pollen in a water suspension.[5] Output rates varied from 1 to 5 x 10^5 grains/sec but were constant during each run. Emissions lasted from 24 to 60 min. The point sources were 0.5 to 3 m above the ground.

Concentrations from area and point sources normalized to 100% at 1 m from the source indicated that from 25 to 65% remain airborne at 60 m. Extrapolation of the data to greater distances indicates that about 1% of the pollen grains remain airborne at 1000 m. Since much of the eastern two-thirds of the United States constitutes a ragweed pollen source region and a single plant can release more than a million grains per day during the height of the pollination season, the ubiquity of airborne ragweed pollen during late summer is not surprising.

The dispersion of pollen from these ragweed sources was also studied to determine the effect of contributions from such sources upon the pollen concentrations originating in more distant areas.[6] Since ragweed pollen is produced throughout a large region, concentrations measured at any given location represent contributions from many sources at various distances along the past trajectory of the air sampled. A local source may produce concentrations several orders of magnitude above this background in a small downwind region. These concentrations decrease with distance and at some point become insignificant in comparison to background concentrations. Distances necessary for concentrations to reach specified fractions of background and areas covered by concentrations greater than specified multiples of background are related to source size, surrounding vegetation, and meteorological conditions. The effects of local sources of the sizes studied (239 to 2000 m^2) become negligible at distances greater than several hundred to a thousand meters.

The areas within which ragweed pollen concentrations equaled or exceeded selected values were determined from measurements around these ten sources.[7] The size of the polluted area was related directly to source size and inversely to wind speed and the removal efficiency of surrounding vegetation. Our data indicate that a ragweed source may pollute an area from 6 to 100 times its own area with concentrations above 100 grains/m^3 and from 11 to 300 times its own area with concentrations above 10 grains/m^3. In the downwind direction, concentrations of 100/m^3 may be found at distances of 2 to 10 times the source diameter and concentrations of 10/m^3 to distances of 3 to 20 times the source diameter. These are averages; day-to-day values may differ greatly.

Fig. 6-2 Ground level view of area source of ragweed pollen.

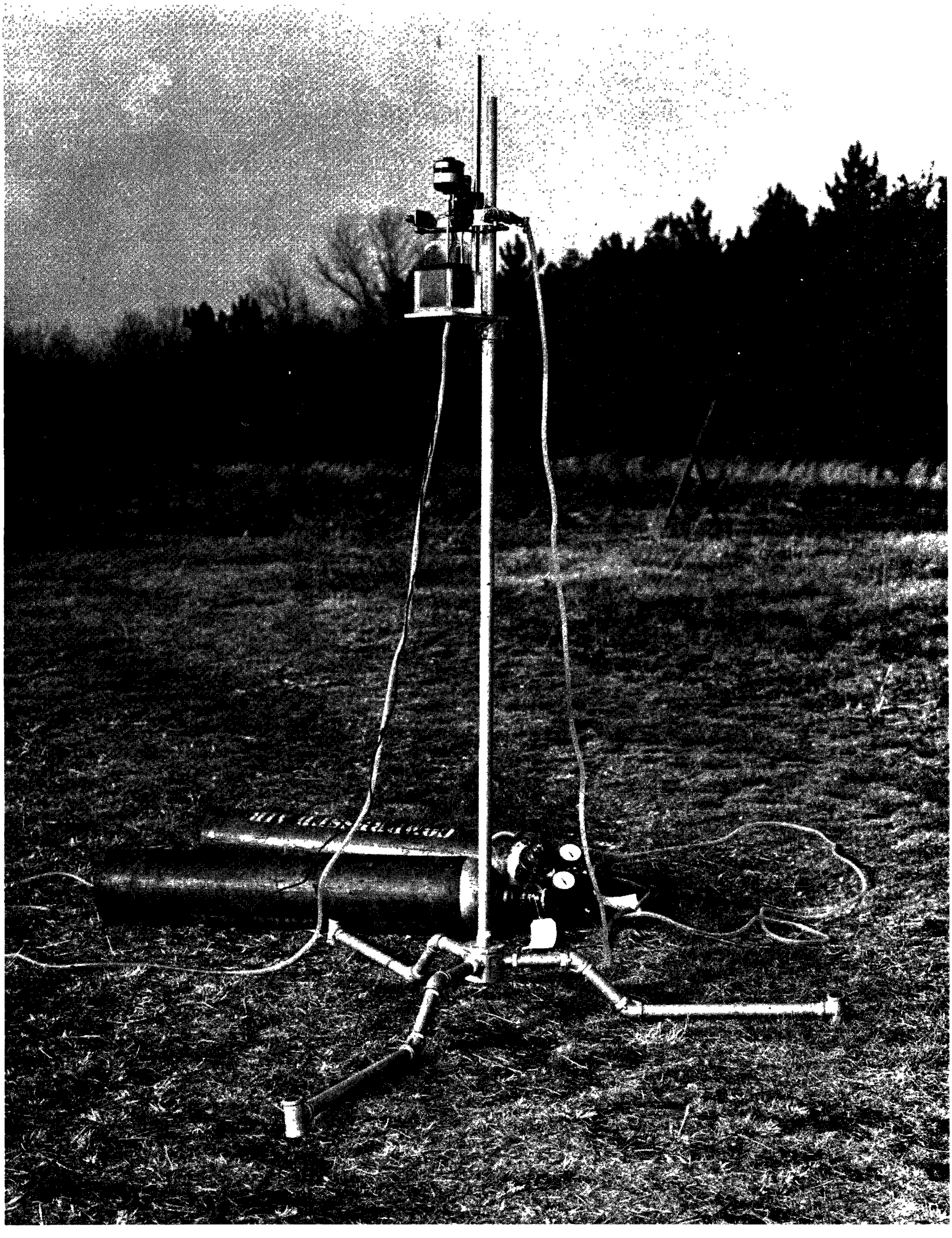


Fig. 6-3 Point source pollen-dispensing apparatus.

Timothy Pollen

Dispersion of timothy (*Phleum*) pollen emitted naturally from three circular area sources of two sizes of cultivated plants was studied over a three-year period.[8,9] Pollen was also emitted artificially from point sources. The sampling arrays were essentially the same as for ragweed pollen and the results reported in the same way.

The data indicate that dispersion and deposition of timothy pollen (34 microns in diameter) differ little from that of ragweed pollen (20 microns) from similar sources despite the difference in size. Normalized distances were generally less for timothy than for ragweed. They range between 2 and 5 source diameters to the 10 grains/m^3 isopleth while the ragweed sources give similar concentrations as far as 5 to 13 source diameters. Our data suggest that source configuration and meteorological conditions are more important variables than particle characteristics in determining both dispersion and deposition rate for ragweed and timothy pollens, but not for the heavier corn pollen.

Corn Pollen

Dispersion and deposition of corn (*Zea*) pollen (90-100 microns) emitted naturally from two circular 18-m-diameter plots of cultivated plants and from pollen emitted artificially from point sources was studied over a two-year period.[8,10] The sampling arrays were essentially the same as for ragweed and timothy. The results were reported in the same way and compared with the data for dispersion and deposition of ragweed and timothy pollens. These studies show that corn pollen is not transported as far by the wind as smaller pollens, does not disperse as widely in either the horizontal or the vertical direction and settles to earth more quickly, much of it within the source itself.

At 60 m from the source in the downwind direction, concentrations averaged about 1% of those at 1 m, compared to 6% for timothy and 9% for ragweed. The total amount of corn pollen remaining airborne at 60 m was 5% of that at 1 m, compared to 37% for timothy and 50% for ragweed.

LINE SOURCES

Dispersion and deposition of pollens emitted naturally from 80-m-long, crosswind, line sources of living plants (Fig. 6-4) and of pollens sprayed from a moving vehicle were studied in a set of 45 experiments.[11,12] Concentrations were measured by 276 slide-edge-cylinder samplers[1] mounted in a square array which included four heights at each of 69 positions. Deposition was measured by greased microscope slides on the ground. Wind speeds were measured by anemometers at each sampling height.

Plants used as pollen sources were giant ragweed (*Ambrosia trifida*), summer cypress (*Kochia scoparia*), and castor bean (*Ricinus communis*). The ragweed pollen was spherical with low spines and about 20 microns in diameter; the summer cypress pollen was spherical, smooth, and about 30 microns; the castor bean pollen was ellipsoidal, smooth, and 24 x 38 microns. Each source included 240 plants grown in 12-quart pails and placed in an 80-m-long line about one meter wide.

Fig. 6-4 Movable line source of *Kochia* pollen.

Ten runs were made with ragweed, seven with summer cypress, and twenty-three with castor bean. Prestained ragweed pollen was emitted from a vehicle moving back and forth along a line in five runs and from a point source to determine angle of spread in seven runs.

The data which were presented as functions of distance from source, pollen type and release height included decrease in concentration, plume height, mass flux, deposition, and deposition velocity. The results were compared with those from previous point and area source dispersion experiments.

REFERENCES

1. Raynor, G. S., J. V. Hayes, and E. C. Ogden. Experimental Data on Ragweed Pollen Dispersion and Deposition From Point and Area Sources. Brookhaven National Laboratory, Upton, N.Y. Publication Number BNL 50224(T-564). February 1970. 33 p.

2. Raynor, G. S., and E. C. Ogden. Twenty-four-hour Dispersion of Ragweed Pollen From Known Sources. Brookhaven National Laboratory, Upton, N.Y. Publication Number BNL 957(T-398). December 1965. 17 p.

3. Raynor, G. S., E. C. Ogden, and J. V. Hayes. Dispersion and Deposition of Ragweed Pollen From Experimental Sources. J Appl Meteor 9(6):885-895, December 1970.

4. Raynor, G. S., and M. E. Smith. A Diffusion-deposition Tracer System. Brookhaven National Laboratory, Upton, N.Y. Publication Number BNL 859(T-343). April 1964. 17 p.

5. Raynor, G. S., L. A. Cohen, J. V. Hayes, and E. C. Ogden. Dyed Pollen Grains and Spores as Tracers in Dispersion and Deposition Studies. J Appl Meteor 5(5):728-729, October 1966.

6. Raynor, G. S., E. C. Ogden, and J. V. Hayes. Effect of a Local Source on Ragweed Pollen Concentrations From Background Sources. J Allergy 41:217-225, April 1968.

7. Raynor, G. S., J. V. Hayes, and E. C. Ogden. Areas Within Isopleths of Ragweed Pollen Concentrations From Local Sources. Arch Environ Health 19(1):92-98, July 1969.

8. Raynor, G. S., J. V. Hayes, and E. C. Ogden. Experimental Data on Dispersion and Deposition of Timothy and Corn Pollen From Known Sources. Brookhaven National Laboratory, Upton, N.Y. Publication Number BNL 50266(T-595). October 1970. 32 p.

9. Raynor, G. S., E. C. Ogden, and J. V. Hayes. Dispersion and Deposition of Timothy Pollen From Experimental Sources. Agr Meteor (The Netherlands). 9(1971/1972):347-366, 1972.

10. Raynor, G. S., E. C. Ogden, and J. V. Hayes. Dispersion and Deposition of Corn Pollen From Experimental Sources. Agron J 64(4):420-427, July-August 1972.

11. Raynor, G. S., J. V. Hayes, and E. C. Ogden. Experimental Data on Dispersion and Deposition of Pollens From Low-level, Crosswind Line Sources. Brookhaven National Laboratory, Upton, N.Y. Publication Number BNL 16334. November 1971. 17 p.

12. Raynor, G. S., E. C. Ogden, and J. V. Hayes. Dispersion of Pollens From Low-level, Crosswind Line Sources. Agr Meteor (The Netherlands). 11(1973):177-195, 1973.

SECTION VII

PARTICULATE DISPERSION INTO AND WITHIN A FOREST

Particulate dispersion into and within a 10- to 13-m tall pine forest (Fig. 7-1) was studied using stained ragweed pollen and other tracers ranging from 14 to 54 microns in diameter.[1-4,6]

During 42 tests, 119 continuous point source releases lasting 20 to 40 minutes were made from atomizing nozzels at various locations from within the forest to 60 m upwind and at heights of 1.75 to 14 m. In most experiments, differently colored ragweed pollen was released simultaneously from three locations. Thirty-six other tests from 2 to 5 hours in length were made using pollen released naturally from area sources of ragweed planted upwind of the forest and three with pollen from distant sources. All tests were made during the day with steady winds and unstable lapse rates outside the forest. The sampling network consisted of 119 rotoslide samplers mounted at heights from 0.5 to 21 m on 57 towers and lower-level supports along seven rows 10 m apart extending 100 m into the forest. Deposition was sampled by greased microscope slides at each sampling position. Meteorological measurements were taken in and near the forest.[5]

Data were classified by particle characteristics; source type, distance, and height; and by meteorological parameters. Isopleths were drawn on scale diagrams of the sampling grid in the horizontal at each sampling level, along each tower row in the downwind-vertical plane and at each distance in the crosswind-vertical plane to illustrate concentration patterns. Changes in centerline concentration, crosswind integrated concentration, mass flux, plume width, plume height, and deposition were related to distance within the forest and other variables. Results were compared to those of similar releases over open terrain and those of previous forest dispersion studies elsewhere.

DISPERSION FROM UPWIND POINT SOURCES

All particles used in the upwind point source dispersion experiments were emitted in a liquid spray at locations from just within the forest edge to 60 m upwind and from 1.75 to 14 m above the ground.[1,4] In most tests prestained ragweed pollen was used and in nearly all tests simultaneous emissions of differently colored pollen were made from three locations. In a few tests other particles were used: timothy (*Phleum*) pollen, paper mulberry (*Broussonetia*) pollen, club moss (*Lycopodium*) spores, fern (*Osmunda* and *Dryopteris*) spores, rust (*Cronartium*) spores, and copper spheres. Seventy-two releases were made in 27 tests.

Fig. 7-1 Experimental forest showing some of the towers.

The plume approaching the forest was broadened both vertically and horizontally by divergence at the forest edge and flowed mainly into the trunk space and above the forest. Lateral spread was slow within the forest but vertical spreading in the equilibrium region was greater than in the open. Particles became mixed uniformly below the canopy while appreciable interchange took place through this layer. Concentration within the forest decreased at a faster rate than in the open, but change in total mass flux within and above the forest was not significantly different. Loss of material took place by impaction near the forest edge and in the treetops and by deposition within the forest where plume movement was slow. Most loss took place to the foliage rather than the ground and larger particles were lost faster than smaller ones.

DISPERSION FROM UPWIND AREA SOURCES

Dispersion of ragweed pollen into the forest from a rectangular 30- x 15-m plot of cultivated preseason and inseason ragweed plants upwind of the forest was studied in a series of 36 tests.[2,4] After the ragweed season, three additional tests were made with background pollen from distant sources.

The sampling grid and experimental procedures were the same as those used in point source experiments except that test periods were longer, usually several hours in length. Data were classified by the same variables and analyzed in similar fashion. Results were qualitatively similar except that plumes were wider due to the size of the source and greater wind variability during the longer sampling periods.

DISPERSION FROM WITHIN THE FOREST

Dispersion from within and above the forest was studied during 47 releases in 17 tests.[3,6] Sources were located at heights from 1.75 to 14.0 m at locations near the north end of the sampling grid. Procedures were similar to those used for point source releases upwind of the forest and data were analyzed in the same manner. These tests documented interchange through the canopy and some channeling within the forest.

Centerline and crosswind integrated concentrations decreased more rapidly with distance in the forest than over open terrain. Source-height centerline concentrations decreased most rapidly from sources in the canopy, least rapidly from sources above the trees and at intermediate rates from sources in the trunk space.

The plumes spread less in the crosswind direction than plumes from similar sources over open fields but spread faster in the vertical direction. Rate of vertical spread was correlated with wind speed above the forest but horizontal spread showed an inverse relationship near the source and no correlation at greater distances.

Total airborne particles from 1.75 m sources decreased at about the same rate as in the open field but decreased at rates inversely proportional to wind speed. Large particles were lost faster than smaller ones.

FOREST METEOROLOGICAL STUDIES

Measurements of wind speed and temperature were taken in and near the forest during all dispersion tests. Cup anemometers were located at 25 locations at selected distances within the forest at heights from 1.75 to 21 m. Temperature sensors were mounted at 4 heights within the forest and 6 heights in the field. Data were also taken continuously for a period to compare the micrometeorology of the forest to that of an open location. This study included humidity as well as wind and temperature measurements. Much of the earlier data has been published.[5] Measurements of turbulence were made with sensitive bivanes on several occasions and assisted in the interpretation of dispersion data.

With winds penetrating the forest edge, speeds in the trunk space are greater than those in the canopy for a distance of ±60 m. With a longer fetch through the forest, wind speeds vary little with height to midcanopy. During the day, a temperature inversion is found beneath the canopy and a negative lapse rate above. During the night, an isothermal layer or a slight lapse below the canopy and an inversion above are typical.

REFERENCES

1. Raynor, G. S., J. V. Hayes, and E. C. Ogden. Experimental Data of Particulate Dispersion Into and Within a Forest. Part I: Dispersion From Upwind Point Sources. Brookhaven National Laboratory, Upton, N.Y. Publication Number BNL 17750. December 1972. 95 p.

2. Raynor, G. S., J. V. Hayes, and E. C. Ogden. Experimental Data on Particulate Dispersion Into and Within a Forest. Part II: Dispersion From Upwind Area Sources. Brookhaven National Laboratory, Upton, N.Y. Publication Number BNL 18064. June 1973. 39 p.

3. Raynor, G. S., J. V. Hayes, and E. C. Ogden. Experimental Data on Particulate Dispersion Into and Within a Forest. Part III: Dispersion From Within and Above the Forest. Brookhaven National Laboratory, Upton, N.Y. In press.

4. Raynor, G. S., J. V. Hayes, and E. C. Ogden. Particulate Dispersion Into and Within a Forest. Boundary Layer Meteorology. In press.

5. Raynor, G. S. Wind and Temperature Structure in a Coniferous Forest and a Contiguous Field. Forest Sci 17(3):351-363, September 1971.

6. Raynor, G. S., J. V. Hayes, and E. C. Ogden. Particulate Dispersion From Sources Within a Forest. In preparation.

SECTION VIII

DEPOSITION TO VEGETATED SURFACES: GRASSLAND VS. FOREST

Deposition measurements were made in 395 tests in connection with dispersion studies, 240 in the open grassy field and 155 in the pine forest. From 57 to 90 sampling locations were utilized in each test.[1]

Although airborne pollen grains are often transported long distances and concentrations may be heavy downwind of stands of anemophilous plants, most pollen grains deposit close to their source. Our studies of ragweed pollen released from area sources of various sizes show that ±50% deposited in the first 60 m of travel. Extrapolation of these data suggests that ±99% deposit within a km. However, the remaining 1% can account for the high pollen concentrations during the ragweed season when the number and wide distribution of sources and the amount of pollen per plant are considered.

Corn pollen, at the other extreme, deposits closer to its source. Using 18-m diam plots, we found that more corn pollen reached the ground within the plot than outside while additional amounts deposited on the leaves. Of that portion which did become airborne downwind of the plot, ±95% deposited within 60 m.

Deposition velocity over grass (mowed field) was determined from area, point, and line sources. Individual measurements varied widely between locations and between tests. However, they tended to average about three times the terminal velocity of the pollen grains.

Deposition velocity in the forest was studied using point source releases outside and inside the forest and an area source adjacent to the forest edge. Deposition velocity averaged close to the calculated terminal velocity. This is probably due to the light wind speeds and low level of turbulence near the forest floor which minimize turbulent impingement. Mass flux calculations showed that most particles were lost to the foliage rather than to the ground.

Assuming that the measurements are reasonably representative of the natural surfaces, the data show that velocity of deposition to short grass, during unstable conditions with light to moderate winds, appreciably exceeds the terminal velocity of the particles. Turbulent impingement is added to gravitational settling. In the forest with the same conditions outside, a slight inversion or an isothermal layer is present under the canopy, wind speeds are light and turbulence levels low.[2] Here, gravitational settling seems to be the predominant deposition mechanism.

REFERENCES

1. Raynor, G. S. Experimental Studies of Pollen Deposition to Vegetated Surfaces. Brookhaven National Laboratory. (Presented at Proc. of Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants. 1974 Symposium, Richland, Washington. September 4-6, 1974.) Brookhaven National Laboratory, Upton, N.Y. Publication Number BNL 19219. September 1974. 32 p.

2. Raynor, G. S. Wind and Temperature Structure in a Coniferous Forest and a Contiguous Field. Forest Sci 17(3):351-363, September 1971.

SECTION IX

DIURNAL PATTERNS OF EMISSION

Hourly measurements of pollen emission were made from a total of 15 cultivated plots of ragweed (*Ambrosia*), timothy (*Phleum*), corn (*Zea*), and castor bean (*Ricinus*) during several pollination seasons.[1]

A Hirst spore trap was mounted at the center of each circular plot for this purpose. A characteristic diurnal emission pattern was found for each genus, but the emission patterns for an individual day sometimes differed appreciably from the seasonal mean.

Ambrosia pollen emission normally begins an hour or two after sunrise, peaks a few hours later, decreases in the afternoon, and is minor during the night. Emission most typically begins when stable, moist nighttime conditions change to unstable and drier air shortly after sunrise.

Phleum emission starts during the night, peaks about two hours after sunrise, and slowly declines during the day. Pollen emission may begin anytime from 2100 to 0600 EST. If emission started during the night, it usually ended by 0800 but, if the beginning was delayed until after sunrise, appreciable amounts continued until noon.

Zea emits pollen fairly uniformly during the period from two hours after sunrise to about sunset, with only small amounts at night. The peak varied from midmorning to midafternoon.

Ricinus pollen emission began two to three hours after sunrise, with a peak at 0900 to 1100, and decreased gradually through the afternoon.

REFERENCE

1. Ogden, E. C., J. V. Hayes, and G. S. Raynor. Diurnal Patterns of Pollen Emission in *Ambrosia, Phleum, Zea,* and *Ricinus*. Amer J Bot 56:16-21, January 1969.

SECTION X

TEMPORAL VARIATION IN POLLEN CONCENTRATIONS

Diurnal patterns of occurrence close to a source are influenced primarily by the patterns of emission but distant from sources by meteorological variables. In several different phases of the study on the travels of airborne pollen, the patterns of occurrence were routinely determined, primarily with sequential rotoslides and Hirst spore traps. The principal locations were Brookhaven, Albany, Saratoga Springs, Raquette Lake, Blue Mountain Lake, and Whiteface Mountain near Wilmington. For most of these studies, the sequential data are described in other sections.

However, four sequential swing-shield rotoslide samplers (Fig. 4-3) were operated to study the variation with time of natural pollen concentrations, not directly influenced by local sources, to determine peak to mean concentration ratios over various sampling intervals and to assess the representativeness of single station measurements.[1]

Sampling was conducted in Albany, Saratoga Springs, and Brookhaven to examine patterns in both urban and rural areas. Sequential rotoslide samplers with time periods of 5 minutes plus one hour and 2 hours plus 24 hours were used in each location. Saratoga Springs was used in 1971, Albany in 1972, and Brookhaven in both years. Sampling was conducted during tree pollen and ragweed pollen seasons. Two hundred ninety-four tests were made, 72 in Saratoga, 95 in Albany, and 127 at Brookhaven. Since tree pollens were sometimes separated by genera, 567 separate cases were available for analyses. These were composed of 415 tree and 152 ragweed pollen cases. Two hundred seventy-nine were taken in 1971 and 288 in 1972. Three hundred three were five minute and one hour tests and 264 were 2 and 24 hour sampling periods.

Analyses of short-period samples show that agreement in catch is good between consecutive 5-minute periods, but slowly becomes poorer over the course of the hour. Little consistent difference was evident between species and locations.

Agreement between consecutive 2-hour samples is slightly poorer than between 5-minute samples an hour apart. Agreement decreases over the next 12 hours and usually becomes better again toward the end of the 24-hour period. This is attributed to the diurnal cycle. Again, similar patterns were found for all species and for all locations except Albany where an improvement toward the end of the period was not evident.

Coefficients of variation averaged about one for 2-hour periods and 0.3 to 0.5 for 5-minute samples. Values of maximum/mean usually ranged from 3 to 5 for 2-hour samples and from 1-2 for 5-minute periods. Values of minimum/mean were usually less than 0.3 for 2-hour samples and about 0.5 for 5-minute samples.

REFERENCE

1. Raynor, G. S., E. C. Ogden, and J. V. Hayes. Temporal Variation in Airborne Pollen Concentrations. In preparation.

SECTION XI

SPATIAL VARIABILITY IN POLLEN CONCENTRATIONS

Tests were conducted to determine the relationship between airborne pollen concentrations and distance.[1] Simultaneous samples were taken in 171 tests, using sets of eight rotoslide samplers, 1.5 m above the ground and 1 to 486 m apart in straight lines. Use of all possible pairs gave 28 separation distances. These tests were conducted over a two-year period in urban (Saratoga Springs and Albany) and rural (Brookhaven) locations during both tree and ragweed pollen seasons. Each run was of short duration to minimize the smoothing effect of longer exposures, most lasted 10 minutes but 5-min and 20-min periods were also used. During the second summer, to improve accuracy, mechanical counters were added for determining the actual number of revolutions each sampler made during each run, and four slides were rotated instead of the usual two (Fig. 11-1). Forty-two tests were made during the two tree pollen seasons and 129 during the ragweed seasons.

The tests were grouped by pollen type, location, and wind direction relative to the line. The data were analyzed to evaluate variability without regard to sampler spacing and variability as a function of separation distance. The mean, standard deviation, coefficient of variation, ratio of maximum to the mean, and ratio of minimum to the mean were calculated for each test, each group of tests, and all cases.

The average coefficient of variation is 0.21, the maximum over the mean 1.39, and the minimum over the mean 0.69. No relationship was found with experimental conditions. Samples taken at the minimum separation distance had a mean difference of 18%. Differences between pairs of samples increased with distance in 10 of 13 groups.

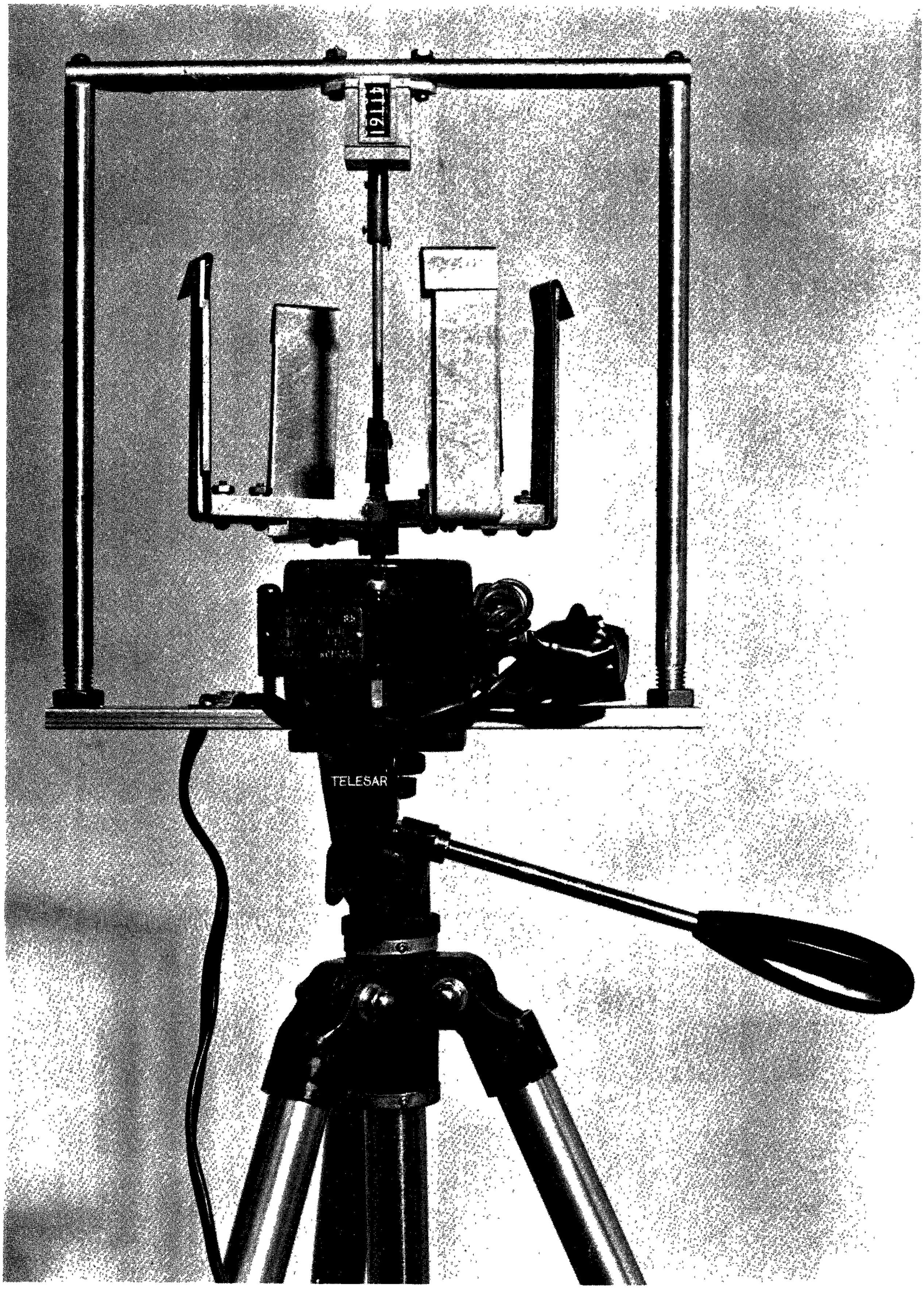


Fig. 11-1 Rotoslide sampler with revolution counter.

This increase in variability with distance appears to be caused by actual differences in pollen concentrations. They may be due to inequalities in emission which atmospheric mixing has not yet smoothed out or they may be caused by the action of local obstacles in modifying the pollen content of previously well-mixed air. The data make the first possibility more plausible since the variability at Albany with many large, local obstacles was not significantly different from that at Brookhaven, where the terrain is relatively smooth and major obstacles absent.

These results suggest that airborne pollens are not always well mixed in the lower atmosphere and that a sample becomes less representative of concentrations at increasing distances from the sampling location.

REFERENCE

1. Raynor, G. S., E. C. Ogden, and J. V. Hayes. Spatial Variability in Airborne Pollen Concentrations. J. Allergy Clin Immunol. In press.

SECTION XII

VARIATION IN POLLEN CONCENTRATION WITH HEIGHT

Variation in concentration with height from near and distant pollen sources was studied on the 128-m tower in an open area at Brookhaven on Long Island, on the 38-m tower in an extensive forest at Raquette Lake in the Adirondack Mountains, on the 16-m mobile tower at various locations, and by the use of aircraft up to 1000 m over the Long Island area. Most of the data are only a part of other studies and are discussed elsewhere in this report.

Ragweed pollen concentrations were measured at five levels from 1.5 to 108 m on the meteorology tower at Brookhaven.[1] Samples were taken over an 11-year period using both rotoslide and slide-edge-cylinder samplers. Vertical pollen profiles showed great variability from day to day but, when averaged over pollen seasons or longer periods, little systematic change with height was found. These results suggest that long-term patient exposure at upper levels of tall buildings would be similar to that at ground level in the absence of nearby pollen sources. This would not apply close to a local source where low-level concentrations would be much greater than those at higher elevations and may not apply in cities or other dissimilar locations where vertical mixing and removal patterns may differ from those at Brookhaven.

REFERENCE

1. Raynor, G. S., E. C. Ogden, and J. V. Hayes. Variation in Ragweed Pollen Concentration to a Height of 108 Meters. J Allergy Clin Immunol 51:199-207, April 1973.

SECTION XIII

ENHANCEMENT OF POLLEN CONCENTRATIONS DOWNWIND OF VEGETATIVE BARRIERS

Studies on dispersion into a forest gave information on the removal rate of a large vegetated area which extended far beyond the sampling array in the downwind direction. Information on the effects of narrower strips of vegetation was sought by sue of sampling arrays on the two sides of a hedge.[1] The area selected for study in 1971 was at a tree nursery near Saratoga Spring (Fig. 13-1), where large fields are bordered and separated by dense hedges of arbor-vitae (*Thuja occidentalis*). The hedge selected was about 100 m long, 6 m tall, 3.7 m thick, and oriented in a north-south direction. The upwind and downwind distances to the next obstacles were the same, about 100 m.

Two parallel rows of masts supporting swing-shield rotoslide samplers were installed 5 m apart at right angles to the hedge. Four pairs of masts were located on each side of the hedge. Samplers were mounted at heights of 1.5, 3.0, and 4.5 m on each mast, giving a total of 48 samplers. A totalizing anemometer, 50 m upwind, recorded the air travel during each run. As these runs were taken only when the mean wind direction was approximately at right angles to the hedge, only four were obtained during the spring tree pollen season and five during the ragweed season.

A hedge of broad-leaved shrubs and trees was chosen for 1972. The sampling design was the same. Seven runs were taken during the tree and eight during the ragweed pollen season.

To visually determine the effects of these hedges on air flow, oil fog smoke was released upwind of each hedge. These observations indicated that much of the air mass goes up and over the hedges rather than through, particularly at the arbor-vitae hedge.

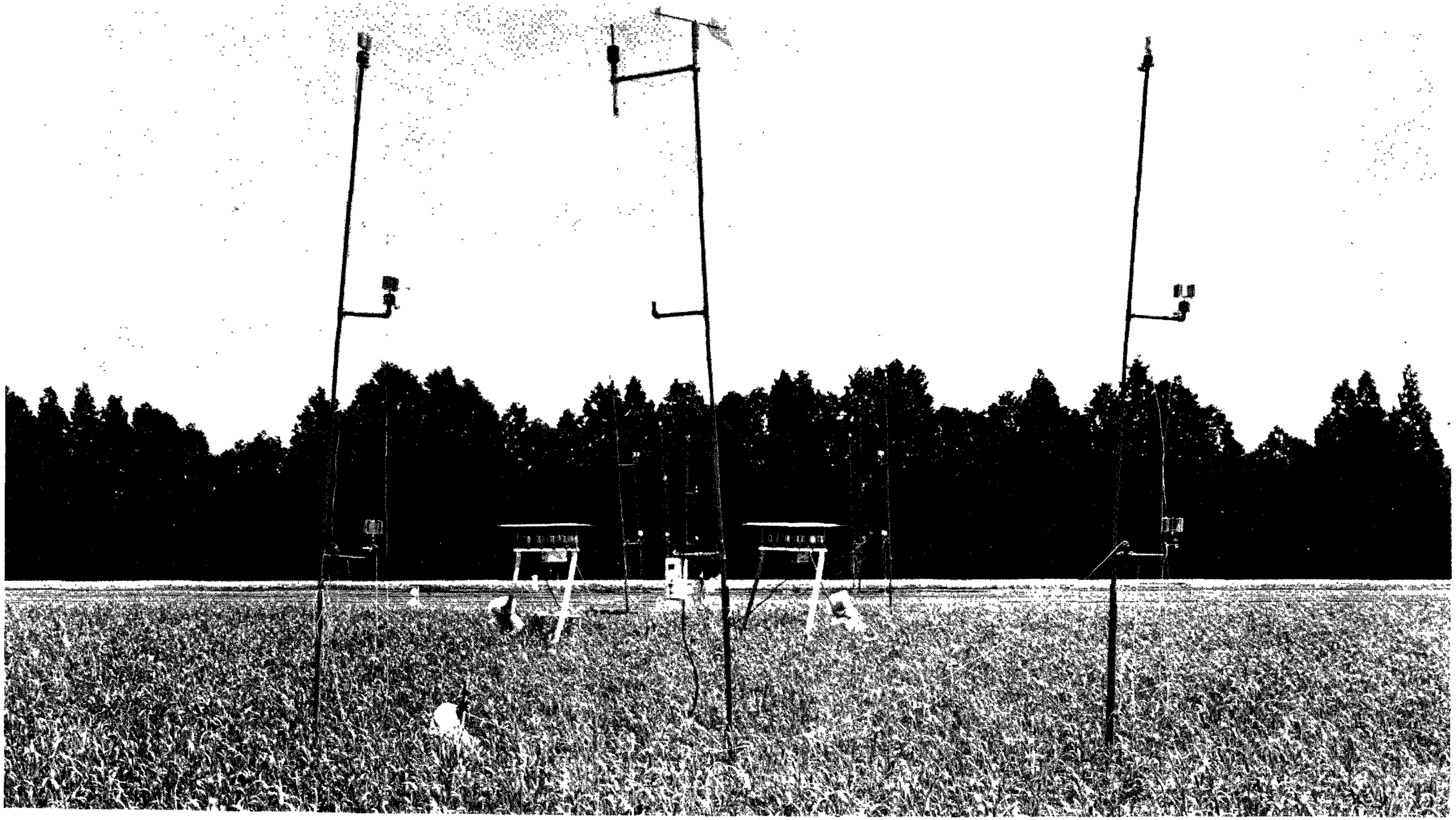


Fig. 13-1 Sampling array for studying the effect of a hedge on pollen concentrations. The two sequential rotoslide samplers are not a part of the vegetation barrier study but are a part of the study on temporal variation in pollen concentrations.

Examination of the data showed that the low-level concentration pattern was markedly altered by both hedges. A pronounced concentration maximum was found in the cavity region (also called wake eddy or standing zone eddy) downwind of each hedge. Apparently airborne particles as large as pollen, because of their significant settling rates and appreciable inertia in a moving airstream, accumulate in the cavity downwind of vegetative barriers. Similar behavior downwind of other obstacles may be inferred. The pollen grains appear to move more readily into the cavity than out of it and accumulate there. The process must result from inertial effects so gases and small particles would not behave in similar fashion.

Several applications are apparent: (1) other large airborne particles such as pesticides and plant disease spores should be affected in similar fashion; (2) maximum deposition should occur in the same region as maximum concentration and deposition sampling could indicate the location of the cavity; (3) multiple impaction surfaces, such as scattered trees and bushes in the cavity region of a large barrier, probably would be more efficient removers of particles than the barrier itself; and (4) allergic individuals should avoid wake regions when aeroallergens are prevalent.

REFERENCE

1. Raynor, G. S., E. C. Ogden, and J. V. Hayes. Enhancement of Particulate Concentrations Downwind of Vegetative Barriers. Submitted to: Agric Meteor.

SECTION XIV

MESOSCALE TRANSPORT AND DISPERSION OF AIRBORNE POLLENS

Pollen transport and dispersion from generalized area sources were studied by 29 flights to distances of 100 km and heights to 3 km using an aircraft-mounted isokinetic sampler.[1] Tree pollens and ragweed pollen were sampled. Four types of flights were made to study various aspects of pollen transport: (1) ascents over a fixed location to investigate vertical distribution, (2) flights over a source-free area to document change of concentration with distance, (3) east-west flights along Long Island to study the influx of pollen from the mainland with westerly winds and, (4) vertical ascents and horizontal flights during sea breeze flows to determine their effect on pollen concentrations.

It was found that large quantities of pollen are transported in orderly fashion from their source regions, but pollen often travels in large, discrete clouds. Pollen is transported to Long Island from the mainland in some quantity. Sea breeze flows greatly decrease low-level concentrations, but pollen is carried aloft at the sea breeze front and recirculated in the return flow aloft. Vertical distribution is reasonably well related to lapse rate, although secondary concentration peaks, which often occur below elevated inversions, cannot be explained by the data obtained.

REFERENCE

1. Raynor, G. S., J. V. Hayes, and E. C. Ogden. Mesoscale Transport and Dispersion of Airborne Pollens. J Appl Meteor 13(1):87-95, February 1974.

SECTION XV

EXPERIMENTAL PREDICTION OF DAILY RAGWEED POLLEN CONCENTRATIONS

A method was developed by which daily ragweed pollen concentrations were predicted on an experimental basis over a four-year period.[1] Predictions were made by referring to the mean annual concentration curve of earlier years, previous concentrations of the current year, and the weather forecast. The predicted weather was evaluated primarily for: (1) its suitability for ragweed pollen emission, locally and in potential source regions; (2) whether expected air trajectories would pass from source regions over the forecast site; and (3) whether precipitation, which might remove previously emitted pollen from the air, would occur at the site or between there and the source region. More accurate results were obtained than by use of alternative methods such as using the average for the date in past years (climatology) or using the previous day's concentration (persistence).

Forecasts were verified by comparisons with concentrations measured with an intermittent rotoslide sampler at a height of five feet in an open area. Verification criteria were selected arbitrarily as a factor of 2 or 10 grains/m^3. Thus, a forecast of 100 grains/m^3 would be considered correct if the measured concentration fell between 50 and 200. The standard of 10 grains/m^3 was included to take care of low concentrations where the forecast could be very close but not within a factor of 2, such as forecast of one and an actual concentration of three.

Results for the four years are given in the following table for all actual pollen forecasts, and for all forecasts for days on which the weather forecast was correct. Also, given are the results which would have been obtained if climatology and persistence had been used. The averages in the last column are weighted by the number of cases in each year.

PERCENT OF FORECASTS WITHIN A FACTOR OF 2 OR 10 GRAINS/m^3

	1966	1967	1968	1969	Average
Climatology	72	55	58	68	62
Persistence	49	50	62	59	56
Forecast	71	71	58	70	67
Forecast with correct weather forecast	80	82	62	76	75
Number of cases	27	17	36	30	

REFERENCE

1. Raynor, G. S., and J. V. Hayes. Experimental Prediction of Daily Ragweed [Pollen] Concentration. Ann Allergy 28:580-585, December 1970.

SECTION XVI

OCCURRENCE OF RAGWEED POLLEN IN A SOURCE-FREE AREA

From mid-August to late September, ragweed (*Ambrosia*) pollen originates in a multitude of sources throughout eastern and central United States and southern Canada. Although most of the pollen which becomes airborne returns to earth near its source, the small percentage from many sources which reaches altitudes above surface obstacles and travels long distances causes significant concentrations over vast areas. Pollen concentrations at some distance downwind from these sources during dry weather can be expected to be appreciable. Rain may wash most of the pollen from the atmosphere. A frontal passage may replace a pollen-laden air mass with one relatively pollen-free or vice-versa.

In the heart of the Adirondack Mountains of northern New York, local sources of ragweed pollen are negligible. It may be assumed that the pollen present would have come from distant sources and, for the most part, from areas several hundred kilometers to the southwest, this being the direction of greatest ragweed production and of prevailing winds at this time of year. Most of the Adirondack area is covered with forest. Ragweeds, especially *A. artemisiifolia*, can grow here in waste lots and along roadsides. However, this is a recognized hayfever resort area where the stray ragweed plants that appear are removed by an alert citizenry before the pollen is shed. Numerous persons, afflicted by ragweed pollinosis, have attested to the relief they experience in this region. Ragweed pollen counts, reported for several localities in this region over many years[1,2] would seem to indicate low concentrations. Several questions arise. Were the sampling techniques sufficiently trustworthy to indicate the true concentrations? What are the true concentrations here? Do the forests remove large quantities of pollen? Are the concentrations at ground level and above the forest materially different? How do meteorological variables such as wind direction, wind speed, turbulence, humidity, and precipitation affect the pollen concentrations? Do the diurnal patterns of concentration show correlation with time of day or any meteorological parameters? Is this pollen, after transport one or more days in varying humidities and exposed to cosmic rays and solar radiation, as allergenic as fresh pollen?

To answer some of these questions, pollen sampling assemblages were operated at three locations in the Adirondack Park during 1963, 1966, and 1967. Valuable data were obtained, but there were frequent periods of rain during the ragweed season each year. In 1968, sampling was continued at one of the locations with the hope of obtaining data during longer periods of dry southwest winds.

SAMPLING SITES

Samplers were installed on a 100-km line beginning near Raquette Lake and running northeast to Whiteface Mt. near Wilmington. The most southwesterly location was at Sagamore Pond, six km south of Raquette Lake Village. To the southwest are many km of unbroken forest without any nearby land elevations to greatly modify the air flow. The next location was at Blue Mt. Lake, 22 km northeast, with forest intervening. The third location was on Whiteface Mt., 78 km further along.

INSTRUMENTATION

Samplers employed were intermittent rotoslides, sequential rotoslides, and Hirst spore traps. The intermittent rotoslide sampler[3] took pollen samples representative of the daily average concentration by sampling for one minute in each 12 during a 24-hr period. The efficiency of catch varies with wind speed from 50-70% but with an average of approximately 64% at the wind speeds mostly encountered. This efficiency correction was used for all rotoslide samples. The corrected count from each sample represented the number of pollen grains in 4.5 m^3 of air; the data were then reduced to grains/m^3.

The sequential rotoslide sampler[4] automatically took 12 consecutive samples, each continuous over a chosen time period. For most of the sampling, a 2-hr time period was chosen. Two units were operated in tandem on occasion, for obtaining 24 one-hour samples during the 24-hr day.

The Hirst spore trap[5] is an automatic sequential volumetric air sampler. A vacuum pump draws air through a narrow orifice which is oriented into the wind by a vane tail. The pollen is impacted on a microscope slide, coated with a suitable adhesive, which moves past the orifice at 2 mm/hr. The 24-hr sample is spread in a 48-mm-long band from which counts are made that represent each hour. The efficiency varies with wind speed, from about 60-120% for ragweed pollen, with a probable average efficiency around 70% at the wind speeds of that time of year.

<u>Sagamore</u>

At the Sagamore Pond location, a tower was installed in the forest at the Sagamore Conference Center of Syracuse University (Fig. 16-1B). This tower is of open construction steelwork, allowing the air to pass through freely. There are four working levels: 1.5, 12, 26, and 38 meters. Treetop level here is approximately 20 m. Two of the levels are below the forest canopy. The 26-m level is above the trees but where air turbulence may be affected by the forest. The 38-m level is at a height where the flow of air is less affected by the vegetation. Samplers at the three upper levels were raised and lowered on tracks by means of electrically powered winches.

Sampling was conducted at six positions, of which three were near the ground (1.5 m): in a large clearing at the Conference Center which is

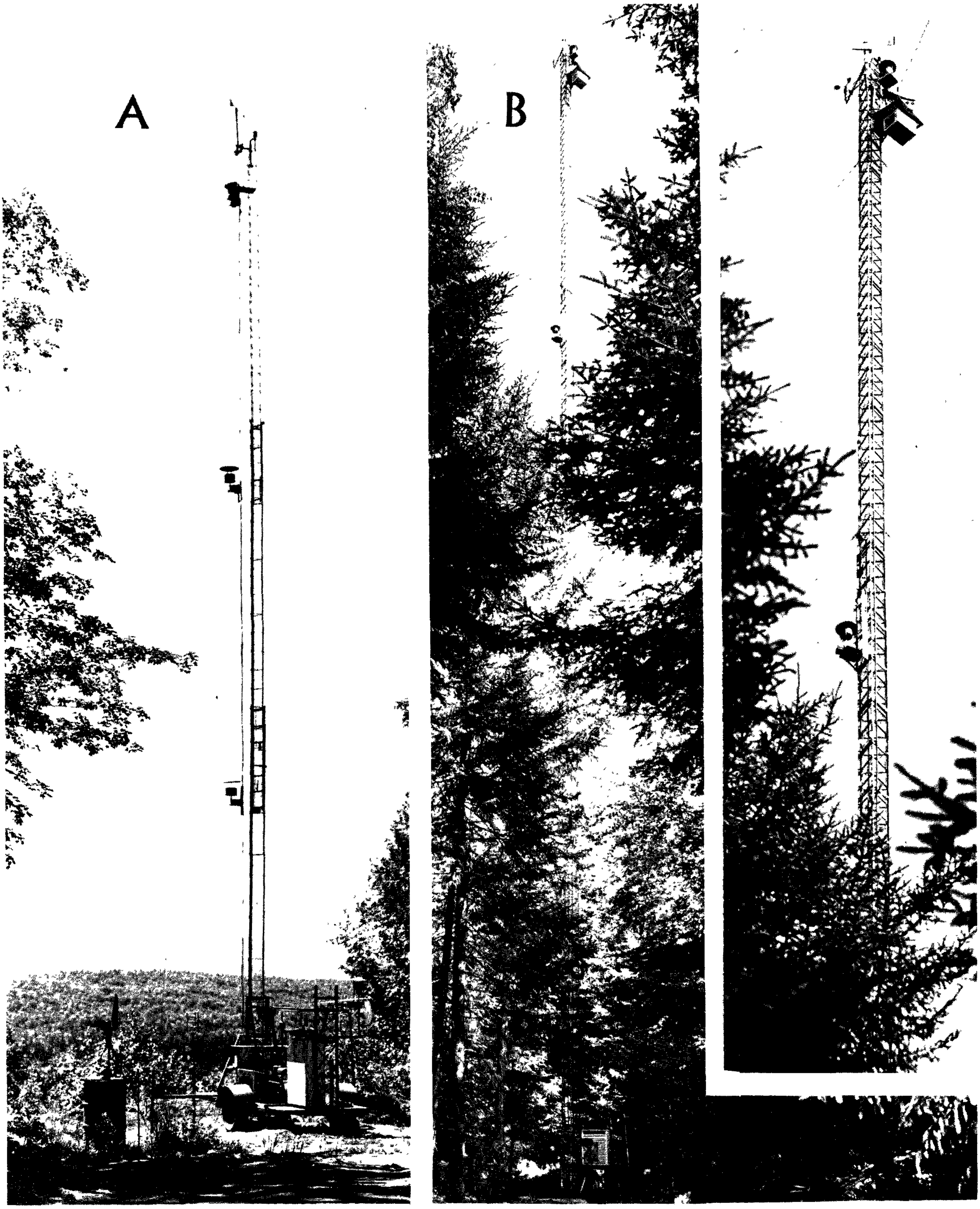


Fig. 16-1 Mobile tower at Blue Mountain Lake (A) and tower at Sagamore Pond near Raquette Lake (B).

0.5 km southwest of the tower (C), in a small glade near the tower (G), and in the dense forest at the tower (S1). The other three positions were on the tower: at 12 m (S2), 26 m (S3), and 38 m (S4). An intermittent rotoslide obtained daily average pollen concentrations at each of the six positions. In 1963, sequential rotoslides determined average concentrations for each 2-hr period at positions S1 and S4. For 1966 and 1967, the sequential rotoslides were replaced by Hirst spore traps which allowed determination of concentrations for each 1-hr period.

Blue Mt. Lake

In 1963, an intermittent and a sequential rotoslide were operated at the 1.5-m level in a large clearing at the Minnowbrook Conference Center of Syracuse University. In 1966, a mobile tower sampling assemblage (Fig. 16-1A) was located on a bluff, approximately 15 m above the lake level, at the Adirondack Museum. Sampling positions were at 1.5 m (B1), 6 m (B2), 11 m (B3), and 16 m (B4). An intermittent rotoslide was at each level. At the 1.5-m level, a sequential rotoslide took consecutive 2-hr samples. A sensitive anemometer recording system, using counters that print out each hour, recorded airflow at the B1 and B4 levels. In 1967, the assemblage was identical to that in 1966 but with the addition of a Hirst trap. In 1968, the tower assemblage was located near lake level in an open area, approximately 50 m from the surrounding forest. These three locations are essentially one, as they are near together at the east end of the lake. The 1968 assemblage included all samplers used in 1967, except that two sequential rotoslide machines were operated in tandem to take consecutive 1-hr samples. In addition, at the B1 level, two intermittent rotoslides, coupled with a switch timer, each operating on alternate days, obtained daily samples beginng at 0000 EST.

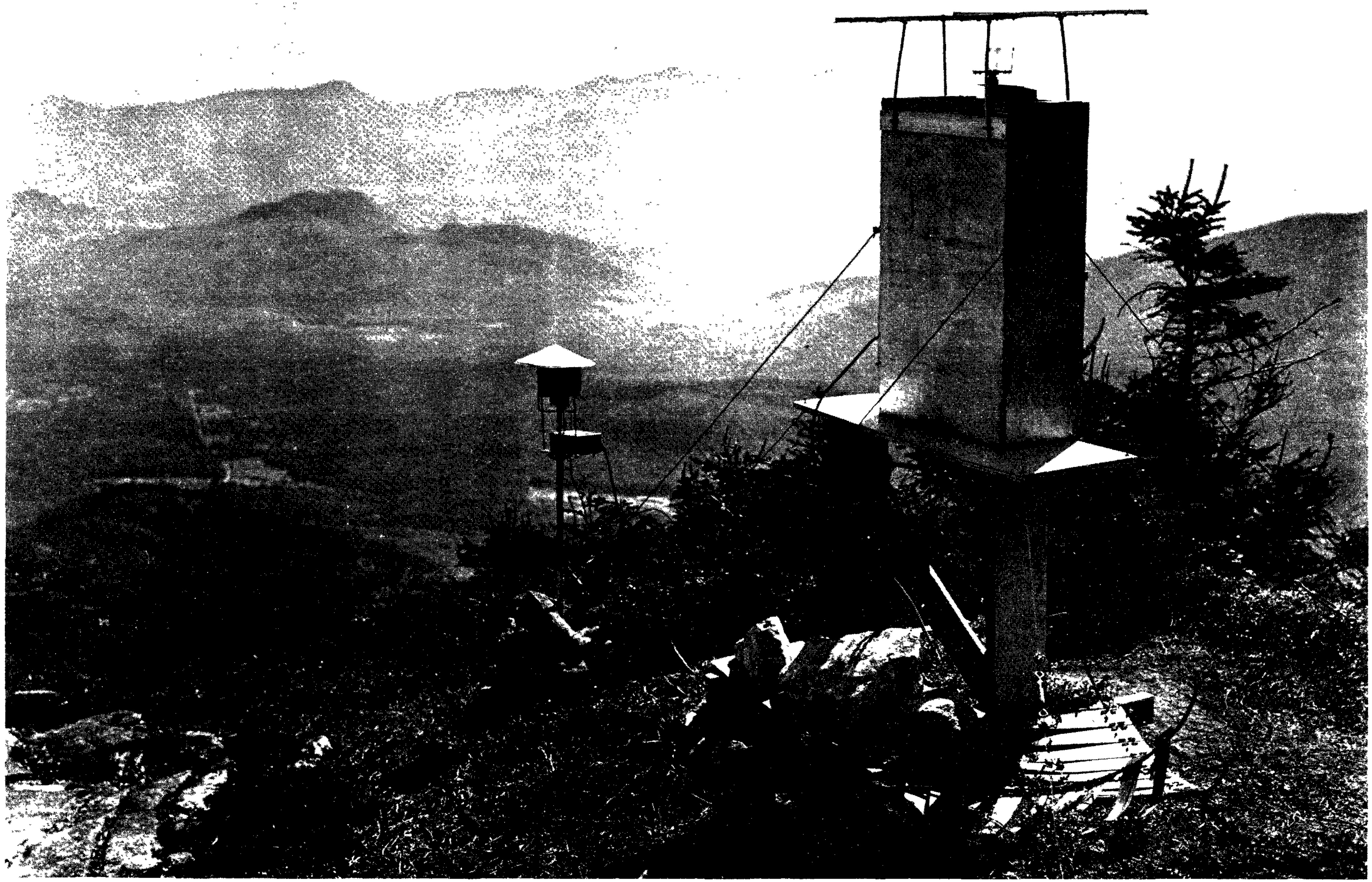


Fig. 16-2 Rotoslide pollen samplers on the summit of Whiteface Mountain.

Whiteface Mt.

During the 1963 season, an intermittent rotoslide and a Hirst trap were operated on an exposed cliff on the southwest side near the summit, approximately 1480 m (4850 ft) above sea level (S) and an intermittent rotoslide at the Atmospheric Sciences Research Center Building (A) on the northeast side of the mountain.

In 1966 and 1967, intermittent rotoslides were at these two positions. In 1966, a sequential rotoslide was installed at the summit position but almost continuously developed mechanical troubles so was moved to the roof of a building, called the turnhouse, near the summit on the northeast side (T), a slightly less exposed position. In 1967, after several modifications, it was again operated at the summit (Fig. 16-2).

RESULTS

The average concentrations during the ragweed season for the four years at the three regions are the daily averages at the thirteen locations. The concentrations for each hour or two-hour period at four of these locations are charted in detail in several Progress Reports.[6-9]

Seasonal Patterns

The daily average concentrations varied greatly, from day to day, from mid-August to mid-September. On most days, the concentrations were low at all stations. What minimum number of grains per cubic meter would be judged a high concentration is difficult to choose. However, a concentration of $25/yd^3$ has been generally considered by many allergists to produce marked symptoms of hayfever among most persons allergic to ragweed pollen. Although this figure has never been adequately tested, it will serve as a reasonable guess. This would be approximately 30/m^3.

Assuming an average daily concentration of 30 or more per cubic meter to be a hayfever day, the following chart indicates the number of such days at each of the three sampling stations in the open at 1.75 m, as determined with intermittent rotoslides.

Year	Station	Time	Total days	Hayfever days
1963	Sagamore	Aug. 19 - Sept. 8	21	5
"	BML	"	21	0
"	Whiteface	"	21	3
1966	Sagamore	Aug. 18 - Sept. 14	28	4
"	BML	"	28	4
"	Whiteface	"	28	2
1967	Sagamore	Aug. 14 - Sept. 14	32	4
"	BML	"	32	6
"	Whiteface	"	32	2
1968	BML	Aug. 15 - Sept. 19	36	4

Diurnal Patterns

At the Sagamore tower, two Hirst traps obtained the average concentration for each hour at 1.75 m in the dense forest and at 38 m well above the treetops. These data are graphically shown in Figs. 16-3 and 16-4. Similar data for Blue Mountain Lake were obtained with sequential rotoslides and are shown in Fig. 16-5.

Variation With Vegetation

At the Sagamore tower in the dense forest, two sampling positions were below (1.75 and 12 m) and two were above (26 and 38 m) the tops of the

Figure 16-3. AVERAGE DIURNAL PATTERNS OF RAGWEED POLLEN AT THE SAGAMORE TOWER FOR 1966. Figures at left indicate mean percent of daily total.

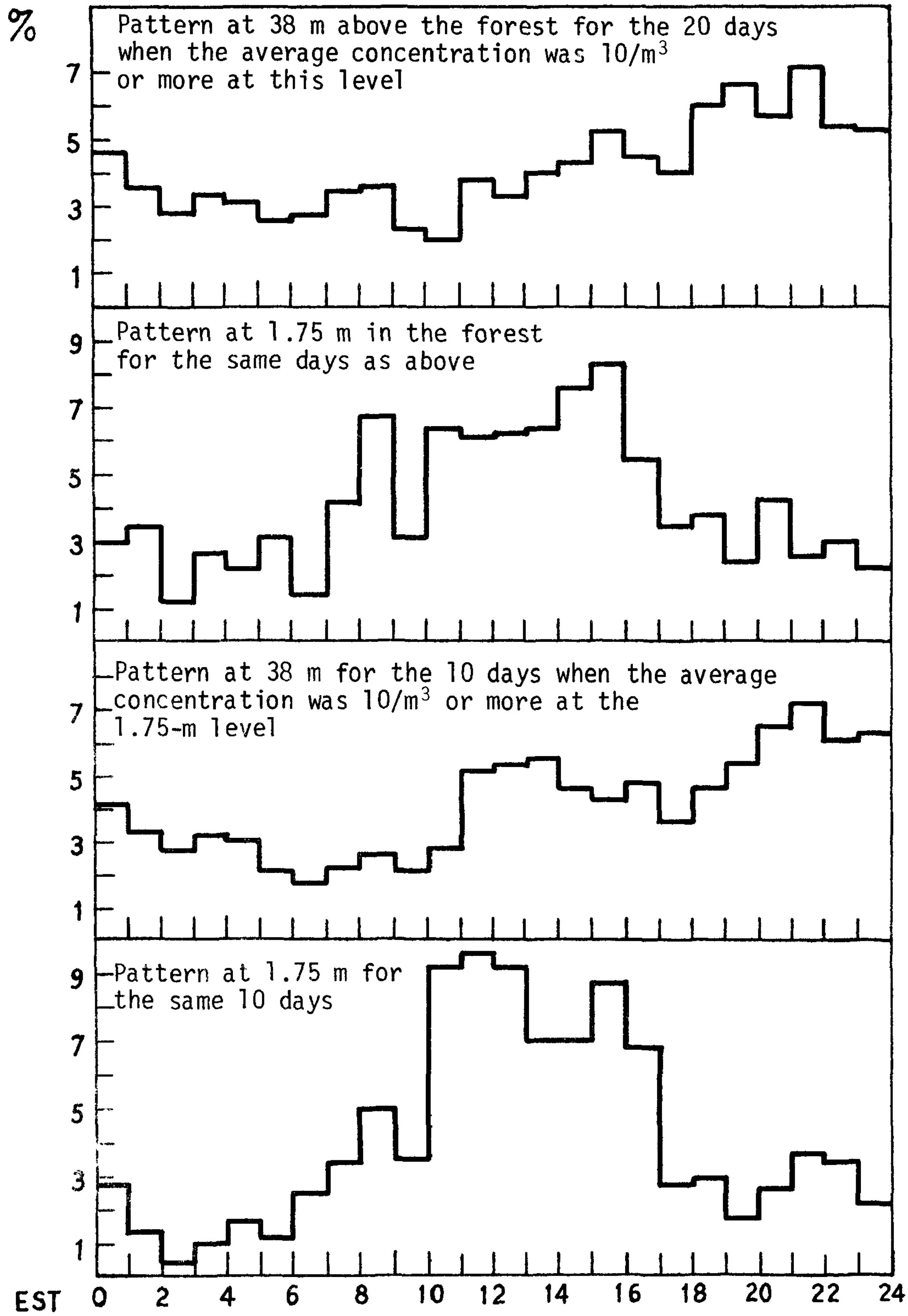


Figure 16-4. AVERAGE DIURNAL PATTERNS OF RAGWEED POLLEN AT THE SAGAMORE TOWER FOR 1967. Figures at left indicate mean percent of daily total.

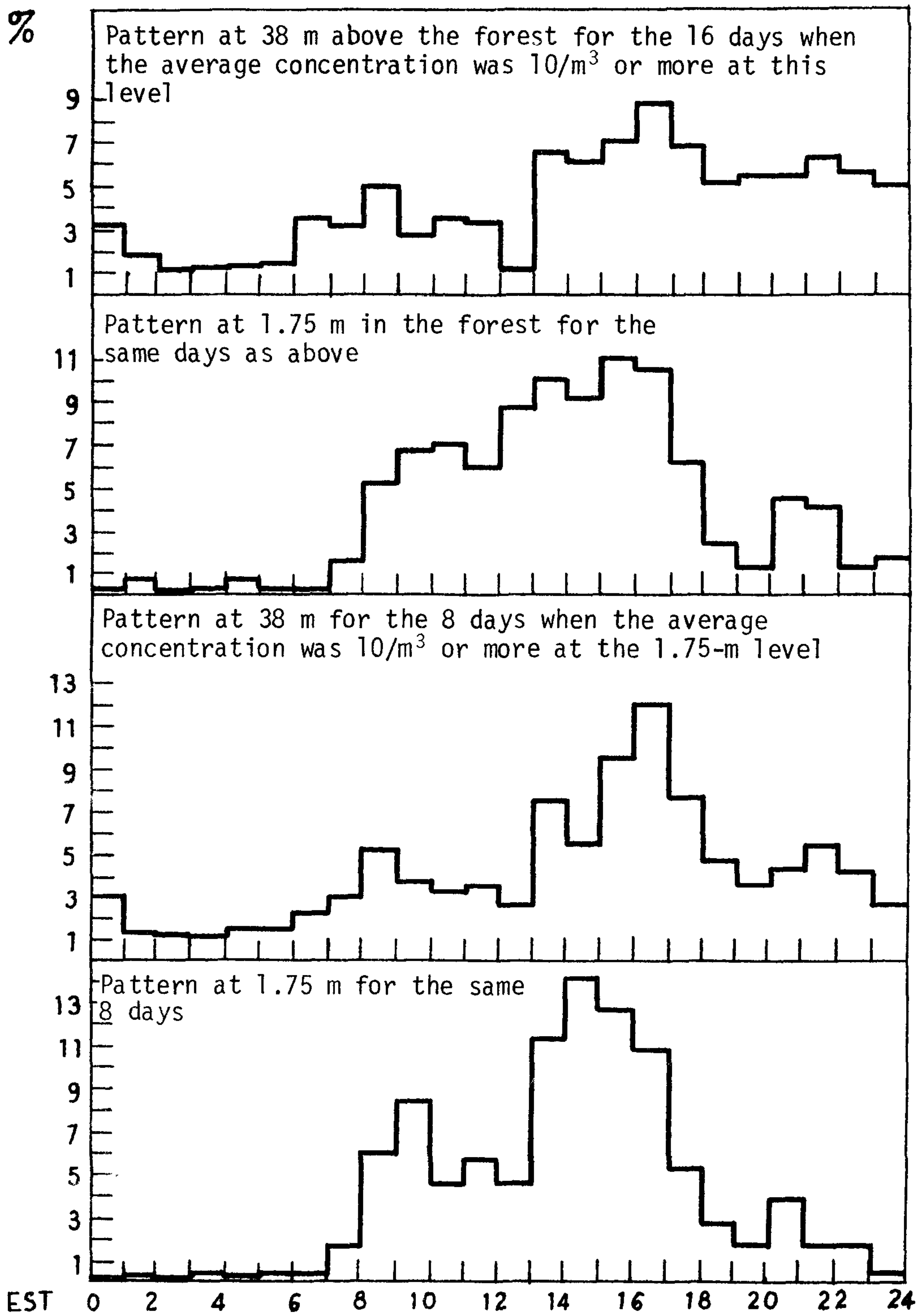
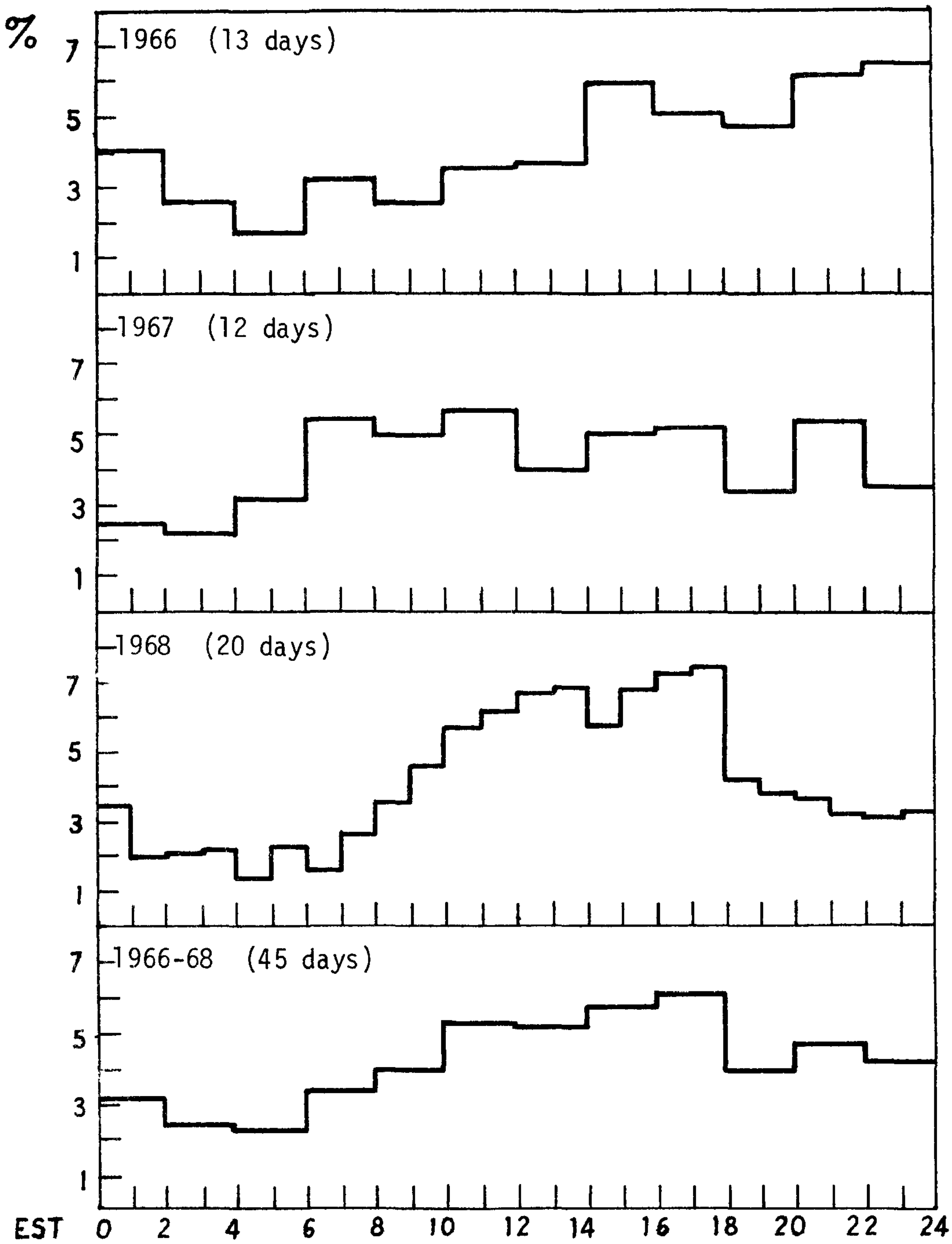


Figure 16-5. AVERAGE DIURNAL PATTERNS OF RAGWEED POLLEN AT THE 1.75-m LEVEL IN AN OPEN AREA AT BLUE MOUNTAIN LAKE FOR THOSE DAYS WHEN THE AVERAGE DAILY CONCENTRATION WAS 10/m^3 OR MORE. Figures at left indicate mean percent of daily total.



trees (20 m). The effect of this forest on the pollen concentrations is difficult to assess because the daily comparisons were so variable. Excluding those days when the concentrations at neither of the levels being compared was at least 10/m^3, the following data apply:

Year	No. of days	Range in % at 1.75 m of that at 38 m	Av. %
1963	6	11 to 325	45
1966	13	12 to 169	25
1967	17	0 to 800	48

Year	No. of days	Range in % at 12 m of that at 38 m	Av. %
1963	8	46 to 425	91
1966	12	35 to 136	95
1967	15	0 to 2850	106

Year	No. of days	Range in % at 26 m of that at 38 m	Av. %
1963	8	53 to 600	93
1966	9	59 to 140	90
1967	15	9 to 2300	78

Variation in daily average concentrations for three positions at the Sagamore location are graphically shown in Figures 16-6 and 16-7. It is seen that while the concentrations are usually highest above the forest, lowest in the forest at ground level, and intermediate in the open area at ground level, this is not always so, especially when concentrations are low at all three positions. Figure 16-8 illustrates the comparative concentrations for those days during the two years when the pollen grains per cubic meter were at least 30 (presumably a hayfever day) at one or more of the positions.

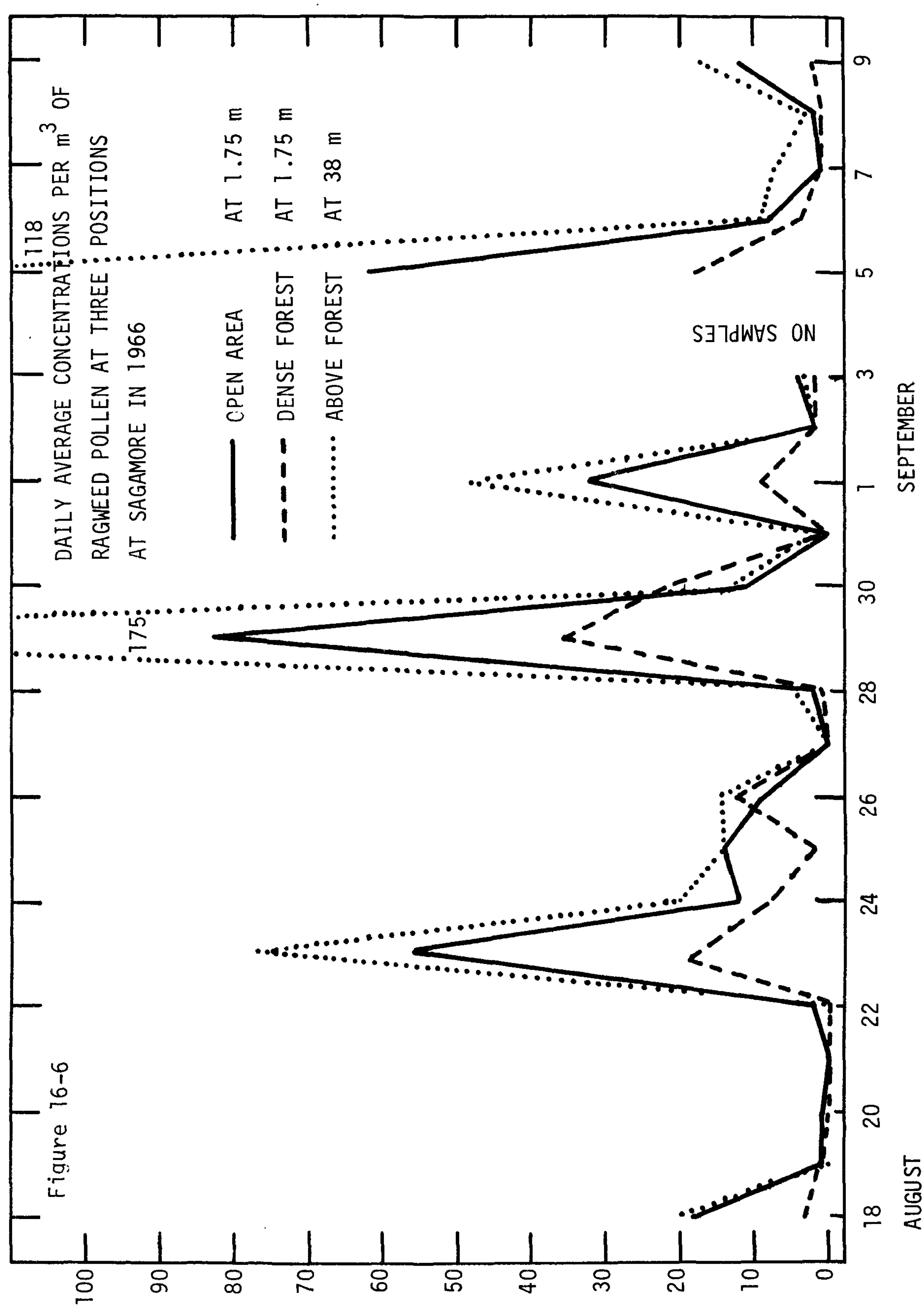


Figure 16-6
DAILY AVERAGE CONCENTRATIONS PER m^3 OF
RAGWEED POLLEN AT THREE POSITIONS
AT SAGAMORE IN 1966
OPEN AREA AT 1.75 m
DENSE FOREST AT 1.75 m
ABOVE FOREST AT 38 m
175
118
NO SAMPLES
0
10
20
30
40
50
60
70
80
90
100
18
20
22
24
26
28
30
1
3
5
7
9
AUGUST
SEPTEMBER

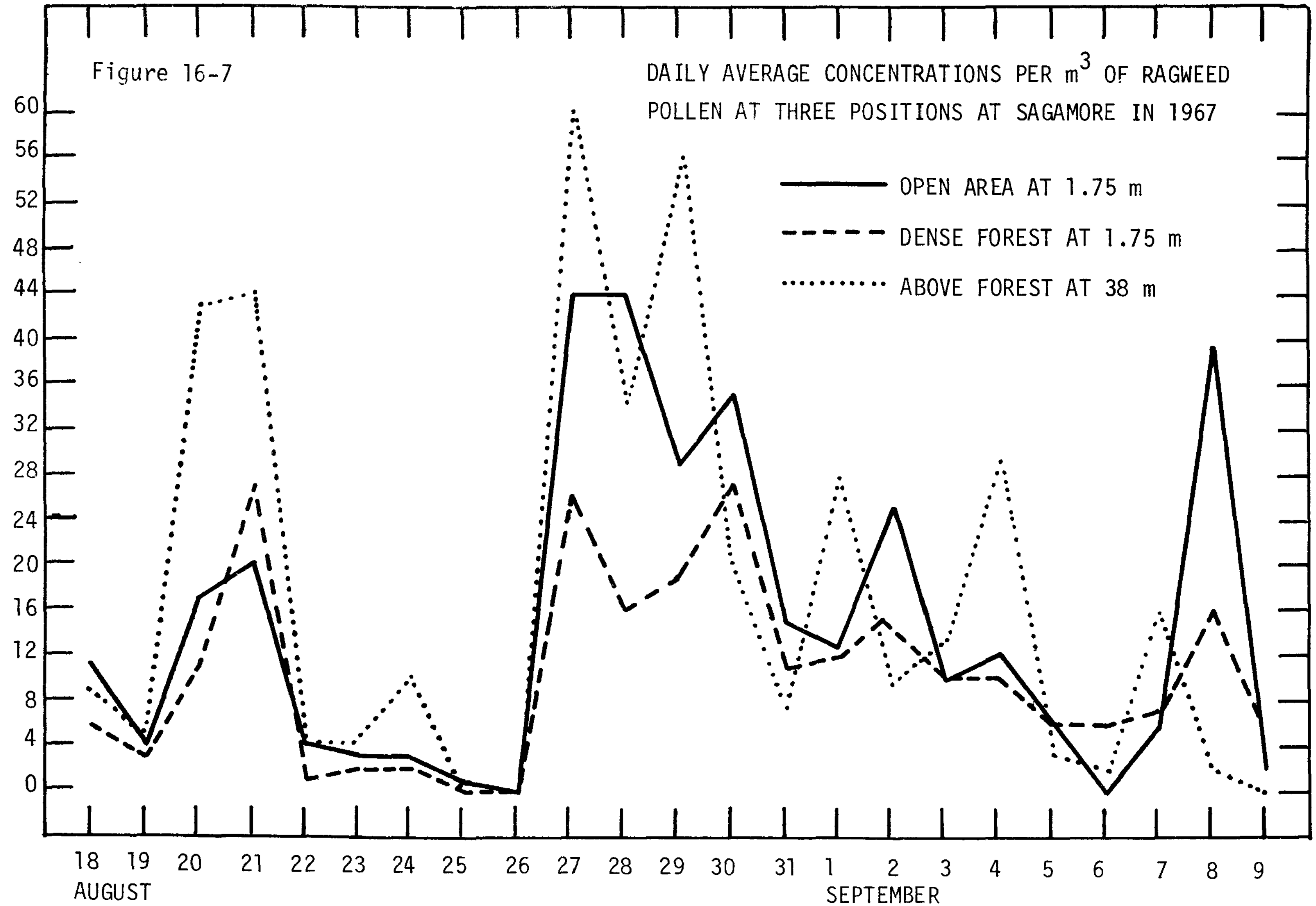


Figure 16-7

DAILY AVERAGE CONCENTRATIONS PER m^3 OF RAGWEED POLLEN AT THREE POSITIONS AT SAGAMORE IN 1967

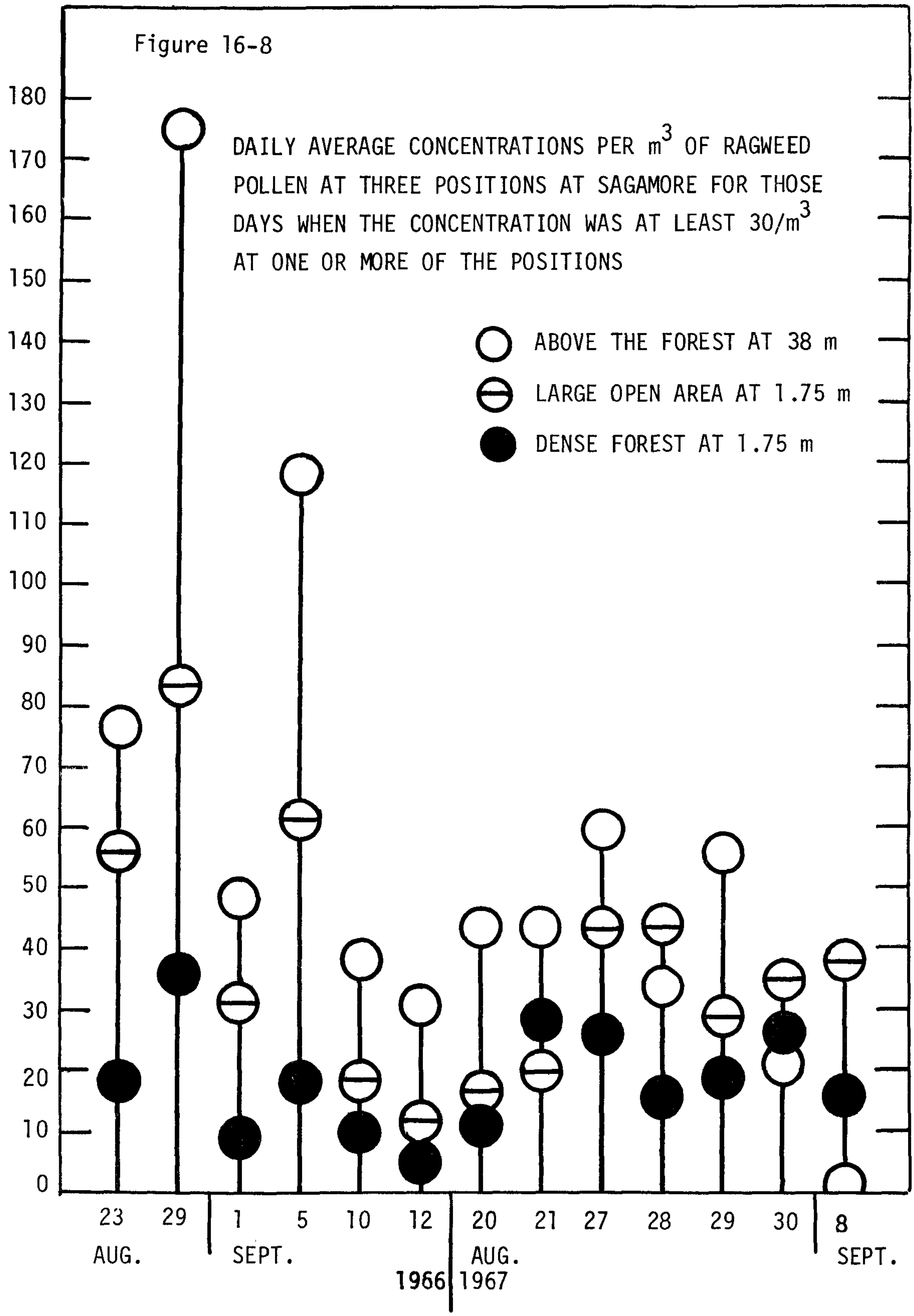


Figure 16-8
DAILY AVERAGE CONCENTRATIONS PER m3 OF RAGWEED POLLEN AT THREE POSITIONS AT SAGAMORE FOR THOSE DAYS WHEN THE CONCENTRATION WAS AT LEAST 30/m3 AT ONE OR MORE OF THE POSITIONS
ABOVE THE FOREST AT 38 m
LARGE OPEN AREA AT 1.75 m
DENSE FOREST AT 1.75 m
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
23
29
AUG.
1
5
10
12
SEPT.
1966
20
21
27
28
29
30
AUG.
1967
8
SEPT.

Comparison of Sites

The 1966 and 1967 data allow some comparison of agreement at the sampling positions at the Sagamore forest and between the Sagamore and Blue Mountain Lake locations. For determining the probability of agreement between pairs of positions, correlation coefficients (r) were obtained, using the method of least squares. For determining the relationship between two positions, the constants m and b for the line of best fit ($y = m\,x + b$) were calculated by the method of least squares. Using the above formula, it is possible to use each experimental value of x to calculate the expected corresponding value of y. It was arbitrarily decided that the correlation between individual sample pairs was sufficiently close if the experimental value of y was not less than half nor more than twice the calculated value, or the two differed by no more than 10 pollen grains per cubic meter. p is the fraction of samples which met these criteria.

Positions	Year	r	p	m	b
S1 & S4	1966	0.85	0.86	4.06	-1.51
S1 & S4	1967	0.63	0.64	1.41	4.42
G & S4	1966	0.99	1.00	2.02	0.66
G & S4	1967	0.51	0.60	0.72	7.96
G & S1	1967	0.88	1.00	0.56	2.02
S4 & B4	1966	0.96	0.92	0.79	4.41
S4 & B4	1967	0.39	0.60	0.45	18.44
S1 & B4	1966	0.86	0.90	3.42	0.92
S4 & W	1967	0.36	0.64	0.32	4.38
W & A	1967	0.61	0.57	0.75	13.20

S1 = Sagamore tower in the forest at 1.75 m

S4 = Sagamore tower above the forest at 38 m

G = Small open area in the Sagamore forest near the tower

B4 = Blue Mountain Lake tower at 16 m

W = Whiteface Mountain at the summit

A = Atmospheric Sciences Research Center on the east slope of Whiteface Mountain

The above chart shows the relationships of simultaneous (hourly) pollen concentrations at different locations. We assumed that if any relationship existed, it would be linear. r (correlation coefficient) is a measure of the extent to which two variables are related. p is the fraction of sample pairs in which the experimental and calculated concentrations agreed within a factor of two or $10/m^3$. m is the actual ratio of the concentrations at one chosen position with the concentrations at another position. For example: in 1966, the concentrations at the 38-m level above the forest at Sagamore averaged 4.06 times the concentrations at the 1.75-m level in the forest directly below; in 1967 the comparable ratio was 1.41. b is the intercept, or the value of y when x is zero. For example: in 1966, with a concentration of $100/m^3$ at the 38-m-level at the Sagamore tower, the expected concentrations at the 16-m-level at Blue Mountain Lake would be $0.79 \times 100 + 4.41 = 83.41/m^3$.

To use examples which actually occurred: with a concentration of 175 at 38 m at Sagamore, the expected concentration would be 142 at BML; it was 141. With a concentration of 118 at Sagamore; the expected concentration at BML would be 97; it was 88. However, with a concentration of 77 at Sagamore, the expected concentration at BML would be 65; it was 95. Thus, it is evident that a formula based on a seasonal average, may not be reliably used for estimating a day's average concentration at one of these locations based on the concentration at the other.

Correlation With Weather

Official weather data for wind direction, wind speed, and precipitation during the ragweed seasons of 1966 and 1967 were obtained and charted for eight locations surrounding the Adirondack area. These indicate much variation among these locations at identical times. As expected, dry southwest winds were correlated with high pollen concentrations but little more can be inferred.

Conclusions

The average daily ragweed pollen concentrations at all 13 positions at the three locations varied from zero to more than $50/m^3$ and in some situations to more than 100. On some days the concentrations reached two or three hundred for short periods. Usually, but not always, the concentrations above the trees or at ground level in large open areas were higher than in the forest. The frequent rains usually lowered the concentrations to zero but, during the dry periods that followed, the concentrations increased rapidly, especially if the winds were from the southwest sector. It is possible that the lower concentrations in the forest are due, at least in part, to less air speed and less turbulence, allowing the grains to settle to earth more rapidly.

Thus, it is apparent that there may be, at times, rather high concentrations of ragweed pollen distant from the sources of this pollen, and while the extensive forest may have but little influence on removal of pollem from the air mass passing high above the forest, it seems obvious that there is significant removal by the forest below treetop level.

REFERENCES

1. Durham, O. C. Pollen Prevalence and Pollen-free Areas. J Amer Med Ass 148:716-720, March 1952.

2. Ogden, E. C., and D. M. Lewis. Airborne Pollen and Fungus Spores of New York State. New York State Museum and Science Service Bulletin 378, Albany, N.Y. January 1960. 104 p.

3. Ogden, E. C., and G. S. Raynor. A New Sampler for Airborne Pollen: The Rotoslide. J Allergy 40(1):1-11, July 1967.

4. Ogden, E. C., G. S. Raynor, and J. M. Vormevik. Travels of Airborne Pollen. Progress Report 4. New York State Museum and Science Service, Albany, N.Y. June 1963. 12 p.

5. Hirst, J. M. An Automatic Volumetric Spore Trap. Ann Appl Biol 39:257-265, June 1952.

6. Ogden, E. C., G. S. Raynor, and J. M. Vormevik. Travels of Airborne Pollen. Progress Report 5. New York State Museum and Science Service, Albany, N.Y. May 1964. 30 p.

7. Ogden, E. C., G. S. Raynor, and J. V. Hayes. Travels of Airborne Pollen. Progress Report 7. New York State Museum and Science Service, Albany, N.Y. March 1967. 25 p.

8. Ogden, E. C., G. S. Raynor, and J. V. Hayes. Travels of Airborne Pollen. Progress Report 8. New York State Museum and Science Service, Albany, N.Y. February 1968. 36 p.

9. Ogden, E. C., G. S. Raynor, and J. V. Hayes. Travels of Airborne Pollen. Progress Report 9. New York State Museum and Science Service, Albany, N.Y. March 1969. 27 p.

SECTION XVII

CONCENTRATIONS OF RAGWEED POLLEN IN RELATION TO REDUCTION OF SOURCE PLANTS

The mobile tower assemblage was operated in Saratoga Springs in cooperation with a planned program of citywide ragweed eradication. This small city (population 20,500) has the usual abundance of ragweed plants in its unattended areas and in the surrounding countryside. Sampling was conducted before and after the eradication activities. However, the eradication, conducted by another agency, was less than complete and the average pollen concentration was higher during 1971 following the attempts at eradication than during 1970 (Fig. 17-1). The diurnal patterns of occurrence for the two years were essentially the same (Fig. 17-2). The data, detailed in Progress Reports,[1,2] indicate that the hourly concentrations of pollen varied greatly, usually more than half of the pollen occurred between 0700 and 1300 EST, and the highest concentrations were between 0800 and 1000. There was a tendency for the daily peak concentrations in 1971 to be an hour later than in 1970. Perhaps this is due to the ragweed eradication activities causing the diurnal patterns of occurrence in the city to lag behind the diurnal patterns of emission in the areas outside the three-mile radius of ragweed reduction. If so, then it is obvious that these more distant ragweed pollen sources supply pollen to the city air in far greater amounts than what is produced locally. The higher average concentrations for 1971, in comparison with 1970, apparently are due to higher regional concentrations. Whether the 1971 concentrations in the center of the city were lower than would have occurred with no eradication is not known, but it seems likely that any difference would be negligible.

CONCLUSIONS

Ragweed eradication over a small area surrounded by a large area with many ragweed plants is unlikely to result in a significant reduction in ragweed pollen average concentrations. We offer no opinion with regard to any possible effect on incidence of pollinosis. However, it is probable that eradication of abundant ragweed in an area that is surrounded by an extensive ragweed-free area would have a marked effect on local ragweed pollen concentration reduction. See Section XVI.

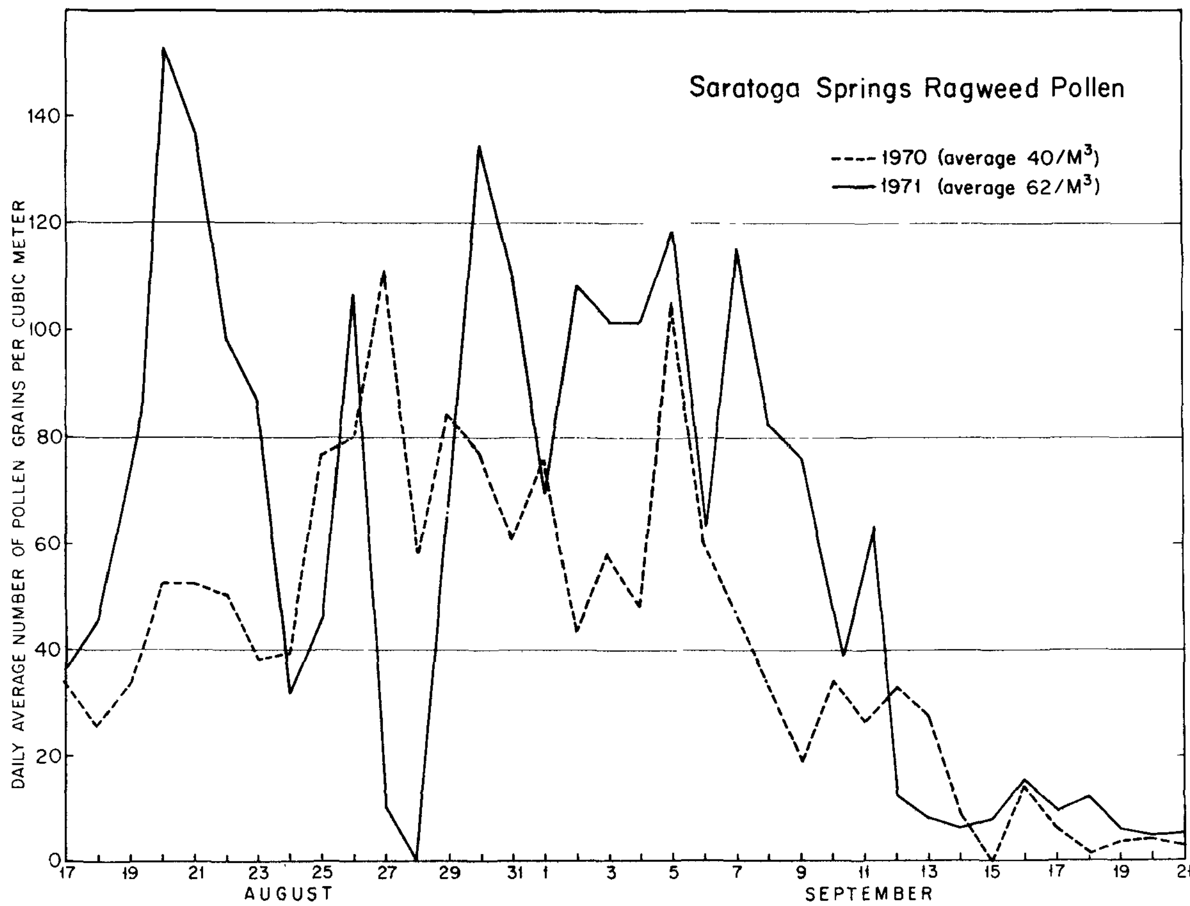


Fig. 17-1 Daily Average Concentrations of Ragweed Pollen at Saratoga Springs.

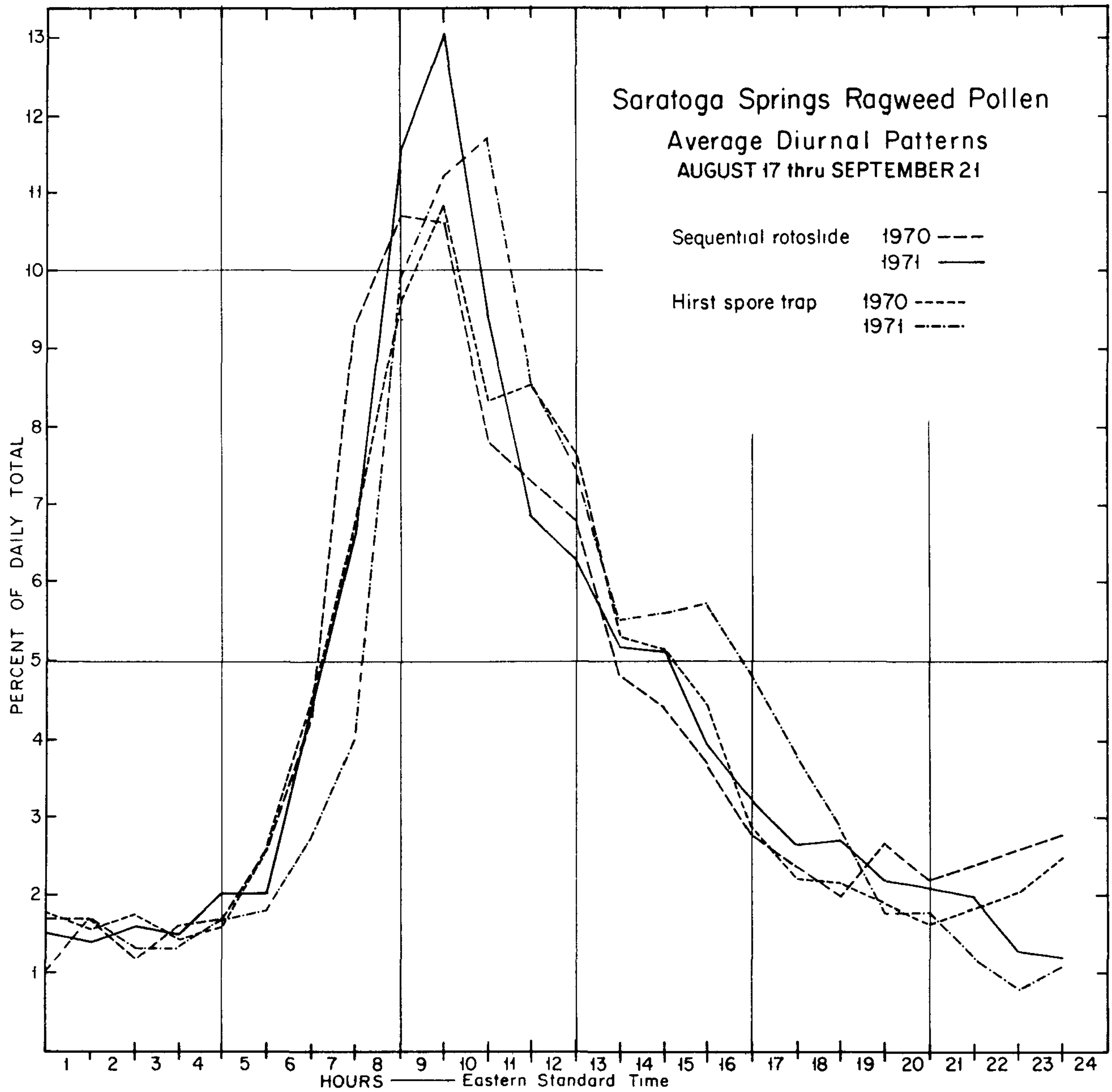


Fig. 17-2 Average Diurnal Patterns of Ragweed Pollen at Saratoga Springs.

REFERENCES

1. Ogden, E. C., G. S. Raynor, and J. V. Hayes. Travels of Airborne Pollen. Progress Report 11. New York State Museum and Science Service, Albany, N.Y. February 1971. 25 p.

2. Ogden, E. C., G. S. Raynor, and J. V. Hayes. Travels of Airborne Pollen. Progress Report 12. New York State Museum and Science Service, Albany, N.Y. February 1972. 26 p.

SECTION XVIII

AIRBORNE POLLEN FROM ENTOMOPHILOUS PLANTS

The pollens of most flowering plants are not found in the atmosphere far from the source plants. They are seldom seen in atmospheric samples and not reported in airborne pollen surveys. Such pollens are transported by agencies other than wind, primarily by insects. As a consequence, they are generally ignored when searching for possible causes of pollinosis. However, some of these entomophilous species emit pollen that becomes airborne in appreciable amounts close to the source plants. In some situations an individual allergic to such pollen might be exposed to concentrations sufficiently high to cause pronounced discomfort. These concentrations would vary greatly according to time of year, time of day, weather conditions, abundance of flowers, pollen characteristics, and other factors. Thus, the concentrations in the vicinity of such plants under favorable conditions during anthesis would vary from zero to some appreciable number.

Durham[1] called attention to several of these. He reported rather high concentrations of their pollen in the air near the entomophilous species: *Melilotus alba, Pyrus communis, Chrysanthemum leucanthemum, Solidago canadensis, Cichorium intybus,* and *Brassica niger*. Burchill[2] reported high concentrations of apple pollen (*Pyrus malus*) in an apple orchard, especially during early afternoon, with a maximum of 2385/m^3.

There are many published references to airborne pollen in the vicinity of source plants which are primarily, at least, pollinated by insects. These data are seldom from volumetric measurements. Daily rhythms of pollen presentation were reported by Percival[3] for several entomophilous species. These suggest when maximum concentrations might be expected.

As time permitted, concentrations of pollen in the air were measured close to a large number of species of flowering plants known to be entomophilous or essentially so. Battery-powered rotoslide samplers were operated 1.5 m above the ground (average adult nose level) and 1 m or more from the nearest flowers. In all cases, 1 m^3 or more of air was sampled. Although the rotoslide samples ragweed pollen at an efficiency of ±64% in the wind speeds usually encountered, its efficiency for the larger entomophilous pollens was estimated to average ±80%, which was used in all calculations. In a few cases, concentrations were measured also 0.1 m from the flowers. Attempts were made to determine the maximum concentrations that might occur by sampling downwind of large plants or large numbers of plants, choosing the time of season, time of day, and kind of weather thought to be most favorable for pollen emission. Several common species were sampled several times with greatly different results. Many times the number of samples taken would be needed for properly determining maximum possible concentrations. Although the concentrations of airborne entomophilous pollen do not closely approach the concentrations of pollen found close to many anemophilous plants, the following data indicate significant amounts. All figures represent the maximum recorded at 1.5 m above ground and at least 1 m from nearest flowers. Those below 10/m^3 are not listed.

Sambucus canadensis 125,000, *Sorbaria sorbifolia* 3736, *Spiraea vanhouttei* 1272, *Prunus serotina* 305, *Hypericum perforatum* 286, *Daucus carota* 281, *Cleome lutea* 253, *Pyrus malus* 208, *Galium verum* 178, *Lotus corniculatus* 160, *Rubus allegheniensis* 160, *Solidago juncea* 157, *Thalictrum polygamum* 130, *Potentilla recta* 121, *Ceanothus americanus* 114, *Aster novae-angliae* 113, *Viburnum cassinoides* 111, *Eupatorium maculatum* 106, *Galium palustre* 103, *Spiraea latifolia* 98, *Ranunculus acris* 77, *Centaurea maculosa* 76, *Aesculus hippocastanum* 75, *Hesperis matronalis* 72, *Prunus virginiana* 66, *Anthemis cotula* 65, *Brassica kaber* 64, *Barbarea vulgaris* 57, *Taraxacum officinale* 57, *Rosa* sp. 55, *Solidago rugosa* 55, *Smilacina racemosa* 54, *Syringa vulgaris* 53, *Sisymbrium altissimum* 52, *Cichorium intybis* 52, *Senecio glabellus* 51, *Rudbeckia hirta* 39, *Erigeron strigosus* 38, *Pastinaca sativa* 38, *Rosa rugosa* 34, *Conyza canadensis* 33, *Sambucus simpsonii* 31, *Polygonum cuspidatum* 31, *Chrysanthemum leucanthemum* 23, *Saxifraga virginiensis* 22, *Helianthus annuus* 21, *Amelanchier canadensis* 18, *Anaphalis margaritacea* 18, *Erigeron annuus* 17, *Prunus incisa* 16, *Berteroa incana* 16, *Melilotus* *alba* 14, *Carvum carvi* 14, *Philadelphus coronarius* 13, *Cornus racemosa* 12, *Eupatorium rugosum* 12, *Lonicera tatarica* 12, *Ceanothus ovatus* 11, *Melilotus officinalis* 10, *Tanacetum vulgare* 10, *Dipsacus laciniatus* 10.

The surprisingly high concentration of *Sambucus canadensis* pollen (125,000/m^3) was downwind of and below a large patch of the plants on a side hill and approaching the end of its pollination season. The air was calm at the beginning of sampling but became gusty during the sampling period. The sample was processed too late for repeated sampling and for obtaining counts from the earlier flowering *Sambucus pubens*. These await the next pollination season. The concentration of 31/m^3 for *Sambucus simpsonii* was also unexpected as the bush was small and isolated.

The *Spiraea* was sampled five times at 1.5 m with pollen grains/m^3 of 1272, 450, 374, 184, and 79. The highest count was a morning sample with many grains in clumps; the others were afternoon samples with less clumping.

Prunus serotina concentrations were 305 at 1600 EST, 91 and 21 from separate trees at 0730, and 17 at 1240.

Hypericum perforatum midday concentrations were 286, 282, 206, and 67.

Daucus carota midday concentrations were 281, 30, 26, and 18.

Solidago juncea afternoon concentrations were 157, 64, 43, and 32. A forenoon concentration of 38 was measured.

Lotus corniculatus midday concentrations were 160, 148, 117, 98, 78, 65, 61, 40, and 13. At first glance, it would seem strange that pollen from this plant could become airborne. Its papilionaceous flowers have the stamens completely enclosed. Pollination is effected by insects heavy enough to depress the keel petal. However, in age the petals wither and expose the stamens and the now dry pollen.

Simultaneous samples at 1.5 m and at 0.1 m from the nearest flowers indicated concentrations of grains/m^3 as follows:

	1.5	0.1
Galium verum	178	518
Lotus corniculatus	148	587
Potentilla recta	121	303
Lotus corniculatus	117	308
Ceanothus americanus	114	233
Anthemis cotula	65	157
Brassica kaber	64	54
Taraxacum officinale	57	153
Daucus carota	26	94
" "	18	37
Berteroa incana	13	20
Chrysanthemum leucanthemum	11	35
Ranunculus acris	10	51
Melilotus officinalis	10	19
Origanum vulgare	9	40
Saponaria officinalis	3	20

Although more than 200 samples were taken from 120 species, it should be emphasized that these data are preliminary and might be greatly changed through further sampling. Most of the samples were obtained and processed during odd moments in a busy schedule. Time did not permit as full a coverage as was hoped and originally planned.

REFERENCES

1. Durham, O. C. The Volumetric Incidence of Atmospheric Allergens. V. Spot Testing in the Evaluation of Species. J Allergy 18:231-238, July 1947.

2. Burchill, R. T. Air-borne Pollen in Apple Orchards. Rept East Malling Res Sta for 1962 (London). p. 109-111, 1963.

3. Percival, M. S. Floral Biology. New York, Pergamon Press, 1965. 243 p.

SECTION XIX

OCCURRENCE OF AIRBORNE POLLENS IN WINTER

Donald M. Lewis*

Deposition of pollen on the rooftop of the Education Building Annex in Albany, New York has been monitored continuously since March 1966. The discovery of pollen types several weeks in advance of the flowering of local species producing pollen of the same or similar morphology posed the question as to the origin of these pollens and whether exotic types originating in the southern and western United States might be detected in midwinter. Pollen recovered from November through February accounts for only 0.1 or 0.2% of the yearly pollen catch. Most of this is damaged to some degree and is likely refloated from local sources, but some is definitely fresh and can be vaguely attributed to distant source areas. Although totals for this winter season are commonly low (less than 200/cm^2), the few types found in fresh condition are occasionally trapped during brief periods in amounts comparable to seasonal maxima for the same pollen types produced locally but many weeks later. So far, these fresh pollens have never been recovered in fair weather and failure of other workers to record their presence is probably due to the use of samplers which do not function properly in wet or cold weather.

The sampling location (EBA) is in downtown Albany, 38 m above street level. The building is immediately bordered on the north by a small valley with a waste strip of weedy herbaceous and shrub growth and a few mature trees of *Acer platanoides*, *A. saccharinum*, *Ailanthus altissima*, *Robinia pseudoacacia*, and *Salix fragilis*; on the west by the blocklong State Education Building (slightly higher than the EBA); on the south by the State Capitol; and on the east by a small park and municipal and business buildings of downtown

*New York State Museum and Science Service, Albany, New York

Albany at gradually lower elevations.

METHODS

Daily and weekly deposition samples were taken in replicates throughout the local flowering season and for at least two or three weeks before and after those dates, or from about March 1 to October 15. Weekly samples only were taken through the winter months except for special short-term samples taken in conjunction with periods of unusual weather.

These samples were AEC-fallout papers[1] attached to 1 x 3-inch microscope slides with DC-269 pressure sensitive adhesive. They were fastened to a 1 m^2 redwood board which is moored in the center of the roof. The roof itself is a layer of crushed stone on an asphalt base. Pollen becomes washed into the loose material and samples from the stones are removed and deposited on Millipore filters, from time to time, as checks for types and physical conditions of the most likely contaminating pollens. The sampling board is cleaned at intervals to prevent a build-up of contamination. Regular sample positions are assigned to the board as 1,2,3,4,...,etc. The long axis of each microscope slide is oriented in an east-west direction. Sample number 3 in the northwest quadrant of the board was examined in this study with occasional comparisons with sample number 4 in the southeast quadrant and other special samples. In the laboratory, the slides were mounted in glycerine jelly prestained with basic fuchsin under a 22 mm square coverglass so that something less than one-half of the sample surface is prepared. The remaining portion can be examined for uniformity of pollen distribution or for other studies.

Particles adhere firmly to AEC-fallout paper,[2] (perhaps requiring a short residence time), and are not subsequently moved by mounting procedures. The retention of all particles coming in contact with the adhesive is likely not uniform. Previous tests indicate high "bounce-off" when this adhesive is used with powered impaction samplers and although tests have shown that pollen carried down in rain is at least sometimes sampled with high efficiency, it is likely that drop size, intensity of precipitation, temperature, and other factors influence catch.[1] The effectiveness of catch during storms has been compared to Millipore-filtered samples of rain collected in battery jars on numerous occasions, but these have not been fully analyzed.

Most pollen falling in rain must be directly impacted on the adhesive. The adhesive is not wetted and it is probable that pollen which is not easily wetted and is carried on the surface of the drop is selectively sampled over hygroscopic particles.[3] Sampling of pollen in snow on AEC-paper is probably often a matter of chance. Snow on this roof melts sooner than that of surrounding rooftops, but commonly through late December and January brief periods of slow thawing and many hours of below freezing temperatures will ice the board in, so that on two occasions samples were not changed for two to four weeks. The insulating effect of the board accentuates this condition, so that it may be covered with a dome of ice three to four inches thick at the center. Under these conditions, the sampler is unretentive to new pollen and will lose much of that in the ice.

Unsheltered slides covered with AEC-fallout paper have been compared directly with Modified Durham samples on numerous occasions in the tree flowering seasons of 1961 and 1962 at Brookhaven National Laboratory. The catch on AEC-fallout paper was 8 to 16 times that of the Modified Durham. The samples discussed here caught 5 to 8 times as much pollen over the local flowering season as that collected by us[4] on standard Durham samplers on the Education Building in 1953, 1954, and 1955 and on the EBA in 1962 by Hayes.[5] The greater catches may be due to a number of factors acting singly or in combination.

With experience it is usually possible to determine if pollen and other spores are strictly fresh or somewhat older (i.e., refloated). Pollen is recorded on data sheets according to condition by means of superscripts which indicate if pollen is: eroded, degraded, crumpled, broken, obscured, or exine-thinned. Criteria for determining these categories are modified from those used by fossil pollen workers.[6] In addition, conditions concerning only fresh pollen are employed: degeneration of intine and cell contents, natural pigmentation of cell contents and/or exine, changing staining reaction of exine and/or cell contents, and capacity of the pollen to imbibe water. These effects such as staining or characteristic breakage patterns are often specific for different types of pollen.

AEC-fallout paper provides an adhesive surface superior to any of those in common use (silicone grease, rubber cement, DC-269, etc.) for the trapping and retention of pollen carried down in rain and also for the retention of pollen sampled before rains. Dry deposition and washout by rain should be about equally effective over long periods in humid climates.[7] The unsheltered AEC-fallout paper will collect some of this pollen in rain, but the effectiveness of the process relative to dry deposition is unknown. More data are required for a fuller understanding of the dimensions of this effect. The rain-sheltered Durham sample will collect virtually no pollen brought down in rain.

It is known that horizontal microscope slides in holders similar to the Durham sampler produce an edge effect in moderate winds which can strongly alter pollen catch.[8] The random distribution of pollen over the slides and the remarkable uniformity of catch between replicate slides on the sampling board indicate that under average conditions edge effects are nil for these deposition samples. Silicone grease slides (and other adhesives) have been compared with AEC-fallout paper in parallel tests on the sampling board during times of abundant airborne pollen. There is little difference in catch during periods of fair weather indicating that "bounce-off" of particles from the paper is not normally a factor under these conditions. In stormy weather, however, catches on silicone grease slides are frequently much less than those on AEC-fallout paper and at times the grease is almost completely removed by rain. Samples previously collected during fair weather and re-exposed during stormy periods commonly show high losses for silicone grease slides, but no detectable loss for AEC-fallout paper.

The reasons, then, for the much higher catch of pollen on unsheltered AEC-fallout paper samples compared to silicone greased, horizontal slides in Durham-type holders seem to be these:

(1) In moderate wind speeds an edge effect reduces catch on the 1.5-meter-high Durham samples relative to the roof level deposition samples.

(2) Rain or evaporation of condensed moisture will remove adhesives such as silicone grease and consequently reduce pollen catch.

(3) Pollen carried down in rain is sampled by unsheltered AEC-fallout paper, but is not sampled by rain-sheltered greased slides. The efficiency of this collection is probably highly variable under different weather conditions.

(4) There is greater opportunity for contamination by redeposited pollen on deposition samples than on Durham samples, although precautions are taken to prevent it.

It seems that reason No. 1 would be most important in explaining these differences in catch, although there are not enough experimental data for samples taken in periods of fair weather, moderate wind speeds, and abundant pollen to corroborate this. At somewhat increased wind speeds, wind tunnel experiments have shown that the "edge shadow" effect decreases for horizontal slides and pollen trapping efficiency increases due to turbulent impaction.[7] Under these higher wind speeds, AEC-fallout paper may trap relatively less pollen due to the high "bounce-off" factor which has been demonstrated in its use as an adhesive for impaction samples.

Pollen carried down in rain (reason No. 3) is an unknown quantity. On one occasion, AEC-fallout paper collected with nearly 100% efficiency as compared to Millipore-filtered rain water. At other times, additional large areas of the paper had to be examined to find the same pollens collected on the filtered samples, with collection efficiency probably somewhere around 10%. It would seem that this method of collection would not account for the large differences in total seasonal pollen.

RESULTS

Weekly samples for the four winters of 1966 through 1970 and many subsequent samples into the winter of 1973-74 have been examined. Total pollen recorded for the months of November through February have been: 155 grains/cm^2 for 1966-67; 94/cm^2 for 1967-68; 155/cm^2 for 1968-69; and 71/cm^2 for 1969-70. Pollen recovered in January and February has consistently outnumbered that for November and December by about two to one in spite of the fact that sampling may not be active due to weather conditions in the later months. Pteridophyte spores are recorded, but not included in the totals. Lycopodium spores reach their yearly maximum in the first half of November.

Pollen frequency is expected to be low on most winter samples and a minimum of 4.84 cm^2 sample surface is examined for each of these. The pollen caught in the months of November and December is almost all from redeposited pollen, mostly from those local plants which last produced airborne pollen in quantity: *Ambrosia*, miscellaneous Compositae of several types; Chenopodiaceae and Amaranthaceae (Cheno-Ams), and Gramineae. The ubiquitous pollen of *Pinus* is found practically year around in at least small amounts. Some pollens are identifiable much longer after normal flowering than others because of more recognizable features and innate chemistry which allows them to withstand degenerative processes. Soon after their normal flowering periods, the pollen of most plants are either not represented in the record or are found in sporadic trace amounts. The tendency of pollen to be refloated (after once being impacted on vegetation, for instance) is slight.[7] Large pollens (e.g., winged pollen of conifers) and clumped pollen might be expected to be refloated more often than others, since it would be easier for them to escape through the laminar boundary layer. Common airborne pollens of spring flowering trees are found sporadically throughout the summer and fall (*Betula*, *Quercus*); but others, produced at about the same time in fairly large amounts, are rarely found after their normal season (*Ulmus*, *Populus*, *Fraxinus*). It is felt that later recovery of most of these is a measure of their ability to withstand degradation. An increase in refloated pollen is seen in the fall. This is mostly from fall-flowering plants, but also includes many of the spring-flowering trees. This increase is thought to be due to increased wind speeds and particularly to senescence of vegetation. Occasionally, portions of leaf epidermal tissue, stomates, etc. can be recognized on the samples. Pollen and fungus spores are sometimes rafted with these tissues and it is deduced that many of the tree pollens which show effects of age are released by leaf fall and the death and shattering of herbaceous vegetation. Also, the depletion of foliage will create better conditions for the dispersal of particles by the increase of wind speed through trunk spaces, etc.[9] There are differences in condition of refloated pollen and these should be expected when the variety of surfaces from which they were dispersed and their microenvironments are considered. Fungus spores and hyphae may be intimately associated with "old" pollen.

Most of the fall-collected pollen appears old. *Ambrosia* is frequently eroded with the spines blunted and sometimes with one side abraded flat. The same conditions are common for other pollens. The exceptions are rare collections of *Artemisia*, Cheno-Ams, or pollens of unknown affinity which appear strictly fresh. Rarely a grain or two of some member of the Cupresssaceae is found. This type of pollen shows age quite rapidly by a reversal of staining reaction and fresh pollen is usually easily recognized. The "out-of-season" Cupressaceae appears fresh; and those rare grains found in November and December may have been derived from southwestern or southern states. These grains become somewhat more common in January and February at the same time that records show increased catches in the deep south.[10,11] The four winters analyzed show only an average of 40 pollens per cm^2 for November and December. Of these, probably no more than four or five would be considered "fresh" from late composites or Cheno-Ams in frost protected situations, and probably less than one might have been derived from very distant (one or two thousand km) sources.

Some minor constituents of the spring pollen flora are occasionally found in fall in amounts higher than would be expected. Old pollen of *Picea* and *Abies*, for example, are sometimes found in low amounts in November and December, but these amounts are often equivalent to their local in-season maxima. The possibility of refloatation of these pollens from a source area perhaps 100 km to the north where the producing plants are much more numerous should not be ignored.

Old pollen of *Zea* is found as commonly in the fall as in season, although in very low amounts. Erdtman[12] sampled pollen of *Zea* in December which was presumably derived from old, desiccated plants a short distance away. Source areas here are some distance away, but late fall winds or late harvesting of corn for grain may release old pollen trapped on the plants.

Most of the "fresh" pollen sampled in winter is trapped from late January through February and is, so far, always associated with stormy weather. The types commonly encountered are: *Taxodium*, Cupressaceae, *Alnus*, and *Ulmus*. One of the first significant records for distant "fresh" pollen in winter was from a rain sample of January 27, 1967. The rain was deposited on a Millipore filter. Numerous pollens were seen, some obviously fresh, in a tangle of plant hairs and industrial debris. A number of cupressaceous pollen types appeared to have "papillae", but these were not taken seriously since the optical qualities of the sample were poor. The filter was dissolved in acetone and the pollen was recovered by centrifugation. It was felt that a considerable amount of pollen was lost by this method. About 600 fresh pollen were counted on four standard microscope slides, or about one fresh pollen per square centimeter of the sampling surface. The sample was collected during a seven-hour rain storm following a week of unusually warm weather (highs of 50°F.). The majority of this pollen was of cupressaceous types. The "papillae" seen were leptoma of pollen of the Taxodiaceae. Unfortunately, centrifugation broke most of these, but it was estimated that perhaps one-fourth of the cupressaceous types were actually Taxodiaceae. In later years, identification techniques have been employed which allow a preliminary screening of probable taxodiaceous pollens at low magnifications. About one-fourth of the total fresh pollen was *Alnus*. By chance, these rain samples were collected at the same time the weekly AEC-fallout paper samples were changed, so that the total rain is represented by two weekly samples. These weekly samples average twice the total pollen trapped in the preceding and following weeks.

In the period from February 10-17, 1967, there were 38 pollen grains/cm^2 for the week. This was a period of mild weather with rain early on February 16. The weather became cold and so windy that the sampling board was removed until the regular weekly change the next day. The rain samples are inadequate and it is not known if the pollen recorded occurred in rain or through the mild part of the week. Experience in subsequent years would indicate that the pollen arrived with the rain on the morning of February 16. Of the total, 13 were cupressaceous pollen and 12 were *Alnus*. There are 212 pollens of Cupressaceae recorded per cm^2 for the year; 48 of these occur "out-of-season". There are 90 *Alnus* pollen recorded per cm^2 per year; 21 are "out-of-season".

Most of these "out-of-season" pollens of the four taxa mentioned as common are "fresh" and are generally recovered in two to four episodes of precipitation in each of the four winters studied. Spot samples in subsequent winters have shown that *Taxodium* pollen can be expected at least once in February and occasionally in late January. Local airborne pollen records and regional floras would indicate that the source of this pollen is somewhat south of the Carolinas. *Ulmus* is occasionally found in low amounts at about the same time as *Taxodium*. It is thought to have a similar source area. *Alnus* pollen and that of the Cupressaceae is found along with that of the other taxa and later, sporadically, until the beginning of their local flowering seasons. Other pollens are found well in advance of their local flowering season, but this is after March 1 and they are not the subject of this report.

Some winter rains and snows are exceptionally clean. There may be some early washout of homeheating and industrial pollutants, but little else. Some snowstorms accompanied by strong winds may bring fairly large quantities of "old" pollen. In many cases this is thought to be scoured from available pollen-holding surfaces (rooftops, branches, etc.) and redeposited at the sampling site. But sometimes most of these surfaces are already covered with snow which does not contain pollen. The pollen appears to be associated with the storm system, but its source is puzzling.

CONCLUSIONS

A small amount of pollen was recorded on samplers between November 1 and March 1. Most of that for November and December was probably refloated from locally derived, "old" pollen. About twice this amount of pollen was trapped during January and February and about one-half of that was "fresh". So, for the entire winter season about one-third, which would amount to a maximum of 0.1% of the yearly pollen total, would be considered to be "fresh" pollen of distant origin. The point of origin, based on flowering time, regional floras, and aeropalynological records is probably the southern to southwestern United States at distances of over 1,000 km from the sampling site in Albany, New York. Some of the best records of "fresh" pollen in winter are at the end of weeklong warm periods followed by rain or snow. This does not mean that unusually early flowering times occurred only a few hundred km to the south. *Taxodium*, flowering in late January and early February for instance, is six weeks in advance of its normal flowering in North Carolina. Most of this "fresh" pollen, perhaps all of it, is carried down in precipitation. These records are for pollen sampled on AEC-fallout paper. It is known that the efficiency of this material is quite variable for particles carried in rain drops. A better method of assessing airborne pollen in winter would be to take all-weather samples on AEC-fallout paper and compare them to precipitation samples taken in jars and deposited on molecular membrane filters. It is likely that the winter totals and those for "fresh" pollen would be appreciably higher.

REFERENCES

1. Rosinski, J. Some Studies on the Evaluation of Gummed Paper Collectors Used in Determining Radioactive Fallout. Amer Geophys Union Trans 38(6):857-863, December 1957.

2. Lewis, D. M. Comparisons of Adhesives and Mounting Media. In: Travels of Airborne Pollen. Progress Report 8, Ogden, E. C., G. S. Raynor, and J. V. Hayes. Albany, New York State Museum and Science Service, 1968. p. 4-8.

3. Gregory, P. H. The Leaf as a Spore Trap. In: Ecology of Leaf Surface Micro-organisms, Preece, T. F. and C. H. Dickinson (eds.). New York, Academic Press, 1971. p. 239-243.

4. Ogden, E. C., and D. M. Lewis. Airborne Pollen and Fungus Spores of New York State. Albany, New York State Museum and Science Service Bulletin 378, January 1960. 104 p.

5. Hayes, J. V. Comparison of the Rotoslide and Durham Samplers in a Survey of Airborne Pollen. Ann Allergy 27:575-584, November 1969.

6. Cushing, E. J. Redeposited Pollen in Late-Wisconsin Pollen Spectra from East-central Minnesota. Amer J Sci 262(9):1075-1088, November 1964.

7. Chamberlain, A. C. Deposition of Particles to Natural Surfaces. In: Airborne Microbes, Gregory, P. H. and J. L. Monteith (eds.). London: Cambridge University Press, 1967. p. 138-164.

8. Gregory, P. H. Microbiology of the Atmosphere, 2nd ed. New York, John Wiley and Sons, 1973. 377 p.

9. Raynor, G. S., J. V. Hayes, and E. C. Ogden. Particulate Dispersion Into and Within a Forest. Accepted by: Boundary Layer Meteorology.

10. Wodehouse, R. P. Hayfever Plants. Waltham, Chronica Botanica Co., 1945. 245 p. Table on seasonal occurrence on page 180. This table is deleted in the revised edition, Hafner Press, 1971.

11. Wawrzyn, B., and J. Tomblin (eds.) Statistical Report of the Pollen and Mold Committee of the American Academy of Allergy, 1973. Columbus, Ross Laboratories, 1974.

12. Erdtman, G. An Introduction to Pollen Analysis. Waltham, Chronica Botanica Co., 2nd printing, 1954. 239 p.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-650/3-75-003

2.

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE
Travels of Airborne Pollen

5. REPORT DATE
January 1975

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Eugene C. Ogden, Gilbert S. Raynor* and Janet V. Hayes
*Brookhaven Natl. Laboratory

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
University of the State of New York
Albany, New York 12234

10. PROGRAM ELEMENT NO.
1AA009 (21AD0

11. CONTRACT/GRANT NO.
800677

12. SPONSORING AGENCY NAME AND ADDRESS
Office of Research and Monitoring
U. S. Environmental Protection Agency
Washington, D. C. 20460

13. TYPE OF REPORT AND PERIOD COVERED
Final 10/1/70 - 12/31/ 74

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The following studies were conducted on the transport and dispersion of airborne pollen: (a) Development and evaluation of sampling devices for pollen; (b) development and evaluation techniques for tagging pollen in living plants with dyes and radioisotopes; (c) dispersion and deposition of pollen from known sources of various configurations; (d) effects of forested areas on the removal of pollen from the atmosphere; (e) concentration variations of pollen from natural sources with distance, height, time and other variables; (f) feasibility of predicting ragweed pollen concentrations from unknown sources; (g) measurements on ragweed pollen concentrations in a large source-free area; and (h) comparisons of the ragweed pollen concentrations before and after ragweed eradication efforts.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Pollen Dispersion	Dispersion of Airborne Pollen	Primary 06 Biological and Medical Sciences 0603 Biology Secondary 04 Atmospheric Sci. 0401 Atm. Physics

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Release Unlimited	Unclassified	106
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

INSTRUCTIONS

1. **REPORT NUMBER**
Insert the EPA report number as it appears on the cover of the publication.

2. **LEAVE BLANK**

3. **RECIPIENTS ACCESSION NUMBER**
Reserved for use by each report recipient.

4. **TITLE AND SUBTITLE**
Title should indicate clearly and briefly the subject coverage of the report, and be displayed prominently. Set subtitle, if used, in smaller type or otherwise subordinate it to main title. When a report is prepared in more than one volume, repeat the primary title, add volume number and include subtitle for the specific title.

5. **REPORT DATE**
Each report shall carry a date indicating at least month and year. Indicate the basis on which it was selected *(e.g., date of issue, date of approval, date of preparation, etc.)*.

6. **PERFORMING ORGANIZATION CODE**
Leave blank.

7. **AUTHOR(S)**
Give name(s) in conventional order *(John R. Doe, J. Robert Doe, etc.)*. List author's affiliation if it differs from the performing organization.

8. **PERFORMING ORGANIZATION REPORT NUMBER**
Insert if performing organization wishes to assign this number.

9. **PERFORMING ORGANIZATION NAME AND ADDRESS**
Give name, street, city, state, and ZIP code. List no more than two levels of an organizational hirearchy.

10. **PROGRAM ELEMENT NUMBER**
Use the program element number under which the report was prepared. Subordinate numbers may be included in parentheses.

11. **CONTRACT/GRANT NUMBER**
Insert contract or grant number under which report was prepared.

12. **SPONSORING AGENCY NAME AND ADDRESS**
Include ZIP code.

13. **TYPE OF REPORT AND PERIOD COVERED**
Indicate interim final, etc., and if applicable, dates covered.

14. **SPONSORING AGENCY CODE**
Leave blank.

15. **SUPPLEMENTARY NOTES**
Enter information not included elsewhere but useful, such as: Prepared in cooperation with, Translation of, Presented at conference of, To be published in, Supersedes, Supplements, etc.

16. **ABSTRACT**
Include a brief *(200 words or less)* factual summary of the most significant information contained in the report. If the report contains a significant bibliography or literature survey, mention it here.

17. **KEY WORDS AND DOCUMENT ANALYSIS**
(a) DESCRIPTORS - Select from the Thesaurus of Engineering and Scientific Terms the proper authorized terms that identify the major concept of the research and are sufficiently specific and precise to be used as index entries for cataloging.

(b) IDENTIFIERS AND OPEN-ENDED TERMS - Use identifiers for project names, code names, equipment designators, etc. Use open-ended terms written in descriptor form for those subjects for which no descriptor exists.

(c) COSATI FIELD GROUP - Field and group assignments are to be taken from the 1965 COSATI Subject Category List. Since the majority of documents are multidisciplinary in nature, the Primary Field/Group assignment(s) will be specific discipline, area of human endeavor, or type of physical object. The application(s) will be cross-referenced with secondary Field/Group assignments that will follow the primary posting(s).

18. **DISTRIBUTION STATEMENT**
Denote releasability to the public or limitation for reasons other than security for example "Release Unlimited." Cite any availability to the public, with address and price.

19. & 20. **SECURITY CLASSIFICATION**
DO NOT submit classified reports to the National Technical Information service.

21. **NUMBER OF PAGES**
Insert the total number of pages, including this one and unnumbered pages, but exclude distribution list, if any.

22. **PRICE**
Insert the price set by the National Technical Information Service or the Government Printing Office, if known.

ENVIRONMENTAL PROTECTION AGENCY
Technical Publications Branch
Office of Administration
Research Triangle Park, N.C. 27711

OFFICIAL BUSINESS

POSTAGE AND FEES PAID
ENVIRONMENTAL PROTECTION AGENCY
EPA - 335

Return this sheet if you do NOT wish to receive this material ☐, or if change of address is needed ☐. (Indicate change, including ZIP code.)

PUBLICATION NO. EPA-650/3-75-003