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POLLUTION MONITORING IN THE FLATHEAD VALLEY WITH HONEY BEES

by

Mark L. Dewart

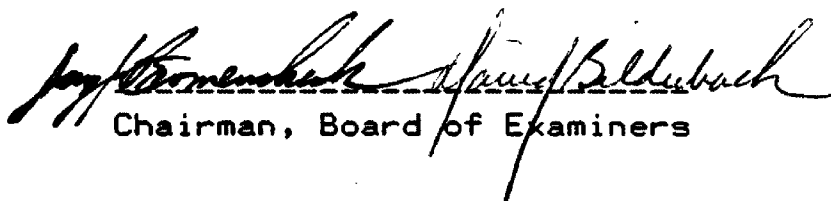
B.S., Eastern Kentucky University, 1977

Presented in Partial Fulfillment of the Requirements
for the Degree of
Master of Science

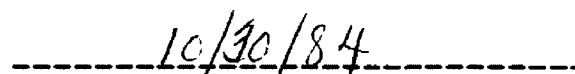
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Pollution Monitoring in the Flathead Valley With Honey Bees
(22 pp.)

Directors: J.J. Bromenshenk, D.E. Bilderback

HB JEP

Honey bees, Apis mellifera.L. were studied to assess their utility as environmental monitors of fluoride and to determine routes of entry and transfer of fluoride to bees. Pollen, alfalfa blossoms, leaves and stems, water and ambient air were sampled in forage areas surrounding eleven commercial apiaries located downwind at 4-36 km from an aluminum smelter. Calcium formate plates were used to provide a relative estimate of ambient fluoride concentrations in each forage area.

Bee fluoride levels ranged from 5.05 ug/g to 86.1 ug/g at sites where ambient air fluoride ranged from 0.03 ug/m³ to 1.40 ug/m³. Pollen and alfalfa parts generally had fluoride concentrations of less than 10.ug/g. Because pollen from a variety of plants and the leaves, stems and blossoms of alfalfa accumulated relatively little fluoride and since variability within sites was high, few significant site to site differences in fluoride content of vegetation could be detected using the Student-Newman-Kuels means test. Formate plates were useful indicators of site differences in fluoride, but the fluoride content of bees provided a basis for distinguishing more significant differences among sites than formate plates.

Fluoride in or on bees may be due to ingestion of nectar or pollen, or accumulation from the air or other possible routes of entry. Partial correlation analysis suggests that bees accumulated a substantial amount of fluoride from ambient air. Pollen, alfalfa leaves, stems, and blossoms contributed considerably less of the fluoride found in or on bees.

Bees were effective monitors of fluoride distribution within a given geographic area and provided a basis for comparing pollutant levels with other regions as well as following changes in pollutant concentration through time.

ACKNOWLEDGEMENTS

Gene Speelman owned and managed the colonies studied in the Flathead Valley. At a busy time of year he generously shared his intimate knowledge of his bees and their habits which facilitated the sampling of water sources and forage areas at each apiary.

Steve Merli's boundless energy and enthusiasm for bees gave the field work a lot of momentum. His resourcefulness proved invaluable in solving the practical problems of field work.

The comments of Dr. John Thomas were very helpful in the statistical analysis of the data. The interest John took in bees as pollution monitors of fluoride and in my growth as a student of statistics was deeply appreciated.

Chemical analysis proceeded efficiently and accurately with the help and advice of Hedwig Tourangeau. I benefited from the air pollution research experience of Peter Rice and Dr. Carrie Johns. An important contribution to the study was made by Dr. Ron Erickson, Dr. David Bilderback and Dr. Tom Birch who reviewed the work as it progressed.

Contributions from the Environmental Studies Program and Greg Mohr, Jim Hearst, and Don McMullin helped meet the costs of the study.

The idea and plans to do this study grew out of my apprenticeship with Dr. Jerry Bromenshenk during his investigations of the pollution monitoring capabilities of bees around the Colstrip power plants in eastern Montana. The thoroughness, attention to detail and dedication he brings to the search for an effective monitoring tool for complex air pollution problems are qualities I've tried to equal in this study.

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INTRODUCTION

Human activities add thousands of tons of toxic substances into the environment each year. The magnitude and extent of the problem is difficult to assess because chemicals are released not only from large, fixed industrial sources, but by small commercial, residential and mobile sources as well. Contaminants may enter the environment as single, known chemicals or in complex, unknown mixtures. There is great need for a monitoring tool that will evaluate hazardous substances over large areas in a cost effective manner.

It is well known that honey bees Apis mellifera. L. have a low tolerance for many pollutants and that bees and bee products accumulate heavy metals, pesticides and radionuclides (Debackere, 1972; Atkins et al., 1968; Kirkham and Corey, 1972). This tendency of bees to accumulate contaminants in or on their tissues has lead several investigators to suggest bees as biological monitors of temporal and spatial trends in the distribution of pollutants over large areas (Debeckere, 1972; Toshkov, 1974; Bromenshenk, 1981).

This study determined fluoride levels in bee colonies in the vicinity of an aluminum smelter. Fluoride levels in

air, water, pollen, alfalfa leaves, stems and blossoms were examined to investigate routes of entry and transfer of fluoride from air to vegetation to honey bees. The primary objective was to assess bees as biological monitors.

THE STUDY AREA

The Flathead Valley lies in northwestern Montana, U.S.A. The valley is rimmed on three sides by mountains that rise from 5,000 to 10,000 feet and by Flathead Lake on the fourth side. Three rivers, numerous streams and sloughs and over 1000 farms and ranches occupy the valley floor. The principal agricultural products are cattle, wheat, alfalfa, christmas trees and cherries.

The major heavy industry in the valley is an aluminum reduction plant (Figure 1). The plant emitted 1,760 - 1,980 kg total fluorides per day during the study in 1980, a considerable decline from the 16,500 kg per day released between 1968 and 1971 (Montana Department of Health, 1968 -1981).

Diurnal variations in surface wind direction have significant effects on the distribution of fluoride in the valley. Nighttime drainage of a large area of mountainous terrain through Badrock Canyon results in northeast winds in the immediate vicinity of the plant and causes fluoride to

accumulate to the west and southwest of the smelter (Gelhaus et al., 1979). During the day, vertical air currents develop over the sun heated valley floor lifting accumulated effluents into high level southwesterly winds that carry these materials over the mountains to areas northeast of the smelter (Gelhaus et al., 1979).

MATERIALS AND METHODS

Eleven commercial bee apiaries, located at distances of 4-36 km from the aluminum facility were sampled the first weeks of August and September in 1980. Figure 1 shows the location of these apiaries with an estimated 3 km radius of foraging area. Typically, the area foraged by bees contains about 10,000 acres from which bees will collect materials for the colony (Gary et al., 1972). No apiaries were available for sampling northeast of the smelter because of the danger of bear predation in that area.

Sampling and analytical materials and methods for bees and pollen were detailed by Bromenshenk (1980). Briefly, an acrylic aspirator affixed to a portable 12 volt vacuum was used to vacuum foraging bees into acid washed collection jars as they landed on hive entrance boards. Seven colonies were randomly selected from the 20-40 at each apiary for sampling. A 30 g (wet weight) sample of foraging bees was

taken from each of the seven colonies. Bee samples were immediately frozen under dry ice and kept frozen until processed.

A 2-4 g sample of pollen was removed from combs in each of the seven colonies sampled for bees using an acid washed plexiglass pick. Pollen was stored at room temperature in plastic vials.

The foraging area surrounding each apiary was sampled for alfalfa foliage (leaves and stems), alfalfa blossoms, ambient air and water. Random samples of ten alfalfa plants in bloom were taken from fields being foraged by bees. An acid washed, stainless steel knife and plastic gloves were used to pick the aboveground portion of alfalfa. A sample of blossoms was removed from the alfalfa foliage in the field for separate analysis. Seven calcium formate plates (Robinson, 1957) were deployed at bee flight height (approximately 75 cm) for 30 days between the August and September collections. The plates were deployed in alfalfa fields throughout each bee forage area to provide a relative measure of ambient fluoride concentrations. A water sample was taken from the primary water source for each apiary and frozen until analyzed.

Bees, pollen, alfalfa foliage and blossoms were dried

before analysis at 45^o C for seven days and then ground in a Wiley Mill[®] to pass through a 40 mesh screen. Ground and dried material weighing 0.50 grams was placed into a clean metal crucible and slurried with distilled-deionized water and 0.05 grams of low fluorine calcium oxide. Samples were then charred under infrared lamps, and ashed overnight in a muffle furnace at 600^o C. Ashed samples were digested in 2 ml of 50% perchloric acid and then diluted to 100 ml total volume with a 50% solution of Orion Tisab[®] total ionic strength buffer and distilled-deionized water. Water was analyzed by bringing a 50 ml sample to 100 ml with 100% buffer solution. Calcium formate papers were removed from their plastic holders and leached for 24 hours in 20 ml of 50% buffer solution, then diluted to 100 ml total volume with 50% buffer solution.

Fluoride content of all samples was determined using the Orion 601[®] ion specific electrode. Prior to each day's analysis, the millivolt response of the electrode was determined for standard solutions of fluoride containing 0.05, 0.10, 1.0, 5.0, 10.0 and 19.0 ug/g fluoride. These standard solutions were prepared daily from an Orion[®] 100 ug/g standard stock solution. Fluoride concentration in sample solutions was determined by a computerized interpolation of millivolt values for samples compared to

the calibration curve for standards.

Five quality assurance reference standards were routinely employed. Two standards were vegetation with a mean fluoride content of 1.95 ug/g (2 SD=1.5) and 9.9 ug/g (2 SD=1.9). Three standards were bee tissue with a mean fluoride value of 3.3 ug/g (2 SD=1.6), 12.7 ug/g (2 SD=3.8) and 52.5 ug/g (2 SD=9.2).

To determine if fluoride was lost from samples during the charring and ashing phase of analysis, standard additions ranging from 5-300 ug of sodium fluoride were made to samples of low fluorine calcium oxide and bee tissue standard before and after charring.

All statistical analysis were parametric tests based on methods given in Sokal and Rohlf (1969, 1981) and utilized data that underwent a common logarithmic transformation. Analysis and transformations were performed either on a Decsystem-20 or Hewlett-Packard 97 computer.

RESULTS

When fluoride standard additions were made to calcium oxide and bee tissue before ashing, recoveries ranged from 85.0%-102.6%. Recoveries ranged from 86.5% to 108.6% when additions were made after ashing.

Statistical evaluations of August and September collections were conducted separately. Mean fluoride and 95% confidence intervals (C.I.) for August and September bees are given in Table I.

TABLE I. AUGUST AND SEPTEMBER 1980 MEAN BEE FLUORIDE LEVELS AND 95% CONFIDENCE INTERVALS AT 11 FLATHEAD VALLEY APIARIES

SITE#	AUGUST		SEPTEMBER	
	MEAN BEE FLUORIDE	95% C.I.	MEAN BEE FLUORIDE	95% C.I.
1	38.66	27.00 to 55.35	38.45	28.34 to 52.14
2	27.15	24.28 to 30.35	28.07	24.22 to 32.50
3	26.73	24.38 to 29.30	34.30	31.35 to 37.51
4	11.89	9.83 to 14.38	13.16	11.14 to 15.50
5	10.46	7.73 to 14.17	16.95	12.16 to 23.49
6	12.02	9.51 to 15.18	20.35	15.60 to 26.43
7	4.99	4.12 to 6.03	8.11	5.69 to 11.40
8	7.23	5.67 to 9.23	14.17	12.52 to 16.03
9	13.50	12.10 to 15.06	16.18	14.47 to 18.09
10	10.05	7.73 to 13.08	16.69	15.29 to 18.21
11	7.34	5.15 to 10.46	12.01	10.28 to 14.01

For most receptors, a one way analysis of variance for the August and for the September collections demonstrated highly significant statistical differences ($P < 0.001$) due to treatment effects at the different sites. Water was the only receptor that the analysis of variance failed to show differences between sites.

Since there were significant differences for other receptors, the Student-Newman-Kuels (SNK) test was used to perform a multiple comparison of the means to further investigate specific site differences. The results of this analysis are listed in Table II.

TABLE II. SNK TEST FOR SIGNIFICANT DIFFERENCES AMONG FLUORIDE MEANS

RECEPTOR	SITES*										
	7	5	8	11	6	10	9	4	3	2	1
FORMATE PLATES	7	5	8	11	6	10	9	4	3	2	1
AUGUST BEES	7	8	11	10	5	4	6	9	3	2	1
SEPTEMBER BEES	7	11	4	8	9	10	5	6	2	3	1
AUGUST POLLEN	10	8	11	7	1	9	6	5	4	2	3
SEPTEMBER POLLEN	7	11	10	5	9	8	4	2	6	1	3
AUGUST ALFALFA BLOSSOMS	5	11	10	6	4	7	9	8	3	1	2
SEPTEMBER ALFALFA BLOSSOMS	6	5	4	9	11	10	8	1	7	3	2
AUGUST ALFALFA FOLIAGE	11	10	9	8	7	3	6	2	5	1	4
SEPTEMBER ALFALFA FOLIAGE	11	7	9	5	4	8	6	3	1	10	2

*Means at 11 sites are ranked from left to right in order of increasing magnitude of fluoride. Means encompassed by any one line were not statistically different ($P < 0.05$).

Spatial trends in the distribution of fluoride in the valley are shown in Figure 1 based on the September collection of bees. This collection serves as the basis of the distribution map because calcium formate plates determined ambient fluoride levels during a 30 day exposure period prior to this collection.

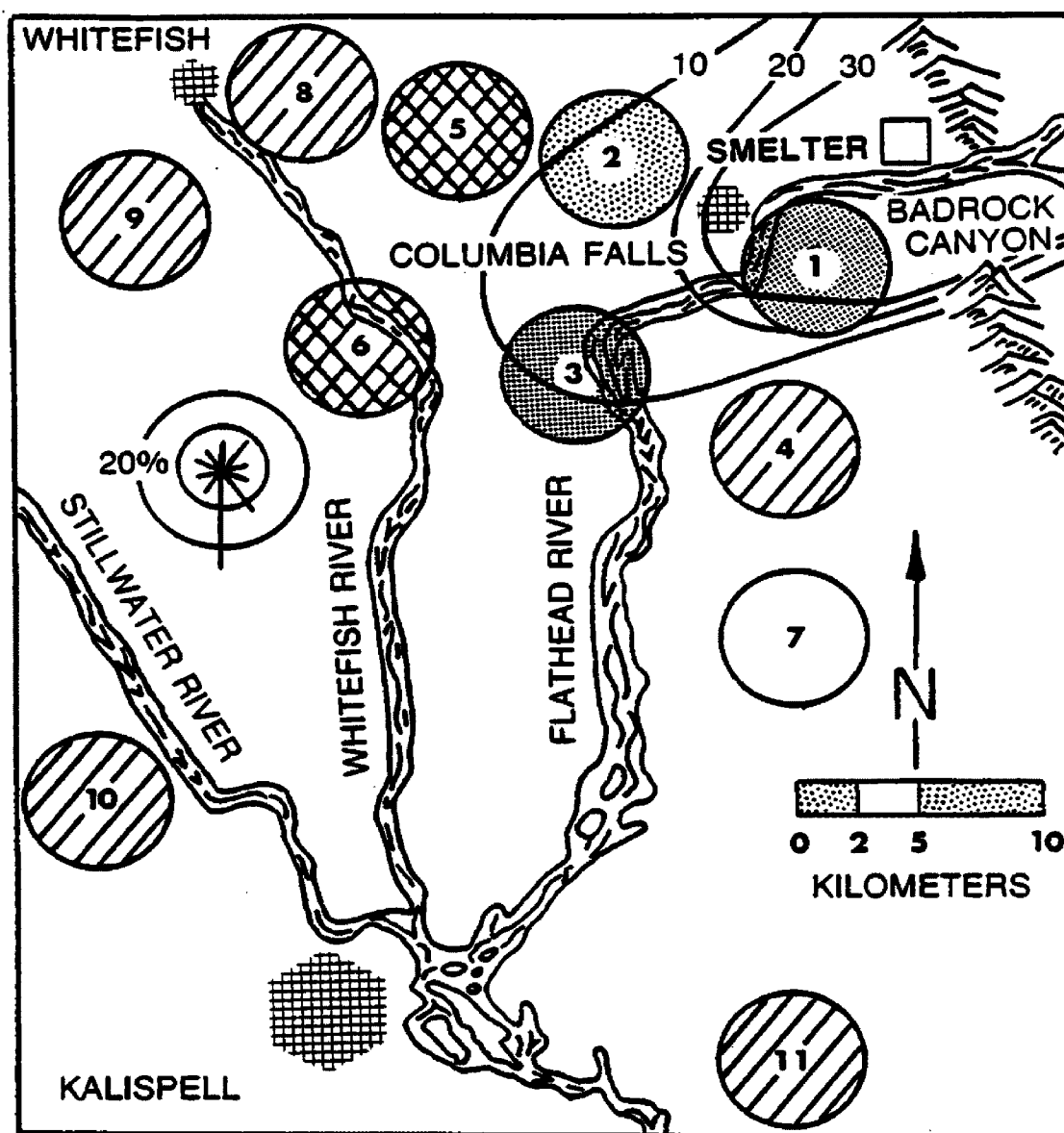


FIG.1 September, 1980 Bee Mean Fluoride Values in the Flathead Valley. Estimated forage areas are shown by circles and have been shaded to indicate magnitude and statistical differences of mean fluoride for bees from apiaries at the center of each forage area. Areas with darker shading demonstrated higher mean fluoride. Forage areas with differently shaded patterns had mean fluoride levels that were statistically different ($P < 0.05$). Patterns are based on mean fluoride data for bees summarized in Table I.

In an effort to investigate more closely the contribution of air, water, and vegetation to the fluoride in or on adult honey bees we utilized partial correlation analysis. The results are given in Table III.

TABLE III. ZERO-ORDER AND PARTIAL CORRELATIONS BETWEEN HONEY BEE FLUORIDE AND OTHER VARIABLES

CORRELATION BETWEEN BEE FLUORIDE AND	ZERO ORDER CORRELATION r	PROB. p	PARTIAL CORRELATIONS CONTROLLING FOR	FIRST ORDER CORRELATION r	PROB. p
AMBIENT FLUORIDE	.7195	<0.001	ALFALFA FOLIAGE POLLEN ALFALFA BLOSSOMS	.6450	<0.001
POLLEN	.3978	<0.001	ALFALFA FOLIAGE AMBIENT FLUORIDE ALFALFA BLOSSOMS	.2708	<0.05
ALFALFA FOLIAGE	.4253	<0.001	AMBIENT FLUORIDE POLLEN ALFALFA BLOSSOMS	.3262	<0.05
ALFALFA BLOSSOMS	.3422	<0.001	AMBIENT FLUORIDE POLLEN ALFALFA FOLIAGE	-.0727	<0.318

DISCUSSION

In the range of 10.5 to 15.5 ug, loss of fluoride during chemical analysis was minute. Above 15.5 ug fluoride, recoveries were depressed by 10-18%. In this study, only 2.8% of the samples analyzed contained more than 15.5 ug fluoride in the sample aliquot. Fluoride concentration probably was underestimated in these samples, all of which were bee tissue, by approximately 15%. Percent bias for samples containing less than 15.5 ug of fluoride ranged from

-0.8 to +2.6%.

Calcium formate plates can be used to estimate ambient air concentrations of fluoride using the conversion factor ($\text{ug F/cm}^2/\text{day} \times 8.74 \pm 1.62 = \text{ug F/m}^3$) developed by Lynch et al. (1978). Using this conversion factor, sites 1-4 have mean ambient fluoride levels that range from 1.40 ug F/m^3 to 0.54 ug F/m^3 . A dispersion model based on meteorological conditions and plant emissions for April through September 1980 predicted ambient fluoride levels to range from 0.1 ug/m^3 to 0.7 ug/m^3 in the immediate vicinity of the smelter (Montana Department of Health, 1982). Using data from formate plates deployed in forage area 1 by the Montana Air Quality Bureau, 1.49 ug F/m^3 was present at site 1 during the study (Sternberg, 1981) which agrees with the 1.40 ug F/m^3 value obtained from our formate plates. Sites 1,2,3,4 have ambient fluoride levels similar or higher than fluoride levels in the immediate vicinity of the smelter as predicted by dispersion modeling (Montana Department of Health, 1982).

Thompson et al. (1971) reported 2164 24 hour measurements of ambient fluoride concentration in rural areas of the U.S. over a three year period. Ambient fluoride concentrations were determined with high-volume samplers. This study found 98.5% of the samples were less than the detection limit of 0.05 ug F/m^3 and 1.3% of the samples were between 0.05 ug

F/m^3 and $0.09 \text{ ug } F/m^3$. One sample, later found to be downwind from a uranium mine, averaged $0.16 \text{ ug } F/m^3$. Based on calcium formate plate data, the mean and confidence interval for ambient fluoride levels at site 7 fell below the detection limit of the high-volume monitors used by Thompson et al. (1971). Ambient air at site 7 appears to be similar in fluoride levels to rural non-industrial atmospheres. Sites 5,6,7,9,10,11 exceed the $0.05 \text{ ug } F/m^3$ detection limit of the Thompson et al. study (1971). These forage areas appear to be exposed to higher than background levels of fluoride.

Mean fluoride values for alfalfa foliage, alfalfa blossoms and pollen were similar between many sites that appeared to be significantly different based on ambient fluoride levels. Alfalfa foliage at only one site had a mean fluoride content greater than 10.0 ug/g . These samples were taken from an abandoned field containing older plants. Suttie (1969) collected 107 samples of alfalfa from plots across the U.S.A. believed to be more than 16 km from industrial sources of atmospheric fluoride. Seventy-five percent of his samples were below 3 ug/g fluoride, and only 7% were found to have more than 10 ug/g fluoride, 5 of which were found to have come from within 8.1 km of major industrial centers.

Fluoride in alfalfa blossoms tended to be below 4 ug/g fluoride and did not differ significantly ($P < 0.05$) from the fluoride found in the leaves and stems. Bortitz (1977) reports that blossoms of Dandelion, Pussy Willow, and Red Clover are capable of accumulating as much as 24-4150 ug/g fluoride in industrial atmospheres. The internal floral parts tended to have higher concentrations of fluoride than the petals. He did not compare blossom fluoride levels to concentrations in the leaves and stems.

Over half of the pollen samples from sites 1,2,3,4 had fluoride levels in excess of 3.0 ug/g while the majority of samples from other sites had less than 3.0 ug/g fluoride. Bromenshenk (1978) found fluoride concentrations below 3.0 ug/g in 96% of 57 pollen samples from a pristine airshed in eastern Montana. In the Flathead Valley, as with alfalfa samples, pollen concentrations of fluoride revealed little trend in geographic distribution of fluoride.

Kirkham and Corey (1977) concluded that pollen was a more sensitive indicator of radionuclides and some inorganic elements than bees or honey but results in Table II suggest that pollen is not useful for distinguishing site to site differences in mean fluoride. Bees were more sensitive indicators than either alfalfa or pollen based on their ability to detect significant differences in fluoride

between sites.

September bees show a pattern of fluoride distribution (Figure 1) that is consistent with ambient fluoride concentrations as indicated by Table II and with diurnal wind patterns near the smelter (Gelhaus et al., 1979). The one exception was site 4. Gelhaus et al. (1979) monitored winds in this forage area and found the station was too far south to regularly detect fluoride carried by nighttime winds through Badrock Canyon. Formate plates used in this study were mainly deployed at the north end of the forage area, which may have experienced rather variable winds carrying fluoride. In addition, bees may have preferentially foraged south of areas influenced by Badrock Canyon winds.

Carlson (1973) estimated accumulation isopols for fluoride based on vegetation samples taken near the smelter. Figure 1 shows that bees extend the ability to map fluoride distribution over greater distances and are consistent with patterns determined by Carlson (1973) using vegetation.

Honey bees also detected temporal changes in fluoride in the valley. Dewey (1973) reported that bees sampled 1 km south of the smelter in 1971 had 221 ug/g fluoride. Since 1971, smelter emissions have declined by 88% (Montana

Department of Health, 1968-1981). In 1980, no bee sample contained more than 86.5 ug/g fluoride which is a 61% reduction from the fluoride value in bees reported in 1971.

Based on bee fluoride levels, site 7 is comparable to pristine areas. Bromenshenk (1978) reported fluoride levels in 103 samples taken from eastern Montana. In these samples, 80% contained less than 10 ug/g fluoride and 16% had concentrations that fell between 10 ug/g and 15 ug/g fluoride. Only 4% of the samples contained more than 15.1 ug/g with a maximum value of 20.5 ug/g fluoride. At site 7 in the Flathead Valley, 86% of the samples in 1980 were below 10 ug/g in fluoride and the rest were below 15 ug/g fluoride. In contrast, site 1 had mean fluoride levels of 41.671 (1 SD=20.328) in August and 40.366 (1 SD=14.335) in September. Though these were the highest bee fluoride levels found at any site in the Flathead valley in 1980, they are lower than fluoride levels reported for bees downwind from other aluminum smelters. Bromenshenk et al.(1984) found bees with fluoride concentrations as high as 182 ug/g fluoride near Tacoma, Washington. Rice (1984) found fluoride levels in bees to range from 185 - 406 ug/g at several sites on Cornwall Island, Ontario.

Since there were no significant site differences in fluoride concentration in water, water does not appear to be

a major source of fluoride in bees. The pathway by which fluoride reaches the bee is not clearly understood. Fluoride can get into the bee through respiration, or by being absorbed from particles that adhere to their bodies. Fluoride could transfer to bees from accumulated concentrations on or in plants. Debackere (1972) and Toshkov et al. (1974) suggest that much of the fluoride found in bee tissue may have come from pollen that bees consumed during larval development. Bortitz, (1977) reports total fluoride levels ranging from 15-3420 ug/g in Willow, Dandelion, and Apple blossoms in industrial areas. The water soluble fraction of these values range from 7-40% and further indicates that a substantial amount of mobile fluoride may be available in flowers for bees to accumulate through ingestion. Nevertheless, Alstad et al., (1982) suggest that fluoride is unavailable for biological accumulation through ingestion since fluorides are biologically active and as such should be quickly bound by plant tissues. Other studies report little transfer and retention of ingested fluoride. Less than 0.1% of the fluoride ingested by Mexican bean beetles feeding on fumigated bean foliage was retained in the tissue of the beetles (Weinstein et al., 1973; Weinstein, 1977). However, because of differences in physiology bean beetles may respond differently to ingested fluoride than honey bees.

Little transfer or retention of pollen borne fluoride by bees is consistent with the observations of Bromenshenk (1980) who examined fluoride in pollen, pupae, young and adult bees exposed to fluoride from water and air sources. Pupae demonstrated little accumulation of fluoride via ingestion, pupae fluoride levels were approximately the same as pollen. Even when adult bees averaged 76.30 (1 SD=19.94) ug/g fluoride pupae averaged only 2.20 (1 SD=0.72) ug/g fluoride.

Bees fly tremendous distances in collecting a variety of materials for the hive. In atmospheres contaminated with fluoride, bees would come in contact with substantial amounts of reactive fluoride. Zero-order correlations between bees and ambient air fluoride (Table III) were high and significant ($r=.7162$ $P<0.001$). Zero-order correlations between bee tissue fluoride and pollen, alfalfa foliage, and alfalfa blossoms were significant but generally low. Based on Zero-order correlations alone, it appears that air and other receptors may contribute to fluoride found in bees. However, some of these correlations may be spurious.

Fluoride in pollen, alfalfa foliage, and alfalfa blossoms may only coincidentally correlate with fluoride in bees because all receptors may be influenced by ambient air

fluoride. Partial correlation can reveal spurious correlations by measuring the association between two variables while adjusting for the effects of one or more additional variables. Controlling variables by means of partial correlations reduced correlations between bees and alfalfa blossoms, alfalfa foliage and pollen even further while the correlation between bees and ambient air fluoride remained high.

CONCLUSIONS

Honey bees accumulated fluoride in the vicinity of an aluminum smelter to levels that were 2-40 times the level found in pollen, alfalfa foliage and alfalfa blossoms in the bee's forage area. Water, pollen, alfalfa foliage and blossoms contribute relatively small amounts of fluoride to bees. Much of the fluoride in or on bees appears to be acquired from fluoride in the ambient air.

Because bees accumulated greater amounts of fluoride than other fluoride receptors studied, they were more sensitive indicators of the spatial distribution of fluoride. Bees detected more site to site differences in mean fluoride levels and were able to follow distribution patterns of fluoride for greater distances than pollen or alfalfa. The spatial distribution of fluoride detected by bees was

consistent with changes in ambient air fluoride levels determined during the study and with other studies of fluoride dispersal in the Flathead Valley (Carlson 1973, E.P.A. 1973).

Bees not only can be used to determine the fluoride patterns within a given geographic area, but they provide a basis for comparing pollutant levels with other areas or regions as well as following changes in pollutant concentrations through time. Man has long benefited from these insects in terms of products such as honey, wax and pollination services. Perhaps man can further benefit from the industry of these insects by using honey bees to detect and define areas of serious environmental contamination before critical damage has been done.

REFERENCES

- Alfonsus, E.C.: 1933, 'Zum Pollenverbrauch des Bienenvolkes,' Arch. Bienenk. 14, 220-223.
- Alstad, D.N., Edmunds, G.F., and Weinstein, L.H.: 1982, 'Effects Of Air Pollutants On Insect Populations,' Ann.Rev.Entomol. 27, 369-84.
- Atkins, E.L., Anderson, L.D., and Greywood, E.A.: 1968, 'Research on the Effects of Pesticides on Honey Bees, Part I,' Am. Bee J. 110, 387-389.
- Bortitz, S., Reuter, F.: 1977, 'Studies in the Fluorine Content of Flowers In Areas With Emissions Harmful to Bees,' Archiv. fur. Gartenbau 25, 247-255.
- Bromenshenk, J.J.: 1978, 'Investigations of the Impact of Coal-Fired Power Plant Emissions upon Insects,' In: The Bioenvironmental Impact of a Coal-Fired Power Plant, Third Interim Report, Colstrip, Montana. E.M. Preston and R.A. Lewis, eds. EPA-600/3-78-021, U.S. Environmental Protection Agency, Corvallis, Oregon, pp. 146-312.
- Bromenshenk, J.J.: 1980, 'Accumulation and Transfer of Fluoride and Other Trace Elements in Honey Bees Near The Colstrip Power Plants,' In: The Bioenvironmental Impact of A Coal-Fired Power Plant, Fifth Interim Report, Colstrip, Montana E.M. Preston and D.W. O'Guinn eds. EPA-600/3-80-052, U.S. Environmental Protection Agency, Corvallis, Oregon, pp. 72-95.
- Bromenshenk, J.J.: 1981, 'Fluoride and Arsenic Concentrations In Honey Bees Near Colstrip,' In: The Bioenvironmental Impact of A Coal-Fired Power Plant, Sixth Interim Report, Colstrip, Montana E.M. Preston, D. O'Guinn, and R.Wilson, eds. EPA-600/3-81-0071, U.S. Environmental Protection Agency,, Corvallis, Oregon, pp. 210-227.
- Bromenshenk, J.J., Carlson, S.R., Simpson, J.C., and Thomas, J.M.: 1984, 'Pollution Monitoring in Puget Sound With Honey Bees,' In Press.
- Carlson, C.E.: 1972, 'Monitoring Fluoride Pollution in Flathead National Forest and Glacier National Park,' Insect and Disease Branch, Division of State and Private Forestry, U.S.D.A., U.S. Forest Service, Northern Region, Missoula, Montana, 25pp.

- Debackere, M.: 1972, 'Industrial Pollution and Apiculture,' Vlaams Imkersblad, 2, 145-155.
- Dewey, J.E.: 1973. 'Accumulation of Fluorides by Insects Near an Emission Source in Western Montana,' Environ. Entomol. 2, 179-182.
- Environmental Protection Agency,: 1973, 'Fluoride in Glacier National Park: A Field Investigation,' EPA 908/1-73-001, Region Eight Air and Waters Programs Division, U.S. Environmental Protection Agency, Denver, Colorado, 69 pp.
- Gary, N.E., Witherell, P.C., and Marston, J.: 1972, 'Foraging Range and Distribution of Honey Bees Used for Carrot and Onion Pollination,' Environ. Entomol. 1, 71-78.
- Gelhaus, J.W., Machler, M., and Roach, M.D.: 1979, Meteorological Study of Columbia Falls, Montana Montana Department of Health and Environmental Sciences, Air Quality Bureau, Helena, Montana, 75 pp.
- Guilhon, J.: 1961, 'Atmospheric Pollution by Sublimated Fluorines of Industrial Origin.' Revue Ass. Prev. Atmosperique. 3, 260 - 272.
- Kirkham, M.B., amd Corey, J.C.: 1977, 'Pollen as Indicator of Radionuclide Pollution,' J. Nuclear Agric. Biol. 6, 71-74.
- Livingston, D.A.: 1963, 'Chemical Composition of Rivers and Lakes,' In: Data of Geochemistry. M. Fleischer ed. Geological Survey Professional Paper 440-6, U.S. Dept. of Interior, Wash., D.C. pp. 1-61.
- Lynch, A.L., McQuaker, N.R., and Gurney, M: 1978, 'Calibration Factor Estimation of Atmospheric SO and Fluoride by Use of Solid Absorbent,' Environ. Sci. Technol. 12, 169-173.
- Montana Department of Health and Environmental Sciences, Air Quality Bureau,: 1968 - 1981, 'Quarterly Fluoride Emissions Reports,' Unpublished file data, Helena, Montana, n.p.
- Montana Department of Health and Environmental Sciences, Air Quality Bureau,: 1982, 'Columbia Falls Dispersion Modeling,' Unpublished file data, Helena, Montana, n.p.

- Rice, P.: 1984, "Report of Peter Rice Concerning Fluoride Pollution of Cornwall Island, Ontario, by Emissions from Reynolds Metals Company and ALCOA Aluminum Smelters in New York," Botany Department, University of Montana, Missoula, Montana, 118 pp.
- Robinson, E.: 1957, "Determining Air Fluoride Concentrations by Exposing Lined Filter Papers," Am. ind. Hyg. Ass. J., 18, 145-148.
- Sokal, R.R., and Rohlf, F.J.: 1969, Biometry W.H. Freeman and Company, San Francisco, 766 pp.
- Sokal, R.R., and Rohlf, F.J.: 1981, Biometry W.H. Freeman and Company, San Francisco, 859 pp.
- Sternberg, S.: 1981, Montana Air Quality Data Information. Summary For 1979-1980. Montana Department of Health and Environmental Sciences, Air Quality Bureau, Helena, Montana, 178pp.
- Suttie, J.W.: 1969, "Fluoride Content of Commercial Dairy Concentrates and Alfalfa Forage," J. Agr. Food Chem. 17, 1350-1352.
- Thompson, R.J., McMullen, T.B., and Morgan, G.B.: 1971, "Fluoride Concentrations in the Ambient Air," J. Air Pollut. Control Assoc. 21, 484-487.
- Toshkov, A.S., Shabanov, M.M., and Ibrishimov, N.I.: 1974, "Attempts To Use Bees To Prove Impurities in the Environment," Toxicol. 27, 699-702.
- Weinstein, L.H.: 1977, "Fluoride and Plant Life," J. Occup. Med. 19, 49-78.
- Weinstein, L.H., McCune, D.C., Mancini, J.F., and van Leuken, P.: 1973, "Effects of Hydrogen Fluoride Fumigation of Bean Plants on the Growth, Development, and Reproduction of the Mexican Bean Beetle," Proc. Third Int. Clean Air Congr. VDI-Verlag, pp. A150-153.