PUBLIC PARTICIPATION IN ENVIRONMENTAL MONITORING: A MEANS OF ATTAINING NETWORK CAPABILITY*

JERRY J. BROMENSHENK**

Gordon Environmental Studies Laboratory, University of Montana, Missoula, MT 59812, U.S.A.

and

ERIC M. PRESTON

Air Pollution Effects Branch, Corvallis Environmental Laboratory, 200 S.W. 35th Street, Corvallis, OR 97330, U.S.A.

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Abstract. In the Puget Sound region of the United States a task force of community volunteers using bees monitored environmental pollution. This paper discusses advantages and limitations of public involvement in the assessment of regional environmental problems, particularly with respect to biological monitoring. This approach not only yielded extensive information about pollution levels but also was very cost effective.

1. Introduction

Environmental pollution is a global problem. Each year thousands of different chemicals from numerous sources are introduced into air soil and water. Knowledge of hazards associated with many contaminants and the ability to adequately assess or monitor these substances on a regional scale is limited. In the absence of effective monitoring programs, serious environmental contamination may be detected only after critical damage has occurred (Luepke, 1979).

Biological monitoring is a way to assess pollution regionally. According to two 1979 U.S. Environmental Protection Agency reviews (Murphy, 1980; The Ecology Committee, 1979), biological monitoring should be a part of many monitoring programs because biological methods can directly evaluate processes such as accumulation and effects such as toxicity.

In 1981, researchers at the University of Montana began research aimed at a biological monitoring method that could be standardized and would be suitable for network monitoring. We chose the honey bee (*Apis mellifera*) for this purpose. By 1982, we were ready to test the concept on a regional scale in the Puget Sound area of Washington.

This paper evaluates our experience in designing and implementing a biological monitoring network using a task force of community volunteers.

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** To whom correspondence should be addressed.

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2. Selection of the Biological Monitor

Biological monitoring is the repeated measurement of one or more attributes of a unit of biological organization for the purpose of determining spatial or temporal trends.

Usually, the advantages of a biological monitor over a physiochemical monitor are that the biological monitor provides an integrated or average sample, indicates the bioavailability and the occurrence of environmental contaminants and can be less expensive.

Biological monitoring conceptually can be divided into two types. Bioexposure monitoring is directed toward the systematic determination of pollutant exposure as a function of time and space. Bioeffects monitoring is directed toward determination of the effects of pollutant exposure and the structure or function of biological systems.

Important criteria in selection of broad-spectrum bioexposure monitors are:

(1) A relatively large amount of the environmental medium of interest passes by the absorptive or adsorptive surfaces of the selected organism.

(2) The organism accumulates a wide range of anthropogenic chemicals.

(3) The organism has relatively low sensitivity to the chemicals it accumulates. (One does not want the sampler to be killed in the process of sampling).

(4) The organism is ubiquitous in environments of interest, and its populations are large enough to permit statistically valid sampling without significantly affecting population size or performance.

Criteria for selection of effects monitors are dependent upon the level of biological organization and the taxonomic group of interest; i.e. criteria for individuals, populations, communities, and ecosystems differ greatly.

An effective broad-spectrum, bioeffects monitor may not exist. Instead a battery of monitors may be required to deal with the variety of specific problems.

Nevertheless, some considerations apply to the selection of bioeffects monitors:

(1) It is often advantageous for the monitor to be extremely sensitive to the pollutants of concern. An effect observed by the response of the monitor provides an early warning of possible problems. Lack of an effect indicates that other similar organisms are not likely to be affected.

(2) An effect chosen for monitoring should be interpetable; its significance to the biological system should be well established.

(3) The effect monitored should be extrapolative either to other species in a taxonomic group or to other ecological systems. It should be possible to assure that if the effect is observed, the potential exists for other biological systems not being monitored to be in jeopardy.

(4) The effect observed should be quantitative and easy to measure at regular intervals.

Honey bees have been used as self-sustaining monitors of the effects of contaminants ranging from trace elements to low-level radioactivity (reviewed by Wallwork-Barber *et al.*, 1982; Debackere, 1972). Contaminant levels in the environment may be reflected by the bees themselves or by hive components, such as wax, pollen, or even honey, although levels in honey tend to be very low. Also, bees have a low tolerance for many toxic chemicals (Bromenshenk, 1983; Debackere, 1972; Atkins *et al.*, 1973; Johansen, 1972), thereby providing a potentially sensitive effects monitor.

Bees are well-suited to exposure monitoring because they obtain an average sample from the area encompassed within their flight range (more than 7 km^2, Toshkov *et al.*, 1975; Wallwork-Barber, 1982). Pollutants may enter the colony by many routes, including the water, nectar, pollen, and resin gathered by bees. In addition, contamination of the bee itself by contact with dusty surfaces or with airborne materials may occur. Pollutants may become attached to the surface hairs or other exterior body parts or may reach the interior of the bee by ingestion, inhalation, or absorption through the exoskeleton (see Bromenshenk *et al.*, 1985 for a more detailed discussion; also Debackere, 1972).

In addition, colonies of bees are kept across the United States and occur worldwide providing an in-place and accessible monitoring network from which beekeepers can take samples (The Ecology Committee of the Science Advisory Board to EPA, 1980), thereby reducing sampling and field-measurement costs.

3. Selection of the Study Site

Our objective was to assess the viability of using honey bees as a means of monitoring a diverse array of pollutants on a regional scale. Selection criteria included:

(1) A Pacific Northwest location not overly distant from any of three cooperative facilities – the University of Montana, Pacific Northwest Laboratories, and the U.S. EPA Corvallis Environmental Research Laboratory. The objectives were to maximize accessibility and reduce travel costs.

(2) A large number of beekeepers who maintain bees in a variety of settings.

(3) Bee colonies well distributed throughout both rural and urban settings.

(4) Distinct geographical or climatic boundaries defining the limits to the region.

(5) More than one source of pollutants, but not so many that the region becomes a large diffuse source composed of numerous individual sources. In other words, point sources should be rather clearly defined, and sampling can be executed along exposure gradients.

(6) An area reasonably well characterized in terms of available biotic and abiotic data. Many point sources of pollutants have been studied over long periods of time and have ongoing research and conventional monitoring of air or water quality.

After researching maps of major industrial pollution sources, land use, apiary locations, prevailing winds, and other relevant data about various regions of the Pacific Northwest, we selected the Puget Sound area of Washington. This region has more than 120 monitored pollution sources, clearly defined boundaries such as the Pacific Ocean and the Cascade Mountains, and more than 1000 registered beekeepers. About 400 of the beekeepers belong to one of four beekeeping associations, which greatly simplified contacting prospective participants.

4. Recruitment of Beekeepers and Tasks

Assistance in recruitment of volunteers can be obtained from the American Beekeeping Federation, the American Honey Producers, U.S. Department of Agriculture bee-research laboratories, state departments of agriculture, and state and local beekeeping associations. In addition, we enlisted the aid of four Puget Sound associations comprising 391 beekeepers.

Each volunteer was asked to establish at least one sampling site where they would:

(1) Measure percent brood survival.

(2) Collect forager bees.

(3) Trap pollen.

The methods employed were developed and tested during the study of an industrial complex in Montana (Bromenshenk *et al.*, 1985). The brood survival data provide an index of colony condition; while the bee and pollen samples were analyzed for residues of inorganic pollutants. This information was then used to map pollution distribution according to procedures described in Section 5.

5. Equipment Distribution and Training

To assure overall reliability of data, the all-volunteer task force was trained at beekeeper association meetings in June and July, 1982.

Each participant was given a pair of plastic pollen traps, pre-labeled plastic bags for storing samples of bees and pollen, and sample identification cards to accompany the sample bags. For bee collection, groups of two to three beekeepers were lent a 12-V vacuum aspirator designed to plug into a car cigarette-lighter socket. All sampling equipment was acid washed and packaged in plastic before distribution to ensure cleanliness.

Packets for conducting brood-survival tests, which cost about 80¢ each, included data sheets, instructions, and dressmaker pins, and were mailed to all bee-association members. The brood survival test consisted of marking six rows of cells on a brood comb and conducting two independent determinations – an initial recording of eggs and young larvae for 100–120 cells and a follow-up scoring of cell contents by developmental stage performed 13 to 17 days later. Observations were scored on a self-guiding data sheet and later processed using a computer program we developed.

Each participant established at least one sampling site and picked at random one colony per site for testing. The bee and pollen samples, identified in the field, were placed in plastic bags and frozen as soon as possible after collection. Pickup of frozen samples was coordinated by association members. Brood-survival results were returned by mail to the University of Montana. Procedural questions were referred to the University by a Seattle-based answering service and also were handled at club meetings.

To assure overall reliability of data with an all-volunteer task force, we:

(1) Evaluated our sampling design and subsequent sample collection, handling, custody, and processing.

TABLE I

Summary of beekeeper response for 1982

Beekeeping association	No. of club members	No. of participants (% of membership)	No. of sites	Bees		Pollen		No. of Brood Tests	Total All tests
				# Samples	# Sites	# Samples	# Sites		
Puget Sound	211	36 (17%)	36	38	21	20	13	21	79
Pierce County	85	11 (13%)	16	15	15	15	13	16	46
Vashon Island	35	7 (20%)	7	9	5	2	2	5	16
Whidbey Island	42	10 (24%)	13	11	8	10	8	10	31
Total	371	64 (17%)	72	73	49	47	36	52	172

(2) Identified and separated field and laboratory sources of error.

(3) Used kriging, a relatively new statistical approach (Clark, 1979; Journal and Huijbregts, 1978) that offered a means of dealing with the sample design limitations, as well as providing a potentially effective and reliable means of data analysis, reporting, and validation. Scientists at Pacific Northwest Laboratories performed the kriging. Kriging is a weighted moving-averaging technique that calculates point estimates or block averages over a specified grid that are then used to map pollution distribution.

(4) Used chain of custody, a method for documenting handling.

(5) Audited 30% of the program participants in the field.

Mistakes were corrected through on-site instruction and reports written to participating members.

Internal and external analytical performance and systems audits of the chemical residue analyses were performed. Principal components of the quality control for the laboratory included standard additions, daily inclusion of one or both of two internal bee reference materials (one obtained from a clean area in western Montana and the other from an apiary near a lead-smelting complex) and one or both of National Bureau of Standards SRM Orchard Leaves 1571 and SRM Bovine Liver 1577, as well as replication of analysis for all samples containing chemical levels above reported background levels and replication of at least 10% of all samples considered to contain background levels. In addition, control charts were maintained and analysis was not allowed to progress if results exceeded control limits for any of the recoveries (standard additions, bee or NBS reference materials). The instrument drift was monitored every tenth sample and corrective action taken as needed.

6. Recruitment Success

Beekeeper response for the two sampling periods conducted in 1982 is summarized in Table I. By midsummer, 1983, 114 beekeepers had provided samples and contributed 968 hours of time. They provided 108 brood-survival forms, 254 samples of bees, and 66 samples of pollen.

7. Evaluation of Beekeeper Data

Of the brood-survival tests attempted, 86.4% of the 1982 and 98% of the 1983 tests were considered valid.

Completeness for bee samples collected in 1982 were: As (95.9%) – three samples lacked an identification/chain of custody card – F (90.4%), Pb (95.6%), Cd (94.5%), Cu (94.5%), and Zn (94.5%). In almost all cases, a lower percentage of valid samples existed for chemicals other than arsenic due to insufficient sample size to analyze for other elements.

The values for pollen collected in 1982 were: As (93.8%), F (61.3%), Pb (67.5%), Cd (73.5%), Cu (71.4%), and Zn (71.4%). Fewer pollen samples and insufficient sample size account for the lowered percentages in these categories.

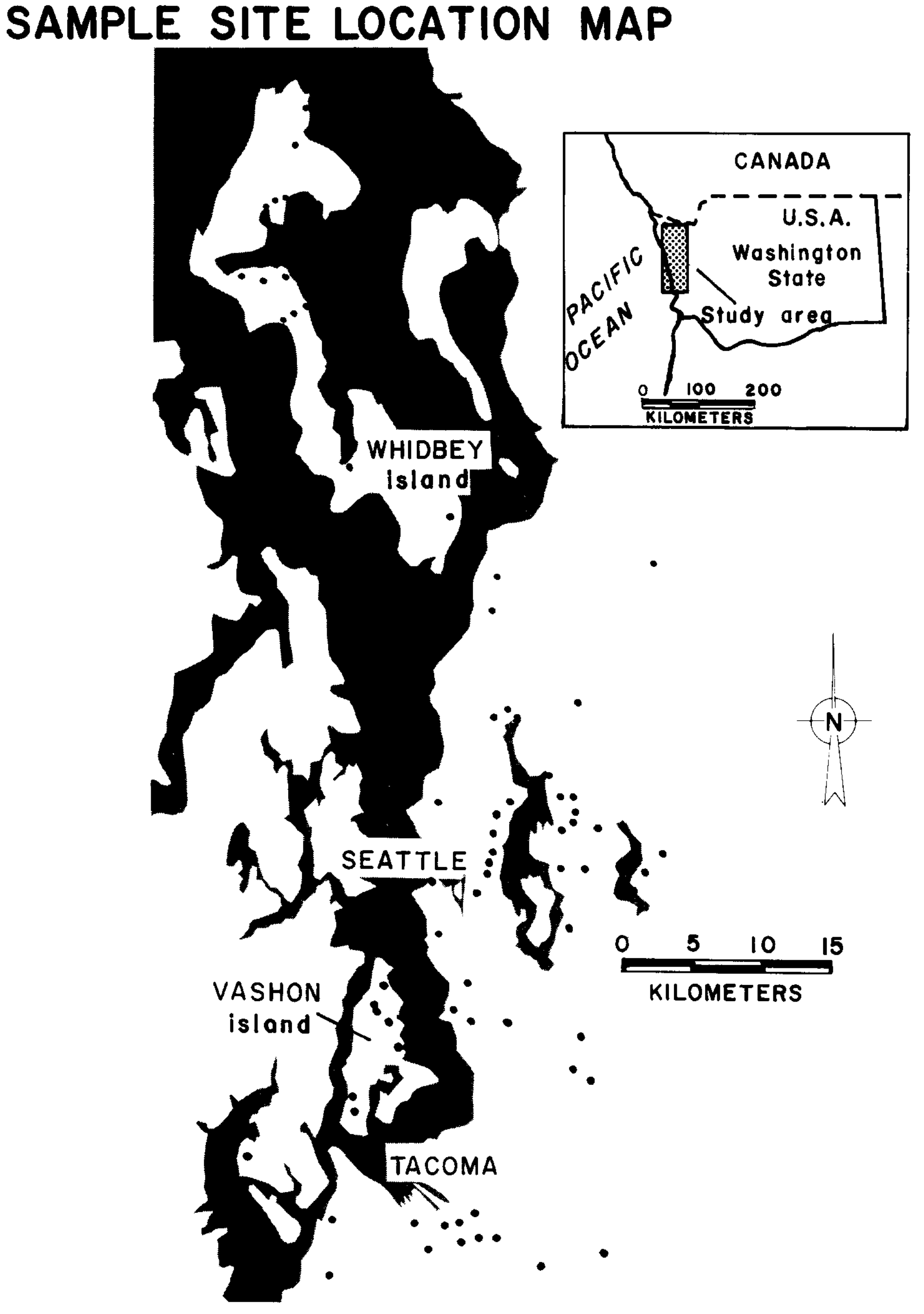

Fig. 1. 1982 Sample Sites in Puget Sound.

Because the time interval between the first and second developmental-stage inventory was too long – largely due to delays caused by inclement weather – 7.6% of the 1983 brood survival returns were invalidated. The other 6.0% were incorrect because of readily apparent mistakes or brood kills due to mishandling.

In terms of the initial program goal of obtaining data from a minimum of 45 monitoring sites, the 1982 brood survey rates 118% completeness, while the 1983 brood survey rated 104%.

From the sites sampled in 1982, we obtained valid brood-survival results from 74.3% and 78.8% of the sites also yielding valid bee or pollen-residue results, respectively. The figures are based on adequate samples for arsenic determination. Ideally, all three tests conducted – sampling bees, trapping pollen, and measuring brood survivals – would have been performed at each site. However, because of problems, beekeepers were able to complete only two of the three tests at many of our sites.

One problem stemmed from the role self-interest played in the tests beekeepers completed. For example, we had the most valid samples from brood-survival tests. We reasoned that because the beekeepers had a direct financial stake in brood survival and could immediately estimate the results by viewing their completed forms, they quite assiduously performed that test, the most difficult and time consuming of the three. Also, a quick remedy for low brood survival was sometimes within the owner's control, such as replacing lethargic queens. By contrast, analysis of the bee and pollen tests took weeks, and the remedy for contaminated bees or pollen obviously exceeds the capability of a single beekeeper. Thus, enthusiasm was less for those tests especially in areas not known to be exposed to high levels of toxic materials.

Other problems limiting the number of valid tests included cases where no brood was present in the colony sampled, relocating a colony, difficulties in attaching pollen traps, or failure to acquire all of the needed equipment.

Some sampling gaps occurred. The sites the volunteer task force established concentrated in relatively urbanized areas with fewer and less densely clustered sites in the more rural regions (Figure 1). In 1983, we found that it was possible to obtain sites and participants even in areas as close as 1 km to the heavily industrialized area of Commencement Bay. Usually, we could locate potential sites by driving through areas, watching for bee hives, and talking with the owners of those we found. In only one case were we denied access to hives. For the most part, these beekeepers did not belong to any of the local beekeeping associations.

8. Performance of Volunteers

Approximately 30% of the beekeepers participating in the program in September, 1982, April, 1983, and August, 1983, were audited to determine whether their performance levels met quality assurance standards.

The audits showed that no more than a 5% variance existed between brood score sheets recorded by the volunteers and those recorded by auditors.

Some procedural errors were corrected. The most frequent problem identified on the brood test was using too long an interval between the first and second developmental-stage inventory thus invalidating the test because healthy brood would have emerged before the final inventory. The improvement in the number of valid tests obtained in 1983 was primarily due to correction of this error.

A more serious error was being unduly rough in removing bees from a frame. Instead of brushing the bees off or lightly shaking the frame, the frame was rapped sharply against the hive, dislodging eggs, giving false readings. This may have occurred in 1 to 3% of the 1982 tests, but it was not detected in the 1983 audits.

Another error was failing to notice eggs and later finding pupae. (These data, however, were recorded 'improbables', and are discounted in data computations of brood survival.) For 1982, maximum error of this type was 2.5%. Overall, mean error was less than 0.2%. In 1983, nine out of 56 sheets contained improbables. One person's maximum error was 20%, although most were 5% or less.

Probably the best estimate of accuracy and precision of the brood survival test was provided by an independent experiment conducted by a beginning beekeeping class at Eastern Washington University, that participated in our program. Members of the class carried out a round-robin determination. All class members were novices; some had never observed brood before. Two colonies were tested, one of which had chalk brood, which probably contributed to depressed brood survival. Colony OWP displayed a mean mortality of 80.5% $\pm$ 14.6, CV = 18.2 (4 observers). Colony OWN was tested on two different days. Mean mortality observed was 41.3% $\pm$ 8.0, CV = 19.4% (3 observers), and 46.9% $\pm$ 9.4, CV = 22.7% (7 observers, day 2). Based on our prior studies, a trained research aide could successfully use this procedure to detect differences of about 20% between sites or along a particular gradient. The relatively high CV values for the beekeeping class warranted closer examination. Observer difficulties were not primarily due to difficulties in seeing eggs (0.7–2.4%, CV), but a consequence of misjudging the development stage in the second count – the greatest source of error occurring in the number of calculated dead (cells containing brood younger than the interval between counts).

In reviewing the actual data sheets, we found consistent observer bias in scoring the age of the pupae. One person might score all pupae as being one age category older or younger than other observers, for example.

Age determination is made mainly by eye color – which changes from white to pink to brownish to dark. The problem in scoring appears to be one of interpretation. Although our own computer analysis allowed for $\pm$ 1 day developmental stage error, the planned corrective action is to provide a color-reference key for aging pupae.

Audits showed that most beekeepers were careful in taking residue samples. In addition, those who did not follow proper sampling techniques usually were easy to identify and constituted less than 3% of the samples.

One problem that resulted in insufficient tissue samples in 1982 was caused by ineffective use of equipment, such as the inability to vacuum bees from hives quickly or smoothly enough or to attach pollen traps correctly.

The ultimate test of the overall performance in terms of sampling can be assessed by the maps of pollutant distribution. We were able to construct maps showing distinctive exposure gradients over relatively widespread areas for As, Cd, and F. In addition, confidence bands and error estimates could be constructed and plotted. Also, we were able to identify some potential 'pollution hot spots'. These maps covered areas three to five times larger than any other available maps based on data such as ambient-air monitoring or analysis of soils or vegetables. Our maps were consistent with the patterns known to exist from these other types of studies, although we were able to follow pollutants over longer distances (Bromenshenk *et al.*, 1985).

9. Beekeeper Difficulties

In September, we interviewed 49% of the participants by telephone or in person. The following difficulties were reported: five vacuum aspirators with insufficient suction, problems in positioning pollen traps resulting in inadequate pollen collection, problems in executing the brood-surival test (too time-consuming and required an assistant), hives on rooftops or other places where a car could not be used as a power source, bees removed pins marking the brood area, inclement weather preventing completion of tests on schedule and not enough drop points for sample collection and transfer.

10. Cost-Effectiveness

When employing many sites for a one-time or occasional screening of a large area, using honey bees is cheaper than the most basic air monitoring instruments – high-volume air samplers. Major instrument costs include initial purchase price, setup, provision of electrical power, and audits of the system and its performance. A beehive and colony of bees can be purchased for about 10–15% of the cost of a high-volume air sampler and does not require a source of electrical power. If the bees are owned by a project volunteer, the total costs consist of relatively inexpensive sampling gear, training, and performance checks. The yearly cost to establish an air monitoring station with a high-volume sampler is about $2240.00; the same cost for a project-owned bee colony is roughly $612.00; a beekeeper-owned colony is clearly the cheapest for a year's operation of $190.00. Bees are more costly in terms of liaison time, while high-volumes are more costly for setup and installation.

Because repetitive, routine sampling of bees would probably require paying the people conducting the sampling to ensure that it is done regularly, the day-to-day operational costs of continuous biomonitoring would be about the same as for high-volumes. However, for occasional sampling, the costs of samples taken by unpaid volunteers are substantially less. It should be kept in mind that the two approaches generate somewhat different information. Whereas it is not possible yet to use bees for determining total suspended particulate levels, high-volumes cannot provide an average sample of a several kilometer-square area, nor can they indicate pollutants in nearby water sources or biological effects.

11. Discussion

Participation by private individuals or communities in monitoring their own environment has several potential advantages, including:

(1) Opportunities for personal involvement in assessing environmental quality.

(2) A better informed and educated populace concerning environmental problems.

(3) Cost-effectiveness in terms of reduced expenditures associated with conducting measurements and taking samples.

By employing this approach, it was possible to considerably broaden the practical size of the geographical area and the number of pollutants addressed under limited funding. We hoped that as people became more aware of local pollution problems through environmental monitoring, they might be motivated to pose community solutions.

Wy hypothesized that in the future it might even be possible to shift some of the responsibility for identifying, monitoring, and mitigating these types of problems for regulatory agencies and industry to people living in regions of concern. In other words, communities might begin to take a more active part in dealing with these complex issues, and they might gain a better understanding and appreciation of the difficult nature of these problems.

The greatest disadvantage we met when monitoring with bees was that the validity of our tests largely depended on beekeeper interest and performance. This hindered us primarily in three ways:

(1) Beekeepers sometimes lacked experience to adequately perform the tests.

(2) Gaps in the sampling grid tended to occur in rural areas where fewer beekeepers lived.

(3) Beekeeper interest was harder to sustain in relatively non-polluted areas which were needed for controls.

These problems are resolvable. Usually by the second attempt and with a little additional training, any beekeeper could satisfactorily perform the tests. Gaps in the sampling design could be reduced by a more concentrated effort on our part to locate beekeepers in areas of interest and by moving colonies to points where bees were needed for monitoring. Several beekeepers volunteered to move their colonies for this purpose. Sustaining beekeeper interest presents the most significant difficulty, but it can be influenced by liaison efforts, feedback, and special interests.

At the time of initiation of the Puget Sound study, we had no way of anticipating that Commencement Bay would be listed as one of the ten worst toxic waste sites in the nation by the EPA Superfund program or that EPA would conduct hearings concerning emission of inorganic arsenic in Tacoma with the public being asked to help decide what level of pollution controls will provide 'an ample margin of safety to protect public health (Jacobson, 1983)'.

The degree to which these vested interests influenced participation in the honey bee study is difficult to assess.

Those observers living in areas shown by initial study results to be relatively pollutant free, such as north and south of Seattle, appeared to have less interest in continuing participation in the program. However, the degree of liaison offset this effect somewhat, as later sampling efforts indicated that the number of participants was proportional to the number of personal contacts and program visibility.

For example, during 1983, the project was publicized by at least 16 newspaper articles, six television broadcasts, including a regional one, and at least two radio spots. These appeared to influence public interest and enthusiasm, including support by regulatory agencies and the congressional delegation. A typical comment was one received from the Puget Sound Air Pollution Control Agency (1983): '... citizen interest is becoming noticeable and is spreading to the Seattle area as well as Tacoma and Vashon.'

One of the most encouraging results of the media coverage is that our research will be incorporated into the curriculum of primary and secondary public schools in Washington State. According to an official of the Washington Department of Ecology, the curriculum will include:

- Reading assignments from several newspaper articles written about our project.
- Teaching students about hazardous substances that industry releases into the environment and why we chose bees to monitor them.
- Class discussions concerning who is responsible for controlling hazardous waste and how to control it.
- And guest lectures by local beekeepers who will talk about their involvement in our project and about pesticide poisoning.

The media coverage had one undesirable effect: Some of the beekeepers who participated in our research complained that honey sales slumped after several articles about the project were published. The owners claimed that reports of honey bees accumulating industrial pollutants in or on their bodies caused potential customers to suspect the bees' honey to be contaminated.

Tests conducted by the Seattle-King County Health Department (1983) on honey from bees in the most heavily polluted areas included in our study demonstrated no detectable levels of arsenic or cadmium. Fortunately, the area news services were very cooperative in publishing or broadcasting that the honey was safe for consumption.

This is consistent with studies that have shown that heavy metals levels in honey roughly parallel such levels in bees, but are found in negligible quantitities (Wallwork-Barber, 1982).

12. Conclusions

Network monitoring employing honey bees and a volunteer task force is feasible and can be cost effective. Successful application of the approach requires close liaison with volunteers and feedback. It appears that for longterm application, vested interests may be a primary motivation for continuance. Potentially, one of the major benefits, in addition to providing a means of following pollution distribution and identifying emergent environmental problems, may be the stimulation of community awareness and the sense of accomplishment of volunteers in actively taking part in evaluating the quality of their own surroundings.

Further research is necessary to determine the degree to which volunteer beekeepers can successfully use bees as biomonitors in other settings and situations. Results to date are encouraging and surpassed our expectations.

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