Pollution Monitoring of Puget Sound with Honey Bees

Abstract. *To show that honey bees are effective biological monitors of environmental contaminants over large geographic areas, beekeepers of Puget Sound, Washington, collected pollen and bees for chemical analysis. From these data, kriging maps of arsenic, cadmium, and fluoride were generated. Results, based on actual concentrations of contaminants in bee tissues, show that the greatest concentrations of contaminants occur close to Commencement Bay and that honey bees are effective as large-scale monitors.*

Honey bees have been used as monitors of a variety of environmental contaminants, including trace elements, low-level radioactivity, and pesticides (*1*). However, most work has emphasized deleterious impacts to bees rather than the use of bees as chemical monitors. An averaged sample of pollutants can be obtained from an area of more than 7 km^2 with honey bees (*1, 2*). Because bees have low tolerance to many toxic chemicals (*3*), they provide a potentially sensitive indication of pollutant-induced harm. Pollination services and bee products such as wax, pollen, and honey can be affected by environmental contamination. Bees are thus a rather unusual biological monitor since they are of considerable economic value. In 1981, U.S. bees provided $124.6 million worth of honey and wax (*4*) while pollinating $8 billion to $40 billion of crops (*5*).

Pollutants may reach honey bee colonies by several routes. Contamination of the body, mouth parts, and spiracles during flight is possible, and bees may mistake dust for pollen (*6*). Our observations indicate that some particulate pollutants may become intermixed with pollen grains, since particles can readily be seen with a light microscope (*7*). Electrostatic charges on the surface of the bee body may contribute to the insect's ability to gather pollen (*8*). We speculate that this may partially account for the gathering of other small particles.

Nectar and pollen may become contaminated by atmospheric deposition of pollutants onto plants as well as by plant uptake of these substances from soil. Uptake dynamics from food have been studied with radiotracers (*9, 10*). Feeding tests in which a uranium tracer was used resulted in high concentrations in bee tissues, with lower levels in comb, larvae, and honey (*10*). These findings are consistent with field studies, which indicate that levels of trace elements tend to be highest in or on bees and pollen (*1*).

Pollutants, which are likely to be encountered either in a gaseous form or a water-soluble form, such as fluoride, appear to be taken up by both the hard external and soft internal body tissues by ingestion, inhalation, or absorption (*11, 12*). Regardless of pollutant form, colonies may become contaminated not only through foraging activities but also by forced-air circulation and evaporative cooling employed by bees to control hive temperature and humidity. Contaminant levels in the environment may be reflected in the bees themselves or in hive components, including wax, pollen, and honey (*1*).

How best to use the potential of bees as environmental pollution monitors on a large geographic scale has been the subject of considerable debate. The several million existing bee colonies in the United States provide an in-place and accessible monitoring network from which beekeepers can take samples (*13*). We implemented this concept in 1982 in the Puget Sound region of Washington where a large number of beekeepers keep bees in rural and urban locations.

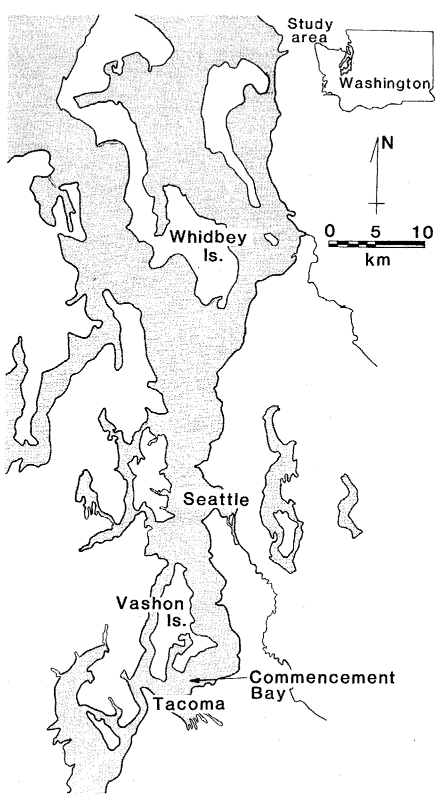

Fig. 1. Location map showing Puget Sound study area.

The region, although large, is clearly bounded by the Pacific Ocean and the Cascade Mountains. Over 130 pollutant sources are routinely monitored by regulatory agencies (*14*). These sources include smelters, chemical plants, and other large industries, but the actual distribution and extent of emissions has never been adequately established.

From July through mid-September 1982, 64 beekeepers collected samples and performed measurements at 72 sites over approximately 7500 km^2 (Fig. 1). Each volunteer was asked to (i) establish at least one sampling site, (ii) measure the percentage of brood survival, (iii) collect forager bees, and (iv) trap pollen. The methods employed were developed and tested during a study of a lead smelting complex in Montana (*15*).

For the brood-survival test, dressmaker pins were used to mark six rows of 20 cells on a brood comb, and two independent determinations were made. An initial record was made of eggs and young larvae, and a follow-up scoring of cell contents by developmental stage was performed 13 to 17 days later. Observations were scored on a standardized data sheet and later processed by a computer program that we had developed (*15*). Pollen was trapped at the hive entrance through a tube of polyvinyl chloride (PVC) with a grid of 5-mm holes (*15*). As bees passed through the holes, pollen was scrapped off the legs into the tube. Pollen traps were left on hives for 6 to 10 hours. Blocking the hive entrance with a strip of fiber glass screening allowed collection of bees returning to the hive. These bees were aspirated into a polyethylene sample bag with a PVC and acrylic aspirator attached to a 12-volt vacuum (*15*). Pollen traps and nozzles were washed with acid before use. Bee and pollen samples were placed into Whirl-Pac bags and frozen.

Samples, in acid-washed beakers, were covered with a clean watch glass and dried in a forced-air oven at 45°C. For fluoride measurement, samples were dry-ashed at 600°C and analyzed by an Orion 601 ion specific electrode (*16*). For arsenic and heavy metal measurements, samples were dissolved in Instra-analyzed nitric acid in a sealed-tube pressured system for 3 hours at 175°C (*17*). Analyses were performed with a Varian AA 275BD and an Instrumentation Laboratories IL 251 atomic absorption spectrophotometer, the former equipped with a model 65 vapor generator for the introduction of arsenic as arsine and the latter with a model 555 flameless atomizer, which was used for some of the cadmium analyses. Vapor generation, flameless atomization, and flame aspiration were done as described (*18, 19*). Performance was monitored by standard additions and National Bureau of Standards reference materials (SRM orchard leaves 1571 and SRM bovine liver 1577), as well as our own standard bee tissue.

Kriging (*20–22*), a weighted moving average technique in which point estimates or block averages can be calculated over a specified grid, was used to map the distribution of pollutants. The derivation of the kriging weights takes into account the proximity of the observations to the point or area of interest, the "structure" of the observations (that is, the relation of the squared difference between pairs of observations and the intervening distance between them), and any systematic trend or drift in the observations. Kriging also provides a variance estimate for constructing a confidence interval for the kriging estimate. From the grid of estimates, contour maps can be obtained. From the confidence intervals for the kriging estimates, confidence bands for individual isopleths can be obtained. For the analysis natural logarithms were used.

Over 64 percent of the colonies tested displayed low brood viability; 40 percent sustained a 75 percent or greater loss of eggs and larvae. At some locations, colonies lost 97 to 100 of the brood.

Kriging maps of arsenic (Fig. 2A), fluoride (Fig. 2E), and cadmium (Fig. 2D), based on actual concentrations from bee tissues, display distinct distributional patterns. Fig. 2B illustrates the 5 parts per million (ppm) arsenic confidence band, and Fig. 2C presents kriging standard deviations. The highest arsenic concentrations occur northwest of Tacoma and apparently are rather smoothly disbursed by atmospheric forces, at least to the Lake Sammamish Plateau. In contrast, cadmium seems to follow a similar pattern but for a much shorter distance, and fluoride appears to be concentrated east of Tacoma. Measured levels of arsenic and fluoride for bees near Commencement Bay were as high as 12.5 and 182 ppm, respectively, whereas bees from Whidbey Island generally contained less than 0.5 ppm arsenic and 4 ppm fluoride.

Arsenic, cadmium, lead, zinc, copper, and fluoride concentrations in pollen were of little use for mapping, both because too few pollen samples were received and because no patterns could be identified. Copper, zinc, and lead concentrations in or on bees showed no patterns related to pollutant distribution. However, high lead values tended to be associated with highways, and individual pollen samples displayed values for heavy metals comparable to those for bees.

Arsenic and fluoride concentrations in bees near Commencement Bay were higher than any we have previously observed [that is, 8.2 ppm arsenic (*23*) and 123 ppm fluoride (*12*)]. Our kriging maps of arsenic and cadmium in bee tissues show patterns similar to isopleth maps developed by regulatory agencies (based on measured soil concentrations) and to deposition isopleths produced by the industrial source complex long-term model

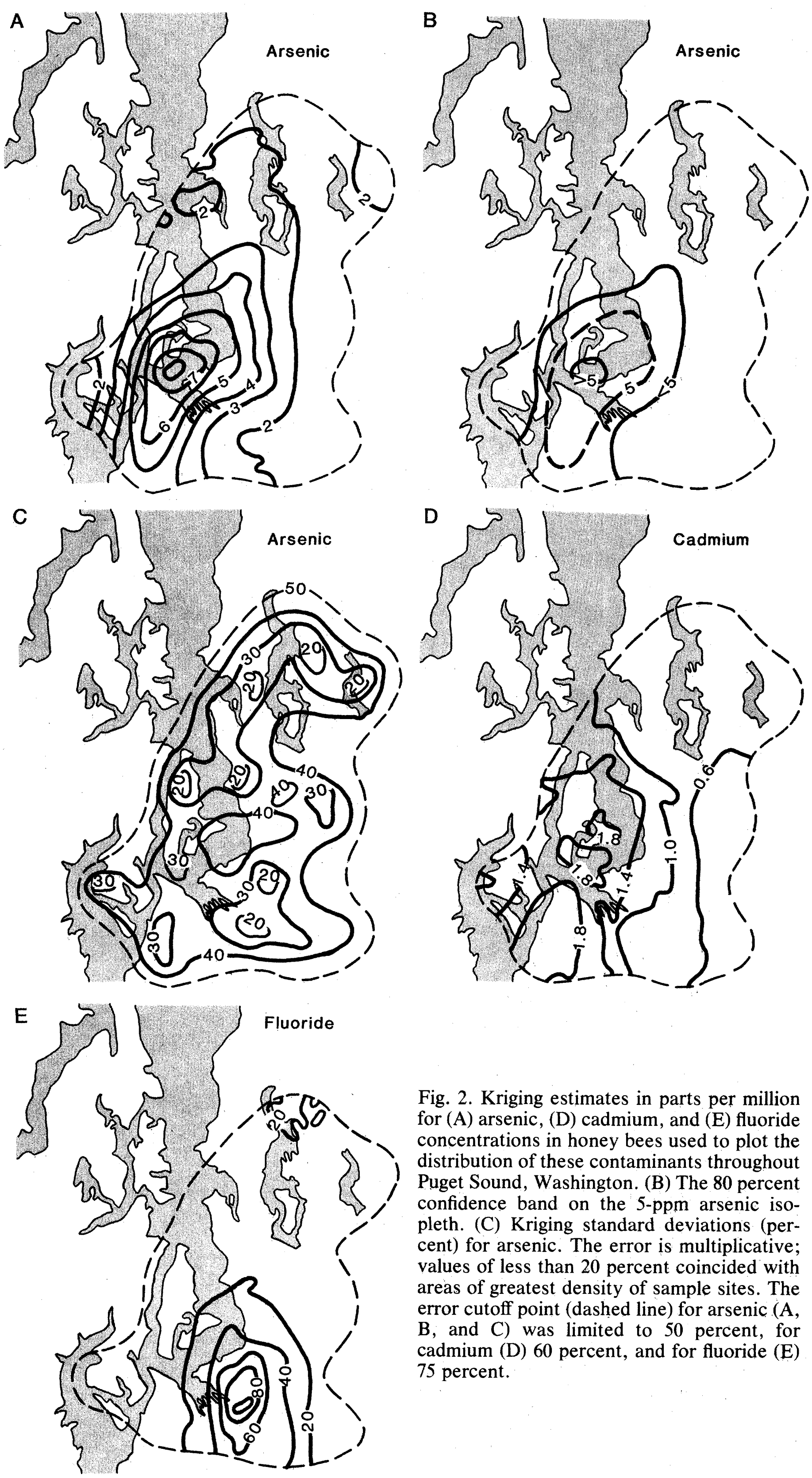

Fig. 2. Kriging estimates in parts per million for (A) arsenic, (D) cadmium, and (E) fluoride concentrations in honey bees used to plot the distribution of these contaminants throughout Puget Sound, Washington. (B) The 80 percent confidence band on the 5-ppm arsenic isopleth. (C) Kriging standard deviations (percent) for arsenic. The error is multiplicative; values of less than 20 percent coincided with areas of greatest density of sample sites. The error cutoff point (dashed line) for arsenic (A, B, and C) was limited to 50 percent, for cadmium (D) 60 percent, and for fluoride (E) 75 percent.

(*24*). However, these other maps describe an area circumscribed by our 5 and 6 ppm arsenic isopleth (soil map) and our 3 and 4 ppm isopleth (dispersion model). Thus, our maps cover a more extensive area. Further, our map (Fig. 2A) suggests long-range transport of arsenic from Commencement Bay to the Lake Sammamish Plateau. This observation may explain reports of somewhat elevated arsenic levels occasionally observed at distant monitoring stations (*24*).

There were no statistical differences for arsenic or fluoride for bees collected during July or September at similar sites. However, limited data were available so that the power of the test was low. The same result was obtained in a follow-up experiment conducted in 1983. Bees sampled weekly for 10 weeks at two sites near Commencement Bay displayed temporal coefficients of variation of about 20 percent.

Kriging errors for arsenic (Fig. 2C) show that estimated error is related to data density (that is, the number of sites sampled in a given area). Error was relatively small in the urban areas of Seattle and near Tacoma where many beekeepers obtained samples. In contrast, errors were larger in the rural areas, where sample locations were more scattered. Largest errors occurred at the perimeter of the study area and in those places where a section of the kriging grid encompassed a large mass of water. Kriging error is not synonymous with a standard deviation determined from replicate hives at a single location. Results from our studies indicate that coefficients of variation of about 20 percent with a range of 1.7 to 43 percent can be expected, depending on time of year, proximity to source, and other factors.

The predicted fluoride concentration map (Fig. 2E) suggests a different source and dispersion mechanism. On the basis of our studies in Montana (*12*), we predicted that fluoride concentrations in nearby vegetation would also be proportionately high. Data provided by the Washington State Department of Ecology show that levels in grasses near the tide flats area of Commencement Bay contained up to 100 ppm (*25*), whereas background levels for grass should be about 1 to 6 ppm (*26*). In much of the area of high concentrations of arsenic and cadmium in bees, levels are also so high in vegetables that the Pierce County Department of Health has advised against consumption (*27*).

Our results show that beekeepers can effectively use colonies of bees as a self-sustained system for environmental monitoring over large geographical areas. Honey bees provide a spatially integrated sample of all three (gas, liquid, and particulate) modes in which pollutants may be transported. Moreover, our experience indicates that this monitoring system is less expensive than, for example, high volume air samplers that only monitor particulate pollutants. To determine how bee colonies can most effectively contribute to monitoring needs, especially in terms of integrating the information obtained with decision-making and regulatory processes, will require better understanding of the extent and limitations to which colonies of bees can be used in other places and for other pollutants.

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Nigerian Geophagical Clay: A Traditional Antidiarrheal Pharmaceutical

Abstract. *The chief geophagical clay entering the West African market system comes from the village of Uzalla, Nigeria. Village inhabitants ascribe antidiarrheal properties to the clay, and they use it in traditional medicinal preparations to counteract intestinal problems. Mineralogical analyses demonstrate a striking similarity between the Uzalla village clay and the clay in the commercial pharmaceutical Kaopectate.*

Geophagy, the practice of eating earth, occurs throughout the world (*1*). In tropical West Africa, the practice appears ubiquitous among the various ethnic groups and it occurs most commonly among pregnant women. One geophagical clay that comes from the village of Uzalla, Nigeria, is widely sold in the markets of West Africa. Although considerable investigation has been devoted to nutritional questions and medical implications of geophagy (*2, 3*), we are unable to find studies of the pharmaceutical properties of geophagical clays. Our mineralogical analyses of the Uzalla clays indicate a kaolinitic composition strikingly similar to that of the clays in the pharmaceutical Kaopectate.