SURVEY METHODOLOGY IN AN ENVIRONMENTAL EXPOSURE STUDY: METHODS TO ASSURE SOUND INFERENCE

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Introduction

The University of Michigan Dioxin Exposure Study (UMDES) carefully designed and executed methods from the field of survey methodology in order to select a representative sample, develop and test a survey questionnaire, collect interview, blood, soil, and dust data, monitor field data collection, and compute statistically appropriate summary measures from study data. The study design, field and laboratory methods, and study findings are reported elsewhere.[1,2,3,4,5,6] This paper reviews the survey methodologies used to assure a high degree of rigor in the design, collection, and processing of findings from the overall Study.

Materials and Methods

Survey design begins with a succinct and explicit description of the populations to be studied[7] in order to identify suitable sampling frames for sample selection, to specify population inference (as opposed to causal inference), and to identify statistical procedures appropriate for estimation. In the UMDES, the population was defined as persons usually residing in any one of five counties of Michigan who had lived in their current usual residence for at least five years, were 18 years of age or older, and lived in a residence outside the flood plains of the Shiawassee and Saginaw Rivers in Saginaw county.

The sample used a two-stage area probability selection of housing units in the study area, and a third stage of selection of an eligible person within each sample housing unit. The first stage of selection employed stratified cluster sampling methods in which a sample was drawn from a list of all US Census blocks in the study. The list was divided into four groups: 1) blocks in Midland and Saginaw counties which contained any land area in the Federal Emergency Management Administration defined 100 year flood plain of the Tittabawassee River below the Dow Chemical Company facility in Midland, Michigan, and above the mixed flood plains of the Tittabawassee and Shiawassee Rivers; 2) blocks in the area of deposition from emissions stacks at the Dow Chemical Company in Midland, Michigan, as defined by environmental modeling of the plume of the historical emission data; 3) blocks outside of the Tittabawassee flood plain (1 above) or the plume (2 above) and outside the flood plain of the Shiawassee and Saginaw Rivers; and 4) blocks in Jackson and Calhoun counties (control area for the study).

Blocks were systematically selected from a geographically ordered list using probabilities proportionate to the count of occupied housing units obtained from the 2000 Census of Population and Housing. For the sake of study efficiency, small blocks with fewer than 50 occupied housing units were linked together to form ‘segments’ for subsequent sample selection and data collection.

Data collection was in-person and used paper-and-pencil questionnaires, computer assisted questionnaires on laptop computers, and physical measurements (blood draw, soil sample, and dust sample).[1,2,3] Survey questionnaires were developed through a process of writing or adopting questions from other surveys, review by project stakeholders and Science Advisory Board, and pretesting in a small sample of residents in Midland and Saginaw counties. Extensive development was devoted to an 'event history calendar' which provided a framework for collection of data about activities, fish and game consumption, and residency over an interviewed person's entire life.

The sample in Midland and Saginaw counties was divided into replicates such that each replicate represented the study area. The first replicate was contacted in fall 2005 for a first round of data collection. Interviewers were recruited and hired from Midland and Saginaw counties. They were trained in general interviewing techniques, the specific study protocol and questionnaire, and refusal aversion techniques. Study staff monitored daily data collection progress, and high response rates were achieved. Sample households were visited by interviewers multiple times, if necessary, to obtain cooperation. Interviewers also offered a financial incentive totaling $100 if the person participated in the interview and the blood, soil, and dust sampling.

Each household was screened to determine whether eligible persons lived in the household. If one or more eligible persons lived in the household, one was chosen at random and interviewed. If the respondent was eligible for blood, s/he was asked to provide a blood sample collected through an in-home visit from a phlebotomist from a local health care facility. If the respondent owned the housing unit, s/he was asked to permit soil samples to be gathered from around the housing unit (excluding apartments and condominiums). Soil samples were collected by trained teams around the housing unit (perimeter samples), from contact zones (e.g., gardens), and from an area in the flood plain (if the housing unit was located on a property in the flood plain of the Tittabawassee River – group 1 above). Most housing units owned by the chosen person only had soil samples from the perimeter and contact zones. Finally, if housing unit was a single family home or condominium, the respondent was asked for permission to collect dust from a living area in the home. Environmental dust sampling teams visited all such households and vacuumed dust samples from the floor surface (typically a rug) of a living area in the home.

In spring 2006 the second replicate in Midland and Saginaw counties and the entire sample in Jackson and Calhoun (the control) counties was released. Between the fall and spring data collection, the survey interview was converted from paper-and-pencil format to computer-assisted format (CAPI) on laptop computers. All survey components, including the 'event history calendar' were converted to CAPI. In addition, households and persons failing to respond to interview requests were recontacted, and cooperators were administered a shorter questionnaire with the same incentive to determine whether substantial differences exist between respondents to the full survey and those who refused or could not be interviewed in the fall data collection.[8] Fall interviewers from Midland and Saginaw counties were supplemented by additional interviewers from Midland and Saginaw counties and by new interviewers hired and trained locally in Jackson and Calhoun counties. The spring data collection also achieved higher than expected response rates to the interview and the blood, dust, and soil collection. The spring data collection was followed by additional non-response interviewing with a shorted questionnaire.

Results

A commonly used indicator of survey quality is the response rate, the proportion of eligible persons for whom complete data were obtained. Survey response in the present study must be measured at several different stages: interviewing and blood, dust, and soil collection. Table 1 shows cooperation rates (proportion of known eligible persons who provided data) at each stage, as well as final interview response rates (proportion of known eligible persons providing data, adjusted for estimated number of eligible among those with unknown eligibility) computed following guidelines from the American Association for Public Opinion Research.[9]

Cooperation rates were substantially higher than anticipated, falling slightly in areas where the issues of dioxin contamination were less salient (i.e., the non-flood plain and the control areas). The overall interview response rate

is lower than the cooperation rate because the response rate incorporates estimates of eligible persons in households that were not successfully screened.

Table 1. Cooperation rates for interview, blood, dust, and soil sampling and final interview response rate, by study area, University of Michigan Dioxin Exposure Study, 2005-2006.

Study area	Cooperation rate				Interview response rate
	Interview	Blood	Dust	Soil	
Flood plain	83.7%	83.9%	91.0%	91.3%	--
Non-flood plain	82.4%	73.7%	90.9%	93.2%	--
Control (Jackson & Calhoun counties)	82.2%	78.4%	93.8%	91.9%	--
Total	82.9%	79.6%	91.7%	92.0%	74.3%

Surveys often make adjustments to compensate for unit missing values, such as occurred in the UMDES. The adjustments are often incorporated into a 'weight' variable used in all subsequent analyses. In the UMDES, weights were developed first to compensate for unequal probabilities of selection (to correct for over-representing flood plain residences under-representing persons living alone, for example). Then, through a series of logistic regression models, the probability that a household responded to the screening request, or that a selected eligible individual responded to the interview, gave blood (if eligible), allowed a dust sample (if eligible), or allowed a soil sample (if eligible) was estimated. These models produced predicted probabilities of cooperation. The inverse of these predicted probabilities for respondents at each stage were then used as non-response adjustment factors and multiplied times the unequal probability of selection weight for each person. Some of these adjusted weights were much larger than the other weight values. Extremely large values were 'trimmed' or reduced to a smaller value because the weighted value could be overly influential in an estimate.

These weights were then used in all analyses to compute weighted estimates that would be sound estimates for the population from which the sample was drawn.[10] For example, for the TEQ blood value in parts per trillion for the i*th* person, say y_i, and non-response adjusted weight w_i, the weighted mean TEQ value was computed as $\bar{y}_w = \sum_{i=1}^{n} w_i y_i \Big/ \sum_{i=1}^{n} w_i$. The same 'global' weight was used for all analyses.

In addition to the unit non-response adjustment, a further adjustment was made to the data to account for item missing values, missing values for a single variable for an individual who otherwise provided data. For example, the most sensitive item asked in the survey was family income. Approximately 10% of the subjects refused or did not know the family income. If the missing values are left in the data set, there are several consequences for most analyses done with these data.

First, for a single variable analysis, sample size is reduced (slightly in most cases) and standard errors of estimates increased. For the most part, though, this effect is small and typically can be ignored in an analysis of single variables at a time. Second, there is the potential for bias. Many analysts will 'ignore' the missing values in a variable by using a 'case-wise deletion' of missing data feature in statistical software. In the careful population inference being used for the UMDES, 'ignoring' the missing values effectively imputes or assigns the mean of the cases without missing values to the value for each case for which the value is missing. This imputation is based on a strong 'missing completely at random' assumption.[11] Many population based surveys will instead replace the missing value with a predicted value, predicted using other data for the case that had been collected. If there are correlates of the variable with missing values in the data set, a reasonably good prediction might be achieved through a procedure such as linear regression. If the predicted value replaces, or is imputed to, the missing value, the imputation is based on a weaker assumption. In many survey variables, such imputations will produce estimates

that have smaller bias than the estimates produced under case-wise deletion of missing values. Third, in multivariable analyses, case-wise deletion will remove more cases because item missing values are often additive across cases. More substantial losses in sample size occur, and standard errors increase.

For these reasons, the item missing values in the survey questionnaire and the blood, dust, and soil samples, were imputed. There are many different imputation techniques used in surveys.[10] A sequential regression imputation procedure[12] was used to replace item missing values in the UMDES data, and imputed values were used in estimating various statistics from the survey.

Discussion

The UMDES used a carefully designed sample survey as the basis for selecting and interviewing subjects for an environmental exposure study. Population based sample surveys imply inference to the population from which the sample was selected. Surveys employ a number of techniques to provide accurate estimates for the population. The UMDES used many survey design and estimation techniques. Geographic subgroups were deliberately over- and under-represented in the sample. Data collection employed computer assisted methods, extensive training of interviewers and blood, soil, and dust samplers. The sample was selected in multiple stages using known non-zero chances of selection of households and persons within households. Sampling weights were developed to compensate for unequal probabilities of selection and unit non-response. And item missing values were replaced by predicted or imputed values to improve the accuracy of survey estimates.

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