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Concentrations of Organochlorine Pesticides and PCBs in Nestling Bald Eagle Plasma from Michigan, 1999-2003, and Relations to Productivity at Multiple Geographic Scales

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INTRODUCTION

The bald eagle (*Haliaeetus leucocephalus*) is a tertiary predator of the Great Lakes Basin aquatic food web. Due to its position at the top of the food chain, the bald eagle is susceptible to accumulation and biomagnification of a wide array of xenobiotics, including mercury and organochlorine compounds. The bald eagle is recognized as a biological indicator of exposure of piscivorous wildlife to toxic organochlorine compounds and as a monitor of the effects of contaminants that bioaccumulate and biomagnify in the Great Lakes (IJC 1994, SOLEC 1998, 2000).

The Michigan Department of Environmental Quality (MDEQ) began monitoring persistent and toxic contaminants in bald eagles and herring gulls in 1999 and 2002, respectively. These studies are part of the wildlife contaminant monitoring component of the MDEQ's Monitoring Strategy (MDEQ 1997). The 1998 passage of the Clean Michigan Initiative-Clean Water Fund (CMI-CWF) bond proposal resulted in a substantial increase in annual funding for statewide surface water quality monitoring. Some of these funds have been used to monitor contaminants in these two wildlife species.

The compounds measured in bald eagles include polychlorinated biphenyls (PCBs), organochlorine pesticides (OCs), and mercury (Hg). The state has been divided into major "watershed years" with 20% of Michigan's watersheds being sampled each year (Figure 1). During annual banding activities, blood and feather samples from nestling bald eagles are collected within these designated watersheds. This sampling procedure allows for the entire state to be sampled every five years. Concentrations of total PCBs, dichlorodiphenyltrichloroethane (total DDT), 1,1-dichloro-2,2-bis(p-chlorophenyl)-ethylene (p,p'-DDE), and other organochlorine pesticides have been measured in nestling plasma from the first five watershed years (Roe 2001, Summer et al. 2002, Roe et al. 2003b, Roe et al. 2004a,b).

The monitoring program allows for the assessment of contaminants in bald eagles at five geographic scales: entire state; nest category; sub-population (Bowerman et al. 1994, 2003, Roe 2001); Great Lakes watershed; and, individual watershed. The three categories in Michigan were defined as inland (IN), Great Lake (GL), and anadromous (AN) nests. The IN location nests were greater than 8.0 km from the shorelines of the Great Lakes and were not along tributaries open to Great Lakes fish runs. Great Lakes nests were within 8 km of the Great Lakes, while AN nests were along tributaries open to Great Lakes fish runs. Category 1 comparisons included GLAN (GL plus AN) and IN nests, whereas, Category 2 comparisons included GL, IN, and AN.

The six sub-populations in Michigan were the inland Upper Peninsula (UP), inland Lower Peninsula (LP), Lake Superior (LS), Lake Michigan (LM), Lake Huron (LH), and Lake Erie (LE). The inland sub-population nests were greater than 8.0 km from the shorelines of the Great Lakes and were not along tributaries open to Great Lakes fish runs. The remaining sub-population nests, LS, LM, LH, and LE, were within 8.0 km of the shorelines of the Great Lakes and/or were along tributaries open to Great Lakes fish runs (Bowerman et al. 1994, Roe 2001, Bowerman et al. 2003).

The watershed designation was delineated into two levels, Great Lakes watersheds and individual watersheds. The Great Lakes watershed designations were defined by which water body (Lake Superior, Lake Michigan, Lake Huron, or Lake Erie) the surrounding land drained into by way of streams and rivers (Roe 2004). The Great Lakes watersheds, except for Lake Erie, were further delineated into IN and GL based upon whether the nests were greater than or less than 8.0 km from the shoreline of the Great Lakes. The Lake Michigan watershed IN designation was the only Great Lakes watershed where the IN designation was further refined based on whether the nests were located in the Upper Peninsula (LM-IN-UP) or in the Lower Peninsula (LM-IN-LP) of Michigan. Inland Lake Michigan nest sites were divided into LM-IN-UP and LM-IN-LP due to the large geographic area the water body covers. Lake Erie was only considered at the GL level because sample collection only occurred from Lake Erie nests sites. The second watershed designation, Hydrologic Unit Code (HUC), pertained to the individual watersheds differentiated by the US Geological Survey (USGS) watershed name and eight-digit HUC number, that were within the larger Great Lakes drainage watersheds.

The five-year watershed monitoring cycle allows for a portion of the watersheds within the state of Michigan to be sampled every year. A complete cycle of five years of sampling data (1999 – 2003) should be representative of the concentrations of contaminants and of productivity and success rates for the entire state. This comprehensive data set is useful for making human health and wildlife management recommendations and decisions. The 2004 field sampling season represented the beginning of the second five-year watershed monitoring cycle. Therefore, an evaluation of the first five-year cycle of the monitoring program presents the MDEQ with information on the ability of the Michigan bald eagle biosentinel monitoring program to meet MDEQ's goals (MDEQ 1997). We used concentrations of organochlorine pesticides and total PCBs in 489 plasma samples, collected from 1999 – 2003, to evaluate the watershed cycle monitoring program.

The overall goal of this study was to evaluate the ability of the bald eagle biosentinel sampling method to detect trends in contaminants in Michigan after completing the first five year (1999 – 2003) watershed monitoring cycle. Specifically, the objectives were to: 1) determine whether the same patterns in sub-population concentrations of total PCBs and p,p'-DDE observed in 1987-1992 (Bowerman et al. 2003) are still evident; 2) determine if a correlation exists between the success and productivity rates of bald eagles and concentrations of total PCBs or p,p'-DDE in the nestling blood plasma; 3) determine the precision (i.e. the sample sizes required to estimate mean contaminant concentrations with a margin of error of $\pm$ 5, 10, or 20 ppb, from the true mean, for Michigan at the following five geographic scales: entire state, category, sub-populations, Great Lakes watersheds, and HUCs); and, 4) determine the mean power (i.e. the sample size necessary to detect differences in concentrations of total PCBs and total DDT, with a power (β) of 0.8 and 0.9), at four geographic scales: category, sub-populations, Great Lakes watersheds, and HUCs); 5) determine the trend power (i.e. the sample size needed to detect trends of ± 5 and 10%, per year, for the contaminant concentrations over time (5 and 10 years) for the five geographic scales, at a power (β) of 0.8 and 0.9; and, 6) determine, at the individual watershed geographic sampling scale, if HUCs with few eagle breeding areas that fail to meet the objectives for trend analysis can be combined with adjacent HUCs without compromising the ability to detect trends in contaminants over time.

METHODS

Nestling bald eagles were sampled from the Upper and Lower Peninsulas of Michigan and from the surrounding Michigan Islands. Blood was collected during normal banding activities from mid-May through early June from 1999 - 2003. Nestlings were between 5 and 10 weeks of age. Aseptic techniques were used to collect 10 - 13 cc of blood from the brachial vein with heparinized syringes fitted with 22 or 25 gauge needles. Morphometric measurements were used at this time to determine sex and age of the nestlings (Bortolotti 1984a, b). A total of 489 nestling eagles were sampled and analyzed from 1999 to 2003. Samples of whole blood were transferred to heparinized vacuum tubes, stored on ice in coolers, and centrifuged within 48 hours of collection. Blood plasma was decanted, transferred to new heparinized vacuum tubes, sealed, and then frozen. All samples were shipped and stored at the U.S. Fish and Wildlife Service East Lansing Field Office until analysis at Clemson University (Roe 2001).

Analytical Methods

Plasma samples were extracted following Clemson Institute of Environmental Toxicology Standard Operating Procedure (SOP) 401-78-01. Extraction methods transfer the compounds of interest from a lipid-protein matrix to another solvent, such as hexane, which is more suitable for analysis. Briefly, one milliliter of plasma was denatured, extracted, and purified using alumina and silica solid phase extraction. Appropriate quality control samples were analyzed concurrently to ensure that the extraction methods were valid. Internal gas chromatography standards were added to each sample to ensure proper detection by the gas chromatograph. The sample extracts were analyzed by gas chromatography with electron-capture detection (GC-ECD) with a reportable detection limit of 2 ng/L (Roe 2001). A 30 m x 0.25 mm-inner diameter x 0.25 mm film thick DB-5 fused silica capillary column was used for the analyses.

Statistical Methods

All statistical analyses were performed using SAS (SAS version 9.1, 9.2; SAS Institute 1999). The Type I error, α, was set at 0.05 for all analyses. Analyses were conducted using non-parametric methods due to the non-normal nature of the underlying distributions. The use of non-parametric analysis also provided consistency with previous years' analyses allowing for longitudinal comparisons of OCC concentrations within and among geographic scales. Geometric means and standard deviations at all geographic scales were calculated using log transformed data, then back transformed. Since detection limits for analytical chemistry had improved between the two time periods, the latter data (1999-2003) were analyzed using the method of Bowerman et al. (2003) for comparison between the two time periods. Contaminant concentrations for the 1999-2003 data that were below the detection limits reported by Bowerman et al. (2003) for total PCBs (10 ppb) and p,p'-DDE (5 ppb) were set at one half the detection limit, 5 and 2.5 ppb, respectively, for total PCBs and p,p'-DDE.

Kruskal-Wallis and Wilcoxon equivalent tests were conducted using rank-converted ANOVAs and Fisher's LSD and Tukeys post-hoc comparisons (Conover, 1980). The more liberal Fisher's LSD was used for tests of the first four geographic scales because, while it only controls pair-wise error rate, it retains more power. At the final geographic scale, HUC, the more conservative Tukeys test was used. This test was chosen because there were 45 levels at the HUC scale and it restricts experiment-wise error rate to protect against the problems of highly inflated alpha values associated with large numbers of comparisons.

Reproductive productivity and reproductive success rates for all occupied breeding areas were assessed on three scales: 1) category 1; 2) category 2; and 3) sub-population. Productivity was determined using a period of five years by taking the total number of fledged young per occupied nest for each nest for the period from 1999-2003 (Wiemeyer et al. 1993). Success rates – the proportion of occupied breeding areas successfully producing at least one fledged young – were calculated for the years within the five-year span that the breeding area was occupied (Wiemeyer et al. 1993). General linear regression analysis (SAS Institute Inc. 1999) was conducted to look for relationships between the geometric mean concentrations of total PCBs and p,p'-DDE in blood plasma from 1999-2003 and five-year annual productivities and success rates at the three different scales. If total PCB and p,p'-DDE data within a territory spanned more than one year, the average of the concentration data was taken for that territory.

Analysis of sample sizes necessary to determine trends and precision were analyzed differently. Consistent with the reporting format of the MDEQ, total PCBs and total DDT concentrations utilized in the sample size analyses and concentrations less than the method detection limits were reported as non-detects and were set at zero (Roe et al. 2004a, b). Concentrations of p,p'-DDE comprised greater than 90% of the total DDT concentrations. For this reason, p,p'-DDE concentrations are reported below. When results differ, both p,p'-DDE and DDT will be reported.

Sample size analysis was performed, on a natural log scale, for three possible methods of analyses for these data: 1) confidence intervals for mean contaminant concentrations in each geographic scale; 2) analysis of variance (ANOVA) for detecting differences in mean contaminant concentrations among the geographic scales; and, 3) regression analysis for detecting trends in contaminant concentrations over time within the geographic scales. Confidence interval sample size analyses (Zar 1999) considered margins of error of $\pm$ 5, 10, or 20 ppb for the confidence intervals. ANOVA sample size analyses (O'Brien 1986) considered power of 0.8 and 0.9 and used the existing contaminant data differences in the geographic scales. Sample size analyses for regression (Dupont and Plummer 1998) were conducted with slopes of 0.05 and 0.10, power of 0.8 and 0.9, and time spans of 5 and 10 years.

RESULTS

Geographic Scale and Time Period Comparisons

Significant differences were found for PCBs, DDT, and p,p'-DDE at all geographic scales (P<0.001). Post-hoc analysis also showed significant differences at all levels of comparison (Tables 3-8). PCBs, DDT, and p,p'-DDE geometric mean concentrations for breeding areas in Category 1 in declining order were AN > GL >IN (Tables 3 - 5). PCBs, DDT, and p,p'-DDE geometric mean concentrations for breeding areas in Category 2 were greater for GLAN (GL and AN combined) than IN (Tables 3-5).

Tables 3, 4, and 5 provide geometric means and post-hoc comparison at the sub-populations and Great Lakes Watershed geographic scales. Concentrations of total PCBs and p,p'-DDE in plasma of nestling bald eagles declined for most sub-populations in Michigan between 1987-1992 (Bowerman et al. 2003) and 1999-2003. Between 1987-1992 and 1999-2003, total PCB concentrations significantly decreased in all sub-populations (max P=0.0233; Table 1). Concentrations of p,p'-DDE measured from 1999-2003 were significantly less than those measured from 1987-1992 for LE, LS, UP, and LP sub-populations (max P=0.0037; Table 2). The exceptions to this trend were LM and LH where geometric mean p,p'-DDE concentrations did not show a significant decline from 1987-1992 to 1999-2003 (P=.6916 and P=.1553, respectively; Table 2).

Reproductive Parameter Associations

Geometric mean productivity (Prod1) and success rate (Suc1) were calculated at three geographic scales. Productivity and success were also calculated as a single overall measure for each level of the three geographic scales (Prod2 and Suc2, respectively). Both of these productivity and success measures for 1999-2003 are shown in Table 9. Overall, the state of Michigan had a Prod1 productivity rate of 1.11, a Suc1 success rate of 67.34, a Prod2 productivity estimate of .94 and a Suc2 success estimate of 60.63. Subsequent delineation by geographic scale showed no significant differences in Prod1 measures of productivity (min P=.3122). Suc1 Success rates also showed no significant differences as a function of geographic scale (min P=.6590).

Few significant correlations were found among geographic scales between productivity and success rates and total PCBs and p,p'-DDE concentrations in blood plasma for 1999-2003 (Table 10). For the state as a whole, there was no correlation between productivity and success rates and either PCBs or p,p'-DDE concentrations in nestling plasma. Similarly, no significant correlations were found at either the geographic scale including GL and IN, or at the geographic scale including GL, IN, and AN. At the sub-population level, significant negative correlations between productivity and success and PCB concentrations were found for LE and LM. Significant positive correlations were found between productivity and success for both PCB and p,p'-DDE concentrations for LH. No correlations existed at the watershed level between productivity and success rates and concentrations of PCBs and p,p'-DDE.

Precision, Mean Power, and Trend Power

The sample sizes for the 1999 – 2003 contaminant data ranged from 37 to 265 for total PCBs and DDT at the category scale (Table 3) and 1 to 39 at the HUC geographic scale (Table 6). The sample sizes required for 95% confidence intervals of the mean contaminant concentrations with margins of error of $\pm$ 5, 10, or 20 ppb at the five geographic scales are listed in Table 11. Generally, the sample sizes required to estimate mean total PCBs were greater than the sample sizes needed to estimate mean total DDT. As the margin of error increased from $\pm$ 5 to 20 ppb (i.e., the precision of the confidence intervals decreased), the sample size required to estimate that margin of error decreased (Table 11). The sample sizes also increased as the geographic scale increased from HUCs to the entire state.

The sampling method was effective at detecting total PCB and DDT concentration differences at the four geographic scales: category ($F_{2, 224} = 118.90$, $P < 0.0001$); sub-populations ($F_{5, 122} = 61.24$, $P < 0.0001$); Great Lakes watersheds ($F_{7, 92} = 45.42$, $P < 0.0001$); and, individual watersheds ($F_{47, 35} = 11.47$, $P < 0.0001$). The sampling method was also effective at detecting total DDT concentration differences at the four geographic scales: category ($F_{2, 224} = 97.38$, $P < 0.0001$); sub-populations ($F_{5, 122} = 52.14$, $P < 0.0001$); Great Lakes watersheds ($F_{7, 92} = 38.60$, $P < 0.0001$); and, individual watersheds ($F_{47, 35} = 6.17$, $P < 0.0001$). The sample sizes necessary, at a power of 0.8 and 0.9, to detect the contaminant concentration differences are listed in Table 12.

The sample sizes needed to detect significant linear regression decreases of $\pm$ 5 and 10% for total PCB and total DDT concentrations over 5 and 10 years, at the five geographic scales are listed in Tables 13 and 14. The sample sizes needed to detect linear changes increased as the standard deviation increased from 0.5 to 2.0 and also increased as power increased from 0.8 to 0.9. Fewer total samples were required to detect changes over ten vs. five years. Smaller sample sizes were also required to detect 10% vs. 5% decreases in contaminant concentrations.

Grouping of adjacent HUCs, due to the lack of eagle breeding areas within those watersheds, was accomplished for 18 HUCs without compromising the ability to detect linear regression decreases in contaminants over time. However, only 18 individual HUCs could be combined due to the criteria that the HUCs must be adjacent. Four HUCs could not be combined due to the lack of adjacent watersheds within that sampling year cycle. The sample sizes, for the combined HUCs, were sufficient to detect linear decreases over ten years for 100% of the HUCs at all ranges of slope, standard deviations, and power, except a slope of 0.5 and a standard deviation of 2.0, where only 50% of the HUCs had sufficient sample sizes to detect linear decreases.

DISCUSSION

Geographic Scale and Time Period Comparisons

The trends of PCBs, DDTs, and p,p'-DDE concentrations at all geographic scales in this report were similar to past reports. Anadromous and Great Lake breeding areas did not significantly differ, but both showed higher concentrations for PCBs, DDTs, and p,p'-DDE than Inland areas. This suggests that even though the Anadromous and Great Lakes areas are separate spatially, the foraging ecology of eagles in these areas is similar.

Comparisons between total PCBs and p,p'-DDE concentrations in plasma of nestling eagles from 1987-1992 (Bowerman et al. 2003) and 1999-2003 indicate that in general, concentrations of these contaminants have declined in Michigan. Not all comparisons between the time periods were statistically significant, although a decreasing trend was present. A significant decline was not observed for p,p'-DDE in Lake Michigan or Lake Huron sub-populations.

The lack of a decline in p,p'-DDE concentrations for the LM sub-population may be due to the previous heavy use of pesticides on agricultural crops in the area, and the extreme persistence of p,p'-DDE in the environment. The western portion of the Lower Peninsula of Michigan, along Lake Michigan, is known for its heavy agricultural uses such as wineries, apple orchards, and cherry farms and has been termed "the fruit belt of Michigan" (US EPA 2000a). Before DDT was banned in the US, it was used heavily on many agricultural crops as an insecticide (Dunlap 1980). The heavy use of DDT in the Lake Michigan portion of the Lower Peninsula of Michigan, and DDT's environmentally persistent metabolite, p,p'-DDE (Harris et al. 2000), may be the reason why there was no decline in concentrations of p,p'-DDE between 1987-1992 (Bowerman et al. 2003) and 1999-2003.

While PCB concentrations declined significantly between the time periods for all sub-populations, the Lake Erie sub-population exhibited highest current levels and the least decline. Existing Lake Erie PCB contamination probably contributes to the overall higher LE eagle PCB concentrations. Eagles nesting along the Michigan shorelines of Lake Erie are exposed to higher concentrations of PCBs in their prey, mainly due to environmental cycling of earlier industrial point source contamination. High concentrations of PCBs in fish and wildlife inhabiting Lake Erie have resulted in consumption advisories for fish and wildlife species due to PCB contamination (US EPA 2002). These consumption advisories for Lake Erie have lead to the listing of PCBs as a "critical pollutant" within Lake Erie. Sediment PCB concentrations within the Lake Erie Basin are significantly greater along the western portion of Lake Erie in Michigan and Ohio compared to the eastern portion of Lake Erie in Pennsylvania and New York (US EPA 2002).

Organochlorine contaminants in plasma of nestling bald eagles from the Great Lakes have previously been documented (Dykstra et al. 1998, Donaldson et al. 1999, Dykstra et al. 2001, Bowerman et al. 2003). The contaminant concentrations in plasma from nestling bald eagles along the Canadian portion of Lake Erie (Donaldson et al. 1999) were higher than those reported in this study. The geometric mean of total PCB and p,p'-DDE plasma concentrations from the Canadian portion of Lake Erie were reported at 129.5 ppb and 22.4 ppb, respectively. These concentrations are similar to the geometric mean total PCB and p,p'-DDE plasma concentrations measured in nestling eagles from the U.S. portion of Lake Erie, during the same time period (Bowerman et al. 2003). Geometric mean p,p'-DDE nestling concentrations from the Michigan shores of Lake Superior (Dykstra et al. 1998), collected from the late 1980s to early 1990s (109 ppb) were also higher than LS sub-population p,p'-DDE concentrations reported in this study for the time period of 1999 - 2003 (11 ppb) and for the time period of 1987 - 1992 (Bowerman et al. 2003). Geometric mean nestling plasma concentrations of 207 ppb total PCBs and 53 ppb p,p'-DDE from the Wisconsin shores of Lake Michigan (Dykstra et al. 2001), collected from 1987-1995, were higher than the concentrations of 154 ppb total PCB and 35 ppb p,p'-DDE concentrations measured from the nestling eagles along the Michigan shores of Lake Michigan, during the same time period (Bowerman et al. 2003). The decrease in contaminant concentrations from studies conducted in the early 1990s to the levels found in our study is most likely due to decreases in the input of contaminants to the Great Lakes ecosystem.

Nestling bald eagle contaminant concentrations are representative of contaminant concentrations in the top predators within Michigan and the Great Lakes Basin ecosystem as a whole. Nestling eagles in Michigan receive their prey and therefore their contaminant load from within the adults' local territory. The Great Lakes Basin was heavily impacted by organochlorine contamination, from the early 1940s through the late 1970s, primarily from industrial and agricultural uses (Dolan et al. 1993, Office of the Great Lakes 2000, US EPA 2000b). Now atmospheric transport and cycling, sediment sequestration and recycling, and biota inputs account for a large portion of the contaminant sources in the Great Lakes ecosystem (Hesselberg and Gannon 1995, Harris et al. 2000, Office of the Great Lakes 2000, US EPA 2000b).

Reproductive Parameter Associations

Evaluation of the concentrations of PCBs and p,p'-DDE in the plasma of nestling eagles from 1987-1992 (Bowerman 1993) and 1999-2003 indicate that these compounds have declined between the two time periods in the Great Lakes Basin. This suggests that concentrations of organochlorine contaminants in the aquatic food webs of Michigan have declined. Unlike for the years 1987-1992 (Bowerman 1993), the years 1999-2003 no longer indicate an overall negative correlation between the rates of success and productivity for bald eagles and the concentrations of PCBs and p,p'-DDE in nestling plasma. Instead, negative correlations between success and productivity rates and PCBs and p,p'-DDE exist only at certain levels within the sub-population scale.

Positive correlations found between PCBs and p,p'-DDE concentrations and productivity at the LH level are likely the result of a confounding factor. A positive correlation shows only that two measures have moved in the same direction. It is important to recognize that a significant correlation does not suggest a causal relationship. While concentrations of organochlorine contaminants in the aquatic food webs along Lake Huron may have declined along with the productivity and success, it is most likely that some other factor such as land use or adult turnover is causing depressed rates of productivity and success.

Sprunt et al. (1973) used territory success and fecundity levels to create a model to determine the health of bald eagle populations. If a population is to remain stable, it must produce at least 0.7 fledged young per active nest with a minimum of 50 % of the active territories successfully producing fledglings. Under ideal conditions, the number of fledglings for each successful territory would be 1.4 or more. When examined at several geographic scales, the productivity rate for bald eagles nesting during 1999-2003 was above the Sprunt et al. (1973) criterion for stability of 0.7 fledged young per active nest (Table 9). None of the geographic scales met the requirements for “ideal conditions.”

While LE had the highest productivity, one factor that must be taken into account when considering the LE sub-population is that this group consistently has the smallest sample size. Sample size for the LE sub-population only comprised seven nests while LH, for example, had 76. Productivity estimates based on smaller samples are less reliable, and more easily biased by a few extreme observations. LH had the lowest productivity of all sub-populations, but at Prod1=1.03 (Prod2=.84) it was not significantly lower than other sub-populations.

Precision, Mean Power, and Trend Power

The sample sizes necessary to meet the objectives of precision, mean power, and trend power were achieved with the sample sizes from the actual contaminant data set from 1999 – 2003. The five-year monitoring cycle sampling method was sufficient to estimate true means of total PCBs from the broadest scale (entire state) to 66 % of the HUCs (finest scale) with a $\pm$ 20 ppb margin of error. Total DDT sample sizes were sufficient to estimate true means from the entire state for 87% of the HUCs with a margin of error of $\pm$ 20 ppb. It also met the required sample sizes necessary to detect decreases in total PCBs and total DDT concentrations with a power of 0.8 and 0.9, at the geographic scales of category, sub-populations, Great Lakes watersheds, and many of the HUCs. Depending on the standard deviation and power utilized, the five-year cycle sampling and monitoring program met the sample size requirements to detect trends of $\pm$ 5 and 10% per year over a time period of five and ten years.

This study has also shown that combining adjacent watersheds, with few eagle breeding areas, does not compromise the ability to detect trends of contaminants at the HUC geographic scale. The HUCs that could not be combined due to lack of adjacent watersheds within the sampling year cycle may be grouped with adjacent HUCs from different sampling years. The USGS delineation of the HUCs subdivided some of the HUCs into “a” and “b”. In the five year sampling cycle, HUC subdivision “a” might be sampled one year while the HUC subdivision “b” is sampled the next year. In terms of eagle breeding areas, this may cause a HUC that might have met the sample size requirement for trend detection to fall below the required sample size, if the HUC is subdivided into HUC “a” and HUC “b”. Grouping adjacent HUCs from different sampling years would allow for greater sample sizes, which would allow for greater power in contaminant shift and trend detection at the HUC geographic scale.

A key principle to the MDEQ's environmental quality monitoring program was the timing of the collection, analyses, and reporting of the monitoring data for each HUC watershed. The monitoring program strategy was such that the data for the HUCs were available prior to the initiation of the National Pollutant Discharge Elimination System (NPDES) permit development and renewal process (MDEQ 1997). Consequently, the eagle monitoring program was on a five-year watershed cycle that allows for the HUCs to be monitored two to three years prior to the actual permit issuance year. In accordance with the MDEQ's timing goal, grouping of adjacent HUCs from different sampling years should occur so that the combined HUCs are sampled in the monitoring year that allows for the data collection and analyses to occur prior to the actual permit issuance year. For example, if two adjacent HUCs are combined from the sampling years one and three, the combined HUCs should both be sampled and analyzed in sampling year one. This will allow for timely reporting of the data before the NPDES permit process begins for the HUCs in sampling year one.

With the statistical power and sample size determined for each of the geographic scales in Michigan, more emphasis should be placed upon contaminant shifts and trends at the geographic scales of interest. This may lead to a decrease in the number of samples collected and analyzed each year. As an example, the MDEQ has expressed interest in focusing on the detection of contaminant trends of $\pm$ 10% per year, over ten years at the Great Lakes watershed scale. Upon examination of Table 6, the sample sizes required per year, for a slope of 0.10, ranges from two to four samples per year with a maximum of only 39 samples required for collection and analysis from each of the Great Lakes watershed delineations over the ten year period.

To our knowledge, the bald eagle monitoring program, employed by the MDEQ, to provide data for the statewide and watershed trend assessment is the only program of its kind in the U.S. Many nestling eagle contaminant monitoring studies have been conducted; however, no other states have used the top predators in conjunction with other monitoring data to assess current and emerging contaminants at the HUC watershed level.

In conclusion, these results show that the Michigan bald eagle monitoring program achieved the objective of detecting significant differences in total PCB and p,p'-DDE concentrations from the time period 1987 – 1992 and 1999 – 2003. The five-year sampling design also achieved the sample size objectives for precision, mean power, and mean trend analyses. This research has shown that HUCs with few eagle breeding areas can be successfully combined without compromising trend detection. Therefore, after completing five years, 1999 – 2003, of the watershed monitoring cycle contaminant analyses, the MDEQ bald eagle contaminant monitoring program is an appropriate method by which to detect trends in contaminants in Michigan and the Great Lakes.

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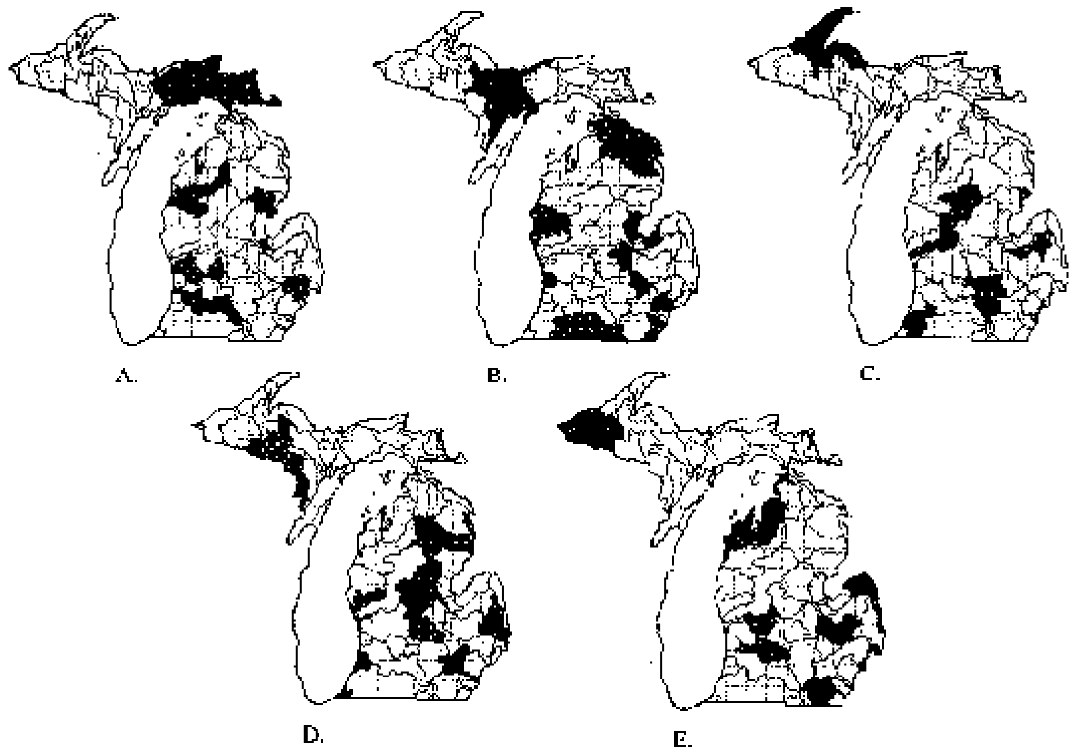

Figure 1. Michigan's watershed delineations and monitoring 'basin years' (MDEQ 1997). A.) 1999 basin year watersheds (shaded), B.) 2000 basin year watersheds (shaded), C.) 2001 basin year watersheds (shaded), D.) 2002 basin year watersheds (shaded), and E.) 2003 basin year watersheds (shaded).

Table 1. Geometric mean and range of detectable concentrations of total PCBs in plasma of 489 nestling bald eagle samples collected in Michigan from 1999 – 2003 compared to 241 samples collected and analyzed in Michigan from 1987 – 1992 (Bowerman et al. 2003).

Sub-population		Geometric Mean	Range (ppb)	P-value
Inland Upper Peninsula				
	1987 – 1992	29	<10 -177	P<0.0001
	1999 – 2003	9	<10 -189	
Inland Lower Peninsula				
	1987 – 1992	31	<10 – 200	P<0.0001
	1999 – 2003	8	<10 – 123	
Lake Erie				
	1987 – 1992	199	81 – 1325	P=0.0233
	1999 – 2003	110	52 – 213	
Lake Huron				
	1987 – 1992	105	5 – 928	P=0.0093
	1999 – 2003	40	<10 – 268	
Lake Michigan				
	1987 – 1992	154	14 – 628	P<0.0001
	1999 – 2003	63	<10 – 302	
Lake Superior				
	1987 – 1992	127	12 – 640	P<0.0001
	1999 – 2003	20	<10 – 368	

Table 2. Geometric mean and range of detectable concentrations of p,p'-DDE in plasma of 489 nestling bald eagle samples collected in Michigan from 1999 – 2003 compared to 241 samples collected in Michigan from 1987 –1992 (Bowerman et al. 2003).

Sub-population	Geometric Mean	Range (ppb)	P-value
Inland Upper Peninsula			
1987 – 1992	11	<5 – 245	P<0.0001
1999 – 2003	5	<5 – 83	
Inland Lower Peninsula			
1987 – 1992	10	<5 – 193	P<0.0001
1999 – 2003	5	<5 – 96	
Lake Erie			
1987 – 1992	22	<5 – 429	P=0.0037
1999 – 2003	9	6– 21	
Lake Huron			
1987 – 1992	25	<5 – 78	P=0.1553
1999 – 2003	17	<5 – 78	
Lake Michigan			
1987 – 1992	35	<5 – 235	P=0.6916
1999 – 2003	34	<5 – 212	
Lake Superior			
1987 – 1992	25	<5 – 306	P<0.0001
1999 – 2003	12	<5 – 257	

Table 3. Sample sizes, geometric means, standard deviations, and differences among Total PCB concentrations in plasma of nestling bald eagles among three geographic scales in Michigan, 1999-2003. Like letters are not significantly different within a geographic scale comparison.

			PCB						
Geographic Scale	**Level**	**n**	Geometric Mean						Standard Deviation
Category 1	AN	37	39.08	A					2.68
	GL	187	36.75	A					3.06
	IN	265	8.39		B				2.40
Category 2	GLAN	224	37.12	A					2.99
	IN	265	8.39		B				2.40
Sub-populations	LE	7	109.75	A					1.81
	LM	63	62.55	A	B				2.57
	LH	76	39.98		B				2.52
	LS	78	20.40			C			2.98
	UP	150	8.69				D		2.60
	LP	115	8.06				D		2.17
Great Lakes Watersheds	LE-GL	7	109.75	A					1.81
	LM-GL	62	62.41	A	B				2.59
	LH-GL	79	39.33		B				2.55
	LS-GL	76	20.54			C			2.98
	LM-IN-UP	102	10.39				D		2.90
	LM-IN-LP	35	8.74				D	E	2.44
	LH-IN	81	7.73				D	E	2.04
	LS-IN	41	5.94					E	1.64

Table 4. Sample sizes, geometric means, standard deviations, and differences among p,p'-DDE concentrations in plasma of nestling bald eagles among three geographic scales in Michigan, 1999-2003. Like letters are not significantly different within a geographic scale comparison.

			p,p'-DDE							
Geographic Scale	**Level**	**n**	Geometric Mean							Standard Deviation
Category 1	GL	187	17.90	A						2.75
	AN	37	16.95	A						2.35
	IN	265	4.94		B					2.57
Category 2	GLAN	224	17.74	A						2.68
	IN	265	4.94		B					2.57
Sub-populations	LM	63	34.40	A						2.20
	LH	76	16.73		B					2.20
	LS	78	11.73		B	C				2.88
	LE	7	9.01			C				1.53
	LP	115	5.30				D			2.46
	UP	150	4.67				D			2.66
Great Lakes Watersheds	LM-GL	62	34.34	A						2.21
	LH-GL	79	16.58		B					2.24
	LS-GL	76	11.86		B	C				2.87
	LE-GL	7	9.01			C	D			1.53
	LM-IN-LP	35	6.90				D	E		2.64
	LM-IN-UP	102	5.40					E		2.92
	LH-IN	81	4.69					E	F	2.32
	LS-IN	41	3.31						F	1.85

Table 5. Sample sizes, geometric means, standard deviations, and differences among Total DDT concentrations in plasma of nestling bald eagles among three geographic scales in Michigan, 1999-2003. Like letters are not significantly different within a geographic scale comparison.

			DDT						
Geographic Scale	**Level**	**n**	Geometric Mean						Standard Deviation
Category 1	AN	37	18.63	A					2.29
	GL	187	18.32	A					2.74
	IN	265	4.97		B				2.58
Category 2	GLAN	224	18.37	A					2.66
	IN	265	4.97		B				2.58
Subpopulations	LM	63	35.28	A					2.18
	LH	76	17.66		B				2.15
	LS	78	11.90			C			2.89
	LE	7	10.21			C			1.45
	LP	115	5.31				D		2.47
	UP	150	4.71				D		2.67
Great Lakes Watersheds	LM-GL	62	35.24	A					2.20
	LH-GL	79	17.48		B				2.20
	LS-GL	76	12.03			C			2.88
	LE-GL	7	10.21			C			1.45
	LM-IN-LP	35	6.94				D		2.66
	LM-IN-UP	102	5.47				D		2.92
	LH-IN	81	4.69				D	E	2.33
	LS-IN	41	3.32					E	1.86

Table 6. Sample sizes geometric means, standard deviations, and differences among Total PCB concentrations in plasma of nestling bald eagles among USGS watersheds (HUCs) in Michigan, 1999-2003. Like letters are not significantly different within a geographic scale comparison.

HUC Code	HUC Name	n	PCB Geometric Mean	PCB Standard Deviation		
4030111	Tacoosh-Whitefish	2	124.18	2.41	A	
4100002	Raisin	3	110.99	2.36	A	
4060200	Lake Michigan	6	96.84	1.95	A	B
4080206	Saginaw	1	85.96	.	A	
4030112	Fishdam-Sturgeon	9	73.7	3.67	A	B
4080102	Kawkawlin-Pine	2	62.19	1.17	A	B
4080300	Lake Huron	8	61.68	2.24	A	B
4050003	Kalamazoo	3	59.92	1.57	A	B
4080203	Shiawassee	3	58.61	3.48	A	B
4100001	Ottawa-Stony	3	58.53	8.59	A	B
4080103	Pigeon-Wiscoggin	7	53.8	1.56	A	B
4060105	Broadman-Charlevoix	11	49.9	2.99	A	B
4030109	Cedar-Ford	11	47.61	4.53	A	B
4060107	Brevoort-Mellecoquins	4	43.03	2.05	A	B
4050006	Lower Grand	1	39.82	.	A	B
4080205	Cass	6	38.04	3.05	A	B
4030110	Escanaba	9	36.52	4.99	A	B
4080101	Au Gres-Rifle	13	27	3.04	A	B
4020300	Lake Superior	11	25.21	4.3	A	B
4070001	St. Marys	14	22.92	3.07	A	B
4020105	Dead-Kelsey	25	21.46	2.69	A	B
4060101	Pere Marquette-White	11	18.87	2.83	A	B
4070005	Black	9	16.6	4.29	A	B
4060106	Manistique	18	16.5	3.91	A	B
4030108	Menominee	28	16.41	2.8	A	B
4060104	Betsie-Platte	2	16.27	5.31	A	B
4020103	Keweenaw Peninsula	14	15.76	3.59	A	B
4060103	Manistee	16	15.62	3.51	A	B
4070002	Carp-Pine	7	15.46	3.52	A	B
4020201	Betsy-Chocolay	19	14.05	2.59	A	B
4070003	Lone Lake-Ocqueoc	16	13.07	2.44	A	B
4070007	Au Sable	39	11.53	2.76	A	B

4020101	Black-Presque Isle	11	11.3	3.53	A	B
4070006	Thunder Bay	15	10.45	2.55	A	B
4060102	Muskegon	29	10.02	2.68	A	B
4020202	Tahquamenon	2	9.13	2.34	A	B
4030107	Michigamme	17	8.75	2.6	A	B
4090001	St. Clair	2	8.32	2.05	A	B
4020102	Ontonagan	26	8.18	2.03	A	B
4080201	Tittabawassee	9	7.81	2	A	B
4020104	Sturgeon	10	7.76	2.53	A	B
4030106	Brule	27	6.69	2.22	A	B
7070001	Upper Wisconsin	5	5.00	1.00		B
4080202	Pine	2	5	1		B
4070004	Cheboygan	3	5	1		B

Table 7. Sample sizes, geometric means, standard deviations, and differences among p,p'-DDE concentrations in plasma of nestling bald eagles among USGS watersheds (HUCs) in Michigan, 1999-2003. Like letters are not significantly different within a geographic scale comparison.

HUC Code	HUC Name	n	p,p'-DDE Geometric Mean	p,p'-DDE Standard Deviation			
4030111	Tacoosh-Whitefish	2	64.42	3.16	A		
4030112	Fishdam-Sturgeon	9	48.49	2.55	A	B	
4060200	Lake Michigan	6	43.7	1.71	A	B	
4080300	Lake Huron	8	32.79	2.5	A	B	C
4030109	Cedar-Ford	11	29.38	3.07	A	B	C
4060105	Broadman-Charlevoix	11	23.32	2.78	A	B	C
4060107	Brevoort-Mellecoquins	4	21.54	2.53	A	B	C
4080205	Cass	6	19.5	1.68	A	B	C
4030110	Escanaba	9	17.45	4.62	A	B	C
4020300	Lake Superior	11	15.95	4.72	A	B	C
4080103	Pigeon-Wiscoggin	7	15.87	1.94	A	B	C
4080102	Kawkawlin-Pine	2	15.45	1.09	A	B	C
4080206	Saginaw	1	14.81	.	A	B	C
4100001	Ottawa-Stony	3	14.26	5.01	A	B	C
4070005	Black	9	12.96	2.54	A	B	C
4050003	Kalamazoo	3	12.78	1.25	A	B	C
4100002	Raisin	3	12.69	1.91	A	B	C
4080203	Shiawassee	3	12.59	4.62	A	B	C
4080202	Pine	2	12.51	1.36	A	B	C
4060103	Manistee	16	12.42	3.18	A	B	C
4060101	Pere Marquette-White	11	11.68	3.11	A	B	C
4080101	Au Gres-Rifle	13	11.36	3.2	A	B	C
4070001	St. Marys	14	11.28	2.68	A	B	C
4070002	Carp-Pine	7	10.68	2.67	A	B	C
4070003	Lone Lake-Ocqueoc	16	10.24	1.98	A	B	C
4020105	Dead-Kelsey	25	9.23	2.86	A	B	C
4060106	Manistique	18	9.17	4.09	A	B	C
4020103	Keweenaw Peninsula	14	7.73	3.03	A	B	C
4060102	Muskegon	29	7.02	2.89	A	B	C
4070006	Thunder Bay	15	6.39	3.25	A	B	C
4070007	Au Sable	39	6.22	2.38	A	B	C
4050006	Lower Grand	1	6.06	.	A	B	C

4020101	Black-Presque Isle	11	5.92	3.51	A	B	C
4030108	Menominee	28	5.55	2.77	A	B	C
4030107	Michigamme	17	5.43	2.8	A	B	C
4060104	Betsie-Platte	2	5.38	2.96	A	B	C
4020202	Tahquamenon	2	5.01	2.67	A	B	C
4020102	Ontonagan	26	4.9	2.28	A	B	C
4020201	Betsy-Chocolay	19	4.84	2.23	A	B	C
4080201	Tittabawassee	9	4.84	2.23	A	B	C
4030106	Brule	27	3.94	2.32	A	B	C
4090001	St. Clair	2	3.64	1.7	A	B	C
4070004	Cheboygan	3	3.33	1.64		B	C
4020104	Sturgeon	10	3.27	1.86		B	C
7070001	Upper Wisconsin	5	2.5	1			C

Table 8. Sample sizes, geometric means, standard deviations, and differences among Total DDT concentrations in plasma of nestling bald eagles among USGS watersheds (HUCs) in Michigan, 1999-2003. Like letters are not significantly different within a geographic scale comparison.

			DDT				
HUC Code	HUC Name	n	Geometric Mean	Standard Deviation			
4030111	Tacoosh-Whitefish	2	64.42	3.16	A		
4030112	Fishdam-Sturgeon	9	49.58	2.57	A	B	
4060200	Lake Michigan	6	44.15	1.72	A	B	
4080300	Lake Huron	8	32.79	2.50	A	B	C
4030109	Cedar-Ford	11	29.67	3.10	A	B	C
4080206	Saginaw	1	24.29	.	A	B	C
4060105	Broadman-Charlevoix	11	23.32	2.87	A	B	C
4080205	Cass	6	22.54	1.39	A	B	C
4060107	Brevoort-Mellecoquins	4	21.90	2.56	A	B	C
4100001	Ottawa-Stony	3	19.60	3.21	A	B	C
4030110	Escanaba	9	17.68	4.65	A	B	C
4080102	Kawkawlin-Pine	2	16.67	1.21	A	B	C
4080103	Pigeon-Wiscoggin	7	16.47	1.94	A	B	C
4020300	Lake Superior	11	15.99	4.74	A	B	C
4050003	Kalamazoo	3	14.95	1.39	A	B	C
4080203	Shiawassee	3	14.53	4.86	A	B	C
4100002	Raisin	3	14.39	1.79	A	B	C
4070005	Black	9	13.27	2.60	A	B	C
4080202	Pine	2	12.51	1.36	A	B	C
4060103	Manistee	16	12.50	3.21	A	B	C
4060101	Pere Marquette-White	11	12.00	3.15	A	B	C
4080101	Au Gres-Rifle	13	11.72	3.20	A	B	C
4070001	St. Marys	14	11.54	2.69	A	B	C
4070002	Carp-Pine	7	10.89	2.69	A	B	C
4070003	Lone Lake-Ocqueoc	16	10.29	1.99	A	B	C
4020105	Dead-Kelsey	25	9.47	2.88	A	B	C
4020201	Betsy-Chocolay	19	9.38	2.71	A	B	C
4060106	Manistique	18	9.19	4.10	A	B	C
4020103	Keweenaw Peninsula	14	7.97	3.03	A	B	C
4060102	Muskegon	29	7.12	2.93	A	B	C
4070006	Thunder Bay	15	6.39	3.25	A	B	C
4070007	Au Sable	39	6.23	2.39	A	B	C

4020101	Black-Presque Isle	11	6.15	3.59	A	B	C
4050006	Lower Grand	1	6.06	.	A	B	C
4030108	Menominee	28	5.96	2.73	A	B	C
4060104	Betsie-Platte	2	5.82	3.30	A	B	C
4030107	Michigamme	17	5.43	2.80	A	B	C
4020202	Tahquamenon	2	5.01	2.67	A	B	C
4020102	Ontonagan	26	4.92	2.29	A	B	C
4080201	Tittabawassee	9	4.83	2.23	A	B	C
4090001	St. Clair	2	4.64	2.40	A	B	C
4030106	Brule	27	3.94	2.33	A	B	C
4070004	Cheboygan	3	3.33	1.64		B	C
4020104	Sturgeon	10	3.27	1.86		B	C
7070001	Upper Wisconsin	5	2.50	1.00			C

Table 9. Geometric Mean productivity (Prod1) & success (Suc1) rates and combined single measure productivity (Prod2) & success (Suc2) by location for bald eagles sampled in Michigan during 1999-2003. GLAN = Great Lakes & Inland combined; GL = Great Lakes; IN = Inland; AN = Anadromous; LE = Lake Erie; UP = Upper Peninsula; LS = Lake Superior; LH = Lake Huron; LP = Lower Peninsula; LM = Lake Michigan; LMS = Lakes Michigan and Superior. There were no significant differences in productivity or success at these scales.

	N	Prod1	Suc1	Prod2	Suc2
Overall	489	1.11	67.34	0.94	60.63
Scale 1					
GLAN	222	1.11	69.58	0.91	58.16
IN	266	1.11	65.42	0.96	62.04
Scale 2					
GL	185	1.14	70.87	0.93	58.75
IN	267	1.11	65.42	0.96	62.04
AN	37	0.99	63.46	0.81	55.05
Scale 3					
LE	7	1.23	75.38	1.31	69.23
LM	63	1.19	72.08	0.93	60.00
LP	115	1.15	67.39	0.99	64.36
LS	78	1.11	67.56	0.90	55.76
UP	151	1.08	64.06	0.92	59.80
LH	76	1.03	68.80	0.84	42.66

Table 10. Correlation values between productivity & success rates and PCB, p,p'-DDE, and Hg concentrations by location for bald eagles sampled in Michigan during 1999-2003. P values are stated in parenthesis next to correlation values and significance is represented by a (*). GL & AN = Great Lakes & Anadromous combined; GL = Great Lakes; IN = Inland; AN = Anadromous; LE = Lake Erie; UP = Upper Peninsula; LS = Lake Superior; LH = Lake Huron; LP = Lower Peninsula; and LM = Lake Michigan.

	Prod vs PCB	N	Prod vs p,p'-DDE	N	Succ vs PCB	N	Succ vs p,p'-DDE	N
Overall	-.01785 (.6938)	489	.01424 (.7534)	489	.02558 (.5726)	489	.05335 (.2390)	489
Scale 1								
GL & AN	-.03937 (.5595)	222	.06409 (.3419)	222	-.00419 (.9505)	222	.08395 (.2128)	222
IN	-.04627 (.4524)	266	-.09211 (.1340)	266	.04547 (.4602)	266	-.00797 (.8971)	266
Scale 2								
GL	-.03872 (.6007)	185	.03754 (.6119)	185	.01978 (.7893)	185	.04905 (.5073)	185
IN	-.04538 (.4602)	267	-.09167 (.1352)	267	.05279 (.3902)	267	-.00409 (.9469)	267
AN	-.04805 (.7776)	37	.29786 (.0734)	37	-0.01296 (0.9568)	37	0.02279 (0.9240)	37
Scale 3								
LE	-.85934 (.0132) *	7	.06715 (.8863)	7	-.84527 (.0166) *	7	-.08267 (.8601)	7
UP	-.04366 (.5946)	151	-.12522 (.1255)	151	.05305 (.5177)	151	-.01321 (.8721)	151
LS	-.08686 (.4526)	77	-.05639 (.6262)	77	.02984 (.7967	77	.05364 (.6431)	77
LH	.29329 (.0101) *	76	.30865 (.0067) *	76	.24734 (.0312) *	76	.24671 (.0317) *	76
LP	-.00308 (.9741)	114	.01246 (.8953)	114	.06224 (.5106)	114	.02319 (.8066)	114
LM	-.31221 (.0127) *	63	-.03402 (.7912)	63	-.28401 (.0241) *	63	-.02489 (.8465)	63

Table 11. Sample sizes required for 95% confidence intervals of the true mean total PCB and total DDT concentrations with a ± 5, 10, or 20 ppb margin of error for the five geographic scales in Michigan.

Geographic Scale	± 5 DDT	± 5 PCB	± 10 DDT	± 10 PCB	± 20 DDT	± 20 PCB
Entire State	27	74	10	25	4	10
Category	18	46	6	16	3	6
Sub-populations	16	40	6	14	2	5
Great Lakes watersheds	16	39	6	13	2	5
HUCs	15	28	6	10	2	4

Table 12. Sample sizes necessary to detect differences in mean total PCB and DDT concentrations among geographic regions, at a power of 0.8 and 0.9, in four of the geographic scales considered in Michigan.

Geographic Scale	Power	n PCB	n DDT
Category	0.8	7	9
	0.9	9	11
Sub-populations	0.8	4	5
	0.9	4	6
Great Lakes watersheds	0.8	3	3
	0.9	4	3
HUCs	0.8	2	2
	0.9	2	2

Table 13. Total sample sizes, and sample sizes per year, needed to detect linear regression decreases in total PCB and total DDT concentrations over five years, within all five geographic scales in Michigan, within a range of means, on a natural log scale of 1-4 ppb, slopes of 0.05 and 0.10, and power of 0.8 and 0.9.

Slope	ln Log Mean	Standard Deviation	Power	N	n per Year
0.05	1-4	0.5	0.8	46	8
0.05	1-4	0.5	0.9	61	11
0.05	1-4	1.0	0.8	180	30
0.05	1-4	1.0	0.9	241	41
0.05	1-4	1.5	0.8	404	68
0.05	1-4	1.5	0.9	541	91
0.05	1-4	2.0	0.8	718	120
0.05	1-4	2.0	0.9	961	161
0.10	1-4	0.5	0.8	12	2
0.10	1-4	0.5	0.9	16	3
0.10	1-4	1.0	0.8	46	8
0.10	1-4	1.0	0.9	61	11
0.10	1-4	1.5	0.8	102	17
0.10	1-4	1.5	0.9	136	23
0.10	1-4	2.0	0.8	180	30
0.10	1-4	2.0	0.9	241	41

Table 14. Total sample sizes, and sample sizes per year, needed to detect linear regression decreases in total PCB and total DDT concentrations over ten years, within all five geographic scales in Michigan, with a range of means, on a natural log scale of 1-4 ppb, slopes of 0.05 and 0.10, and power of 0.8 and 0.9.

Slope	ln Log Mean	Standard Deviation	Power	N	n per Year
0.05	1-4	0.5	0.8	8	2
0.05	1-4	0.5	0.9	10	2
0.05	1-4	1.0	0.8	29	3
0.05	1-4	1.0	0.9	39	4
0.05	1-4	1.5	0.8	65	6
0.05	1-4	1.5	0.9	87	8
0.05	1-4	2.0	0.8	115	11
0.05	1-4	2.0	0.9	154	14
0.10	1-4	0.5	0.8	2	2
0.10	1-4	0.5	0.9	3	2
0.10	1-4	1.0	0.8	8	2
0.10	1-4	1.0	0.9	10	2
0.10	1-4	1.5	0.8	17	2
0.10	1-4	1.5	0.9	22	2
0.10	1-4	2.0	0.8	29	3
0.10	1-4	2.0	0.9	39	4