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TRENDS OF CONTAMINANTS AND EFFECTS IN BALD EAGLES OF THE GREAT LAKES BASIN

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Abstract. Bald eagle *(Haliaeetus leucocephalus)* numbers in North America have increased since the ban of DDT and other organochlorine compounds in the 1970s. The decrease in the environmental concentrations of *p,p'*-DDE has lead to the lessening of egg-shell thinning and has been a major reason for the current resurgence of bald eagle populations in temperate North America, however, this recovery has not been uniform. Eagles nesting along the shorelines and islands of the Great Lakes have continued to experience impaired productivity. In order to examine some of the reasons for the current recovery of bald eagles in the Great Lakes Basin and the potential use of eagles as a bioindicator species of Great Lakes water quality, we analyzed trends in reproductive activity, concentrations of PCBs and *p,p'*-DDE in unhatched eggs, and rates of developmental deformities. Numbers of occupied nests, fledged young, and yearly productivity rates have increased across the basin. No trends have been observed in changes in the concentrations of *p,p'*-DDE nor Total PCBs in unhatched eggs. An increasing rate in the incidence of developmental deformities in nestlings has been observed in Michigan. The recovery of the bald eagle population along the Great Lakes is most likely due to immigration of relatively uncontaminated adults from Interior regions.

1. Introduction

The number of breeding pairs of bald eagles *(Haliaeetus leucocephalus)* in North America has increased since the ban of DDT and other organochlorine compounds in the 1970s. The decrease in the environmental concentrations of *p,p'*-DDE has lead to the lessening of egg-shell thinning and has been a major reason for the current resurgence of bald eagle populations in temperate North America (Grier 1982, Postupalsky 1978, Grier 1982, Wiemeyer *et al.* 1984, Colborn 1991). However, the recovery has not been uniform and several regions where populations are not

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reproducing at a level considered to be healthy continue to exist (Colborn 1991, Bowerman 1993, Best *et al.* 1994, Bowerman et al. 1994). One of these areas is the Basin of the Laurentian Great Lakes, where *p,p'*-DDE and polychlorinated biphenyls (PCBs) have been linked to poor reproductive success (Kozie and Anderson 1991, Bowerman 1991, Bowerman 1993, Best et al., 1994). Other areas which have lower reproductive success associated with high levels of environmental contaminants include the lower Columbia River in Oregon and Washington, Maine, and the Channel Islands in California (Anthony *et al.* 1993, Welch 1994, Garcelon *et al.* 1989). Recent proposals to alter the status of the eagle under the Federal Endangered Species Act (Federal Register 1990) focused solely on the increasing numbers of breeding pairs and overall reproductive rate in the contiguous United States. It is equally important to understand and incorporate the dynamics of the population recovery and the role of PCBs and similar toxicants, as well as *p,p'*-DDE, in this decision.

Bald eagle productivity is correlated with some types of chlorinated hydrocarbon compounds especially polychlorinated diaromatic hydrocarbons (PCDH). Productivity is correlated with concentrations, determined in addled eggs, of some of these compounds, while exposure to other compounds has been suggested as causing teratogenic effects based on studies of surrogate species (Wiemeyer *et al.* 1984, Kubiak *et al.* 1989, Gilbertson *et al.* 1991, Wiemeyer *et al.* 1993, Bowerman *et al.* 1994a, Giesy *et al.* 1994, Bowerman *et al.* 1994b, Bowerman *et al.* 1995). Consequently, the bald eagle has been suggested as a biological indicator species of toxic effects of organochlorine compounds on piscivorous wildlife and the effects of bioaccumulation and biomagnification in the Great Lakes. Eagles forage primarily on fish and other vertebrates associated with the coastal zone of the Great Lakes, rivers, and interior aquatic systems. Concentrations of *p,p'*-DDE and PCBs in the plasma of nestlings reflect exposure to these compounds from the prey species within the breeding area (Frenzel 1985, Bowerman 1993). To examine some of the reasons for the current recovery of bald eagles in the Great Lakes Basin and the potential use of eagles as a bioindicator species of Great Lakes water quality, we analyzed trends in reproductive activity, concentrations of PCBs and *p,p'*-DDE in unhatched bald eagle eggs, and rates of developmental deformities in nestling eagles.

2. Trends in Regional Bald Eagle Reproduction

The bald eagle is currently distributed as a breeding species along the shorelines and islands of four of the five Great Lakes: Lake Superior; Lake Michigan; Lake Huron; and Lake Erie (Bowerman, 1993). Eagles nest along the Great Lakes shorelines of the states of Michigan, Minnesota, Ohio, Wisconsin, and the Province of Ontario. Surveys for bald eagle reproductive activity are conducted yearly for the entirety of Michigan and Ohio, and for smaller areas of Minnesota, Wisconsin, and Ontario. Two aerial surveys are conducted in Michigan, Minnesota, Wisconsin, and Ohio, while ground observations are utilized in Ontario. Timing of the aerial surveys coincide with nest initiation and post-hatch, and are dependent on local conditions and previous experience (Postupalsky 1974). Nestling eagles are banded at 5-9 weeks of age and these observations are utilized to update aerial survey data. In recent years, data for the states of Minnesota and Wisconsin have been incomplete for the second aerial survey which is used to determine the number of fledged young produced.

Regional bald eagle reproductive data were examined for the period 1973-1995 for the four states bordering the Laurentian Great Lakes that had eagles that nest along their shorelines or islands, Michigan, Minnesota, Ohio, and Wisconsin. Reproductive parameters examined included number of occupied nests and number of fledged young. Productivity was calculated by dividing the total number of fledged young by the number of occupied nests, using the method of Postupalsky (1974).

The number of occupied nests in all four states increased between 1973 and 1995 (Figure I). The greatest increases in numbers of nests occurred in Minnesota and Wisconsin, where the number of occupied nests increased from 115 to 618

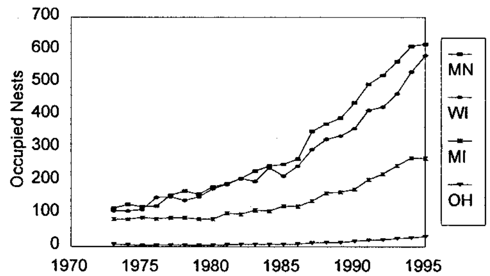

Figure I. Number of Occupied Bald Eagle Nests in Minnesota (MN), Wisconsin (WI), Michigan (MI), and Ohio (OH), 1973-1995. Source: U.S. Fish and Wildlife Service

(537%), and from 108 to 583 (540%), respectively. The increases of occupied nests in Michigan and Ohio were from 83 to 268 (323%), and from 7 to 30 (429%), respectively. In all four states, the number of occupied breeding areas have had the greatest increases since 1985.

The number of fledged young in all four states also increased between 1973 and 1995 (Figure II). The greatest increases in numbers of fledged young occurred in Minnesota and Wisconsin, where the number of fledged young increased from 113 to 797 (705%), and from 106 to 694 (655%), respectively. The increases of fledged

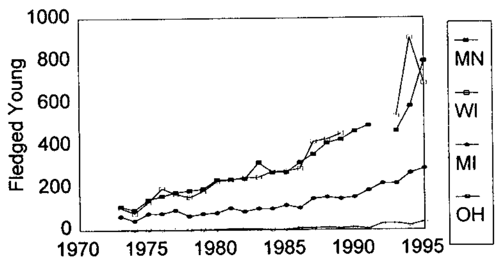

Figure II. Number of Young Fledged from Occupied Bald Eagle Nests in Minnesota (MN), Wisconsin (WI), Michigan (MI), and Ohio (OH), 1973-1995. Source: U.S. Fish and Wildlife Service

young in Michigan and Ohio were from 66 to 292 (442%), and from 2 to 38 (1900%), respectively.

The number of young per occupied nest, or annual productivity rate, increased in all four states between 1973 and 1995 (Figures III and IV). The greatest increases occurred in Ohio and Michigan, where annual productivity rates increased from 0.29 to 1.27, and from 0.80 to 1.09, respectively. The increases of annual productivity rates in Minnesota and Wisconsin were from 0.98 to 1.29, and from 0.98 to 1.19, respectively. Recent increases in Michigan and Ohio in excess of the 1.0 productivity rate associated with a healthy population are rare when one compares the rate over the entire period, while eagles in Wisconsin and Minnesota have consistently exceeded this rate.

The continuity of data collection from the annual surveys for determining whether there are continued effects of Great Lakes pollutants on bald eagle reproduction is threatened by budget constraints. Michigan and Ohio maintain statewide annual surveys. However, in Minnesota and Wisconsin, surveys of the

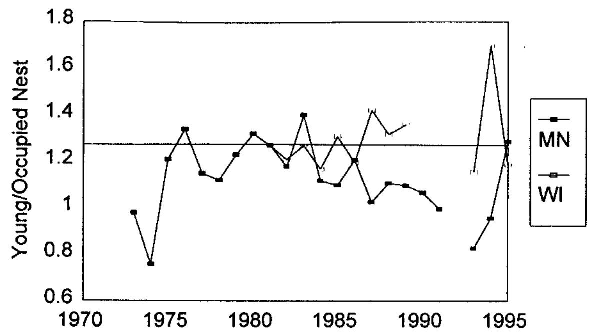

Figure III. Number of Young Fledged per Occupied Bald Eagle Nest in Minnesota (MN), and Wisconsin (WI), 1973-1995. The line at 1.0 young per occupied nest is the rate associated with healthy eagle populations (Sprunt *et al.*, 1973). Source: U.S. Fish and Wildlife Service.

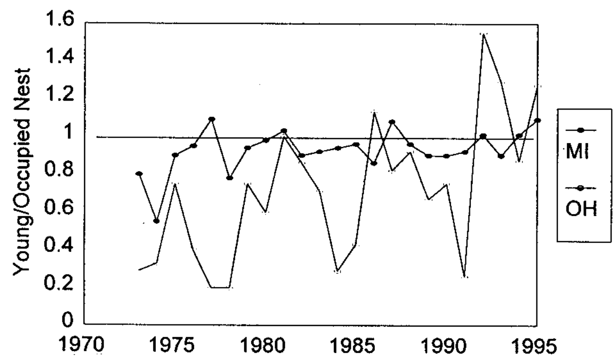

Figure IV. Number of Young Fledged per Occupied Bald Eagle Nest in Michigan (MI), and Ohio (OH), 1973-1995. The line at 1.0 young per occupied nest is the rate associated with healthy eagle populations (Sprunt *et al.*, 1973). Source: U.S. Fish and Wildlife Service number of young produced have been conducted during the 1990s only as estimates based on smaller regions within each state. This has prevented utilization of these data in direct comparisons on a statewide basis.

3. Trends in Bald Eagle Reproduction in Michigan

The bald eagle is currently distributed along the Michigan shorelines and islands of Lake Superior, Lake Michigan, Lake Huron, and Lake Erie (Bowerman 1993). Surveys of bald eagle reproductive activity have been conducted annually for the entire State of Michigan since the early 1960s and include annual site visits and banding of young at over 85% of all occupied nests. We used Michigan since it had the only complete data set of sufficient sample size for comparing differences in bald eagle reproductive performance among regions near to and remote from the Great Lakes shoreline. While Ohio has a long term program for monitoring of their eagle population, the yearly sample size is less than 40 breeding pairs, with fewer than 10 of these pairs located in interior areas.

Within Michigan, regional bald eagle reproductive data were examined for the period 1961-1995 in 'Great Lakes' and 'Interior' regions. These are, respectively,

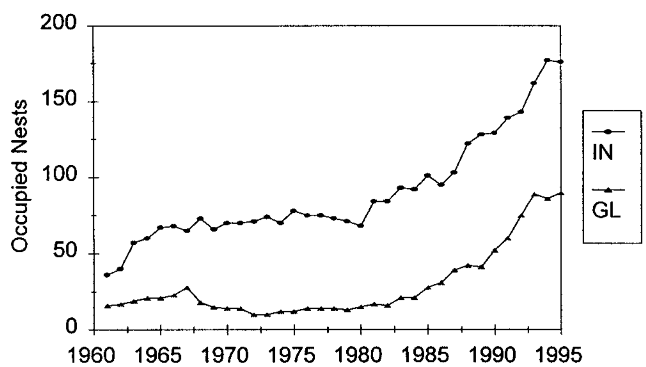

Figure V. Number of Occupied Bald Eagle Nests Between 1961 and 1995 in Two Regions of Michigan. Great Lakes (GL) includes those eagles nesting within 8.0 km of the shorelines of the Great Lakes and along rivers accessible to spawning runs of Great Lakes fish, and Interior (IN) includes those eagles nesting greater than 8.0 km from the Great Lakes and not along rivers accessible to spawning runs of Great Lakes fish. Source: U.S. Fish and Wildlife Service bald eagles nesting within 8.0 km of the shorelines or on islands of the Great Lakes or along rivers open to spawning runs of Great Lakes fishes, and those nesting greater than 8.0 km from a Great Lake or nesting along a river that is not open to Great Lakes spawning runs of fishes.

The number of occupied nests in both regions increased between 1961 and 1995 (Figure V). The number of occupied nests increased from 16 to 90 (563%), and from 36 to 176 (489%), in Great Lakes and Interior regions, respectively.

The number of fledged young in both regions increased between 1961 and 1995 (Figure VI). The number of fledged young increased from 0 to 81, and from 34 to 207, in Great Lakes and Interior regions, respectively.

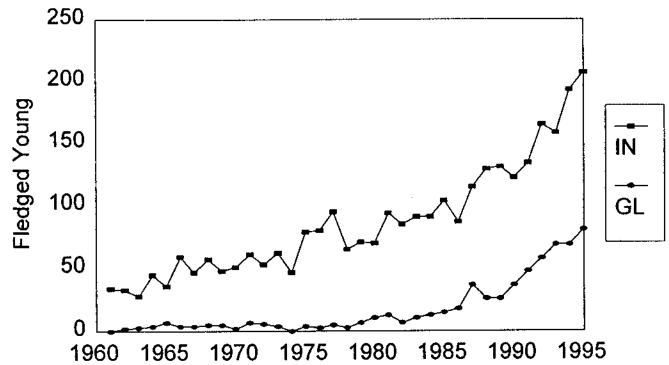

Figure VI. Number of Young Fledged from Occupied Bald Eagle Nests Between 1961 and 1995 in Two Regions of Michigan. Great Lakes (GL) includes those eagles nesting within 8.0 km of the shorelines of the Great Lakes and along rivers accessible to spawning runs of Great Lakes fish, and Interior (IN) includes those eagles nesting greater than 8.0 km from the Great Lakes and not along rivers accessible to spawning runs of Great Lakes fish. Source: U.S. Fish and Wildlife Service

The number of young per occupied nest, or annual productivity rate, also increased between 1961 and 1995 for both regions (Figure VII). The annual productivity rates increased from 0.00 to 0.90, and from 0.94 to 1.19, in Great Lakes and Interior regions, respectively.

The number of Interior occupied nests doubled from 1980 to 1995, while the Great Lakes nests doubled from 1989 to 1995. Increases in new occupied nests and

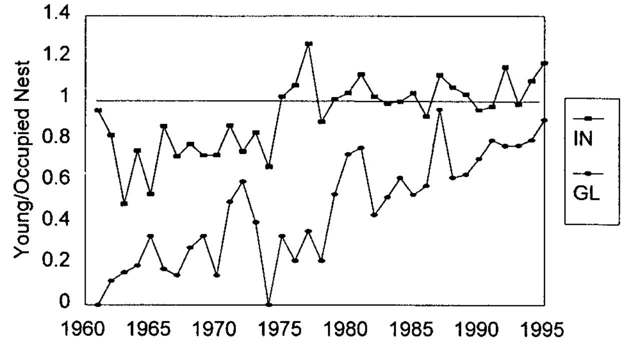

Figure VII. Number of Young Produced from Occupied Bald Eagle Nests Between 1961 and 1995 in Two Regions of Michigan. Great Lakes (GL) includes those eagles nesting within 8.0 km of the shorelines of the Great Lakes and along rivers accessible to spawning runs of Great Lakes fish, and Interior (IN) includes those eagles nesting greater than 8.0 km from the Great Lakes and not along rivers accessible to spawning runs of Great Lakes fish. The line at 1.0 young per occupied nest is the rate associated with healthy eagle populations (Sprunt *et al.*, 1973). Source: U.S. Fish and Wildlife Service

fledged young in the Great Lakes region correspond to an increase in the productivity rate for the entire State of Michigan. Based on the productivity rate for the Great Lakes region prior to 1989, this increase in new occupied nests can only be explained by immigration of adults from the Interior regions of Michigan, Minnesota, and Wisconsin (Colborn 1991, Bowerman 1993, Best *et al.* 1994, Bowerman *et al.*, 1995).

4. Trends in PCBs and DDE in Eggs

We examined the changes in Total PCBs and *p,p'*-DDE concentrations in 61 unhatched eggs collected from Michigan, Ohio, and Wisconsin, along the shorelines and islands of the Great Lakes since 1968 (Figures VIII and IX). Concentrations were reported on a fresh, wet weight concentration to account for moisture loss prior to collection (Bowerman *et al.* 1994c). The No Observable Adverse Effect Concentrations (NOAEC) based on a productivity rate of 1.0 were determined by weighted sigmoidal regression analysis to be 2.7 mg/kg for *p,p'*-DDE (Wiemeyer *et al.* 1993) and by regression analysis to be 4.0 mg/kg for Total PCBs (Wiemeyer *et.*

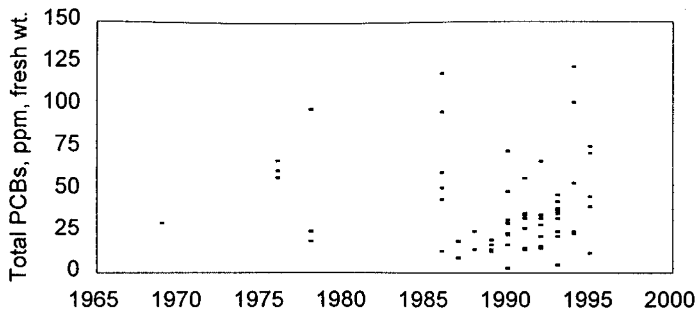

Figure VIII. Concentrations of Total PCBs, mg/kg, Fresh Wet Weight, in Unhatched Bald Eagle Eggs Collected from the Great Lakes, 1968-1995. Source: Wiemeyer *et al.*, 1984 and Best, unpubl. data.

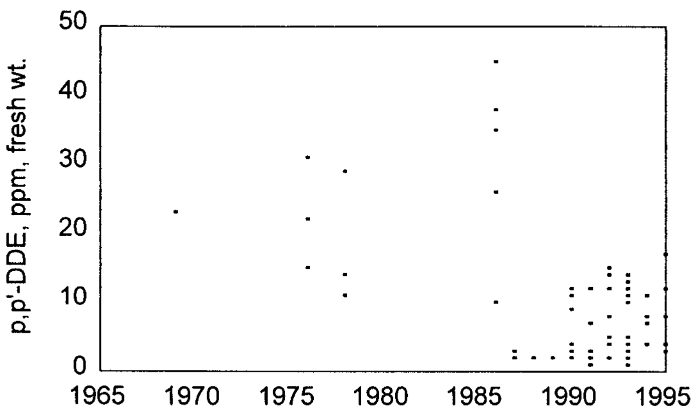

Figure IX. Concentrations of *p,p′*-DDE, mg/kg, Fresh Wet Weight, in Unhatched Bald Eagle Eggs Collected from the Great Lakes, 1968-1995. Source: Wiemeyer *et al.*, 1984 and Best, unpubl. data.

al. 1984). Concentrations associated with near total reproductive failure, i.e., a productivity rate of <0.10, were determined by weighted sigmoidal regression analysis to be 27 mg/kg for *p,p'*-DDE (Wiemeyer *et al.* 1993) and by regression analysis to be 35 mg/kg for Total PCBs (Wiemeyer *et al.* 1984).

There were no significant trends using autocorrelation and autocorrelation on first differences (Box and Jenkins, 1976) for the period 1968-1995 in the concentrations of either Total PCBs (Figure VIII) nor *p,p'*-DDE (Figure IX) in unhatched eggs of bald eagles from the Great Lakes region. Only one egg (n=60) collected since 1985 from the Great Lakes region has had Total PCB concentrations less than the calculated NOAEC, while 41.7% (n=25) have had concentrations greater than the concentration associated with nearly complete reproductive failure. Few eggs (n=16, 17.7%) collected since 1985 have had *p,p'*-DDE concentrations less than the calculated NOAEC, but only of these five eggs (8.3%) have had concentrations greater than the concentration associated with 15% egg shell thinning (16 mg/kg *p,p'*-DDE), a concentration associated with significant decreases in eagle productivity rates (Wiemeyer *et al.* 1984; Wiemeyer *et al.* 1993).

A problem encountered with interpretation of the effects of particular chemicals on bald eagle productivity rates lies in the intercorrelation among various organochlorine compounds (Wiemeyer *et al.* 1984, Wiemeyer *et al.* 1993, Best *et al.* 1994, Bowerman *et al.* 1994c, Bowerman *et al.* 1995). We have previously observed that eggs collected from the Great Lakes from 1986-1990 have shown a greater inverse correlation between Total PCBs (r^2= 0.80) and productivity than with *p,p'*-DDE concentrations (r^2= 0.63) (Best *et al.* 1994; Bowerman *et al.* 1994c).

5. Trends in Observed Abnormalities

The first nestling bald eagle with a crossed bill was reported by Grier (1968). More recently, our group has reported five additional observations: one near the Menominee River in the western Upper Peninsula of Michigan in 1968; one in the northern Lower Peninsula of Michigan in 1982; two in northern Wisconsin near the Menominee River in 1986 and 1987; and one in northern Minnesota in Voyageurs National Park in 1989 (Bowerman *et al.* 1994b).

Since 1989, six additional observations of deformities have been observed in bald eagles in Michigan. In 1992, near Hardwood Lake within the Saginaw Bay Watershed, a nestling with fused vertebrae and deformed legs which resulted in inability to stand upright, was observed. In 1993, four nestlings were observed with deformities, three with crossed bills and one without a crossed-bill, but with deformities in both feet. The nestlings with crossed bills occurred at nests located along the Raisin River and Wood Tick Peninsula near Lake Erie, and at Tomahawk Flooding in the northern Lower Peninsula of Michigan. The nestling with deformed feet occurred at a nest located at Black River Flooding in the eastern Upper Peninsula of Michigan. In 1995, a second nestling with a crossed bill was observed at the same nest located along the Raisin River. During the period between finding the first and second deformed nestling at the Raisin River site, at least one of the two adults in this breeding pair was replaced.

The incidence of deformed nestling eagles within Michigan for the period 1968-1995 was 26.6 per 10,000. The rate has changed from 12.5 per 10,000 for the period 1968-1989, to 42.3 per 10,000 for the period 1990-1995. Since the actual percentage of nestling eagles examined and banded in Michigan has not changed since 1964, this change in incidence appears to be real. We theorize that the increase in incidence is most likely attributed to a decrease in the egg shell thinning influence of *p,p'*-DDE as a factor in nesting success of bald eagles in the region which has allowed for a greater rate of survival and thus expression of deformities. Based on results of studies on other colonial waterbirds and poultry, these teratogenic effects in nestling eagles are likely due to dioxin-like congeners of PCBs (Bowerman *et al.* 1994b, Giesy *et al.* 1994, Ludwig *et al.* 1996).

6. The Bald Eagle as an Indicator Species of Water Quality

The bald eagle has been proposed as a basin-wide bioindicator of Great Lakes water quality by the International Joint Commission (IJC 1994). There are a number of advantages and of utilizing the bald eagle in this manner. The major strength of using the bald eagle as a bioindicator species lies in the fact that it is one of the only species where we can obtain a near total count of all breeding pairs and their reproductive outcome. We therefore, have a population "measure" rather than relying on an estimate or "index" of the actual population. These data exist for the entire area of Michigan and Ohio, and along the Lake Erie shoreline of Ontario, from the early 1960s. A number of other areas within the basin have data sets that also date back to the mid-1960s. Individual breeding areas can be followed from that time period to the present and compared to regional contaminant concentrations in bald eagles and other "surrogates" to determine relative contamination of the Great Lakes.

The eagle is primarily a year-around resident of the Great Lakes Basin, and in many areas is non-migratory. Unhatched eggs of eagles, therefore, are reflective of the local contamination of their breeding area. This is also true of egg concentrations of the non-migratory population of Great Lakes herring gulls *(Larus argentatus)*. While terns *(Sterna spp.)* and double-crested cormorants *(Phalacrocorax auritus)*, are migratory , they accumulate contaminant levels at rates that are reflective of the degree of pollution of their local nesting environments (Weseloh *et al.* 1983, Kubiak *et al.* 1989, Fox *et al.* 1991, Tillitt *et al.* 1992, Giesy *et al.* 1994).

Another advantage lies in the amount of information that is known about the life history and habitat requirements of bald eagles. Their prey preferences during the breeding season, their preferences in nest trees, and potential habitat within 1.6 km of the Great Lakes shoreline have been identified (Bowerman 1993). In addition, the effects of some of the organochlorine compounds are correlated to reproductive performance.

The large body size of bald eagles make it easy for the collection of large samples of blood and eggs of sufficient volume to conduct a number of chemical as well as genetic tests. Blood samples can be analyzed for organochlorine contaminants and associated changes in biochemical markers, and evaluated genetically to determine parentage of nestlings (Bowerman 1993). Since most nests are accessible by an experienced climber, samples of blood and feathers can be easily obtained each year from known breeding areas and changes in concentrations of environmental contaminants can be determined over time.

There is a number of disadvantages, however, in using the bald eagle as a bioindicator species. Since this species has been a "threatened" or "endangered" species throughout most of its range, and is highly prized by the public, it is not a suitable laboratory animal. Its legal status and importance to the public also makes it difficult to justify collection of fresh eggs. There are several areas along the shorelines of the Great Lakes and the connecting channels where the bald eagle has not reestablished territories either as the result of continuing severe environmental contamination or as a result of habitat destruction, urbanization and disturbance. For example, bald eagles do not currently nest along Lake Ontario shorelines after being extirpated in the 1950s.

A further problem with use of the bald eagle as a bioindicator species is the difficulty in collecting addled eggs from areas of interest, due to predation by scavengers. This problem results in low numbers of samples collected throughout the Great Lakes, with many samples being collected from accessible sites rather than at random sites.

A final problem with the eagle as an ecosystem monitor is the difficulty of separating the factor of prey availability from the effects of environmental contaminants on nest productivity. For example, there was no correlation between estimates of 5-year nest productivity at sites along the Wisconsin shoreline of Lake Superior and measures of either prey delivery rates or environmental contaminants measured indirectly as *p,p'*-DDE and Total PCBs in nestling plasma (Dykstra *et al.*

1998). It is suggested that a comparison of egg concentrations, as a direct measure of exposure, with threshold levels might be preferable in investigating the contribution of these two factors on reproductive success.

Some of the weaknesses of using the bald eagle as a bioindicator species can be overcome by combining and contrasting contaminant and reproductive data on various colonial waterbird species with data on bald eagles from the same areas. The development of these interspecies correlations might permit prediction of the contaminant status of areas where either eagles or colonial waterbirds do not currently nest. This could be used not only to expand upon the shoreline areas which can be assessed throughout the basin, but also to predict the further degree of remedial progress required for restoration of populations of these indicator species.

7. Conclusions

Bald eagle populations have generally increased throughout the Great Lakes Basin after the suspensions or cancellations of the registered uses of DDT and other organochlorine compounds in the early 1970s. The populations in the western portion of the basin, in Minnesota and Wisconsin, have had the largest increase in numbers of breeding eagles and fledglings produced and are the primary source of the recovery of the basin's eagle population. Eagles nesting along the shorelines and islands of the Great Lakes continue to experience impairment of reproduction and are likely a population "sink". The key to sustaining the current recovery of the bald eagle population within the Great Lakes Basin lies in maintaining sufficient reproductive rates within the relatively clean Interior population to compensate for the continued reproductive impairment of the Great Lakes eagle population (Bowerman 1993).

There are no trends in concentrations of PCBs or DDE in eggs of bald eagles nesting along the Great Lakes, although in a small number of eggs collected recently, concentrations are below thresholds associated with reproductive impairment.

We conclude that the bald eagle would make a good choice for adoption as a bioindicator of Great Lakes water quality, in combination with several colonial waterbird species. This would strengthen the use of avian species as bioindicators of Great Lakes health, as well as appeal to the public as suitable species for use in educational programs related to the effects of environmental pollutants in the Great Lakes Basin.

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