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Assessment of environmental endocrine disruptors in bald eagles of the Great Lakes

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Abstract

Environmental endocrine disruption in wildlife has primarily focused on estrogenic/androgenic end points and their antagonists. We describe here the work that has occurred within the Great Lakes of North America that has used the bald eagle (*Haliaeetus leucocephalus*) as a sentinel species of the effects of environmental toxicants, including endocrine disruption. Our data suggests that population level effects of hormone disrupting chemicals, not necessarily estrogen/androgen mimics and their antagonists, have been associated with reproductive and teratogenic effects observed in the bald eagle population within the Great Lakes Basin. Additional laboratory and field studies are necessary to further clarify the role of environmental endocrine disruptors on reproduction in avian populations. The use of sea eagles (*Haliaeetus* spp.) as biosentinels of pollution in other regions of the world is also discussed.

Keywords: Bald eagle; *Haliaeetus leucocephalus*; Endocrine disruptors; Teratogen

1. Introduction

The debate over the effects of environmental endocrine disruptors has primarily focused on estrogenic, anti-estrogenic, androgenic and anti-androgenic pathways and effects within wildlife and human populations. While these pathways are important, the potential effects of these compounds on other metabolic pathways, which are also a part of the endocrine system, have largely been overlooked. A recent review of xenobiotic modulation of endocrine function in birds found that there is plausibility of environmental endocrine disruptors being a causative agent in many different reproductive problems in avian species (Feyk and Giesy, 1998). The complexity of the endocrine system and differential effects among species, however, make direct cause-effect linkages difficult. In the case of female–female pairings and low male/female ratios in some gull (*Larus* spp.) populations, both environmental endocrine disruptors and other mechanisms that could cause differential male mortality are equally plausible (Feyk and Giesy, 1998).

While *p,p'*-DDE studies have been primarily focused on the weakly estrogenic effects of this compound as the mechanism for egg shell thinning in birds (Feyk and Giesy, 1998), the most current theory regarding the

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effects of *p,p'*-DDE on egg shell thinning in avian species involves the inhibition of prostaglandin synthesis in the egg shell gland muscosa (Lundholm, 1997; Feyk and Giesy, 1998). The reduction of prostaglandin synthetase, prostaglandin E_2, and uptake of Ca by the egg shell gland mucosa is linked to *p,p'*-DDE influenced egg shell thinning. The degree of shell thinning is species specific, however (Lundholm, 1997). While this relationship is not an estrogenic receptor mediated effect of an environmental endocrine disrupting chemical, it is still responsible for population level effects in birds. As this case illustrates, it is necessary not only to focus our research on estrogen/androgen mimics and antagonists, but also to explore the mechanisms and pathways of other endocrine modulated adverse effects. Additional laboratory and field studies are necessary to further clarify the role of environmental endocrine disruptors on reproduction in avian populations. As the following example, the bald eagle (*Haliaeetus leucocephalus*) population in the Great Lakes region, illustrates, there still are chemicals in the environment at low concentrations that do cause subtle effects in birds resulting in population level impacts.

2. Bald eagles and xenobiotics

Bald eagle populations in North America have increased in numbers of breeding pairs since the ban of DDT and other organochlorine compounds in the 1970s. The lessening of egg shell thinning effects of DDT's metabolite, *p,p'*-DDE, has been a major reason for the current resurgence of bald eagle populations in temperate North America (Grier, 1982; Postupalsky, 1985; Colborn, 1991). However, the recovery has not been uniform and several regions, where populations are not reproducing at a level considered to be healthy continue to exist (Colborn, 1991). One of the areas is the Basin of the Laurentian Great Lakes, where *p,p'*-DDE and polychlorinated biphenyls (PCBs) have been linked to poor reproductive success (Bowerman, 1991; Kozie and Anderson, 1991; Best et al., 1994).

Bald eagles are sensitive to some types of chlorinated hydrocarbon compounds especially polychlorinated diaromatic hydrocarbons (PCDH). For instance, the ability to produce viable eggs is impaired by exposure to some of these compounds while others are teratogenic (Wiemeyer et al., 1984; Kubiak et al., 1989; Gilbertson et al., 1991; Bowerman et al., 1994; Giesy et al., 1994). The bald eagle has been suggested as a biological indicator species of toxic effects of organochlorine compounds on piscivorus wildlife and the effects of bioaccumulation and biomagnification in the Great Lakes. Eagle forage primarily on fish and other vertebrates associated with coastal Great Lakes, riverine and interior aquatic systems. Concentrations of *p,p'*-DDE and PCBs in plasma of nestlings reflect their exposure to these compounds from prey species within the breeding area (Frenzel, 1985; Bowerman et al., 1994; Giesy et al., 1994).

We will review the evidence for reproductive and teratogenic effects in bald eagles of the Great Lakes and the relationship of these effects to environmental endocrine disrupting chemicals.

3. Concentrations in eggs

We recently examined the concentrations of *p,p'*-DDE and total PCBs in 61 unhatched eggs collected for the period 1968–1995 from bald eagles nesting along the shorelines and islands of the Great Lakes (Bowerman et al., 1998). The no observable adverse effect concentrations (NOAEC) based on a productivity rate of 1.0 fledged young per occupied nest were determined by 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 al., 1984). Concentrations associated with near total reproductive failure, i.e., a productivity rate of <0.10, were determined by weighted sigmoidal regression 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 for the period 1968–1995 in the concentrations of either total PCBs or *p,p'*-DDE (Bowerman et al., 1998). Only one of 61 eggs collected since 1985 from along the shorelines or islands of the Great Lakes has had total PCB concentrations less than the calculated NOAEC, while 25 of these eggs (41.7%) 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 five of these 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 decrease 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; Bowerman et al., 1995, 1998). 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 ($r^2 = 0.63$) (Best et al., 1994; Bowerman et al., 1995).

4. Concentrations in blood

We utilized blood plasma collected from nestling bald eagles to also examine the influence of locally available toxicants to reproduction (Bowerman, 1993; Best et al., 1994). This method was developed for two reasons: the inability to collect 'fresh' eggs due to the bald eagles' status under the US Federal Endangered Species Act; and, as a means to supplement the existing contaminants data from unhatched eggs for areas of interest. Since nestlings can only derive the concentrations of environmental toxicants through their food, levels in their blood plasma indicate the extent of localized contamination. We have observed that concentrations of *p,p′*-DDE and total PCBs in blood plasma of nestlings is significantly and inversely correlated to productivity of nesting eagles across the Great Lakes Basin (Bowerman, 1993; Best et al., 1994). Those breeding populations that nest remote from the Great Lakes food web have significantly greater and unimpaired reproduction in contrast to those populations that feed from the Great Lakes and whose populations have reproductive impairment (Bowerman, 1993; Best et al., 1994).

5. Developmental deformities

We have documented 12 incidences of developmental deformities in nestling bald eagles in the Great Lakes Region (Bowerman et al., 1994; Bowerman et al., 1998). Developmental deformities observed have been primarily bill deformities including not only crossed-bills ($n = 9$) and 1 shortened upper mandible, but also one case of bilateral foot deformities, and one case of fused-vertebrae and hip displacement (Bowerman et al., 1994, 1998).

The incidence of deformed nestling eagles within Michigan 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 (Bowerman et al., 1994). 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 (Giesy et al., 1994; Bowerman et al., 1998).

6. Laboratory to field linkage

While field studies have observed teratogenic effects in bald eagles and other waterbirds of the Great Lakes (Yamashita et al., 1993; Giesy et al., 1994; Bowerman et al., 1994, 1998), the need to link contaminant concentrations from potential food items in the Great Lakes to observed effects in birds was necessary. A number of laboratory studies using white leghorn chickens (*Gallus domesticus*) (Yamashita et al., 1993; Summer et al., 1996a,b) and American kestrels (*Falco sparverius*) (Hoffman et al., 1998) have shown a linkage between the concentrations associated with Great Lakes fishes typically taken by bald eagles and waterbirds. The same suite of developmental deformities seen in the field were observed in these controlled laboratory studies.

7. Regional reproduction

The bald eagle is currently distributed as a breeding species along the shorelines and islands of four of the five Great Lakes: Superior, Michigan, Huron, and Erie (Bowerman, 1993). Surveys for bald eagle reproductive activity have been conducted yearly for the entirety of Michigan and Ohio, and for smaller regions of Minnesota, Wisconsin, and Ontario. Two aerial surveys are utilized except in southern Ontario, where ground observations are used. Timing of the surveys coincide with nest initiation and post-hatching, and are dependent on local conditions and previous experience (Postupalsky, 1974).

We analyzed reproductive data for the states that have nesting eagles along the shorelines and islands of the Great Lakes (Michigan, Minnesota, Ohio, and Wisconsin) for the period 1973–1995 (Bowerman et al., 1998). The number of occupied nests and fledged young have increased over time in all four states. The productivity rate, (e.g., the number of fledged young divided by the number of occupied nests) has increased over time and is consistently near or above the 1.0 rate associated with a healthy population (Bowerman et al., 1998).

We also examined reproductive data for the state of Michigan on a regional basis for the period 1961–1995. We compared eagles that nest along the shorelines and islands of the Great Lakes or along rivers open to Great Lakes fish runs (Great Lakes nests) to those that nest further inland (Interior nests) (Bowerman et al., 1998). The number of occupied nests and fledged young have increased over time in both regions. However, the productivity rate of Great Lakes nests is significantly less than the productivity rate of Interior nests. The Interior nests are consistently at or above the rate associated with an impaired population. However, the Great Lakes nests exhibit a consistently increasing trend in productivity rate and are approaching the rate associated with a healthy population (Bowerman et al., 1998).

Based on the productivity rate for the Great Lakes nests prior to 1989, the increase in new nests located along the Great Lakes can only be explained by immigration of adults from Interior regions of Michigan, Minnesota, and Wisconsin (Colborn, 1991; Bowerman, 1993; Best et al., 1994; Bowerman et al., 1995). This fact, coupled with concentrations in abandoned eggs and blood plasma from nestlings from the Great Lakes nests that are above NOAEC, clearly indicate that the Great Lakes nests have been acting as a population 'sink' for the Midwest regional bald eagle population. The two primary compounds currently linked to reproductive effects in bald eagles in the Great Lakes nests, *p,p′*-DDE and total PCBs, have both been classified as environmental endocrine disruptors.

8. Use as an ecosystem monitor species

The bald eagle is one of the species put forward as a potential ecosystem monitor of Great Lakes water quality under the Great Lakes Water Quality Agreement. Previously, the International Joint Commission developed a set of criteria for a General Objective of Ecosystem Quality which have been adopted for use in designating an ecosystem monitor species (International Joint Commission, 1985). These criteria were:

- be indigenous and maintain itself through natural reproduction;
- interact directly with many components of its ecosystem;
- have well documented and quantified niche dimensions expressed in terms of metabolic and behaviourial responses;
- exhibit a gradual response to a variety of human induced stresses;
- serve as a diagnostic tool for specific stresses of many sorts;
- respond to stresses in a manner that is both identifiable and quantifiable;
- be a suitable species for laboratory investigations;
- be generally recognized as important to humans; and
- serve to indicate aspects of ecosystem quality other than those represented by presently accepted parameters.

A number of workshops convened by the International Joint Commission have explored the use of the bald eagle and other potential ecosystem monitors by determining the strengths and weaknesses of each species by using these criteria. Eagles have consistently been one of the species that have been recommended for inclusion in the Great Lakes Water Quality Agreement (International Joint Commission, 1991, 1992).

Bald eagles are indigenous to the Great Lakes Basin and as a tertiary predator at the top of the Great Lakes food web, are a good indicator of the effects of bioaccumulative organochlorine compounds. It is one of the most studied species in North America and a great amount of natural life history information, including the response of various stressors on its ability to reproduce are well known. As the symbol of the United States and a well-known species to citizens of both the US and Canada, it is of importance to humans. It is also non-duplicative of the other two designated ecosystem monitors for eutrophication, the lake trout (*Salvelinus namaycush*) and *Pontoporeia hoyi*.

The bald eagle is one of the only avian species that one can get an actual 'measure' of their populations, rather than an 'index' of the population. Eagles have been censussed since the early 1960s throughout the Basin using aerial breeding surveys. Two separate surveys are conducted, an early survey to document occupancy of breeding areas (the area encompassing the nests and territory defended by an individual pair of eagles) by adults, and a late survey to determine if hatchlings were produced and to count the number of hatchlings. A third survey occurs in many areas when nest trees are climbed and young are banded. The results of the second survey are corrected based on the number of young found in the nest during banding, and then the productivity (the ratio of fledged young per occupied breeding area) is determined. Since annual breeding area data exist for many breeding areas for over 35 years, this database is quite important for understanding the effects of organochlorine compounds in the Great Lakes Basin.

Some of the limitations of using the bald eagle include its distribution on only 4 of the 5 Great Lakes and its limited use as a laboratory animal due to its protected status under the US Endangered Species Act. However, the US proposed the removal of the bald eagle from the Endangered Species list during 1999. This may allow for the increased ability to use the bald eagle as a laboratory species.

9. Potential for using sea eagles as environmental monitors

We believe that there is direct applicability of our experience using our indigenous sea eagle, the bald eagle, in the Great Lakes region, to the potential use of other sea eagle species (*Haliaeetus* spp.) across the world to monitor local environmental quality. Since sea eagles typically nest in the tops of trees and actual population counts can be done for specific areas, collection of abandoned eggs, feathers, and blood plasma from nestlings can be accomplished for these species. The large size of these birds permits large samples of these tissues for analysis. Since sea eagles are at the top of the avian aquatic food webs, they too can be used as indicator species of ecosystem health, much like we have done with the bald eagle in the Great Lakes. The transfer of this technology and methodology has previously been successful for the white-tailed sea eagle (*Haliaeetus albicilla*) in Sweden (Björn Helander, personal communication).

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