CONTAMINANT EXPOSURE OF BALD EAGLES VIA PREY AT VOYAGEURS NATIONAL PARK, MINNESOTA, 1993

by

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ABSTRACT

Voyageurs National Park (VNP) represents a major concentration site for nesting bald eagles (Haliaeetus leucocephalus), which are currently listed in Minnesota as a federally threatened species under the Endangered Species Act of 1973, as amended. Despite the increase in numbers and progress toward recovery in Minnesota from DDE years, the bald eagle population at VNP has lagged behind the recovery of other eagle populations. Recent studies have shown that bald eagles in VNP contain elevated concentrations of certain pesticides and industrial contaminants. Elevated concentrations of polychlorinated biphenyls (PCBs), dichloro diphenyl dichloroethylene (DDE), and mercury and other compounds in the prey base may be contributing to the reduced reproductive success in VNP's eagle population. In order to assess the potential route and degree of contaminant exposure of bald eagles at VNP and the relationship of that exposure to reproductive performance, we obtained eaglet plasma and feathers and known preferred prey items (fish and bird) from selected sites in VNP and adjacent exterior sites during the 1993 breeding season for organochlorine and mercury analysis. Eaglet mercury concentrations, but not total PCBs or DDE, differed among the four major lakes within VNP. However, no significant correlations between eaglet tissue and mean five-year productivity for total PCBs, DDE, or total mercury were observed. Total PCBs and organochlorine pesticides were found in significantly higher concentrations in herring gulls than the fish species obtained throughout the park. Mercury concentrations, on the other hand, were found in high concentrations among all of the four species measured. Mercury concentrations, but not total PCBs or organochlorine pesticides, in VNP prey were equal to fish concentrations determined to have the potential to cause adverse effects on bald eagles in the Great Lakes.

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INTRODUCTION

Voyageurs National Park (VNP) represents a major concentration site for nesting bald eagles (Haliaeetus leucocephalus), which are currently listed in Minnesota as a federally threatened species under the Endangered Species Act of 1973, as amended (16 U.S.C., 1531 et seq.). The productivity and distribution of bald eagle nesting territories in VNP and within three kilometers of the boundary of the park has been monitored since 1973 (Grim and Kallemeyn 1995). The purpose of the ongoing monitoring of the bald eagle population is compliance with the management guidelines of the Endangered Species Act of 1973 (16 U.S.C., 1531 et seq.), the Northern States Bald Eagle Recovery Plan (U.S. Fish and Wildlife Service 1983) and the management policies of the National Park Service. The results are used by VNP to protect bald eagles from human disturbance and park facility expansions and to manage bald eagle habitat in the park (Grim and Kallemeyn 1995).

Preliminary results of the monitoring indicated that, despite the increase in numbers and progress toward recovery in Minnesota from the ban of persistent organochlorine insecticide use (i.e., DDT, dieldrin and metabolites), the bald eagle population at VNP has lagged behind the recovery of other eagle populations. More specifically, monitoring revealed that VNP bald eagle productivity has been significantly lower than in eagle populations of adjacent and nearby forest areas (Superior and Chippewa National Forests) (Grim and Kallemeyn 1995). Since 1973, bald eagles in Voyageurs have consistently occupied most breeding areas and initiated the reproductive process and begun

incubation. In 17 of the last 22 years, however, VNP bald eagles failed to achieve a level of 1.0 young/occupied pair, a rate regularly surpassed in healthy uncontaminated eagle populations (Wiemeyer et al. 1974). While several non-contaminant related factors may be contributing to the lower productivity of this population including human disturbance (Fraser et al. 1985, Fink 1992, Grim and Kallemeyn, 1995), severe spring weather (Grim and Kallemeyn 1995), and limited food source availability in early spring (Grim and Kallemeyn 1995, Cole 1987), the bald eagle's position as an upper trophic level predator enables it to bioaccumulate persistent contaminants from a diverse prey base.

Environmental contaminants have been correlated with impaired reproduction rates in eagle populations (Krantz et al. 1970, Wiemeyer et al. 1972, 1984, 1993, Bowerman 1993, Welch 1994). Historically, correlations between bald eagle production rates and environmental contaminants were restricted to a limited sample of unhatched (addled) eggs. Recently, strong correlations between contaminants in eaglet blood samples and productivity rates have been identified in the Great Lakes region (Bowerman 1993). Eaglet blood samples are unique in that they represent a localized area of contamination over a relatively short period of time. Due to these results and the bald eagle's high trophic status in the food web, the analysis of bald eagle blood samples have become an effective tool in monitoring the health of the ecosystem.

Recent studies have shown that plasma collected from nestling bald eagles in VNP contain elevated concentrations of certain pesticides and industrial chemicals (Bowerman et al. 1991, Bowerman 1993, Kozie unpubl. data). In fact, their research has documented that VNP eaglets, which largely reflect local contamination, have some of the highest concentrations of polychlorinated biphenyls (PCBs) and mercury relative to all other Great Lakes areas sampled (MN, WI, MI, OH). Six eaglets bled in 1989 at VNP had plasma total PCB concentrations ranging from 7 to 1615 ug/L. The highest VNP eaglet plasma PCB concentration (1615 ug/L) was much greater than the average Great Lakes eaglet plasma concentration (183 ug/L) and inland eaglet plasma concentration (24 ug/L) (Bowerman et al. 1991, Bowerman 1993). DDE plasma concentrations of the six VNP eaglets ranged from 5-206 ug/L. Two of the eaglets had DDE values (88 and 206 ug/l) that exceeded the Great Lakes bald eaglet mean of 61 ug/l (range 13-306 ug/l) and Great Lakes interior mean value of 20 ug/l (range 2-193 ug/l)). In addition, total mercury levels in eaglet breast feathers collected in VNP in 1989 averaged 20 ug/g (range 5-27 ug/g) as compared to average mercury levels of <10 ug/g (E. Evans, MDNR, unpubl. data) for inland eaglets and the Great Lakes Basin eaglet mean of 9 ug/g (Bowerman 1993).

Elevated concentrations of PCBs, DDE and/or mercury in the prey base may be contributing to the reduced reproductive success in VNP's eagle population. Additive and/or synergistic effects of the three contaminants together is not known. However, low reproductive success coupled with high egg and plasma levels of DDE and PCBs has been noted on the Columbia River where the diet of nesting eagles consists of fish and

fish-eating birds (Garrett et al. 1988, Anthony et al. 1993). Maine eagle productivity was significantly correlated with DDE blood residues, but no correlations were found for PCBs and mercury (Welch 1994). Predation on fish-eating birds (i.e., gulls, herons, grebes, etc.) has been implicated as the primary cause of contaminant-related reproductive problems for nesting eagles in the Apostle Islands National Lakeshore (Kozie 1986, Kozie et al. 1991) and in the Klamath Basin and lake in Oregon (Frenzel 1984). Avian prey are generally elevated in organochlorine concentrations well above those found in fish and other aquatic organisms on which they forage. The additional trophic levels added to its prey base have contributed to some of the highest organochlorine residues in addled eggs and blood encountered in eagles (Wiemeyer et al. 1984, Bowerman 1991, Bowerman and Giesy 1991).

The primary sources of organochlorine pesticides and PCB contaminants in VNP eaglets are largely unknown. However, during 1958-1961 approximately 5,265 ha of forest land (which now lies within VNP) were treated with dichlorodiphenyltrichloroethane (DDT) to control the eastern spruce budworm (Choristoneura fumiferana)[Clem.] (Minnesota Department of Agriculture and United States Forest Service 1973). After the United States banned the use of DDT in 1972, bald eagle populations throughout North American began recovering from depressed reproduction and began returning to healthy population sizes (Kaiser et al. 1980, Wiemeyer et al. 1984).

Mercury is a persistent neurotoxin that bioaccumulates in aquatic systems and can negatively affect survival and reproductive success in high trophic-level wildlife. Atmospheric deposition of mercury from anthropogenic sources occurs on both a regional and global scale. In Minnesota, virtually all mercury in aquatic systems is from atmospheric deposition; today approximately 75% of this mercury is human-generated (Swain et al. 1992). The main anthropogenic sources in Minnesota are fossil fuel combustion, municipal waste combustion, and the intentional use of mercury in manufactured products (MPCA Mercury Task Force 1994).

The Fish and Wildlife Service (USFWS), through the Endangered Species Program, has the responsibility to assure that the recovery of the bald eagle proceeds according to the Northern States Bald Eagle Recovery Plan (USFWS 1983). Recovery 2000 addresses limiting factors for the eagle and states that "the species needs a contaminant-free prey base (fish and waterfowl)...". In order to assess the potential level of contaminant exposure of bald eagles at VNP and the relationship of that exposure to reproductive performance, we collected blood and feathers from eaglets at 18 nest sites and known preferred prey items (fish and birds) obtained from 26 breeding territories associated with those sites in or near VNP during the 1993 breeding season. The samples were then analyzed for organochlorine pesticides, total PCB and mercury. The purpose of these collections was to provide samples from which we could determine (a) the source of organochlorine and mercury pollutants found in the eaglets; (b) whether organochlorine and mercury levels were different in areas with dissimilar rates of eagle reproductive success; (c) whether geographical variation in metal and organochlorine levels among

nestling plasma and select prey species exists within each lake; and (d) whether gross changes in residue levels in fish had occurred through time.

The overall goal of the study was to provide U.S. Fish and Wildlife Service endangered species personnel and National Park Service management with an assessment of whether locally obtained environmental contaminants may be responsible for the impaired reproductive success of VNP bald eagles. This information may then be used by the U.S. Fish and Wildlife Service to develop appropriate management initiatives to further protect the eagles at VNP. The results may also provide the basis for further assessments of the impacts of biocontaminant exposure to bald eagle productivity at VNP.

STUDY AREA DESCRIPTION

Voyageurs National Park lies within the forested lake country along Minnesota's northern border with Ontario, Canada, and is part of a relatively undisturbed ecosystem of 2.7 million acres that includes the 1.2 million acre Boundary Waters Canoe Area Wilderness and the 1.1 million acre Quentico Provincial Park (Figure 1). This region typifies the Canadian shield topography, having been shaped by glaciation into rolling hills and a complex system of lakes and waterways. Voyageurs encompasses approximately 218,055 acres, of which 83,789 (38.4% of total park area) acres are water. Four major lakes (Rainy, Kabetogama, Namakan, Sand Point) comprise 39% of the park's total area and 96% of the park's total lake area.

The park is part of the southern boreal-northern hardwood forest border (Cole 1987, Pastor and Mladenoff 1992). Vegetative types within Voyageurs include boreal forests of black spruce (Picea mariana), eastern tamarack (Larix laricina), and eastern arborvitae (Thuja occidentalis), and mixed northern hardwood-pine forests of quaking aspen (Populus tremuloides), white, jack, and red pine (Pinus strobus, P. banksiana, P. resinosa), balsam fir (Abies balsemea), maple (Acer ssp.), and paper birch (Betula papyrifera) (Cole 1987). Voyageurs has a broad cross section of wildlife, including 48 species of fish, 16 species of amphibians and reptiles, over 240 species of resident and migratory birds, and 42 species of mammals. Of particular concern are the bald eagle and the gray wolf (Canis lupus), both of which are federally listed as threatened in Minnesota. A more detailed description of the study area is provided elsewhere (Grim and Kallemeyn 1995).

METHODS AND MATERIALS

Nestling Bald Eagle Blood and Feather Collection

Up to 11 cc of blood were collected by Michigan State University Pesticide Research Center (MSUPRC) staff in June 1993 from individual nestling bald eagles (6-8 weeks old) at selected nest sites in VNP. Blood was collected from one nestling per nest. Little variation in contaminant levels among siblings are expected because they are fed the same general prey (Lindberg and Odsjo 1983) and have not exhibited significant differences in residues when compared (Wood et al. 1993, Welch 1994). Blood was collected using sterile techniques from the brachialus vein with heparinized glass syringes fitted with 22 or 24 gauge needles (syringes previously washed with acetone and hexane) (Bowerman 1993). Samples of whole blood were transferred to heparinized vacuum tubes, placed on ice in coolers, and centrifuged within 48 hours of collection. Blood plasma was decanted and transferred to vacuum tubes and frozen. Plasma samples were analyzed for total PCBs and p,p'-DDE. Concentrations of these compounds in the plasma of nestlings reflect their exposure to these compounds from the prey species within the breeding area (Bowerman 1993, Giesy et al. 1993). Whole blood samples were analyzed for total mercury. Mercury concentrations in blood are less variable than those in feathers and represent mercury obtained from prey recently ingested (Stan Wiemeyer, pers. comm. in Wood et al. 1993).

When possible, breast feather samples (n = 3 per nestling) were also obtained for total mercury analysis. Breast feathers emerge on nestlings at about 4-6 weeks after hatch (Bortolotti 1984). Body feathers (versus primaries) provide the most representative sample for estimating mercury concentrations and show the least variation between feathers (Furness et al. 1986). In addition, mercury concentrations in the feathers of young birds show little variation (Solonon and Lodenius 1990). Mercury levels in feathers are assumed to reflect the level circulating in the blood during the period of feather growth (Johnels and Westermark 1969, Westermark et al. 1975). More specifically, the mercury concentrations in feathers reflect both the concentration in food and concentrations accumulated in other tissues of the body at the time of feather formation.

All eaglets in each nest visited were banded with U.S. Fish and Wildlife Service leg bands. Age and sex of nestlings was determined by measuring the eighth primary feather and foot pad and using these measurements in a mathematical growth rate and sexual dimorphisms equation (Bortolotti 1984). Collection methods and sample analysis were coordinated with concurrent studies being done along the Great Lakes shoreline (including Minnesota, Wisconsin, Michigan) to allow comparison of data among populations.

All eaglet blood and feather collections were made in collaboration with MSUPRC under the supervision of Drs. J.P. Giesy and W.W. Bowerman.

Bald Eagle Prey Collections

Avian and fish collection sites (based on active eagle breeding areas) were identified by the USFWS in consultation with VNP, Ontario Ministry of the Environment (OMOE) and MSUPRC personnel. Data on existing eagle nest sites of concern via recent eaglet tissue contaminant analysis and the most current VNP bald eagle reproductive performance (B. Bowerman, L. Grim, L. Kallemeyn, pers. comm) were utilized to prioritize fish and gull breeding colony sampling sites. The sites chosen covered all four major lakes within VNP (Kabetogama, Namakan, Sand Point, Rainy) and included some eagle nest areas sampled in previous years by MSUPRC for eaglet tissue contaminant analysis.

Prey species to be obtained for chemical analysis were determined on the basis of prey remains collected by MSUPRC within and under 44 nests while banding eaglets at VNP from 1989-91 (Bowerman 1993) (Table 1). Predominant fish prey species identified were northern pike (Esox lucius), white sucker (Catostomus commersoni) and walleye (Stizostedion vitreum). The avian prey species collected for the study was the Herring gull (Larus argentatus). The relative importance of fish in the diet of bald eagles may be underestimated by this sampling method because fish parts are easily digested and decompose more rapidly than birds or mammals (Dunstan and Harper 1975; Todd et al. 1982, Mersmann et al. 1992).

In June and July of 1993, 3-5 fish of each of the three species were collected, where possible, within a 1-3 mile radius of each of 11 selected active eagle breeding areas. In addition, fish samples were obtained from a location on the Rainy River (International Falls) downstream of Rainy Lake which serves as an important early season eagle congregating and feeding area. Gill nets and/or trap nets were employed to obtain the necessary samples. Attempts were made to replicate similar size class among individual species. Individual fish were weighed and measured prior to being grouped into composites (Table 2). Fish were stored at -20 degrees C until shipment to the laboratory. Each fish sample chemically analyzed represented a homogenized composite of 3-5 individuals of the same species that were collected from the same sampling location.

In May and June of 1993, samples of 3-5 individual adult herring gulls per breeding colony were trapped or shot (air gun) (Table 3). Young gulls were collected prior to fledging. Trapped adult and chick herring gulls were sacrificed using carbon dioxide asphyxiation. Bird carcasses were transported in iced coolers and then frozen at -20 degrees C until shipment. Each bird was weighed whole and then the feet, beak, wings and feathers of gulls were removed prior to homogenizing. Gulls were grouped into composites based on age and colony location. Gull livers were excised for separate analysis and GI tracts were opened (food habit analyses) but retained prior to shipment to laboratory.

Between 4 and 12 eggs were collected at five gull breeding colonies May 25-28 and June 15, usually within the first 10 days of incubation (Table 3). One egg was taken, at

random, from each completed (three-egg) clutch (where possible), and nests were selected at irregular intervals across the entire colony. Eggs were collected in this manner in order to reduce any biases which may have arisen because of differential ages of birds at the center or edge of the colonies (Coulson 1968, Aebischer and Coulson 1990, Weseloh et al. 1994). Eggs were transported in padded containers and stored at 4 degrees C within 4-8 hours of collection. Egg samples were refrigerated for no more than two weeks prior to measuring and opening. Collections and storage of herring gull eggs and carcasses closely followed the Great Lakes International Herring Gull Surveillance Plan (GLISP) handbook (Weseloh et al. 1991).

Within one to two weeks after collection, eggs were cut open around the equator with hexane-rinsed dissecting scissors, and individual egg contents were removed and frozen at -20 degrees C in chemically clean jars until shipment to the laboratory. Burger and Gochfield (1995) have determined that there are no differences in contaminant results for herring gull eggs analytically sampled at 1, 6, 12, or 24 months post collection date. Consequently, we have no reason to believe storage time was a factor in differences between contaminant levels between gull colonies.

Before measuring eggshell thickness (shell plus shell membranes), the eggs were rinsed with water and air-dried for approximately 2 months. Eggshell thickness was measured at three sites around the equator of each egg using a Starrett dial-gauge micrometer accurate to 0.001 mm. The mean of these three measurements was reported as eggshell thickness (mm). The length and breadth of eggs was measured with Vernier calipers (accurate to 0.1 mm) and a volume index was calculated (length X breadth^2).

The appropriate United States, Canadian (including provincial) and state permits were obtained for all collections.

Chemical Analysis of Samples

Levels of environmental contaminants in bald eagles were determined by residue analysis of samples of eaglet whole blood, plasma, and breast feathers collected in the study area. Whole fish and herring gull eggs, carcasses and livers were chemically analyzed to determine if potential eagle prey items were accumulating environmental contaminants.

Eaglet plasma samples were analyzed by the Aquatic Toxicology Laboratory at Michigan State University (MUS-ATL) for total PCBs and chlorinated hydrocarbons. MSU-ATL analytical methods are described elsewhere (Bowerman 1993). Total concentrations of PCBs were determined by congener summing. The calibration standard consisted of a 1:1:1:1 mixture of Aroclors 1242, 1248, 1254, and 1260.

All composites of homogenized whole fish and herring gull carcass (skin and GI tract intact), liver, and whole egg samples were analyzed for organochlorine pesticides, total PCBs and mercury (Table 5). Birds were not sexed; however, mean residues in

organochlorines in male gulls have not been found to be significantly different from those in females in other studies (Braune and Norstrom 1989). Eaglet whole blood was also analyzed for total mercury. Organochlorine, total PCB and mercury analyses for these samples were performed by Hazleton Environmental Services, Inc. (Madison, Wisconsin), a contract laboratory to the Service's Patuxent Analytical Facilities Laboratory in Laurel, Maryland.

All the chemical analyses of egg composites were performed by Hazleton Environmental Service, Inc. (Madison, WI). At the laboratory, individual egg contents were then thawed and homogenized and aliquots of each egg were analyzed as egg pools by colony. Usually, fresh eggs were collected to reduce intersample variance in contaminant levels and to facilitate homogenization. Occasionally, however, embryonated eggs were collected. For this reason, all residue levels were expressed on a fresh-weight basis since this method of calculation is less affected by embryonic development (Peakall and Gilman 1979).

Sample preparation, extraction, and cleanup of organochlorine pesticides and PCBs followed methods outlined by the EPA (1986). Samples were homogenized, ground and prepared with anhydrous sodium sulfate. Analytes were recorded by Soxhlet extraction using the solvent methylene chloride and concentrated in Kaderna-Danish apparatus. Sample cleanup occurred by gel-permeation chromatography. Additional cleanup and separation of PCBs from organochlorine pesticides was conducted using silica gel.

Sample preparation for mercury analysis included digestion with a sulfuric and nitric acid mixture and reduction of mercury using sodium borohydride (Monk 1961). Mercury was determined by cold vapor atomic absorption.

All mercury, total PCB and organochlorine pesticide values are reported in ug/g (whole fish, carcass, liver, or feather) or mg/L (ppm) (blood), wet weight. PCB levels are quoted relative to a 1:1 mix of Arochlor 1254:1260 as the reference standard. DDE and DDD levels quoted are for the p,p'-homolog.

Productivity Data

Aerial surveys have been conducted annually from 1973 to the present by VNP staff to monitor the reproduction and distribution of bald eagles in VNP and immediately adjacent areas (Grim and Kallemeyn 1995). Two sets of data are annually collected from a fixed-winged aircraft. Surveys are conducted on approximately April 10 to determine occupancy of breeding areas and on July 10 to deterine productivity and reproductive success. Traditional survey guidelines, initiated in 1973 by the Minnesota Department of Natural Resources, Chippewa National Forest, and Superior National Forest, were utilized until minor changes were made when new guidelines for aerial surveys for bald eagles became available (Postupalsky 1974; Leighton et al. 1979; Grier et al. 1981; Fraser et al. 1983, 1984). Further explanation of the aerial surveys and eagle

productivity/distribution in VNP are found in Grim and Kallemeyn (1995).

A breeding area may contain several alternate nests, but only one is used for raising young within a given year. Productivity data for the breeding areas were obtained by Grim and Kallemeyn (1995), Minnesota Department of Natural Resources Natural Heritage Information System, and personal communications with Lee Grim (VNP). Data for five-year mean productivity included the year of sampling (1993), the three years preceding the year of collection, and the year following collection for each breeding area sampled (Wiemeyer et al. 1984). Five-year production is considered a better measure of actual production at a breeding area than production in the year of collection because it averages out factors other than contaminants (i.e., severe weather, food availability, human disturbance, etc.) that may have an impact on production. In addition, bald eagle pairs appear to occupy the same breeding area over a period of years (Howell 1954).

Statistical Analysis

Samples containing nondetectable residues were assigned values equal to one-half the detection limit in computing means and other values. Residue levels are presented as arithmetic means in order to facilitate comparisons with published accounts of concentrations of total PCBs, organochlorines and mercury in eaglet, gull, and fish tissue samples. Data was analyzed with PC version 6.11 of the Statistical Analysis Syste (SAS) on a microcomputer. The significance level for all statistical tests was set at the $P<0.05$ level.

Differences of eagle productivity among lakes were determined using either the Kruskal-Wallis one-way analysis of variance, a chi-square approximation test, or the Wilcoxon rank sums test (NPAR1WAY procedure, SAS/STAT 6.11, SAS Institute Inc. 1996). Differences among individual locations were determined using the Duncan's multiple range test. Only breeding areas with at least two years of production data were included in the analyses determining relationships between mean 5-year productivity and contaminant levels in eaglet tissues. One-way ANOVA was used to test for differences in mean 5-year productivity among intervals. Duncan's Multiple Range Test was used to separate means if ANOVA showed significant differences.

Concentrations of mercury, PCBs, and p,p'-DDE in blood and/or feathers of eaglets were compared statistically among geographic areas using the Kruskal-Wallis one-way analysis of variance (NPAR1WAY procedure, SAS/STAT 6.11, SAS Institute Inc. 1996). Correlations among the variables were determined using the Pearson rank correlation procedures (SAS). Relationships between geometric mean concentrations of mercury, PCBs, or p,p-DDE in blood and/or feathers of eaglets and means of five-year mean productivities or nest success rates for the lakes were determined using general linear models for regression analysis (PROC GLM, SAS/STAT 6.11, SAS Institute Inc. 1996).

Differences between contaminant burdens in herring gulls and fish were determined by

the Kruskal-Wallis one-way analysis of variance, a chi-square approximation test, or the Wilcoxen rank sums test (NPAR1WAY procedure, SAS/STAT 6.11, SAS Institute Inc. 1996). Correlations among the variables were determined using the Pearson rank correlation procedures. Relationships between geometric mean concentrations of mercury, PCBs, or p,p-DDE in herring gulls and fish and geographic areas were determined using general linear models for regression analysis (PROC GLM, SAS/STAT 6.11, SAS Institute Inc. 1996).

RESULTS

Eagle Productivity

Individual sampled nest reproductive summaries for all bald eagle breeding areas observed within and immediately adjacent to VNP are provided in Table 6 with all years of eaglet tissue collections (by several researchers) in VNP being designated. In addition, Table 7 provides a mean five-year (1990-1994) summary of observed bald eagle reproduction within and immediately adjacent to VNP.

Bald eagles nesting in Voyageurs National Park and immediately adjacent to the Park along the Canadian border of Rainy and Namakan Lakes produced an average of 0.97 young/occupied breeding area from 1990-1994 and had an average nest success of 65%. Limited statewide eagle productivity data for 1990-1994 precluded any comparisons. Historically, however, the Park has fallen well below the Minnesota state averages (1973-1993), with average productivity being 0.68 and 45% nest success versus 1.15 young/occupied breeding area and 69% nest success, respectively (Figures 2 and 3). Voyaguers National Park average productivity and percent of nest success have not yet met the criteria of at least 50% of the nesting pairs successfully producing 1.0 young/occupied nest to maintain a healthy population (Wiemeyer et al. 1984). Productivity and percent of nest success in VNP were below those criteria 76% and 90% respectively, for all 21 years observed and were not realized in 70% and 81%, respectively, of the VNP breeding areas (Grim and Kallemeyn 1995).

Within and directly adjacent to VNP, average productivity and percent of nest success among all occupied nests during the 1990-1994 period varied among the four major lakes, but were not significantly different. For example, Kabetogama Lake (n = 16) had the highest young per occupied nest (1.2) and nest success (76%) followed by Sand Point (n = 4, 0.99 and 59%), Rainy Lake (n = 27, 0.80, 55%) and Namakan Lake (n = 10, 0.76 and 52%), respectively.

Due to the limited breeding areas in and directly outside VNP (n = 37), caution must be taken when interpreting these reproductive parameters. In order to measure population stability, productivity figures (i.e., annual values) have been useful indicators (Sprunt et al. 1973). However, caution must be applied to small eagle populations (Kozie and

Anderson 1991).

Contaminant Levels in Nestling Bald Eagles

Analysis of plasma, whole blood and breast feathers from 18 eaglets (8-11 weeks of age) representing 18 different breeding areas collected in 1993 revealed detectable levels of DDE, PCBs, and mercury in all samples where analysis occurred (Table 8).

Total mercury mean concentrations within and immediately adjacent to VNP in eaglet whole blood and feathers were 0.34 mg/L (range 0.13-0.98 mg/l) and 9.91 ug/g (range 3.59-23.10 ug/g), respectively. Because nestling mean feather mercury concentrations were determined to be significantly higher than nestling mean blood mercury concentrations, mercury from the two tissues were independently statistically analyzed. The relationship between mercury concentrations in nestling feathers and blood were examined. A Pearson product-moment correlation on non-transformed data of mercury levels in nestling blood samples were significantly positively correlated ($r^2 = 0.79$) with feather mercury sample levels.

Significant differences in mercury exposure in both blood and feathers were observed among the four lake types (Table 9). Mean concentrations of whole blood mercury from eaglets in Sand Point/Mukooda Lake were significantly higher (0.81 mg/L) than whole blood mercury concentrations from Rainy (0.39 mg/L) and Namakan (0.36 mg/L) lake eaglets. These three lakes had significantly higher whole blood mercury concentrations than Kabetogama lake (0.17 mg/L). Mean breast feather mercury concentrations were also significantly higher (19.95 mg/L) at Sand Point/Mukooda lake than Namakan (12.62 mg/L), Rainy (9.06 mg/L) and Kabetogama lakes (6.24 mg/L). Lowest mercury concentrations occurred at both W. Zollner Island and Watson's Cabin (Kabetogama Lake) nest sites. Highest concentrations occurred at Swanson's Bay (Sand Point Lake) and Mukooda (Sand Point) nest sites.

No significant correlations between nestling whole blood or feather mercury concentrations and mean five-year productivity were observed.

Mean eaglet plasma concentrations from within and directly adjacent to the park for total PCBs and p,p'-DDE were 0.06 mg/L (range 0.01-0.34 mg/L) and 0.02 mg/L (range 0.004-0.154 mg/L), respectively. No significant differences were found among the lakes in eaglet plasma PCB or p,p'-DDE mean concentrations (Table 10). Mean eaglet plasma PCB concentrations in the four major lakes were as follows: Rainy Lake (0.10 mg/L, $n=4$), Namakan Lake (0.09 mg/L, $n=3$), Sand Point Lake (0.07 mg/L, $n=2$) and Kabetogama (0.02 mg/L, $n=7$). Mean eaglet p,p'-DDE concentrations within the four lakes are as follows: Rainy Lake (0.04 mg/L, $n=4$), Namakan Lake (0.04 mg/L, $n=3$), Sand Point Lake (0.02 mg/L, $n=2$), and Kabetogama Lake (0.01 mg/L, $n=7$).

Although not significant, concentrations varied among breeding areas and lakes, with the

lowest concentration of PCBs found in nestlings from Gold Portage II breeding area (Black Bay, Rainy Lake) and the highest in a nestling from West Eight Mile III breeding area (Rainy Lake). Lowest and highest p,p'-DDE concentrations in 1993 occurred at the same nest sites mentioned above, respectively.

No significant correlations were observed between PCB and p,p'-DDE concentrations in nestling plasma samples and mean five-year productivity.

Mean eaglet whole blood mercury concentrations were not significantly correlated ($P<0.001$) with plasma PCB concentrations ($r^2 = 0.30$) or plasma DDE concentrations ($r^2 = 0.23$). However, mean breast feather mercury concentrations were significantly correlated ($P<0.001$, $r^2 = 0.73$) with plasma PCB concentrations and DDE concentrations ($P<0.001$, $r^2 = 0.70$). Mean plasma PCB concentrations were significantly correlated ($P<0.001$, $r^2 = 0.98$) with mean plasma p,p'-DDE concentrations.

Contaminants in Eagle Prey

Fish

Analysis of 11 northern pike, 9 walleye, and 6 sucker composite samples (n=26 samples, n=75 individuals) collected from VNP and Rainy River showed detectable concentrations of total Hg in all samples (Table 11). Mean mercury concentrations were significantly higher in northern pike (0.55 ug/g) and walleye (0.40 ug/g) than in white sucker (0.08 ug/g) within VNP. In addition, mean mercury concentrations among all fish species were significantly higher in Sand Point Lake (0.68 ug/g) and Namakan (0.43 ug/g) than in Rainy Lake (0.32 ug/g) and Kabetogama Lake (0.18 ug/g). The highest total Hg concentrations were found in northern pike at Mukooda (0.95 ug/g)(Sand Point Lake), Gull Island (0.90 ug/g)(Namakan Lake), Saginaw-Paysan (0.85 ug/g)(Rainy Lake), and Swanson's Bay (0.74 ug/g)(Sand Point Lake). The only differences within individual species and lakes occurred with northern pike: mean mercury concentrations in this species was significantly higher in Sand Point Lake (0.84 ug/g) than in Kabetogama Lake (0.15 ug/g).

Total PCBs, p,p'-DDE, p,p'-DDT, and trans-nonachlor were detected in fish but at low concentrations or in only a few samples (Table 11); detectable concentrations of total PCBs, DDE, DDT and trans-nonachlor occurred in 3, 17, 1, and 1 of 26 samples, respectively. A white sucker composite from Anchor Bay (Rainy Lake) measured 0.19 ug/g p,p'-DDE. No significant differences were found in PCB or p,p-DDE concentrations among the three fish species or four major lakes.

Hexachlorobenzene, alpha BHC, beta BHC, gamma BHC, alpha chlordane, gamma chlordane, heptachlor epoxide, oxychlordane, endrin, toxaphene, mirex, o,p'-DDD, p,p'-DDE, and o,p'-DDT were not detected in fish.

Herring Gulls

Analysis of 4 adult (n = 10 individuals), 4 chick (n = 17 individuals), and 5 egg (n = 35 eggs) herring gull composite samples collected from five colonies from VNP showed detectable concentrations of total Hg, total PCBs, and DDE in all liver, carcass and egg samples (Table 12). Detectable, but low concentrations of DDT occurred in four samples. One exception was an adult Seven Sister's Island herrng gull whole carcass composite which had a DDT concentration of 1.6 ug/g. Dieldrin, p,p'-DDD, hexachlorobenzene, heptachlor epoxide, alpha chlordane, trans-chlordane, oxychlordane, and mirex were also detected but concentrations were low.

The mean total Hg concentration for adult whole carcass, chick whole carcass, and whole egg composites of herring gulls from within and directly adjacent to the VNP were 0.97 (range 0.46-1.91), 0.13 (range 0.04-0.29), and 0.27 ug/g (0.10-0.44 ug/g), respectively. The mean total Hg concentration for liver in adult and chick herring gulls were 2.96 (range 0.89-6.98 ug/g) and 0.33 ug/g (range 0.11-0.66 ug/g), respectively. The highest total Hg adult gull carcass and liver composite concentration (1.91 and 6.98 ug/g, respectively) and chick concentrations (0.29 and 0.66 ug/g, respectively) occurred at the Anchor Island colony (Rainy Lake) (Figure 6). Mean mercury concentrations in adults (2.0 ug/g) were significantly greater than mean mercury concentrations in eggs (0.3 ug/g) and chicks (0.2 ug/g).

Mean total PCB concentrations for whole carcass adult, whole carcass chick, and whole egg composites of herring gulls were 6.70 (range 3.8-9.0), 0.66 (range 0.45-1.0), and 5.18 ug/g (range 4.8-6.10), respectively. The highest concentrations for both adult and chick carcass concentrations occurred at Seven Sister's Island colony (Rainy Lake) (Figure 7). Mean total PCB concentrations for adult and chick liver composites were 3.78 (range 3.10-4.50) and 0.19 ug/g (range 0.10-0.30), respectively. Highest total PCB adult and chick liver concentrations both occurred at the Anchor Island colony (Rainy Lake). Mean PCB concentrations in both eggs (5.3 ug/g) and adults (5.3 ug/g) were significantly greater than mean PCB concentrations of nestlings (0.4 ug/g).

Mean p,p'-DDE concentrations for whole carcass adult and chick, and whole egg composites of herring gulls were 2.15 (range 1.1-3.2), 0.22 (range 0.13-0.31), and 1.94 ug/g (range 1.3-3.0), respectively. Highest total p,p'-DDE concentrations for whole carcass adult and chick gulls occurred at Seven Sister's Island colony (Rainy Lake). Highest whole egg DDE concentrations occurred at Anchor Island colony (Rainy Lake) (Figure 8). Mean DDE concentrations in eggs (1.9 ug/g) and adults (1.5 ug/g) were significantly greater than mean DDE concentrations in nestlings (0.1 ug/g).

Alpha BHC, beta BHC, gamma BHC, endrin, gamma chlordane, toxaphene, o,p'-DDD, o,p'-DDE, and o,p'-DDT were not detected in herring gulls.

Among species, overall mean concentrations (adult, chick, egg) of PCBs in herring gulls

(3.4 ug/g) were significantly higher than mean concentrations in white sucker (0.06 ug/g), northern pike (0.03 ug/g) and walleye (0.03 ug/g). Herring gull overall mean concentrations of DDE (1.1 ug/g) were significantly higher than white sucker (0.04 ug/g), northern pike (0.02 ug/g) and walleye (0.02 ug/g). No significant differences of mean mercury concentrations were found among the four species.

Eggshell thickness

Mean herring gull eggshell thickness ranged between 0.36 mm and 0.41 mm at the five study colonies (Table 13), with an overall unweighted mean thickness of 0.384 mm. There were no significant differences in eggshell thickness amongst colonies, but Pine Island (Kabetogama Lake) averaged 10-14% thicker than those in the other colonies. Eggshells from Anchor (Rainy Lake) and Seven Sister's Islands (Rainy Lake) were thinner (0.5-4%) than in pre-1947 (i.e., pre-DDT) samples measured in museum collections (Anderson and Hickey 1972). However, eggshells from Gull (Namakan Lake), Pine (Kabetogama Lake), and Boob's Islands (Rainy Lake) were thicker (1.3-10%) than the pre-1947 samples. For this sample of five colonies, mean eggshell thickness was not correlated significantly with the compounds.

DISCUSSION

Eagle Contaminant Burdens

Mercury

Mercury levels recorded in eaglet blood and feather samples collected within VNP and adjacent areas varied geographically and were significantly higher in Sand Point Lake than in other major VNP lakes. Mean mercury concentrations recorded in VNP eaglet whole blood in 1993 were similar to mercury concentration in eaglets in Maine (Welch 1994), the Columbia River (Anthony et al. 1993) and Washington (Wiemeyer et al. 1989) (Table 14) where eagle productivity is impaired. Mercury concentrations recorded in the breast feathers of VNP eaglets in 1989 (Kozie, unpubl. data) and 1993 exceeded levels observed in the Great Lakes (Bowerman 1993, E. Evans, unpubl. data), Maine (Welch 1994) and Florida (Wood et al. 1993) since 1985.

Two of the main water bodies, namely Sand Point and Namakan lakes, had mean eaglet feather mercury concentrations greater than 11 ug/g. In addition, six of the fifteen eaglets from all four major lakes had feather mercury concentrations exceeding 11 ug/g. Eisler (1987) reported that 5-11 ug/g of mercury in feathers for various bird species was associated with reduced hatch and sterility. Heinz (1979) reported that 9-11 ug/g mercury in mallard feathers was associated with behavioral changes and reduced reproduction. Sterility was observed in sparrowhawks (Accipiter nisus) at 40 ug/g of mercury in feathers (Solonen and Lodenius 1984). Although we do not know what

mercury concentrations are in VNP adult eagles, Wood et al. (1993) found that nests with high adult feather mercury concentrations also had high nestling feather concentrations. Thus, it appears that VNP eaglets are bioaccumulating mercury at levels that may be of concern.

Welch (1994) observed a 30% reduction in feather mercury concentrations of Maine eaglets between two sampling periods (6 weeks and 9 weeks of age). She stated that the change in mercury levels may be the result of a simple dilution process with increasing body weight suggesting that mercury deposition into developing feathers may provide eaglets a significant degree of protection from elevated levels of mercury. Feather mercury levels may account for 50-93% of the body's mercury burden (Honda et al. 1986, Braune and Gaskin 1987). This protective "barrier" may decrease and/or diminish as an eagle matures, due to the limited number of feathers growing at any one point in time (Welch 1994). Great white egrets (Egretta alba modesta) have also demonstrated a similar pattern in mercury levels (Honda et al. 1986). However, post-fledging birds continued to accumulate mercury with age.

Mercury concentrations in blood and feathers have not been correlated with reduced reproductive rates in bald eagles (this study, Welch 1994, Bowerman et al. 1994, Bowerman 1993, Bowermn et al. 1991); however, limited studies exist that have used eaglet feathers and/or blood as an indicator of metal exposure. Wiemeyer et al. (1993), however, suggested that adverse effects of mercury on bald eagle reproduction might be expected when eggs contain more than 0.5 ug/g mercury. No eagle eggs have been successfully collected and analyzed for mercury at VNP. Lack of information relating known exposures of mercury to concentrations in blood and feathers and effects on bald eagle health prevents a completely adequate interpretation of the data. However, mercury hazards to bald eagles via prey have been determined (Giesy et al. 1995). Potential impacts of mercury in prey of bald eagles at VNP will be discussed elsewhere in this report.

Polychlorinated biphenyls

PCB mean levels recorded in VNP nestlings in 1993 were slightly higher than mean concentrations reported for eagles in the adjacent Chippewa and Superior National Forests and Upper and Lower Peninsulas of Michigan (Bowerman 1993), but were lower than mean concentrations reported in the Great Lakes (Bowerman 1993), Oregon (Wiemeyer et al. 1989), Columbia River (Anthony et al. 1993), and Maine (Welch 1994) (Table 15) where eagle productivity is impaired. (Please note: reports reported for whole blood must be multiplied by two to compare with plasma concentrations.) PCB concentrations in eaglets sampled along other inland lakes in Minnesota averaged approximately 0.006 ug/g (Bowerman 1993) versus VNP average of 0.6 in 1993.

PCB concentrations in eaglet blood (Bowerman 1993) and eggs (Wiemeyer et al. 1993)

have been correlated with reduced reproductive rates in bald eagles. Total PCB concentrations in plasma were significantly and inversely correlated with reduced productivity in bald eagles in the Great Lakes from 1989-1991 (Bowerman 1993), but were not correlated along the Columbia River estuary (Anthony et al. 1993) or Maine (Welch 1994). No correlation was observed between PCBs and productivity rates in this study which is contrary to results reported with VNP eagle data collected from 1989-91 (Bowerman 1993). Eaglets sampled from Maine (both estuarine and inland lakes) (Welch 1994) had geometric means that were 6-20 times the PCB levels from eaglets from the shores of the Great Lakes (Bowerman 1993) and were 30 time higher than levels reported for eagles along the Columbia River estuary (Anthony et al. 1993). The elevated levels of total PCBs at non-correlated sites possibly reflect a high percentage of low toxicity congeners. For example, Welch (1994) found that Maine nestlings that had similar PCB levels had toxicity levels that varied considerably based on H4IIe bioassays and ethoxyresorufin-0-deethylase (EROD) induction.

The effects of PCBs on eagles are difficult to assess because their residues are often highly intercorrelated with organochlorines, especially DDE, making separation of the effects of these two contaminants difficult (Haseltine et al. 1981, Wiemeyer et al. 1984, Anthony et al. 1993). Although PCBs may contribute to adverse effects on reproduction and eggshell thickness of bald eagles, uncertainty to this effect has been addressed (Wiemeyer et al. 1993, 1984, Anthony et al. 1993). Perhaps as DDE concentrations continue to slowly decline in certain areas, PCB effects on bald eagle reproduction will be more readily measured.

DDE

DDE levels recorded in VNP nestlings were higher than concentrations reported in Chippewa and Superior National Forest (Bowerman 1993), but were similar to Great Lakes (Bowerman 1993), Upper and Lower Peninsula of Michigan (Bowerman 1993), and Oregon (Wiemeyer et al. 1989) concentrations (Table 16). Nestlings sampled from the Columbia River estuary (Anthony et al. 1993) and Maine (Welch 1994) had DDE concentrations greatly exceeding concentrations measured in VNP eaglets.

DDE concentrations in eaglet eggs (Wiemeyer et al. 1984, Frenzel 1985, Anthony et al 1993, Weimeyer et al. 1993) and blood (Bowerman 1993, Welch 1994) have been correlated with reduced productivity in bald eagles. No correlation was observed between DDE and productivity rates in this study which is contrary to results reported with VNP eagle data collected from 1989-91 (Bowerman 1993). The significance of PCBs and DDE in nestling blood and feather samples prevents the separation of effects due to the individual compounds. Therefore, the significance of each individual compound may become more discernable when residues decline throughout VNP.

One clarification should be made at this point: contaminant residues identified in nestling plasma samples represent current dietary exposure and may not be proportional

to long-term residues in adult eagles. Contaminant burdens in the adult eagles reflect the individuals' net contaminant exposure and directly influence their reproductive capabilities. Therefore, it must be remembered that survival of the reproducing adults is an important parameter in determining the success of bald eagle populations (Grier 1980).

Contaminants in Eagle Food Items

Contaminant concentrations observed in VNP nestlings represent exposure to a contaminated local prey base. Among individual eagles, this prey base may include various avian species (i.e., herring gulls), and fish species (i.e., walleye, northern pike, white sucker). Eagles from VNP appear to be heavily dependent on fish during the breeding season, with 80% of the diet being identified from prey remains of bald eagle nests from 1989-1991 (Bowerman 1993). However, the actual incidence rate (% of nests in which species were found) included 68% suckers, 66% northern pike, 23% walleye, and 36% gulls. This compares to reported findings in nearby Chippewa National Forest where birds comprised 8%, fish 90%, and mammals 1% of prey remains (Dunstan and Harper 1975).

Fish

Northern pike, sucker, and walleye are the most common fish consumed by eagles at VNP. Mean mercury concentrations were significantly higher in northern pike and walleye than white sucker within VNP. Therefore, differences in mercury exposure and uptake by individual eagles based on selected fish prey species could result at VNP. Mean mercury concentrations among the three fish species were significantly higher in Sand Point lake and Namakan lake than in Rainy and Kabetogama lakes (however, please note limited sucker samples in 1993). This same lake trend was observed with eaglet mercury concentrations and may represent mercury exposure and uptake trends to eagles via fish prey in VNP. In addition, the 1993 advisory for Minnesota lakes (Minnesota Department of Health 1993) shows overall lower Hg levels in fish in Kabetogama Lake than in Sand Point, Namakan or Rainy lakes, parallel to the trends among lakes seen in this study's fish and eaglet mercury samples.

Based on hazard assessments conducted to determine the potential for adverse effects on bald eagles that could consume fish prey above and below dams on three primary rivers in Michigan and along the Great Lakes shoreline (Giesy et al. 1995), VNP northern pike, walleye, and white sucker mercury concentrations would represent a potential hazard to bald eagles feeding on them. The threshold mercury levels cited in their study for walleye, white sucker, and northern pike which were determined to potentially cause adverse effects on eagles were 0.38 mg/kg, 0.11 mg/kg, and 0.18 mg/kg respectively. Mean mercury concentrations of VNP walleye composites that equalled and/or exceeded these values occurred in Sand Point Lake (0.51 ug/g), and Rainy Lake (0.38 ug/g) (Table 4). Individual walleye composites within Namakan Lake also exceeded these values

(range: 0.28-0.61 ug/g). Northern pike mean mercury concentrations in Rainy Lake (0.43 ug/g), Sand Point (0.85 ug/g), Namakan (0.64 ug/g) and Rainy River (0.23 ug/g) exceeded the Michigan threshold level of 0.18 ug/g; however, Kabetogama Lake did not (0.15 ug/g). White sucker VNP collections from the Rainy River had mean mercury concentrations (0.19 ug/g) that also exceeded the Giesy et al. threshold. Because sampling of white sucker was limited in our study, comparisons could not be made for Sand Point or Kabetogama Lake. Ranges of sucker composites in Rainy Lake (0.04-0.15), however, also fell in the range of potential adverse effect to eagles feeding on them. Lastly, northern pike and walleye collected at VNP between 1987-1992 (MDNR 1994) had mercury levels in all the four major lakes that exceeded the threshold established to potentially cause adverse effects on eagles.

Giesy et al. (1995) calculated these hazard assessments based on weighted average exposure, i.e., based on the relative proportions of each species of fish in the diet. Determination of the relative proportions of each species of fish in the eagle diet were obtained from visual observations of the prey taken by eagles in the various areas (Bowerman 1993). The percentage of the three fish species (also observed by Bowerman (1993)) at VNP (Table 1) exceeded all other percentages of these fish observed being consumed by eagles in the Great Lakes. Although we do not know the relative size class of fish used in their study and thus how appropriate our comparison may be, VNP fish exceeded both mercury concentrations and percentage of each species consumed by eagles within the Great Lakes. Because these fish make up a considerable part of the bald eagle diet at VNP, it is possible that current concentrations of mercury may be a cause of productivity-level effects.

Based on a Minnesota Pollution Control (MPCA) study (Swain and Helwig 1989), trend analyses indicates that mercury concentrations in fish are increasing in the northeastern region of Minnesota where VNP is located. Analyses of fish since 1970 indicated an average annual increase of 0.017 ug/g per year or about a 5% increase per year. Atmospheric deposition of mercury has accounted for most of the mercury accumulating in remote undisturbed lakes in the upper Midwest (Swain et al. 1992) with local geology appearing to contribute minor amounts of mercury. Their study also determined that mercury deposition in this continental area has increased by a factor of 3.7.

Mercury in its organic form has a greater toxicological significance in the environment. Trophodynamic studies on mercury in aquatic ecosystems generally indicate biomagnification becomes a more important pathway than bioconcentration as trophic levels increase (Potter et al. 1975; Francesconi and Lenanton 1992). Organic mercury (methylmercury) represents over 90% of the mercury in fish (Huckabee et al. 1978,/> Bloom 1992). Because the primary mode of mercury accumulation in piscivorous birds (i.e., bald eagle) is through ingestion of contaminated prey, levels in prey and choice of prey by individual eagles have a large impact on their individual rate of mercury accumulation. The transfer of methylmercury from aquatic systems to piscivorous birds is particularly efficient because methylmercury in the diet is very efficiently absorbed by

birds and elimination is low (Fimreite 1979).

Fish: PCBs and DDE

A comparison of PCB and DDE contaminant concentrations in fish from VNP with those reported in prey items of bald eagles and white-tailed eagles (H. albicilla) from Lake Superior, Maine, Oregon, and Finland (Kozie and Anderson 1991, Koivursaari et al. 1976, Wiemeyer et al. 1978; Frenzel 1984; Risebrough and Jarman 1985) indicated organochlorine concentrations in fish from VNP were low. No discernable trends of these contaminants with each fish species by lakes in VNP could be found. No trends of these contaminants could also be determined in eaglet tissues within VNP. DDE levels in VNP fish were lower than those found to cause eggshell thinning in American kestrels (Falco sparverius) (2.8 ug/g) (Wiemeyer and Porter 1970) and also below 0.5 ug/g which would represent the lower limit for concern for eggshell thinning in bald eagles (U.S. Fish and Wildlife Service 1986).

Based on hazard assessments conducted to determine the potential for adverse effects on bald eagles that could consume fish prey above and below dams on three primary rivers in Michigan (Giesy et al. 1995), neither PCB or DDE concentrations measured in VNP northern pike, walleye or white sucker should have an adverse effect on bald eagles feeding on them. In addition, no fish species collected from VNP lakes between 1987-1992 (MDNR 1994) reached levels of PCBs established by the Giesy et al. study to have potential for adverse eagle effects.

Herring Gulls

Eggs and Eggshell Thinning

Herring gull eggs have been used as a monitoring tool for organochlorine and metal contaminants (Struger et al. 1983, Mineau et al. 1984, Burger 1994, Weseloh et al. 1994, Burger and Gochfeld 1995) for years. Organochlorine and metal concentrations in eggs are derived from females and represent recent exposure as well as mobilization from stored materials (Burger and Gochfeld 1995). In the VNP area, most herring gulls migrate farther south during the cold winters. Even so, most herring gulls return to the vicinity of their breeding colony at VNP by the beginning of April (Lee Grim, pers. comm.), nearly 6-8 weeks prior to egg-laying in May and June. Thus, it is suggested that levels of toxics in the eggs may represent primarily local exposure to the female.

Mercury concentrations in eggs (0.33-0.44 ug/g) obtained from five colonies at VNP were similar to concentrations collected in the New York Bight area (0.12-0.46 ug/g) (Burger and Gochfeld 1995) where mercury exposure has been documented. Concentrations of PCBs in VNP eggs (4.8-6.1 ug/g) were 3-6 times lower than in eggs (14.5-39.7 ug/g) collected from Lake Superior in 1984 (Weseloh et al. 1994). Dieldrin concentrations in VNP eggs (0.07-0.96 ug/g) equalled or exceeded dieldrin levels measured in the Lake

Superior eggs in 1984 (0.13-0.47 ug/g) (Weseloh et al 1994). However, DDE concentrations from VNP eggs (1.3 - 3.0 ug/g) were similar to concentrations reported from Lake Superior (1.1 - 4.8 ug/g) where eggshells averaged 8% thinner than in pre-1947 samples. Eggshell thinning was measured (up to 4% below a pre-1947 mean value) in two (Anchor and Seven Sister's Island) of the five VNP colonies, the areas where the highest concentrations of DDE in gulls occurred in 1993. Weseloh et al. (1994) determined that although DDE residues of 2.7-4.7 ug/g were associated with eggshell thinning of 3-10% overall, no evidence of reproductive failure was observed due to broken, flaked or dented eggs. Unlike other piscivorous bird and raptors, herring gulls appear to be fairly insensitive to the effects of DDE, and eggs concentrations of approximately 160 ug/g are reportedly necessary before one finds "critical" eggshell thinning of 15-20%, and elevated risks of egg breakage during incubation (Keith and Gruchy 1972). Mercury has also been shown to cause eggshell thinning in the laboratory, as well as reduced egg production, lighter eggs, and altered chick behavior (Spaan et al. 1972, Peakall and Lincer 1972; Heinz 1979; White et al. 1984, Scheuhammer 1990). However, mercury levels observed in VNP eggs were less than 1 ppm, well within the normal range reported from the literature.

Since contaminant levels in herring gull eggs have not been monitored at VNP, temporal trends in contaminants are unknown. However, a single herring gull egg composite collected from VNP in 1989 (Ensor et al. 1993) at Central Shipwreck Island, (Kabetogama Lake) indicated similar concentrations of total PCBs (5.4 ug/g) and mercury (0.32 ug/g) as observed in VNP in 1993, but had lower concentrations of p,p'-DDE (0.65 ug/g). In a larger geographical perspective, since 1980, contaminant levels in herring gull eggs from Lake Superior appear to have declined relatively little (Weseloh et al. 1994). In an overall Great Lakes context in 1983, herring gull eggs from Lake Superior colonies contained relatively low levels of PCBs, hexachlorobenzene, and 2,3,7,8, TCDD, but similar levels of DDE and mirex to other lakes (excepting mirex on Lake Ontario), and higher dieldrin levels than in all other lakes except Lake Michigan.

Although it is unknown what female adults were specifically eating prior to and during egglaying in VNP, most adult herring gulls from the lower Great Lakes population (Lakes Erie, Ontario, and southern Lake Huron) appear to feed mainly on fish and garbage in winter and early spring (much as during the breeding season), but any locally abundant food source is probably exploited opportunistically (Ewins et al. 1994). Overall, acknowledging the large range of temporal and spatial variation apparent in their study, herring gulls were acknowledged as opportunistic foragers, with individuals frequently specializing in restricted diet types, the composition of which has been related to offspring condition and survival (Pierotti and Annet, 1990, 1991).

Chicks and Adults

Herring gull chick contaminant burdens were significantly lower than adult or egg concentrations throughout the five VNP colonies. A general food habit analysis of the

chicks sampled (Table 5) indicated a broad range of prey including dragonfly nymphs, fish, chicken skin, and trash. It must be noted, however, that chicks were collected at various times of the day and thus the presence and type of prey could have varied significantly. In addition, remains of small fish, invertebrates, and even birds and garbage items, could have originated in the stomachs of larger fish, rather than being taken by the parent gull directly. As soon as chicks are able to swallow large food items, parents preferably feed them with food which constitutes a high energy and more predictable food supply (Pons 1994).

At VNP, ice-out typically does not occur until late April or early May so aquatic foods are probably unavailable when the gulls reoccupy territories in April. The open waters available below the dam on the Rainy River at International Falls (Minnesota-Fort Frances, Ontario), fish entrails thrown on the ice by ice fishermen at VNP, and available nearby dumps (Fort Frances) likely offer good foraging for both fish and garbage items. However, weather conditions, age, sex and breeding status, the premium on high quality nesting sites, nutrient and energy requirements, and the distribution of suitable alternative food sources are all factors which likely influence where and when a herring gull forages prior to and during the breeding season at VNP.

A confounding factor in interpreting gull contaminant patterns in different areas is the occurrence of local dumps of entrails from fish discarded by commercial fishermen (Kozie and Anderson 1991, Weseloh et al. 1994). A known fish entrail dump in International Falls was present until the fish processing plant closed in September, 1992 (Larry Kallemeyn and Lee Grim, pers. comm.). Prior to that time, VNP staff located lake trout tags (fished from the Apostle Islands in Lake Superior) in VNP gull colonies. Apparently, the fish processing plant in International Falls was processing lake trout obtained from Lake Superior with such designated tags and discarding the fish remains at a local dump. Concentrations of total PCBs, DDT and mercury in samples of lake trout obtained from Lake Superior had ranges of 0.21 -6.30 ug/g, 0.11-3.11 ug/g, and 0.02-0.60 ug/g, respectively (L. Kallemeyn, pers. comm). Although this information is anecdotal, it does suggest that gulls breeding in VNP may travel well over 25 miles to obtain food. We know of only one other dump distributed in the area (Fort Frances, Ontario) where current consumption of livers, entrails and other tissues of large fish by gulls during the egg-formation period would presently represent a major source of contaminants which may enter the egg. Ewins et al. (1994) found that gull colonies "closest to centers of human population tended to have the highest frequency of garbage items in samples. Taking 40 km (24.8 miles) as a maximum foraging distance from a colony (Cramp and Simmons 1983), in five col
onies within 40 km of a large urban center (>50,000 people), garbage was found in significantly more samples than at the other four colonies.

Choice of Prey Effects VNP Eagle Contaminant Burdens

The high organochlorine residue levels in VNP eaglet plasma appears to come primarily

from fish-eating avian species in their prey. This has been indicated as an important source for eagles in Finland (Koivusaari et al. 1976), Maine (Wiemeyer et al. 1978) and the Wisconsin shoreline of Lake Superior (Kozie and Anderson 1991). The disproportionately large number of bald eagle nests within 1000-2000 m of herring gull colonies (22 of 129 nests) suggests that bald eagles in VNP are opportunistic feeders, exploiting the available food resources (Grim and Kallemeyn 1995). In addition, gulls are seemingly an important prey item at VNP because approximately 36% of VNP eagles nests visited during banding of eaglets between 1989-91 contained gull remains (Bowerman 1993). Bald eagles that perch and forage in the gull colonies are commonly observed (Grim and Kallemeyn 1995, author (pers. obs.)), and the proportion of avian prey in the bald eagle diet in the park is closer to that of bald eagles nesting along ocean and Great Lakes coasts (Kozie and Anderson 1991, Bowerman 1993, Welch 1994) than that of bald eagles in inland areas (Dunstan and Harper 1975). Other investigations indicate that fish-eating birds preyed upon by bald eagles are a greater source of organochlorine compounds in eagle diets than fish (Frenzel 1984, Kozie and Anderson 1991, Anthony et al. 1993). For example, eagles consuming a piscivorous avian diet are thought to have a total PCB exposure rate 2.3 times higher than eagles consuming a diet limited to fish (U.S. Environmental Protection Agency 1993). This phenomenon is likely occurring at VNP: the eagle's three primary species of fish prey at VNP had significantly lower concentrations of DDE and PCBs than the eagle's avian prey counterpart, the herring gull. Therefore, many contaminants that are barely detectable in fish are present in sufficiently higher quantities in herring gulls and their eggs.

We do not know what impacts a greater diet in contaminated gulls may have on eagle reproduction. However, two of the herring gull adult carcass composites (Gull Island/Namakan Lake, Seven Sister's Island/Rainy Lake) had residues of DDE (2.7 and 3.2 ug/g) that approached or exceeded the relatively low dietary levels of DDE (2.8 and 3.0 ppm, wet weight) found to cause significant eggshell thinning in captive American Kestrels (Falco sparverius) (Wiemeyer and Porter 1970, Lincer 1975). At the present, we do not know if bald eagle eggs from VNP are experiencing eggshell thinning.

On the other hand, mercury concentrations in both VNP fish and adult gulls were comparable to fish mercury concentrations determined to have the potential to cause adverse effects on bald eagles in the Great Lakes (Giesy et al. 1995). Both fish and avian prey appear to be major sources of mercury to eagles in VNP. No significant differences of mean mercury concentrations were found among the avian and fish species, although white sucker had significantly lower mercury concentrations when compared within fish species. The high incidence of mercury in both fish and herring gull prey implicates the lakes of VNP as the main source of mercury contamination. More specifically, the location of foraging among the four lakes in VNP may affect an individual eagle's mercury burden uptake. Both eaglet and fish mercury concentrations differed by lake, with the highest concentrations being found in Sand Point Lake.

Although mercury's potential adverse impacts on VNP eagles in unknown, evidence

exists that common loons (Gavia immer) in north central and northeastern Minnesota are accumulating mercury to the point that reproduction may be impaired (Ensor et al. 1992). Reductions in common loon clutch size, nest fidelity, and territory fidelity were associated with mercury concentrations in fish prey ranging from 0.3 to 0.4 ug/g (wet weight) (Barr 1986). Fifteen of the 26 whole fish composites collected at VNP in 1993 exceeded these concentrations. Also, mercury levels in blood and feather tissues in red-necked grebes (Podiceps grisegena), common merganser (Mergus merganser), and hooded mergansers (Lophodytes cucullatus) sampled at VNP in 1993-94 were similar to levels found to cause decreased reproductive success in experiements with captive mallards (Anas platyrhynchos) (Derr 1995). Fur from river otters (Lutra canadensis) from VNP in 1986 had mercury concentrations as high as 75 ug/g (Route and Peterson 1988). Mercury levels were higher from otter from Rainy Lake than from Kabetogama Lake (Ensor et al. 1993). Although mercury fur thresholds have not been established for otter, normal levels of mercury in fur appear to range from 1-5 ug/g (Sheffy and St. Amant 1982). Because mercury is a neurotoxin, it may be a particularly insidious toxin for predators, such as eagles, loons, and furbearers, who rely on speed and coordination to obtain food. This, in turn, could indirectly impact reproductive success by reducing the parent's ability to obtain the appropriate quantity, or quality of prey, for their young.

The residue levels in the diet of the eagles probably vary seasonally with the highest levels during the early breeding season when the eagles are feeding on adult herring gulls (when the gulls arrive in early April prior to iceout). A shift to a higher percentage of fish and potentially younger gull prey later in the season may decrease the PCB/DDT impact but increase the mercury loading. Thus, it is possible that food choice on the breeding grounds during the weeks preceding egg-laying can differ from food choice later in the season. The time between egg-laying and fledging is approximately four months. The entire breeding cycle, from initial activity at a nest through the period of fledgling dependency, is approximately six months. Therefore, discerning potential impacts of early PCB/DDT/mercury exposure to the developing embryo and young versus potential later exposure of increased mercury to the developing chicks needs to be investigated.

RECOMMENDATIONS

1. Concentrations of mercury in nestlings from one year to the next in the same nest may vary (Welch 1994, Wood et al. 1993). Therefore, an attempt should be made to analyze all eaglet tissue contaminant results acquired since 1989 and determine potential correlations with productivity. Additional eaglet samples were collected in 1994-96, but no funds have been available for chemical analysis. Completing these analyses and analyzing all available data will provide a more comprehensive analysis of the contaminant effects on bald eagle productivity in VNP.

2. The potential uptake of dioxin by bald eagles via fish obtained from the Rainy River needs to be investigated. More specifically, questions have arisen during this study regarding bald eagle foraging at below the dam in International Falls, Minnesota-Fort Frances, Ontario. The river directly below the dam is the only significant open water area available to eagles prior to ice-out on the major lakes (late April to mid-May). Eagles begin arriving in the area in February. Known dioxin levels in the river have resulted in state fish advisories (Minnesota Department of Health 1994). In addition, work by Canadian counterparts have measured dioxin in clams within the river (Hayton and Hollinger 1990).

3. Attempts to acquire addled eggs should continue. In addition to standard analytical procedures, eggs should be analyzed using the H4IIE bioassay for determining dioxin equivalents (TCDD-EQ). This procedure determines overall toxicity of the contaminants in the sample, as compared to traditional methods of determining contaminant concentrations.

3. Attempts to determine general foraging behaviors/patterns of VNP adult eagles prior to, during, and after nesting would help determine what potential contamination exists both within VNP and adjacent areas (please refer to #2).

4. Because adult herring gulls arrive early at VNP prior to egglaying, the birds can serve as additional indicators of contaminant trends (versus fish collections). Concentrations of mercury in herring gull feathers have been determined to be as useful as eggs to assess intersite and interspecific variability in mercury contamination (Becker et al. 1993). This is to be expected as chicks accumulate the mercury in the egg, 90% of which is methylmercury (Umweltprobenbank, 1989 as cited in Becker et al. 1993). They also eliminate most of their body burden of mercury accumulated in soft tissues into their growing feathers (Lewis and Furness 1991, Becker et al. 1993).

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