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REPRODUCTIVE SUCCESS, ENVIRONMENTAL CONTAMINANTS, AND TROPHIC STATUS OF NESTING BALD EAGLES IN EASTERN NEWFOUNDLAND, CANADA

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ABSTRACT.—Eastern Newfoundland contains a large breeding population of Bald Eagles (*Haliaeetus leucocephalus*). Our objectives were to determine the reproductive success, contaminant levels, and trophic status of Bald Eagles in eastern Newfoundland, and to compare contaminant levels of eagles in industrialized and nonindustrialized coastal bays (Placentia and Bonavista bays, respectively). Bald Eagle breeding density in eastern Newfoundland was 0.09 occupied nests/km shoreline, and reproductive success suggested a healthy population (1.1 young/occupied nest). Geometric mean concentrations of PCBs and DDE in nestling plasma were significantly higher in Placentia Bay (PCBs = 30.0 ng/g [wet wt]; DDE = 9.0 ng/g) than in Bonavista Bay (PCBs = 10.0 ng/g; DDE = 2.0 ng/g). Within Placentia Bay, concentrations of PCBs and DDE in nestlings were negatively related to the nest distance from the former U.S. naval base at Argentia. Geometric mean concentration of mercury in whole blood of eagle nestlings was 87 ng/g (wet wt). Analysis of prey remains collected at nests and of stable-carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$) isotope ratios in nestling blood indicated some differences between nests in food sources, but not in relative trophic level. Prey remains collected at 30 Bald Eagle nests were composed of 64% birds, 29% fish, and 7% mammals. Contaminant burdens in Bald Eagles in eastern Newfoundland were lower than those in populations from more industrialized areas of North America and were below thresholds for reproductive impairment. These results provide an essential baseline for future monitoring of the eagle population as industrial development increases in Placentia Bay.

KEY WORDS: *Bald Eagle;* Haliaeetus leucocephalus; *contaminants; diet; stable isotopes; Newfoundland; productivity.*

EXITO REPRODUCTOR, CONTAMINANTES AMBIENTALES, Y ESTATUS TRÓFICO DE ÁGUILAS CALVAS EN NIDIFICANTES EN EL ESTE DE TERRANOVA (NEWFOUNDLAND), CANADÁ

RESUMEN.—El este de Terranova alberga una gran población residente grande de Águilas Calvas (*Haliaeetus leucocephalus*). Los objetivos de la investigación fueron: determinar el éxito reproductor, los niveles de contaminación, y el estatus trófico de las Águilas Calvas en el este Terranova y comparar los niveles de contaminación de las águilas de bahías costeras industrializadas y no industrializadas (Bahías de Placentia y de Bonavista, respectivamente). La densidad del Águila Calva en reproducción en Terranova oriental fue de 0.09 nidos ocupados/km de costa y el éxito reproductor resultó ser el de una población sana (1.1 juvenil/nido ocupado). La media geométrica de las concentraciones de PCBs y DDE en plasma de polluelos fue significativamenta más alta en la Bahía de Placentia (PCB = 30.0 ng/g [peso fresco]; DDE = 9.0 ng/g) que en la Bahía de Bonavista (PCB = 10.0 ng/g; DDE = 2.0 ng/g).

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En la Bahía de Placentia, se observó una relación inversa entre las concentraciones de PCBs y DDE en polluelos y las distancias desde los nidos a la antigua base naval de los EE.UU. en Argentia. La media geométrica de la concentración de mercurio en la sangre de polluelos fue de 87 ng/g (peso fresco). El análisis de restos de presas recolectadas en los nidos y las proporciones de los isótopos de carbono ($^{13}C/^{12}C$) y nitrógeno ($^{15}N/^{14}N$) en sangre de polluelos, indicaron algunas diferencias entre las fuentes de alimento de los nidos, pero no en el nivel trófico relativo. Los restos de presas recogidos en 30 nidos de Águila Calva estuvieron compuestos por aves (64%), peces (29%) y mamíferos (7%). Los niveles de contaminación en las Águilas Calvas del este de Terranova fueron más bajos que en las de poblaciones de áreas más industrializadas de Norteamérica y se encontraron por debajo del umbral a partir del cual afectan a la reproducción. Estos resultados proporcionan una base esencial para el futuro seguimiento de la población de águilas, a medida que aumente el desarrollo industrial en la Bahía de Placentia.

[Traducción de César Márquezs, Laura Dominguez y Rafael Mateo]

Bald Eagle (*Haliaeetus leucocephalus*) populations were affected seriously throughout North America from the 1950s–1970s by the widespread use of organochlorine pesticides (OCs) such as DDT (Grier 1982, Colborn 1991). Although many breeding populations began recovering in the 1980s–1990s (Grier 1982, Wiemeyer et al. 1993, Bowerman et al. 1995), contaminants still appear to be a limiting factor in the reproductive success of several North American populations (Anthony et al. 1993, 1999, Welch 1994, Bowerman et al. 1995).

One of the densest breeding concentrations of Bald Eagles in eastern North America is in Placentia Bay, Newfoundland (Dominguez 1999). Placentia Bay is also home to several industrial sources of chronic pollution. OC, polychlorinated biphenyl (PCB), and metal pollution was found at the former U.S. naval base in Argentia, which closed in 1994 (JWEL 1996). Fluoride and phosphorus pollution was caused by the phosphorus plant in Long Harbour (Osbourne 1978), which closed in 1989. Other industrial developments in the bay include an oil refinery at Come-By-Chance, a crude oil storage facility at Whiffen Head, a shipyard at Marystown, and associated heavy shipping traffic. Chronic oil pollution in Placentia Bay has been documented by the high incidence of oiled seabirds regularly washing up along its shores (Montevecchi and Tuck 1987, Lock et al. 1994, Wiese and Ryan 2003). Contaminants transported atmospherically or through ocean currents are other possible sources of chronic pollution (Furness 1993, Anthony et al. 1999). A recent study confirmed that PCBs and metals from the former U.S. naval base at Argentia are bioaccumulating in the local marine food web (JWEL 1996). However, there has been no monitoring of contaminant accumulation in top predators, such as Bald Eagles, that are sensitive to the presence of toxic chemicals that biomagnify up food chains (Howells et al. 1990).

This study was undertaken to assess the reproductive success, contaminant exposure, and trophic status of nesting Bald Eagles prior to further industrial development in Placentia Bay. For comparison, we measured the same parameters in a breeding population of Bald Eagles 80 km to the north in Bonavista Bay, which has had no major industrial development.

We hypothesized that concentrations of PCBs and DDE would be higher in eagle nestlings in Placentia Bay than in Bonavista Bay, and higher in eagle nestlings located closer to the former naval base than in those further away along Placentia Bay. Contaminant concentrations were measured in Bald Eagle nestlings because they are good bioindicators for assessing local contamination over a relatively short period (Welch 1994), and they have been used widely in contaminant monitoring studies across Canada and the United States (Anthony et al. 1993, Bowerman et al. 1995, Elliott and Norstrom 1998, Kumar et al. 2002). The trophic status of nesting Bald Eagles was compared by studying the composition of prey remains at nests and by analyzing stable-carbon and nitrogen isotope ratios in nestling blood samples (Hobson and Montevecchi 1991, Hobson et al. 1994).

METHODS

Placentia Bay, located on the southeastern coast of Newfoundland (Fig. 1), is one of the richest fishing areas in Newfoundland waters, and has important seabird colonies, wintering and staging grounds for millions of seabirds and seaducks, breeding and wintering grounds for Bald Eagles, and feeding areas for several species of marine mammals (LEML and OL 1984, Montevecchi and Tuck 1987, Cairns et al. 1989). Bonavista Bay, located on the northeast coast of Newfoundland (Fig. 1), is also rich in fish, seabird, seaduck, eagle, and marine mammal populations (Deichmann and Bradshaw 1984). The study

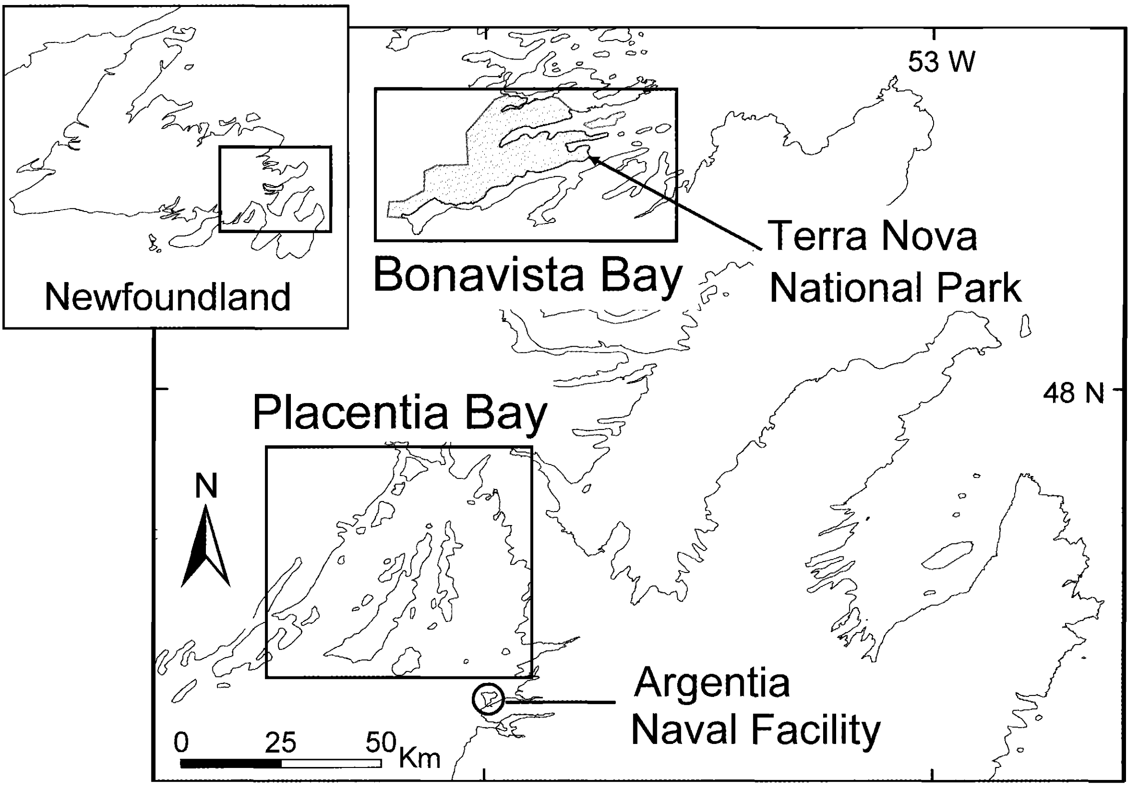

Figure 1. Location of Bald Eagle study areas in eastern Newfoundland, 1996–97.

area in Bonavista Bay was located within the boundaries of Terra Nova National Park (TNNP).

Reproductive Surveys. We studied Bald Eagle breeding density, nest success, and productivity in Placentia Bay in 1996 and 1997 and in Bonavista Bay in 1997. Definitions of these terms and others used to describe reproductive parameters follow those of Postupalsky (1974) and Kozie and Anderson (1991). We conducted a minimum of two surveys per breeding season along the coastline by aircraft or boat, extending 50–200 m inland from the shoreline, depending on topography. Boat surveys were conducted by cruising at 20–50 m from shore, in a 6-m fiberglass boat at a speed of 10–20 km/hr. Boat surveys in late April–early May assessed breeding population size and nest occupancy. Total shoreline surveyed was measured with MapInfo (MapInfo Corp., Troy, NY) to calculate breeding density (number of occupied nests per kilometer of shoreline). Aerial surveys were conducted by helicopter (Bell 206) in Placentia Bay and by fixed-wing aircraft (Twin Otter) in Bonavista Bay, with cruising speeds of 120–140 km/h and flying altitudes of 50–100 m above tree line. Aerial survey schedules and methodology followed standard methods (Postupalsky 1974, Grier 1982, Fraser et al. 1983). Aerial surveys in early June assessed clutch/brood size and chick development, and nest visits in late June–early July assessed nest success and productivity. Nest visits involved climbing into the nests to collect blood samples from the chicks for contaminant analyses.

Contaminant Analyses. Blood samples from one nestling per nest (Welch 1994) were collected in late June and early July in 1996 and 1997 in Placentia Bay and in 1997 in Bonavista Bay. Approximately 12–15 ml of blood was drawn from the left brachial vein directly into heparinized vacuum tubes when eaglets were 6–8 wk old. From each sample, 4–6 ml of whole blood were frozen in nitric-acid-rinsed cryovials for mercury analysis. The remaining blood was centrifuged and 3–6 ml of plasma were frozen in acetone-hexane-rinsed glass vials for OC analyses. Samples were stored at −20°C until analyzed. Further details on blood collection and processing are provided by Dominguez (1999).

Plasma and whole blood samples were sent to the Canadian Wildlife Service National Wildlife Research Center (NWRC) in Hull, Quebec, for OC and mercury analyses. Measurement of 21 OC pesticides and metabolites and 42 PCB congeners in plasma was conducted by gas-chromatography mass spectrometry (Hewlett Packard model 5890 gas chromatograph, coupled to a Hewlett Packard model 5971 Ni^{63} electron capture detector, Palo Alto, CA). Methods follow those of Norstrom and Won (1985). Recoveries of internal standards ranged from 74–104%. Detection limits were 0.1 ng/g wet weight (wet wt) for both OCs and PCBs. Plasma lipids were measured by

Table 1. Reproductive success of Bald Eagle breeding pairs in Placentia and Bonavista Bays, Newfoundland, 1996–97.

LOCATION	YEAR	NO. OCCUPIED NESTS	NO. SUCCESSFUL NESTS	NEST SUCCESS (%)	NO. YOUNG/ OCCUPIED NEST	NO. YOUNG/ SUCCESSFUL NEST
Placentia Bay	1996	31	25	81	1.3	1.6
Placentia Bay	1997	27	18	67	0.9	1.4
Bonavista Bay	1997	12	10	83	0.9	1.1

sulpho-phospho-vanillin reaction (Frings et al. 1972). Total mercury in blood was analyzed by cold-vapor atomic-absorption spectrophotometry (Perkin-Elmer 3030-AAS equipped with Varian VGA-76 hydride generator, Shelton, CT; Scheuhammer and Bond 1991, Neugebauer et al 2000). National Research Council of Canada DOLT-2 and DORM-2 were used as standard reference materials to ensure the accuracy of the mercury results. Two blanks were included in each set of digestions. All blood samples were analyzed in duplicate. Recoveries of reference materials were within the certified range. The detection limit for mercury was 40 ng/g (wet wt). Field procedural blanks were included in all chemical analyses. All contaminant concentrations are presented in ng/g (wet wt).

Trophic Analyses. Prey remains and a sample of fine nest material (to check for fish scales and other small remains) were collected from each nest bowl and the nest-site area, and were classified as fish, bird, or mammal. Composition of prey remains is expressed as percent occurrence of minimum number of individuals for each of the three prey classes (Todd et al. 1982, Knight et al. 1990). Regurgitated pellets below nests could not be retrieved because most nests were located on cliffs overhanging the sea. Stable nitrogen isotope ratios ($^{15}N/^{14}N$) were used to compare the dietary trophic level of Bald Eagles between and within study areas (Hobson et al. 1994), and to investigate relationships between contaminant concentrations and trophic level (Braune et al. 2002). Stable carbon isotope ratios ($^{13}C/^{12}C$) were used to investigate food sources (i.e., freshwater vs. marine, benthic vs. pelagic marine food chains; Hobson et al. 1994). Dried blood samples were loaded into tin cups and combusted at 1850°C in a Robo-Prep elemental analyzer (Europa Ltd., Crewe, England) interfaced with a Europa 20:20 continuous-flow isotope-ratio mass spectrometer (Hobson et al. 1999). Two standards (egg albumin) were measured in sequence for every five unknowns. Analytical error is estimated to be $\pm 0.3‰$ for ^{15}N and $\pm 0.1‰$ for ^{13}C analyses. Stable isotope ratios in blood samples are reported in delta notation as parts per thousand according to the following: $\delta X\ (‰) = [(R_{sample}/R_{standard}) - 1] \times 1000$ where X is ^{15}N or ^{13}C and R is the corresponding ratio $^{15}N/^{14}N$ or $^{13}C/^{12}C$. $R_{standard}$ for ^{15}N and ^{13}C are atmospheric N_2 (AIR) and the PDB standard, respectively.

Statistical Analyses. Contaminant data were $\log_{10}$-transformed to achieve a normal distribution, and geometric means were calculated. Contaminant data were not lipid-normalized for statistical analyses because there were no correlations between plasma lipid concentrations and log-transformed concentrations of contaminants (e.g., r = 0.07, 0.2, and 0.2 for DDE, PCB, and mercury, respectively). When samples had contaminant concentrations below the analytical detection limit, and 50% or more of the samples had values above detection limits, a value of one-half the detection limit was assigned (Anthony et al 1999).

One-way analysis of variance (ANOVA) was used to test differences in the mean contaminant concentrations between years in Placentia Bay, and between Placentia and Bonavista Bays. Within Placentia Bay, relationships between contaminant concentrations in nestling tissues and nest distance (km) to the former U.S. naval base were assessed using linear regression. Differences in composition of prey remains between years in Placentia Bay and between study areas were tested with a chi-square test of independence and Fisher's exact test, respectively. Differences in the means of $\delta^{15}N$ and $\delta^{13}C$ values between study areas were tested with a one-way ANOVA. Linear regression was used to assess relationships between contaminant concentrations and isotopic ratios. Multiple regression analysis was used to assess the relative strength of associations between contaminant concentrations, nest distance to the former naval facility and trophic differences reflected by stable isotope ratios. Randomization tests (Adams and Anthony 1996) were conducted (10 000 runs) to produce reliable P values when residuals from ANOVAs did not show a normal distribution (test results indicated as P_{rand}). A value of $\alpha = 0.05$ was used in all tests. Statistical tests were conducted with Minitab (Minitab Inc., State College, PA) and SYSTAT (SPSS Inc , Chicago, IL).

RESULTS

Reproductive Success. We identified 55 and 13 breeding territories in Placentia and Bonavista Bays, respectively; some of them containing more than one nest. Breeding density was 0.10 and 0.06 occupied nests/km of shoreline for Placentia and Bonavista Bays, respectively (overall mean = 0.09 occupied nests/km). Nest success and productivity (Table 1) were not significantly different between study areas ($\chi^2 = 0.46$, $P = 0.5$ and $F_{1,41} = 2.5$, $P = 0.1$, respectively). Overall, mean nest success in eastern Newfoundland was 76% and mean productivity was 1.1 young/occupied nest.

Organochlorines. Plasma concentrations of OCs were low in all samples in both Placentia and Bonavista Bays (Table 2). In Placentia Bay, there were no significant differences in mean concentrations between years (e.g., $F_{1,20} = 0.58$, $P_{\text{rand}} = 0.1$ and $F_{1,20} = 1.9$, $P_{\text{rand}} = 0.1$ for DDE and PCBs, respectively). Therefore, results were pooled for 1996 and 1997 and mean values were used for nests sampled in both years. Geometric mean concentrations of plasma DDE and PCBs were significantly higher in Placentia Bay than in Bonavista Bay ($F_{1,21} = 4.0$, $P_{\text{rand}} = 0.03$ and $F_{1,21} = 6.3$, $P_{\text{rand}} = 0.003$, respectively; Table 2). There were no significant differences in mean concentrations of other OCs (Table 2). Dieldrin; *pp'*-DDD; *pp'*-DDT; pentachlorobenzene; 1234- and 1245-tetrachlorobenzene; octachlorostyrene; α-, β- and γ-hexachlorocyclohexane; *trans*-chlordane; and tris(4-chlorophenyl)methanol were detected in less than half of the plasma samples. In Placentia Bay, DDE and PCB concentrations were negatively related to nest distance from the former U.S. naval site at Argentia ($R^2 = 0.4$, $P = 0.07$ and $R^2 = 0.3$, $P = 0.02$, respectively; Fig. 2). There were no significant relationships between concentrations of other OCs and distance from the naval site.

Mercury. No significant differences were found in geometric mean mercury concentrations in whole blood of eagle nestlings between years in Placentia Bay ($F_{1,20} < 0.001$, $P_{\text{rand}} = 0.3$), or between Placentia and Bonavista Bays ($F_{1,21} = 1.7$, $P = 0.2$). The overall geometric mean concentration for blood mercury in nestlings in eastern Newfoundland was 87 ng/g ($N = 23$, range: 50–250 ng/g wet wt). There was no association between mercury concentrations and nest distance from the naval base in Placentia Bay (Fig. 2).

Trophic Status. Most birds found in prey remains were Black-legged Kittiwakes (*Rissa tridactyla*), and Herring Gulls (*Larus argentatus*), or murres (*Uria* spp.) in both Placentia and Bonavista Bays. Fish species included yellow-tail flounder (*Limanda ferruginea*), wolffish (*Anarhichas* spp.), sculpin (*Myoxocephalus* spp.), lumpfish (*Cyclopterus lumpus*), Atlantic cod (*Gadus morhua*), redfish (*Sebastes* spp.), Atlantic herring (*Clupea harengus*), and American lobster (*Homarus americanus*). The only mammal remains identified were snowshoe hare (*Lepus americanus*). The minimum percent occurrence of avian, fish, and mammalian prey in the remains at 22 Placentia Bay eagle nests and eight Bonavista Bay nests averaged 64, 29, and 7%, respectively. There were no significant differences in the frequency of occurrence of bird and fish re-

Table 2. Geometric mean concentrations of organochlorines[a] (ng/g, wet wt) and percent lipids in plasma of Bald Eagle nestlings from Placentia and Bonavista Bays, Newfoundland, 1996–97. Ranges of plasma concentrations are indicated in parentheses.

Location	Year	Tissue	N	% Lipid	ΣPCB	p,p'-DDE	t-Nonachlor	HCB	Oxychlordane	Cis-Nonachlor	Cis-Chlordane	Mirex	Photomirex	HE
Placentia	96–97	plasma	17	0.79	36 A[b]	8.6 B[b]	1.9	1.0	1.0	0.4	0.3	0.3	0.3	0.3
				(0.65–0.96)	(11–133)	(2.0–41)	(0.8–3.9)	(0.5–3.0)	(0.3–3.6)	(ND[c]–0.8)	(ND–0.9)	(ND–2.5)	(ND–1.2)	(ND–1.1)
Bonavista	97	plasma	6	0.87	14 A	1.9 B	1.6	0.7	0.5	0.4	0.4	ND	0.3	0.1
				(0.71–1.21)	(8.0–35)	(0.4–5.8)	(0.9–2.8)	(0.5–1.3)	(0.2–1.3)	(0.3–0.7)	(0.3–0.5)	(ND–0.3)	(ND–1.0)	(ND–0.4)

[a] Abbreviations are as follows: ΣPCB = sum of 42 PCB congeners, *t*-nonachlor = *trans*-nonachlor, HCB = hexachlorobenzene, HE = heptachlor epoxide.
[b] A, B = means sharing the same letter are significantly different, $P_{\text{rand}} < 0.05$.
[c] ND = below detection limit (0.1 ng/g, wet wt).

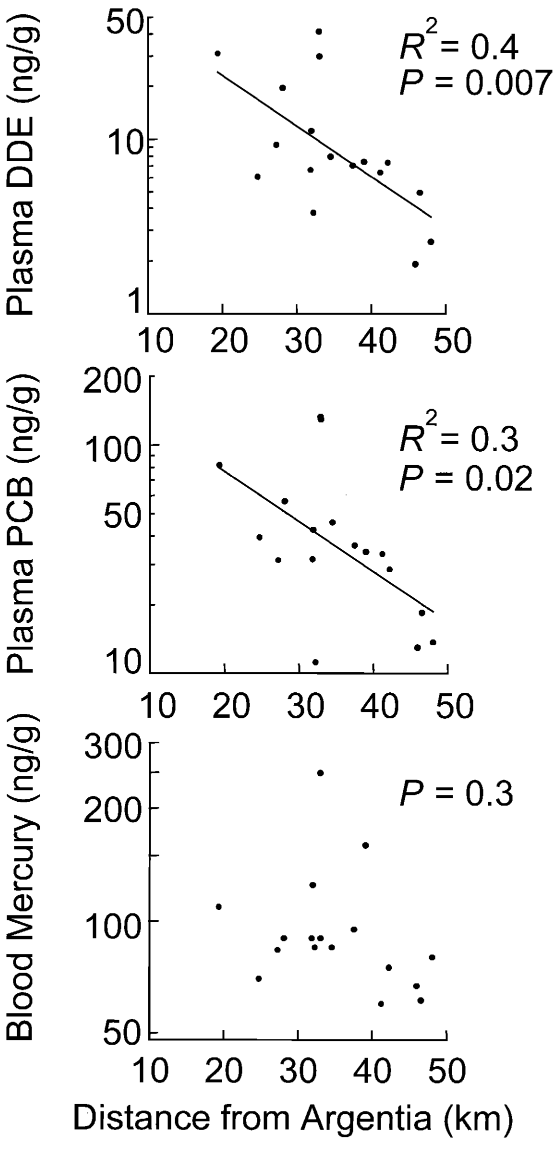

Figure 2. Regressions of contaminant concentrations (ng/g, wet wt) in plasma or whole blood of Bald Eagle nestlings in Placentia Bay and nest distance (km) from the former U.S. naval base at Argentia, Newfoundland.

mains either between years in Placentia Bay (N = 80, χ^2 = 0.1, P = 0.2) or between Placentia and Bonavista Bays (N = 102, χ^2 = 0.9, P = 0.3).

Stable isotope ratios were determined in 13 blood samples from Placentia Bay and six samples from Bonavista Bay collected in 1997. Geometric mean $\delta^{15}N$ values (±SD) in nestling blood were not significantly different between Placentia and Bonavista Bays (16.0 ± 0.4‰ and 15.7 ± 0.2‰, respectively; $F_{1,17}$ = 1.69, P = 0.2). $\delta^{15}N$ values were not significantly related to plasma DDE concentrations (R^2 = 0.004, $F_{1,15}$ = 0.44, P = 0.5), plasma PCB concentrations (R^2 = 0.002, $F_{1,15}$ = 0.03, P = 0.8), blood mercury concentrations (R^2 = 0.002, $F_{1,15}$ = 0.02, P = 0.9), or nest distance from the naval site in Placentia Bay (R^2 = 0.03, $F_{1,11}$ = 0.2, P = 0.6). Geometric mean $\delta^{13}C$ values (±SD) in nestling blood were greater in Bonavista Bay than in Placentia Bay (−17.8 ± 0.2‰ and −18.3 ± 0.5‰, respectively; $F_{1,17}$ = 5.0, P = 0.05). $\delta^{13}C$ values were negatively associated with plasma DDE (R^2 = 0.36, $F_{1,15}$ = 9.3, P = 0.008) and PCB concentrations (R^2 = 0.36, $F_{1,15}$ = 8.7, P = 0.009) in nestlings from both bays. There was no relationship between $\delta^{13}C$ values and blood mercury concentrations (R^2 = −0.09, $F_{1,15}$ = 2.1, P = 0.2). Within Placentia Bay, $\delta^{13}C$ values were positively related to nest distance from the naval base (R^2 = 0.48; $F_{1,9}$ = 8.3; P = 0.02).

Multiple regression results indicated that plasma DDE concentrations in Placentia Bay eagles were associated with nest distance from the naval base but not with $\delta^{13}C$ values (R^2 = 0.66, $F_{1,8}$ = 10.5, P = 0.01; $F_{1,8}$ = 0.4, P = 0.5; respectively). Similar analysis showed that plasma PCB concentrations were associated more with nest distance from the naval base than with $\delta^{13}C$ values, although neither association was statistically significant (R^2 = 0.46, $F_{1,8}$ = 3.4, P = 0.1; $F_{1,8}$ = 0.001, P = 0.9; respectively) for Placentia Bay nestlings.

DISCUSSION

Concentrations of OCs in plasma of Bald Eagle nestlings were low in both study areas in eastern Newfoundland. Observed plasma DDE and PCB concentrations were below thresholds associated with depressed Bald Eagle productivity (i.e., <0.7 young/occupied nest), namely 107 ng/g PCBs and 26 ng/g DDE (Bowerman et al. 1995). Levels of DDE, PCBs, and other OCs were lower than those found in plasma of nestling eagles in more industrialized regions such as the Columbia River Estuary, Great Lakes, and Maine (geometric means: 80–200 ng/g PCB, 20–100 ng/g DDE; Anthony et al. 1993, Bowerman 1993, Matz 1998, Donaldson et al. 1999) but were similar to those found in British Columbia and interior areas of the Midwest and Ontario (5–50 ng/g PCB, 3–24 ng/g DDE; Bowerman 1993, Elliott 1995, Donaldson et al. 1999). We conclude that OC concentrations in eagle nestlings in eastern Newfoundland are below levels associated with population-level impacts.

Mean DDE and PCB concentrations were significantly higher in Placentia Bay than in Bonavista Bay, with an increasing trend in Placentia Bay in nests closer to the Argentia naval base. Concentrations of other OCs were similar in both study areas. Our findings support the hypotheses that the Argentia naval base is a source of PCB contamination to the local marine environment, and that part of the contamination detected in the eagles had a local origin at the base (although we acknowledge the smaller sample size from the reference site in our comparative analyses). The U.S. Navy constructed the Naval Air Station, Dockyard, and associated fuel, ordnance, communication, and support facilities at Argentia in the early 1940s (Argentia Remediation Group 1995). These facilities were gradually closed or abandoned by the American military between 1968 and 1994. Soil, groundwater, marine sediments, and biota at Argentia were contaminated with petroleum hydrocarbons, OCs, PCBs, or metals, which leaked from fuel storage tanks, an electrical power plant, electrical transformers, several landfills, and equipment storage areas (Argentia Remediation Group 1995, JWEL 1996). Our results suggest that PCB contamination of marine fish observed around Argentia (JWEL 1996) is moving up the food web into Bald Eagles (although not reaching toxic concentrations in eagle nestlings).

PCB contamination has been frequently observed around military installations in North America, Europe, and Asia (de March et al. 1998, Gregor et al. 2003, Kuzyk et al. 2003). At these contaminated sites, PCBs are often found in soil adjacent to buildings with electrical equipment, in and around dumps, and migrating from these sources down drainage channels into the ocean (Gregor et al. 2003). In a contaminant study in the Aleutian Islands of Alaska, Anthony et al. (1999) reported higher levels of PCBs in Bald Eagle eggs from nests that were located on islands that had a former military base than in eggs from islands that did not.

Blood mercury levels in Newfoundland Bald Eagle nestlings were similar to those in Florida and coastal Maine nestlings (geometric means: 82–130 ng/g; Welch 1994, Wood et al. 1995), but lower than those in Oregon and Washington nestlings (230–1200 ng/g; Wiemeyer et al. 1989, Anthony et al. 1993). No threshold value for adverse effects is available in the literature for blood mercury concentrations in Bald Eagles. The blood mercury concentrations in Newfoundland eagles were less than those (ca. 1000 ng/g in 5-wk-old chicks) that led to sublethal effects on appetite, body condition, behavioral activity, anemia, and organ histology in dosed Great Egrets (*Ardea alba*) (Bouton et al. 1999, Spalding et al. 2000a, 2000b).

Dietary habits and trophic level can influence contaminant concentrations in eagles. Bald Eagles that feed mainly on seabirds, especially gulls, are known to bioaccumulate higher concentrations of contaminants than eagles feeding mainly on fish or terrestrial herbivores (Kozie and Anderson 1991, Welch 1994, Anthony et al. 1999). Our analysis of bird, fish, and mammal remains at eagle nests indicated that the trophic status of eagles was similar in Placentia and Bonavista Bays. Prey remains collected at Newfoundland nests were similar to other coastal populations of Bald Eagles, where seabirds predominate in the diet (Welch 1994, Todd et al. 1982, Knight et al. 1990). Because analysis of Bald Eagle prey remains overestimates the dietary importance of birds, medium-sized mammals, and bony fish, while underestimating consumption of small fish and mammals (Mersmann et al. 1992), it is important to limit comparisons to similar studies of prey remains.

Traditionally, combined analyses of prey remains, regurgitated pellets, and direct observation of feeding events are required to assess dietary composition accurately for Bald Eagles (Mersmann et al. 1992). However, stable isotopic analyses of bird tissues is another method available to quantitatively assess their trophic status (Hobson et al. 1994). Analyses of $\delta^{15}N$ values in nestling blood samples showed no dietary trophic differences among nestlings, and no relationships between contaminants and $\delta^{15}N$ values. Although $\delta^{15}N$ values of food web components may differ among locations, we feel that the observed differences in contaminant levels are not due to differences in dietary trophic level among nestlings. This conclusion is supported by the prey remains analysis.

In contrast, $\delta^{13}C$ values were greater in Bonavista Bay, and in nests further away from the Argentia naval base in Placentia Bay. Greater $\delta^{13}C$ ratios in birds in marine ecosystems have been related to diets with more inshore or benthic prey, while lower $\delta^{13}C$ ratios have been related to more offshore and pelagic-based diets (Hobson et al. 1994). Nests in Bonavista Bay are located in a long sound with an estuary at the head of the bay. In Placentia Bay, nests further away from the naval base are also located near an estuary at the head of the bay, while nests closer to the base are located on islands nearer the mouth of the bay. This difference in geographical distribution and proximity to freshwater inputs could explain the differences in $\delta^{13}C$ values between study sites and within Placentia Bay. The associations found between $\delta^{13}C$ values and PCB and DDE levels in nestling plasma indicate a possible dietary cause for differences in contaminant concentrations. However, the multiple regression analysis suggests that proximity to the Argentia naval base was more important than $\delta^{13}C$ values in influencing DDE and PCB concentrations in young eagles. Given our small sample sizes, the snap-shot nature of our dietary study, the opportunistic foraging strategies of Bald Eagles (Stalmaster 1987), and the changing availability of different prey through the breeding season (e.g., spawning of different species of fish), there remains much to investigate about Bald Eagle foraging ecology, stable isotope patterns, and their association with contaminant levels in Newfoundland.

Breeding density of Bald Eagles in eastern Newfoundland (0.090 occupied nests/km shoreline) was similar to coastal British Columbia (0.086 nests/km; Hodges and King 1984), greater than coastal New Brunswick (0.014 nests/km; Stocek and Pearce 1981) and Nova Scotia (0.047 nests/km; MacDonald and Austin-Smith 1989), but less than the maximum densities seen along the southeast coast of Alaska (0.28 nests/km; Hodges 1982). High breeding densities and reproductive output of Bald Eagles in marine ecosystems are often associated with high quality and availability of nesting habitat and with food abundance (Hansen 1987).

We cannot draw a definitive conclusion on the reproductive status of the Bald Eagle population in eastern Newfoundland from our study because a minimum of 3 yr of data collection is recommended to reliably determine mean productivity (Elliott 1995). However, our data from the two years in Placentia Bay and the one year in Bonavista Bay indicate that reproductive success was high and are suggestive of a healthy breeding population, i.e., >1 young/occupied nest (Wiemeyer et al. 1993, Bowerman et al. 1995). The breeding densities and reproductive success of Bald Eagles in eastern Newfoundland can presumably be attributed to high availability and quality of food, perches, and nesting habitat (Chandler et al. 1995), and to relatively low contaminant levels in the environment.

We found no evidence that current contaminant levels are impairing reproduction in Bald Eagles in Placentia and Bonavista Bays. Nevertheless, Bald Eagles would be an excellent bioindicator of any ecological impacts of future industrial development in Placentia Bay (e.g., proposed nickel smelter at Argentia), and of any ecological benefits of on-going remediation of existing contaminated sites at Argentia. This study provides the necessary baseline information on Bald Eagle productivity and contamination for any future monitoring program.

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LITERATURE CITED

ADAMS, D.C. AND C.D. ANTHONY. 1996. Using randomization techniques to analyze behavioral data. *Anim Behav.* 51:733–38.

ANTHONY, R.G., M.G. GARRET, AND C.A. SCHULER. 1993. Environmental contaminants in Bald Eagles in the Columbia River Estuary. *J. Wildl. Manage.* 57:10–19.

———, A.K. MILES, J.A. ESTES, AND F.B. ISAACS. 1999. Productivity, diets, and environmental contaminants in nesting Bald Eagles from the Aleutian Archipelago *Environ. Toxicol. Chem.* 18:2054–2062.

ARGENTIA REMEDIATION GROUP. 1995. Phase III/phase IV environmental site assessment, US Naval Facility Argentia, Newfoundland: Report 2, site characterization. Report No. 20000-413. Argentia Remediation Group, Dartmouth, NS Canada.

BOUTON, S.N., P.C. FREDERICK, M.G. SPALDING, AND H MCGILL. 1999. Effects of chronic, low concentrations of dietary methylmercury on the behavior of juvenile great egrets. *Environ. Toxicol. Chem.* 18:1934–1939.

BOWERMAN, W.W. 1993. Regulation of Bald Eagle (*Ha-*

liaeetus leucocephalus) productivity in the Great Lakes Basin: an ecological and toxicological approach. Ph.D. dissertation, Michigan State University, East Lansing, MI U.S.A.

———, J.P. GIESY, D.A. BEST, AND V.J. KRAMER. 1995. A review of factors affecting productivity of Bald Eagles in the Great Lakes region: implications for recovery. *Environ. Health Perspect.* 103(Suppl. 4):51–59.

BRAUNE, B.M., G.M. DONALDSON, AND K.A. HOBSON. 2002. Contaminant residues in seabird eggs from the Canadian Arctic: II spatial trends and evidence from stable isotopes for intercolony differences. *Environ. Pollut.* 117:133–145.

CAIRNS, D.K., W.A. MONTEVECCHI, AND W. THRELFALL. 1989. Researcher's guide to Newfoundland seabird colonies, 2nd Ed. *Memorial Univ. Nfld. Occas. Pap. Biol.* 14.

CHANDLER, S.K., J.D. FRASER, D.A. BUEHLER, AND J.K.D. SEEGAR. 1995. Perch trees and shoreline development as predictors of Bald Eagle distribution on Chesapeake Bay. *J. Wildl. Manage.* 59:325–332.

COLBORN, T. 1991. Epidemiology of Great Lakes Bald Eagles. *J. Toxicol. Environ. Health* 33:395–453.

DEICHMANN, K.H. AND D.B. BRADSHAW. 1984. Terra Nova National Park: resource description and evaluation. Parks Canada, Glovertown, NF Canada.

DE MARCH, B.G.E., C.A. DE WIT, AND D.C.G. MUIR. 1998. Persistent organic pollutants. Pages 183–371 *in* S.J. Wilson, J.L. Murray, and H.P. Huntington [EDS.], AMAP assessment report: Arctic pollution issues. Arctic Monitoring and Assessment Programme, Oslo, Norway.

DOMINGUEZ, L. 1999. Reproductive success and environmental contaminants among Bald Eagles in Placentia and Bonavista Bays, Newfoundland. M.S. thesis, Memorial University of Newfoundland, St. John's, NF Canada.

DONALDSON, G.M., J.L. SHUTT, AND P. HUNTER. 1999. Organochlorine contamination in Bald Eagle eggs and nestlings from the Canadian Great Lakes. *Arch. Environ. Contam. Toxicol.* 36:70–80.

ELLIOTT, J.E. 1995. Environmental contaminants in Bald Eagles on the coast of British Columbia: exposure and biological effects. Ph.D. dissertation, University of British Columbia, Vancouver, BC Canada.

——— AND R.J. NORSTROM. 1998. Chlorinated hydrocarbon contaminants and productivity of Bald Eagle populations on the Pacific Coast of Canada. *Environ. Toxicol. Chem.* 17:1142–1153.

FRASER, J.D., L.D. FRENZEL, J.E. MATHISEN, F. MARTIN, AND M.E. SHOUGH. 1983. Scheduling Bald Eagle reproductive surveys. *Wildl. Soc. Bull.* 11:13–16.

FRINGS, C.S., T.W. FENDLEY, R.T. DUNN, AND C.A. QUENN. 1972. Improved determination of total serum lipids by the sulpho-phospho-vanillin reaction. *Clin. Chem.* 18:673–674.

FURNESS, R.W. 1993. Birds as monitors of pollutants. Pages 86–143 *in* R.W. Furness and J.J.D. Greenwood [EDS.], Birds as monitors of environmental change Chapman & Hall, New York, NY U.S.A.

GREGOR, D., J. STOW, D. KENNEDY, K. REIMER, AND C. OLLSON. 2003. Local sources of contaminants in the Canadian Arctic. Pages 158–183 *in* T. Bidleman, R. Macdonald, and J. Stow [EDS.], Canadian Arctic Contaminants Assessment Report II: sources, occurrence, trends and pathways in the physical environment. Indian & Northern Affairs Canada, Ottawa ON Canada.

GRIER, J.W. 1982. Ban of DDT and subsequent recovery of reproduction in Bald Eagles. *Science* 218:1232–1235.

HANSEN, A.J. 1987. Regulation of Bald Eagle reproductive rates in southeastern Alaska. *Ecology* 68:1387–1392.

HOBSON, K.A. AND W.A. MONTEVECCHI. 1991. Stable isotopic determinations of trophic relationships of Great Auks. *Oecologia* 87:527–531.

———, J.F. PIATT, AND J. PITOCCHELLI. 1994. Using stable isotopes to determine seabird trophic relationships *J Anim. Ecol.* 63:786–798.

———, M. DREVER, AND G. KAISER. 1999. Norway rats as predators of burrow-nesting seabirds: insights from stable isotope analysis. *J. Wildl. Manage.* 63:14–25.

HODGES, J.I., JR. 1982. Bald Eagle nesting studies in Seymour Canal, southeast Alaska. *Condor* 84:125–127.

——— AND J.G. KING. 1984. Bald Eagle breeding population survey of coastal British Columbia. *J. Wildl Manage.* 48:993–998.

HOWELLS, D., D. CALAMARI, J. GRAY, AND P.G. WELLS. 1990. An analytical approach to assessment of long-term effects of low levels of contaminants in the marine environment. *Mar. Pollut. Bull.* 21:371–375.

JWEL. 1996. Marine sampling off landfill 1, former United States naval facility, Argentia, Newfoundland JWEL Report No. 84336. Jacques Whitford Environment Ltd., St. John's, NF Canada.

KNIGHT, R.L., P.J. RANDOLPH, G.T. ALLEN, L.S. YOUNG, AND R.J. WIGEN. 1990. Diets of nesting Bald Eagles, *Haliaeetus leucocephalus,* in western Washington. *Can Field-Nat.* 104:545–551.

KOZIE, K.D. AND R.K. ANDERSON. 1991. Productivity, diet, and environmental contaminants in Bald Eagles nesting near the Wisconsin shoreline of Lake Superior *Arch. Environ. Contam. Toxicol.* 20:41–48.

KUMAR, K.S., K. KANNAN, J.P. GIESY, AND S. MASUNAGA 2002. Distribution and elimination of polychlorinated dibenzo-p-dioxins, dibenzofurans, biphenyls, and *p,p'*-DDE in tissues of Bald Eagles from the Upper Peninsula of Michigan. *Environ. Sci. Technol.* 36:2789–2796.

KUZYK, Z.A., N.M. BURGESS, J.P. STOW, AND G.A. FOX. 2003. Biological effects of marine PCB contamination on black guillemot nestlings at Saglek, Labrador: liver biomarkers. *Ecotoxicology* 12:183–197.

LEDREW ENVIRONMENTAL MANAGEMENT LTD. AND OCEANS

LTD. 1984. Southeastern Newfoundland marine resources: a literature review. Newfoundland and Labrador Dept. of Development, St. John's NF Canada.

LOCK, A.R., R.G.B. BROWN, AND S.H. GERRIETS. 1994. Gazetteer of marine birds in Atlantic Canada: an atlas of seabird vulnerability to oil pollution. Canadian Wildlife Service, Dartmouth, NS Canada.

MACDONALD, P.R.N. AND P.J. AUSTIN-SMITH. 1989. Bald Eagle, *Haliaeetus leucocephalus,* nest distribution on Cape Breton Island, Nova Scotia. *Can. Field-Nat.* 103: 293–296.

MATZ, A.C. 1998. Organochlorine contaminants and Bald Eagles *Haliaeetus leucocephalus* in Maine: investigations at three ecological scales. Ph.D. dissertation, University of Maine, Orono, ME U.S.A.

MERSMANN, T.J., D.A. BUEHLER, J.D. FRASER, AND J.K.D. SEEGAR. 1992. Assessing bias in studies of Bald Eagle food habits. *J. Wildl. Manage.* 56:73–78.

MONTEVECCHI, W.A. AND L.M. TUCK. 1987. Newfoundland birds: exploitation, study, conservation. *Publ. Nuttall Ornithol. Club* 21, Cambridge, MA U.S.A.

NEUGEBAUER, E.A., G.L. SANS CARTIER, AND B.J. WAKEFORD. 2000. Methods for the determination of metals in wildlife tissues using various atomic absorption spectrophotometry techniques. *Can. Wildl. Serv. Tech. Rep.* 337.

NORSTROM, R.J. AND H.T. WON. 1985. Long term preservation of egg and tissue homogenates for the determination of organochlorine compounds: freezing versus freeze drying. *J. Assoc. Off. Anal. Chem.* 68:129–135.

OSBORNE, J.M. 1978. Invertebrate diversity Long Harbour, Placentia Bay, Nfld.: eight years after a pollution crisis. Surveillance Report EPS 5-AR-78-2, Environment Protection Service, Environment Canada, Atlantic Region, St. John's, NF Canada.

POSTUPALSKY, S. 1974. Raptor reproductive success: some problems with methods, criteria, and terminology. *Raptor Res. Rep.* 2:21–31.

SCHEUHAMMER, A.M. AND D. BOND. 1991. Factors affecting the determination of total mercury in biological samples by continuous flow cold vapour atomic absorption spectrophotometry. *Biolog. Trace Element Res.* 31:119–129.

SPALDING, M.G., P.C. FREDERICK, H.C. MCGILL, S.N. BOUTON, AND L.R. MCDOWELL. 2000a. Methylmercury accumulation in tissues and its effects on growth and appetite in captive great egrets. *J. Wildl. Dis.* 36:411–422.

———, ———, ———, ———, L.J. RICHEY, I.M. SCHUMACHER, C.G.M. BLACKMORE, AND J. HARRISON. 2000b. Histologic, neurologic, and immunologic effects of methylmercury in captive great egrets. *J. Wildl. Dis.* 36: 423–435.

STALMASTER, M.V. 1987. The Bald Eagle. Universe Books, New York, NY U.S.A.

STOCEK, R.F. AND P.A. PEARCE. 1981. Status and breeding success of New Brunswick Bald Eagles. *Can. Field-Nat.* 95:428–433.

TODD, C.S., L.S. YOUNG, R.B. OWEN, AND F.J. GRAMLICH. 1982. Food habits of Bald Eagles in Maine. *J. Wildl. Manage.* 46:636–645.

WELCH, L.J. 1994. Contaminant burdens and reproductive rates of Bald Eagles breeding in Maine. M.S. thesis, University of Maine, Orono, ME U.S.A.

WIEMEYER, S.N., R.W. FRENZEL, R.G. ANTHONY, B.R. MCCLELLAND, AND R.L. KNIGHT. 1989. Environmental contaminants in blood of western Bald Eagles. *J. Raptor Res.* 23:140–146.

———, C.M. BUNCK, AND C.J. STAFFORD. 1993. Environmental contaminants in Bald Eagle eggs (1980–84) and further interpretations of relationships to productivity and shell thickness. *Arch. Environ. Contam. Toxicol.* 24: 213–227.

WIESE, F.K. AND P.C. RYAN. 2003. The extent of chronic marine oil pollution in southeastern Newfoundland waters assessed through beached-bird surveys 1984–1999. *Mar. Pollut. Bull.* 46:(in press).

WOOD, P.B., J.H. WHITE, A. STEFFER, J.M. WOOD, C.F. FACEMIRE, AND H.F. PERCIVAL. 1995. Mercury concentrations in tissues of Florida Bald Eagles. *J. Wildl. Manage.* 60: 178–185.

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