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Liver Contaminants in Bald Eagle Carcasses from Maine

Fish and Wildlife Service

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Liver Contaminants in Bald Eagle Carcasses from Maine

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Executive Summary

In Maine, locations of moribund or dead bald eagles are regularly reported to biologists and game wardens and carcasses are immediately collected. Unless a law enforcement case is suspected, eagle carcasses are destined for the National Eagle Repository for use by Native Americans. Prior to shipping to the repository, 51 livers were extracted from bald eagle carcasses recovered throughout the state of Maine between 2001 and 2007. Livers were analyzed for organic and inorganic contaminants to provide state-specific baseline information related to Endangered Species Act post de-listing monitoring of the bald eagle.

Residue burdens in livers are influenced by a variety of factors including the bird's health, age, diet, and body condition. Sick, starving, and weakened birds will mobilize contaminants sequestered in body fat. The liver, as a detoxifying organ, will accumulate mobilized organic compounds and trace elements providing information on contaminant exposure. In 51 bald eagle livers, the following was found:

- Mercury (Hg) – Maine continues to demonstrate higher Hg levels in biota than other regions of the U.S. Mean Total Hg in Maine eagle livers was 14.04 ppm dry weight, which was higher than mean levels recorded in bald eagles from British Columbia (11.8 ppm), several Great Lake states (7.97 ppm), and Alaska (7.10 ppm). In Maine, 64% of the bald eagle livers had low Hg levels (< 20 ppm dry weight), 32% had moderate levels (20 - 80 ppm) and two birds had high levels (> 80 ppm). The maximum recorded Hg value of 191 ppm was in a bird recovered from South Branch Lake in Seboeis Plantation, Penobscot County.

- Lead (Pb) – Despite a ban of Pb shot for waterfowl hunting, Pb continues to adversely affect bald eagles in the U.S. and Canada. Lead ammunition in hunter-killed, but unrecovered wildlife and bullets in carcasses of wildlife used as bait by trappers are suspected Pb sources to scavenging eagles. In 51 Maine eagle livers, 84% had low Pb levels (≤ 6 ppm dry weight), but 16% had concentrations indicative of Pb poisoning (> 30 ppm). Two livers had Pb levels in excess of 130 ppm. In other eagle studies, percentages of Pb-poisoned birds were either similar (e.g., 12%, 14%) to Maine or higher (39%).

- Total Polychlorinated Biphenyl (ΣPCB) – The geometric mean ΣPCB concentration in Maine bald eagle livers was 5.68 ppm wet weight with a large amount of variance. One liver with a ΣPCB concentration of 98.6 ppm approached a suggested ΣPCB toxicity threshold level of 100 ppm, while two livers were 3 and 5 times higher than the suggested toxicity threshold level (319 ppm, 570 ppm). The maximum ΣPCB liver concentration (570 ppm) was found in a banded, 18 year old male bird recovered on the coast in Steuben, Washington County; its ΣPCB level was double the previously reported greatest value in a bald eagle liver (280 ppm, Michigan).

- Dichloro-diphenyl-dichloroethylene (p,p'-DDE) - The highest DDE concentration found in Maine liver samples was 64.2 ppm wet weight, which was well below the suggested DDE toxicity threshold level of 100 ppm. The geometric mean DDE level in Maine bald eagle livers was 1.06 ppm.

Strategies to implement provisions of the USFWS post de-listing monitoring program for the bald eagle are evolving. Bald eagle liver appears to be a suitable tissue for assessing Hg and Pb risk in carcasses. Threshold effect levels for organic contaminants (e.g., DDE, PCB) in eagle livers, however, are not well established and contaminant residues in livers can be influenced by lipid content and body condition.

Keywords: bald eagle, liver, mercury, lead, PCB, DDE, Maine

PREFACE

This report documents environmental contaminant exposure in livers of bald eagles recovered in Maine. The USFWS Region 5 Project Identification Number for this study is 53411-1130-5F42 and the USFWS Division of Environmental Quality Project Identification Number is 200650002.4. Samples were collected between 2001 and 2007. Analytical work was completed under the following USFWS Analytical Control Facility Catalogs and Purchase Orders:

Catalog Numbers	Year Submitted	Catalog Content	Purchase Order Numbers
5100007	2004	1 liver	94420-04-Y353 Organics – GERG
			92220-04-Y354 Inorganics - TERL
5100009	2004	3 livers	94420-04-Y480 Organics – GERG
			94420-04-Y481 Inorganics - TERL
5100017	2006	16 livers	94420-06-Y696 Organics – GERG
			94420-06-Y697 Inorganics - TERL
5100023	2007	12 livers	94420-07-Y842 Organics – TDI
			94420-07-Y843 Inorganics – TERL
5100030	2008	18 livers	94420-08-Y885 Organics – TDI
			94420-08-Y884 Inorganics - TERL
5100035	2008	1 liver	94420-08-Y943 Organics – GERG
			94420-08-Y944 Inorganics - TERL

Questions, comments, and suggestions related to this report are encouraged. Written inquiries should refer to Report Number FY09-MEFO-6-EC and be directed to the principal investigator:

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This report complies with peer review and certification provisions of the Information Quality Act (Pubic Law 106-554, Section 515).

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List of Acronyms and Abbreviations

Al	aluminum
B	boron
Ba	barium
Be	beryllium
BHC	benzene hexachloride
Cd	cadmium
CGC	capillary gas chromatography
Cr	chromium
Cu	copper
DDE	dichloro-diphenyl-dichloroethylene
dw	dry weight
Fe	iron
GERG	Geochemical Environmental Research Group
GM	geometric mean
HCB	hexachlorobenzene
Hg	mercury
Maine IF&W	Maine Department of Inland Fisheries and Wildlife
MeHg	methylmercury
µg/g	microgram per gram (parts per million)
Mg	magnesium
Mn	manganese
Mo	molybdenum
Ni	nickel
Pb	lead
PCB	polychlorinated biphenyl
p,p'	para, para
ppm	parts-per-million
QA/QC	Quality Assurance / Quality Control
Se	selenium
ΣPCB	total polychlorinated biphenyl
Sr	strontium
TDI	TDI Brooks International Laboratory
TERL	Trace Element Research Laboratory
USFWS	U.S. Fish and Wildlife Service
V	vanadium
ww	wet weight
Zn	zinc

1. Introduction

The bald eagle (*Haliaeetus leucocephalus*) was removed from the U.S. list of endangered species in June 2007 and removed from Maine's state list of threatened species in 2009. In Maine, over 600 nesting areas are now occupied by adult bald eagle pairs and more than 300 eaglets fledge annually. The post de-listing monitoring plan for bald eagles (USFWS 2009) requires periodic monitoring of populations and potential limiting factors for 20 years. As in the case of the peregrine falcon (*Falco peregrinus*; USFWS 2003), contaminants monitoring and tracking mortality causes are important components of the bald eagle post de-listing monitoring plan. Detailed, region-specific, baseline data will be needed to evaluate the impact of contaminants on the long-term recovery of the bald eagle in the northeastern United States. Maine remains the stronghold for the species in this region.

More information is needed to adequately assess bald eagle recovery and the role of contaminants in Maine. Currently, non-viable bald eagle eggs in Maine are analyzed for environmental contaminants through studies sponsored by the USFWS Contaminants Program and in biological monitoring programs required by the Maine Department of Environmental Protection permits and licenses.

In the last decade, the Maine Department of Inland Fisheries and Wildlife (Maine IF&W) has collected more than 275 dead or moribund bald eagles from nearly all regions of the state. Cause-of-death is typically not determined in these birds unless it is obvious (e.g., collision with power lines or vehicles) or involves a potential law enforcement case. Most carcasses are ultimately transferred to the National Eagle Repository for use by Native Americans. Samples from these eagle carcasses represent a valuable, under-utilized contaminant data source to evaluate factors potentially influencing bald eagle recovery: notably potential causes of death and contaminants residue levels in tissues. In the present study, livers from archived birds and newly collected carcasses were extracted and examined for environmental contaminants.

The liver is a useful tissue for assessing contaminant exposure in wildlife. Contaminants readily accumulate and concentrate in the liver (Klaassen 1986). The organ is large in bald eagles and other fish-eating birds and provides sufficient mass for chemical analyses. Liver tissue has been used in numerous eagle studies to demonstrate organochlorine compound and trace element contaminant uptake and toxicity (Frenzel and Anthony 1989, Craig *et al*. 1990, Kozie and Anderson 1991, Elliott *et al*. 1996, Wood *et al*. 1996, Garcelon and Thomas 1997, Wayland and Bollinger 1999, Kumar *et al*. 2002, Weech *et al*. 2003, Helander *et al*. 2009).

Although the Maine bald eagle population is considered recovered, additional scientific data is needed to thoroughly evaluate the health of the population, including the establishment of baseline contaminant body (liver) burdens. The examination of liver tissue in Maine bald eagle carcasses provides insight into contributing factors of mortality and provides baseline information to assess and assist long-term recovery efforts. Data gathered in the present study also provides useful information regarding the potential threat of contaminants to other upper-trophic predator bird species, waterfowl, and wading birds in the state.

2. Study Objective

Measure and evaluate liver contaminant levels in bald eagles found dead in Maine, and document instances of contaminant toxicity.

3. Study Area

Bald eagle carcasses recovered throughout the state of Maine between 2001 and 2007 were included in the study (Figure 1, Table 1).

4. Methods

4.1 Carcass Collection. Over the years, residents and visitors to Maine immediately notify local law enforcement, Maine IF&W, or USFWS whenever a dead or injured bald eagle is encountered in the state. These carcasses are usually quickly collected by authorized personnel, and USFWS law enforcement makes a determination of whether the situation may warrant legal action. If the carcasses do not involve a law enforcement case, the birds are held by the Maine IF&W until transferred to the National Eagle Repository in Colorado. In other instances, injured bald eagles are recovered and brought to a licensed wildlife rehabilitator. If the bird does not survive or is euthanized, the carcass is also held for law enforcement personnel or for later shipping to the National Eagle Repository.

Prior to transfer to the National Eagle Repository, 51 carcasses were processed for this liver study. For each recovered carcass, the date of recovery, identity of person finding the carcass, geographic location, location coordinates (if known), and other circumstances (e.g., potential cause of death, Table 2) were recorded. Carcasses with law enforcement potential were not processed. Banded, known-age birds were priority samples during the selection of carcasses for analysis. Scavenged or significantly decomposed carcasses were not selected for contaminant analysis.

4.2 Carcass Processing. Pertinent measurements were taken from each carcass (e.g., total weight, foot measurements (hallux claw, foot pad, tarsus width), bill measurements (depth, width, culmen length), 8th primary length, central rectrix length, etc., Table 3 and Table 4).

Sex of fully grown birds (i.e., adults and immatures) was determined from measurements of the hallux claw and bill depth (Bortolotti 1984a). Sex of nestlings was not determined.

Specific ages were determined from banding data using May 1 as the mean hatching date in Maine. Age categories were determined from head and plumage characteristics (McCollough

1989) and banding data. Various terms have been used to classify bald eagle age classes. In this report, terms for four age classes are: nestling, fledgling, immature, and adult (Buehler 2000).

- Nestling - Hatchlings or juvenile birds that have not fledged. These birds would be up to 8 or 14 weeks old.

- Fledgling - Birds that have departed the nest. Actual age for these birds may be 2 months to 1.5 years.

- Immature - Birds without definitive adult plumage. Actual age for these birds may be 1.5 years to 4.5 or 5.5 years.

- Adult - Birds with definitive adult plumage (i.e., head, tail, and upper- and lower-tail-coverts white with dark brown contour feathers). Actual age for these birds may begin at 4.5 or 5.5 years and run to 20+ years.

Body condition estimates were based on the quantity of pectoral muscle mass and amount of intra-abdominal fat using a 6-point qualitative scale described in Weech *et al*. (2003); where 0 = emaciated, 1 = thin, 2 = fair, 3 = good, 4 = very good, and 5 = excellent.

Cause of death was not determined during carcass examinations. Known or suspected circumstances of death were provided by Maine IF&W (Table 2).

4.3 Extraction Procedures. Since the birds were destined for the National Eagle Repository, Maine IF&W requested minimal cutting of carcasses for liver extractions. Frozen carcasses were placed on decontaminated stainless steel trays and partially thawed to allow liver extractions. Thawing typically took 24 hours. Once sufficiently thawed, the breast skin and feathers were pulled back from the sternum and upper abdomen, and an access hole was cut below the sternum with a decontaminated stainless steel scalpel. In some instances, lower portions of the sternum were removed with decontaminated stainless steel shears to access the upper body cavity. Once access was achieved, a stainless steel scalpel was used to cut the entire liver from connective tissue. Liver lobes were weighed individually, placed together in chemically-clean jars, and frozen until shipped to the analytical laboratories.

4.4 Analytical. Fifty-one liver samples were analyzed for trace metals, methylmercury, organochlorine compounds, percent moisture, and percent lipids.

4.4.1 Trace Metals - Liver samples were analyzed for 19 trace elements and methylmercury by the Trace Element Research Laboratory in College Station, Texas.

Trace metals included in the scan were: aluminum (Al), arsenic (As), boron (B), barium (Ba), beryllium (Be), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), methylmercury (MeHg), magnesium (Mg), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), selenium (Se), strontium (Sr), vanadium (V), and zinc (Zn). Metals were quantified using inductively coupled plasma mass spectrometry, graphite furnace atomic absorption or cold vapor atomic absorption.

Detection limits on a dry weight basis were 0.10 µg/g for Be and Cd; 0.20 for Hg; 0.50 µg/g for Al, Se, Cr, Cu, Ni, Pb, Sr and V; 1.0 µg/g for Ba, Mn, and Zn; 2.0 µg/g for B and Mo; and 5.0 µg/g for Al, Fe, and Mg. The average dry weight detection limit for MeHg was 0.06 µg/g.

4.4.2 Organochlorine compounds - Twenty-six organochlorine compounds and percent lipids in liver samples were measured by two analytical laboratories - the Geochemical and Environmental Research Group (GERG) and TDI Brooks International (TDI) in College Station, Texas.

Organochlorine compounds included in the scan were: total polychlorinated biphenyls (ΣPCB), DDT metabolites (*o*,*p*'-DDD, *o*,*p*'-DDE, *o*,*p*'-DDT, *p*,*p*'-DDD, *p*,*p*'-DDE, *p*,*p*'-DDT), benzene hexachloride or hexachlorocyclohexanes (*alpha* BHC, *beta* BHC, *gamma* BHC, *delta* BHC), chlordane compounds (heptachlor, heptachlor expoxide, oxychlordane, alpha chlordane, gamma chlordane, *cis*-nonachlor, *trans*-nonachlor), aldrin, endrin, dieldrin, hexachlorobenzene (HCB), endosulfan II, mirex, pentachloro-anisole, and toxaphene. Residues were quantified by capillary gas chromatography (CGC) with an electron capture detector for pesticides and PCBs. In cases where analytes co-elute with other analytes (e.g., endosulfan II), CGC with a mass spectrometer detector was used.

Detection limits, on a wet weight basis, were 0.01 µg/g for organochlorine compounds and 0.05 µg/g for Total PCBs and toxaphene.

4.5 Quality Assurance and Quality Control (QA/QC). QA/QC procedures performed by organic and inorganic laboratories included procedural blanks, duplicates, spike recoveries, and standard reference materials. Laboratory analytical packages and QA/QC results were reviewed and approved by the USFWS Analytical Control Facility in Shepherdstown, WV.

4.6 Data Presentations. Trace metal results are presented in µg/g on a dry weight basis. Organochlorine compounds are presented in µg/g on a wet weight basis and lipid weight basis. Statistical analyses were performed using Systat® 12.0 (Systat Software, Inc. 2007). Contaminant residues were summarized by detectable concentrations (i.e., non-detects were not included) for the geometric mean, arithmetic mean, standard deviation, and range (minimum, maximum). In the text of the report, the geometric mean (GM) is used to summarize contaminant concentrations and minimize outlier influence.

A non-parametric statistical test (Kruskal-Wallis) was performed to examine the relationship between contaminant concentrations and body condition. The acceptable level of statistical significance was $p < 0.05$.

5. Results

5.1 Carcasses.

5.1.1 Sex and Age - Based on bill depth and hallux claw measurements of adult, immature, and fledgling birds (Bortolloti 1984a), 23 males and 20 females were processed. Sex could not be determined in two adults. Six nestlings were not sexed.

Based on plumage characteristics (McCollough 1989) and banding information, 37 adult, six immature, two fledgling, and six nestlings were processed. Twelve specimens were banded birds ranging in age from seven months to 23 years, seven months. Among 10 banded adults, four were greater than 20 years old when recovered, three were 15 – 20 years old, and three were 10 – 15 years old. Estimated ages of six nestlings were determined with a linear regression equation for eighth primary length (Bortolotti 1984b).

5.1.2 Body Condition – Body condition was qualitatively assessed in 48 carcasses (94%, Figure 2). Using a six-point scale suggested in Weech *et al*. (2003), 10.4% of the carcasses were emaciated, 20.8% thin, 37.5% fair, 10.4% good, 6.3% very good, and 14.6% in excellent condition.

Grouping these six categories further, where birds with a score of 0 to 2 (i.e., emaciated to fair) were considered in poor body condition and birds with scores of 3 to 5 (i.e., good to excellent) were considered in good condition, places 69% of the birds in poor condition and 31% in good condition.

5.1.3 Season of Collection and Cause of Death – Nearly one-half of the carcasses were recovered in the spring, while the rest were almost evenly distributed among the other three seasons (Figure 3). Cause of death was unknown or undetermined in approximately 80% of the bald eagle carcasses (Figure 4). Collisions with power lines, cables, or vehicles were the most common suspected causes of death (18%). Five birds died in rehabilitation or were euthanized by a rehabilitator. Other suspected causes of death included gunshot, lead poisoning, leg-hold trap, starvation, and lightning strike.

5.2 Analytical.

Six catalogs containing the 51 liver samples were submitted to the USFWS Analytical Control Facility for this project. Catalog numbers and purchase orders are listed on page 3. Table 5 summarizes trace metal results. Tables 6 and 7 summarize organochlorine results.

6. Discussion

The liver can be a useful tissue for assessing contaminant exposure in wildlife. Contaminants readily accumulate and concentrate in the liver (Klaassen 1986). Contaminants sequestered in lipids such as the organochlorine compounds are mobilized during migration, reproduction, molt, cold weather, disease, or other periods of stress when birds stop feeding for extended periods of time. The liver is large in bald eagles and other fish-eating birds and provides sufficient mass for multiple chemical analyses. Exposure to contaminants may result in enzymatic responses leading to liver enlargement or necrosis (Harris and Elliott 2011). Liver residue levels in avian carcasses, however, should be viewed with caution. Organic contaminants may be greatly concentrated in livers of emaciated, starving, or injured birds when fat reserves are being mobilized (Hela *et al*. 2006).

Mercury, methylmercury, selenium, lead, ΣPCB and p,p'-DDE residues in bald eagle livers are discussed. Trace metals (Hg, MeHg, Se, Pb) are discussed on a dry weight basis, and organics (ΣPCB, p,p'-DDE) on a wet weight basis. Concentrations of other inorganics and organics are summarized in Tables 5 and 6, but not discussed.

Attributing contaminant uptake in bald eagle carcasses to a particular location or area is problematic. Bald eagles are migratory. Bald eagle migration behavior is complex and varies by age of the individual, location of breeding site, severity of climate, and food availability (Buehler 2000). Based on banding records, it is known that some birds sampled in this study were clearly of Maine origin. Other eagles in the study, particularly younger non-breeding birds, could be from distant areas. Buehler *et al*. (1991) reported two radio-tagged non-breeding eagles from Chesapeake Bay, MD, had moved north in summer to Maine. Broley (1947) banded a hatch-year bird in Florida that was shot 32 days later in New Brunswick, nearly 1,600 miles away.

Differences in diet composition associated with habitat types may result in differential contaminant exposure rates in bald eagles. Welch (1994) reported that breeding eagles from inland Maine territories fed primarily on fish and tended to have greater Hg burdens compared to eagles on the coast. In contrast, breeding bald eagles from coastal Maine territories had a greater bird component in their diet and tended to have greater organochlorine burdens. Since resident Maine bald eagles may move from inland to coast during winter months and shift their diets from fish to birds, the origin of contaminant burdens in bald eagles sampled for the present study cannot be determined.

6.1 Size, Sex, and Age. As in most other raptor species, female bald eagles are about 25% larger than males. Among the adult birds examined in the present investigation, the same size differential was found between sexes (Table 3). Size and mass of bald eagles increase with increasing latitude. Southern birds engage in northward post-breeding dispersals (Buehler 2000) and these birds are most likely to be encountered in the Northeast during the summer months (Broley 1947, Stocek 1979). Based on size measurements, however, no birds could be classified as southern visitors. One of the smallest adults in the investigation, BELIV701 a male weighing only 2500 grams, was clearly a Maine bird; it had been banded in the state 13 years earlier.

The ratio among 43 birds where sex could be determined was 20F:23M. Sample ages were as young as 2 months and as old as 23 years, 7 months (a banded bird). The age ratio is skewed towards adults because they were preferentially selected for sampling as carcasses with minimal decomposition. Twenty-seven adult carcasses were not banded birds, and specific ages are unknown.

6.2 Body Condition. Several researchers have correlated body condition to contaminant burden (Elliott *et al*. 1996, Kenntner *et al*. 2003, Weech *et al*. 2003, Wienburg and Shore 2004). In a study from Britain, body condition was the single most important factor and accounted for 49% of the variation in PCB liver residues; starved birds had the highest liver concentrations (Weinburg and Shore 2004).

Two of the lightest adult eagles in the 51 sample dataset (BELIV 801 and BELIV 604, both adult males with total body weights of 3000 grams) had the highest inorganic and organic liver concentrations. Sample BELIV801, a banded 18 year old recovered in Steuben (coastal Washington County), exhibited the highest ΣPCB (570.00 µg/g ww) and p,p'-DDE (64.20 µg/g ww) levels; the liver lipid content was 2.31% which was less than the average of 3.66%. Sample BELIV604, an unbanded bird recovered in Seboeis Plantation (interior Penobscot County), had the highest Total Hg (191.00 µg/g dw), MeHg (29.00 µg/g dw), and Se (55.20 µg/g dw) liver concentrations.

6.3 Season of Collection. Weinburg and Shore (2004) found significant seasonal differences in liver PCB levels in first year sparrowhawks (*Accipter nisus*), but did not find significant seasonal variations in adult birds. Elliott *et al*. (1996) attributed increasing DDE and PCB levels in bald eagle livers in spring to normal season lipid dynamics, and found individuals with elevated organochlorine levels occurring mainly in late spring and early summer. Most of the carcasses used in this Maine investigation were recovered in spring (Figure 3). Some birds may have died during winter and were located only after loss of snow cover later in the spring.

6.4 Mercury and methylmercury. Compared to other regions of North America, New England and the Canadian Maritimes have elevated levels of mercury in fish and wildlife tissue (Evers *et al*. 1998, Evers *et al*. 2007, Scheuhammer *et al*. 2008).

Geometric mean Total Hg in Maine eagle livers was 14.04 µg/g dw (range: 2.0 – 191.0 µg/g dw), which was higher than mean levels recorded in bald eagles from British Columbia (11.8 ± 15.8 µg/g, range: 0.5 – 130.0 µg/g dw, Weech *et al*. 2003), several Great Lake states (7.97 ± 10.51 µg/g, range: 0.47 – 61.61 µg/g dw, Rutkiewicz *et al*. 2011), and Alaska (7.10 µg/g dw, range: 1.70 – 17.5 µg/g dw, Stout and Trust 2002). Mercury in 32 bald eagle livers from Florida in the early 1990s ranged from 0.48 to 42.07 µg/g dw (converted from wet weight based on 71% moisture, Wood *et al*. 1996). Eighty-nine bald eagle livers from seven Canadian provinces had Hg levels ranging from 0.5 to 104 µg/g dw (Scheuhammer *et al*. 2008).

In the present study, the highest recorded Total Hg value, 191 µg/g dw, came from a bird recovered at South Branch Lake in Seboeis Plantation, Penobscot County. This level is higher than the 130.0 µg/g dw maximum for bald eagles reported by Weech *et al*. (2003). An unpublished record of an even higher concentration (Scheuhammer pers. comm.) was cited in Weech *et al*. (2003) of 670 µg/g dw Total Hg from a bald eagle liver sample from eastern Canada.

Classifications of Hg exposure levels in bald eagle livers were suggested by Weech *et al*. (2003). Using their classification levels, 32 livers from birds recovered in Maine or 64% had low Hg levels (< 20 µg/g dw), 16 livers or 32% had moderate levels (20 - 80 µg/g dw) and two livers or 4% had high levels (> 80 µg/g dw) including one with 191 µg Hg/g dw (Figure 5a).

There was no apparent pattern of Total Hg exposure by month of collection (Figure 5b)

Methylmercury was measured in 47 livers (GM 5.85 µg/g dw, range: 0.55 – 29.00 µg/g dw). An average of 51% of the Total Hg in livers was comprised of MeHg (range: 5 – 108%). The relationship between Total Hg and MeHg is shown in Figure 5c. Weech *et al*. (2003) reported similar results with MeHg constituting over 50% on average of the Total Hg in bald eagle livers from British Columbia. Rutkiewicz *et al*. (2011) found an average of 59.33 % (range: 11 -107%) of the Total Hg in the organic form (i.e., MeHg).

There was no relationship between Total Hg ($p = 0.733$) or MeHg ($p = 0.803$) concentrations and body condition (Figures 5d and 5e).

6.5 Selenium (Se). Selenium is typically not a contaminant of concern in the northeast U.S. Selenium, however, can protect against the neurotoxicity of methylmercury (Scheuhammer *et al*. 2008) which is a contaminant of concern in Maine and the northeastern U.S. (Evers *et al*. 2007).

Selenium was detected in all liver samples (GM 8.00 µg/g dw, range: 2.27 – 55.20 µg/g dw). Over a third of the liver samples contained Se at concentrations associated with biological risk (> 10 µg/g dw) and two had concentrations associated with deformities (> 30 µg/g dw) (Figure 6a). In the Great Lakes, Se concentrations in bald eagle livers averaged 6.07 ± 3.37 µg/g (range: 1.33 – 16.9 µg/g dw, Rutkiewicz *et al*. 2011). Eighty-nine bald eagle livers from seven Canadian provinces had Se levels ranging from 2.0 to 47 µg/g dw (Scheuhammer *et al*. 2008).

Selenium liver levels varied by month and there was no apparent pattern among season of collection (Figure 6b).

Ohlendorf and Heinz (2011) noted that Se in adult female livers was a poor predictor of reproductive impairment, and eggs were better indicators of potential Se hazard. Selenium levels in bald eagle eggs from Maine are not elevated (mean 2.24 ± 0.87 µg/g dw, n = 76, USFWS unpublished data) and within background ranges (1.5 – 2.5 µg/g dw, Ohlendorf and Heinz 2011).

The relationship between Total Hg and Se in eagle livers (Figure 6c) appeared similar to the results of Weech *et al*. (2003) and Scheuhammer *et al*. (2008). There was no relationship between Se concentrations and body condition (p = 0.094, Figure 6d).

6.6 Lead (Pb). Despite a ban on Pb shot for waterfowl hunting, Pb continues to adversely affect bald eagles in the U.S. and Canada. Lead ammunition in hunter-killed, but unrecovered wild game and bullet fragments in carcasses of wildlife used as bait by trappers are suspected Pb sources to scavenging eagles (Bedrosian and Craighead 2009, Hunt *et al*. 2009, Redig *et al*. 2009).

Wayland and Bollinger (1999) suggested three levels to classify Pb exposure in eagles. Using their classification levels, most of the livers from birds recovered in Maine (42 of 50 samples or 84%) had low Pb levels (≤ 6 µg/g, dw), but eight of the 51 livers or 16% had concentrations indicative of Pb poisoning (> 30 µg/g, dw). Two of the eight livers with elevated Pb had residues greater than 130 µg/g, dw (Figure 7a). The GM concentration of Pb in livers of bald eagles recovered in Maine was 0.88 µg/g dw (range: 0.06 – 150.00 µg/g dw). Highest Pb concentrations were detected in birds recovered during the winter and spring months (Figure 7b). Scavenging behavior by eagles likely peaks during these seasons. There was no relationship between Pb concentrations and body condition (p = 0.385, Figure 7c).

In other eagle studies, percentages of Pb-poisoned birds were lower (5.8%, Reichel *et al*. 1984), similar (e.g., 12%, Wayland and Bollinger 1999; 14% Helander *et al*. 2009), or higher (39%, Neumann 2009) than the present study (16%).

During examinations of the carcasses, only one bird showed evidence of being shot (i.e., BELIV 615, an adult male that had been shot in the head). No other apparent gunshot wounds were visible and it is not known if birds with elevated levels had biologically incorporated Pb from previous encounters with shotgun pellets or bullets. Radiographic examinations of each carcass would have been useful.

Signs of Pb poisoning in birds includes anorexia, emaciation, anemia, lethargy, wing droop, ataxia, green diarrhea staining the vent, leg paralysis, and convulsions (Franson and Pain 2011). However, of the eight birds with highly elevated liver Pb concentrations, no suspected cause of death (Table 2) was attributed by the collectors to these carcasses that would suggest possible Pb poisoning.

6.7 ΣPCB. As in other regions of the U.S (Reichel *et al*. 1984), PCB levels in Maine wildlife have declined over the years. ΣPCB concentrations in Maine bald eagle eggs have declined five-fold since the 1970s (USFWS unpublished data). Current ΣPCB levels in Maine bald eagle eggs collected statewide (5.16 ± 4.35 µg/g ww, n = 73) are four-fold less than suggested threshold levels for reproduction (20 µg/g ww, Elliott and Harris 2002) and population sustainability (26 µg/g ww, Best *et al*. 2010).

ΣPCB toxicity threshold levels in eagle livers have not been established, and hepatic effect levels in other avian species have not been widely reported. A 100 µg/g ww toxicity threshold for ΣPCBs in raptor livers was suggested by Cooke *et al*. (1982). For ΣPCBs, three livers of bald eagle carcasses collected in Maine were near or well above the toxicity threshold level (98.6 µg/g, 319 µg/g, 570 µg/g; all in ww) (Figure 8a). The maximum ΣPCB liver concentration (570 µg/g ww) was found in a banded, 18 year old male bird recovered on the coast in Steuben, Washington County; its ΣPCB level was double the previously reported greatest value in a bald eagle liver from Michigan (280 µg/g ww, Kumar *et al*. 2002).

Geometric mean ΣPCB in all bald eagle liver samples was 5.68 µg/g ww (range: 0.047 – 570.00 µg/g). Reported avian hepatic sublethal effect levels vary. Hario *et al*. (2004) found reduced fledgling rates in black-backed gull chicks with PCB levels ranging from 8 to 21 µg/g ww. Kuzyk *et al*. (2003) found ethoxyresorufin-*O*-deethylase (EROD) responses in black guillemot chicks at low PCB exposures (0.073 µg/g ww).

Average concentrations of ΣPCB by month of collection were highest in May and September (Figure 8b). ΣPCB tended to be lower in birds with better body condition and there was a significant relationship between ΣPCB concentrations and body condition ($p = 0.031$, Figure 8c).

6.8 p,p'-DDE. DDT was widely used for spruce budworm (*Choristoneura fumiferana*) control in Maine forests between 1958 and 1967 (Dimond and Owen 1996) as well as for mosquito control and agriculture. DDT metabolite concentrations in fish and wildlife have declined since the compound was banned, but residues persist in the state's cold, acidic soils (Owen *et al*. 1977). Current p,p'-DDE levels in Maine bald eagle eggs (1.18 ± 0.91 µg/g ww, n = 73; USFWS unpublished data) are five-fold less than suggested threshold levels for reproduction (6 µg/g ww, Elliott and Harris 2002) and population sustainability (6.5 µg/g ww, Best *et al*. 2010).

DDE was detected in all 51 bald eagle liver samples. A 100 µg/g ww toxicity threshold for DDE in bird livers was suggested by Cooke *et al*. (1982). Highly elevated DDE levels have been previously reported in eagle livers. An adult bald eagle found on Santa Catalina Island considered poisoned by DDE contained liver residues of 838 µg/g ww (Garcelon and Thomas 1997).

The highest p,p'-DDE concentration found in Maine liver samples was 64.2 µg/g, ww (Figure

9a), which was well below the suggested toxicity threshold. Geometric mean p,p'-DDE in all liver samples was 1.06 µg/g ww. Concentrations of p,p'-DDE were similar to Total PCB by month of collection and were highest in May and September (Figure 9b). DDE tended to be lower in birds with better body condition and there was a significant relationship between DDE concentrations and body condition ($p = 0.050$ Figure 9c). Bald eagle livers did not exhibit elevated levels (> 50 µg/g ww, Elliott *et al*. 1996) of p,p'-DDE and ΣPCB (Figure 10).

6.9 Known Age Birds. Eighteen known age birds (i.e., banded or nestlings), were included in the study. Known age liver samples were skewed towards very young birds (i.e., less than 7 months old) or fairly old birds (i.e., greater than 13 years). Plots of liver total mercury, methylmercury, selenium and lead concentration versus known age did not show strong relationships (Figures 11 through 14). Similarly, plots of ΣPCB and DDE liver concentrations versus known age did not show strong relationships (Figures 15 and 16)

7. Summary and Recommended Management Actions

Bald eagle liver appears to be a suitable tissue for assessing Hg and Pb risk in carcasses. Threshold effect levels for organic contaminants (e.g., DDE, PCB) in eagle livers, however, are not well established and contaminant residues in livers can be influenced by lipid content and body condition.

Livers in this study were limited to routine organochlorine and trace metal analyses. In the future, researchers should consider a wider analytical suite that includes newly emerging contaminants such as flame retardants, perfluorinated chemicals, nano pollutants, and various classes of endocrine disruptors.

Strategies for implementing the USFWS post de-listing monitoring program for the bald eagle are in development. Policymakers, wildlife managers, and biologists will need credible scientific data to support their decisions and management actions. If regional bald eagle populations experience significant declines, more information will be required regarding causal effects related to environmental contaminants and the liver is an organ that should be included in targeted research and monitoring.

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Figure 1. Locations of bald eagle carcass recoveries

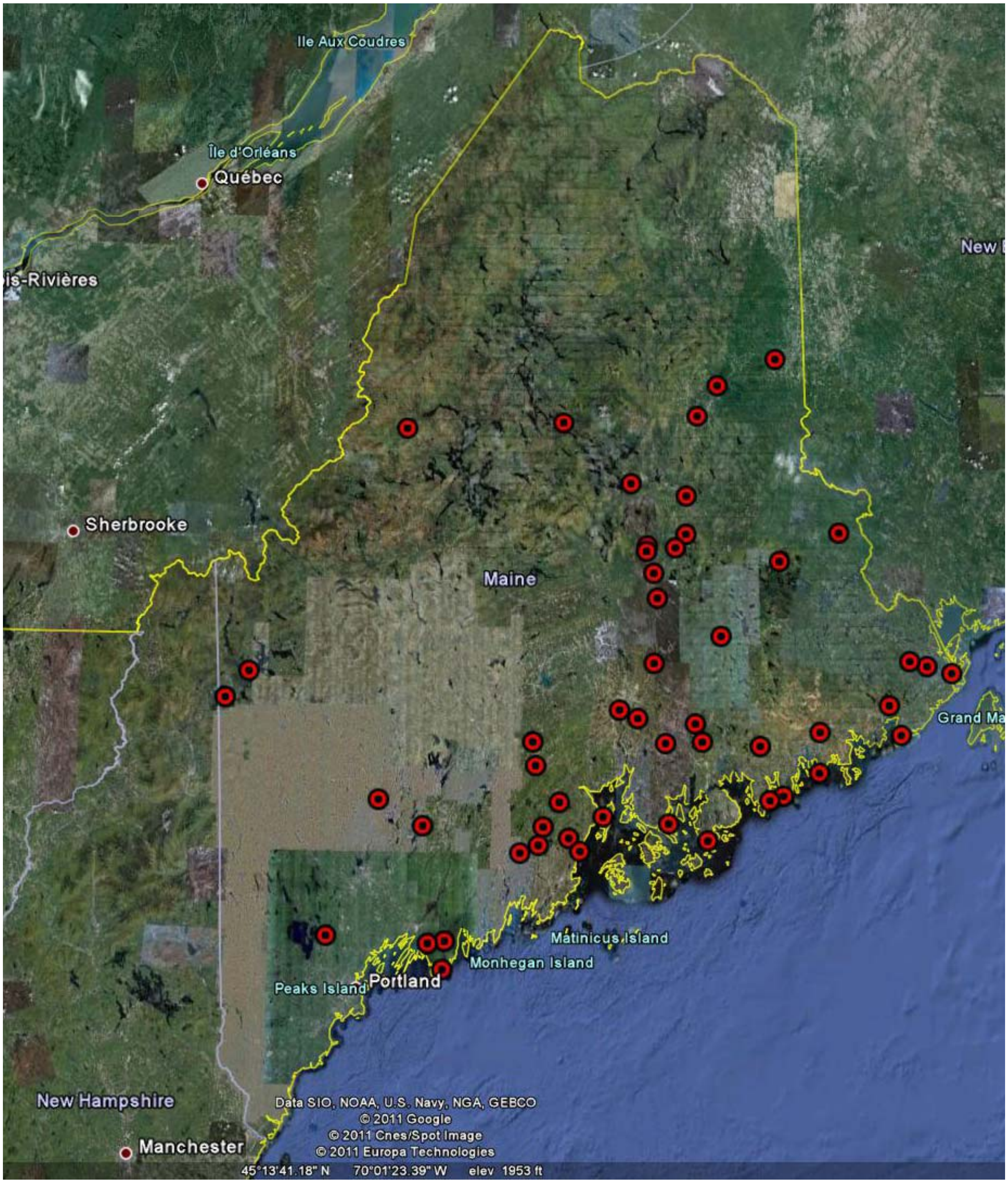
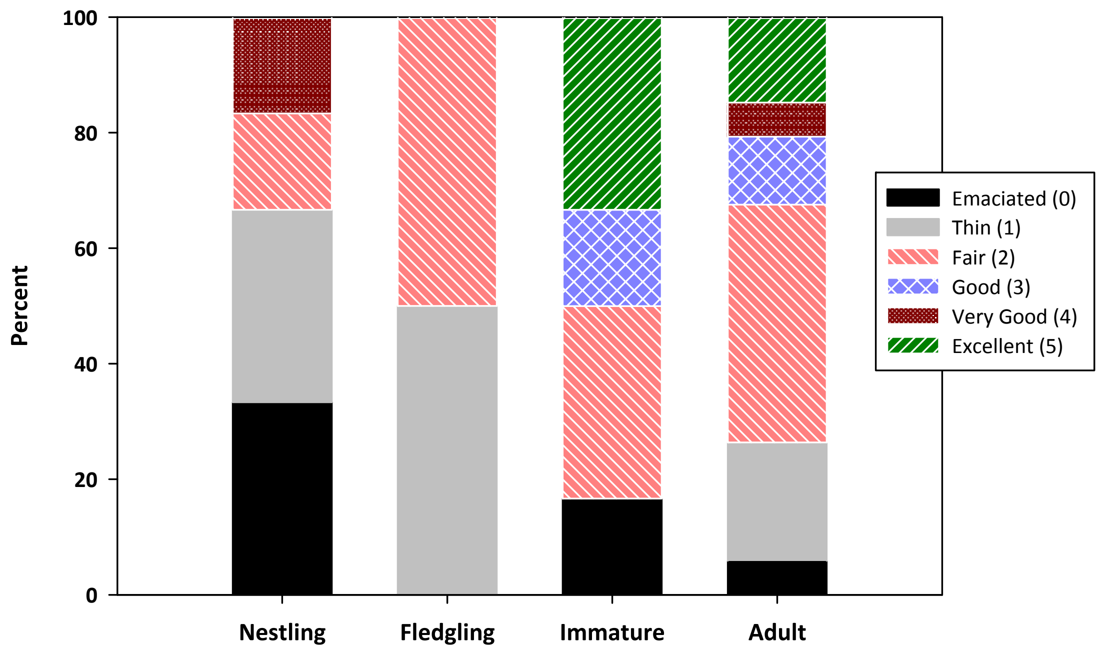


Figure 2. Body condition of recovered bald eagle carcasses by age class



Condition classes from Weech *et al*. 2003
Graph adapted from Kenntner *et al*. 2003

Figure 3. Bald eagle carcass recoveries by season

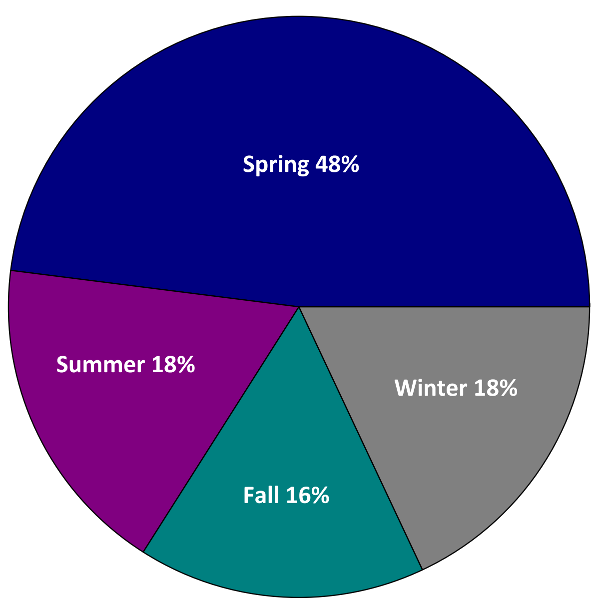


Figure 4. Suspected causes of death for 51 bald eagles

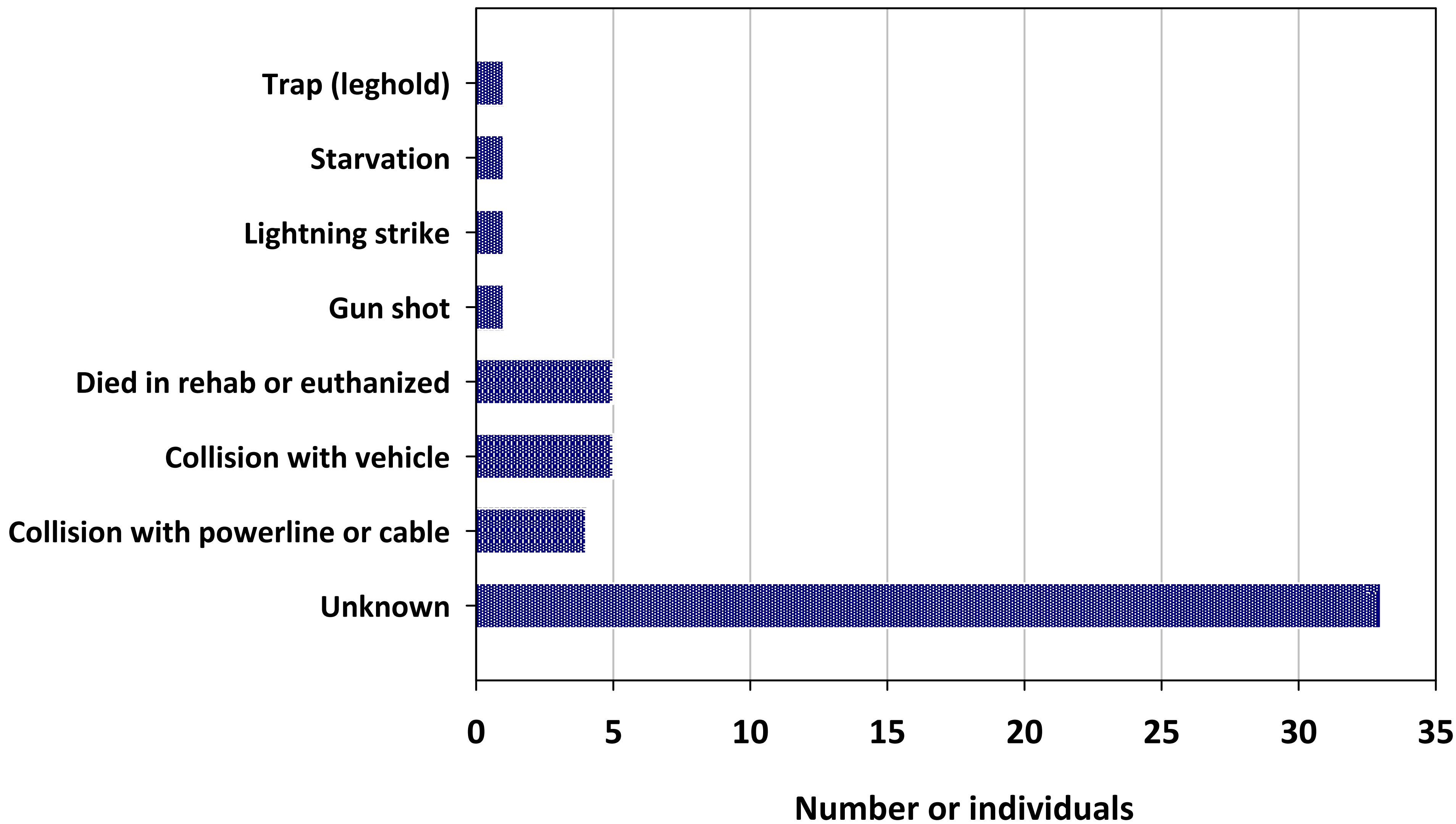


Figure 5a. Mercury (Hg) in bald eagle livers by age class, ug/g dry weight

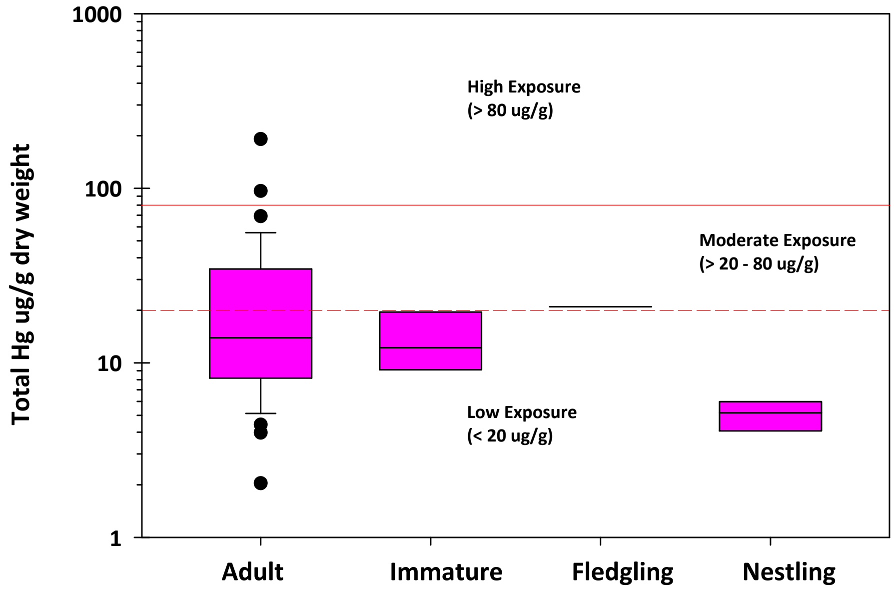
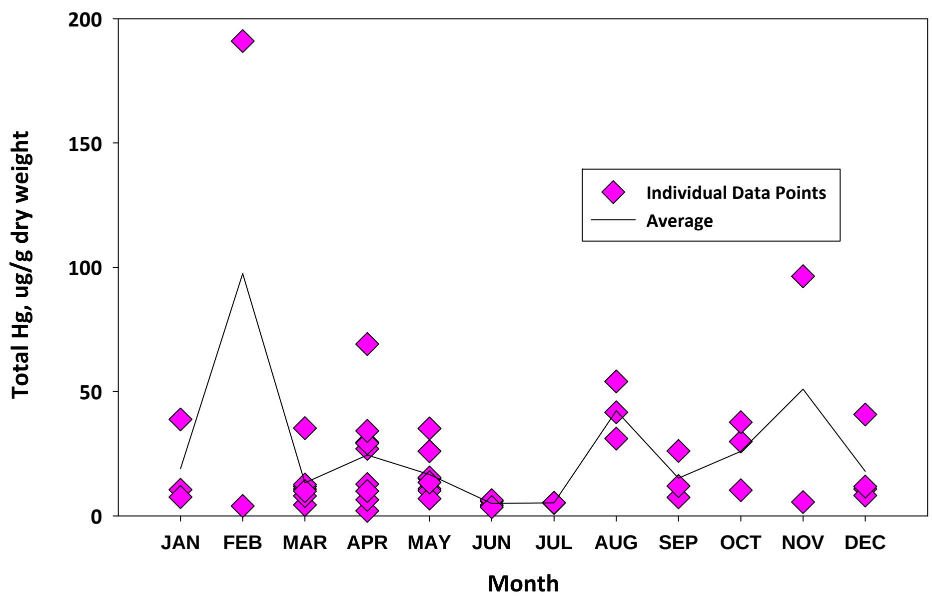


Figure 5b. Mercury in bald eagle livers by month of collection



Graph format adapted from Elliott *et al*. 1996

Figure 5c. Relationship between Total Hg and MeHg in bald eagle livers, ug/g dry weight

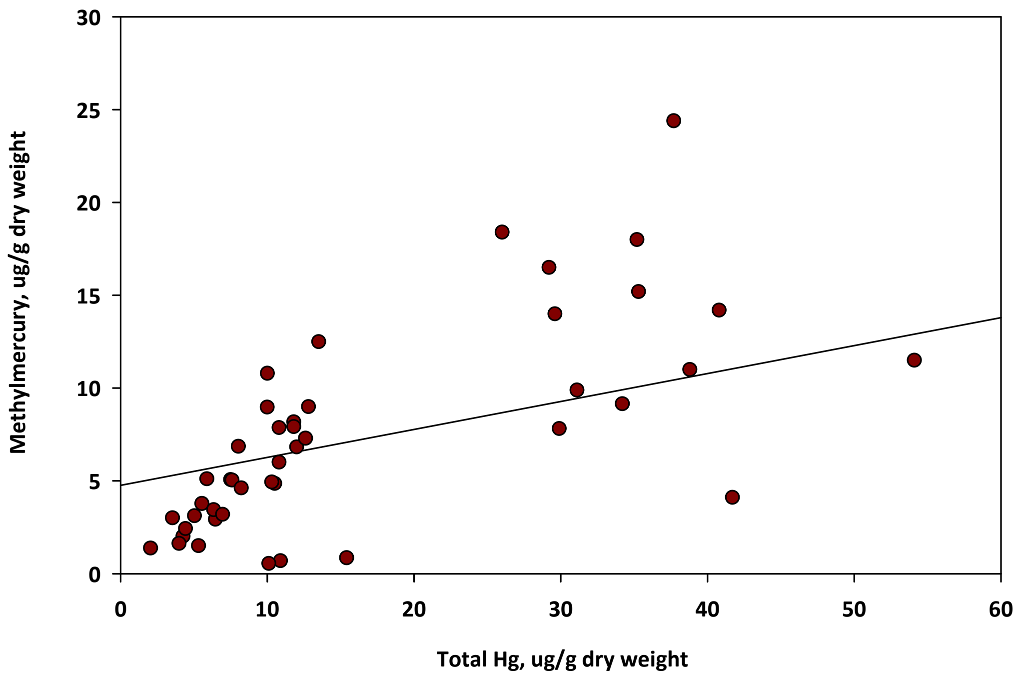


Figure 5d. Body condition versus Total Hg concentration in bald eagle livers

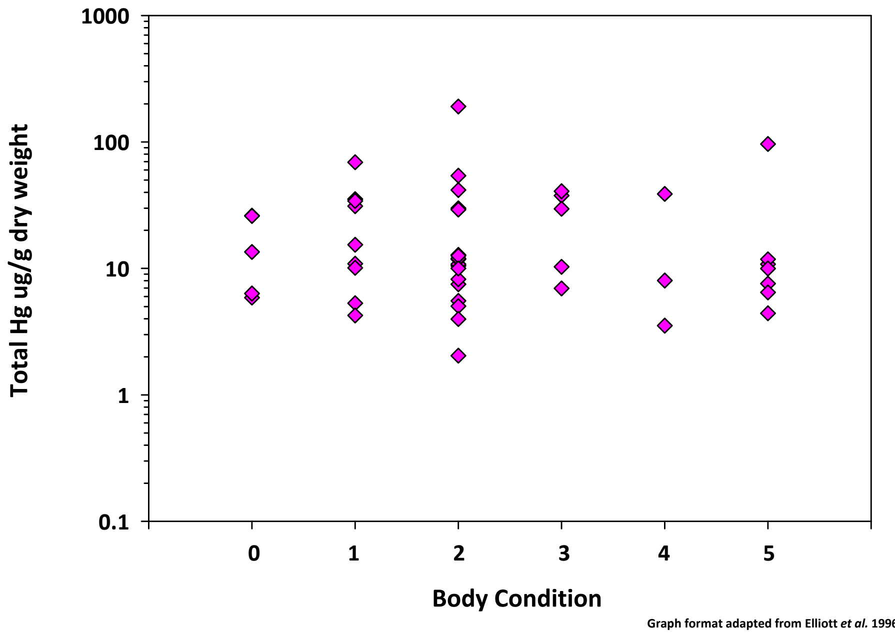


Figure 5e. Body condition versus MeHg concentration in bald eagle livers

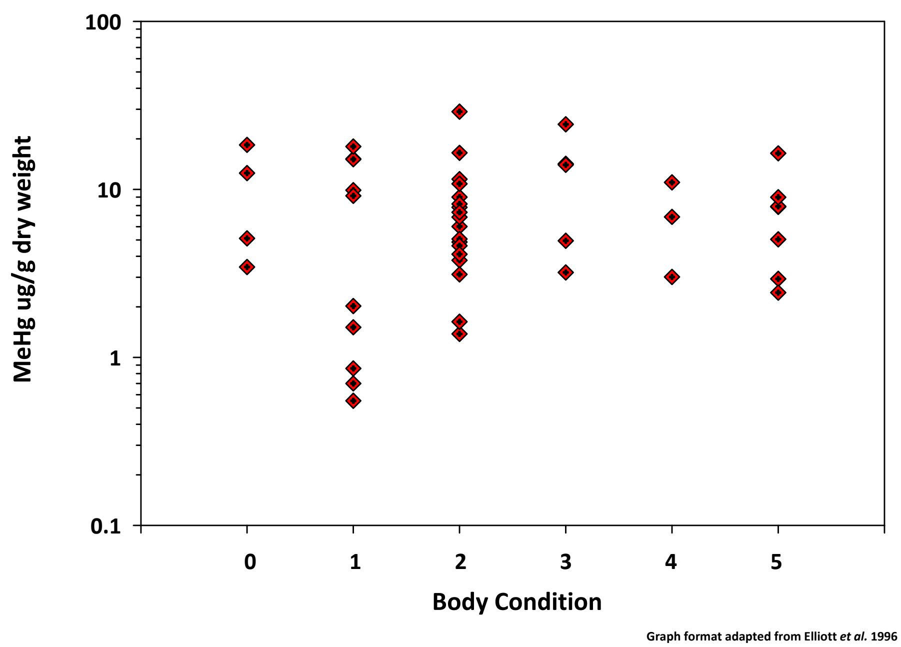


Figure 6a. Selenium (Se) in bald eagle livers by age class, ug/g dry weight

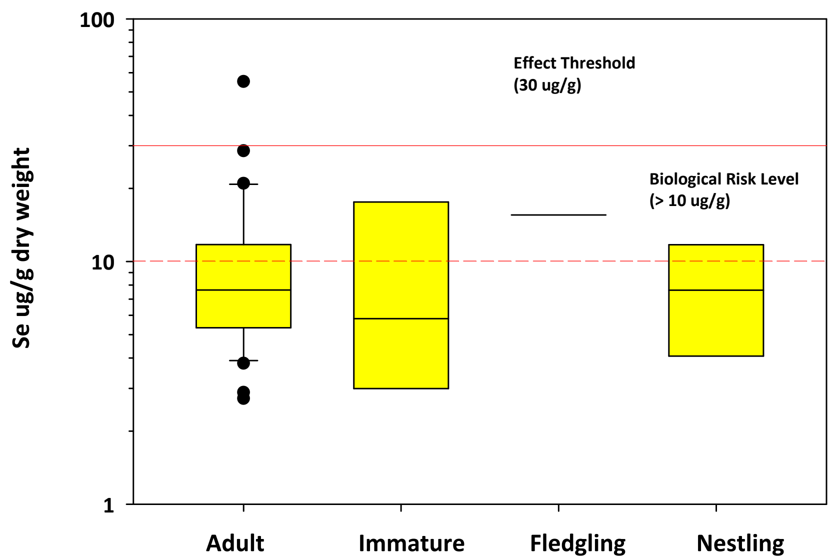


Table 6b. Selenium in bald eagle livers by month of collection

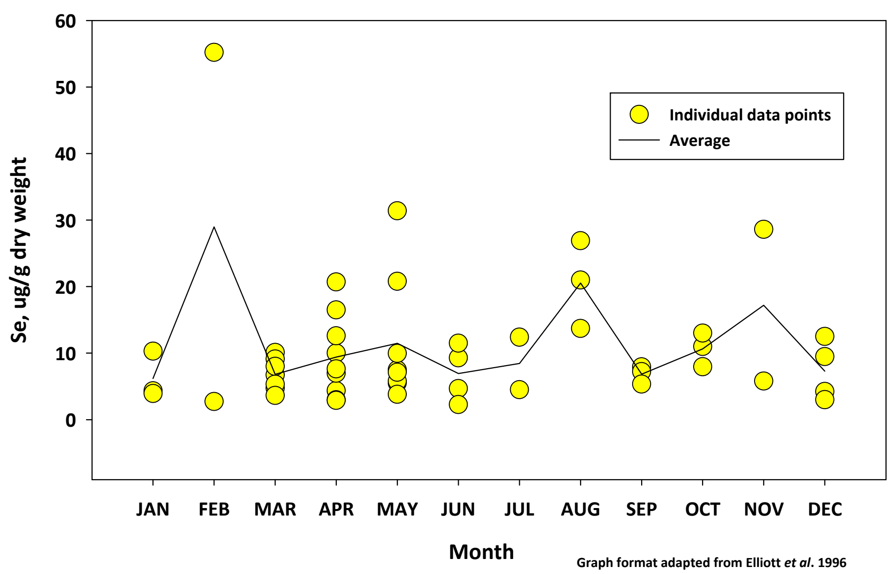


Figure 6c. Relationship between Total Hg and Se in bald eagle livers, ug/g dry weight

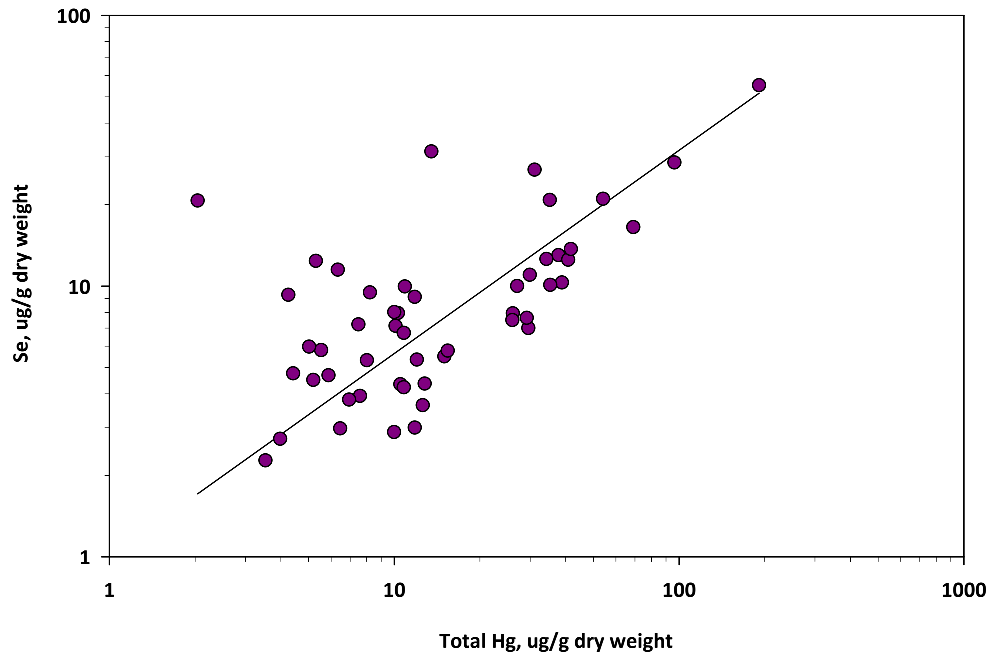


Figure 6d. Body condition versus selenium (Se) concentration in bald eagle livers

Figure 7a. Lead (Pb) in bald eagle livers by age class, ug/g dry weight

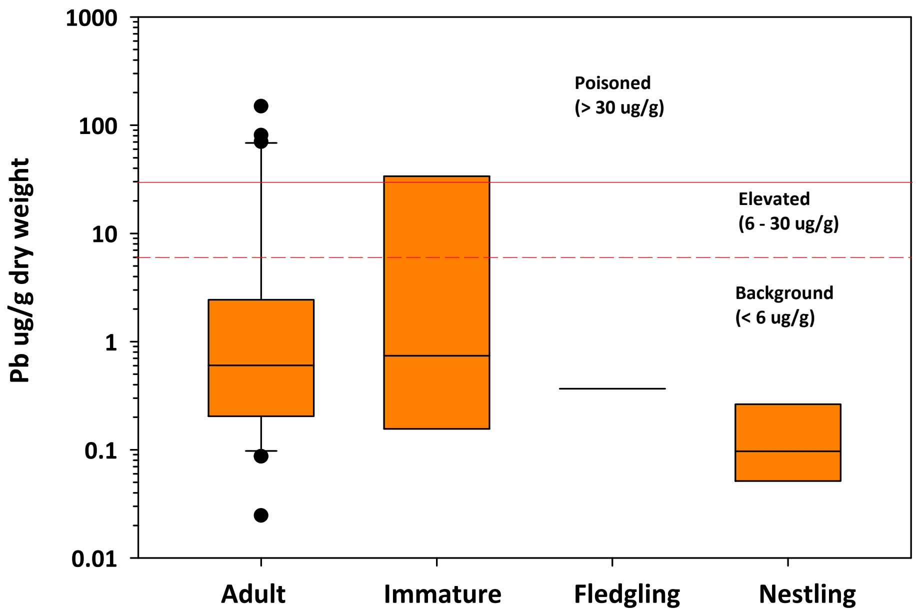
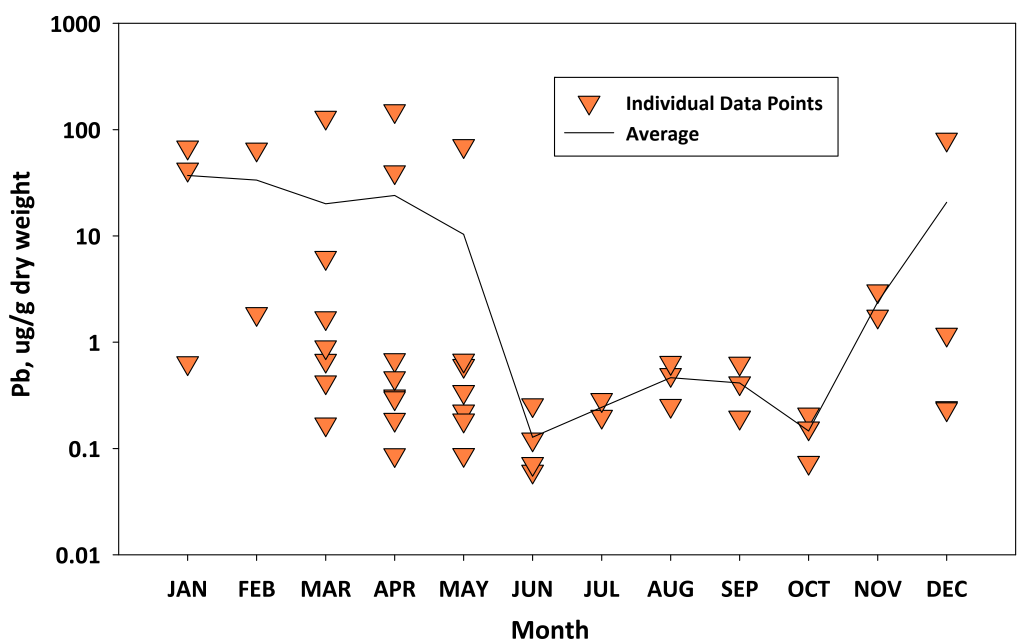
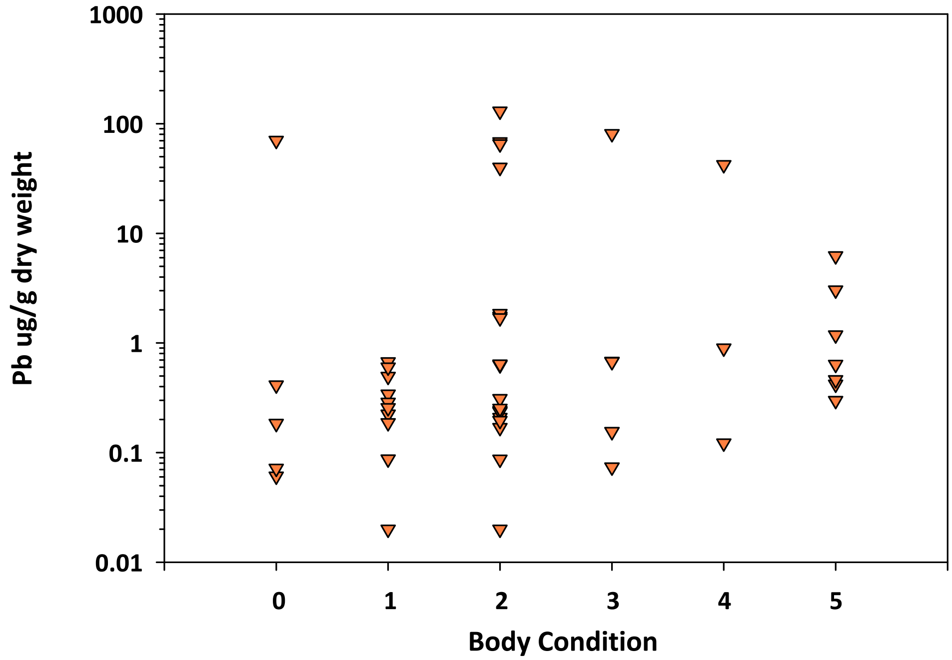


Figure 7b. Lead in bald eagle livers by month of collection



Graph format adapted from Elliott *et al*. 1996

Figure 7c. Body condition versus lead (Pb) concentration in bald eagle livers



Graph format adapted from Elliott *et al.* 1996

Figure 8a. Total PCB in bald eagle livers by age class, ug/g wet weight

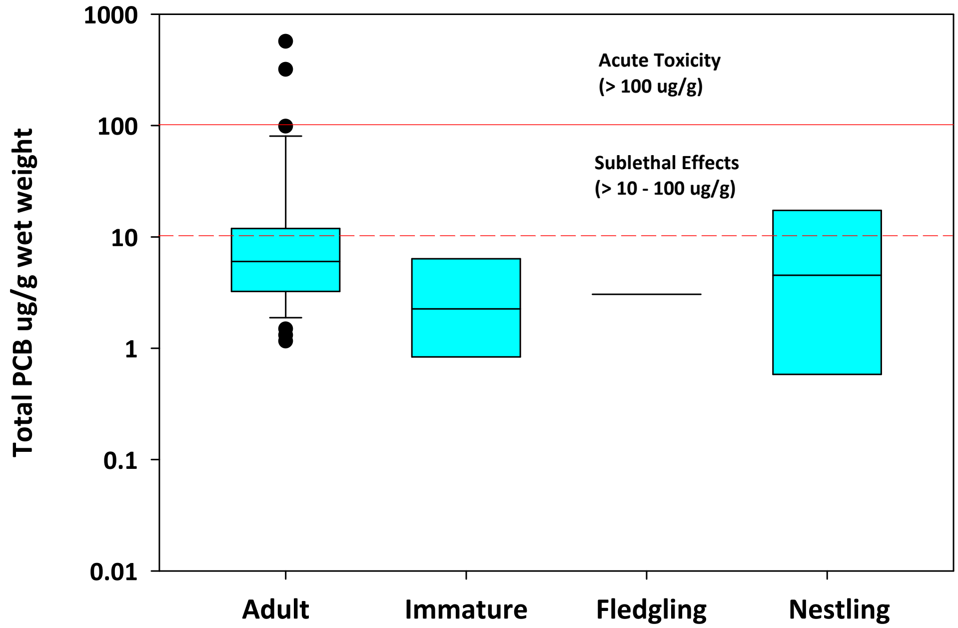
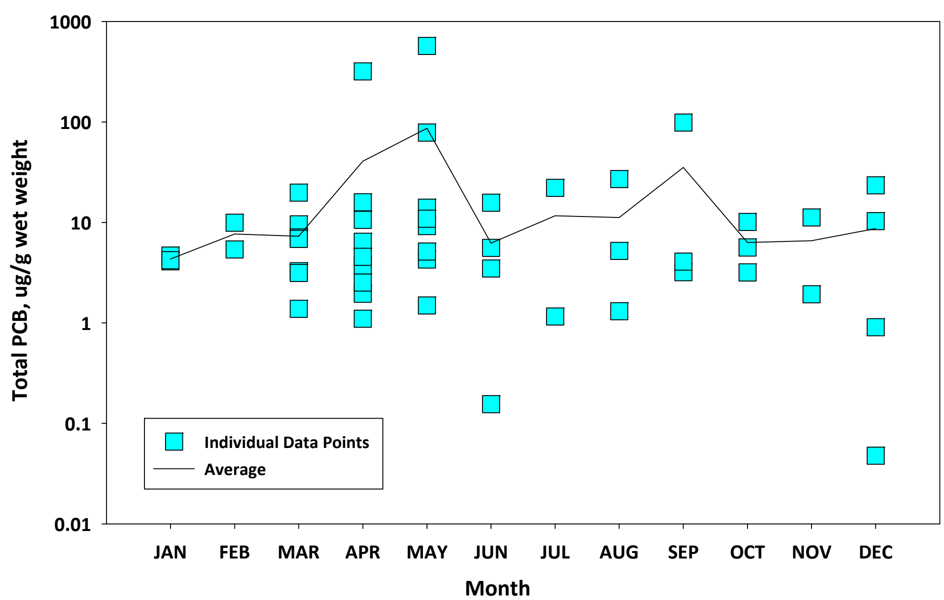
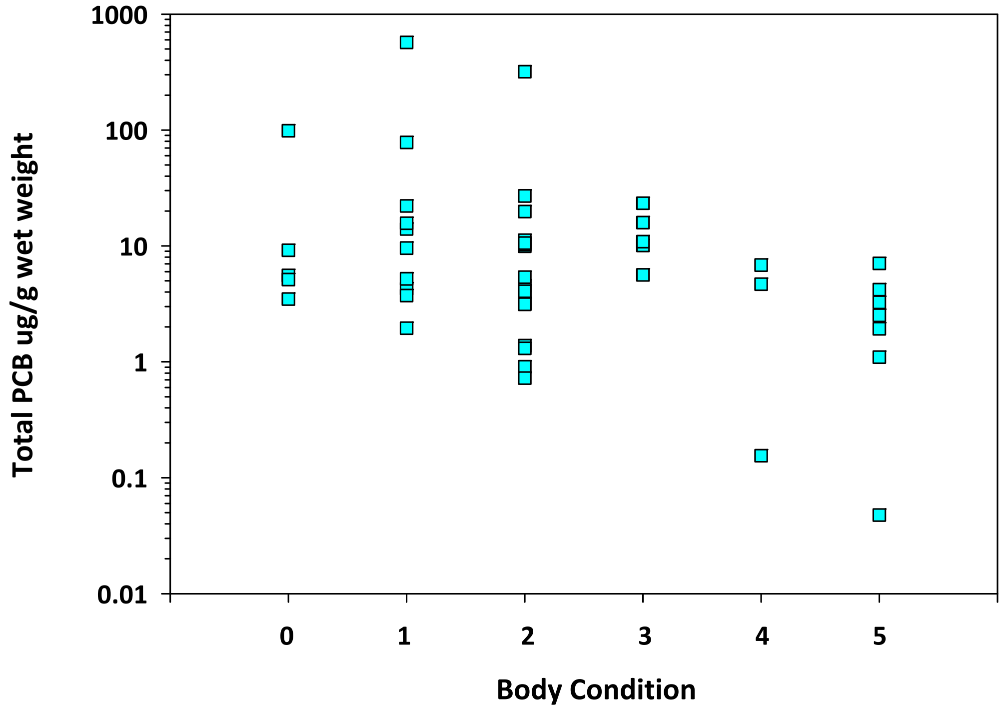


Figure 8b. Total PCB in bald eagle livers by month of collection



Graph format adapted from Elliott *et al.* 1996

Figure 8c. Body condition versus Total PCB concentration in bald eagle livers



Graph format adapted from Elliott *et al.* 1996

Figure 9a. p,p'-DDE in bald eagle livers by age class, ug/g wet weight

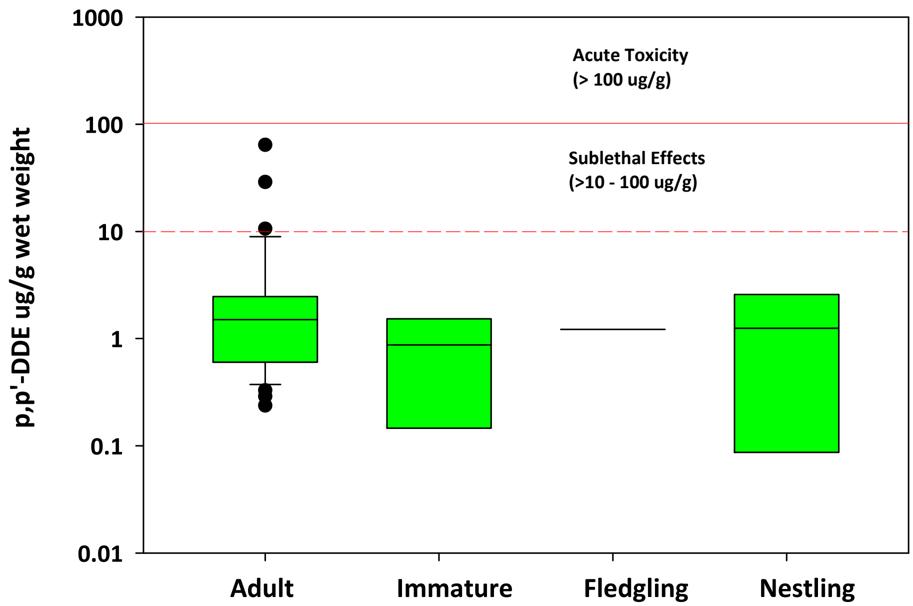


Figure 9b. p,p'-DDE in bald eagle livers by month of collection

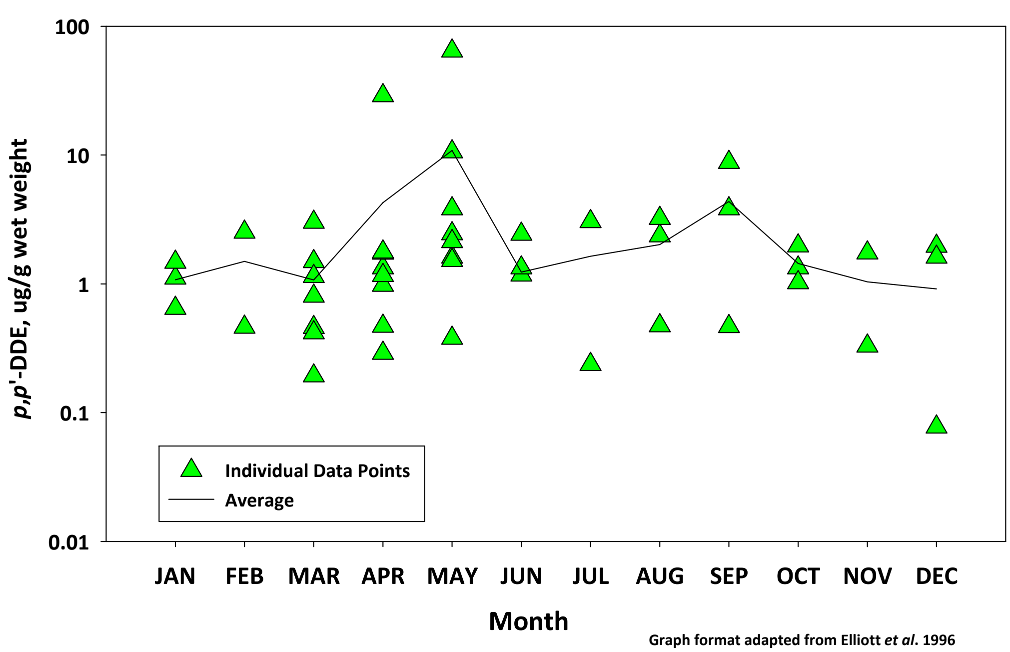


Figure 9c. Body condition versus DDE concentration in bald eagle livers

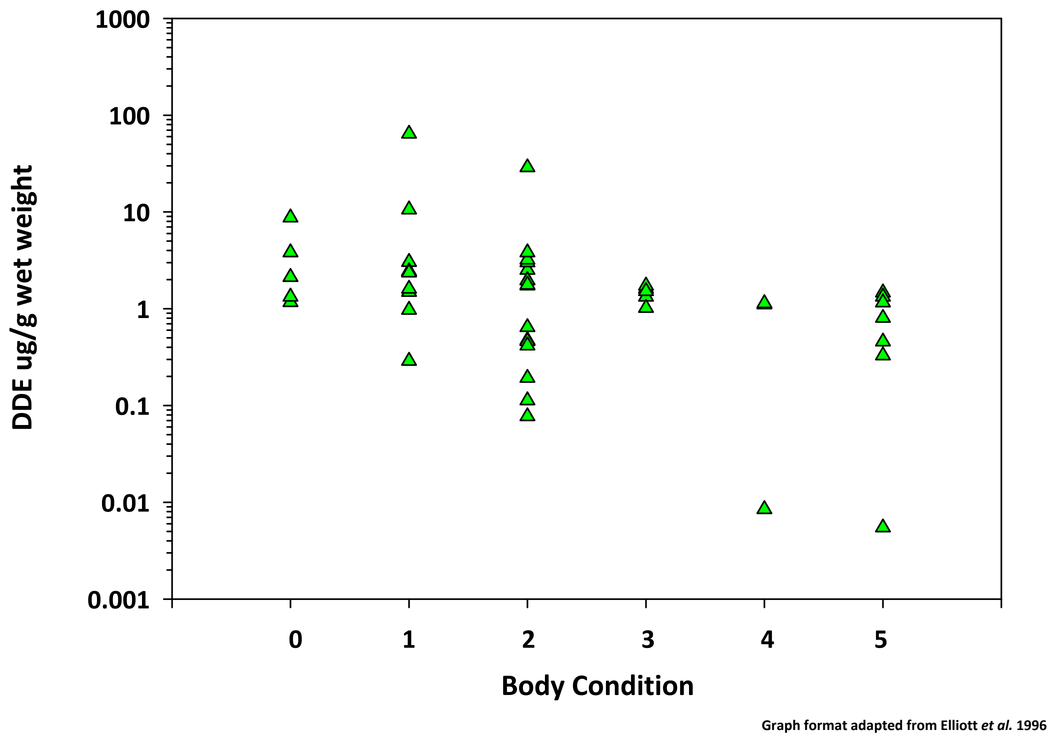
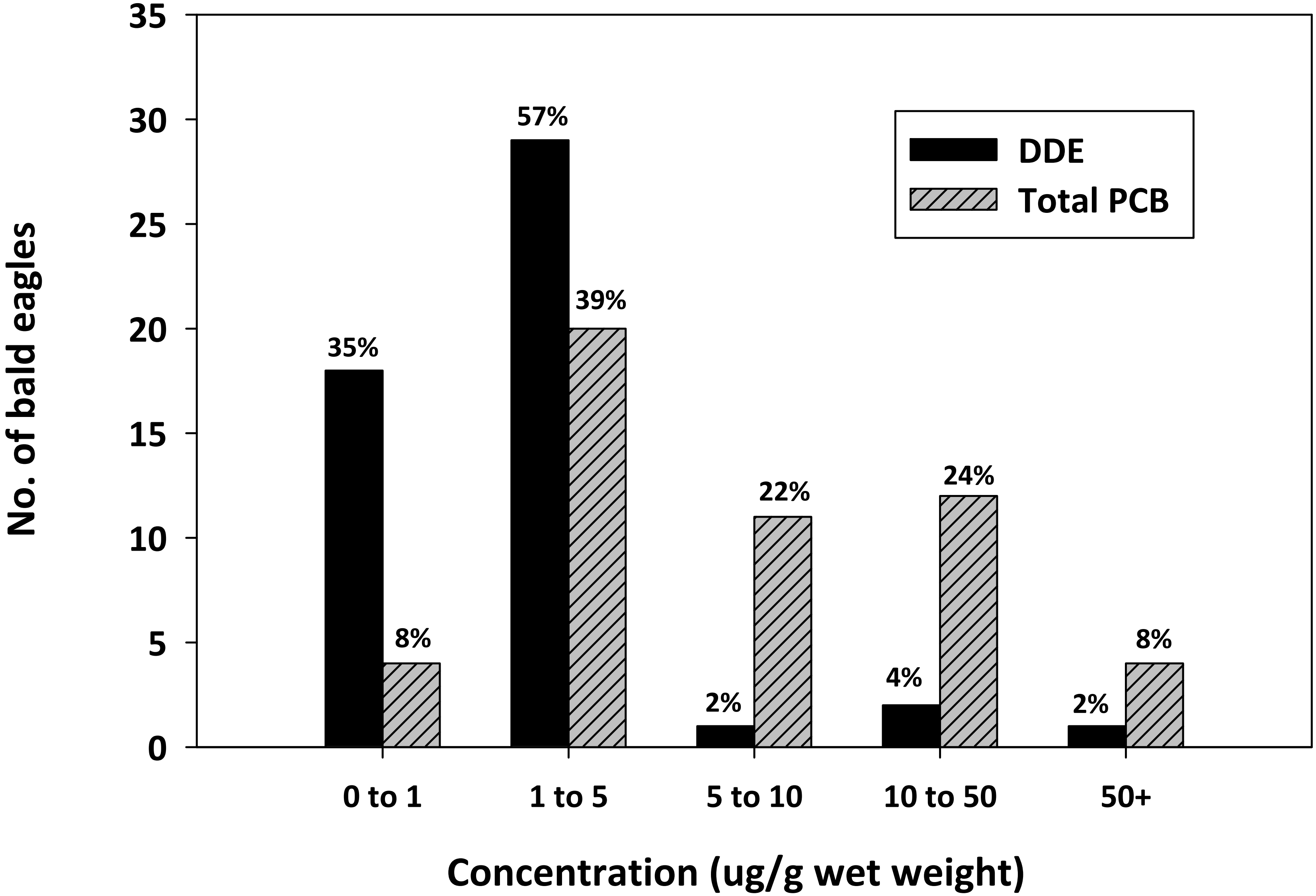


Figure 10. Numbers of bald eagles showing different DDE and PCB levels in livers



Graph format from Elliott *et al*. 1996

Figure 11. Total Hg in livers of known-age bald eagles, ug/g dry weight

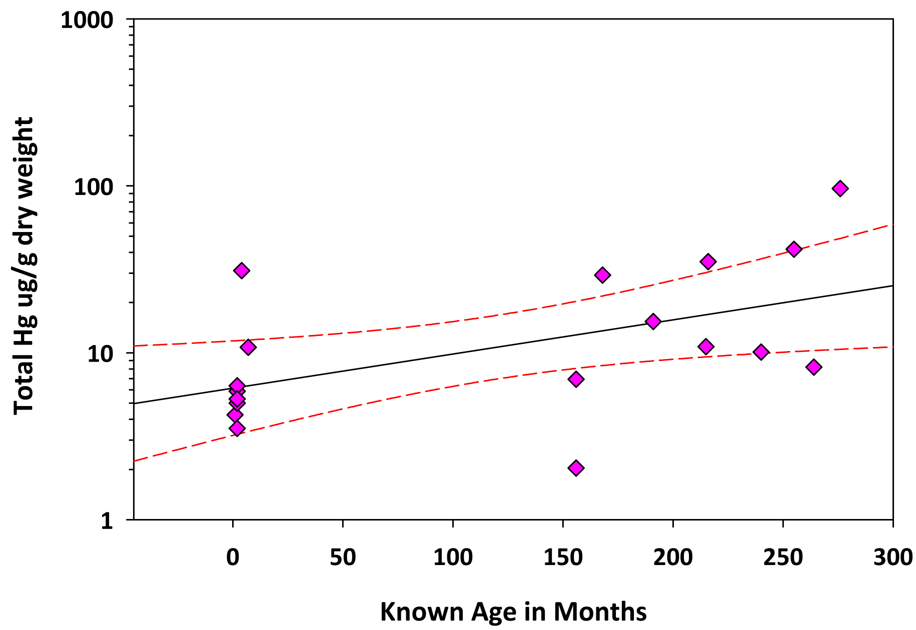


Figure 12. MeHg in livers of known-age bald eagles, ug/g dry weight

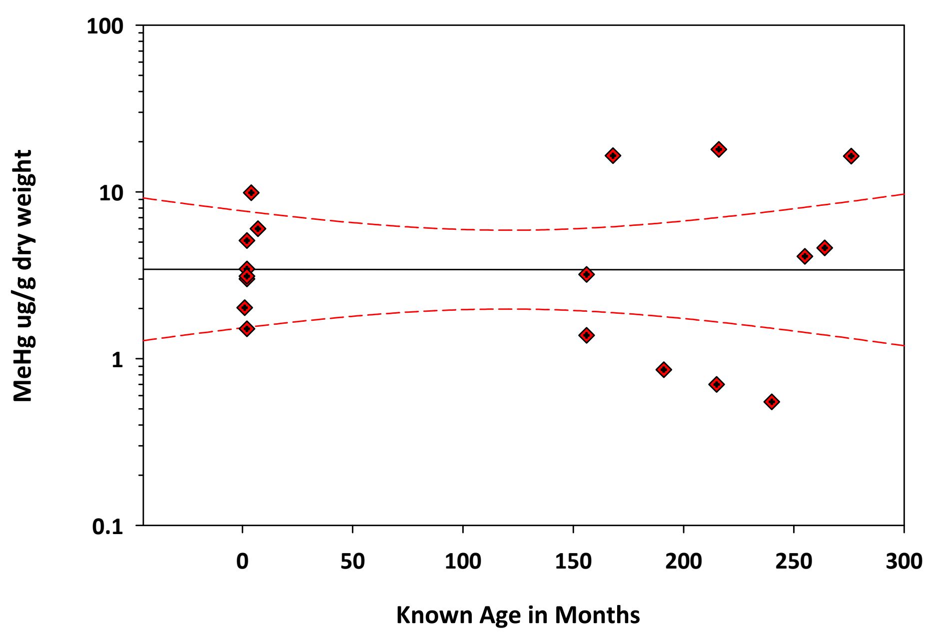


Figure 13. Selenium (Se) in livers of known-age bald eagles, ug/g dry weight

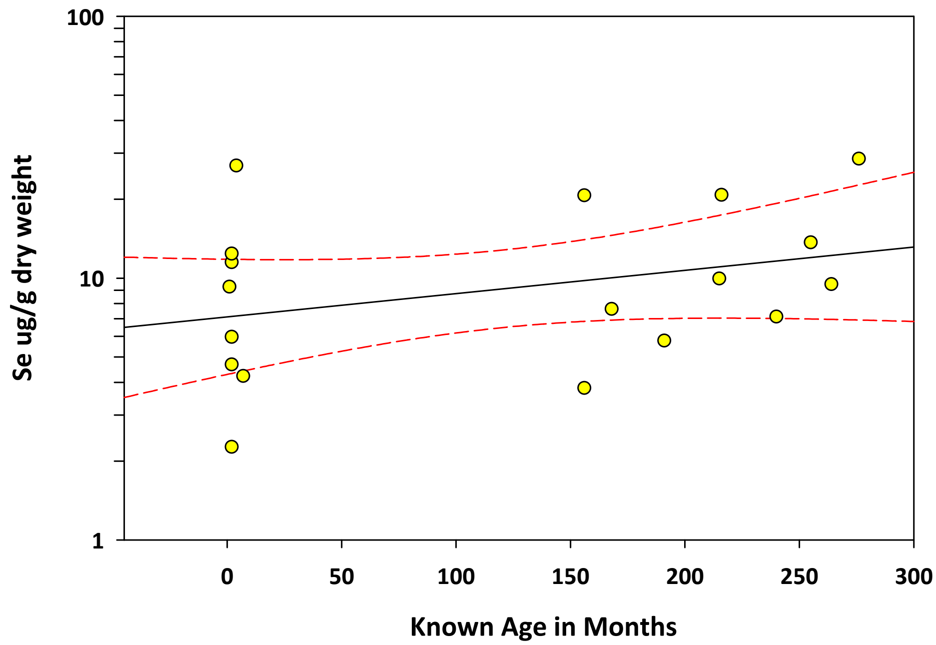


Figure 14. Lead (Pb) in livers of known-age bald eagles, ug/g dry weight

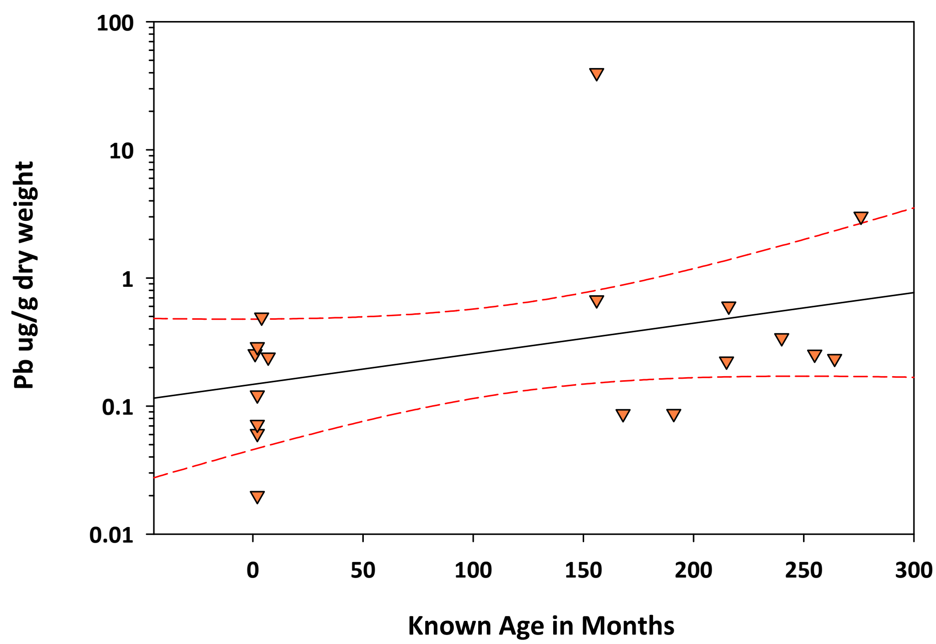


Figure 15. Total PCB in livers of known-age bald eagles, ug/g wet weight

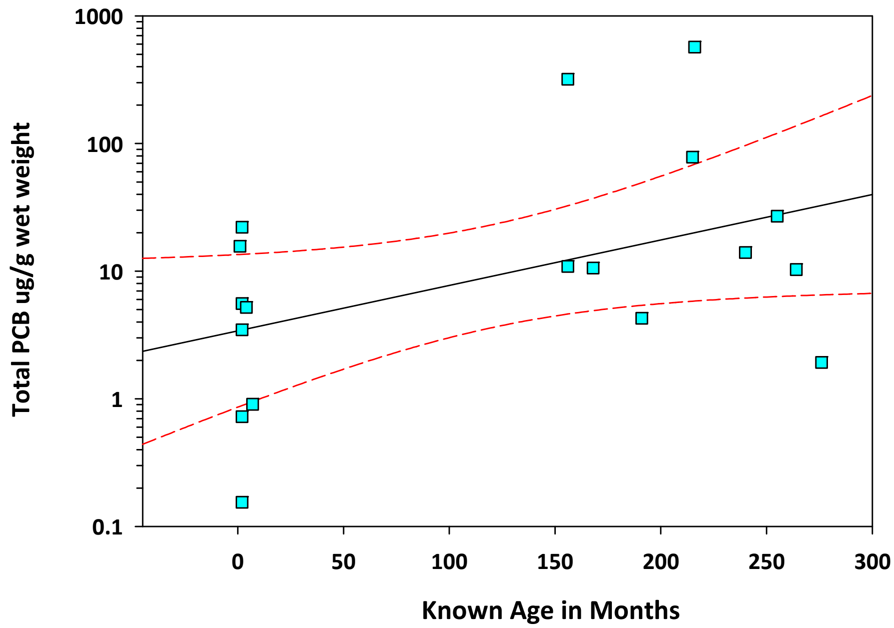


Figure 16. DDE in livers of known-age bald eagles, ug/g wet weight

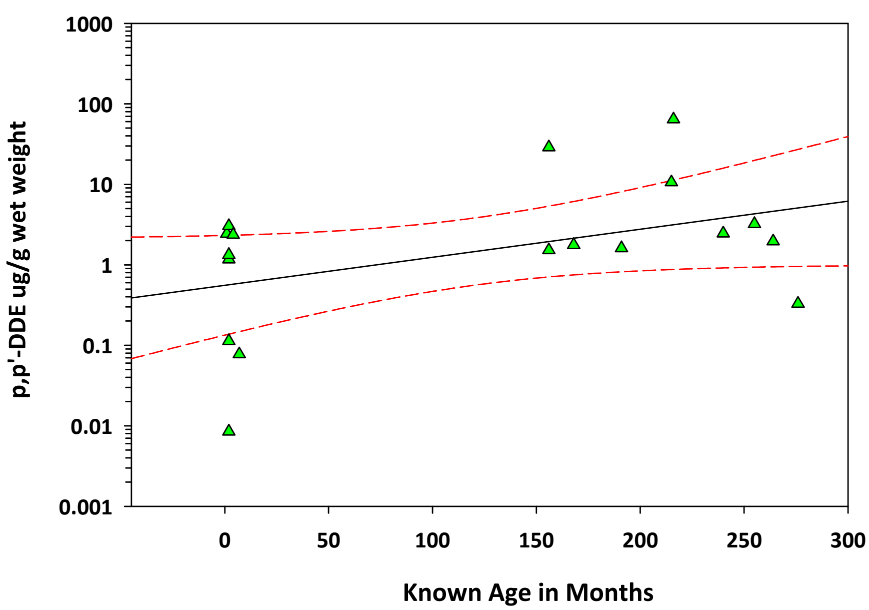


Table 1. Locations and coordinates of bald eagle carcass recoveries

USFWS Sample No.	Recovery Area	Township	County	Recovery Date	Recovery Coordinates Latitude	Longitude
ME277L	French Island	Old Town	Penobscot	15-Sep-03	44N 55' 54"	68W 38' 30"
ME075L	Brandy Pond	T39 MD	Hancock	10-May-04	45N 02' 09"	68W 16'09"
ME096L	Piscataquis River	Howland	Penobscot	21-Jul-04	45N 17' 06"	68W 38' 23"
ME403L	Medomak Lake	Waldoboro	Lincoln	26-Apr-04	44N 11' 40"	69W 22' 32"
BELIV-601	Spillman Cove, Lake Umbagog	Magalloway Plt	Oxford	30-Jan-05	44N 46' 45"	70W 59' 45"
BELIV-602	Quantabicook Lake	Searsmont	Waldo	28-Jan-05	44N 23' 30"	69W 09' 45"
BELIV-603	Canada Falls Lake [1]	Pittston Academy Grant	Somerset [1]	15-Dec-04	45N 50' 44"	70W 01' 15"
BELIV-604	South Branch Lake	Sebois Plt	Penobscot	3-Feb-05	45N 22' 15"	68W 40' 45"
BELIV-605	Appleton	Appleton	Knox	26-Mar-05	44N 17' 45"	69W 15' 00"
BELIV-606	Prospect Harbor	Prospect Harbor	Hancock	9-Sep-04	44N 23' 45"	68W 00' 45"
BELIV-607	Freedom	Freedom	Waldo	5-Jan-05	44N 32' 00"	69W 17' 30"
BELIV-608	Big Eddy, W Branch Penobscot	T3 R11 Wells	Piscataquis	2-May-05	45N 52' 30"	69W 08' 30"
BELIV-609	Horse Island, Little Sebago Lake	Gray	Cumberland	4-Oct-05	43N 52' 00"	70W 25' 00"
BELIV-610	Pleasant Bay, Cape Split	Addison	Washington	9-May-02	44N 30' 00"	67W 44' 15"
BELIV-611	Gardiner Lake	Whiting	Washington	6-May-03	44N 45' 30"	67W 20' 30"
BELIV-612	Cobscook Bay	Eastport	Washington	6-May-01	44N 52' 45"	66W 59' 15"
BELIV-613	Leighton Point Road	Pembroke	Washington	9-Dec-02	44N 54' 30"	67W 07' 30"
BELIV-614	South Branch Lake	Seboeis Plt	Penobscot	20-Apr-02	45N 23' 30"	68W 40' 30"
BELIV-615	Graham Lake	T8 SD	Hancock	1-Nov-01	44N 37' 30"	68W 22' 45"
BELIV-616	Penobscot River	Chester	Penobscot	10-Apr-02	45N 23' 04"	68W 31' 04"
BELIV-617	Tomah Stream	Codyville Plt	Washington	17-Jun-06	45N 26' 18"	67W 35' 58"
BELIV-701	Popham State Park	Phippsburg	Sagadahoc	20-Apr-06	43N 44' 33"	69W 47' 19"
BELIV-702	Interstate 95	Sherman	Aroostook	29-Apr-03	45N 54' 12"	68W 23' 12"
BELIV-703	Curtis Island	Camden	Knox	11-Jul-04	44N 12' 06"	69W 03' 00"
BELIV-704	Richardson Lake	Richardsontown TWP	Oxford	12-Jun-02	44N 53' 00"	70W 52' 12"
BELIV-705	Branch Lake	Ellsworth	Hancock	11-Jun-04	44N 37' 12"	68W 34' 52"
BELIV-706	Megunticook Lake	Camden	Knox	3-Aug-05	44N 15' 09"	69W 06' 40"
BELIV-707	Houghton Pond	West Bath	Sagadahoc	24-Mar-04	43N 50' 32"	69W 52' 07"
BELIV-708	Brewer Lake	Orrington	Penobscot	28-Jul-01	44N 43' 02"	68W 43' 59"

[1] Banded at Canada Falls Lake, Pittston Academy Grant, Somerset County, Maine on 6/24/04; recovered in Lebonan, New Jersey on 12/15/04

Table 1 (continued). Locations and coordinates of bald eagle carcass recoveries

USFWS Sample No.	Recovery Area	Township	County	Recovery Date	Recovery Coordinates	
					Latitude	Longitude
BELIV-709	West Penobscot Bay	Northport	Waldo	2-Mar-07	44N 20' 09"	68W 55' 25"
BELIV-710	East of Smith Pond / NW of Millinocket	T3 Indian Purchase	Penobscot	30-Nov-06	45N 38' 10"	68W 45' 49"
BELIV-711	Popham Beach uplands	Arrowsic	Sagadahoc	7-Oct-06	43N 51' 07"	69W 46' 39"
BELIV-712	Tunk Lake	T10 SD	Hancock	17-Dec-06	44N 36' 26"	68W 03' 39"
BELIV-801	Dyer Neck	Steuben	Sagadahoc	1-May-03	44N 24' 45"	67W 56' 15"
BELIV-802	Pleasant River	Columbia Falls	Washington	15-Mar-06	44N 39' 30"	67W 43' 45"
BELIV-803	Blue Hill Bay	Brooklin	Hancock	23-Mar-07	44N 18' 30"	68W 34' 00"
BELIV-804	Bass Harbor	SW Harbor	Hancock	6-Aug-07	44N 14' 30"	68W 21' 15"
BELIV-805	Unity Pond	Unity	Waldo	30-Sep-07	44N 37' 30"	69W 18' 30"
BELIV-806	Penobscot River	Chester	Penobscot	10-Apr-02	45N 26' 15"	68W 27' 30"
BELIV-807	St. George River	Union	Knox	8-May-07	44N 13' 30"	69W 16' 30"
BELIV-808	Dennys River	Dennysville	Washington	30-Oct-04	44N 55' 45"	67W 13" 15"
BELIV-809	Penobscot River	Passadumkeag	Penobscot	20-Apr-06	45N 11' 15"	68W 37' 15"
BELIV-810	Penobscot River	Medway	Penobscot	7-Jun-07	45N 35' 15"	68W 27' 15"
BELIV-811	Cobbosseecontee Lake	Winthrop	Kennebec	27-May-05	44N 17' 45"	69W 54' 15"
BELIV-812	Soudabscook Stream	Hampden	Penobscot	13-Mar-06	44N 45' 00"	68W 50' 00"
BELIV-813	Scraggly Lake	T6 R1 NBPP	Washington	9-Aug-06	45N 19' 45"	67W 56' 15"
BELIV-814	Meduxnekeag River	New Limerick	Aroostook	25-Feb-06	46N 07' 45"	67W 56' 15"
BELIV-815	Androscoggin River	Livermore Falls	Androscoggin	27-Dec-05	44N 23' 45"	70W 08' 45"
BELIV-816	Graham Lake	Mariaville	Hancock	21-Mar-05	44N 41' 45"	68W 25' 00"
BELIV-817	Culter VLF Station - US Navy	Cutler	Washington	18-Apr-05	44N 38' 30"	67W 16' 45"
BELIV-818	Mattawamkeag River uplands - Interstate 95	Island Falls	Aroostook	4-Apr-07	46N 01' 35"	68W 17' 10"

Table 2. Circumstances associated with carcass recovery and banding information

USFWS Sample No.	Township	Age Class	Sex	Known or suspected cause of death. Other information.	Banded	Band No.	Banding Date	Recovery Date	Known Age [a]
ME277L	Old Town	Adult	Male	Died in rehab. Liver extracted at National Wildlife Health Center, Madison, WI.				15-Sep-03	
ME075L	T39 MD	Adult	Female	Unknown				10-May-04	
ME096L	Howland	Adult	unknown	Recovered along Piscataquis River in vicinity of nest #96				21-Jul-04	
ME403L	Waldoboro	Adult	unknown	Unknown				26-Apr-04	
BELIV-601	Magalloway Plt	Adult	Female	Unknown				30-Jan-05	
BELIV-602	Searsmont	Adult	Female	Unknown				28-Jan-05	
BELIV-603	Pittston Academy Grant	Fledgling	Male	Banded in Maine on 6/24/04. Recovered in New Jersey.	Y	629-45198	24-Jun-04	15-Dec-04	7 mo.
BELIV-604	Sebois Plt	Adult	Male	Unknown				3-Feb-05	
BELIV-605	Appleton	Adult	Male	Found under powerline				26-Mar-05	
BELIV-606	Prospect Harbor	Adult	Male	Weakened eagle found with bilateral cateracts; euthanized				9-Sep-04	
BELIV-607	Freedom	Adult	Female	Hit by car				5-Jan-05	
BELIV-608	T3 R11 Wells	Adult	Female	Unknown				2-May-05	
BELIV-609	Gray	Adult	Male	Unknown				4-Oct-05	
BELIV-610	Addison	Adult	Male	Color band: Orange, EOE-EOE	Y	629-12287	4-Jun-84	9-May-02	17 yr. 11 mo.
BELIV-611	Whiting	Adult	Male	Color band: Orange, JOM-JOM	Y	629-18331	13-Jun-87	6-May-03	15 yr. 11 mo.
BELIV-612	Eastport	Adult	Female	Unknown	Y	629-05876	10-Jun-80	6-May-01	20 yrs.
BELIV-613	Pembroke	Adult	Female	Unknown	Y	629-05882	19-Jun-80	9-Dec-02	22 yrs.
BELIV-614	Seboeis Plt	Adult	Female	Significant decomposure				20-Apr-02	
BELIV-615	T8 SD	Adult	Male	Shot in head				1-Nov-01	
BELIV-616	Chester	Adult	Male	Open body cavity				10-Apr-02	
BELIV-617	Codyville Plt	Nestling	unknown	Liver taken in field from decomposing nestling carcass found in nest. Carcass left behind.				17-Jun-06	2 mo.
BELIV-701	Phippsburg	Adult	Male	Unknown	Y	629-38332	26-Jun-93	20-Apr-06	13 yrs
BELIV-702	Sherman	Immature	Female	Found along Route I-95 at Sherman/Crystal town line.				29-Apr-03	
BELIV-703	Camden	Nestling	unknown	Presumed starvation				11-Jul-04	2 mo.
BELIV-704	Richardsontown TWP	Nestling	unknown	Dead in nest				12-Jun-02	1 mo.
BELIV-705	Ellsworth	Nestling	Unknown	Unknown				11-Jun-04	2 mo.
BELIV-706	Camden	Fledgling	Male	Color band: Red 4/2	Y	629-45120	7-Jun-05	3-Aug-05	4 mo.
BELIV-707	West Bath	Adult	Female	Unknown				24-Mar-04	
BELIV-708	Orrington	Nestling	unknown	1 of 2 Brewer Lake siblings.				28-Jul-01	2 mo.
BELIV-709	Northport	Adult	Female	Unknown				2-Mar-07	
BELIV-710	T3 Indian Purchase	Adult	Male	Color band: Black, B2B. Died in rehab.	Y	629-12264	24-Jun-83	30-Nov-06	23 yrs., 7 mo.

[a] Assumed 2 mo. of age at time of banding

Table 2 (continued). Circumstances associated with carcass recovery and banding information

USFWS Sample No.	Township	Age Class	Sex	Known or suspected cause of death. Other information.	Banded	Band No.	Banding Date	Recovery Date	Known Age [a]
BELIV-711	Arrowsic	Immature	Female	Unknown				7-Oct-06	
BELIV-712	T10 SD	Adult	Female	Apparently resident adult from nearby nest #528A.				17-Dec-06	
BELIV-801	Steuben	Adult	Male	Color band: Gold, H 9 H	Y	629-14170	7-Jun-85	1-May-04	18 yrs.
BELIV-802	Columbia Falls	Adult	Female	Hit powerlines. Large bird.				15-Mar-06	
BELIV-803	Brooklin	Adult	Male	Euthanized at Avian Haven 3/27/07. "Flightless" near water near Blue Hills Falls.				23-Mar-07	
BELIV-804	SW Harbor	Adult	Female	Color band: Orange, KOM (horizontal).	Y	629-18280	20-Jun-86	6-Aug-07	21 yr. 3 mo.
BELIV-805	Unity	Adult	Male	Unknown				30-Sep-07	
BELIV-806	Chester	Adult	Female	Unknown				10-Apr-02	
BELIV-807	Union	Adult	Female	Rehab/Released/Recovered/Died in Rehab. Color band: Red 6 / V (horizontal).	Y	629-38370	10-Jun-94	8-May-07	13 yrs.
BELIV-808	Dennysville	Adult	Male	Found under powerlines with a red squirrel still in its talons				30-Oct-04	
BELIV-809	Passadumkeag	Adult	Male	Unknown	Y	629-36997	23-Jun-92	20-Apr-06	14 yrs.
BELIV-810	Medway	Nestling	Unknown	Found beneath nest #97D.				7-Jun-07	2 mo.
BELIV-811	Winthrop	Immature	Male	Unknown				27-May-05	
BELIV-812	Hampden	Immature	Female	Unknown				13-Mar-06	
BELIV-813	T6 R1 NBPP	Adult	Male	Found beneath nest #189E at the base of a tree hit by lightning.				9-Aug-06	
BELIV-814	New Limerick	Adult	Female	Found in U.S. Route 2; apparent vehicle collision				25-Feb-06	
BELIV-815	Livermore Falls	Immature	Male	Caught in a otter set and taken to Avian Haven where it was euthanized.				27-Dec-05	
BELIV-816	Mariaville	Immature	Male	Found in snowbank next to SR 181 in Mariahville				21-Mar-05	
BELIV-817	Cutler	Adult	Male	Apparent collision w/ tower cables				18-Apr-05	
BELIV-818	Island Falls	Adult	Female	Found along Insterstate 95 at mile #277; apparent vehicle collision				4-Apr-07	

[a] Assumed 2 mo. of age at time of banding

Table 3. Summary of bald eagle carcass measurements by age and sex

Metric	Units	Adult Females (n = 17) Mean ± Standard Deviation	Adult Males (n = 18) Mean ± Standard Deviation	Immature Females (n = 3) Mean ± Standard Deviation	Immature Males (n = 3) Mean ± Standard Deviation
Total Carcass Weight	(g)	4782 ± 820	3696 ± 754	3633 ± 950	3400 ± 1044
Total Liver Weight	(g)	72.7 ± 24.4	67.7 ± 25.1	66.2 ± 16.8	53.8 ± 33.7
Culmen Length	(mm)	56.3 ± 2.4	50.1 ± 5.2	57.0 ± 2.2	51.3 ± 1.9
Bill Width	(mm)	23.4 ± 1.1	21.8 ± 1.8	23.9 ± 0.9	22.5 ± 0.8
Bill Depth	(mm)	36.5 ± 1.3	32.7 ± 2.4	34.9 ± 0.1	32.8 ± 0.7
Foot Pad Length	(mm)	108.9 ± 12.2	101.9 ± 14.7	106.4 ± 15.0	91.4 ± 12.6
Hallux Claw	(mm)	43.5 ± 1.6	39.2 ± 2.3	43.3 ± 1.6	41.2 ± 1.0
Tarsus Width	(mm)	16.6 ± 0.9	14.4 ± 1.5	16.1 ± 1.1	13.8 ± 1.3
8th Primary Length	(mm)	443 ± 19	418 ± 18	463 ± 21	433 ± 11
Tail Feather Length	(mm)	265 ± 19	254 ± 19	309 ± 17	278 ± 25
Body Condition	(0 to 5)	3 ± 2	2 ± 1	3 ± 1	2 ± 3

Metric	Units	Fledgling Females (n = 0)	Fledgling Males (n = 2) Mean	Nestlings (n = 6) Mean ± Standard Deviation
Total Carcass Weight	(g)		2525	2290 ± 953
Total Liver Weight	(g)		44.2	62.1 ± 43.7
Culmen Length	(mm)		49.0	44.6 ± 6.2
Bill Width	(mm)		20.7	19.0 ± 2.2
Bill Depth	(mm)		32.8	30.9 ± 3.5
Foot Pad Length	(mm)		105.5	111.0 ± 13.7
Hallux Claw	(mm)		36.9	33.8 ± 4.4
Tarsus Width	(mm)		14.5	13.8 ± 1.7
8th Primary Length	(mm)		390.5	292 ± 34
Tail Feather Length	(mm)		248.0	194 ± 32
Body Condition	(0 to 5)		1.5	1 ± 2

Mean is arithmetic mean.
Note: Sex of two adults unknown. Sex not determined in nestlings.

Table 4. Carcass metrics

USFWS Sample No.	Total Carcass Weight (g)	Total Liver Weight (g)	Percent Lipids (%)	Culmen Length (mm)	Bill Width (mm)	Bill Depth (mm)	Foot Pad Length (mm)	Hallux Claw (mm)	Tarsus Width (mm)	8th Primary (mm)	Tail Length (mm)	Body Condition (0 to 5)	Age Class	Sex
ME277L	2190	18.1	2.70	nm	nm	nm	nm	nm	nm	nm	nm	0	Adult	Male
ME075L	5400	113.4	1.40	nm	nm	nm	nm	nm	nm	nm	nm	nm	Adult	Female
ME096L	nm	112.0	2.30	nm	nm	nm	nm	nm	nm	nm	nm	nm	Adult	unknown
ME403L	nm	110.0	1.50	nm	nm	nm	nm	nm	nm	nm	nm	nm	Adult	unknown
BELIV-601	4300	71.7	3.38	56.0	nm	36.6	123.9	44.0	17.4	457	295	4	Adult	Female
BELIV-602	3650	72.4	4.33	50.4	22.2	36.3	95.1	41.0	15.4	428	280	2	Adult	Female
BELIV-603	3050	59.8	2.79	47.9	19.8	32.3	91.4	35.6	12.7	426	276	2	Fledgling	Male
BELIV-604	3000	42.6	2.77	51.5	21.5	33.1	108.6	40.3	14.9	426	228	2	Adult	Male
BELIV-605	3972	71.1	3.18	49.0	20.1	30.7	82.9	38.2	13.7	409	266	1	Adult	Male
BELIV-606	3315	67.8	1.70	52.4	19.0	30.6	94.1	36.6	12.6	440	230	2	Adult	Male
BELIV-607	6100	73.7	2.31	56.4	23.2	35.4	87.5	43.0	16.3	477	290	5	Adult	Female
BELIV-608	3500	36.5	4.56	57.5	23.9	36.4	106.3	44.1	15.8	410	233	0	Adult	Female
BELIV-609	3500	80.7	2.08	31.1	22.8	32.6	125.3	42.0	13.2	401	257	2	Adult	Male
BELIV-610	5250	91.6	3.08	53.5	25.4	28.3	123.4	36.6	18.3	441	277	1	Adult	Male
BELIV-611	3500	65.4	4.78	51.1	24.8	31.7	120.1	37.4	14.2	390	267	1	Adult	Male
BELIV-612	5100	65.8	3.65	54.8	26.0	38.3	nm	41.7	17.8	452	277	1	Adult	Female
BELIV-613	4900	53.6	2.70	57.8	23.5	36.1	121.9	44.7	16.5	416	272	2	Adult	Female
BELIV-614	5200	94.3	1.19	56.5	22.5	36.0	127.2	44.7	16.9	465	272	1	Adult	Female
BELIV-615	4150	64.0	3.22	50.6	18.6	40.1	102.1	33.3	17.0	417	285	2	Adult	Male
BELIV-616	4000	55.5	3.58	50.5	21.5	32.2	104.3	41.4	13.8	424	261	2	Adult	Male
BELIV-617	nm	54.4	2.50	nm	nm	nm	nm	nm	nm	nm	nm	0	Nestling	unknown
BELIV-701	2500	45.5	2.43	53.3	20.7	33.5	91.1	40.6	13.2	412	255	2	Adult	Male
BELIV-702	4600	79.9	7.25	59.1	24.8	34.8	111.2	44.2	17.4	449	292	5	Immature	Female
BELIV-703	1950	21.9	5.71	45.8	21.0	30.7	87.8	34.0	12.2	331	225	1	Nestling	unknown
BELIV-704	1600	36.8	5.79	35.6	16.0	26.1	109.4	28.5	13.8	nm	nm	1	Nestling	unknown
BELIV-705	1300	26.5	5.45	nm	nm	nm	119.2	31.3	13.6	nm	nm	0	Nestling	Unknown
BELIV-706	2000	28.6	4.10	50.1	21.5	33.2	119.5	38.1	16.3	355	220	1	Fledgling	Male
BELIV-707	5150	110.1	4.87	54.7	22.0	35.7	101.4	40.4	15.5	435	254	5	Adult	Female
BELIV-708	3400	122.4	5.54	50.0	19.0	34.3	121.6	40.3	16.6	278	162	2	Nestling	unknown
BELIV-709	5000	99.6	3.63	53.6	24.1	35.0	100.6	45.1	17.2	458	225	5	Adult	Female
BELIV-710	4400	125.4	3.32	49.0	21.7	32.5	81.2	40.7	14.3	414	231	5	Adult	Male
BELIV-711	2700	71.1	2.79	54.8	23.0	35.0	118.5	41.4	15.3	488	308	3	Immature	Female
BELIV-712	3500	69.2	3.52	54.6	23.0	40.1	98.1	43.8	16.2	445	272	3	Adult	Female
BELIV-801	3000	61.1	2.31	51.9	22.9	34.8	108.1	39.7	13.5	429	247	1	Adult	Male
BELIV-802	6200	73.3	6.93	59.4	24.3	35.7	100.3	44.7	17.0	456	271	4	Adult	Female

nm = not measured

Table 4 (continued). Carcass metrics

USFWS Sample No.	Total Carcass Weight (g)	Total Liver Weight (g)	Percent Lipids (%)	Culmen Length (mm)	Bill Width (mm)	Bill Depth (mm)	Foot Pad Length (mm)	Hallux Claw (mm)	Tarsus Width (mm)	8th Primary (mm)	Tail Length (mm)	Body Condition (0 to 5)	Age Class	Sex
BELIV-803	3350	92.9	4.88	53.7	21.9	32.2	111.2	39.0	14.4	449	251	2	Adult	Male
BELIV-804	4100	41.7	5.02	58.2	24.3	36.8	111.5	45.7	17.6	439	260	2	Adult	Female
BELIV-805	3800	74.9	2.87	51.8	21.4	33.3	98.0	39.0	15.3	414	234	2	Adult	Male
BELIV-806	5000	57.2	5.60	59.0	22.1	36.8	102.3	43.5	17.2	438	256	3	Adult	Female
BELIV-807	4000	69.7	3.91	56.8	22.4	34.6	119.0	42.0	14.9	417	256	3	Adult	Female
BELIV-808	4600	77.6	3.01	53.0	23.7	32.7	nm	41.3	15.1	435	nm	3	Adult	Male
BELIV-809	3700	64.3	2.97	48.2	21.2	31.5	90.4	40.5	13.4	403	230	2	Adult	Male
BELIV-810	3200	110.4	3.73	46.9	20.1	32.3	116.9	34.7	13.0	267	194	4	Nestling	Unknown
BELIV-811	2200	17.5	3.29	52.1	22.4	33.1	105.6	40.4	15.2	427	307	0	Immature	Male
BELIV-812	3600	47.5	4.47	57.0	23.9	35.0	89.6	44.3	15.7	454	327	2	Immature	Female
BELIV-813	3900	91.1	2.37	49.5	22.5	33.3	110.8	40.9	13.1	385	273	2	Adult	Male
BELIV-814	5000	32.7	4.77	55.2	23.3	36.1	120.9	42.6	16.3	449	275	2	Adult	Female
BELIV-815	4100	84.0	5.30	49.1	21.8	32.0	87.0	42.3	13.2	446	261	5	Immature	Male
BELIV-816	3900	59.9	3.43	52.7	23.3	33.3	81.5	40.8	12.9	426	265	2	Immature	Male
BELIV-817	4400	28.9	4.48	51.6	21.1	33.1	79.2	38.1	14.2	416	269	1	Adult	Male
BELIV-818	5200	100.3	3.16	59.5	23.8	37.5	117.8	45.5	17.4	444	259	5	Adult	Female

nm = not measured

DRY WEIGHT

Table 5. Summary of trace metals in bald eagle livers, µg/g dry weight

		No. of Samples Analyzed	No. of Samples with Detections	Geometric Mean	Arithmetic Mean	±	S.D.	Range of Detections Low	-	High
Silver	Ag	47	9	0.67	0.96	±	0.99	0.21	-	3.40
Aluminum	Al	51	20	3.05	3.98	±	3.19	0.87	-	13.00
Arsenic	As	51	27	0.85	1.13	±	0.83	0.04	-	3.83
Boron	B	51	4	1.51	1.91	±	1.35	0.60	-	3.39
Barium	Ba	51	19	0.21	0.32	±	0.45	0.10	-	2.09
Cadmium	Cd	51	51	0.35	0.47	±	0.38	0.04	-	1.95
Cobalt	Co	48	1	1.08	1.08					
Chromium	Cr	51	8	0.34	0.38	±	0.21	0.20	-	0.70
Copper	Cu	51	51	22.23	29.12	±	30.23	8.88	-	196.00
Iron	Fe	51	51	1953	2753	±	2375	272	-	9620
Mercury	Hg	51	51	14.04	22.70	±	30.23	2.00	-	191.00
Potassium	K	48	48	7532	7607	±	1089	5280	-	10600
Methylmercury	MeHg	47	47	5.85	8.24	±	6.36	0.55	-	29.00
Magnesium	Mg	51	51	615.3	637.4	±	184.7	391.0	-	1320.0
Manganese	Mn	51	51	10.75	11.35	±	3.87	4.75	-	22.10
Molybdenum	Mo	51	46	1.83	1.93	±	0.68	1.01	-	3.98
Sodium	Na	47	47	5018	5340	±	2104	2890	-	12700
Nickel	Ni	51	12	0.95	1.18	±	1.02	0.54	-	4.02
Phosphorus	P	47	47	8762	8909	±	1658	5740	-	13200
Lead	Pb	51	48	0.88	14.04	±	33.82	0.06	-	150.00
Sulfur	S	47	47	9502	9596	±	1370	6860	-	13400
Selenium	Se	51	51	8.00	10.37	±	9.28	2.27	-	55.20
Strontium	Sr	51	50	0.56	1.23	±	2.36	0.08	-	14.20
Zinc	Zn	51	51	159.8	191.4	±	126.2	61.1	-	648.0

µg/g = parts-per-million
Geometric mean, arithmetic mean, and standard deviation (S.D.) calculated for samples with detectable concentrations.
Non-detects not included in calculations.
Beryllium and vanadium below detection limits in all samples.
Metals discussed in text highlighted.

WET WEIGHT

Table 6. Summary of organochlorine compounds in bald eagle livers, µg/g wet weight

	No. of Samples Analyzed	No. of Samples with Detection	Geometric Mean	Arithmetic Mean	±	S.D.	Range of Detections Low	-	High
Total PCB	51	51	5.683	27.321	±	90.402	0.0476	-	570.000
Total BHC	51	39	0.006	0.020	±	0.036	0.0004	-	0.163
Total Chlordane	51	50	0.157	0.402	±	0.902	0.0007	-	5.413
heptachlor epoxide	51	47	0.006	0.016	±	0.037	0.0007	-	0.189
heptachlor	51	5	0.003	0.003	±	0.003	0.0011	-	0.008
p,p'-DDE	51	51	1.063	3.456	±	9.664	0.0055	-	64.200
Total DDT	51	51	1.136	3.574	±	9.732	0.0055	-	64.668
aldrin	51	3	0.006	0.008	±	0.007	0.0032	-	0.015
endrin	51	11	0.004	0.010	±	0.016	0.0006	-	0.052
dieldrin	51	49	0.031	0.066	±	0.133	0.0039	-	0.872
endosulfan II	51	5	0.003	0.008	±	0.011	0.0006	-	0.028
HCB	51	51	0.011	0.018	±	0.020	0.0014	-	0.090
mirex	51	49	0.029	0.120	±	0.325	0.0015	-	1.610
pentachloro-anisole	51	38	0.001	0.001	±	0.001	0.0003	-	0.005

µg/g = parts-per-million

Total BHC is the sum of alpha, beta, gamma, and delta BHC

Total Chlordane is the sum of alpha chlordane, gamma chlordane, cis-nonachlor, trans-nonachlor, and oxychlordane

Total DDT is the sum of o,p'-DDD, o,p'-DDE, o,p'-DDT, p,p'-DDD, p,p'-DDE and p,p'-DDT

Toxaphene was below detection limits in all samples

Geometric mean, arithmetic mean and standard deviation (S.D.) calculated for samples with detectable concentrations.

Non-detects not included in calculations.

Compounds discussed in text highlighted.

LIPID WEIGHT

Table 7. Summary of organochlorine compounds in bald eagle livers, µg/g lipid weight

	No. of Samples Analyzed	No. of Samples with Detection	Geometric Mean	Arithmetic Mean	±	S.D.	Range of Detections Low	-	High
Total PCB	51	51	167.16	1042.34	±	3869.03	0.9000	-	24675.32
Total BHC	51	39	0.18	0.70	±	1.42	0.0200	-	7.06
Total Chlordane	51	50	4.61	14.28	±	38.12	0.0100	-	234.33
heptachlor epoxide	51	47	0.17	0.56	±	1.50	0.0150	-	8.18
heptachlor	51	5	0.09	0.13	±	0.14	0.0448	-	0.37
p,p'-DDE	51	51	31.26	128.26	±	415.84	0.1000	-	2779.22
Total DDT	51	51	33.42	131.91	±	418.63	0.1000	-	2799.49
aldrin	51	3	0.21	0.28	±	0.25	0.1193	-	0.57
endrin	51	11	0.13	0.37	±	0.58	0.0261	-	1.91
dieldrin	51	49	0.92	2.28	±	5.66	0.0699	-	37.75
endosulfan II	51	5	0.11	0.26	±	0.42	0.0267	-	1.02
HCB	51	51	0.32	0.55	±	0.69	0.0258	-	3.91
mirex	51	49	0.87	4.42	±	13.15	0.0271	-	66.26
pentachloro-anisole	51	38	0.03	0.05	±	0.04	0.0124	-	0.12

µg/g = parts-per-million
Total BHC is the sum of alpha, beta, gamma, and delta BHC
Total Chlordane is the sum of alpha chlordane, gamma chlordane, cis-nonachlor, trans-nonachlor, and oxychlordane
Total DDT is the sum of o,p'-DDD, o,p'-DDE, o,p'-DDT, p,p'-DDD, p,p'-DDE and p,p'-DDT
Toxaphene was below detection limits in all samples
Geometric mean, arithmetic mean and standard deviation (S.D.) calculated for samples with detectable concentrations.
Non-detects not included in calculations.
Compounds discussed in text highlighted.