CHANGES IN PRODUCTIVITY AND ENVIRONMENTAL CONTAMINANTS IN BALD EAGLES NESTING ALONG THE LOWER COLUMBIA RIVER

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FINAL REPORT

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

ABSTRACT

Numbers of bald eagles (*Haliaeetus leucocephalus*) nesting along the lower Columbia River have doubled in the last six years, yet five-year running productivity averages are well below statewide values for eagles nesting in other areas of Oregon and Washington. While productivity of eagles along the Columbia River is low, nesting success in other areas of the two states is close to the goals established to delist the species from the Federal Endangered Species list. Previous contaminant studies conducted from 1985 to 1987 along the river found poor productivity associated with elevated DDE (dichlorodiphenyldichloroethane) and total polychlorinated biphenyls (PCBs) in eagle eggs. In addition, 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) and 2,3,7,8-tetrachlorodibenzofuran (TCDF) concentrations were found in five eggs collected in 1987 and 1991. From 1994-95, fresh bald eagle eggs were collected from nests in 19 of 43 occupied territories along the river. Eggshell thickness was determined on all eggs, and the contents were analyzed for organochlorine pesticides, total PCBs, polychlorinated dibenzo-*p*-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), and planar PCBs (non-ortho and mono-ortho substituted congeners). Halogenated dioxin-like compounds in eggs were also evaluated based on a H4IIE rat hepatoma bioassay. Productivity and egg contaminant results from1994 to 1995 were compared to a previous study to evaluate changes over time. Recent increases in productivity averages were due to new pairs nesting along the river, yet productivity at 23 older breeding areas remained low and was not different (P=0.713) between the two study periods. Eggshells averaged 11 percent thinner than shells measured prior to the use of the pesticide DDT (dichlorodiphenyltrichloroethane), and thickness of eggs from older breeding territories had not improved (P=0.404) between the two study periods. Decreases in p,p -DDE (P=0.022) and total PCBs (P= 0.0004) in eggs from older breeding areas occurred between the two study periods, but concentrations were still above values associated with poor productivity. TCDD toxic equivalents (TEQs) exceeded estimated no-effect values for bald eagles during both studies. Bald eagle productivity over a five-year time period encompassing egg collection was not correlated to individual organochlorine compounds. Some dioxins, furans, planar PCBs, and TEQ values were correlated to nest location as river mile, with highest concentrations occurring at downriver breeding territories near the mouth. Although total productivity has increased due to the success of new nesting pairs moving into the region, results indicate that organochlorine contaminants continue to impact the breeding success of lower Columbia River eagles. The greatest impact of appears to occur at older breeding territories, which were located predominantly in the lower estuary below river mile 60. Eagles nesting toward the mouth of the river may be at greater risk of exposure to some dioxin-like compounds, and the reproductive success of some new pairs nesting in this area could be impacted in the future.

INTRODUCTION

The lower Columbia River (LCR), located along the border of Oregon and Washington (Figure 1), supports a variety of fish and wildlife resources. The area provides important foraging habitat to bald eagles (*Haliaeetus leucocephalus*), which are currently listed in Oregon and Washington as a threatened species under the Endangered Species Act of 1973. Bald eagle nesting territories and productivity of eagles along the LCR have been monitored since the early 1970s, and the number of occupied nesting territories has increased every year. By 1997, 60 resident pairs of bald eagles occupied sites along the LCR, along with a wintering population of over 100 birds (Garrett et al. 1988, Isaacs et al. 1997). However, five-year running productivity averages of these eagles have been nearly half that of state-wide averages for eagles nesting in either Oregon or Washington (Figure 2; Isaacs et al. 1997, Washington Department of Fisheries and Wildlife, unpubl. annual census reports). While productivity of eagles along the river is low, numbers of nesting pairs in other areas of the two states are meeting some recovery goals (U.S. Fish and Wildlife Service 1986).

The organochlorine pesticides including DDT (dichlorodiphenyltrichloroethane), dieldrin, and their metabolites have been implicated in causing declines in bald eagle populations, either though direct mortality or by impacting breeding success (Prouty et al. 1977, Kaiser et al. 1980, Wiemeyer et al. 1993). Bald eagle populations have rebounded nationwide since the early 1970s following the banning of DDT and other organochlorine pesticides (Grier 1982), although reproductive success of various local subpopulations has not improved (Colborn et al. 1991, Anthony et al. 1993, Welch 1994). During a study conducted along the LCR from 1985 to 1987, Anthony et al. (1993) found elevated concentrations of p,p -DDE (dichlorodiphenyldichloroethane) and polychlorinated biphenyls (PCBs) in fresh bald eagle eggs, in blood obtained from eight- to ten-week-old nestlings, and in eagle carcasses collected near the river. Eagles occupied 23 territories along the river in 1987, and their five-year running productivity averages were 30-50 percent lower than statewide values for every year evaluated. Shell thinning associated with p,p -DDE concentrations was observed in fresh eagle eggs, and prey items collected from the LCR exhibited detectable concentrations of p,p -DDE, PCBs, and other organochlorines (Anthony et. al. 1993). In addition, the presence of p,p -DDE and PCBs in blood of eagle nestlings indicated localized exposure from contaminated prey from the river (Anthony et al. 1993).

Fresh and addled bald eagle eggs collected from the estuary in 1987 and 1991 also exhibited elevated concentrations of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) and 2,3,7,8-tetrachlorodibenzofuran (TCDF; Anthony et al. 1993). The TCDD concentrations found in the five eggs analyzed were within a range of TCDD concentrations found in eggs of fish-eating birds exhibiting poor reproductive success in Michigan (Kubiak et al. 1989, Anthony et al. 1993). Moreover, fish collected from the LCR exhibited TCDD concentrations exceeding human health guidelines (U.S. Environmental Protection Agency 1986a, 1991a, 1991b; U.S. Fish and Wildlife Service 1994). High TCDD concentrations in the fish tissues led to the designation of the Columbia River as Water Quality Limited in 1990 under provision of the Clean Water Act, Section 303(d). Recently, organochlorine pesticides and dioxin-like compounds in eggs of double-crested cormorants (*Phalacrocorax auritus*) and great blue herons (*Ardea herodia*) from

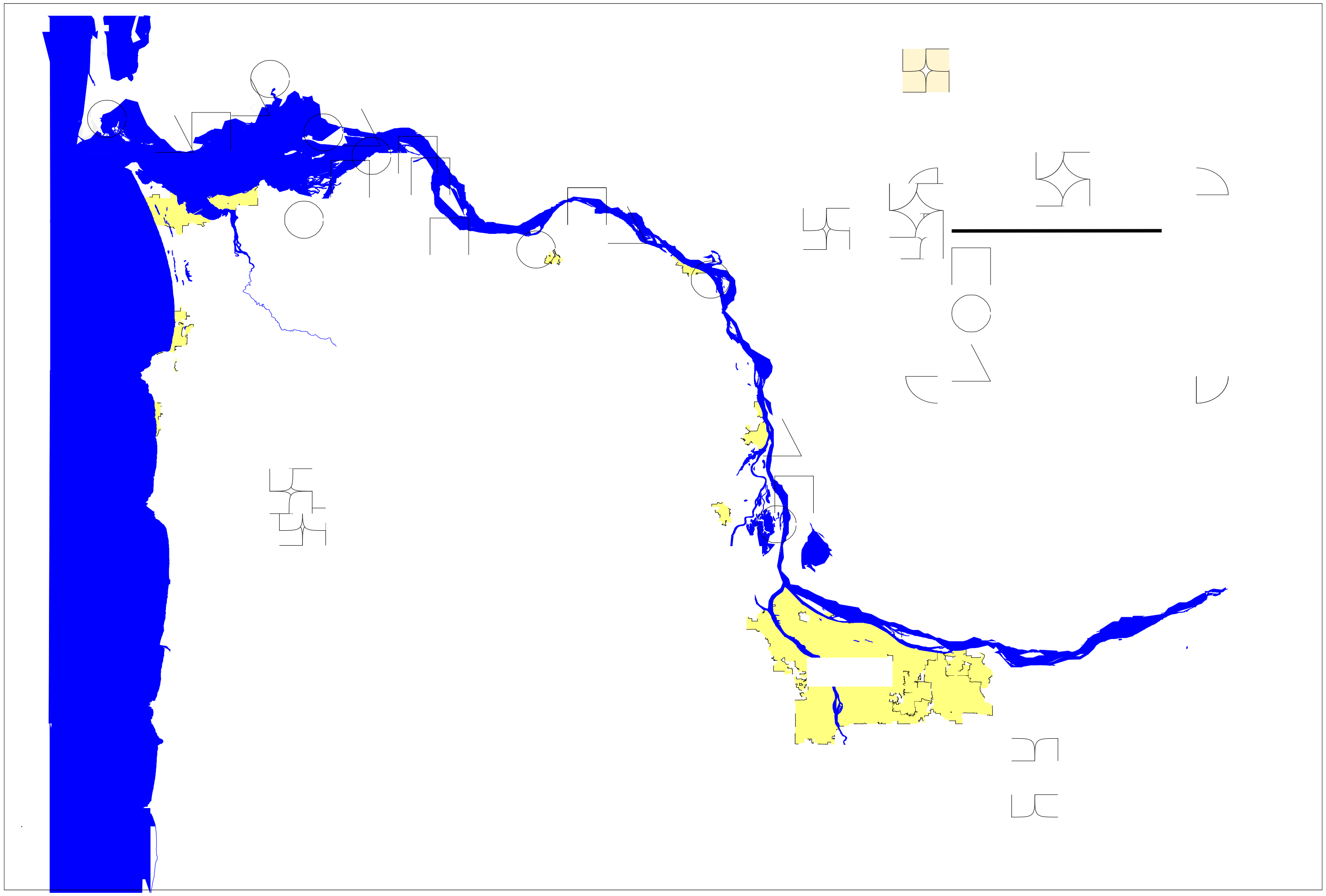

Figure 1. Bald eagle nest sites where eggs or eggshells were collected along the lower Columbia River in 1994 and 1995.

Figure 2. Five-year running average productivity (young/occupied territory with known outcome) for bald eagles nesting in Washington, Oregon, and the lower Columbia River. Statewide values for Washington from 1993 to 1995 are estimates. Oregon productivity values exclude lower Columbia River productivity, whereas Washington values include them.

the LCR were found to exceed reference concentrations (Thomas 1997, U.S. Fish and Wildlife Service 1999).

In 1991, the U.S. Environmental Protection Agency (EPA) restricted the discharge of allowable dioxin in the Columbia River through the establishment of a Total Maximum Daily Load (TMDL) for TCDD to protect aquatic resources. EPA set the TMDL for TCDD at 0.013 parts per quadrillion (ppq) at mean harmonic flow, and entered into consultation with the U.S. Fish and Wildlife Service (FWS) under the Endangered Species Act to evaluate whether or not this concentration was protective of LCR bald eagles (U.S. Fish and Wildlife Service 1994). The FWS reported in the resulting biological opinion that a lower target concentration of 0.0013 ppq would be more protective for these eagles (U.S. Fish and Wildlife Service 1994). However, the FWS agreed to the 0.013 ppq TMDL level over the following five year period, with the incorporation of conditions designed to help protect the eagles and the collection of additional data regarding dioxin bioaccumulation in the LCR (U.S. Fish and Wildlife Service 1994).

The current investigation was designed to determine if organochlorine compounds continue to accumulate in bald eagles along the LCR, and to assess whether dioxin-like compounds (dioxins, furans, and planar PCBs) could be contributing to the poor reproductive success observed in eagles nesting in this area. Specifically, four hypotheses were tested during the study to determine if 1) organochlorine contaminants exceeded no-effect threshold concentrations estimated for bald eagles; 2) contaminant concentrations were related to productivity; 3) contaminant concentrations and productivity values changed over time; and 4) contaminant concentrations were related to nest location as river mile. Three objectives were developed to test these hypotheses and to evaluate the productivity and current contaminant relations in the bald eagles. The objectives were to 1) quantify organochlorine pesticides, dioxins, furans, planar PCBs, and mercury in eagle eggs; 2) compare current productivity and egg contaminant concentrations to eagles to earlier studies along the river (Anthony et al. 1993); and 3) determine the relationships among productivity, eggshell parameters, contaminant concentrations, and river mile of nest location.

METHODS

Productivity Surveys and Site Selection

Productivity (the number of young produced per occupied territory with known outcome) were determined for bald eagles along the LCR in coordination with annual state-wide surveys conducted by the Oregon Cooperative Wildlife Research Unit (OCWRU) and the Washington Department of Fisheries and Wildlife (WDFW) using methods and terminology described by Postupalsky (1974). An occupied breeding territory was considered the nest site (including alternate nest sites) and area protected where young were produced (fledged or reached near-fledgling age; Postupalsky 1974). Helicopter overflights and ground surveys were used in April to determine site occupancy, in May to confirm nesting status and locate abandoned nests containing nonviable (addled) eggs, and in early July to determine final productivity. The outcome of nests not monitored by helicopter surveys were determined by volunteers who monitor nests on an annual basis and report findings to OCWRU, WDFW, or Ridgefield National Wildlife Refuge.

Nest site selection for fresh egg collections occurred immediately following the April overflight. Sampling sites included nests within breeding territories where eggs were collected in previous contaminant investigations (Anthony et al. 1993), nests exhibiting historically low productivity or repeated nesting failures, and nests in recently established territories. Only nest trees safely accessible by climbing were selected, and site selection for sampling was not completely representative of eagle pairs at all nest locations due to safety concerns. Consequently, egg contaminant concentrations from territories established within the last five years (newly-established sites) were likely under-represented due to the sampling scheme. However, fresh and addled eggs were collected from 19 of 43 occupied territories, representing nearly half the population of eagles nesting along the lower river.

Egg Collection and Processing

Eggs were collected in April and May of 1994 and in April of 1995. Only one fresh egg was collected from an active nest during incubation, whereas all eggs were collected from abandoned nests. Eggs were wrapped in aluminum foil, cooled with Blue Ice® during transport, and refrigerated at 3°C at the FWS, Oregon State Office in Portland until processing. In addition to eggs, one common carp (*Cyprinus carpio*) and one starry flounder (*Platichthys stellatus*) were collected from nests in two territories in 1994. The prey items were double bagged and frozen at -20°C until shipment to the analytical laboratory.

Eagle egg processing occurred within 24 hours of collection and included measuring length, breadth, whole egg mass, and volume by water displacement. Eggs were cut along the equator and the contents removed to determine embryo mass. Development stage was noted as early, mid, or late in comparison to developing pheasant (*Phasianus colchicus*) embryos (Fant 1957). Egg contents were stored in chemically-cleaned jars and frozen at -20°C until shipment to laboratories for analytical chemistry and bioassay analysis.

Eggshell thickness (shell and membranes) was measured on 25 bald eagle eggs collected intact and on eggshell fragments from four damaged eggs. Each eggshell half was rinsed with water and air-dried for a minimum of 30 days after harvesting. Eggshell thickness was measured with a dial micrometer at five sites along the equator on each eggshell half, resulting in 10 measurements per egg. The 10 measurements were averaged to determine the mean thickness of each shell. Thickness was measured on the four damaged eggs using eggshell fragments large enough to approximate the equator region of the egg. A minimum of five measurements were collected and averaged for damaged eggs. For each eggshell with detached membranes, the estimated thickness (0.13 mm; Stan Wiemeyer, U.S. Fish and Wildlife Service, Reno, Nevada, pers. comm.) of bald eagle eggshell membranes was added to the mean thickness measurement. Eggshell thinning was determined as the percent difference between eggshell thickness of each egg and mean eggshell thickness (0.6088 mm) for bald eagle eggs (museum specimens) collected in the Northwest prior to 1947 (pre-DDT), before DDT was in widespread use (Dan Anderson, Univ. Calif., pers. comm; Anderson and Hickey 1972).

Twenty-six bald eagle eggs were collected from nests in 19 different breeding territoriess over the two-year study. In 1994, nine fresh eggs were collected from nine territories, a broken egg from one territory, and five addled eggs from three territories. Seven of these territories were in Washington and five were in Oregon. Addled eggs from the same clutch were collected from two territories. The broken egg was excluded from calculations of mean contaminant concentrations because fresh weight concentrations could not be determined.

In 1995, eight fresh and three addled eggs were collected from nests in 11 territories. Eggs were obtained from the same four breeding territories during both years of the study. Six eggs were collected from territories on the Oregon side of the river and five eggs were collected from the Washington side. Eggshell fragments were obtained from three of these territories and at one additional territory where no eggs had been collected previously.

Analytical Chemistry
Eagle egg and prey samples were shipped overnight on dry ice to laboratories contracted through the Patuxent Analytical Control Facility, Maryland, for chemical analysis of contaminants. Samples were chemically analyzed for dioxin-like compounds at the U.S. Geological Survey, Environmental Contaminant and Research Center (ECRC) in Columbia, Missouri. The dioxin-like compounds analyzed included eight polychlorinated dibenzo-*p*-dioxins (PCDDs), ten polychlorinated dibenzofurans (PCDFs), and four non- and eight mono-ortho-chloro substituted PCBs (planar PCBs). Nomenclature for the planar PCB congeners discussed in this report follow International Union of Pure and Applied Chemists (IUPAC) numbers (Ballschmiter and Zell 1980). Due to limited funding, mono-ortho PCB congeners were analyzed in eggs collected from 11 territories in 1994 only. Samples collected in 1994 were chemically analyzed for organochlorine pesticides, total PCBs, and mercury at Hazleton Laboratories America, Inc., Madison, Wisconsin. Samples from 1995 were analyzed for organochlorine pesticides and total PCBs at ECRC.

Eagle egg and prey item samples were prepared and analyzed for dioxin-like compounds according to Feltz et al. (1995). Approximately 25 g aliquots of egg or fish tissue were homogenized with anhydrous sodium sulfate for dehydration and extracted with methylene chloride in an extraction column. Extracts were concentrated by rotoevaporation and treated by a two-stage reactive cleanup with sulfuric acid silica gel/potassium silicate column and a column of sulfuric acid silica gel/potassium silicate/silica gel. Extracts were purified with high performance gel phase chromatography. Analytes were separated by an automated C-18/PX-21 carbon column high performance liquid chromatography system, isolating four fractions: 1) bulk and di-ortho-PCB congeners; 2) mono-ortho-PCB congeners; 3) non-ortho-PCB congeners; and 4) PCDD/PCDFs. Following isolation, the PCDD/PCDF fraction was eluted through basic alumina for removal of potential co-contaminants (ethers and residual polychlorinated napthalenes and PCBs), and the alumina fractions were transferred and concentrated using a stream of nitrogen gas.

Aliquants of purified sample extracts were analyzed by capillary gas chromatography/electron capture detection (CGC/ECD) to measure mono ortho-PCB concentrations (Schwartz and

Stalling 1991). The PCDD/PCDF and non ortho-PCB fractions were determined by gas chromatography/high resolution mass spectrometry by monitoring five sequential windows of selected ions during the chromatographic separation (Kuehl et al. 1991). The method detection limits for most dioxin and furan congeners ranged from 0.1 to 0.9 pg/g. However, 1,2,3,4,6,7,8-heptachlorodibenzo-*p*-dioxin in 1995 samples was not quantitated below 3.0 or 4.0 pg/g due to inaccurate ion ratios. Analytical results for the dioxins, furans, and percent lipid on individual samples are reported in Appendices 1 to 4.

Sample preparation, extraction, and cleanup of organochlorine pesticides and total PCBs followed methods outlined by the EPA (1986b). Samples were homogenized, ground, and prepared with anhydrous sodium sulfate. Analytes were recovered by Soxhlet extraction using the solvent methylene chloride and concentrated in Kaderna-Danish apparatus. Sample cleanup occurred by gel-permeation chromatography. Additional cleanup and separation of PCBs from organochlorine pesticides was conducted using silica gel. For organochlorine pesticides, the method detection limits for 1994 samples were 20 ng/g (90 ng/g for total PCBs and toxaphene) and 0.05 to 0.13 ng/g (29 ng/g for total PCBs) for 1995 samples. Analytical results for the organochlorine pesticide and total PCB concentrations on individual samples are reported in Appendix 5.

Sample preparation for mercury analysis included digestion with a sulfuric and nitric acid mixture and reduction of mercury using sodium borohydride (Monk 1961). Mercury was determined by cold vapor atomic absorption (Hatch and Ott 1968). The detection limit for this procedure was <0.01 µg/g. Total mercury results for individual samples are reported in Appendix 5.

Laboratory quality assurance/quality control (QA/QC) samples for all contaminant analyses consisted of procedural blanks, replicates, and spiked samples. Matrix spikes and replicate results for most analytes at each laboratory were within the specified limits for this study. In general, analyte concentrations in egg samples with corresponding matrix spike recoveries outside specified boundaries were below or near detection limits or reported as estimated results. Accuracy and precision as determined by spike sample recovery and replicate sample analysis were within specified ranges for organochlorine pesticides and total PCBs, although insufficient sample material was available in 1994 egg samples and detection limits were elevated. Quality control samples for dioxin-like compounds also included procedural blanks, replicates, chicken egg (matrix) blanks, chicken egg spikes, and positive control Saginaw Bay carp samples, processed and analyzed concurrently with actual samples. Recoveries of the ^{13}C-labeled dioxin-like compounds concentrations were generally within range (± 20 %) of expected values. Analyte concentrations in control carp compared closely with previous QA/QC data.

H4IIE Rat Hepatoma Cell Bioassay

Egg content and prey item samples were used in a H4IIE rat hepatoma cell bioassay to assess exposure to all planar halogenated compounds with the ability to biochemically elicit dioxin-like toxicity. The bioassay was conducted at the ECRC following the methods of Tillitt et al. (1991a) as modified for 96-well microtitre plates (Tysklind et al. 1994). The potency of extracts tested in the H4IIE bioassay was compared to the potency of TCDD. The results were expressed as

TCDD-equivalents (TCDD-EQs) and reflected the overall dioxin-like potency found in the sample, inclusive of TCDD and all other planar halogenated compounds in the samples (Tillitt et al. 1991a). Polyaromatic hydrocarbons (PAHs) exhibiting dioxin-like activity were removed from egg extracts during the two-stage reactive clean-up process, and did not contribute to the total TCDD-EQ values. The H4IIE bioassay was used as a screening tool; the potency of the planar compounds in the bioassay has not been correlated to the ability of these compounds to cause embryo lethality in bald eagles. However, the potency of planar compound mixtures in the H4IIE cells has been correlated to hatching success in double-crested cormorants and Caspian terns *(Sternus caspia*), and to embryonic deformities in these species in the Great Lakes (Tillitt et al. 1992, Ludwig et al. 1996).

Replicate and positive control results from the H4IIE bioassay were acceptable for all eggs collected in 1994. However, all results from eggs collected in 1995 were significantly lower (P=0.010, n=17, two-tailed t-test) than in eggs collected in 1995, and positive control material analyzed alongside the 1995 batch was unusually low. Six double-crested cormorant eggs collected in 1994 were also analyzed with the 1995 eagle egg batch, and results were noticeably lower compared to five cormorant eggs collected in the same year but analyzed previously in a different batch. Because of the discrepancies in egg results between years and the low positive control values, the 1995 eagle egg results from the bioassay were censored from the data set.

Data Analysis

Mean annual productivity, nest success (percentage of occupied breeding territories that successfully produced young), and five-year running productivity averages were calculated for eagles nesting along the lower river and compared to statewide values. Five-year productivity values are considered a better measure of production because they average out other factors besides contaminants that may impact productivity (Herrick 1933, Howell 1954). Bald eagle breeding territories along the river were defined as old or new to compare differences in productivity between 23 well established breeding territories investigated in Anthony et al. (1993) and the breeding territories established in previously unoccupied areas since the earlier investigation. A doubling of the population occurred along the river between 1990 and 1995, and nests established during this time were considered new breeding territories. The older breeding territories were established primarily before 1990, although two breeding territories established in 1987 and 1988 were more characteristic of the new areas and lumped into this category. Old breeding territories were not necessarily occupied by the original nesting pairs, as younger eagles could have replaced one or both of the original pairs at any time.

Total productivity (total number of young produced per breeding territory over the total years occupied) from 1982 to 1986 for eagle pairs at 21 new breeding territories was compared to total productivity at the 23 old breeding territories using a two-sample t-test. Only breeding territories with at least three years occupancy was used in this analysis in order to obtain a more reliable productivity value. Also, total productivity of eagle pairs at the 23 old breeding territories were compared over two time periods (1982 to 1987 and 1990 to 1995) using a paired t-test to determine if reproductive success changed over time for eagles at only these older areas.

Mean five-year productivity (Wiemeyer et al. 1984) was compared to contaminant concentrations and eggshell thinning using simple linear regression. Data for mean five-year productivity included three years of occupancy prior to 1994 and two years after, although fewer years were used for 10 territories without five years of productivity data. Mean five-year productivity was also compared to river mile using linear regression; nests were located near the mouth of the Columbia River (river mile 0) to river mile 150 (four miles above Bonneville dam; Figure 1).

Tree climbing during years when fresh eggs were collected may have influenced productivity values. To evaluate this possible influence, annual productivity in 1994 and 1995 was determined by calculating the number of young produced per nest including sites were the nest tree was climbed (climbed sites), and by calculating the number of young produced per nest for all sites excluding the climbed sites. All other comparisons of productivity were determined using the data set excluding climbed sites to avoid any influence of tree climbing on productivity values.

Concentrations of organochlorine pesticides, dioxin-like compounds, and mercury in LCR bald eagle eggs were compared to estimated no-observable-adverse-effect levels (NOAELs) or lowest-observable adverse-effect-levels (LOAELs) and to concentrations associated with adverse impacts to bald eagles or other avian species. Concentrations of p,p -DDE in eggs were compared to eggshell thinning using linear regression, and regression was used to compare contaminants to river mile. Contaminants concentrations were also compared to values found in eggs collected from 1985 to 1987 by Anthony et al. (1993). Eggshell thickness and concentrations of p,p -DDE, total PCBs, and mercury from eggs at older breeding territories (occupied during both study periods) were compared using a two-sample t-test. Concentration data from breeding territories established since 1990 were excluded from this comparison. A paired t-test was used to compare contaminant concentrations between six individual breeding territories sampled during this study and that of Anthony et al. (1993). Sample numbers were insufficient to reliably compare dioxins, furans, or planar PCBs between the two studies.

The total dioxin-like potency of planar chlorinated compounds in bald eagle egg tissues were summarized as TCDD toxic equivalents (TEQs). TEQs were determined by normalizing concentrations of individual dioxin-like compounds (including planar PCBs), relative to the potency of TCDD, using toxic equivalency factors (TEFs; van den Berg et al.1998). The concentration of each planar chlorinated hydrocarbon in an egg sample was multiplied by its corresponding TEF value. The values obtained for each planar compound were then summed, which resulted in a single TEQ value of dioxin-like potency for a sample. TEQs for a set of samples were then averaged and compared among other avian populations.

Various TEF values have been suggested for use in risk assessment for calculation of TEQs to better represent exposure to multiple dioxin-like compounds in a range of animal groups. Previous authors have used mammalian-based International TEFs (Safe 1990; Ahlborg et al. 1992, 1994), and avian-based TEFs have been derived for some dioxin-like compounds from studies with chickens (reviewed by Bosveld et al. 1995). Recently, TEFs have been adopted by the World Health Organization (WHO) based on mammalian-(M-TEF) and avian-(A-TEF) endpoints (van den Berg et al. 1998), which vary slightly from the previously used International TEFs. In addition, Tillitt et al. (1991a,1993) derived TEFs using the H4IIE bioassay (H4IIE-TEFs). We used mammalian- and avian-based TEFs established by the WHO, and the H4IIE-TEFs, to determine three separate TEQ values (Table 1). Values were reported as M-TEQ for the mammalian-based TEFs, A-TEQ for the avian-based TEFs, and H4IIE-TEQ for the bioassay-derived TEFs. The results of the H4IIE rat hepatoma bioassay conducted on extracts of Columbia River bald eagle eggs are presented as TCDD-EQs to distinguish it from the three calculated TEQ values.

TEFs have been determined for many dioxin-like compounds. However, authors of previous studies have evaluated TEQs using TEFs determined for only PCDDs and PCDFs, while others have included TEF values derived for some planar PCBs in the TEQ calculation. We determined M-TEQ, A-TEQ, and H4IIE-TEQ values using TEF values for only the PCDDs and PCDFs, and also with TEF values established for the planar PCB compounds, in order to compare our data to those from other authors.

Contaminant concentrations for each egg were adjusted for moisture and lipid loss using volume measurements. Volume was estimated as the mean of the whole egg displacement volume and the egg content volume calculated from length and breadth measurements (Stickel et al. 1973) for eggs collected in 1985 and from 1994 to 1995. Egg measurements and displacement volume were unavailable for eggs collected in 1986 to 1987 by Anthony et al. (1993). To correct for moisture loss, we assumed all eggs collected from 1986 to 1987 were in late stage of development (all 1986 and 1987 eggs were collected fresh during incubation) and used an adjustment factor derived by averaging all late stage embryos collected from 1994 to 1995. This conservative adjustment prevented an overestimation of the contaminant concentrations in eggs collected from the earlier study.

Graphing comparisons using a scatterplot matrix (SPSS 1998) indicated natural log transformation improved linearity of analytical chemistry and bioassay data. Therefore, all analytical chemistry and bioassay data were transformed to natural log prior to statistical analysis, and geometric means were reported. Contaminant concentrations below detection limits were assigned a value of one-half the detection limit for computational purposes. Concentrations of dioxin-like compounds below detection or quantification limits were not used in the calculation of TEQs. All egg concentrations (fresh weight) were reported as micrograms per gram (µg/g) or nanograms per gram (ng/g) for organochlorine pesticides and total PCBs, picograms per gram (pg/g) for dioxin-like compounds, and nanograms per gram (ng/g) for planar PCBs. All statistical tests were performed at the 0.05 level of significance using the software program SYSTAT 8.0 (SPSS 1998).

RESULTS

Productivity

The number of occupied territories with known nesting outcome along the LCR was 42 in 1994 and 43 in 1995. Tree climbing to obtain fresh eggs could have influenced productivity of eagle

Table 1. Toxic equivalency factors (TEFs) used to determine Toxic Equivalents (TEQs) in bald eagle eggs collected along the lower Columbia River in 1994 and 1995. TEFs were based on mammalian (M-TEF) and avian (A-TEF) endpoints established by the World Health Organization (van den Berg et. al 1998) and derived from the H4IIE rat hepatoma bioassay (H4IIE-TEF; Tillitt et al. 1991a, 1993).

Chemical	M-TEF	A-TEF	H4IIE-TEF
Chlorinated dibenzodioxins			
2,3,7,8-Tetra	1	1	1
1,2,3,7,8-Penta	1	1	0.42
1,2,3,4,7,8-Hexa	0.1	0.05	0.83
1,2,3,6,7,8-Hexa	0.1	0.01	0.24
1,2,3,7,8,9-Hexa	0.1	0.1	0.34
1,2,3,4,6,7,8-Hepta	0.01	<0.001	0.23
Octa	0.0001	NA[b]	0.00054
Chlorinated dibenzofurans			
2,3,7,8-Tetra	0.1	1	0.2
1,2,3,7,8-Penta	0.05	0.1	0.2
2,3,4,7,8-Penta	0.5	1	1.4
1,2,3,4,7,8-Hexa	0.1	0.1	0.02
1,2,3,6,7,8-Hexa	0.1	0.1	0.06
1,2,3,7,8,9-Hexa	0.1	0.1	0.2
2,3,4,6,7,8-Hexa	0.1	0.1	0.3
1,2,3,4,6,7,8-Hepta	0.01	0.01	0.3
1,2,3,4,7,8,9-Hepta	0.01	0.01	0.3
Octa	0.0001	0.0001	0.02
Non ortho-chlorinated Biphenyls			
3,4,4 ,5-Tetra (81)[d]	0.0001	0.1	0.0019
3,3 ,4,4 -Tetra (77)	0.0001	0.05	0.000018
3,3 ,4,4 ,5-Penta (126)	0.1	0.1	0.022
3,3 ,4,4 ,5,5 -Hexa (169)	0.010	0.001	0.00047
Mono ortho-chlorinated Biphenyls			
2,3,3 ,4,4 -Penta (105)	0.0001	0.0001	0.00008
2,3,4,4 ,5-Penta (114)	0.0005	0.0001	<0.000001
2,3 ,4,4 ,5-Penta (118)	0.0001	0.00001	0.000000035
2 ,3,4,4 ,5-Penta (123)	0.0001	0.00001	0.00012
2,3,3 ,4,4 ,5-Hexa (156)	0.0005	0.0001	0.000055
2,3,3 ,4,4 ,5 -Hexa (157)	0.0005	0.0001	0.000015
2,3 ,4,4 ,5,5 -Hexa (167)	0.00001	0.00001	0.000009
2,3,3 ,4,4 ,5,5 -Hepta (189)	0.0001	0.00001	0.00001

pairs at nine territories (21%) in 1994 and at eight territories (19%) in 1995. Mean annual productivity was reduced by 22 and 16 percent when climbed sites were included in the 1994 and 1995 productivity calculation, respectively (Table 2).

Table 2. Productivity (young produced/occupied territory with known outcome) and nest success for bald eagles nesting along the lower Columbia River and in Oregon in 1994 and 1995.

	Lower Columbia River				Oregon[a]	
	Excluding climbed sites		Including climbed sites		Excluding lower Columbia River territories	
	1994	1995	1994	1995	1994	1995
Mean annual productivity	0.97	0.63	0.76	0.53	0.99	1.00
% Nest success	52	43	40	35	58	63
Total occupied territories[b]	33	35	42	43	201	213

[a] Statewide data obtained from Isaacs et al. (1997).
[b] Total occupied territories with known outcome.

Since 1980, mean annual productivity and nest success for LCR eagles have been consistently lower than for bald eagles nesting elsewhere in Oregon (Table 3). Mean annual productivity and nest success for bald eagles nesting along the LCR (excluding climbed sites) were similar to statewide values for bald eagles nesting elsewhere in Oregon in 1994, but well below statewide values in 1995 (Table 2). In 1995, annual productivity of the LCR eagles was 37 percent lower than average statewide values, and at least 10 nests were abandoned at some point between incubation and hatching in territories where nest trees were not climbed.

Five-year running productivity averages (excluding climbed sites) for LCR bald eagles was 0.79 and 0.78 young/occupied territory with known outcome for the five-year periods ending in 1994 and 1995, respectively. The five-year running averages ending in 1993, 1994, and 1995 were higher than during any previous five-year time period for eagles along the LCR (Table 3, Figure 2). However, five-year running averages were still below values for eagles nesting elsewhere in Oregon (Table 3). Excluding LCR sites, bald eagles in Oregon occupied 201 and 213 sites with known outcome in 1994 and 1995, respectively, and five-year running averages were 0.96 and 0.98 young/occupied territory for periods ending in 1994 and 1995, respectively.

During the two-year study, only one climbed-nest site successfully produced young. However, climbing trees to collect fresh eggs during incubation had minimal influence on five-year running productivity averages, as five-year averages excluding climbed sites did not differ more than 10 percent from averages including climbed sites. Based on past nesting performance along the LCR, many of the climbed nest sites would likely have failed even in the absence of disturbance

Table 3. Success and productivity of bald eagle nest sites along the lower Columbia River and in Oregon (excluding lower Columbia River territories) from 1980-97.

	1980	1981	1982	1983	1984	1985	1986[a]	1987[a]	1988	1989	1990	1991	1992	1993	1994[a]	1995[a]	1996	1997
Lower Columbia River[b]																		
No. occupied sites	6	9	8	11	16	21	17	24	23	20	22	30	37	36	33	35	49	54
No. young produced	0	5	4	7	11	10	16	9	10	9	13	18	30	32	32	22	39	32
Mean annual prod. (young/occupied site)	0	0.56	0.50	0.64	0.69	0.48	0.94	0.38	0.43	0.45	0.59	0.60	0.81	0.89	0.97	0.63	0.80	0.59
% nest success	0	44	38	45	44	33	71	25	30	35	50	47	57	58	52	43	57	39
5-year running productivity	0.61	0.59	0.50	0.48	0.54	0.57	0.66	0.60	0.55	0.51	0.54	0.50	0.61	0.70	0.79	0.78	0.82	0.76
Oregon[b]																		
No. occupied sites	77	92	99	99	103	121	126	131	148	152	156	165	180	191	201	213	230	248
No. young produced	67	92	68	86	99	109	125	115	138	125	141	175	183	158	199	214	215	244
Mean annual prod. (young/occupied site)	0.87	1.00	0.69	0.87	0.96	0.90	0.99	0.88	0.93	0.82	0.90	1.06	1.02	0.83	0.99	1.00	0.93	0.98
% nest success	58	63	48	59	65	60	64	60	61	52	63	66	61	56	58	63	62	63
5-year running productivity	1.02	0.99	0.91	0.87	0.88	0.88	0.89	0.92	0.93	0.90	0.90	0.92	0.95	0.93	0.96	0.98	0.95	0.95

[a] Sites where fresh eggs were collected from the lower Columbia River territories were excluded from analysis during these years.
[b] All parameters refer to occupied sites with known outcome. Data obtained from Isaacs et al. (1997).

caused by climbing. Therefore, the productivity averages determined with climbed sites included probably underestimated the productivity that would have been observed had no climbing occurred.

From 1990 to 1996, 28 additional eagle pairs established breeding territories along the LCR. Total productivity from 1982 to1996 of eagle pairs at 21 of these new breeding territories was higher (P=0.002) than at 23 older territories (Figure 3). The eagle pairs at the 23 older territories exhibited low productivity which did not change (P=0.713) between two six-year time periods (Figure 3).

Mean five-year productivity for eagle pairs at each of 47 breeding territories along the LCR was not correlated (r=0.261, P=0.077) to nest location as river mile, although the significance value was suggestive of a linear relationship (Figure 4). The slope indicated poorer productivity for eagles nesting along the lower estuary below river mile 60, where mostly older breeding territories were located (Figure 4). Mean five-year productivity was not related to any contaminants except dieldrin, which exhibited a positive correlation (Table 4).

Figure 3. Arithmetic mean (bar) and standard deviation (line) of total productivity values (number of young produced per occupied breeding territory) at A) 23 old and 21 new breeding territories for the period 1982 to 1996 and B) 23 old breeding territories during two time periods (1982-87 and 1990-95).

Figure 4. Relationship between mean five-year productivity (number of young produced per occupied territory) against nest location as river mile for bald eagles at old breeding territories (solid circles) and new breeding territories (open circles) along the lower Columbia River.

Table 4. Correlation coefficients (*r*) and significance levels (*P*) for relationships between five-year productivity and river miles against contaminant concentrations and toxic equivalents (TEQs) from mammalian-(M-TEQ), avian-(A-TEQ), and H4IIE bioassay-(H4IIE-TEQ) based toxic equivalency factors (TEFs), and H4IIE bioassay-derived TCDD equivalents (H4IIE-TCDD EQs), in eggs from 19 breeding territories along the lower Columbia River in 1994-95.

	Productivity		River mile	
	r	*P*	r	*P*
Total PCBs & organochlorine pesticides				
Total PCBs	0.007	0.979	-0.213	0.381
p,p -DDT	0.131	0.592	-0.026	0.915
p,p -DDE	-0.126	0.608	-0.371	0.117
p,p -DDD	-0.111	0.650	0.007	0.979
dieldrin	0.592	0.008	0.118	0.629
Hexachlorobenzene	-0.133	0.588	-0.289	0.231
Trans-nonachlor	0.005	0.983	0.058	0.813
Chlorinated dibenzodioxins				
2,3,7,8-Tetra	-0.050	0.839	-0.445	0.056
1,2,3,7,8-Penta	0.139	0.569	-0.310	0.197
1,2,3,6,7,8-Hexa	0.401	0.089	0.122	0.619
Octa	0.061	0.805	-0.087	0.723
Chlorinated dibenzofurans				
2,3,7,8-Tetra	-0.166	0.498	-0.616	0.005
2,3,4,7,8-Penta	0.097	0.694	-0.546	0.015
Octa	0.258	0.287	0.179	0.464
Non-otho-chlorinated PCBs				
3,4,4 ,5-Tetra (81)[a]	0.371	0.118	0.189	0.438
3,3 ,4,4 -Tetra (77)	0.207	0.395	0.002	0.992
3,3 ,4,4 ,5-Penta (126)	0.045	0.855	-0.271	0.262
3,3 ,4,4 ,5,5 -Hexa (169)	-0.021	0.932	-0.528	0.020
Toxic Equivalents (TEQs)				
M-TEQ$_{PCDD/Fs}$[b]	0.032	0.897	-0.476	0.039
M-TEQ $_{nPCBs}$[c]	-0.042	0.865	-0.318	0.185
M-TEQ $_{nmPCBs}$[d] (n=11, 1994 eggs only)	0.252	0.455	-0.307	0.358
A-TEQ $_{PCDD/Fs}$[b]	-0.072	0.770	-0.684	0.001
A-TEQ $_{nPCBs}$[c]	0.120	0.625	-0.258	0.287
A-TEQ $_{nmPCBs}$[d] (n=11, 1994 eggs only)	0.303	0.365	-0.254	0.451
H4IIE-TEQ$_{PCDD/Fs}$[b]	-0.022	0.929	-0.562	0.012
H4IIE-TEQ $_{nPCBs}$[c]	0.022	0.927	-0.425	0.069
H4IIE-TEQ$_{nmPCBs}$[d] (n=11, 1994 eggs only)	0.115	0.736	-0.468	0.146
H4IIE-TCDD-EQs (n=11, 1994 eggs only)	-0.138	0.685	-0.029	0.932

[a] Number in parentheses is based on International Union of Pure and Applied Chemists congener number (Ballschmiter and Zell 1980).
[b] Calculated with TEFs for polychlorinated dioxin and furan congeners only.
[c] Calculated with TEFs for polychlorinated dioxins and furans and non-ortho-chlorinated PCBs.
[d] Calculated with TEFs for polychlorinated dioxins, furans, and non-and mono-ortho-chlorinated PCBs (n=11).

Organochlorine Pesticide, Total PCB, and Mercury Concentrations

All LCR bald eagle eggs contained detectable concentrations of organochlorine pesticides or metabolites, total PCBs, and mercury (Table 5). Total polybrominated diphenyl ethers were also detected in all eggs collected in 1995, and some samples exceeded one µg/g (Table 5). Nine of 29 organochlorine pesticides or metabolites analyzed were below detection limits in all eggs. All organochlorine pesticide concentrations were <1 µg/g with the exception of p,p -DDE and total PCBs (Table 5). Total PCB and p,p -DDE were the most elevated contaminants in eggs, exhibiting geometric means of 5.00 and 5.63 µg/g, respectively. The most elevated concentrations of p,p -DDE and total PCBs in both 1994 and 1995 were observed in eggs from an old breeding territory near the mouth of the river. Concentrations of organochlorine compounds were highly intercorrelated (Appendix 6). Concentrations of p,p -DDE in 19 samples were correlated with other organochlorine compounds, including total PCBs (r=0.887, P<0.001), TCDD (r=0.700, P=0.0009), and 1,2,3,7,8-pentaCDD (r=0.662, P=0.002). Intercorrelations with total PCBs also included TCDD (r=0.741, P=0.003) and 1,2,3,7,8 PCDD (r=0.739, P=0.003). No significant linear relations were apparent between concentrations of selected organochlorine pesticides or total PCBs in eggs and river mile of nest location (Table 4).

Egg contaminant concentrations were compared to concentrations obtained along the lower river from 1985 to 1987 by Anthony et al. (1993). Because productivity was different between old and new nesting pairs, only egg concentrations at older breeding territories were compared between the two studies. Total PCBs and p,p -DDE concentrations declined significantly (P= 0.0004 and 0.022, respectively), and mercury was not different (P=0.647) between the two study periods at old breeding territories (Table 6). In addition, shell thickness and p,p -DDE concentrations did not change (P=0.819 and 0.090, respectively) at six breeding territories sampled during both studies. However, total PCB concentrations were lower (P=0.010) at the same six sites between the two study periods.

Organochlorine pesticide concentrations in a single broken egg collected from one territory in 1994 were determined as lipid weight because it was not possible to calculated egg volume. The lipid weight concentrations of p,p -DDE, p,p -DDD (tetrachlorodiphenylethane), and total PCBs in the broken egg were 152, 8.2, and 133 µg/g, respectively. These concentrations were very similar to lipid weight concentrations for p,p -DDE (= 154 µg/g), p,p -DDD (=9.06 µg/g), and total PCBs (= 138 µg/g) in the 14 eggs collected in 1994, assuming the remaining lipid content of the broken egg was representative of fresh eggs. The shell from this egg was 14 percent thinner than shells from eggs collected pre-DDT.

Eggshell Thickness

All bald eagle eggs collected along the LCR exhibited eggshell thinning except one from a breeding territory sampled in 1995. This shell was up to 12 percent thicker than the pre-DDT average and was collected at the same breeding territory where a shell of normal thickness was collected in 1986 by Anthony et al. (1993). Columbia River eggshells were 0 - 25% thinner (= -11%) than the mean of eggs collected pre-DDT (Table 5). Eggshell thickness was not correlated to p,p -DDE (r=0.005, P=0.985, n=19), and was not correlated to mean five-year productivity (r = -0.254, P= 0.294, n = 20).

Table 5. Eggshell measurements and concentrations (fresh weight) of organochlorine pesticides, total PCBs, mercury, and total polybrominated diphenyl ethers (PBrDE) in bald eagle eggs collected in 1994 to 1995 along the lower Columbia River.

Eggshell Parameter/ Contaminant	Mean[a]	Range	n
Eggshell Parameters			
Eggshell Thickness (mm)	0.543	0.454 - 0.682	29[b]
Percent Change[c]	-11	-25 - +12	29
Chemicals (µg/g fresh weight)			
Total PCBs	5.00	2.90 - 11.4	19
p,p -DDE	5.63	2.89 - 12.5	19
Total mercury	0.22	0.17 - 0.29	11[d]
Chemicals (ng/g fresh weight)			
p,p -DDT	6.92	<0.06 - 34	19
p,p -DDD	273	149 - 498	19
o,p -DDT	NC[e]	<20	19
o,p -DDE	1.77	0.60 - 6.56	11[f]
o,p -DDD	1.95	<0.06 - 5.94	11[f]
dieldrin	46.3	19.2 - 80.6	19
endrin	1.60	0.57 - 3.34	11[g]
hexachlorobenzene	11.7	<20 - 26.9	19
oxychlordane	13.9	<20 - 31.0	19
alpha-chlordane	NC	<20 - 30.0	11[d]
gamma-chlordane	NC	<20	11[d]
trans-chlordane	1.92	<1.0 - 3.80	11[h]
cis-chlordane/octa-chlordane	131	90.6 - 293	11[h]
alpha-BHC	NC	<20	19
beta-BHC	6.39	1.67 - 42.5	11[i]
gamma-BHC (lindane)	NC	<20	19
delta-BHC	NC	<0.06 - 1.85	11[h]
heptachlor epoxide	11.0	5.39 - 28.8	11[j]
heptachlor	NC	<0.10	11[h]
mirex	5.74	3.58 - 17.9	11[f]
toxaphene	NC	<90	11[d]
trans-nonachlor	133	86.5 - 238	19
cis-nonachlor	42.6	31.1 - 103	11[h]
methoxychlor	NC	<0.06	11[h]
pentachloroanisole[i]	0.68	0.35 - 1.46	11[h]
Dacthal[j]	NC	<0.05	11[h]
Total PBrDE	745	446 - 1206	11[h]

[a] Arithmetic mean for eggshell parameters and geometric mean for chemical concentrations.
[b] Combined sample size of 29 eggshells and fragments collected in 1994 and 1995.
[c] Change in mean eggshell thickness from value (0.6088 mm) determined for bald eagle eggs collected prior to 1947.
[d] Compound analyzed in 1994 eggs only.
[e] Geometric mean not calculated because majority of samples were less than detection limits.
[f] 1994 eggs excluded because all concentrations were below detection limits (<20 ng/g).
[g] 1994 eggs excluded because all concentrations were <20 ng/g except 1, which was 22 ng/g.
[h] Compound analyzed in 1995 eggs only.
[i] 1994 eggs excluded because all concentrations were below detection except 2, which were 11 and 29 ng/g.
[j] 1994 eggs excluded because all concentrations were below detection except 1, which was 18 ng/g.
[k] Bioaccumulative metabolite of the fungicide pentachloronitrobenzene.
[l] Bioaccumulative pre-emergent herbicide (tetrachloro-bis-methylterpthalate).

Table 6. Comparison of eggshell parameters (arithmetic means, range in parentheses) and selected contaminants and mammalian-based Toxic Equivalents (M-TEQs; geometric means, range in parentheses) in bald eagle eggs collected from old breeding territories along the lower Columbia River during two time periods. Mammalian-based Toxic Equivalents (M-TEQs) were calculated using Toxic Equivalent Factors (TEFs) from (van den Berg et al. 1998).

	1985-87 Anthony et al. (1993)	n	1994-95 Old breeding territories	n
Eggshell Parameters				
Eggshell Thickness (mm)	0.552A[a]	10	0.538A	13
	(0.497 - 0.618)		(0.454 - 0.623)	
Percent Change[b]	-9.3	10	-11.6	13
	(-18 - +2)		(-25 - +2.3)	
Contaminants (µg/g fresh weight)				
p,p -DDE	9.6A	10	6.3B	13
	(4.3 - 21)		(3.5 - 12.5)	
Total PCBs	10.5A	10	5.4B	13
	(5.1 - 20)		(3.4 - 11.4)	
Mercury[e]	0.21A	10	0.22A	9
	(0.12 - 0.40)		(0.17 - 0.29)	
Contaminants (pg/g fresh weight)				
2,3,7,8-TCDD	26	5[c]	24	13
	(11 - 38)		(18 - 37)	
2,3,7,8-TCDF	15	5	22	13
	(4 - 38)		(9 - 53)	
M-TEQs $_{PCDD/Fs}$ [d]	55	5	43	13
	(25 - 79)		(33 - 68)	
M-TEQs $_{nPCBs}$ [e]	326	3	196	13
	(186 - 475)		(149 - 344)	
M-TEQs $_{nmPCBs}$ [f]	406[g]	3	316	11[h]
	(227 - 574)		(223 - 536)	

[a] Means with different capital letters across rows were significantly different. Dioxins, furans, planar PCBs, and M-TEQ values were not statistically compared due to insufficient sample size.
[b] Change in mean eggshell thickness below value (0.6088 mm) determined for bald eagle eggs collected prior to 1947.
[c] Includes 3 eggs collected in 1987 and 2 addled eggs collected in 1991.
[d] M-TEQs calculated with TEFs for polychlorinated dioxin and furan congeners only.
[e] M-TEQs calculated with TEFs for polychlorinated dioxins and furans and non-ortho-chlorinated PCBs.
[f] M-TEQs calculated with TEFs for polychlorinated dioxins and furans and non-and mono-ortho-chlorinated PCBs.
[g] Only one mono-ortho congener (PCB 105) was determined.
[h] Data included from 1994 eggs only.

Mean eggshell thickness at 13 older territories in this study was not different (P=0.404) from eggshells collected at 10 territories along the river in 1985 to 1987 (Table 6). In addition, shell thickness did not change (P=0.819) at six breeding territories sampled during both studies. Mean eggshell thickness from both studies were well below the pre-DDT average of 0.6088 mm (Table 6).

Concentrations of Dioxin-like Compounds
All egg samples contained dioxins and furans, although 1,2,3,7,8,9-hexaCDF was rarely above detection limits (Table 7). TCDD and TCDF were the most elevated congeners in eggs, and the highest concentrations were observed in eggs from two older breeding territories near the mouth of the estuary. Other congeners elevated well above detection limits included 1,2,3,7,8-pentaCDD, 1,2,3,6,7,8-hexaCDD, octaCDD, and 2,3,4,7,8-pentaCDF (Table 7). Individual dioxin and furan congeners were not correlated to mean five-year productivity (Table 4). TCDD and TCDF concentrations appeared similar between eggs collected in 1994 and 1995 and the earlier study along the LCR (Anthony et al. 1993), although slight differences in analytical methods and small sample size obtained in the earlier study precluded statistical comparisons.

A significant linear relationship was observed between river mile and the furan congeners TCDF and 2,3,4,7,8-pentaCDF (Figure 5). Concentrations of these two congeners increased in eggs from territories toward the lower part of the river (Figure 5). Other dioxin and furan congeners were not correlated to river mile (Table 4), although a linear relationship between river mile and TCDD was suggestive (P=0.056; Figure 5).

Planar PCBs also accumulated in all bald eagle eggs. The most elevated non ortho-substituted PCBs were 77 and 126, and the most elevated mono-ortho-substituted PCBs were 118 and 105 (Table 7). Mean five-year productivity was not correlated to the non-ortho PCBs measured during the study (Table 4). Of the non-ortho PCBs, only PCB 169 was correlated to river mile (Table 4, Figure 5).

The geometric means for all M-TEQ and H4IIE-TEQ calculations were lower than corresponding A-TEQ concentrations (Table 8). This reflects the greater sensitivity (higher TEF values) of the chicken cytochrome P450 enzymes in response to some dioxin-like compounds, especially the tetra- and pentaCDFs and the ortho-substituted tetrachlorinated biphenyls (Table 1). The geometric means for M-TEQ and A-TEQ calculated including planar PCBs were four to six times greater than corresponding TEQs for just dioxins and furans alone (Table 8). The H4IIE-

TEQ mean (excluding TEFs for planar PCBs) was very similar to the M-TEQ value, although mean H4IIE-TEQ values including the planar PCBs were much lower than corresponding M-TEQ or A-TEQ values (Table 8). TEFs for planar PCBs used in the H4IIE-TEQ calculation were less than TEFs for planar PCBs used in the chicken or mammalian-based TEQs (Table 1), reflecting the lower sensitivity of the H4IIE bioassay to individual planar PCBs.

Mean five-year productivity was not correlated to any TEQ value (Table 4). All TEQ values including only the dioxin and furan congeners were correlated with river mile, and a linear relationship was suggested (P=0.069) between river mile and the H4IIE-TEQs calculated including non-ortho PCBs (Figure 5). M-TEQ concentrations for samples collected in 1994 and 1995 were similar to concentrations from the earlier investigation (Anthony et al. 1993), although sample size was insufficient to statistically compare results.

Table 7. Concentrations (pg/g fresh weight) of polychlorinated dibenzo-*p*-dioxins, polychlorinated dibenzofurans, and planar chlorinated biphenyls in bald eagle eggs collected from 19 territories along the lower Columbia River in 1994 and 1995.

Chemical	Geometric Mean	Range
Chlorinated dibenzodioxins		
2,3,7,8-Tetra	22	10 - 37
1,2,3,7,8-Penta	11	5.3 - 21
1,2,3,4,7,8-Hexa	1.2	<0.7[a] - 4.1
1,2,3,6,7,8-Hexa	9.1	4.4 - 19
1,2,3,7,8,9-Hexa	0.57	0.50-2.0
1,2,3,4,6,7,8-Hepta	1.6	0.68 - 6.0
Octa	19	5.3 - 84
Chlorinated dibenzofurans		
2,3,7,8-Tetra	22	9 - 53
1,2,3,7,8-Penta	1.4	0.70 - 2.9
2,3,4,7,8-Penta	6.2	4.0 - 11
1,2,3,4,7,8-Hexa	0.83	<0.60 - 3.2
1,2,3,6,7,8-Hexa	1.4	0.60 - 3.5
1,2,3,7,8,9-Hexa	NC[c]	<0.20 - 0.20
2,3,4,6,7,8-Hexa	2.0	0.90 - 4.9
1,2,3,4,6,7,8-Hepta	2.1	0.90 -7.8
1,2,3,4,7,8,9-Hepta	0.86	<0.50 - 2.5
Octa	3.7	1.6 - 13
Non ortho-chlorinated Biphenyls		
3,4,4 ,5-Tetra (81)[d]	339	214 - 491
3,3 ,4,4 -Tetra (77)	2,580	1,820 - 3,810
3,3 ,4,4 ,5-Penta (126)	1,390	626 - 2,720
3,3 ,4,4 ,5,5 -Hexa (169)	133	49.5 - 353
Mono ortho-chlorinated Biphenyls (analyzed in eggs collected from 11 sites in 1994 only)		
2,3,3 ,4,4 -Penta (105)	148,000	96,100 - 230,000
2,3,4,4 ,5-Penta (114)	11,700	7,600 - 16,300
2,3 ,4,4 ,5-Penta (118)	513,100	345,000 - 859,000
2 ,3,4,4 ,5-Penta (123)	5,490	<200 -13,100
2,3,3 ,4,4 ,5-Hexa (156)	71,320	37,800 - 146,000
2,3,3 ,4,4 ,5 -Hexa (157)	19,360	11,600 - 38,100
2,3 ,4,4 ,5,5 -Hexa (167)	61,700	30,900 - 135,000
2,3,3 ,4,4 ,5,5 -Hepta (189)	7,260	3,840 - 16,200

[a] The < sign = less than detection limits. The number following the sign is the highest detection limit for the group of samples.
[b] Toxic Equivalency Factor not available.
[c] Geometric mean not calculated because majority of samples were less than detection limits.
[d] Number in parentheses is based on International Union of Pure and Applied Chemists congener number (Ballschmiter and Zell 1980).

Figure 5. Regression of nest location as river mile against the natural log of selected contaminant and toxic equivalent (TEQ) concentrations for 19 bald eagle egg samples along the lower Columbia River (solid circles represent old breeding territories, open circles new breeding territories). Selected contaminants include: A) 2,3,7,8-tetrachlorinated dibenzo-*p*-dioxin; B) 2,3,7,8-tetrachlorinated dibenzofuan; C) 2,3,4,7,8-pentachlorinated dibenzofuran; D) polychlorinated biphenyl (PCB) 169; E) mammalian-based TEQs including only the polychlorinated dioxins and furans (PCDD/Fs); F) avian-based TEQs including only the PCDD/Fs; G) H4IIE-TEQs including only the PCDD/Fs; and H) H4IIE-TEQs including PCDD/Fs and the non-ortho-chlorinated PCBs.

Figure 5. Continued.

Table 8. Geometric means (range in parenthesis) of toxic equivalents (TEQs) from mammalian-(M-TEQ), avian-(A-TEQ), and H4IIE bioassay-(H4IIE-TEQ) based endpoints, and H4IIE bioassay-derived TCDD equivalents (H4IIE-TCDD EQs), in bald eagle eggs collected from the lower Columbia River in 1994-95.

	n	M-TEQ	A-TEQ	H4IIE-TEQ	H4IIE-TCDD EQs
PCDD/F[a]	19	40.9 (20.6 - 67.8)	63.9 (37.6 - 103)	42.9 (23.5 - 68.1)	--
PCDD/F + nPCBs[b]	19	181 (83.9 - 344)	369 (213 - 594)	74.3 (37.7 - 129)	--
PCDD/F + n &mPCBs[c]	11	325 (228 - 546)	424 (332 - 617)	88.2 (69.2 - 137)	--
H4IIE bioassay-derived dioxin-like activity[d]	11	--	--	--	41 (14 - 280)

[a] TEQ calculated using only TEF values for PCDD and PCDF isomers (van den Berg et al. 1998).
[b] TEQ calculated using TEF values for PCDDs, PCDFs, and non-ortho-chloro PCBs (van den Berg et al. 1998).
[c] TEQ calculated using TEF values for PCDDs, PCDFs, and non-ortho-chloro and mono-otho-chloro PCBs (van den Berg et al. 1998). Values based on eggs collected from nests in 11 territories in 1994 only.
[d] TCDD-Equivalents derived from the H4IIE rat hepatoma bioassay (Tillitt et al. 1991a).

The non-ortho PCBs contributed the most dioxin-like activities to all three TEQ models, especially to the A-TEQs (Figure 6). The mono-ortho PCBs were not as important as the non-ortho PCBs toward the total contribution, and the furans and dioxins other than TCDD contributed very little (Figure 6). Of the individual planar compounds, PCB 126 provided the greatest contribution of dioxin-like toxicity in nearly all TEQ models calculated with non-ortho PCBs. PCB 126 contributed the most dioxin-like toxicity (76%) towards the geometric mean M-TEQs, followed in the pattern TCDD>1,2,3,7,8-pentaCDD > 2,3,4,7,8,-pentaCDF. A-TEQs were primarily influenced by PCB 126 (38%) and PCB77 (35%), followed by PCB 81> TCDD >TCDF. Similarly, the H4IIE-TEQs were most influenced by PCB 126 (41%) and TCDD (30%), followed by 2,3,4,7,8,-pentaCDD>1,2,3,7,8-pentaCDD>TCDF.

PCBs 126 was also the most important dioxin-like toxicity contributor for the TEQ values calculated including the non- and mono-ortho PCBs for 11 egg samples collected in 1994, although PCBs 77 and 118 were nearly equal contributors for some TEQ values. M-TEQs were dominated by PCB 126 (48%) and 118 (16%), followed by 156>TCDD>PCB 105. For the A-TEQs, PCB 126 and 77 contributed 37 and 31% of the dioxins-like activity, respectively. The A-TEQ pattern followed as PCB 126>77>81>TCDD>TCDF. PCB 126 and TCDD contributed the most dioxin-like toxicity (39% and 31%, respectively) to the average H4IIE-TEQs, and followed the pattern PCB 126>TCDD>2,3,4,7,8-pentaCDF>1,2,3,7,8-pentaCDD>PCB 156>TCDF.

Figure 6. Geometric means of toxic equivalents (TEQs) from mammalian-(M-TEQ), avian-(A-TEQ), and H4IIE bioassay (H4IIE-TEQs)-based additive models in eggs from 19 bald eagle breeding territories from the lower Columbia River, 1994-95. TEQs were determined using toxic equivalent factors (TEFs) reported for polychlorinated dioxins and furans (PCDDs and PCDFs), non-ortho chlorinated PCBs (non-o-PCBs), and mono-ortho-chlorinated PCBs (mono-o-PCBs) (van den Berg et al. 1998, Tillitt et al. 1991). Values for the mono-ortho-PCBs are for 11 eggs collected in 1994 only.

TCDD-EQs as derived from the H4IIE bioassay were detected in all eggs sampled in 1994. The geometric mean was similar to the additive TEQ values including only dioxins and furans, but was much lower than other TEQs including planar PCBs (Table 9). Bioassay derived H4IIE-TCDD-EQs in 11 egg samples from 1994 were not correlated to TEF-derived H4IIE-TEQs calculated including dioxins and furans (r=-0.160, P=0.638), non-ortho PCBs (r=-0.155, P=0.650), or non- and mon-ortho PCBs (-0.184, P=0.589). H4IIE TCDD-EQs were not correlated to mean five-year productivity or to river mile (Table 4).

Contaminants in Prey Items From Eagle Nests

Organochlorine pesticide, total PCB, and mercury concentrations in two prey items (starry flounder and common carp) from two nests were near or below detection limits. The carp sample contained 0.23 µg/g wet weight of total PCBs and 0.12 µg/g wet weight of p,p -DDE, whereas the concentrations of these two contaminants in the starry flounder were below detection limits.

TCDD and TCDF were the only dioxin and furan congeners detected in the two prey items, and TCDF greatly exceeded TCDD in both samples. TCDD and TCDF were 0.65 and 4.9 pg/g (respectively) wet weight in carp, and were double the concentrations (0.30 and 2.4 pg/g wet weight, respectively) in the flounder. The non-ortho PCBs 81, 77, and 126 were detected in the carp sample at 18, 280, and 26 pg/g wet weight, respectively, and only PCB 77 was detected (32 pg/g wet weight) in the flounder. The total for the three PCB congeners in the carp sample was 324 pg/g wet weight. The mono-ortho PCBs 105 and 118 were detected in the carp sample at 4.0 and 12 pg/g wet weight, respectively, and at 3.6 and 0.9 pg/g wet weight in the flounder, respectively. Other mono-ortho PCBs were below or near quantification limits. The bioassay-derived TCDD-EQ values for the carp and flounder were 3 and 1 pg/g wet weight, respectively.

DISCUSSION

Earlier studies associated environmental contaminants, including p,p -DDE and total PCBs, with poor reproduction and eggshell thinning in LCR eagles (Anthony et al. 1993). Compared to egg concentrations in the mid-1980s, mean concentrations of p,p -DDE declined by 34 percent and total PCBs by 49 percent in eagle eggs from the LCR. Mean total PCB concentrations also declined at six breeding territories sampled during both studies, but mean p,p -DDE did not change. Even with these concentration decreases, mean total PCBs in eggs were higher than either threshold values or no observable adverse effect levels (NOAELs) estimated for bald eagles (Table 9; Wiemeyer et al. 1984, Kubiak and Best 1991, Giesy et al. 1995). In addition, p,p -DDE concentrations were nearly double the values typically associated with reduced productivity in bald eagles from other areas (Table 9; Wiemeyer et al. 1993). Other organochlorine pesticides were present in eagle eggs but were considered to be below levels associated with poor reproduction (Wiemeyer et al. 1993). However, the effects of multiple contaminants and their ability to interact to produce adverse impacts during embryo development is not well known.

Wiemeyer et al.(1993) derived three regression equations relating DDE concentrations in failed-to-hatch bald eagle eggs to mean five-year productivity. Using the weighted sigmoidal equation,

Table 9. Eggshell measurements and fresh weight egg contaminant concentrations (geometric means, range in parenthesis) for bald eagles nesting along the lower Columbia River, and estimated threshold values (fresh or wet weight) in eggs of bald eagles and other avian species.

Eggshell parameter or Contaminant	Lower Col. River Eggs	Estimated threshold values in eggs of various species			Reference
		Value	Type of effect[a]	Species	
Percent Eggshell Change[b]	11	>15-20	Productivity	Bald eagle	Anderson and Hickey 1972
		10[c]	Productivity	Bald eagle	Wiemeyer et al. 1993
p,p -DDE (µg/g)	5.63	3.6	Productivity	Bald eagle	Wiemeyer et al. 1993
total PCBs (µg/g)	5.0	4.0	NOAEL	Bald eagle	Wiemeyer et al. 1984
		6.0[d]	Reproduction	Bald eagle	Kubiak and Best 1991
mercury (µg/g)	0.22	>0.5	Productivity	Bald eagle	Wiemeyer et al. 1993
2,3,7,8-TCDD or TEQs (pg/g)	22 (41 – 385)	7	NOAEL/LOAEL	Bald eagle	Giesy et al. 1995
		65	NOAEL	Bald eagle	Hoffman et al. 1998
		6,500	LD50	Kestrel	Hoffman et al. 1998
		195	LOAEL	Kestrel	Hoffman et al. 1998
		6-10	LOAEL	Kestrel	Giesy et al. 1995
		10	Mortality	Chicken	Verrett 1970
		15	Reference	Bald Eagle	Elliott et al. 1996b
TEQ- PCDD/F (pg/g)	41	15	Reference[e]	Bald eagle	Elliott et al. 1996a
		>20-50	Reproduction	Wood duck	White and Seginak 1994
TEQ with PCBs (pg/g)	181-385	100	NOEL	Bald Eagle	Elliott et al. 1996a
		210	LOEL	Bald Eagle	Elliott et al. 1996a
PCB 126 (pg/g)	1,384	65,000	LD50	Kestrel	Hoffman et al. 1998
PCB 77, 126, 169 (pg/g)	4,095	5,500[f]	Reproduction	Forster s terns	Kubiak et al. 1989
		2,070[g]	Reproduction	Peregrine falcon	Jarman et al. 1993

[a] Effects include concentrations attributed toEffects include concentrations attributed to reducing average productivity for a population, (Productivity), levels ass successsuccess in field studies (Reproduction), egg injection value success in fieldstudies (Reproduction), egg injection valuecausingsuccess in field studies (Reprod effecteffect level (NOAEL), loweffect level (NOAEL), lowest observable adverse effect level (LOAEL),effect level (NOAEL), lowest observable adverse effect lethal dose by egg injection needed to kill an estimated 50 percent of the test population (LD50).

[b] Change in mean eggshell thickness below value determined for bald eagle eggs collected prior to 1947.

[c] Mean shell thinning value below which mean production increased in other eagle populations (Wiemeyer et al. 1993).

[d] Estimate of threshold concentration for healthy productivity (Kubiak and Best 199).

[e] Reference values from five bald eagle eggs collected from coastal British Columbia.

[f] Median concentration in eggs of Forster s terns exhibiting reproductive problems in Green Bay, Wisconsin.

[g] Geometric mean concentration in eggs of peregrine falcons exhibiting reproductive problems in California.

a mean five-year productivity would be predicted for LCR eagles of 0.52 young/occupied territory based on mean p,p -DDE values of 5.63 µg/g. This predicted value is lower than mean five-year productivity (0.82 in 1996) for all LCR eagles, but is very similar to the five-year productivity (0.56 in 1996) observed at 23 older breeding territories. The equation derived by Wiemeyer et al. (1993) represented addled bald eagle eggs collected after failure to hatch, and the estimates from the equation may not apply to populations where fresh eggs were collected. The equation typically predicts productivity values that are lower by 0.1 to 0.4 young per occupied breeding territory than the total population productivity (Wiemeyer et al 1993), which may explain in part the higher observed than predicted productivity values from the LCR population.

Concentrations of p,p -DDE have been linked to eggshell thinning in raptors and other birds (Bitman et al. 1969, Wiemeyer and Porter 1970). Shells of eggs from the LCR were thin and shell thickness at older sites had not improved since the mid-1980s. Similar to findings in other field studies (Frenzel 1984, Elliott et al. 1996b), eggshell thinning was not correlated to p,p -DDE concentrations or productivity. Mean eggshell thinning (-11%) for LCR eagles were below values (>15-20%) considered severe and associated with population declines, although Wiemeyer et al. (1993) reported that mean production increased in other eagle populations when shell thinning was less than 10% (Table 9). Eggshells from five territories along the river were >15 percent thinner than the pre-DDT average, and productivity at four of these territories ranged from 0 to 1.00 young/occupied territory. Eggshell thinning may impact some individual pairs of LCR eagles, although thinning alone would not likely be impacting the population. One broken egg collected from a nest site during incubation exhibited p,p -DDE values similar to the lipid weight concentrations in other thin-shelled eggs collected along the river, and the eggshell was 14% thinner than the pre-DDT average. The eggshell exhibited moderate to severe eggshell thinning and could have broken during incubation as a result of DDE contamination.

Other contaminants such as heavy metals can impact bald eagle productivity (Wiemeyer et al. 1993). Mercury concentrations in eggs collected in 1994 did not change from concentrations found in eagle eggs collected along the river from 1985 to 1987 (Anthony et al. 1993). The highest concentration of mercury in eggs collected by Anthony et al. (1993) and during the present study did not exceed concentrations associated with adverse effects on bald eagle production (Table 9; Wiemeyer et al. 1984). Anthony et al. (1993) also found lead and cadmium in eggs collected from 1985 to 1987, but concentrations were below levels considered to cause deleterious effects to the population.

Currently, no controlled laboratory studies have evaluated the dose-response relationship of dioxin-like chemicals in bald eagle eggs. However, a variety of responses to TCDD in other avian species have been observed in both laboratory and field studies (Kubiak et al. 1989; Nosek et al. 1992; Powell et al. 1996, 1997; Henshel et al. 1997; Henshel 1998). In experimental studies, chicken embryos exhibited mortality, edema, and teratogenic effects with egg injections of TCDD as little as 10 pg/g (Verrett 1970), yet field studies on great blue heron reported normal reproduction when mean TCDD in eggs were 92 pg/g (Elliott et al. 1988). TCDD in LCR eagles was well above values associated with effects in chickens, but below values impacting great blue herons (Table 9). Similar to other studies (Elliott et al. 1996a), TCDD was not correlated to mean five-year productivity of LCR eagles and did not appear to be the sole contaminant limiting eagle reproduction.

TEQs in LCR eggs were elevated above reference or threshold values estimated for bald eagles or other avian species (Table 9). In wood ducks (*Aix sponsa*) studied near a dioxin- and furan-contaminated site, White and Seginak (1994) found impaired nesting and hatching success and reduced duckling production when geometric mean TEQs (excluding planar PCBs) were >20 to 50 pg/g. TCDD contributed 70 percent of the dioxin-like toxicity towards the M-TEQs in the wood duck study, which was somewhat higher than the contribution (55%) from TCDD in eagle eggs from the LCR. Based on numerous field and laboratory studies, Giesy et al. (1995) estimated a no- or lowest-observable adverse effect level (NOAEL/LOAEL) for TEQs in bald eagle eggs of 7 pg/g. Hoffman et al. (1998) estimated a NOAEL of 65 pg/g for TEQs in eagle eggs, based on kestrel (*Falco sparverius*) eggs dosed with PCB 126. Elliott et al. (1996a) estimated a no-observable effect level (NOEL) of 100 pg/g and a low-observable-effect-level (LOEL) of 210 pg/g for TEQs (including planar PCBs) based on bald eagle eggs collected near pulp mill sites and a reference site, and hatched under experimental conditions. The mean M-TEQ (excluding planar PCBs) in LCR eagle eggs was nearly three times higher than found in five reference bald eagle eggs collected off the coast of British Columbia (Elliott et al. 1996a) and was within the range associated with reproductive impacts to wood ducks. LCR egg TEQs (including planar PCBs) exceeded all estimated NOELs, and exceeded the LOEL concentration of 210 pg/g when contributions of the mono-ortho PCBs were included in the TEQ calculation (Table 9; Elliott et al. 1996a).

Data from this study showed that non-ortho and mono-ortho planar PCBs greatly contributed toward the total dioxin-like toxicity of the TEQ values in bald eagle eggs along the Columbia River. Non-ortho and mono-ortho PCBs were considered the primary contaminants associated with increased incubation period, reduced hatchability, lower body weight, increased liver to body weight ratio, and edema in Green Bay s Forster s terns (*Sterna fosteri*; Kubiak et al. 1989). Jarman et al. (1993) suspected p,p -DDE and non-ortho PCBs were the most important compounds adversely affecting reproduction in peregrine falcons in California. Total geometric mean concentration (4,100 pg/g, range=2,500 to 6,880 pg/g) of three non-ortho PCBs (PCB 77, 126, and 169) in LCR bald eagle eggs was slightly lower than the median total (5,500 pg/g wet weight) of these three congeners found in Forster s terns in Green Bay (Kubiak et al. 1989) and nearly double the geometric mean (2,070 pg/g) of these PCBs found in peregrine falcon eggs in California (Table 9; Jarman et al. 1993). In contrast, Elliott et al. (1996b) reported that the concentration of non- and mono-ortho PCBs were of lesser importance than PCDDs and PCDFs in bald eagle eggs collected near three-bleached-kraft pulp mills along the Pacific Coast of Canada, and were more important in samples outside the pulp-mill-influenced area.

Numerous studies have documented the importance of planar PCBs, especially PCB 126, in contributing total dioxin-like toxicity in TEQ calculations (Kubiak et al. 1989, Giesy et al. 1994, Hoffman et al. 1998). In eggs from the LCR, PCB 126 contributed the majority of dioxin-like activity towards calculations of all TEQ values (A-TEQ, M-TEQ, and H4IIE TEQ). PCB 126 accounted for 76 percent of the M-TEQ value including non-ortho PCBs, followed by TCDD

(12%). PCB 126 contributed 48 percent of the M-TEQ including the mono-ortho PCBs, and PCBs 118, 156, and 105 contributed 32 percent. PCBs 77 and 81 contributed 39 percent towards the A-TEQ non-ortho PCB calculation, but were not important influences on the other TEQ calculations. Mono-ortho PCBs contributed less than 8 percent towards the A-TEQ calculation. In the Great Lakes region, PCB congeners 126 and 105 accounted for more than 90 percent of the estimated TEQ eggs of Forster s from Green Bay (Kubiak et al. 1989). In California, PCB 126 accounted for 83 percent of the total TEQs in peregrine falcon eggs, although mono-ortho PCBs were not included in the analysis (Jarman et al. 1993). Similar to eggs collected from bald eagles and other avian species in the Great Lakes region (Geisy et al. 1994), TEQ values in LCR eagle eggs were highly influenced by the contribution of the non-ortho PCBs, primarily PCB 126.

TCDD-EQs derived from the H4IIE bioassay conducted on LCR eagle egg extracts were similar to the mean M-TEQ calculated including only dioxins and furans, and exceeded some estimated NOELs for TEQs (Table 9). However, the TCDD-EQs were well below all other mean TEQ values. Similarly, Thomas (1997) reported that total calculated TEQs were up to 24 times greater than H4IIE bioassay-derived TCDD-EQs in great blue heron eggs from the LCR. The H4IIE bioassay accounts for interactions of multiple planar halogenated hydrocarbons in egg extracts (Tillitt et al. 1991b), and antagonism among hydrocarbons could explain the lowered total dioxin-like potency of Columbia River eggs as measured by the bioassay.

Mean bioassay-derived TCDD-EQs from LCR eggs were well below the geometric mean (162.4 pg/g) for TCDD-EQs measured in eggs of bald eagles with poor productivity in Maine (Welch 1994) and were comparable to the less contaminated sites in the Great Lakes (Ankley et al. 1991; Tillitt et al. 1991b, 1992; Jones et al. 1993). In the Great Lakes, TCDD-EQs in bird eggs derived from the H4IIE bioassay were shown to be correlated to TEQ values determined by an additive model, and the additive model underestimated TCDD-EQs (Giesy et al. 1994). In LCR eggs, TCDD-EQs were not correlated to the H4IIE-TEQs calculated from TEF values. Additional information is needed on the biological significance of TCDD-EQs and adverse impacts to bald eagles before an adequate risk evaluation can be determined using the H4IIE bioassay.

Productivity of the bald eagle population nesting along the LCR has increased as a result of greater reproductive success of new nesting pairs. Between 1990 and 1996, 28 new pairs established breeding territories along the river, and recent five-year running productivity averages have improved due to the higher breeding success of eagle pairs at the new sites. In contrast, eagles at 23 older breeding territories produced about half the number of young as the eagles at newer sites, and reproductive success of eagles at the older territories has not improved in over ten years (Figure 3). Average productivity of LCR eagles, especially at the older sites, remains well below eagle productivity in other areas of Oregon and below values (one young per occupied nest) indicative of a healthy population (Sprunt et al. 1973).

Mean five-year productivity for LCR bald eagles was not inversely correlated to organochlorine pesticides, total PCBs, PCDDs, PCDFs, or TEQs in eggs. Productivity was positively correlated with dieldrin, but dieldrin was below concentrations considered to effect the species. Other investigations on bald eagles experiencing poor productivity and elevated egg contaminants in

Oregon, Maine, and along the Pacific Coast of Canada have found no correlations of these individual compounds in eggs to productivity (Frenzel 1984, Welch 1994, Elliott et al. 1996b, Elliott and Norstrom 1998). Investigations in the Great Lakes reported productivity was inversely related to various contaminants in bald eagle plasma and eggs (Best et al. 1994, Bowerman et al. 1995), although productivity was compared on a regional basis rather than from individual territories. Elliott et al. (1996a) found stronger correlations between biochemical and physiological endpoints and TCDD or TCDF concentrations as opposed to the TEQ values and suggested that use of the TEFs may overestimate contribution of PCBs to dioxin-like toxicity (Elliott et al. 1996a, Elliott and Norstrom 1998). Although no relationship between individual contaminant concentrations and productivity was demonstrated, many organochlorine contaminants exceeded NOELs and multiple chemicals could interact to contribute to the poor reproductive success observed in LCR bald eagles at older breeding territories.

Numerous factors influence bald eagle productivity and population numbers. In the Great Lakes region, bald eagle productivity was affected by habitat availability, degree of human disturbance to nesting pairs, and environmental contaminants (Bowerman et al. 1995). Bald eagles exhibiting declines in egg concentrations of DDE and PCBs along Lake Superior appeared most limited by food availability, as determined by videography of prey deliveries (Dykstra 1995). These same factors, along with weather conditions and competition, could impact eagle productivity along the LCR. Earlier studies reported that limited prey, weather conditions, and competition were not obvious influences on eagle productivity along the LCR (Watson et al. 1991), although human disturbance may influence foraging success of some eagle pairs (McGarigal et al. 1991). The recent increase in successful new eagle breeding territories located throughout the lower estuary also indicates that competition, habitat, and food availability are not limiting. Environmental contaminants, possibly combined with human disturbance, are the most prominent factors influencing productivity for the LCR eagles. DDE concentrations appear to have the greatest impact on reproductive success of older nesters, based on the similarities between the predictive weighted sigmoidal equation (Wiemeyer et al. 1984) and observed productivity. Dioxins, furans, and PCBs exceeded estimated NOELs and may be interacting to further impact reproductive success at older breeding territories.

Bald eagles nesting along the river are exposed to DDE, PCBs, dioxins and furans by consuming contaminated prey. Bald eagles at older breeding territories foraged on fish (predominantly largescale sucker (*Catostomus macrocheilus*), American shad (*Alosa sapidissima*), and carp, which accounted for 71 percent of prey remains found at nest sites and 90 percent of direct foraging observations (Watson et al. 1991). Birds (primarily mallards (*Anas platyrhynchos*), western grebes (*Aechmophorus occidentalis*), cormorants (*Phalacrocorax* spp.), and gulls (*Larus* spp.) comprised 26 percent of nest remains and 7 percent of direct observations (Watson et al. 1991). Accumulation of organochlorine compounds has been documented throughout the Columbia River food web in fish, eggs of fish-eating birds, and in mammals (Henny et al. 1981, 1984, 1996; Schmitt et al. 1985; Anthony et al. 1993; Thomas 1997; U.S. Fish and Wildlife Service unpubl. data). Home ranges of LCR bald eagles can be as large as 22 km^2, but most eagle activity occurs within 0.5 - 1 km of the nest site (Garrett et al. 1993) where contaminated prey is captured and consumed or delivered to nestlings (Anthony et al.1993). Concentrations of p,p -DDE, PCBs, PCDDs, and PCDFs were found in all samples of fish (including carp and sucker) and eggs of fish-eating birds (including cormorants and gulls) along the LCR (Anthony et al. 1993, U.S. Fish and Wildlife Service, unpubl. data). The highest concentrations of dioxin-like compounds were found in eggs of double-crested cormorants and Caspian terns (U.S. Fish and Wildlife Service, unpubl. data). Concentrations of p,p -DDE, PCBs, TCDD, and TCDF in two whole fish samples collected from nest sites in 1995 were similar to values obtained from carp and other fish species collected from the LCR in the early 1990s (Anthony et al. 1993, U.S. Fish and Wildlife Service, unpubl. data). In Lake Ontario, the estimated apparent biomagnification factors (BMFs) from fish prey (alewife; *Alosa pseudoharengus*) to herring gull (*Larus argentatus*) egg were 34 for p,p -DDE, 32 for total PCBs, and 21 for TCDD (Braune and Norstrom 1989). The high BMFs indicate that even small concentrations in fish prey can be biomagnified in to levels that could impair reproduction in top predators. Fish in the LCR continue to be a source of organochlorine contamination of LCR bald eagles, as these eagles predominately feed on fish during the breeding season (Watson et al. 1991).

TEQs (excluding planar PCBs), TCDF, 2,3,4,7,8-pentaCDF, and PCB 169 were correlated to nest location as river mile, with higher values observed in eggs from breeding territories near the mouth of the river. This indicates that exposure to dioxin-like compounds is less in new pairs established upriver from the older breeding territories. The new pairs may not have accumulated contaminants to the extent of older pairs along the LCR, and some pairs nesting in upriver locations (above river mile 60) may be foraging on prey with minimal contamination.

Dioxin-like compounds may be deposited and become more bioavailable in the lower reaches of the river. Some dioxin-like compounds, DDE, total PCBs, and other contaminants were sequestered in semi-permeable membrane devices (SPMDs) from Columbia River water in the lower and upper reaches of the estuary (McCarthy and Gale 1999). These chemicals were transferred down the river in the dissolved phase and in association with particulate matter (McCarthy and Gale 1999). Once in the flow lane of the river, fine materials and organic matter containing hydrophobic organochlorine contaminants could be transported to slow-moving shallow areas, tidal flats, or other depositional zones in the lower estuary. For example, particulate matter transported from upper reaches of the estuary will encounter a wider river and more large islands below river mile 40, and saline waters in the lower estuary near river mile 18 (the estuarine turbidity maximum or ETM). The ETM serves as a physical circulation trap for organic matter, where particle cohesion and flocculation will increase the settling rate of the particles when contacting the salt water, as been shown to occur in other estuaries (Meade 1972, May 1973). In depositional zones near the ETM, aquatic organisms could mobilize and accumulate contaminants adhered to the particulate matter, exposing predators of the organisms to greater concentrations along the food chain (Zuranko et al. 1997). Foraging patterns of eagles have been evaluated in the lower estuary reaches where tidal flats were more abundant, and eagles along the river with territories associated with the shallow bays consumed more waterfowl than other eagles (Watson et al. 1991). Fish-eating birds are usually a greater source of organochlorine compounds in eagle diets than fish (Frenzel 1984, Kozie and Anderson 1991). Colonies of fish-eating birds (gulls, terns, and cormorants) are predominately located in these lower reaches near older breeding territories, whereas shallow bays and fish-eating birds may be much less available to the new eagle pairs nesting in the upper reaches. Mean concentrations of organochlorine compounds were highest in eggs from nests in the lower estuary below river mile 60, where predominantly older breeding territories occur (Figures 4 and 5). Moreover, total productivity was lowest (0.42 young/occupied site) between river miles 13 to 31. Contaminant concentrations appeared higher in eggs from older breeding territories than from newly established breeding territories, but insufficient samples were obtained from newer breeding territories to make statistical comparisons.

New pairs nesting along the LCR exhibited greater productivity than pairs at older breeding territories. In contrast, productivity of newly-established pairs along the coastline in the Great Lakes region was significantly lower than productivity for older, experienced pairs breeding at less contaminated inland sites (Best et al. 1994). For the Great Lakes eagles, productivity gradually declined with age (Best et al. 1994). In the LCR, older territories have never achieved normal productivity levels, indicating poor reproduction is unrelated to the age of the mated pairs. In addition, increases in coastal breeding populations in the Great Lakes were attributed to immigration of young eagles from inland sites (Best et al. 1994). Similarly, newly-established pairs along the LCR likely originate from areas outside the river. Without immigration of new pairs, the low productivity at older breeding territories (0.50 to 0.60 young per occupied nest site) and survival of adult and immature eagles (30 to 87%; Grier 1980, Buehler et al. 1991) would likely preclude the population from doubling as fast as currently observed.

Sources of organochlorine pesticides and PCB contaminants in the Columbia River Basin are considered to result primarily from non-point source runoff. The use of large quantities of DDT in orchard crops in the Columbia Basin prior to 1974 (Terriere et al. 1966, Blus et al. 1987) and use of PCBs in electrical transformers, along road as dust suppressants, or spills at dam sites could have contributed to the p,p -DDE and PCB burdens found in Columbia River biota. Tributaries of the Columbia, such as the Willamette River, also contribute greatly to the contaminant loading (Rosetta and Borys 1996). In addition, Thomas (1997) found the highest concentrations of organochlorine contaminants in great blue heron eggs at a site in the Willamette River. Streambed sediment in the Willamette River contain DDT, PCBs, dioxins, and furans (Fuhrer 1989), and DDT and its metabolites have recently been detected in water in the Yakima River, which drains into the LCR (Rinella et al. 1992).

Dioxin and furan contamination in the river result from point and nonpoint sources. Nine pulp and paper mills are located along the Columbia River or tributaries, and release dioxins and furans into the river as a result of the chlorine bleaching process for wood pulp. Other sources of dioxins and furans could include wood treatment plants, municipal wastewater treatment plants, industrial sites, agricultural areas, and urban areas (U.S. Environmental Protection Agency 1991a). In Canada, elevated concentrations of TCDD, 1,2,3,7,8-pentaCDD, 1,2,3,6,7,8-hexaCDD, and TCDF in bald eagle plasma and eggs were attributed to pulp mill sources, and elevated 1,2,3,4,6,7,8- heptaCDD, OCDD and higher chlorinated PCDFs reflected sources from pulp mills using chlorophenol-treated wood chips for feedstock, and possibly from local combustion sources (Elliott et al. 1996b, 1996c; Elliott and Norstrom 1998). Similarly, the most elevated PCDDs and PCDFs in LCR eagle eggs were the 2,3,7,8-tetra and pentachlorinated dioxin and furan congeners, and one hexachlorinated dioxin. The dioxin and furan pattern in the LCR eggs were similar to the pattern in eggs from Canada indicative of pulp and paper mill sources. Reduction of PCDD and PCDFs in effluent by a pulp mill in Canada led to a corresponding decrease in the contaminant burden in eggs of great blue herons and improved embryo condition (Whitehead et al. 1992, Elliott et al. 1996c). Recently, pulp mills along the Columbia River have changed from elemental chlorine to chlorine dioxide in the bleaching process. It remains to be seen whether or not Columbia River biota will exhibit corresponding decreases in PCDD and PCDF burdens as a result of the change in bleaching process.

In summary, concentrations of p,p -DDE and total PCBs in eggs of LCR bald eagles were shown to decline since the mid-1980s, and individual organochlorine contaminant concentrations were not correlated to mean five-year productivity. However, concentrations of DDE, total PCBs, and dioxin-like compounds still exceeded estimated NOAELs, reference concentrations, or concentrations associated with reduced productivity for bald eagles in other studies. Concentrations of p,p -DDE and PCBs were not correlated to nest location along the river, suggesting these compounds do not increase as one moves downriver. In contrast, some dioxin, furan, and TEQ concentrations were related to river mile, which may reflect releases of the contaminants from upriver discharges and deposition in specific areas (e.g, tidal flats) of the lower estuary. Dioxin, furan, and TEQ concentrations were highest at older breeding territories, which were located predominantly in the lower estuary below river mile 60. Productivity at new breeding territories was much higher than productivity at older breeding territories. This evidence suggests that pairs at older breeding territories are impacted by contaminants to a greater extent than pairs at newly-established sites. Although total number of bald eagles nesting along the river is increasing, continued foraging on contaminated prey from the LCR and subsequent bioaccumulation of p,p -DDE, PCBs, and dioxin-like contaminants could limit future productivity of some new pairs as these chemicals accumulate in the adult birds with age.

RECOMMENDATIONS

The Columbia River drains nearly 260,000 square miles and receives contaminants from numerous point and non-point sources, including regulated industrial and municipal discharges, runoff from timber-harvested and agricultural areas, and atmospheric deposition. DDT and its metabolites, PCBs, and dioxin-like contaminants have been detected at various locations in water and sediment along the river and in major tributaries such as the Willamette River (McCarthy and Gale 1999). Uptake and biomagnification of these contaminants have resulted in harmful concentrations in bald eagles and other top predators. Limiting entry of these contaminants into the Columbia River and its tributaries, along with removing or minimizing disturbance to contaminated sediments, would reduce the availability of contaminants to bald eagles and their prey.

A basin-wide strategy for controlling non-point source pollution for agricultural, forested, industrial, and urban areas, along with establishment and enforcement of Water Quality Management Plans to achieve TMDLs (Oregon Department of Environmental Quality 1997), would support efforts to reduce loading of organochlorine pesticides and PCBs into the river. Establishing controls such as buffer zones along riparian areas in agricultural and timber-harvested areas could also reduce organochlorine pesticide-associated soil or sediment particles from entering the Columbia River or its tributaries. Declines in some dioxin and furan concentrations in pulp and paper mill effluent may have occurred following adoption of the chlorine dioxide process in the 1990s, but no investigations have been conducted to evaluate corresponding changes in tissue concentrations of dioxins and furans in biota. Whitehead et al.(1992) and Elliott et al. (1996c) reported decreases in dioxins and furan egg concentrations in fish-eating birds and an increase in productivity of great blue herons within six months following process changes at a pulp and paper mill in Canada. Further reductions in dioxin and furan point-source discharges and identification of other sources of these chemicals may be warranted to reduce concentrations in the prey base of eagles to NOELs. In addition, TMDLs for compounds exhibiting dioxin-like activity other than TCDD should be established, and sources of dioxin-like compounds such as hazardous waste sites, wood-treating plants, and municipal facilities should be better quantified. In order to better assess the contribution of other planar compounds, guidelines for risk assessment using TEQs or similar additive approach should be used when addressing management issues. The contributions of other ongoing contaminant studies by USGS, including an osprey study and use of passive samplers (e.g., SPMDs), should help to better identify stretches of the river where contaminants are predominant and help focus efforts to economically reduce nonpoint source problems.

Natural events such as flooding, and anthropogenic activities such as dredging, ship passage, and other bottom-disturbing activities, could resuspend persistent chemicals from sediment and increase contaminant bioavailability to aquatic organisms. In Saginaw Bay, Ludwig et al. (1993) attributed reproductive problems and embryonic abnormalities in Caspian terns to release of contaminants from sediment following a 100-year flood. In laboratory studies, Seelye et al. (1982) demonstrated the potential for uptake of contaminants such as p,p -DDE and PCBs from disturbing dredge spoils. Areas within the main channels of the lower Columbia and Willamette Rivers are routinely maintained for navigational purposes by dredging, and private parties dredge and maintain connecting channels, ports, marinas, and other areas under a permitting process with the U.S. Army Corp of Engineers. The main navigation channels primarily consist of course-grained materials, yet areas around some docks, marinas, and ports have deposits of fine-grained sediment containing contaminants which could be resuspended when disturbed. In addition, material dredged from these areas, and from Columbia River tributaries, can contain organochlorines and other contaminants. Current practices of disposing dredged material meeting inwater disposal guidelines from contaminated areas into the flow lane of the LCR increases the risk of exposure in aquatic organisms and enhances the potential for bioaccumulation in higher animals such as river otter and bald eagles. Information is needed regarding the contribution of natural flood-events or dredging and disposal activities toward total availability of contaminants to fish and wildlife within the lower Columbia and Willamette Rivers.

RESEARCH IMPLICATIONS

Bald eagles have been ideal indicators to represent biomagnification of organochlorine compounds, and have been studied in numerous aquatic systems. Bald eagles along the LCR serve as indicators for detecting changes in contaminants over time, and for evaluating contaminant exposure and toxic impacts in fish-eating birds and mammals. Collections of bald eagle eggs for contaminant analysis should occur at periodic intervals to determine if PCBs and DDE continue to decline along the river, to determine if recent changes in the bleaching process by pulp and paper mills will result in declines of dioxins and furan in eagle eggs, and to gather more information regarding toxicity from mixtures of organochlorine pesticides and dioxin-like compounds.

New eagle pairs continue to establish breeding territories along the river; currently, there are over 70 occupied territories. New eagle breeding territories have been established in both the lower part of the estuary near older sites, and in the upper part of the estuary (a little above Bonneville Dam) where no eagles have nested previously. Pairs at newer sites currently experience greater reproductive success than pairs at the older sites, and could be foraging on less contaminated prey. Older pairs may have had more time along the river to accumulate a greater body burden of organochlorines than the newer pairs. It remains to be seen if the new pairs established near traditional nesting pairs and in the upper reaches will increase their body burden of contaminants over time and experience reproductive problems in the future. Productivity and egg contaminant concentrations should continue to be monitored in these eagles, and results between old and new breeding territories should be compared. Foraging patterns should be evaluated and compared between old and new breeding territories. These evaluations could be completed using video monitoring at breeding territories and comparing prey delivery, parental incubating behavior, human disturbance, hatching success, and other potential factors influencing productivity between old and new breeding territories.

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APPENDICES

Appendix 1. Percent lipid and polychlorinated dibenzo-*p*-dioxin and furan concentrations (pg/g fresh weight) in individual egg samples from bald eagles nesting along the lower Columbia River in 1994 and 1995.

		Chlorinated Dibenzo-*p*-dioxins								Chlorinated Dibenzofurans									
Sample Number	% Lipid	2,3,7,8-tetra	1,2,3,7,8-penta	1,2,4,7,8-penta	1,2,3,4,7,8-hexa	1,2,3,6,7,8-hexa	1,2,3,7,8,9-hexa	1,2,3,4,6,7,8-hepta	Octa	2,3,7,8-tetra	1,2,3,7,8-penta	2,3,4,7,8-penta	1,2,3,4,7,8-hexa	1,2,3,6,7,8-hexa	1,2,3,7,8,9-hexa	2,3,4,6,7,8-hexa	1,2,3,4,6,7,8-hepta	1,2,3,4,7,8,9-hepta	Octa
1994 SAMPLES																			
CRTIBE02	4.2	24	8.7	<0.2	<0.7	4.4	<0.4	2.0	11	9.3	0.7	4.2	<0.6	0.9	<0.2	2.0	2.4	<0.5	3.0
CRJCBE03	5.5	30	11	<0.2	0.9	6.1	0.6	0.9	11	40	2.0	6.1	0.9	0.9	<0.2	2.9	3.3	0.9	3.6
CRGPBE04	4.4	22	9.9	<0.2	0.7	5.7	<0.4	<0.7	3.3	31	0.9	4.7	0.6	0.6	<0.2	0.9	0.9	<0.3	0.9
CRFCBE05	6.8	38	21	<0.2	0.9	11	0.6	0.8	11	31	0.9	8.1	0.9	2.0	<0.2	2.0	2.9	2.0	2.5
CRFIBE06	1.9	24	9.7	<0.2	0.9	6.9	<0.5	<2.0	3.8	6.9	0.5	3.7	<0.4	<0.6	<0.2	1.0	2.0	<0.4	2.0
CRWABE07	4.7	31	13	0.2	0.9	11	0.9	2.0	9.8	13	0.8	6.5	0.6	0.9	<0.2	2.0	2.0	0.4	2.0
CRWABE07	4.7	30	13	<0.2	0.9	12	0.9	2.0	8.9	13	0.7	6.2	0.7	0.9	<0.2	2.1	2.5	0.7	2.1
CRRIBE08	7.2	20	14	<0.2	2.4	13	2.0	3.1	16	16	2.0	5.8	0.8	0.8	<0.2	1.0	2.0	0.4	2.7
CRCIBE09	4.4	26	10	<0.2	<0.8	5.5	<0.5	0.9	15	17	0.9	5.2	0.5	0.8	<0.2	2.1	2.7	0.7	2.7
CRCPBE10[a]	4.5	28	13	<0.5	0.9	7.2	<0.5	0.9	14	31	0.9	7.6	0.9	0.9	<0.2	2.0	2.7	<0.8	2.3
CRCPBE10[a]	4.5	29	13	<0.2	0.9	7.2	<0.8	0.9	13	30	0.9	7.6	0.8	0.9	<0.2	2.6	2.5	0.9	2.3
CRBSBE11	4.0	37	14	<0.2	2.0	8.4	0.6	2.0	11	16	2.0	7.1	2.0	2.1	<0.2	4.9	6.5	2.1	5.9
CRBEGP12	4.6	21	9.5	<0.2	0.9	6.2	0.4	0.8	5.5	28	0.9	4.6	0.5	0.5	<0.2	0.9	0.9	0.4	2.0
CRBEGP13	5.6	28	11	0.3	0.9	7.7	<0.5	0.9	7.1	35	0.9	5.7	0.5	0.7	<0.2	0.9	0.9	0.5	2.0
CRWIBE14	4.9	23	9.9	<0.2	0.8	6.0	0.3	0.8	5.8	22	0.8	5.5	<0.6	0.7	<0.2	0.8	2.0	<0.5	2.0
CRWIBE15	5.1	21	9.4	<0.2	0.9	6.0	<0.3	0.8	7.6	21	0.9	4.9	<0.5	0.8	<0.2	2.0	2.2	<0.9	2.3
1995 SAMPLES																			
CRMSBE16	3.8	25.5	15.3		2.0	13.6	1.0	1.9	9.4	30.6	2.9	11.1	3.2	3.2	<0.3	3.0	<4.0	2.5	7.7
CRWOBE17	5.8	21.1	9.7		1.1	8.8	0.4	0.9	31.7	29.9	1.6	5.5	0.9	1.6	0.2	1.9	<3.0	1.1	5.5
CRJCBE18	6.2	14.3	6.0		0.7	4.6	0.3	0.9	44.9	21.1	1.2	4.6	0.6	1.8	<0.1	2.6	4.1	1.5	4.0
CRRPBE19	5.8	19.4	11.4		1.8	10.6	0.7	2.0	83.6	52.8	2.6	8.8	1.0	1.7	0.1	1.8	<3.0	1.1	4.8
CRMFBE20	7.0	17.5	11.5		4.0	18.9	1.7	6.0	21.6	12.9	1.8	5.5	1.7	3.5	0.1	3.9	7.8	1.7	12.9
CRLIBE21[a]	3.0	10.1	5.5		1.5	7.3	0.6	3.3	9.2	17.5	1.2	4.0	0.6	1.6	<0.2	1.7	2.9	0.7	4.6
CRLIBE21[a]	3.0	10.1	5.3		1.3	7.3	0.6	3.1	8.9	16.6	1.0	4.0	0.6	0.9	<0.1	1.7	2.8	0.8	4.2
CRLIBE21[a]	3.0	10.1	5.2		1.2	7.3	0.6	3.0	8.7	18.4	1.0	4.0	0.7	1.1	<0.2	1.4	2.6	<0.6	3.8
CRMCBE22	5.4	16.2	7.4		1.4	10.2	0.7	2.0	43.4	22.1	1.6	5.7	0.9	1.4	<0.1	1.8	<3.0	1.1	5.0
CRMABE23	4.5	16.4	7.4		1.1	8.0	0.5	3.0	77.1	16.4	1.1	4.7	0.8	1.7	0.1	1.6	<3.0	1.0	3.5
CRCPBE24[a]	4.8	21.6	15.0		2.0	16.0	0.8	1.6	52.6	28.2	1.8	10.3	1.2	2.6	<0.2	2.0	<3.0	2.0	4.1
CRCPBE24[a]	4.8	20.7	16.0		1.9	16.0	0.8	1.5	48.9	30.1	2.0	10.3	1.1	2.3	<0.2	2.0	<3.0	1.6	4.0
CRCPBE24[a]	4.8	20.7	16.0		1.9	15.0	0.8	1.5	50.8	29.1	1.9	10.3	1.2	2.4	<0.2	1.9	2.5	1.8	3.7
CRKLBE25	5.7	20.9	10.5		1.6	12.4	1.0	2.6	73.2	28.5	1.7	6.6	1.0	1.9	0.2	1.7	<3.0	1.0	3.4
CRFCBE26	6.0	34.4	20.8		1.6	16.0	1.0	<1.0	33.6	37.6	2.6	12.0	1.3	2.9	<0.1	1.7	<3.0	1.4	3.3

[a] Samples with the same number are laboratory replicates.

Appendix 2. Non-ortho-chlorinated biphenyl congeners (pg/g fresh weight) in individual egg samples from bald eagles nesting along the lower Columbia River in 1994 and 1995.

	Non-ortho-chlorinated biphenyls[a]			
Sample Number	3,4,4',5-Tetra (PCB 81)	3,3',4,4'-Tetra (PCB 77	3,3',4,4',5-Penta (PCB 126)	3,3',4,4',5,5'-Hexa (PCB 169)
1994 Samples				
CRTIBE02	355	2,120	1,220	110
CRJCBE03	380	3,090	1,620	135
CRGPE04	235	2,600	920	235
CRFCBE05	370	3,310	2,620	325
CRFIBE06	335	2,040	1,230	84.5
CRWABE07[b]	375	2,060	1,670	165
CRWABE07[b]	365	2,220	1,880	160
CRRIBE08	445	3,810	1,430	100
CRCIBE09	330	2,290	1,510	115
CRCPBE10[b]	300	2,230	1,790	155
CRCPBE10[b]	315	2,370	1,780	160
CRBSBE11	490	3,210	2,170	170
CRBEGP12	230	2,510	1,090	230
CRBEGP13	295	3,180	1,310	290
CRWIBE14	300	2,380	1,380	120
CRWIBE15	310	2,320	1,410	110
1995 Samples				
CRMSBE16	466	3,300	1,540	164
CRWOBE17	345	2,870	1,070	97.0
CRJCBE18	239	1,680	964	94.7
CRRPBE19	345	3,060	1,190	113
CRMFBE20	491	3,170	1,490	123
CRLIBE21[b]	215	1,750	618	50.4
CRLIBE21[b]	206	1,820	622	48.7
CRLIBE21[b]	222	1,890	639	49.5
CRMCBE22	219	2,020	843	72.2
CRMABE23	317	2,180	1,060	94.4
CRCPBE24[b]	291	2,570	1,780	256
CRCPBE24[b]	307	2,620	1,780	254
CRCPBE24[b]	309	2,480	1,700	255
CRKLBE25	329	2,230	1,580	191
CRFCBE26	463	3,780	2,820	380

[a] International Union of Pure and Applied Chemists congener number (Ballschmiter and Zell 1980) in parenthesis.
[b] Samples with the same number are laboratory replicates.

Appendix 3. Mono-ortho-chlorinated biphenyl congeners (ng/g fresh weight) in individual egg samples from bald eagles nesting along the lower Columbia River in 1994.

	Mono-ortho-chlorinated biphenyls[a]							
Sample Number	2',3,4,4',5-Penta (PCB 123)	'2,3',4,4',5-Penta (PCB 118)	2,3,4,4',5-Penta (PCB 114)	2,3,3',4,4'-Penta (PCB 105)	2,3',4,4',5,5'-Hexa (PCB 167)	'2,3,3',4,4',5-Hexa (PCB 156)	'2,3,3',4,4',5-Hexa (PCB 157)	2,3,3',4,4',5,5'-Hepta (PCB 189)
CRTIBE02	7.09	420	8.62	122	44.1	51.8	14.9	5.58
CRJCBE03	< 0.2	450	11.2	131	66.2	72.8	15.8	7.44
CRGPBE04	3.27	326	8.23	95.7	29.9	37.9	11.0	3.79
CRFCBE05	13.1	859	14.1	230	135	146	38.1	16.2
CRFIBE06	7.08	523	12.6	140	47.3	61.6	17.2	5.82
CRWABE07	9.63	529	11.5	158	69.4	82.5	22.4	7.94
CRWABE07	10.3	567	12.2	161	77.5	85.5	15.5	8.29
CRRIBE08	7.80	555	14.6	187	44.8	61.2	17.5	5.66
CRCIBE09	9.10	479	13.3	137	62.9	69.5	20.1	7.10
CRCPBE10	9.77	507	14.3	150	73.2	78.4	22.5	7.88
CRCPBE10	12.2	617	18.2	186	89.2	97.2	26.7	9.91
CRBSBE11	8.95	629	13.9	186	89.1	97.0	27.8	10.4
CRBEGP12	4.69	320	8.22	83.0	28.0	33.9	11.8	3.50
CRBEGP13	5.59	389	6.33	109	34.8	41.6	11.9	4.24
CRWIBE14	5.79	420	8.37	116	55.4	62.5	16.8	6.87
CRWIBE15	7.30	443	7.45	118	58.2	61.9	18.2	6.19

[a] International Union of Pure and Applied Chemists congener number (Ballschmiter and Zell 1980) in parenthesis.
[b] Samples with the same number are laboratory replicates.

Appendix 4. Polychlorinated biphenyl congeners (ng/g fresh weight), including select mon-ortho-chlorinated biphenyls, in individual egg samples from bald eagles nesting along the lower Columbia River in 1994.

IUPAC[a] Congener no.	CRTIBE02	CRJCBE 03	CRGPB E04	CRFCB E05	CRFIBE06	CRWA BE07[b]	CRWA BE07[b]	CRRIBE 08	CRCIBE 09	CRCPB E10[b]	CRCPB E10[b]	CRBSBE 11	CRBEG P12	CRBEG P13	CRWIB E14	CRWIB E15
004, 010	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	17.9	14.8	< 0.1	< 0.1	26.8
007, 009	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
006	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
005, 008	< 0.1	< 0.3	< 0.1	< 0.1	< 0.3	< 0.1	< 0.3	0.5	0.5	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
019	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
018	0.4	< 0.3	< 0.3	< 0.1	0.4	0.4	< 0.3	1.1	0.8	< 0.1	< 0.3	< 0.3	< 0.1	< 0.1	0.4	< 0.1
017, 015	0.9	0.7	0.4	< 0.3	1.8	1.1	0.8	2.3	1.8	< 0.3	0.4	0.8	< 0.3	0.7	0.9	< 0.3
024, 027	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
016, 032	1.1	1.2	0.5	0.5	1.7	1.3	1.1	2.8	1.9	0.4	0.7	1.1	0.4	< 0.1	1.0	0.3
029	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
026	3.5	3.6	2.8	4.3	3.5	4.3	3.9	6.1	4.3	2.7	3.3	4.4	2.8	3.2	3.3	2.7
025	1.1	1.4	1.3	1.2	1.0	1.3	1.0	1.9	1.1	1.1	1.3	1.3	1.1	1.6	1.0	0.8
031	2.6	2.2	1.2	2.4	2.1	2.6	2.5	3.7	2.6	1.2	1.4	2.1	1.1	1.6	1.8	1.6
028	11.1	13.1	9.3	12.5	12.2	12.0	10.7	16.6	11.1	9.0	10.2	16.9	10.5	12.7	11.2	9.8
020,033,053	0.9	0.8	0.5	0.7	1.0	1.0	0.8	2.0	1.8	0.3	0.5	0.8	0.4	0.7	0.8	0.6
051	0.6	0.5	< 0.3	< 0.3	0.9	0.6	0.4	1.6	0.7	< 0.3	< 0.3	0.6	< 0.3	0.5	0.5	< 0.3
022	0.7	0.7	< 0.3	0.4	0.6	0.6	0.5	1.5	1.1	< 0.3	0.4	0.6	< 0.3	0.5	0.7	0.3
045	0.4	0.6	1.1	3.7	0.8	0.4	0.5	1.4	0.8	< 0.1	< 0.1	0.7	< 0.3	0.6	0.6	< 0.3
046	< 0.1	0.4	1.8	3.8	< 0.1	0.4	< 0.3	0.4	1.3	< 0.1	< 0.1	1.4	1.6	0.5	< 0.1	1.3
052	24.0	32.1	22.5	29.0	24.7	19.9	19.1	43.1	24.1	18.6	24.0	26.3	23.5	31.5	21.0	18.6
049,043	42.8	49.6	25.1	41.3	49.0	43.9	38.1	74.5	49.0	25.5	31.5	57.6	29.1	39.0	41.1	35.5
047,048	54.6	69.0	55.2	65.0	68.2	64.6	59.9	101	60.1	44.2	54.1	89.6	59.0	77.6	56.0	53.2
044	9.3	9.1	4.8	6.6	9.0	7.6	5.5	18.6	9.7	6.5	4.5	10.2	6.4	0.6	5.5	8.2
042	10.7	9.5	4.8	4.8	11.4	10.1	7.4	21.0	10.9	3.7	4.7	11.9	4.8	5.2	6.2	6.8
041	7.3	5.8	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	5.3	8.9	< 0.1	6.0	7.8	0.7	< 0.1	4.2
064	14.4	15.1	7.3	12.8	15.2	14.1	12.3	21.8	15.6	8.2	10.3	16.7	7.2	9.4	11.1	10.2
040	1.3	1.5	0.8	1.4	1.7	1.4	1.1	3.2	1.3	0.6	0.8	1.3	1.6	2.2	2.6	1.2

IUPAC[a] Congener no.	CRTIBE02	CRJCBE03	CRGPBE04	CRFCBE05	CRFIBE06	CRWABE07[b]	CRWABE07[b]	CRRIBE08	CRCIBE09	CRCPBE10[b]	CRCPBE10[b]	CRBSBE11	CRBEGP12	CRBEGP13	CRWIBE14	CRWIBE15
067	4.9	6.8	3.2	5.6	4.9	5.1	5.8	4.8	5.9	4.9	4.2	8.3	2.9	5.2	4.5	3.3
063	6.4	5.3	3.8	4.3	4.3	8.3	3.9	12.3	7.1	3.5	5.1	9.6	3.3	4.6	5.5	4.3
074	6.7	9.4	8.1	17.4	7.0	9.5	7.7	19.1	8.2	7.0	8.1	26.7	8.4	11.1	8.3	9.9
070,076	10.0	13.1	6.8	12.3	13.8	10.2	7.2	27.2	9.7	4.9	7.5	23.8	4.7	8.5	7.9	9.2
066,095,088	49.0	54.3	35.5	60.8	54.9	54.5	46.2	91.3	50.2	32.9	41.1	92.6	35.3	47.9	43.3	44.0
091	33.5	32.5	19.4	35.3	33.0	33.7	29.6	42.4	31.3	19.6	24.7	40.6	16.6	26.4	29.7	24.5
056,060	1.4	1.7	1.3	1.8	1.2	2.1	1.2	6.0	1.7	0.8	1.2	4.5	0.6	1.4	1.5	1.1
092	21.8	35.0	10.7	17.3	26.2	32.1	20.3	104	18.1	11.6	13.7	28.9	12.6	12.6	21.5	18.8
084	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
101,090	181	182	104	222	190	205	173	267	204	129	157	243	115	155	169	158
099	166	165	150	277	160	199	158	236	173	154	174	244	172	216	171	164
119	11.4	17.3	7.9	22.7	13.4	14.8	14.8	22.1	16.9	14.5	17.2	21.7	10.5	8.6	16.5	8.6
083	7.9	10.1	< 0.1	5.3	5.6	< 0.1	< 0.1	16.5	5.2	< 0.1	< 0.1	9.3	2.1	4.3	7.1	3.8
097	27.6	19.7	12.6	13.6	29.5	27.3	21.9	45.2	23.1	10.5	11.9	34.0	12.6	18.6	26.8	23.7
087	64.9	66.4	32.1	67.7	69.3	67.4	63.7	94.5	68.2	40.5	46.3	91.6	32.2	43.0	53.6	52.1
136	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
110	59.5	79.6	43.1	88.1	55.7	73.8	75.0	117	78.9	59.6	62.9	91.4	51.4	56.0	49.6	72.4
082	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	31.8	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
151	46.4	38.4	25.3	31.5	51.4	41.8	36.6	65.5	36.9	19.6	24.4	47.2	27.6	35.6	37.5	37.8
135,144,124	31.8	33.3	18.0	38.8	30.1	37.6	32.6	44.8	24.3	21.1	26.1	38.4	17.5	24.6	29.7	28.2
107	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	8.5	2.9	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
123,149	179	185	104	204	205	219	201	236	207	131	153	251	114	148	177	170
118	< 0.1	8.6	2.6	7.6	7.1	8.4	7.4	6.9	7.2	5.7	6.4	8.2	4.2	3.9	5.6	5.9
134	0.8	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
146	131	158	91.8	252	131	166	150	124	143	133	152	203	101	126	137	139
153	470	605	333	968	434	606	552	443	510	467	555	744	352	457	500	481
132	71.4	52.8	43.8	136	162	71.4	97.8	102	110	75.1	54.2	84.4	90.2	53.1	79.0	131
105	5.4	< 0.1	5.0	8.8	17.4	4.6	12.4	7.0	12.7	7.4	6.5	14.0	10.1	< 0.1	1.0	12.3
141	66.2	67.2	27.6	88.8	65.8	86.2	75.8	73.5	72.9	51.5	66.3	93.3	28.6	38.3	65.3	61.1
179	2.9	5.4	1.7	< 0.1	12.4	2.0	2.6	6.1	0.9	< 0.1	< 0.1	4.5	2.5	1.3	3.3	4.9

IUPAC[a] Congener no.	CRTIBE02	CRJCBE 03	CRGPB E04	CRFCB E05	CRFIBE06	CRWA BE07[b]	CRWA BE07[b]	CRRIBE 08	CRCIBE 09	CRCPB E10[b]	CRCPB E10[b]	CRBSBE 11	CRBEG P12	CRBEG P13	CRWIB E14	CRWIB E15
137	39.5	48.1	26.5	74.2	39.6	52.7	46.6	44.4	43.3	37.6	44.5	62.2	27.0	37.5	42.1	40.5
176	9.0	< 0.1	< 0.1	< 0.1	< 0.1	8.0	5.5	7.6	8.4	< 0.1	< 0.1	119	< 0.1	< 0.1	< 0.1	< 0.1
130	43.8	61.1	31.0	82.1	44.1	56.5	49.6	45.2	51.9	44.3	52.3	< 0.1	28.7	38.4	48.3	46.4
138	542	670	377	1,07	547	714	669	576	617	553	644	870	419	514	573	570
158	57.0	82.8	32.0	133	73.4	83.5	85.3	51.7	75.9	73.8	76.2	103	30.5	43.7	63.2	72.2
129	11.2	9.0	4.6	5.5	12.9	10.9	10.2	18.2	10.2	5.4	5.6	12.2	4.4	5.2	10.8	9.4
178	47.3	58.9	34.3	94.4	45.9	62.4	57.5	43.7	54.6	47.7	55.6	67.6	30.7	38.7	49.9	50.1
182,187	311	397	189	665	311	412	392	269	355	344	385	509	204	259	349	361
183	132	189	75.2	318	117	177	166	115	161	152	171	236	88.3	113	148	147
128	124	157	85.9	255	129	159	144	140	145	133	140	206	91.9	121	132	126
167	2.3	7.9	< 0.1	5.8	4.5	< 0.1	< 0.1	3.2	5.0	2.5	< 0.1	4.8	3.2	3.6	4.4	6.4
185	5.9	5.6	2.7	7.8	7.1	7.5	5.9	8.0	6.2	4.1	4.7	8.5	2.7	3.9	6.4	5.9
174	49.7	41.9	22.1	48.2	55.5	54.6	49.7	58.3	48.5	31.3	34.6	62.0	23.5	28.5	44.7	43.6
177	88.8	120	48.9	171	91.4	119	114	84.9	110	91.3	105	156	52.7	66.8	97.5	101
202,171,156	81.1	109	48.7	173	84.2	108	102	79.0	93.8	86.0	99.9	140	48.7	65.9	88.0	90.9
157,201	16.5	16.3	8.7	26.6	12.7	18.8	15.2	17.4	16.0	11.6	14.5	22.3	8.3	10.4	15.4	13.7
172	25.5	39.3	14.1	63.8	20.6	38.4	35.5	21.7	33.5	31.1	36.2	50.2	15.1	19.0	31.4	31.5
180	566	779	339	1,145	591	751	719	508	706	586	672	959	360	453.4	639	639
193	25.9	33.6	15.2	60.7	22.9	36.0	30.9	21.2	30.5	27.3	33.3	43.1	16.7	22.3	29.4	28.7
191	15.6	25.5	8.2	42.8	21.7	21.1	20.7	15.9	22.0	19.8	20.3	25.6	12.2	12.2	18.8	23.4
200	1.8	7.4	< 0.1	10.7	1.8	< 0.1	< 0.1	2.1	7.8	< 0.1	< 0.1	0.9	0.7	4.5	7.7	1.5
170,190	133	202	85.7	320	148	202	191	131	176	164	188	263	95.8	113	164	168
199	60.5	94.3	32.3	135	67.0	81.6	78.0	60.7	84.3	71.1	78.7	117	39.4	43.2	71.2	80.3
196,203	58.5	79.1	35.9	135	58.4	75.6	69.8	59.2	71.8	63.7	72.9	104	40.0	48.2	65.4	67.4
208,195	17.6	20.3	11.7	35.2	18.2	21.6	19.8	19.6	19.5	16.5	19.5	29.7	12.5	15.4	18.5	18.5
194	53.3	86.5	29.8	137	52.4	71.5	69.6	50.1	72.5	64.7	72.7	107	33.4	39.4	64.6	68.0

[A] International Union of Pure and Applied Chemists congener number (Ballschmiter and Zell 1980). Congener numbers separated by commas co-eluted on the gas chromatograph and were not distinguished.

[a] Samples with the same number are laboratory replicates.

Appendix 5. Total polychlorinated biphenyls (PCBs), organochlorine pesticides, total mercury, and total polybrominated diphenyl ethers (PBrDE) concentrations (ng/g fresh weight) in individual egg samples from bald eagles nesting along the lower Columbia River in 1994 and 1995.

Sample Number	Total PCBs	p,p'-DDT	p,p'-DDE	p,p'-DDD	o,p'-DDT	o,p'-DDE	o,p'-DDD	dieldrin	endrin	HCB[a]	alpha-BHC[b]	beta-BHC	lindane (gamma-BHC)	delta -BHC
1994 samples														
CRMFBE01[c]	21,000	<20	24,000	1,300	<20	<20	21.0	140	<20	50.0	<20	<20	<20	
CRTIBE02	4,660	33.6	6,058	429	<20	<20	<20	43.8	<20	21.4	<20	<20	<20	
CRJCBE03	7,604	57.5	8,346	482	<20	<20	<20	41.7	<20	30.6	<20	<20	<20	
CRGPBE04	3,615	33.4	5,964	298	<20	<20	<20	28.9	<20	28.0	<20	<20	<20	
CRFCBE05	11,716	51.4	12,618	595	<20	<20	<20	61.3	21.6	35.1	<20	26.1	<20	
CRFIBE06	5,819	22.0	6,436	414	<20	<20	<20	39.7	<20	19.4	<20	<20	<20	
CRWABE07	6,343	25.0	7,415	402	<20	<20	<20	59.0	<20	25.9	<20	<20	<20	
CRRIBE08	5,063	17.1	4,736	498	<20	<20	<20	69.4	<20	19.6	<20	<20	<20	
CRCIBE09	3,931	20.1	3,474	219	<20	<20	<20	19.2	<20	<20	<20	<20	<20	
CRCPBE10	5,492	27.5	7,102	388	<20	<20	<20	34.1	<20	26.5	<20	<20	<20	
CRBSBE11	7,780	18.1	7,599	398	<20	<20	<20	65.1	<20	20.8	<20	<20	<20	
CRBEGP12	3,098	<20	4,561	241	<20	<20	<20	35.3	<20	24.1	<20	<20	<20	
CRBEGP13	3,568	24.4	5,656	322	<20	<20	<20	38.3	<20	28.7	<20	17.4	<20	
CRWIBE14	6,575	18.9	6,657	386	<20	<20	<20	60.8	<20	24.7	<20	<20	<20	
CRWIBE15	5,112	16.2	5,452	298	<20	<20	<20	43.4	<20	19.6	<20	<20	<20	
1995 samples														
CRMSBE16	4,711	21.7	4,503	175	<0.06	0.65	< 0.06	51.5	1.17	9.71	< 0.06	8.75	< 0.06	< 0.06
CRWOBE17	3,684	14.0	4,553	169	<0.06	3.11	1.55	80.6	2.30	7.98	< 0.06	7.12	< 0.06	< 0.06
CRJCBE18	4,008	8.11	4,788	176	<0.06	1.86	2.58	36.3	1.66	5.91	< 0.06	6.59	< 0.06	< 0.06
CRRPBE19[d]	5,200	< 0.06	7,444	278	<0.06	3.19	5.52	52.3	2.74	11.6	< 0.14	9.81	< 0.06	< 0.06
CRRPBE19[d]	4,776	< 0.06	7,957	281	<0.06	1.50	5.46	52.0	2.65	11.2	< 0.14	10.4	< 0.06	< 0.06
CRRPBE19[d]	3,924	< 0.06	5,287	290	<0.06	1.28	2.07	43.6	2.22	8.47	< 0.06	10.2	< 0.06	< 0.06
CRMFBE20	5,493	< 0.06	6,457	202	<0.06	6.56	5.57	58.0	1.76	4.78	< 0.06	1.67	< 0.06	1.85
CRLIBE21	2,900	8.21	2,888	149	<0.06	0.60	3.01	33.5	0.57	4.57	< 0.06	2.67	< 0.06	< 0.06
CRMCBE22	3,472	10.8	3,911	169	<0.06	1.43	1.90	41.1	1.50	4.22	< 0.06	2.45	< 0.06	< 0.06
CRMABE23	3,711	11.2	3,136	141	<0.06	1.61	3.15	35.1	1.21	4.46	< 0.06	2.31	< 0.06	< 0.06
CRMABE23	3,245	7.99	3,697	141	<0.06	2.30	3.25	35.7	1.24	3.89	< 0.06	2.12	< 0.06	< 0.06
CRMABE23	3,377	10.1	3,275	142	<0.06	1.51	2.92	31.7	1.15	4.31	< 0.06	2.21	< 0.06	< 0.06
CRCPBE24	5,179	< 0.06	5,293	151	<0.06	0.76	1.50	31.3	1.16	5.91	< 0.14	29.4	< 0.06	< 0.06
CRKLBE25	5,466	12.9	6,410	244	<0.06	3.03	3.34	70.0	2.15	5.84	< 0.06	3.53	< 0.06	< 0.06
CRFCBE26	11,063	16.7	12,329	357	<0.06	3.11	5.94	66.7	3.34	15.2	< 0.06	42.5	< 0.06	< 0.06

Appendix 5. Continued.

Sample Number	hepta-chlor	heptachlor-epoxide	*cis*-nonachlor	*trans*-nonachlor	*trans*-chlordane	oxy-chlordane	*cis*-chlordane\ octa-chlordane[e]	alpha chlordane	gamma chlordane	mirex	toxaphene	meth-oxychlor	PCA[f]	dacthal	Total PBrDE	Total Hg
1994 samples																
CRMFBE01		<20		510		<10		76.0	28.0	<20	<90					171
CRTIBE02		<20		177		<20		14.0	<20	<20	<90					204
CRJCBE03		<20		185		<20		<20	<20	<20	<90					193
CRGPBE04		<20		136		26.2		<20	<20	<20	<90					270
CRFCBE05		16.2		243		37.0		<20	<20	<20	<90					292
CRFIBE06		<20		194		17.6		16.8	<20	<20	<90					204
CRWABE07		<20		205		22.3		<20	<20	<20	<90					230
CRRIBE08		<20		171		15.5		24.5	<20	<20	<90					172
CRCIBE09		<20		91		<20		<20	<20	<20	<90					261
CRCPBE10		<20		152		18.0		<20	<20	<20	<90					267
CRBSBE11		<20		154		19.9		<20	<20	<20	<90					167
CRBEGP12		<20		112		18.1		<20	<20	<20	<90					262
CRBEGP13		<20		148		16.5		15.7	<20	<20	<90					238
CRWIBE14		<20		173		14.8		22.2	<20	<20	<90					185
CRWIBE15		<20		145		<10		15.3	<20	<20	<90					178
1995 Samples																
CRMSBE16	< 0.13	13.0	41.4	97.8	1.69	11.2	125			6.55		< 0.06	0.47	< 0.05	1,159	
CRWOBE17	< 0.13	11.3	42.2	137	2.06	14.7	119			4.69		< 0.06	0.56	< 0.05	597	
CRJCBE18	< 0.13	9.71	31.0	91.1	1.55	9.53	112			5.06		< 0.06	1.06	< 0.05	665	
CRRPBE19[d]	< 0.13	17.3	48.2	123	2.62	17.3	160			5.40		< 0.06	0.96	< 0.05	886	
CRRPBE19[d]	< 0.13	15.0	44.2	109	2.34	13.3	151			4.84		< 0.06	0.78	< 0.05	891	
CRRPBE19[d]	< 0.13	12.6	41.8	90.2	1.98	13.5	116			4.13		< 0.06	0.72	< 0.05	858	
CRMFBE20	< 0.13	8.61	53.0	157	3.80	12.9	179			6.00		< 0.06	1.46	< 0.05	560	
CRLIBE21	< 0.13	7.10	34.1	90.4	2.25	11.6	107			3.58		< 0.06	0.62	< 0.05	446	
CRMCBE22	< 0.13	10.0	31.3	107	1.61	11.9	97.0			3.58		< 0.06	0.35	< 0.05	559	
CRMABE23	< 0.13	5.42	35.0	80.5	1.53	7.25	101			4.27		< 0.06	0.82	< 0.05	722	
CRMABE23	< 0.13	5.79	37.8	97.2	1.68	8.59	112			3.84		< 0.06	0.82	< 0.05	692	
CRMABE23	< 0.13	4.95	35.4	80.3	1.43	6.73	103			3.83		< 0.06	0.73	< 0.05	743	
CRCPBE24	< 0.13	10.8	40.6	86.5	1.19	10.1	91.0			6.72		< 0.06	0.35	< 0.05	677	
CRKLBE25	< 0.13	13.0	40.9	113	2.34	16.3	159			8.12		< 0.06	1.04	< 0.05	1,206	
CRFCBE26	< 0.13	28.8	103	233	1.72	25.0	293			17.9		< 0.06	0.65	< 0.05	1,179	

[a] Hexachlorobenzine.
[b] Benzene hexachloride or hexachlorocyclohexane..
[c] Concentrations in wet weight. Fresh weight was not estimated because egg was broken during incubation and some material loss occurred. The percent lipid =15.8 for this egg.
[d] Samples with the same number are laboratory replicates.
[e] The analytes *cis*- and octa-chlordane co-elute and are combined in a single value per sample.
[f] Pentachloroanisole. Bioaccumulative metabolite of the fungicide pentachloronitrobenzene.

Appendix 6. Correlation matrix (*r* value) for mean five-year productivity, nest location as river mile, and selected contaminants in 19 eggs from lower Columbia River bald eagles, 1994 to 1995.

	p,p -DDD	DLDN	HCB	TN	TCDD	PCDD	HxCDD	OCDD	TCDF	PCDF	OCDF	Total PCB	PCB 81	PCB 77	PCB 126	PCB 169
p,p -DDE	0.672	0.461	0.637	0.724	0.697	0.662	0.218	0.086	0.210	0.456	-0.113	0.887	0.475	0.409	0.770	0.695
p,p -DDD		0.286	0.851	0.814	0.620	0.389	-0.228	-0.276	-0.178	-0.010	-0.514	0.638	0.378	0.272	0.532	0.314
Dieldrin (DLDN)			0.268	0.533	0.192	0.341	0.464	0.123	0.049	0.215	0.292	0.435	0.489	0.508	0.270	0.142
Hexachlorobenzene (HCB)				0.746	0.625	0.384	-0.277	-0.464	0.011	0.076	-0.552	0.518	0.266	0.254	0.436	0.415
Trans - nonachlor (TN)					0.539	0.378	-0.001	-0.279	-0.284	-0.061	-0.272	0.669	0.421	0.292	0.489	0.296
2,3,7,8-tetrachlorodibenzodioxin (TCDD)						0.739	-0.022	-0.208	0.069	0.460	-0.258	0.729	0.574	0.399	0.864	0.725
1,2,3,7,8-pentachlorodibenzodioxin (PCDD)							0.563	0.026	0.278	0.814	0.019	0.741	0.705	0.736	0.895	0.809
1,2,3,6,7,8-hexachlorodibenzodioxin (HxCDD)								0.373	0.193	0.618	0.496	0.294	0.439	0.520	0.335	0.327
Octachlorodibenzodioxin (OCDD)									0.344	0.260	0.308	0.033	-0.056	0.006	-0.017	-0.033
2,3,7,8-tetrachlorodibenzofuran (TCDF)										0.619	0.016	0.054	-0.136	0.307	0.099	0.371
2,3,4,7,8-pentachlorodibenzofuran (PCDF)											0.232	0.505	0.400	0.554	0.634	0.653
Octachlorodibenzofuran (OCDF)												-0.035	0.365	0.319	-0.077	-0.213
Total polychlorinated biphenyls (PCBs)													0.557	0.453	0.887	0.638
PCB 81														0.775	0.663	0.436
PCB 77															0.521	0.453
PCB 126																0.801
PCB 169																
M-TEQ$_{PCDD/Fs}$ [a]																
M-TEQ$_{nPCB}$ [b]																
A-TEQ$_{PCDD/Fs}$ [c]																
A-TEQ$_{nPCB}$ [d]																
H4IIE-TEQ$_{PCDD/Fs}$ [e]																
H4IIE-TEQ$_{nPCB}$ [f]																

	M-TEQ$_{DF}$	MTEQ$_{nPCB}$	M-TEQ$_{DF}$	A-TEQ$_{nPCB}$	H4IIEDF	H4IIEN	River mile	5-year prod.
p,p -DDE	0.735	0.780	0.624	0.728	0.726	0.769	-0.371	-0.126
p,p -DDD	0.485	0.509	0.238	0.466	0.409	0.482	0.007	-0.111
Dieldrin	0.287	0.281	0.225	0.414	0.247	0.276	0.118	0.592
HCB	0.504	0.436	0.356	0.419	0.451	0.455	-0.289	-0.133
Trans - nonachlor	0.425	0.499	0.121	0.434	0.324	0.420	0.058	0.005
2,3,7,8-TCDD	0.916	0.844	0.657	0.783	0.875	0.892	-0.445	-0.050
1,2,3,7,8- PCDD	0.932	0.890	0.775	0.956	0.901	0.928	-0.310	0.139
1,2,3,6,7,8-HxCDD	0.314	0.352	0.307	0.469	0.306	0.338	0.122	0.401
OCDD	-0.038	-0.048	0.182	0.024	0.020	-0.000	-0.087	0.061
2,3,7,8-TCDF	0.291	0.155	0.759	0.295	0.418	0.270	-0.616	-0.166
2,3,4,7,8-PCDF	0.751	0.670	0.860	0.741	0.813	0.750	-0.546	0.097
OCDF	-0.074	-0.068	-0.033	0.092	-0.013	-0.034	0.179	0.258
Total PCB	0.774	0.902	0.547	0.796	0.741	0.836	-0.213	0.007
PCB 81	0.665	0.610	0.377	0.790	0.609	0.665	0.189	0.371
PCB 77	0.618	0.527	0.581	0.809	0.601	0.592	0.002	0.207
PCB 126	0.927	0.969	0.669	0.912	0.888	0.969	-0.271	0.045
PCB 169	0.832	0.805	0.754	0.776	0.820	0.831	-0.528	-0.021
M-TEQ $_{PCDD/Fs}$ [a]		0.921	0.838	0.939	0.984	0.985	-0.476	0.032
M-TEQ $_{nPCB}$ [b]			0.697	0.900	0.890	0.957	-0.335	0.042
A-TEQ $_{PCDD/Fs}$ [c]				0.792	0.904	0.813	-0.684	-0.072
A-TEQ $_{nPCB}$ [d]					0.920	0.948	-0.258	0.120
H4IIE-TEQ $_{PCDD/Fs}$ [e]						0.974	-0.562	-0.022

[a] Mammalian-based toxic equivalents including dioxin and furan congeners.
[b] Mammalian-based toxic equivalents including dioxin, furan, and planar PCB congeners.
[c] Avian-based toxic equivalents including dioxin and furan congeners.
[d] Avian-based toxic equivalents including dioxin, furan, and planar PCB congeners.
[e] Toxic equivalents based on H4IIE-derived toxic equivalent factors (TEFs) including dioxin and furan congeners.
[f] Toxic equivalents based on H4IIE-derived toxic equivalent factors (TEFs) including dioxin, furan, and planar PCB congeners.