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

FINAL REPORT

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TABLE OF CONTENTS

List of Tables iii

List of Figures iv

Abstract v

Introduction 1

Methods 4
- Productivity Surveys and Site Selection 4
- Egg Collection and Processing 4
- Residue Analysis 5
- H4IIE Rat Hepatoma Cell Bioassay 6
- Data Analysis 7

Results 9
- Productivity 9
- Egg Thickness and Productivity 11
- Organochlorine Pesticide, Total PCB, and Mercury Concentrations 11
- Concentrations of Dioxin-like Compounds 14
- Contaminants in Two Prey Items From Eagle Nests 19
- Changes in Productivity and Residue Values Over Time 20

Discussion 23

Recommendations 30

Research Implications 31

Acknowledgments 32

References 32

LIST OF TABLES

Table 1. Mean annual bald eagle productivity within the lower Columbia River, and statewide productivity in Oregon and Washington for 1994 and 1995 9

Table 2. Eggshell measurements and concentrations (fresh weight) of organochlorine pesticides, total PCBs, mercury, and total polybrominated diphenyl ethers (PDE) in bald eagle eggs collected from 19 nest sites along the lower Columbia River in 1994 and 1995. 12

Table 3. 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, along with toxic equivalency factors (TEFs) based on mammalian (I-TEF), avian (C-TEF), and H4IIE bioassay (H4IIE-TEF) endpoints. 15

Table 4. Geometric means and extremes (pg/g fresh weight) of mammalian-(I-TEQ), avian-(C-TEQ), and H4IIE bioassay-(H4IIE-TEQ) based toxic equivalents, and H4IIE bioassay-derived TCDD equivalents (H4IIE-TCDD EQs), in bald eagle eggs collected from the lower Columbia River in 1994-95. 19

Table 5. Comparison of eggshell parameters and contaminant residues in bald eagle eggs collected from old nest sites along the lower Columbia River (1985-87 and 1994-95). 22

Table 6. Eggshell measurements and egg contaminant concentrations (fresh weight) 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 25

LIST OF FIGURES

Figure 1. Bald eagle study area (mouth of the Columbia River to the Bonneville Dam) and nest site locations where eggs where collected in 1994 and 1995 2

Figure 2. Five-year average productivity for bald eagles nesting in Washington, Oregon, and the lower Columbia River 3

Figure 3. Regression of river mile of nest site location against productivity at 44 nest sites with at least three years of occupancy along the lower Columbia River 10

Figure 4. Regression of nest site location (as river miles) against the log of A) DDE and B) total PCB residues in bald eagle eggs from 19 nest sites along the lower Columbia River 13

Figure 5. Regression of nest site location as river mile against the log residues of A) 2,3,7,8-TCDD; B) 2,3,7,8-TCDF; C) I-TEQs including PCDDs and PCDFs; D) I-TEQs including the non-ortho PCBs; E) C-TEQs including PCDDs and PCDFs, F) C-TEQs including the non-ortho PCBs; G) H4IIE-TEQs including PCDDs and PCDFs; H) H4IIE-TEQs including the non-ortho PCBs; and I) TCDD-EQs from H4IIE bioassay in bald eagle eggs from 19 nest sites along the lower Columbia River 16

Figure 6. Regression of productivity against the log H4IIE rat hepatoma bioassay-derived TCDD-EQs in bald eagle eggs from 18 nest sites along the lower Columbia River 20

Figure 7. Mean (bar) and standard deviation (line) of productivity values at A) old and new nest sites from 1982 to 1996 and B) only old sites during two time periods (1982-87 and 1990-95) 21

ABSTRACT

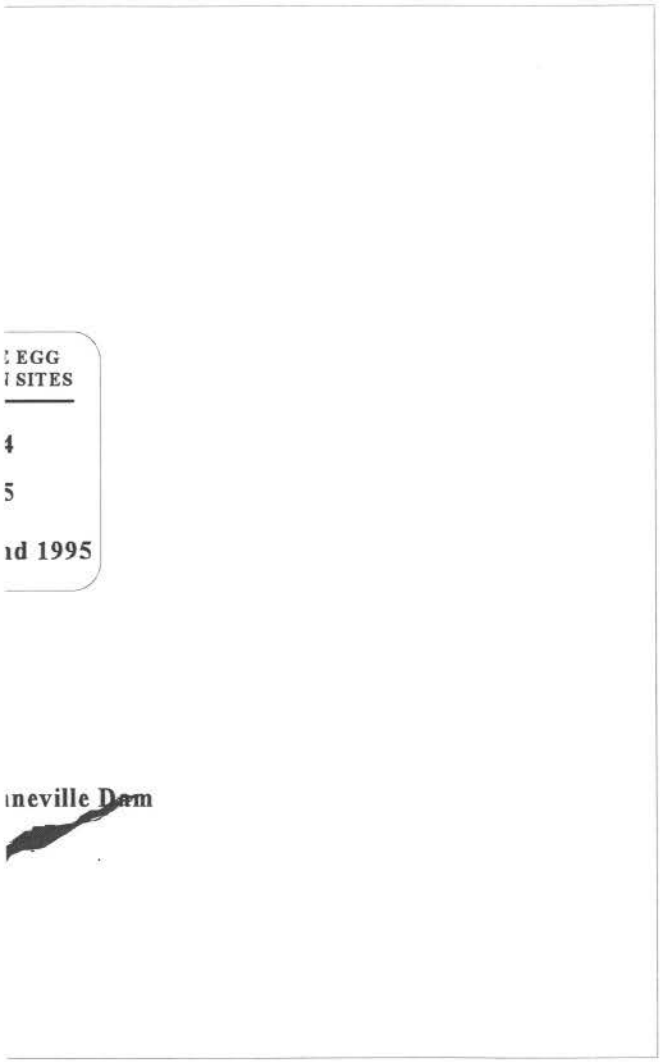
The number of bald eagles (*Haliaeetus leucocephalus*) nesting along the lower Columbia River has doubled in the last six years, yet five-year productivity averages for eagles nesting in Washington and Oregon are well below statewide values. While productivity of eagles along the Columbia River is low, 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 p,p′-DDE and total polychlorinated biphenyls (PCBs) in eagle eggs. In addition, 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) and 2,3,7,8-tetrachlorodibenzofuran (2,3,7,8-TCDF) residues were found in five eggs collected in 1987 and 1991. From 1994-95, bald eagle eggs were collected from nests in 19 of 43 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 congeners). Halogenated dioxin-like compounds in eggs were also evaluated based on a H4IIE rat hepatoma bioassay. Productivity and egg contaminant results from 1994 to 1995 were compared to the previous study to evaluate changes over time. Recent increases in productivity averages were due to new pairs nesting along the river, yet productivity at 19 older nest sites remained low and was not different ($P=0.677$) between the two study periods. Eggshells averaged 11 percent thinner than shells measured prior to the use of DDT, and thickness of eggs in older nests had not improved ($P=0.404$) between the two study periods. Decreases in p,p′-DDE ($P=0.022$) and total PCB ($P > 0.001$) residues in eggs from older nest sites occurred between the two study periods, but residue values were still above concentrations associated with reduced productivity. TCDD and dioxin toxic equivalents (TEQs) exceeded estimated no-effect values for bald eagles during both studies. Bald eagle productivity was not inversely correlated to individual organochlorine compounds ($P>0.05$) but was correlated ($r = -0.48$, $P=0.04$) with TCDD-Equivalents (TCDD-EQs), as measured by the H4IIE bioassay. Some dioxin and furan congeners and all TEQ values calculated without planar PCB contributions were inversely correlated to nest location along the river (as river miles), with lowest values occurring at upriver sites. Although overall 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. Dioxin, furan, and TEQ residues were highest at older nest sites, which were located predominantly in the lower estuary below river mile 40. 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, 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, as amended. By 1997, 60 resident, nesting pairs of bald eagles occupied sites along the lower Columbia River, along with a wintering population of over 100 birds (Garrett et al. 1988, Isaacs et al. 1997). Bald eagle nesting territories and productivity of eagles along the lower Columbia River have been monitored since the early 1970s, and the number of occupied nesting territories has increased every year. However, five-year productivity averages have been nearly 50 percent lower than five-year, 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 levels of eagles along the lower Columbia River are low, levels of nesting populations in other areas of the two states are meeting some recovery guidelines required to remove the species from the endangered species list (U.S. Fish and Wildlife Service 1986).

The organochlorine pesticides DDT, 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 nationwide have rebounded since the early 1970's following the banning of DDT (Grier 1982), although reproductive success of various local subpopulations has not improved (Anthony et al. 1993, Colborn et al.1991, Welch 1994). During a study conducted along the lower Columbia River from 1985 to 1987, Anthony et al. (1993) found elevated concentrations of p,p′-DDE and polychlorinated biphenyls (PCBs) in bald eagle eggs, in blood obtained from eight- to ten-week-old nestlings, and in eagle carcasses collected near the river. Eagles occupied 21 territories along the river in 1985, and their productivity was 30-50 percent lower than statewide values (Figure 2). Shell thinning associated with p,p′-DDE residues was observed in eagle eggs, and prey items collected from the lower Columbia River exhibited detectable concentrations of p,p′-DDE, PCBs, and other organochlorines (Anthony et. al. 1993). In addition, evidence of p,p′-DDE and PCBs in blood of eagle nestlings indicated that recent exposure occurred after the nestlings fed on contaminated prey taken from the river (Anthony et al. 1993).

Bald eagle eggs collected from the estuary in 1987 and 1991 also exhibited elevated concentrations of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD) and 2,3,7,8-tetrachlorodibenzofuran (2,3,7,8-TCDF; Anthony et al. 1993). The 2,3,7,8-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 lower Columbia River exhibited 2,3,7,8-TCDD concentrations exceeding human health guidelines (U.S. Environmental Protection Agency 1986a; 1991a; 1991b; U.S. Fish and Wildlife Service 1994). High 2,3,7,8-TCDD concentrations in the fish tissues led to the designation of the Columbia River as "Water Quality Limited" in 1990.



the lower Columbia River in 1994 and 1995.

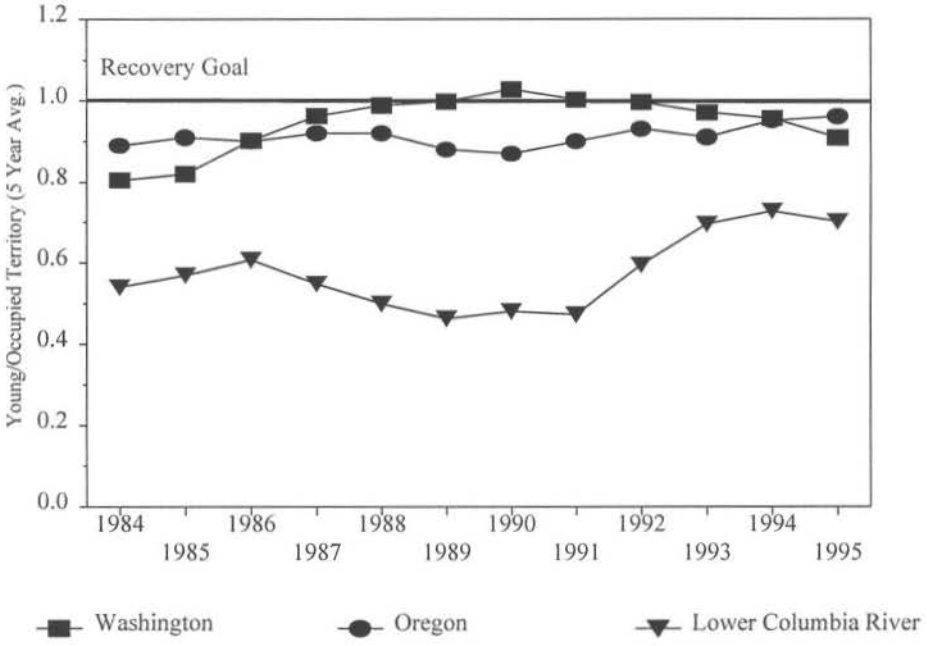


Figure 2. Five-year average productivity (young/occupied territory with known outcome) for bald eagles nesting in Washington, Oregon, and the lower Columbia River. Statewide values for Washington from 1993 to 1995 are estimates. Statewide data include values from the lower Columbia River.

In 1991, the U.S. Environmental Protection Agency (EPA) restricted the concentration of allowable dioxin in the Columbia River through the establishment of a Total Maximum Daily Load (TMDL) for TCDD in order to protect aquatic resources. EPA set the TMDL for 2,3,7,8-TCDD at 0.013 parts per quadrillion (ppq) at mean harmonic flow, and entered formal consultation with the U.S. Fish and Wildlife Service (Service) to ascertain if the concentration attained through implementation of the TMDL was protective of bald eagles along the Columbia River (U.S. Fish and Wildlife Service 1994). The Service determined that a the level of 0.013 ppq would not provide sufficient protection bald eagles nesting along the river, and a lower target concentration of 0.0013 ppg was needed to be protect these eagles. The Terms and Conditions resulting from the Biological Opinion mandated measures to be taken to minimize impacts to bald eagles, and requested additional data be collected on dioxin levels in eagles and other biota along the river (U.S. Fish and Wildlife Service 1994).

The current investigation was designed to evaluate the productivity and current contaminant relations in bald eagles nesting along the lower Columbia River, to identify specific organochlorine residues in the eggs of these eagles, and to determine if productivity and contaminant changes have occurred over time. Information obtained from this study were used

to determine if organochlorine compounds continue to accumulate in eagle eggs and assess whether dioxin-like compounds, which include dioxins, furans, and planar PCBs, are contributing to the reduced reproductive success observed in eagles nesting in this area.

METHODS

Productivity Surveys and Site Selection

Productivity (number of young produced/occupied territory with known nesting success outcome; Postupalsky 1974) of bald eagle nest sites was determined in 1994 and 1995 by helicopter overflights and ground surveys, 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). Overflights were conducted in April to determine site occupancy and nesting status, in May to confirm nesting status and to locate abandoned nests containing nonviable (addled) eggs, and in early July to count juveniles in nests and evaluate final productivity. The outcome of three nests not monitored by helicopter surveys were determined by volunteers who monitor nests on an annual basis and report findings to OCWRU, WDFW, or the Ridgefield National Wildlife Refuge in Washington.

Selection of nesting sites for egg collection occurred immediately following the April overflight. Sampling sites included nests within territories where eggs were collected in previous contaminant investigations, 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. However, eggs were collected from 19 of 43 territories, representing nearly half the population of eagles nesting along the lower river. Only egg residue information from territories established within the last five years (newly-established sites) were under-represented, and statistical comparisons were completed on egg residue data for eagles nesting only at older nest sites.

Egg Collection and Processing

Bald eagle eggs were collected in April and May of 1994 and in April of 1995. Nest trees were climbed by professional tree climbers with experience handling eagle eggs. Only one fresh egg was collected from active nests, and all eggs were collected from abandoned nests. Each collected egg was wrapped in aluminum foil, placed in a well padded can, and lowered to an observer or brought down by the tree climber in a backpack. The can containing the egg was placed in a cooler with Blue Ice® and transported to the Service's, Oregon State Office in Portland, where it was refrigerated at 3 °C until processing. In addition to eggs, one common carp (*Cyprinus carpio*) and one starry flounder (*Platichthys stellatus*) were collected from two different nest sites in 1994. The prey items were double bagged and frozen at -20 °C until shipment to the contract 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 conducting residue and bioassay analysis.

Eggshell thickness (shell and membranes) was measured on shells from 25 bald eagle eggs collected intact and on eggshell fragments from four damaged eggs. Each eggshell half from the intact eggs was rinsed with water and air-dried for a minimum of 30 days after harvesting. Eggshell thickness was measured with a dial micrometer with rounded contacts 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 the 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) determined for bald eagle eggs (museum specimens) collected in the Northwest prior to 1947, when DDT was not in widespread use (Dan Anderson, Univ. Calif., pers. comm, Anderson and Hickey 1972).

Bald eagle eggs were collected from nest sites in 19 different territories over the two-year study. In 1994, 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 (sister eggs) were collected from two territories. The broken egg was excluded from calculations of mean residue 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 four 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.

Residue Analysis

Eagle embryo samples and prey items were shipped overnight on dry ice to laboratories contracted through the Service's. Patuxent Analytical Control Facility for residue analysis. Embryos and prey items 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-orthochloro-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). Mono-orthochloro substituted PCB congners were

analyzed in eggs collected from 11 territories in 1994 only. Embryos and two prey items also were chemically analyzed for organochlorine pesticides, total PCBs, and mercury at Hazleton Laboratories America, Inc., Madison, Wisconsin.

Egg and fish tissue 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 under a steam of nitrogen.

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

Sample preparation, extraction, and cleanup of organochlorines 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.

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.

Laboratory quality control samples for all residue analyses consisted of procedural blanks, duplicates, and spiked samples. Accuracy and precision as determined by spike sample recovery and duplicate sample analysis were within specified ranges for most organochlorine pesticides and total PCBs. 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 ($\pm$ 20 %) of expected values. Analyte concentrations in control carp compared closely with previous QA/QC data.

H4IIE Rat Hepatoma Cell Bioassay

Embryo and prey item tissues 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 Ribick et al. (1981) as modified by Tillitt et al. (1991a). The potency of extracts tested in the H4IIE bioassay is compared to the potency of TCDD. The results are expressed as TCDD-equivalents (TCDD-EQs) and are a reflection of 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 are removed from egg extracts during the two-stage reactive clean-up process, and do not contribute to the TCDD-EQ values resulting from the bioassay. It should be noted that the H4IIE bioassay is a screening tool, and it is not completely understood if the potency of the planar compounds in the bioassay are directly related 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 the hatching success in double-crested cormorants (*Phalacrocorax auritus*) from the Great Lakes (Tillitt et al. 1992).

Data Analysis

Productivity of new nesting pairs at 19 sites was compared to productivity at 25 old sites from 1982 to 1996 using a two-sample t-test. New nesting pairs were defined as those pairs established since 1990 with at least three years of occupancy. Productivity of 19 old nests sites 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 at only the older nest sites. Only nest sites with at least three years occupancy during each time period were included in this comparison. Productivity was also determined from 1982 to 1996 for each site with at least three years of occupancy, and was compared to select contaminant residues and eggshell thinning using simple linear regression. Productivity was compared to nest location as 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).

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 at all nest sites including years at sites when nest trees were climbed (climbed-years), and by calculating the number of young produced per nest for all sites, excluding climbed-years. All other comparisons of productivity were determined using the data set excluding climbed-years to avoid any influence of tree climbing on productivity values.

Residues of organochlorine pesticides, dioxin-like compounds, and mercury in lower Columbia River bald eagle eggs were compared to estimated no-observable-adverse-effect levels (NOAELs) or low-observable adverse-effect-levels (LOAELs), and to concentrations associated with adverse impacts to bald eagles or other avian species. Residues of p,p′-DDE in eggs were compared to eggshell thinning using linear regression, and regression was used to compare select contaminants to nest location as river mile along the river. Residue of select contaminants

were also compared to values found in eggs collected from 1985 to 1987 by Anthony et al. (1993). Eggshell thickness and residues of p,p′-DDE, total PCBs, and mercury from eggs at older nest sites (occupied during both study periods) were compared using a two-sample t-test. Residue data from nest sites established since 1990 were excluded from this comparison. A paired t-test was used to compare residue values between six individual nest sites sampled during both study periods. Sample numbers were insufficient to reliably compare dioxins, furans, or planar PCBs between study periods.

The overall 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) proposed by Safe (1990) and Ahlborg et al. 1992; 1994) as modified by 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 TEQ values have been suggested for use in risk assessment to better represent exposure to multiple dioxin-like compounds in a range of animal groups. International TEFs (TEFs; Ahlborg et al. 1992) have been most commonly used to determine TEQs and are based on mammalian toxicological endpoints. TEFs have also been developed for avian risk assessment, and were derived from studies with chickens (reviewed by Bosveld et al. 1995). Tillitt et al. (1991a;1993) derived TEFs using the H4IIE bioassay. In the present study, these three TEQ values were determined for eagle eggs and the results were presented as I-TEQ for the mammalian-based TEFs, C-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.

TEFs have been determined for many dioxin-like compounds. However, authors of previous studies have evaluated TEQs using TEFs determined for only PCDD and PCDF, while others have included TEF values for the planar PCBs in the TEQ calculation. The I-TEQ, C-TEQ, and H4IIE-TEQ values were determined from eagle egg residue data 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.

Residue values 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 of these 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 residues in eggs collected from the earlier study.

All residue and bioassay data were log transformed prior to data analysis, and geometric means and extreme values 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 residues were reported as micrograms per gram (μg/g) fresh weight for organochlorine pesticides and picograms per gram (pg/g) fresh weight for dioxin-like compounds, unless otherwise noted. Statistical tests were performed at the 0.05 level of significance.

RESULTS

Productivity

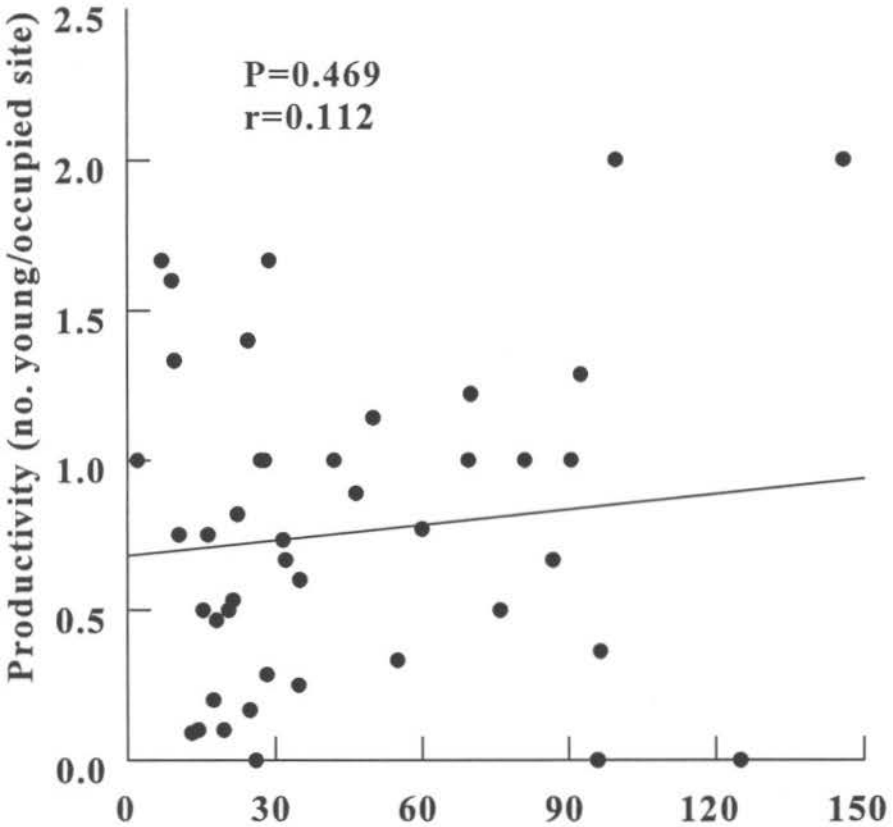
The number of occupied territories with known nesting success outcome for bald eagles along the lower Columbia River was 42 in 1994 and 43 in 1995. Tree climbing to obtain fresh eagle eggs may have influenced productivity at nine nest sites (21%) in 1994 and at eight nest sites (19 %) in 1995. Annual productivity was 16 to 22 percent higher when climbed-years were excluded from the productivity calculation (Table 1).

Table 1. Mean annual bald eagle productivity (young produced/occupied territory with known outcome) within the lower Columbia River, and statewide productivity in Oregon and Washington for 1994 and 1995 (Isaacs et al. 1997, Washington Department of Fisheries and Wildlife, unpubl. annual census reports).

	Lower Columbia River				Statewide	
	Excluding sites during climbed-years		Including sites during climbed-years		Excluding climbed-years along lower Columbia River	
	1994	1995	1994	1995	1994	1995
OR	0.88	0.71	0.75	0.58	0.99	0.95
WA	1.06	0.57	0.77	0.50	0.91[a]	0.86[a]
OR/WA	0.97	0.63	0.76	0.53	0.95	0.91
Total Occupied Territories (OR/WA)[b]	33	35	42	43	771[a]	587[a]

[a] Values for Washington are estimates and are not based on complete counts (Washington Department of Fisheries and Wildlife, unpubl. annual census reports).

[b] Total occupied territories in Washington and Oregon with known outcome (Washington values are estimates, and include nest sites along the Washington side of the Columbia River).


Productivity (no. young/occupied site)
2.5
2.0
1.5
1.0
0.5
0.0
P=0.469
r=0.112
0
30
60
90
120
150

1997). The five-year average productivity values ending in 1993, 1994, and 1995 were higher than during any previous five-year time period (Figure 2).

Climbing trees at Columbia River nest sites to collect fresh eggs during incubation had minimal influence on five-year productivity averages, as five-year productivity values at nest sites excluding climbed-years did not differ more than 10 percent from five-year productivity at sites including climbed-years. Based on past nesting performance, many of the climbed nest sites would likely have failed even in the absence of disturbance caused by climbing. Therefore, the productivity values based on nest sites where climbed trees were included in the analysis were probably an underestimate of the actual productivity values for each year.

Statewide five-year average productivity in Oregon was 0.93 and 0.95 young/occupied territory for the periods ending in 1994 and 1995, respectively (Isaacs et al. 1997). In Washington, estimated statewide five-year productivity averages were 0.96 and 0.91 young/occupied territory for periods ending in 1994 and 1995, respectively (Washington Department of Fisheries and Wildlife, unpubl. annual census reports). Bald eagles occupied 253 and 267 nest sites with known outcome in Oregon in 1994 and 1995, respectively (including nest sites on both sides of the Columbia River). In Washington, bald eagles occupied an estimated 537 sites in 1994 and 330 sites in 1995.

Eggshell Thickness and Productivity

All bald eagle eggshells collected along the lower Columbia River exhibited eggshell thinning except two from a nest site sampled in 1994 and 1995. Eggshell thinning greater than 15-20 percent over a period of years has been associated with poor reproductive success and a declining population (Anderson and Hickey 1972). Columbia River eggshells were up to 25 percent thinner ($\bar{x}$ = -11%) than the mean of eggs collected prior to the use of DDT (Table 2). 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. One eggshell was 12 percent thicker than the pre-DDT average and was collected at the same territory where shells of normal thickness were collected in 1986 by Anthony et al. (1993). Eggshell thickness was not correlated to p,p′-DDE residues (r=0.005, P=0.985, n=19), and was not correlated to productivity during the period 1982 to 1996 (r = 0.07, P = 0.775, n = 19). Productivity was variable, and some nesting pairs with a history of relatively high productivity also produced thin-shelled eggs.

Organochlorine Pesticide, Total PCB, and Mercury Residues

All bald eagle eggs collected along the river contained residues of organochlorine pesticides or metabolites, total PCBs, and mercury (Table 2), although no residues were inversely correlated with productivity (P>0.05, n=18). Total polybrominated diphenyl ethers were also detected in all eggs collected in 1995, and some samples exceeded one μg/g (Table 2). 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 2). Total PCB and p,p′-DDE residues 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 older nest site near the mouth of the river. Residues of p,p′-DDE and total PCBs were not correlated to nest location as river mile along river (Figure 4).

Organochlorine residues in a single broken egg collected from one territory in 1994 were determined as lipid weight because insufficient volume remained in the egg to determine fresh weight. The lipid weight concentrations of p,p′-DDE, p,p′-DDD, 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 ($\bar{x}$ = 154 μg/g), p,p′-DDD ($\bar{x}$ =9.06 μg/g), and total PCBs

Table 2. Eggshell measurements and concentrations (fresh weight) of organochlorine pesticides, total PCBs, mercury, and total polybrominated diphenyl ethers (PDE) in bald eagle eggs collected from 19 nest sites along the lower Columbia River in 1994 and 1995.

Eggshell Parameter/ Contaminant	Geometric Mean	Extremes	n
Eggshell Parameters			
Eggshell Thickness (mm)	0.543	0.454 - 0.682	29[a]
Percent Change[b]	-11	-25 - 12	29
Residues (μg/g fresh weight)			
Total PCBs	5.0	2.90 - 11.4	19
p,p′-DDE	5.63	2.89 - 12.5	19
Total mercury	0.22	0.17 - 0.29	11[c]
Residues (ng/g fresh weight)			
p,p′-DDT	6.92	<0.06 - 34	19
p,p′-DDD	273	149 - 498	19
o,p′-DDT	NC	<18	19
o,p′-DDE	1.77	0.60 - 6.56	11[d]
o,p′-DDD	1.95	<0.06 - 5.94	11[d]
dieldrin	46.3	19.2 - 80.6	19
endrin	1.60	0.57 - 3.34	11[e]
hexachlorobenzene	11.7	<18 - 26.9	19
oxychlordane	13.9	<18 - 31.0	19
alpha-chlordane	NC	<18 - 30.0	11[e]
gamma-chlordane	NC	<18	11[e]
trans-chlordane	1.92	<1.19 - 3.80	11[f]
cis-chlordane/octa-chlordane	131	90.6 - 293	11[f]
alpha-BHC	NC	<18	19
beta-BHC	6.39	1.67 - 42.5	11[g]
gamma-BHC (lindane)	NC	<18	19
delta-BHC	NC	<0.06 - 1.85	11[f]
heptachlor epoxide	11.0	5.39 - 28.8	11[h]
heptachlor	NC	<0.13	11[f]
mirex	5.74	3.58 - 17.9	11[d]
toxaphene	NC	<90	11[e]
trans-nonachlor	133	86.5 - 238	19
cis-nonachlor	42.6	31.1 - 103	11[f]
methoxychlor	NC	<0.06	11[f]
Pentachloroanisole[i]	0.68	0.35 - 1.46	11[f]
dacthal[j]	NC	<0.05	11[f]

Total PDE	745	446 - 1206	11[f]

[a] Combined sample size of 29 eggshells and fragments collected in 1994 and 1995.
[b] Change in mean eggshell thickness below value (0.6088 mm) determined for bald eagle eggs collected prior to 1947.
[c] Compound analyzed in 1994 eggs only.
[d] 1994 eggs excluded because all residues were below detection limits (<18 ng/g).
[e] 1994 eggs excluded because all residues were <18 ng/g except 1, which was22 ng/g.
[f] Compound analyzed in 1995 eggs only.
[g] 1994 eggs excluded because all residues below detection (<18 ng/g) except 2, which were 11 and 29 ng/g.
[h] 1994 eggs excluded because all residues were below detection (<18 ng/g) except 1, which was18 ng/g.
[i] Bioaccuulative metabolite of the fungicide pentachloronitrobenzene.
[j] Bioaccumulative pre-emergent herbicide (tetrachloro-bis-methylterpthalate).

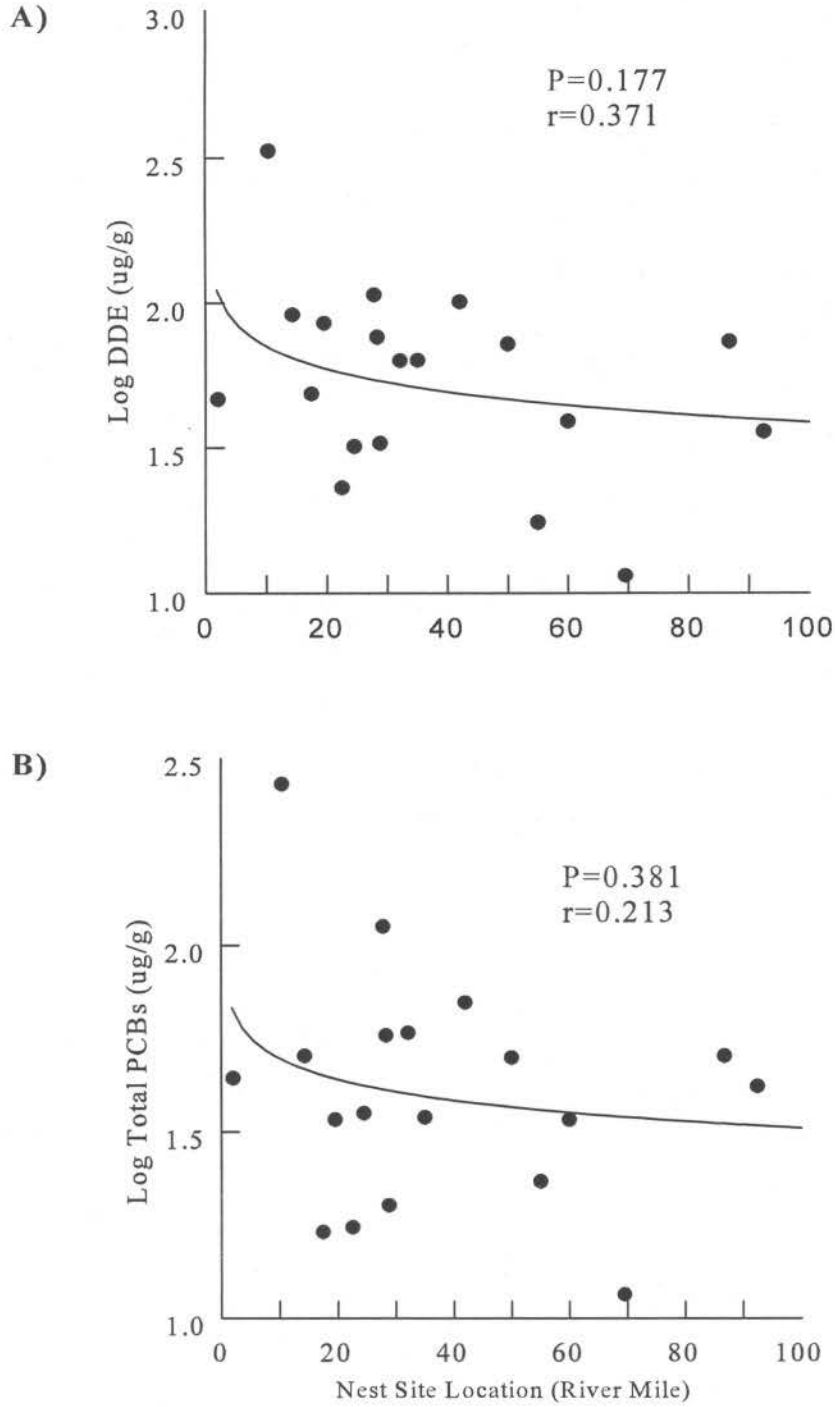


Figure 4. Regression of nest site location (as river miles) against the log of A) DDE and B) total PCB residues in bald eagle eggs from 19 nest sites along the lower Columbia River.

($\bar{x}$ = 138 μg/g) in the 14 eggs collected in 1994. The shell from this egg was 14 percent thinner than shells from eggs collected prior to 1947.

Concentrations of Dioxin-like Compounds

All egg samples contained dioxin and furan residues (Table 3), and only 1,2,4,7,8-pentaCDD and 1,2,3,7,8,9-hexaCDF were at or below detection limits. TCDD and TCDF were the most elevated congeners in eggs (Table 3). TCDD was most elevated in eggs from one older nest site at the mouth of the estuary, and TCDF was highest in an addled egg from an older nest site in the lower estuary. Other congeners elevated 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 3). No individual dioxin, furan, or planar PCB measured in eggs were inversely correlated to productivity ($P > 0.05$, $n = 18$). Dioxin and furan congeners inversely correlated to nest location as river mile included TCDF (Figure 5), 1,2,3,4,6,7,8 heptaCDD ($P=0.002$, $r=-0.665$, $n=19$), and 2,3,4,7,8-pentaCDF ($P=0.015$, $r=-0.546$, $n=19$). TCDD (Figure 5) and PCB 126 ($P=0.262$, $r=0.271$, $n=19$) were not correlated to nest location as river mile.

The overall dioxin-like potency of the planar chlorinated hydrocarbons in eagle eggs was summarized in an additive model using TCDD toxic equivalents (TEQs), as described in the Methods section of this report. TEQs were determined using I-TEFs, C-TEFs, and H4IIE-TEFs (Table 3), and were calculated with and without contributions of individual planar PCBs (Table 4). The geometric means for all I-TEQ and H4IIE-TEQ calculations were lower than corresponding C-TEQ concentrations (Table 4). This reflects the greater sensitivity (higher TEF values) of the chicken cytochrome P450 enzymes to some dioxin-like compounds, especially the tetra- and pentaCDFs and the tetrachlorinated biphenyls (Table 3). The H4IIE-TEQ mean (excluding TEFs for planar PCBs) was very similar to the I-TEQ value, although mean H4IIE-TEQ values including the planar PCBs were much lower than corresponding I-TEQ values (Table 4). No TEQ values were inversely correlated to productivity of lower Columbia River eagles ($P>0.05$, $n=18$), although all TEQ values including only dioxin and furan congeners were inversely correlated with nest location as river mile along the river (Figure 5).

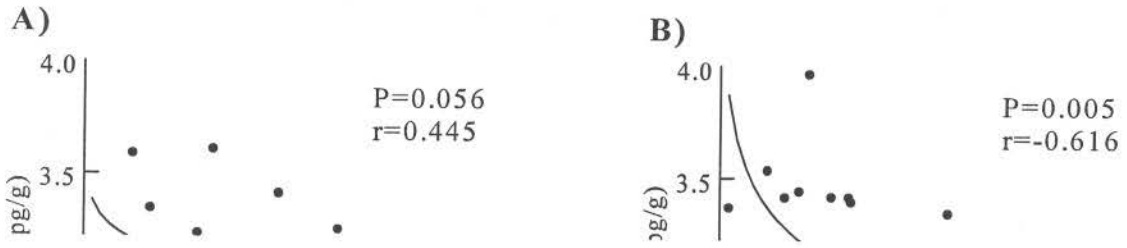
Excluding the planar PCBs, the majority of the dioxin-like potency in the I-TEQ value was due to TCDD (55%) and 1,2,3,7,8-pentaCDD (27%), followed by 2,3,4,7,8-pentaCDF (7.6%) and TCDF (5.3%). The majority of the C-TEQ potency was due to TCDD (35%) and TCDF (34%), followed by 1,2,3,7,8-pentaCDD (17%), and 2,3,4,7,8-pentaCDF (9.7%). TCDF contributed more towards the C-TEQ calculation than in the I-TEQ value, where the contribution was < 6 percent. H4IIE-TEQs were most influenced by TCDD (52%) followed by 2,3,4,7,8-pentaCDF (20%), 1,2,3,7,8-pentaCDD (11%), and TCDD (10%).

Planar PCB residues were elevated in all egg tissue from bald eagles. The most elevated non ortho-substituted PCBs were PCB 77 and 126, and the most elevated mono-ortho-substituted PCBs were PCB 118 and 105 (Table 3). The geometric means for I-TEQ and C-TEQ calculated with planar PCBs were four to six times greater than corresponding TEQs values for just dioxins and furans alone (Table 4). The H4IIE-TEQ mean calculated with planar PCBs was much lower than corresponding I-TEQ and C-TEQ values (Table 4). 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 3), reflecting the lower sensitivity of the H4IIE bioassay to individual planar PCBs.

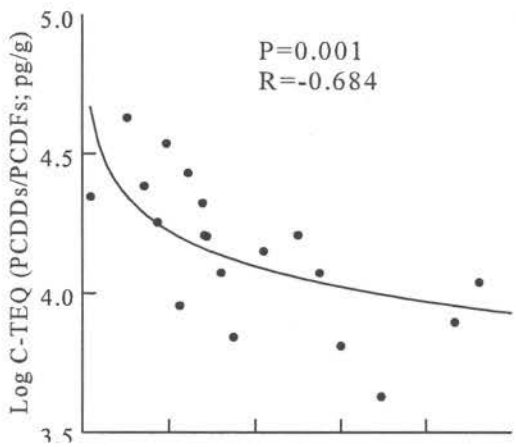
Table 3. Concentrations (pg/g fresh weight) of polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans, and planar chlorinated biphenyls in bald eagle eggs collected from 19 territories along the lower Columbia River in 1994 and 1995, along with toxic equivalency factors (TEFs) based on mammalian (I-TEF), avian (C-TEF), and H4IIE bioassay (H4IIE-TEF) endpoints.

Contaminant	Geometric Mean	Extremes	I-TEF	C-TEF	H4IIE-TEF
Dibenzodioxins					
2,3,7,8-Tetrachloro	22	10 - 37	1	1	1
1,2,3,7,8-Pentachloro	11	5.3 - 21	1	1	0.42
1,2,3,4,7,8-Hexachloro	1.2	<0.7[a] - 4.1	0.1	0.05	0.83
1,2,3,6,7,8-Hexachloro	9.1	4.4 - 19	0.1	0.01	0.24
1,2,3,7,8,9-Hexachloro	0.57	0.50-2.0	0.1	0.1	0.34
1,2,3,4,6,7,8-Heptachloro	1.6	0.68 - 6.0	0.01	<0.001	0.23
Octachloro	19	5.3 - 84	0.0001	NA[b]	0.00054
Dibenzofurans					
2,3,7,8-Tetrachloro	22	9 - 53	0.1	1	0.2
1,2,3,7,8-Pentachloro	1.4	0.70 - 2.9	0.05	0.1	0.2
2,3,4,7,8-Pentachloro	6.2	4.0 - 11	0.5	1	1.4
1,2,3,4,7,8-Hexachloro	0.83	<0.60 - 3.2	0.1	0.1	0.02
1,2,3,6,7,8-Hexachloro	1.4	0.60 - 3.5	0.1	0.1	0.06
1,2,3,7,8,9-Hexachloro	NC[c]	<0.20 - 0.20	0.1	0.1	0.2
2,3,4,6,7,8-Hexachloro	2.0	0.90 - 4.9	0.1	0.1	0.3
1,2,3,4,6,7,8-Heptachloro	2.1	0.90 -7.8	0.01	0.01	0.3
1,2,3,4,7,8,9-Heptachloro	0.86	<0.50 - 2.5	0.01	0.01	0.3
Octachloro	3.7	1.6 - 13	0.0001	0.0001	0.02
Non ortho-chlorinated Biphenyls					
3,4,4′,5-Tetra (81)[d]	339	214 - 491	0.0001	0.1	0.0019
3,3′,4,4′-Tetra (77)	2578	1819 - 3810	0.0001	0.05	0.000018
3,3′,4,4′,5-Penta (126)	1384	626 - 2721	0.1	0.1	0.022
3,3′,4,4′,5,5′-Hexa (169)	133	50 - 353	0.010	0.001	0.00047
Mono ortho-chlorinated Biphenyls (analyzed in eggs collected from 11 sites in 1994 only)					
'2,3,3',4,4'-Penta (105)	147,895	96,054 - 230,398	0.0001	0.0001	0.00008
'2,3,4,4',5-Penta (114)	11,657	7,595 - 16,245	0.0005	0.0001	<0.000001
'2,3',4,4',5-Penta (118)	513,132	344,847 - 859,061	0.0001	0.00001	0.000000035
2',3,4,4',5-Penta (123)	5,487	<200 -13,113	0.0001	0.00001	0.00012
'2,3,3',4,4',5-Hexa (156)	71,320	37,785 - 146,184	0.0005	0.0001	0.000055
'2,3,3',4,4',5-Hexa (157)	19,348	11,556 - 38,141	0.0005	0.0001	0.000015
2,3',4,4',5,5'-Hexa (167)	61,663	30,883 - 135,450	0.00001	0.00001	0.000009
'2,3,3',4,4',5,5'-Hepta (189)	7,264	3,843 - 16,151	0.0001	0.00001	0.00001

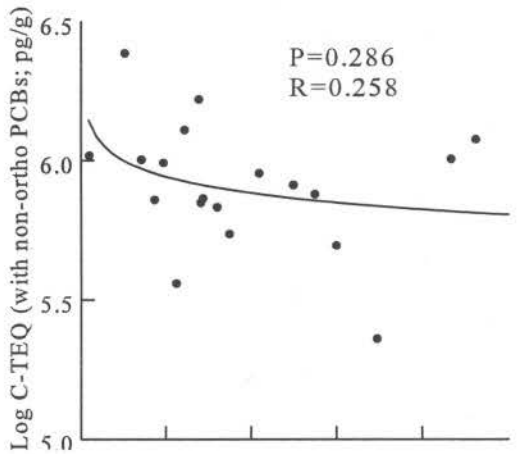
[a] A < symbol denotes value was less detection limits. Detection limits ranged from 0.2 to 0.8 pg/g.
[b] Toxic Equivalency Factor not available.
[c] Geometric mean not calculated because majority of samples were less than detection limits.
[d] Number in parentheses is based on International Union of Pure and Applied Chemists congener number (Ballschmiter and Zell 1980).


A)
4.0
3.5
pg/g)
P=0.056
r=0.445
B)
4.0
3.5
P=0.005
r=-0.616

E)


P=0.001
R=-0.684
Log C-TEQ (PCDDs/PCDFs; pg/g)
5.0
4.5
4.0
3.5

F)


P=0.286
R=0.258
Log C-TEQ (with non-ortho PCBs; pg/g)
6.5
6.0
5.5
5.0

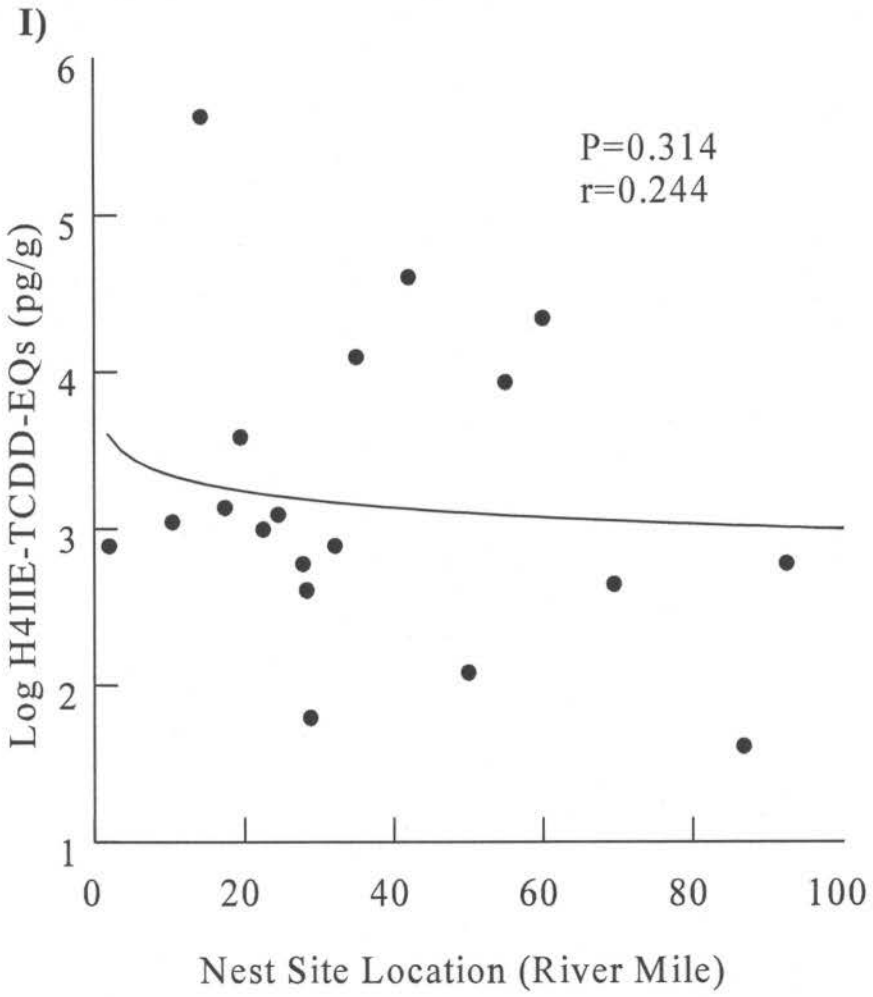


Figure 5. Continued.

Including the non-ortho-PCBs in the additive models, PCB 126 contributed the most dioxin-like toxicity (76%) towards the average I-TEQ value, followed by TCDD (12%), 1,2,3,7,8-pentaCDD (6%) and 2,3,4,7,8,-pentaCDF (1.7%). C-TEQs were primarily influenced by PCB 126 (38%), PCB77 (35%), PCB 81 (9.2%), TCDD (6%), and TCDF (5.9%). Similarly, the H4IIE-TEQs were most influenced by PCB 126 (41%), followed by TCDD (30%), 2,3,4,7,8,-pentaCDD (12%), 1,2,3,7,8-pentaCDD (6.0%), and TCDF (5.9%).

I-TEQs determined in eggs collected in 1994 included the mono-ortho-PCBs. I-TEQs in these eggs were dominated by dioxin-like toxicity from PCB 126 (48%), followed by 118 (16%), 156 (11%), TCDD (8.3%), PCB 105 (4.6%). For the C-TEQs, PCB 126 contributed 37% dioxin-like activity, followed by PCB 77 (31%), PCB 81 (8.3%), TCDD (6.4%), and TCDF (4.4%). PCB 126 contributed the most dioxin-like toxicity (39%) of the average H4IIE-TEQs, followed by

TCDD (31%), 2,3,4,7,8-pentaCDF (9%), 1,2,3,7,8-pentaCDD (5.6%), PCB 156 (4.5%), and TCDF (4.2%).

Table 4. Geometric means (extremes in parenthesis) of mammalian-(I-TEQ), avian-(C-TEQ), and H4IIE bioassay-(H4IIE-TEQ) based toxic equivalents, and H4IIE bioassay-derived TCDD equivalents (H4IIE-TCDD EQs), in bald eagle eggs collected from the lower Columbia River in 1994-95. Eggs were collected from nests in 19 territories unless otherwise noted.

	I-TEQ	C-TEQ	H4IIE-TEQ	H4IIE-TCDD EQs
PCDD/F[a]	41 (21 - 68)	64 (38 - 102)	43 (23 - 68)	--
PCDD/F + nPCBs[b]	181 (84 - 344)	369 (213 - 594)	74 (38 - 129)	--
PCDD/F + n + mPCBs[c] (1994 eggs only)	325 (228 - 546)	424 (332 - 617)	88 (69 - 137)	--
H4IIE bioassay-derived dioxin-like activity[d]	--	--	--	26 (5 - 278)

[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).

TCDD-EQs as derived from the H4IIE bioassay were highly variable in eggs collected from eagles along the lower river. The geometric mean was 37 to 94 percent lower than other TEQ values, and values ranged from 5 to 278 pg/g (Table 4). Bioassay derived H4IIE-TCDD-EQs were not correlated ($P>0.05$, $n=18$) to the H4IIE-TEQs calculated using TEF values, and TCDD-EQs were not correlated to nest location as river mile (Figure 5). However, H4IIE-TCDD-EQs values were inversely correlated to productivity ($r= -0.479$, $P=0.045$, $n=18$; Figure 6).

Contaminants in Two Prey Items From Eagle Nests

Organochlorine pesticide, total PCB, and mercury residues found in two prey items (starry flounder and common carp) collected from two bald eagle nest sites were near or below detection limits. The carp sample contained 0.23 μg/g wet weight total PCBs and 0.12 μg/g wet weight p,p′-DDE, whereas the residues 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 4.9 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

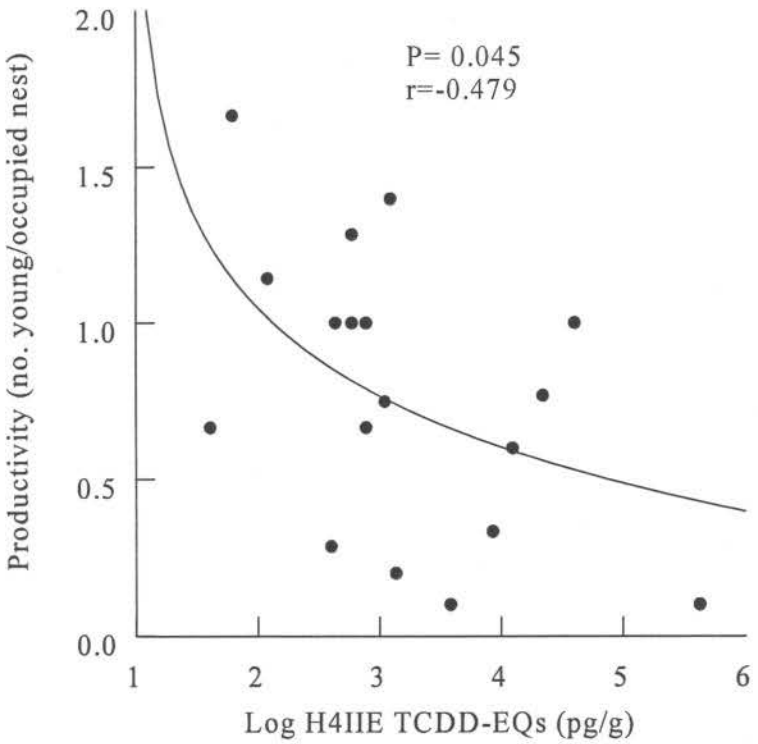


Figure 6. Regression of productivity (number of young produced per occupied territory with known outcome from 1982 to 1996) against the log H4IIE rat hepatoma bioassay-derived TCDD-EQs in bald eagle eggs from 18 nest sites along the lower Columbia River.

324 pg/g wet weight. The mono-ortho PCBs 105 and 118 were detected in the carp sample at 4 and 12.3 pg/g wet weight, respectively, and at 4 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.

Changes in Productivity and Residue Values Over Time

From 1990 to 1996, 28 additional eagle pairs established territories along lower Columbia River. Nineteen of these newly-established pairs occupied the area for at least three years. Productivity observed at the 19 new nest sites established since 1990 was higher (P=0.006) than at older nest sites (Figure 5). Productivity at 19 of the older nest sites was low and not different (P=0.677) between two six-year time periods (1982 to 1987 and 1990 to 1995; Figure 7).

Eggshell thickness and egg residue concentrations were compared to values 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 eggshell parameters and egg residues at older nest sites were compared between the two studies. Thickness was not different (P=0.404) between eggshells from 10 intact eggs collected along the river in 1985 to 1987 and eggshells collected

from 13 older nests in 1994 and 1995 (Table 5). Mean eggshell thickness in both studies was well below the pre-DDT average of 0.6088 mm (Table 5). Total PCBs and p,p′-DDE residues declined ($P < 0.001$ and $P = 0.022$, respectively), and mercury was not different ($P=0.647$)

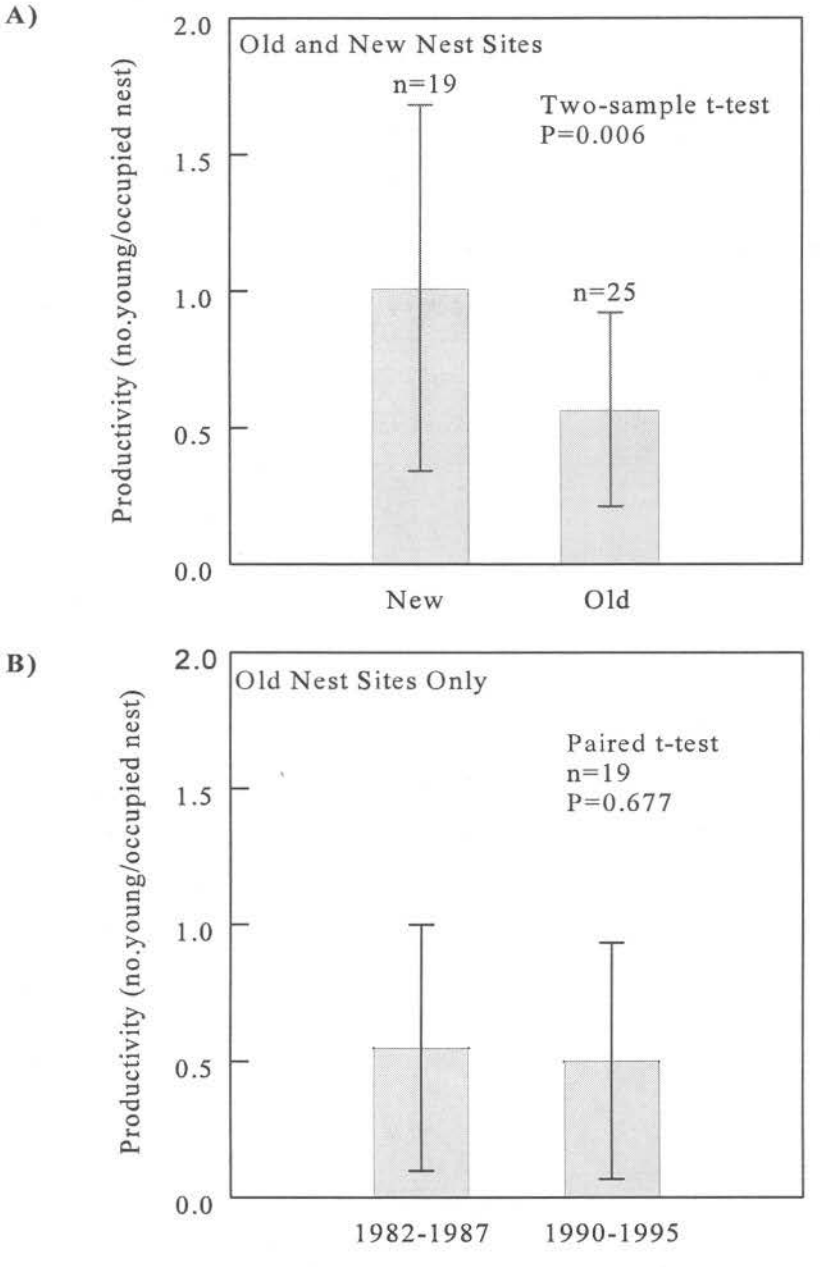


Figure 7. Mean (bar) and standard deviation (line) of productivity values (number of young produced per occupied territory with known outcome from 1982 to 1996) at A) old and new nest sites from 1982 to 1996 and B) only old sites during two time periods (1982-87 and 1990-95).

Table 5. Comparison of eggshell parameters (arithmetic means, extremes in parentheses) and contaminant residues (geometric means, extremes in parentheses) in bald eagle eggs collected from old nest sites along the lower Columbia River (1985-87 and 1994-95).

	1985-87 Anthony et al. (1993)	n	1994-95 Old Nest Sites	n
Eggshell Parameters				
Eggshell Thickness (mm)	0.552[a] (0.497 - 0.618)	10	0.538[a] (0.454 - 623)	13
Percent Change[c]	-9 (-18 - 2)	10	-11 (-25 - 2.3)	13
Residues (μg/g fresh weight)				
p,p′-DDE	9.6[a] (4.3 - 21)	10	6.3[b] (3.5 - 12.5)	13
Total PCBs	10.5[a] (5.1 - 20)	10	5.4[b] (3.4 - 11.4)	13
Mercury[e]	0.21[a] (0.12 - 0.40)	10	0.22[a] (0.17 - 0.29)	9
Residues (pg/g fresh weight)				
2,3,7,8-TCDD	26 (11 - 38)	5[d]	24 (18 - 37)	13
2,3,7,8-TCDF	15 (4 - 38)	5	22 (9 - 53)	13
I-TEQ (PCDD/F)	55 (25 - 79)	5	43 (33 - 68)	13
I-TEQ (PCDD/F + nPCBs)	326 (186 - 475)	3	196 (149 - 344)	13
I-TEQ (PCDD/F + n + mPCBs)	406[e] (227 - 574)	3	316 (223 - 536)	11[f]
TCDD-EQs (H4IIE bioassay)	NA[g]		27 (5 - 278)	13

[a, b] Means with different superscript letters across rows are significantly different. Dioxins, furans, planar PCBs, and I-TEQ values were not statistically compared due to insufficient sample size.
[c] Change in mean eggshell thickness below value (0.6088 mm) determined for bald eagle eggs collected prior to 1947.
[d] Includes 3 eggs collected in 1987 and 2 addled eggs collected in 1991.
[e] Only one mono-ortho congener (PCB 105) was determined.
[f] Analyzed in eggs from 11 territories in 1994 only.
[g] Samples collected in 1985-87 were not analyzed using the rat hepatoma bioassay.

between the two study periods at old nest sites (Table 5). Shell thickness and p,p′-DDE residues did not change (P=0.819 and 0.090, respectively) at six nest sites sampled during both studies. However, total PCB residues were lower (P=0.010) at the same six sites between the two study periods. Dioxin, furan, and TEQ values appeared similar between the two time periods (Table 5), although slight differences in analytical methods and small sample size obtained in the earlier study precluded statistical comparisons.

DISCUSSION

Earlier studies associated environmental contaminants, including p,p′-DDE and total PCBs, with poor reproduction and eggshell thinning in Columbia River eagles (Anthony et al. 1993). Compared to egg residues in the mid-1980s, mean residues of p,p′-DDE declined by 34 percent and total PCBs by 49 percent in eagle eggs collected at older nest sites in 1994 and 1995. Mean PCB residues also declined at six nest sites sampled during both studies, but mean p,p′-DDE did not change. Even with these decreases in residues, mean total PCBs in eggs were higher than either threshold values or no observable adverse effect levels estimated for bald eagles (Table 6; Wiemeyer et al. 1984, Kubiak and Best 1991 *as cited in* Giesy et al. 1995). In addition, p,p′-DDE residues were nearly double the values typically associated with reduced productivity in bald eagles from other areas (Table 6; Wiemeyer et al. 1993). Using the equation $Y=1.081 - 0.709 \log_{10} X$ to predict five-year average productivity (Y) with mean p,p′-DDE contamination (X) (Wiemeyer et al. 1984), a five-year average productivity would be predicted for eagles along the river of 0.55 young/occupied territory based on mean p,p′-DDE values of 5.63 μg/g (Table 2). This predicted value is lower than five-year productivity (0.82 in 1996) for all lower Columbia River eagles, but is similar to the five-year productivity (0.60 in 1996) observed at 25 older nest sites. Wiemeyer et al. (1984) based the equation on residues in addled bald eagle eggs, which could represent higher concentrations than fresh eggs collected during incubation. Therefore, the equation could underestimate average productivity when fresh egg residues are used. Other organochlorine pesticides were present in eagle eggs but were considered to be below levels associated with poor reproduction (Wiemeyer et al. 1993), provided multiple residues did not interact to produce adverse effects during embryo development.

Residues of p,p′-DDE have been linked to eggshell thinning in raptors and other birds (Bitman et al. 1969, Porter and Wiemeyer 1969). Shells of eggs from the lower Columbia River were thin and shell thickness at older sites had not improved since the mid-1980's. Similar to findings in other field studies (Frenzel 1984, Elliott et al. 1996b), eggshell thinning was not correlated to p,p′-DDE residues or productivity. However, mean eggshell thinning (-11%) for Columbia River eagles was similar to values for bald eagles in other areas exhibiting impaired reproduction, and thinning in eggshells of some breeding pairs was above values considered to be biologically significant in causing population declines (Table 6; Anderson and Hickey 1972, Wiemeyer et al. 1993). The p,p′-DDE residues in a broken egg collected from one nest along the river, when compared on a lipid weight basis, was similar to residues in other thin-shelled eggs collected along the river could have contributed to the egg breaking during incubation.

Other contaminants such as heavy metals can impact bald eagle productivity (Wiemeyer et al. 1993). Mercury residues 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 6; 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 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 *(Ardea herodias*) reported normal reproduction when mean TCDD in eggs were 92 pg/g (Elliot et al. 1988). TCDD in lower Columbia River eagles was well above values associated with effects in chickens, but below values impacting great blue herons (Table 6). Similar to other studies (Elliott et al. 1996a), TCDD was not correlated to productivity of lower Columbia River eagles and did not appear to be the sole contaminant limiting eagle reproduction.

TEQs in lower Columbia River eggs were elevated above reference or threshold values estimated for bald eagles or other avian species (Table 6). 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 I-TEQs in the wood duck study, which was somewhat higher than the contribution (55%) from TCDD in eagle eggs from the lower Columbia River. Based on numerous field and laboratory studies, Giesy et al. (1995) estimated a no- or low-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 I-TEQ (excluding planar PCBs) in lower Columbia River 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. Lower Columbia River 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 the TEQ calculation (Table 6; Elliott et al. 1996a).

Data from this study showed non-ortho and mono-ortho planar PCBs greatly contributed toward the overall 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 (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 (4,095 pg/g, range 2,495 to 6,884 pg/g) of three non-ortho PCBs (PCB 77, 126, and 169) in bald

eagle eggs collected along the lower Columbia River 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 6; Jarman et al. 1993). In contrast, Elliott et al.

Table 6. Eggshell measurements and egg contaminant concentrations (geometric means, fresh weight) 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%		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[c]	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 I-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
I-TEQ- PCDD/F (pg/g)	41	15	Reference[d]	Bald eagle	Elliott et al. 1996a
		>20-50	Reproduction	Wood duck	White and Seginak 1994
I-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 2,495-6,884	5,500[e]	Reproduction	Forster's terns	Kubiak et al. 1989
		2,070[f]	Reproduction	Peregrine falcon	Jarman et al. 1993

[a] Effects include concentrations attributed to reducing average productivity for a population, (Productivity), levels associated with poor reproductive success in field studies (Reproduction), egg injection value causing embryo mortality and other development impacts (Mortality), no observable adverse effect livel (NOAEL), low observable adverse effect level (LOAEL), no observable effect level (NOEL), low observable effect level (LOEL), and 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] Estimate of threshold concentration for healthy productivity (Kubiak and Best 1991 *as cited in* Giesy et al. 1995).
[d] Reference values from five bald eagle eggs collected from coastal British Columbia.
[e] Median concentration in eggs of Forster's terns exhibiting reproductive problems in Green Bay, Wisconsin.
[f] Geometric mean concentration in eggs of peregrine falcons exhibiting reproductive problems in California.

(1996b) reported that non-ortho 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 Columbia River, PCB 126 contributed the majority of dioxin-like activity towards calculations of all TEQ values (C-TEQ, I-TEQ, and H4IIE TEQ). PCB 126 accounted for 76 percent of the I-TEQ value including non-ortho PCBs, followed by TCDD (12%). PCB 126 contributed 48 percentof the I-TEQ including the mono-ortho PCBs, and PCBs 118, 156, and 105 contributed 32 percent. PCB 77 and 81 contributed 39 percent towards the C-TEQ non-ortho PCB calculation, but were not important influences on the other TEQ calculations. Mono-ortho PCBs contributed < 8 percent towards the C-TEQ calculation. In the Great Lakes region, PCB congeners 126 and 105 accounted for more than 90 percent of the estimated TEQ in eggs 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 residues in lower Columbia River eagle were highly influenced by the contribution of the non-ortho PCBs, primarily PCB 126.

TCDD-EQs derived from the H4IIE bioassay conducted on lower Columbia River eagle egg extracts were above some estimated NOELs for TEQs (Table 6), and were inversely correlated to eagle productivity. Mean TCDD-EQs were much lower than all TEQ values calculated using an additive model (Table 5). 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 overall dioxin-like potency of Columbia River eggs, as measured by the bioassay. This would indicate that additive models, based on chicken and rat cytochrome P450 responses to determine TEF values, may be inappropriate to estimate risks of dioxin-like compounds to bald eagles in the Columbia River. However, mean Columbia River TCDD-EQs 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 Columbia River eggs, TCDD-EQs were highly variable, were not correlated to the H4IIE-TEQs derived from TEF values, and were higher (P=0.010, n=17, two-tailed t test) in eggs collected in 1994 than eggs collected in 1995.

These factors suggest other mechanisms, possibly differences in culture condition between years, may be influencing the response of the H4IIE bioassay to eagle egg extracts. The adverse effects on bald eagle embryos associated with TCDD-EQ concentrations remains uncertain because the relative potency of planar halogenated compounds to impact early life stage toxicity in bald eagles is unknown. 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.

Overall productivity of the bald eagle population nesting along the lower Columbia River has increased as a result of greater reproductive success experienced by new nesting pairs immigrating into the region. Between 1990 and 1996, 28 new pairs established nest sites along the river, and recent five-year productivity averages have improved due to the higher breeding success at the new sites. In contrast, eagles at 25 older nest sites produced about half the number of young as the eagles at newer sites, and reproductive success at the older sites has not improved in over ten years (Figure 7). Average productivity of eagles along the River, especially at the older sites, remains well below eagle productivity in other areas of Oregon and Washington, and below values (one young per occupied nest) indicative of a healthy population (Sprunt et al. 1973, Wiemeyer et al. 1984).

Bald eagle productivity along the lower Columbia River was not inversely correlated to organochlorine pesticides, total PCBs, individual PCDDs and PCDFs, or TEQ values, but was inversely correlated to bioassay-derived TCDD-EQs. Other investigations on bald eagles experiencing poor productivity associated with 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 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 nest sites. Elliott et al. (1996a) found stronger correlations between biochemical and physiological endpoints and TCDD or TCDF concentrations as opposed to the I-TEQs, and suggested that use of the I-TEF values may overestimate contribution of PCBs to dioxin-like toxicity (Elliott 1996a, Elliott and Norstrom 1998). The inverse correlation of only the H4IIE-derived TCDD-EQs with productivity, and elevation of individual contaminant residues above NOELs, suggests that multiple chemical interactions and possibly other factors contribute to the poor reproductive success observed in bald eagles along the lower Columbia River.

Numerous factors influence bald eagle productivity and population numbers. In the Great Lakes region, bald eagle productivity is affected by habitat availability, degree of human disturbance to nesting pairs, and environmental contaminants (Bowerman et al. 1995). Bald eagles exhibiting declines in egg residues of DDE and PCBs along Lake Superior appeared most limited by food availability (Dykstra 1995). These same factors, along with weather conditions and competition, could impact eagle productivity along the lower Columbia River. Earlier studies reported that limited prey, weather conditions, and competition were not obvious influences on eagle productivity along the Columbia River (Watson et al. 1991), although human disturbance may

influence foraging success of some eagles (McGarigal et al. 1991). The recent increase in successful new eagle nest sites 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 lower Columbia River eagles. DDE residues appear to have the greatest impact on reproductive success of older nesters, based on the similarities between the predictive 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 nest sites.

Bald eagles nesting along the river are exposed to DDE, PCBs, dioxins and furans by consuming contaminated prey. Bald eagles at older nest sites foraged on fish (predominantly largescale sucker, American shad, 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, grebes, cormorants (*Phalacrocorax auritus*), and gulls) 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; U.S. Fish and Wildlife Service unpubl. data). Home ranges of lower Columbia River bald eagles can extend up to 22 km^2, but most eagle activity occurs in the Columbia River within 0.5 - 1 km^2 of the nest site (Garrett et al. 1993) where contaminated prey is captured and consumed or delivered to nestlings (Anthony et al.1993). Residues 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 Columbia River (Anthony et al. 1993, U.S. Fish and Wildlife Service, unpubl. data). The highest residues of dioxin-like compounds were found in eggs of double-crested cormorants and Caspian terns (*Sternus caspia*; U.S. Fish and Wildlife Service, unpubl. data). Residues of organochlorine pesticides, 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 lower Columbia River in the early 1990s (Anthony et al. 1993, U.S. Fish and Wildlife Service, unpubl. data). The estimated biomagnification factors (BMFs), calculated as the ratio of the mean residue concentration in bald eagle eggs to that measured in the prey item, for fish prey (based on average whole-body residues of carp, sucker, and peamouth chub collected from the lower Columbia River in 1991) were 66 (5.63/0.08) for p,p′-DDE, 35 (5.0/0.14) for total PCBs, 16 (22/1.4) for TCDD, and 2.2 (22/10) for TCDF. In Lake Ontario, the 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). Estimated BMFs were similar for total PCBs and TCDD between the two regions, but the BMF for p,p′-DDE for the lower Columbia River was double the Lake Ontario value. Lower Columbia River eagles may accumulate a greater proportion of p,p′-DDE from prey sources other than fish, such as fish-eating birds.

TEQ values (excluding planar PCBs), TCDF, and other dioxin and furan congeners were inversely related to nest location along the river, with higher values observed in eggs from nest sites near the mouth of the river. This indicates that exposure to dioxin-like compounds is less in

new pairs established upriver from the older sites. The new pairs may not have accumulated contaminants to the extent of older pairs along the lower Columbia River, and some pairs nesting in upriver locations (above river mile 40) may be foraging on prey with minimal contamination. In addition, dioxin-like compounds may be deposited, and be bioaccumulated, to a greater extent in the lower reaches of the river. Foraging pattens of eagles have been evaluated in the lower estuary reaches of the Columbia River where tidal flats were more abundant, and eagles along the river with territories associated with shallow bays consumed more waterfowl than other eagles (Watson et al. 1991). Fish-eating birds can be 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 predominantly located in these lower reaches near older nest sites, whereas shallow bays and fish-eating birds may be much less available to the new eagle pairs nesting in the upper reaches. Mean residues of organochlorine compounds were highest in eggs from nests in the lower estuary below river mile 40 (Figures 4 and 5), where predominantly older nest sites occur. Residues appeared higher in eggs from older nest sites than newly established nest sites, but insufficient samples were obtained from newer nest sites to make statistical comparisons.

New pairs nesting along the lower Columbia River exhibited greater productivity than older, more experienced pairs. 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). Increases in coastal breeding populations in the Great Lakes was attributed to immigration of young eagles from inland sites (Best et al.1994). Similarly, newly-established pairs along the lower Columbia River primarily originate from areas outside the region, as low productivity combined with predicted high mortality of subadult eagles (Stalmaster 1987) would 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 be primarily a result of 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). 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 lower Columbia River (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, Elliott et al. (1996c, Elliott and Norstrom 1998) attributed 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 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 some local combustion sources (Elliott et al. 1996b; 1996c; Elliott and Norstrom 1998). Similarly, the most elevated PCDDs and PCDFs in lower Columbia River 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 Columbia River 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 lead 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, residues of p,p′-DDE and total PCBs in eggs of lower Columbia River eagles were shown to decline since the mid-1980s. However, these contaminants, along with dioxin-like compounds, still exceed estimated NOELs, reference concentrations from other studies, or concentrations associated with reduced productivity. Bioassay results indicate a mixture of dioxin-like compounds, rather than individual chemicals, may contribute to impaired productivity of the eagles. Egg residues of p,p′-DDE and PCBs were not linked to nest location along the river, suggesting these compounds are distributed more evenly throughout the system. In contrast, some dioxin, furan, and TEQ residues were related to river mile, which may reflect releases of the contaminants from point source discharges and deposition in specific areas (e.g, tidal flats) of the lower estuary. Dioxin, furan, and TEQ residues were highest at older nest sites, which were located predominantly in the lower estuary below river mile 40. Productivity at new nest sites established by eagle pairs moving into the lower river was much higher than productivity at older nest sites. Preliminary evidence suggests that pairs at older nest sites 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 Columbia River and subsequent bioaccumulation of p,p′-DDE, PCBs, and dioxin-like contaminants could limit future productivity of some new pairs.

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. 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 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 of Water Quality Management Plans to function as non-point source 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 if corresponding changes of dioxin and furan levels in biota have occurred. Whitehead et al. (1992) and Elliott et al. (1996c) reported decreases in dioxins and furan egg residues 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 involving contaminated sediment. The contributions of other ongoing contaminant studies by USGS, including an osprey study and use of passive samplers (semi-permeable membrane devices), 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 disturbance of sediment contaminated with dioxin-like compounds within two years of 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 dredging. 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 low concentrations of organochlorines and other contaminants. Current disposal practices of material dredged from these areas into the flow lane of the Columbia River 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 overall 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 lower Columbia River 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 correspond to 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 nest sites along the river; currently, there are 60 occupied territories. New eagle nest sites have been established in both the lower part of the estuary near older sites, and in the upper part of the estuary (towards Bonneville Dam) where no eagles have nested previously. Pairs at newer sits 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 residues should continue to be monitored in these eagles, and results between old and new nest sites should be compared. Foraging patterns should be evaluated and compared between old and new nest sites. These evaluations could be completed using video monitoring at nest sites and comparing prey delivery, parental incubating behavior, human disturbance, hatching success, and other potential factors influencing productivity between old and new nest sites.

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the lower Columbia River in 1994 and 1995.

map of sampling sites
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