BIOMAGNIFICATION FACTORS, TARGET FISH CONCENTRATIONS, AND HAZARD QUOTIENTS FOR BALD EAGLES IN THE LOWER COLUMBIA RIVER

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Photo 1. Bald eagles nesting along the lower Columbia River contain the highest concentrations of bioaccumulative compounds compared to other biota in the region. Bald eagles are ideal indicators to monitor accumulation and trends in contaminants because the eagles are present year-round and 100% of their diet consists of prey captured from the Columbia River.

Introduction

Previous investigations in the lower Columbia River (LCR) have shown that:

- the LCR receives contaminants from numerous inputs including industrial discharges and runoff from urban, agricultural, and forested areas;
- biota in the LCR are exposed to many persistent, bioaccumulative contaminants resulting from these releases; and
- bioaccumulative contaminants detected in fish-eating birds approach or exceed estimated effect-level concentrations (see photos 1-5 for description of chemical exposure and reproduction in eagles).

To further elucidate contaminant relations in the LCR, we built upon previously information collected by the U.S. Fish and Wildlife Service and:

- evaluated fish collected in 1991 and bald eagle eggs collected in 1994 to 1995 (Photo 1);
- calculated hazard quotients based the most sensitive endpoint (eagle egg) and identified risk to bald eagles in the area;
- derived biomagnification factors (BMFs) and target fish concentrations (TFCs) for persistent, bioaccumulative compounds based on the fish and egg samples; and
- proposed use of eagle egg-based BMFs and TFCs as modeling parameters in risk assessments to minimize contaminant exposure to fish and fish-eating birds.

Photo 2. Common carp. Fish such as carp and sucker make up a large proportion of the bald eagle diet, especially during the breeding season. All fish collected and analyzed were within the size range (<60 cm) that included 94 percent of the fish captured by bald eagles along the lower Columbia River (Watson et al. 1991, U.S. Fish and Wildlife Service 2004).

Methods

Study Sites and Samples Collected

- The LCR was divided into four river segments based on hydrologic and physical characteristics (Figure 1).
- Composite samples of whole-body carp (*Cyprinus carpio*), sucker (*Catostomus* spp.), and peamouth chub (*Mylocheilus caurinas*) were collected in 1991 by electroshocking, seining, or hook and line fishing (Figure 1, Photo 2).
- Fresh eagle egg samples were collected from 19 bald eagle territories in 1994 and 1995 within segments 1 to 3 (Figure 1, Photo 3).
- To better compare variability in BMFs, we also used data for carp, sucker, and peamouth collected concurrently from segments 1 to 3 in 1991 by the Bi-State Study program (Tetra Tech 1993a,b) (see Table 1).

Chemical Analysis

- Chemicals selected for this analysis were DDE, total polychlorinated biphenyls (PCBs) reported as Aroclors, 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD), 2,3,7,8-tetrachlorodibenzofuran (2,3,7,8-TCDF), and mercury.
- DDE/total Aroclor PCBs: Soxhlet extraction, silica/alumina, Florisil column, and/or HPLC purification, silica gel cleanup; quantification by GLC or CGC/ECD; confirmation by mass spec/SIM (MDL=0.01 to 0.05 μg/g for DDE; 0.05 μg/g for PCBs).
- Dioxins and furans: Analysis followed EPA methods 1613 and 1613A incorporating two-stage, silica gel-based reactive cleanup, separation by HPLC and elution through basic alumina. Analytes were determined by HRGS/HRMS (MDL=0.2 to 1 pg/g).
- Mercury: Tissue digestion with sulfuric and nitric acids, or by nitric-reflux digestion; quantification by cold-vapor, atomic absorption spectrometry (MDL=0.05 μg/g).
- Data reported as wet weight for fish and fresh weight (adjusted for moisture/lipid loss) based on volume of bald eagle eggs.

Photo 3. Bald eagle egg in nest. Bald eagles along the lower Columbia River have lower 5-year productivity values than eagles nesting elsewhere in the state, and many eagle eggs fail to hatch.

Data Analysis

Data Analysis

- Apparent biomagnification factors (BMFs) (Braune and Norstrom 1989) were derived as the ratio of the geometric mean of a contaminant in the eagle egg (GM EGG) to the geometric mean in the prey fish (GM FISH):

$$BMF_{fish - BE\ egg} = [GM\ Egg] / [GM\ fish] \qquad (1)$$

- Target fish concentrations (TFCs), or the estimated contaminant concentration in prey fish that would be considered protective of bald eagles, were derived by the following equation:

$$TFC_x = NOAEL_{BE\ egg} / BMF_{fish\ -BE\ egg} \qquad (2)$$

where x is a contaminant, $NOAEL_{BE\ egg}$ is the concentration of contaminant x in the egg considered protective of bald eagle embryos (or no-observable-adverse-effect-level), and the $BMF_{fish\ -BE\ egg}$ is derived from equation 1.

- To better evaluate the relative magnitude of exceedances of concentrations in eggs over reference or threshold values, we used a hazard quotient (HQ) approach similar to Giesy et al. (1995):

$$HQ = [GM\ egg] / [NOAEL_{BE\ egg}] \qquad (3)$$

where [GM egg] is the geometric mean contaminant concentration in eagle eggs and [$NOAEL_{BE\ egg}$] (defined above) is based on 1) reproductive endpoints for PCBs, DDE, and mercury (Wiemeyer et al. 1993); and 2) reference concentrations in eggs of bald eagles reproducing successfully in coastal British Columbia for 2,3,7,8-TCDD and 2,3,7,8-TCDF (Elliott et al. 1996) (Table 1). Contributions from other dioxin-like compounds should be evaluated before making decisions based on results from 2,3,7,8-TCDD and 2,3,7,8-TCDF alone.

Model Assumptions

- Any piscivorous birds consumed by the eagles also would be receiving contaminants by eating the same fish stocks from the river. The BMF represents a field diet normalized to forage fish equivalents, given that eagles also forage on nonfish prey (primarily piscivorous and non-piscivorous birds).
- Organochlorine contaminants are in steady-state conditions among tissues in the river.
- Contaminants in prey fish did not change between 1991 and 1995.

Abstract

- The lower Columbia River is an important resource for fish and wildlife, and persistent contaminants entering the system threaten reproduction of predators feeding at upper trophic levels.
- To evaluate contaminant hazards to a top-level predator, we calculated hazard quotients (HQs) to represent the magnitude of contaminant concentrations in bald eagle (*Haliaeetus leucocephalus*) eggs that exceeded guidance or reference levels, determined biomagnification factors (BMFs) in eggs by comparing contaminant concentrations in eggs to those in fish, and calculated target fish concentrations (TFCs) or the concentrations in fish estimated to be protective of upper trophic level species.
- HQs, presented along with BMF and TFC values, indicated that contaminants in eagles along the river are within one order of magnitude above estimated effect threshold or reference guidance values.
- BMFs for most chemicals were comparable or higher (for polychlorinated biphenyls) to those found in other studies. However, the BMFs for polychlorinated biphenyls and DDE were very different than those estimated using fish data from a concurrent investigation.
- TFCs indicated contaminant concentrations in most fish still exceed levels considered protective of bald eagles.
- These values can be used by regional regulatory agencies in watershed-based strategies (e.g., total maximum daily load programs) and sediment management programs (e.g., sediment cleanup and dredging assessments) to better control releases of bioaccumulative contaminants, monitor changes in contaminants over time, and potentially reduce contaminant uptake from sediment sources.

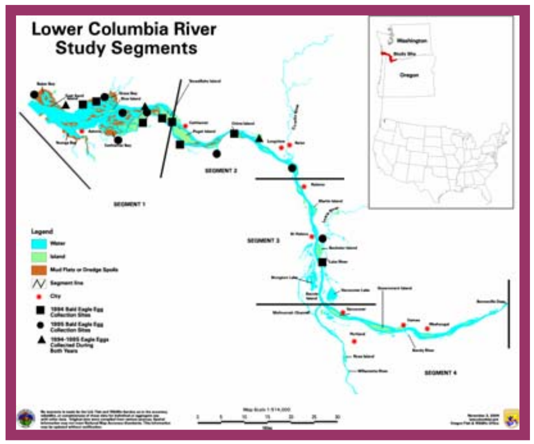

Figure 1. Study segments 1 to 4 within the lower Columbia River. Lower Columbia River study segments were designated based on the river's hydrologic and physical characteristics that influence sediment and contaminant transport and fate. Fish samples were collected in 1991, and bald eagles eggs were collected in 1994 to 1995 (see map legend for specific locations of egg collection). Only samples collected within segments 1 to 3 were used in the evaluation presented here, because no eagle eggs were collected from segment 4.

Acknowledgements

We would like to thank the following individuals for their contributions to this project: Gene Foster, Bruce Hope, Carol Schuler, Bob Anthony, Ted Buerger, and Larry Reigel. We also thank Robert Gale, Paul Peterman, Kathy Echols, Kevin Feltz, George Tegerdine and John Meadows of the Environmental Chemistry Branch of the Columbia Environmental Research Center for chemical analysis.

Photo 4. Bald eagle nestlings. Recent information has shown that DDE and PCBs in eagle eggs have declined along the LCR and productivity at some nest sites has improved. Improved success of eagles is associated with new birds immigrating into the areas, while productivity at some older nest sites has remained well below normal.

Photo 5. Baker Bay. Tidally influenced mudflats in the lower Columbia River have relatively fine-grained sediments and could be depositional areas for contaminants. These areas are common foraging sites for eagles, as fish prey often become stranded with the outgoing tide.

Results & Discussion

- HQs for total PCBs, DDE, 2,3,7,8-TCDD, and 2,3,7,8-TCDF exceeded a value of one, indicating fish prey contain hazardous concentrations for bald eagles (Table 1). The mercury HQ was below this value.
- BMF values were relatively similar among segments and were averaged for segments 1 to 3 (Table 1). BMFs were very different between our study and a concurrent study (Bi-state study) for PCBs and DDE, which was likely a result of differences in detection limits and skewed results for suckers. With the exception of PCBs, the average BMF values were similar to those calculated for osprey in the Willamette River, a tributary to the lower Columbia (Henny et al. 2003).
- BMF values for mercury and TCDF were very low, indicating poor transfer of these compounds from fish to eagle eggs (Table 1).
- The TFCs proposed for protection of bald eagles (Table 1) were slightly lower than protective guidance values reported in other regions (Newell et al. 1987), and indicated a reduction of current fish concentrations is warranted to better protect bald eagles.
- TFCs proposed in this study can be used as attainable goals for State water quality programs, and as an indicator of improving conditions over time.

Table 1. Hazard quotients (HQs), biomagnification factors (BMFs), and target fish concentrations (TFCs) based on fish data collected from segments 1 to 3 in 1991 by the U.S. Fish and Wildlife Service (USFWS) (2004) and the Bi-State study (Tetra Tech 1993a,b), and on eagle egg data collected in 1994 to 1995 by USFWS (1999) (n=19 eggs for organochlorines and 11 eggs for mercury from segments 1 to 3). Proposed TFCs for total PCBs and DDE were selected based on an average TFC value between the two studies, whereas TFCs for the ramaining compounds were selected based on USFWS data.

	No. composite fish samples	Geo. mean in fish	Geo. mean in bald eagle eggs	Estimated NOAEL or reference	HQ	BMF	Comparison BMF [a]	TFC	**Proposed TFC**
Total PCBs							11, 34		**0.06 μg/g**
USFWS study	36	0.044 μg/g	5.0 μg/g	4.0 μg/g	1.3	113		0.04 μg/g	
Bi-State study	42	0.10 μg/g				50		0.08 μg/g	
DDE							87, 32		**0.04 μg/g**
USFWS study	36	0.075 μg/g	5.6 μg/g	3.6 μg/g	1.6	75		0.05 μg/g	
Bi-State study	42	0.04 μg/g				141		0.03 μg/g	
Mercury									**0.2 μg/g**
USFWS study	36	0.08 μg/g	0.22 μg/g	0.5 μg/g	0.6	2.8		0.2 μg/g	
Bi-State study	41	0.10 μg/g				2.2		0.2 μg/g	
2,3,7,8-TCDD							10, 21		**0.9 pg/g**
USFWS study	36	1.4 pg/g	22 pg/g	15 pg/g	1.5	16		0.9 pg/g	
Bi-State study	31	1.1 pg/g				20		0.8 pg/g	
2,3,7,8-TCDF							0.42		**7.5 pg/g**
USFWS study	36	9.5 pg/g	22 pg/g	15 pg/g	1.5	2		7.5 pg/g	
Bi-State study	31	7.3 pg/g				3		5 pg/g	

[a] The first comparison BMF listed is based on osprey eggs and prey in the Willamette River, Oregon (Henny et al. 2003), and the second BMF is based on herring gull eggs and prey from Lake Ontario (Braune and Norstrom 1989).

Conclusions

- Bald eagles in the lower Columbia River feed on fish containing some organochlorine compounds at concentrations that are associated with poor reproduction. However, contaminant concentrations in eagle eggs are within one order of magnitude of effect thresholds, and it is likely that eagle reproduction could improve with relatively small decreases in fish contaminant concentrations.
- Parameters reported in this study such as the TFC can be used to effectively monitor responses in organochlorine contaminant concentrations in fish as a indicator of changes in land management practices or water quality control measures (e.g., increased riparian buffers or habitat modifications minimizing surface runoff). Other parameters such as BMFs can be used in modeling to better assess risk to top level predators in the region, and improve decision making processes for sediment management involving cleanup and dredging actions.

References

Anthony, R.G., M.G. Garrett, and C.A. Schuler. 1993. Environmental contaminants in bald eagles in the Columbia River Estuary. Journal of Wildlife Management 57:10-19.

Braune, B.M. and R.J. Norstrom. 1989. Dynamics of organochlorine compounds in herring gulls. 3. Tissue distribution and bioaccumulation in Lake Ontario gulls. Environmental Toxicology and Chemistry 8(10):957-968.

Elliott, J.E., R.J. Norstrom, and G.E. Smith. 1996. Patterns, trends, and toxicological significance of chlorinated hydrocarbon and mercury contaminants in bald eagle eggs from the Pacific coast of Canada, 1990-1994. Archives of Environmental Contamination Toxicology 31(3):354-367.

Giesy, J.P., W.W. Bowerman, M.A. Mora, D.A. Verbrugge, R.A. Othoudt, J.L. Newsted, C.L. Summer, R.J. Aulerich, S.J. Bursian, J.P. Ludwig, G.A. Dawson, T.J. Kubiak, D.A. Best, and D.E. Tillitt. 1995. Contaminants of fishes from Great Lakes-influenced sections and above dams of three Michigan rivers: III. Implications for health of bald eagles. Archives of Environmental Contamination Toxicology 29(3):309-321.

Henny, C.J., J.L. Kaiser, R.A. Grove, V.R. Bentley, and J.E. Elliott. 2003. Biomagnification factors (fish to osprey eggs from Willamette River, Oregon, U.S.A.) for PCDDs, PCDFs, PCBs and OC pesticides. Environmental Monitoring and Assessment 84(3):275-315.

Newell, A.J., D.W. Johnson, and L.K. Allen. 1987. Niagara River biota contamination project—fish flesh criteria for piscivorous wildlife. Final Report. New York State Department of Environmental Conservation, Division of Fish and Wildlife, Bureau of Environmental Protection Technical Report 87–3. 182 p.

Tetra Tech. 1993a. Reconnaissance survey of the lower Columbia River. Task 6: Reconnaissance report. Volume 3: Data tables, Appendices B, C, D, and E. Final report (TC 8526-06) prepared for Lower Columbia River Bi-State Committee, January. Tetra Tech, Inc., Redmond, Washington.

Tetra Tech. 1993b. Lower Columbia River backwater reconnaissance survey. Reconnaissance report. Volume 3: Data appendix. Final report (TC 9497-06) prepared for Lower Columbia River Bi-State Committee, December. Tetra Tech, Inc., Redmond, Washington.

U.S. Fish and Wildlife Service. 1999. Changes in productivity and environmental contaminants in bald eagles nesting along the lower Columbia River. Final Report. U.S. Fish and Wildlife Service, Oregon State Office, Portland, Oregon. 56 p.

U.S. Fish and Wildlife Service. 2004. Environmental contaminants in aquatic resources from the Columbia River. Final Report. U.S. Fish and Wildlife Service, Oregon Fish and Wildlife Office, Portland, Oregon. 112 p.

Watson, J.W., M.G. Garrett, and R.G. Anthony. 1991. Foraging ecology of bald eagles in the Columbia River estuary. Journal of Wildlife Management 55(3):492-499.

Wiemeyer, S.N., C.M. Bunck, and C.J. Stafford. 1993. Environmental contaminants in bald eagle eggs--1980-84--and further interpretations of relationships to productivity and shell thickness. Archives of Environmental Contamination and Toxicology 24(2):213-227.