ENVIRONMENTAL CONTAMINANTS IN AQUATIC RESOURCES FROM THE COLUMBIA RIVER

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Photo 1. Caspian tens and gulls on Rice Island. East Sand and Rice Islands, located near the mouth of the Columbia River, support the largest breeding colony of Caspian terns in North America, although recently terns have been relocated from Rice to East Sand Island.

Photo 3. Tidally influenced mudflats in the lower river have relatively fine-grained sediments and could be depositional areas for contaminants. However, only low concentrations of bioaccumulative contaminants were found in sediment from these areas.

Abstract

The Columbia River in Oregon and Washington is important for numerous aquatic and terrestrial resources including endangered species. These natural resources are exposed to environmental contaminants entering the river from point and nonpoint sources. In 1990 and 1991, we collected sediment, invertebrates (crayfish and clams), fish, and eggs of piscivorous and non-piscivorous birds within various river segments to determine contaminant concentrations, identify concentrations in biota that exceed guidance or reference levels, and derive apparent biomagnification factors (BMFs) for persistent, bioaccumulative compounds. BMFs were used to develop target fish concentrations (TFCs), or the concentrations in fish that would be protective of bald eagles (*Haliaeetus leucocephalus*). Similar to previous and concurrent studies, we found DDE and DDD were the most commonly detected and most elevated compounds in biota from the river. Polychlorinated biphenyls (PCBs) were found frequently in fish and bird egg samples, but were rarely detected in sediment or invertebrates. PCBs and DDE in most fish samples exceeded estimated guidance values for the protection of avian predators, and concentrations in eggs of some piscivorous birds exceeded estimated no-observed-adverse-effect levels (NOAELs). Nearly all fish sampled also contained 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) and 2,3,7,8-tetrachlorodibenzofuran (TCDF) in excess of guideline values derived for the protection of avian predators, and concentrations in eggs of some piscivorous birds exceeded estimated NOAELs. Based on data from lower Columbia River fish and bald eagle eggs, average BMFs were 113 for total PCBs, 76 for DDE, 2.6 for mercury, 17 for TCDD, and 2 for TCDF. TFCs derived from the BMFs were 0.06 μg/g, 0.04 μg/g, 0.30 μg/g, 0.88 pg/g, and 7.5 pg/g, respectively. Although bioaccumulative contaminants were near or below detection limits in sediment and invertebrates, the results document biomagnification of some organochlorines to concentrations likely resulting in adverse impacts to some piscivorous bird species. A basin-wide strategy is needed to better control releases of bioaccumulative compounds, minimize contaminant exposure to piscivorous birds, and monitor changes in organochlorine concentrations over time.

Introduction

The Columbia River lies within the second largest river basin in the United States, draining about 660,500 square kilometers (Fox et al. 1984, Simenstad et al. 1990). A variety of contaminants enter the river from point and non-point sources such as industrial discharges and runoff from urban, agricultural, and forested areas. The river and estuary provide essential breeding and wintering habitat for colonial nesting and migratory birds, and for threatened or endangered species and anadromous fish (Photo 1). Many of these fish and wildlife species depend on the river for foraging, breeding, and rearing, and therefore are exposed to contaminants entering the river from anthropogenic sources.

Several persistent and bioaccumulative contaminants, primarily organochlorine (OC) pesticides, polychlorinated biphenyls (PCBs), dioxins, furans, and some metals, such as mercury, have been found in Columbia River fish and wildlife. PCB concentrations in mammals such as mink (*Mustela vison*) and river otter (*Lutra canadensis*) exceeded levels shown to be associated with reproductive impairment in mink (Henny et al. 1981, Elliott et al. 1999a), and elevated concentrations of dioxin, furans, DDE, and PCBs have been found in bald eagle (*Haliaeetus leucocephalus*) eggs (Anthony et al. 1993). Fish collected from the lower Columbia River had dioxin concentrations exceeding human health guidelines. The current study was undertaken to determine if persistent, bioaccumulative compounds are present at concentrations hazardous to fish and wildlife inhabiting National Wildlife Refuges and other locations in the Columbia River.

Objectives

- Determine and compare contaminant concentrations in sediment, aquatic invertebrates, fish, and bird eggs within various segments of the Columbia River (segments were designated based on different physical and hydrologic characteristics);
- Compare concentrations in biota to guidance or reference levels to identify primary contaminants of concern and resources at risk;
- Derive biomagnification factors (BMFs) and target fish concentrations (TFCs) for persistent, bioaccumulative compounds.

Photo 2. Eggs and hatchlings of double-crested cormorants. Eggs of cormorants and other birds were collected to determine impacts of bioaccumulative contaminants on fish-eating species.

Methods

Study Sites

- Sediment, invertebrate, fish, or bird eggs (Photo 2) were collected in 1990 and 1991 in the lower Columbia River (LCR) below Bonneville Dam and in the Willamette River near Portland (Figure 1), and in the mid-Columbia River (MCR) near McNary Dam and Crescent Island (Umatilla Segment; Figure 2). Not all species were sampled or found at every site (see Figures 1 and 2).
- The LCR sites were selected to evaluate contaminants in biota within 4 river segments (distinguished based on hydrologic and physical characteristics that influence sediment and contaminant transport and fate) as previously defined by the Bi-State Study (Tetra Tech 1992b). The Umatilla Segment was selected to evaluate biota at the Umatilla National Wildlife Refuge. Eight study areas were selected within the 4 segments of the LCR, the Portland site, and the Umatilla Segment of the MCR.

Samples Collected

- 276 total samples in 1990 and 1991 (73 fish and bird egg samples in 1990; 203 sediment, invertebrates, fish, and bird eggs in 1991).
- 24 composite surface (< 30 cm) sediment samples in 1991 from depositional areas (3 composite samples representing 3 different locations within each of the 8 study areas).
- 48 invertebrate samples in 1991, including Corophium (*Corophium* spp.), Corbicula clam (*Corbicula manilensis*), Macoma clam (*Macoma* spp.), or crayfish (*Cambarus astacus*).
- 1990 Fish: 26 composites of carp (*Cyprinus carpio*), peamouth chub (*Mylocheilus caurinus*), sucker (*Catostomus* spp.), northern pikeminnow (*Ptychocheilus oregonensis*), smallmouth bass (*Micropterus dolomieu*), or largemouth bass (*M. salmoides*) from LCR segments and the Portland site only (Figure 1). 1991 Fish: 52 composites of carp, sucker, peamouth chub, or mountain whitefish (*Prosopium williamsoni*) from the LCR and MCR (Figures 1 and 2). All fish were collected by electroshocking, seining, or hook and line fishing.
- 1990 Bird Eggs: 27 eggs of western (*Larus occidentalis*) or glaucous-winged (*L. glaucescens*) gulls or hybrids, Caspian terns (*Sterna caspia*), or double-crested cormorants (*Phalacrocorax auritus*) from Segment 1, and 20 eggs from ring-billed gulls (*L. delawarensis*), Forster's terns (*S. forsteri*), and Caspian terns from the Umatilla Segment. 1991 Eggs: 79 eggs from 2 non-piscivorous birds from the LCR and 5 piscivorous birds from LCR and MCR. Non-piscivorous birds were mallard (*Anas platyrhynchos*) and Canada goose (*Branta canadensis*); piscivorous birds were western/glaucous-winged gull, Caspian tern, and double-crested cormorant from LCR; ring-billed gull (*L. delawarensis*) and Caspian and Forster's tern from Umatilla (Figures 1 and 2).

Chemical Analyses

- Sediment and tissue: OC pesticides, total PCBs, dioxins and furans. Mercury was analyzed in tissues only. Not all tissues were analyzed for the same group of chemical constituents.
- 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).
- OC Pesticides/Total 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 OC pesticides; 0.05 μg/g for PCBs).
- Dioxins and furans: Analysis followed EPA methods 8280, 1613, and 1613A incorporating 2-stage, silica gel-based reactive cleanup, separation by HPLC and elution through basic alumina. Analytes in 1990 samples were quantified by HRGC/LRMS (monitoring sequential mass windows of 12 selected ions separation); 1991 samples by HRGS/HRMS (MDL=0.2 to 1 pg/g).
- Data reported as dry weight for sediment and wet weight for tissues. Egg concentrations (fresh weight) adjusted for moisture/lipid loss after estimating volume based on egg length and breadth.

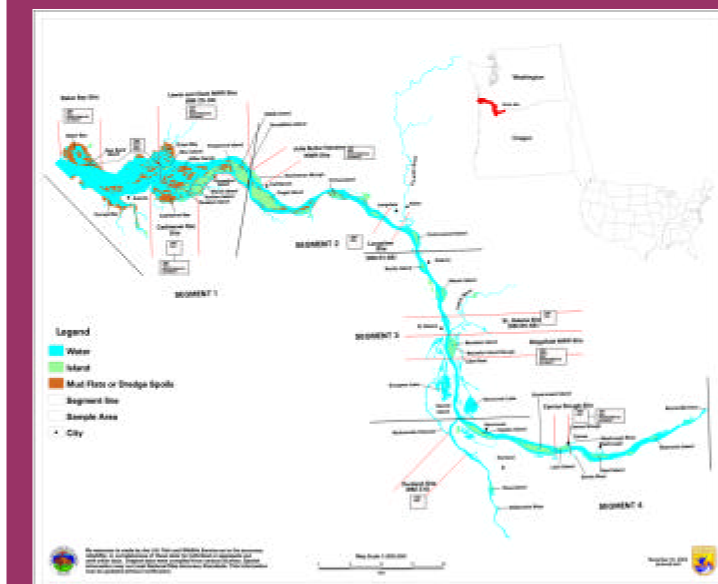

Figure 1. Study sites and sample types collected in 1990 and 1991 along the lower Columbia River below Bonneville Dam and in the Willamette River near Portland. Lower Columbia River sites were separated into Segments 1 to 4 based on the river's hydrologic and physical characteristics that influence sediment and contaminant transport and fate.

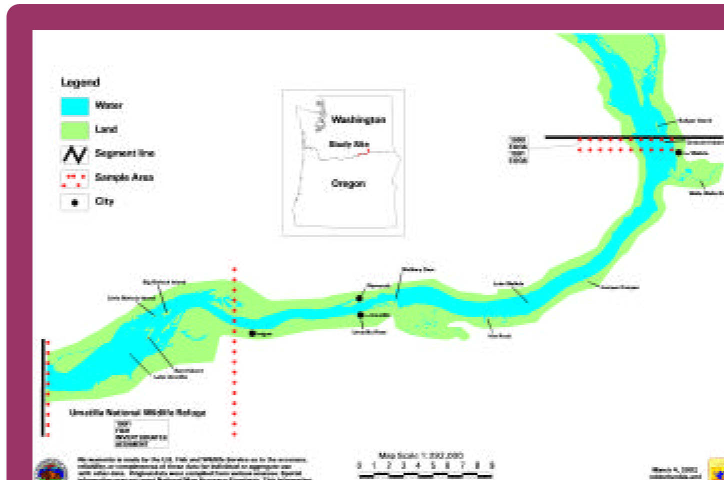

Figure 2. Study sites and sample types collected in 1990 and 1991 in the mid-Columbia River associated with the Umatilla National Wildlife Refuge. Samples were collected in this area to evaluate contaminant exposure to biota using the refuge.

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Results & Discussion

Sediment (Photo 3): No samples contained detectable PCBs, and few samples contained OC pesticides (maximum DDE=30 μg/kg from Segment 2). Likewise, the Bi-State Study (Tetra Tech 1993a, 1994) found few OC compounds in depositional sediment from the LCR, although DDT compounds were the most commonly detected pesticides in both studies. DDE in 1 sample from Segment 2 was the only one to exceed the lower 10 percentile of concentrations associated with biological effects (Long and Morgan 1990), which indicates invertebrates could be impaired at this site. Dioxins and furans were found only infrequently in sediment. Both the present study and the Bi-State Study found no clear spatial trends with OC contaminants in sediment.

Invertebrates: Mercury was below concentrations (0.1 μg/g) considered protective of avian predators, and total PCBs and most OC pesticides were below detection limits. DDE was the most commonly detected OC pesticide, occurring in 54% of the invertebrate samples. DDE was detected in nearly all clam samples (maximum of 0.09 μg/g at Segment 2), but was detected much less frequently in crayfish. Similar to our study, the Bi-State Study found DDE to be the most commonly detected OC pesticide in crayfish. Most dioxins and furans were below detection, although TCDF was detected in 97% of samples (up to 10 pg/g). Few studies have evaluated impacts to invertebrates from OC compounds, and it is unlikely that current concentrations impact invertebrates. However, invertebrates could be a source for OC compounds to predators.

Fish: Mercury was present in nearly all fish sampled, and concentrations in 39% of the fish exceeded the level of 0.1 μg/g in food items considered protective of avian predators. Results from previous studies and this study indicate that mercury is consistently found in samples at all locations, and may be more available to fish in Segments 2 and 3. Total PCBs and DDE were the most common and most elevated OC compounds, detected in 87% and 100% of the fish, respectively. Dioxins and furans were detected relatively frequently and at all sites. Guidance values for total PCBs, DDE, dioxins, and furans derived for the protection of bald eagles or for the protection of piscivorous fish and wildlife were exceeded for at least one species at all river segments. However, similar to results from the Bi-State Study, concentrations of OC compounds were not consistently elevated in any particular species or river segment.

Birds: Total mercury was found in all eggs (up to 2.0 μg/g), and concentrations in a number of eggs from piscivorous birds were within the range of concentrations (0.79 – 2.2 μg/g) associated with impaired reproduction. Nearly all eggs contained DDE and total PCBs, which were the most commonly detected OC compounds. In cormorants, DDE and total PCBs ranged up to 9.9 and 10.8 μg/g, respectively. Total PCBs in some cormorant eggs exceeded estimated guidance values based on egg lethality, and concentrations of DDE in a Caspian tern and a cormorant egg from Umatilla exceeded the range of values associated with embryo death and reproductive impairment. Total PCB and DDE concentrations were below estimated effect levels in all other eggs. Most eggs of piscivorous birds contained dioxins and furans, particularly TCDD. TCDD ranged up to 44 pg/g in a cormorant egg from Segment 1. Although few eggs of most species exceeded estimated effect-level guidelines for dioxin-like compounds, 77% of the cormorant eggs exceeded these guidelines. OC compounds and mercury in eggs of piscivorous birds greatly exceeded concentrations in non-piscivorous birds.

Contaminants within River Segments: Fish and bird eggs had the greatest detection frequencies of DDE, total PCBs, TCDD, and TCDF compared to invertebrates and sediment, yet results did not indicate that individual river segments contributed disproportionately more than others to the overall loading or body burdens of these contaminants (Figure 3). Some individual contaminants were more common in various river segments when all sampling matrices were combined within a river segment (Figure 4). For instance, total PCBs and TCDD were more common in Segment 1 and at Umatilla, whereas DDE was more evenly detected among all river segments (Figure 4). In contrast, TCDF was found most commonly in Segments 2 and 3, and least in Segment 4 and Umatilla. These results suggest that most OC contaminants are evenly distributed in fish and wildlife in the river, and no individual river segment contributes more contaminants into the system than other segments.

BMFs and TFCs (Photo 4): Apparent BMFs (Braune and Norstrom 1989) were determined for mercury, DDE, total PCBs, TCDD, and TCDF for Segments 1 to 3 based on 1991 fish data and data from a 1994 to 1995 bald eagle egg study (U.S. Fish and Wildlife Service 1999). BMFs within segments were relatively similar with the exception of total PCBs, which ranged from 90 for Segment 2 to 155 for Segment 3. BMF values averaged among the 3 segments were 113 for total PCBs, 76 for DDE, 2.6 for mercury, 17 for TCDD, and 2 for TCDF. BMF values for mercury and TCDF values were very low, indicating poor transfer of these compounds from fish to eagle eggs. BMF values for DDE and PCBs were higher than those reported in other studies. The TFCs, or concentrations in fish considered protective of bald eagles based on the apparent BMF values, for PCBs, DDE, mercury, TCDD, and TCDF were 0.06 μg/g, 0.04 μg/g, 0.30 μg/g, 0.88 pg/g, and 7.5 pg/g, respectively, and were lower than estimated protective guidance values reported elsewhere.

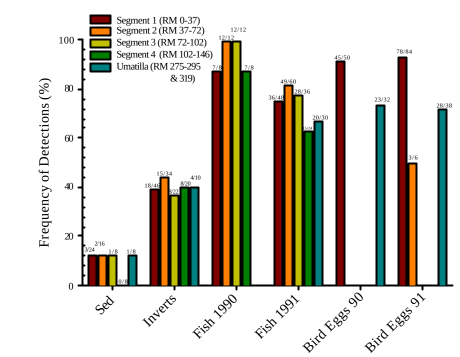

Figure 3. Frequency of detection (number of detections/number of samples) of selected OC compounds in sediment and biota collected in 1990 and 1991 from segments of the Columbia River. Numbers above bars represent total number of samples of sediment and biota above detection within a segment/total number of samples analyzed for the particular compound within the segment.

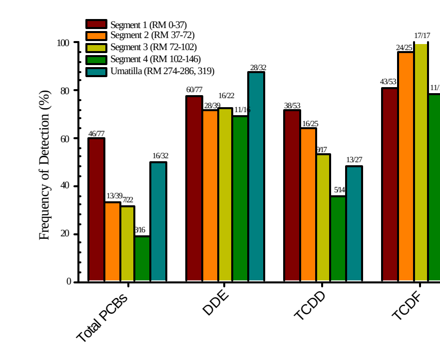

Figure 4. Frequency of detection of selected OC compounds combined by sample matrix (sediment and biota) from the Columbia River, 1990 and 1991. Numbers above bars represent the total number of samples within a segment with concentrations above detection/total number of samples collected within the segment.

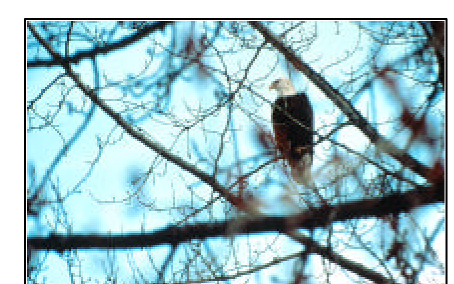

Photo 4. Bald eagles and other fish-eating birds nesting along the Columbia River contain the highest concentrations of bioaccumulative compounds. Bald eagle egg data from 1994 and 1995 were used in combination with fish data from 1991 to determine biomagnification factors.

Conclusions

- Similar to results from concurrent studies, spatial trends in contaminant concentrations in sediment or biota are not apparent in the Columbia River, and distinct source areas of OC compounds within river segments could not be identified.
- Although OC contaminants are primarily below MDLs in sediment and invertebrates, results clearly indicate contaminants are transferred to higher trophic levels; concentrations exceed estimated effect thresholds for some fish-eating birds.
- One reason for the absence of OC compounds in sediment but elevated concentrations in tissue could be that the organic carbon, silts, and clays often associated with contaminants are rare even in depositional areas. Any contaminants that are present in these areas, even at concentrations below detection limits, would be readily available to biota because the clays and silts that strongly bind the contaminants are not present or minimal. The increased availability of these contaminants means that lower concentration in sediment would be a greater concern in this area than in other areas with higher contaminant concentrations but with more silts and clays.
- A basinwide approach is needed to further reduce releases of OC compounds into the Columbia River. Target fish concentrations (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.