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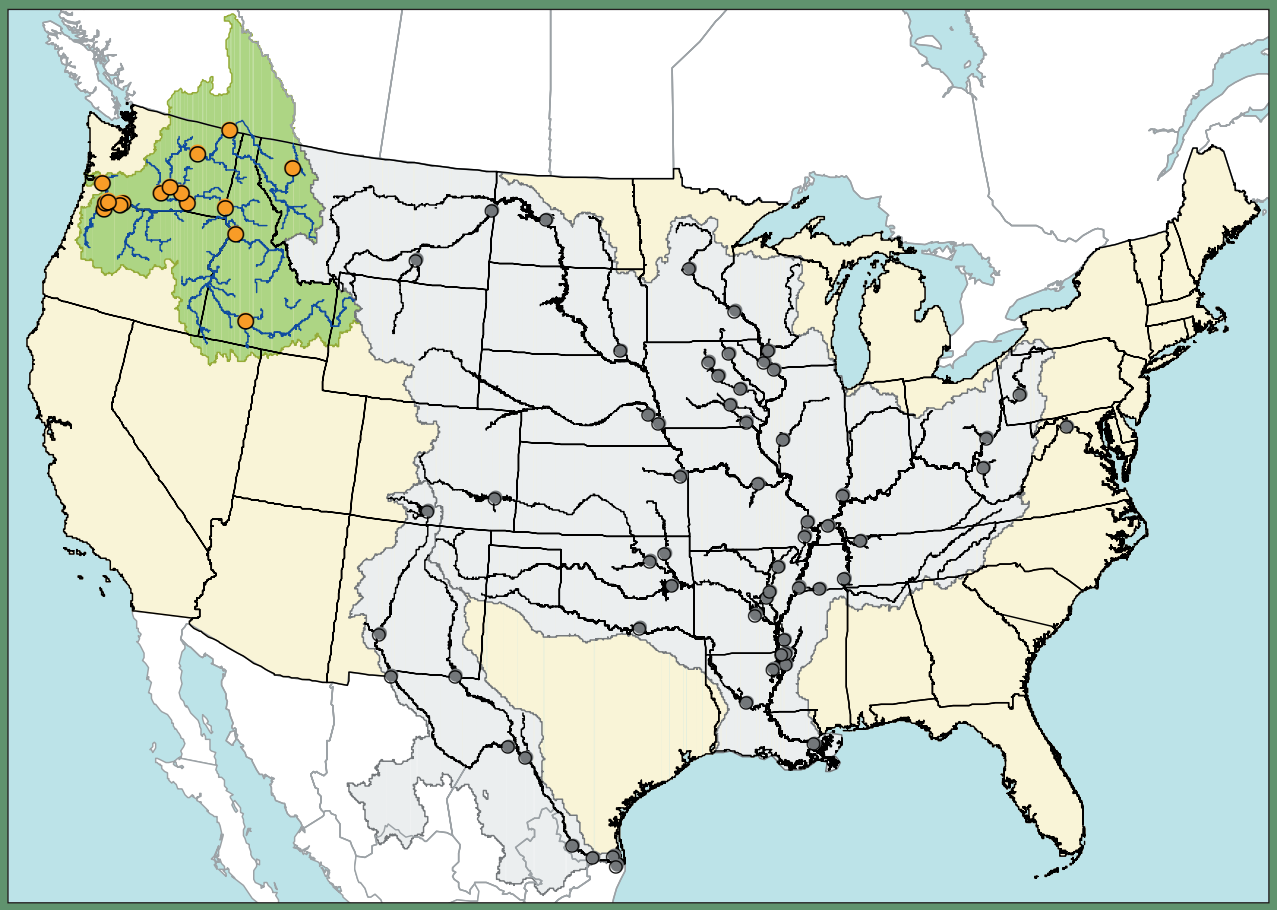
Biomonitoring of Environmental Status and Trends (BEST) Program: Environmental Contaminants and their Effects on Fish in the Columbia River Basin



Scientific Investigations Report 2004—5154

U.S. Department of the Interior
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Front cover. The U.S. map shows the Columbia River Basin (green) and stations sampled in this study (orange). Shown in gray are major river basins and stations in the conterminous U.S. sampled during other Biomonitoring of Environmental Status and Trends Program (BEST) investigations.

Biomonitoring of Environmental Status and Trends (BEST) Program: Environmental Contaminants and their Effects on Fish in the Columbia River Basin

By Jo Ellen Hinck, Christopher J. Schmitt, Timothy M. Bartish, Nancy D. Denslow, Vicki S. Blazer, Patrick J. Anderson, James J. Coyle, Gail M. Dethloff, and Donald E. Tillitt

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U.S. Department of the Interior
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U.S. Geological Survey, Reston, Virginia: 2004

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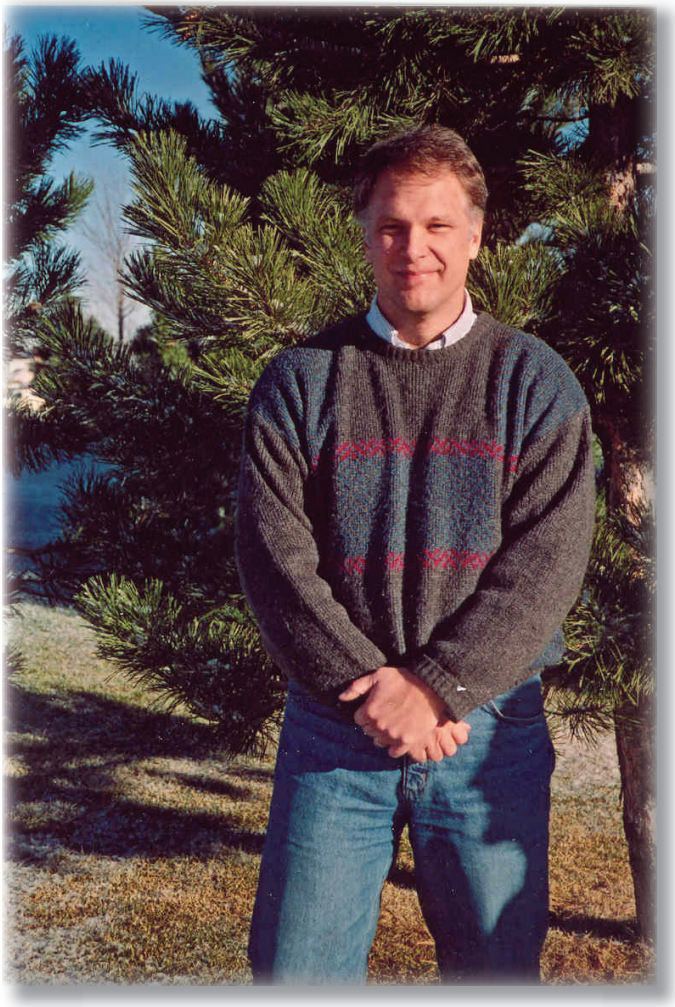
Suggested citation:
Hinck, J.E., Schmitt, C.J.; Bartish, T. M., Denslow, N.D.; Blazer, V.S., Anderson, P.J.; Coyle, J.J., Dethloff, G.M. and Tillitt, D.E., 2004, Biomonitoring of Environmental Status and Trends (BEST) Program: Environmental Contaminants and their Effects on Fish in the Columbia River Basin: U.S. Geological Survey, Columbia Environmental Research Center, Columbia, Missouri, Scientific Investigations Report 2004—5154, 125 p.

In Memoriam



This report is dedicated to Tim Bartish, our leader of the BEST Program. We were all saddened by the sudden loss of Tim when he passed away from pancreatic cancer on 13 February 2004. Tim provided the BEST Program with leadership since 1996; first as assistant coordinator, then as coordinator. Tim was a true leader and provided the program with a stable course of direction while he was at the helm. He was both a biologist concerned about the integrity of our nation's aquatic resources and a friend concerned about the people that he interacted with each and every day. The BEST Program has moved from a conceptual model, through the demonstration stages, to a true national monitoring program under the direction, patience, and care of Tim. We feel that the program has made tremendous progress over the past few years, and that progress would have never been realized without the foresight, guidance, and strength of Tim Bartish.

Preface

The study described in this report was conducted as part of the USGS Biomonitoring of Environmental Status and Trends (BEST) program. BEST evolved from previous federal monitoring programs including the National Pesticide Monitoring Program (NPMP) of the 1960s which was renamed the National Contaminant Biomonitoring Program (NCBP) in the early 1970s which also screened for elemental contaminants. The U.S. Fish and Wildlife Service (USFWS) participated in the NPMP and maintained the NCBP by monitoring concentrations of persistent contaminants in freshwater fish and avian wildlife through 1986. The BEST program was initiated in the 1990s to build on information produced by these earlier programs and to provide more biologically relevant information regarding potential contaminant effects on lands and species under USFWS management. The program was transferred to the National Biological Survey in 1993 and ultimately to USGS in 1996. The Large Rivers program of BEST has principal emphasis to identify, monitor, and assess the effects of chemical contaminants on the fish health in the nation's large rivers. The 1997 Columbia River Basin (CRB) study was implemented with a companion investigation of the Rio Grande Basin. The 1997 investigations represented continuations of a pilot study conducted in the Mississippi River Basin in 1995.

Acknowledgements

This study was conducted jointly by the USGS, through its research centers in Columbia, Missouri (Columbia Environmental Research Center, CERC) and Kearneysville, West Virginia (Leetown Science Center, LSC); and the U.S. Fish and Wildlife Service (USFWS), through its Ecological Services (ES) Field Offices in Portland, Oregon, Spokane, Washington, and Boise, Idaho. The study was facilitated through a Research Work Order with the USGS-Florida Cooperative Fish and Wildlife Research Unit at the University of Florida (UF), Gainesville, Florida. Many individuals representing USGS, USFWS, UF, and other organizations contributed substantially during the conduct of the study. C. Bunck (USGS) managed the BEST program during most of the study, and S. Finger (USGS) coordinated much of the work. S. Zylstra and T. Buerger organized and J. Buck (all USFWS) supervised field portions of the study. Chemical analyses were conducted at laboratories operated by Mississippi State University and the Research Triangle Institute through contracts with the USFWS. These contracts are managed by the USFWS Patuxent Analytical Control Facility (PACF); J. Moore and P. McDonald (PACF) facilitated this part of the study. Laboratory analyses for biomarkers were performed by D. Nicks and S. Birke (CERC), D. Bowling (LSC), and M. Chow and K. Kroll (UF). D. Bowling and K. Spring (LSC) assisted in the histology slide preparation, and E. Frankenberry (LSC) for assisted with the macrophage aggregate evaluation. A. Donahue (CERC) aged the fish, produced report graphics, and edited draft versions of the report. B. Wright and M. Ellersieck assisted with statistical analyses. R. Lipkin (CERC) managed the bibliographic database and prepared the report for publication. J. Whyte (CERC), P. Cirone (USEPA, Seattle, Washington), and M. Munn (USGS Tacoma, Washington) reviewed all or portions of the report and provided additional information.

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Conversion Factors

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in)
millimeter (mm)	0.03937	inch (in)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi)
cubic kilometer (km^3)	0.2399	cubic mile (mi^3)
	Volume	
milliliter (mL)	0.03381	fluid ounce (fl. oz)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
cubic meter (cm^3)	0.0002642	million gallons (Mgal)
	Mass	
kilogram (kg)	2.205	pound, avoirdupois (lb)
	Concentration	
microgram per gram (µg/g)	=	part per million (ppm; 10^6)
nanogram per gram (ng/g)	=	part per billion (ppb; 10^9)
picogram per gram (pg/g)	=	part per trillion (pptr; 10^{12})
milligram per millimeter (mg/mL)	=	part per thousand (ppt; 10^3)
milligram per liter (mg/L)	=	part per million (ppm; 10^6)
microgram per liter (µg/L)	=	part per billion (ppb; 10^9)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8×°C)+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Biomonitoring of Environmental Status and Trends (BEST) Program: Environmental Contaminants and their Effects on Fish in the Columbia River Basin

By Jo Ellen Hinck[1], Christopher J. Schmitt[1], Timothy M. Bartish[2], Nancy D. Denslow[3], Vicki S. Blazer[4], Patrick J. Anderson[5], James J. Coyle[2], Gail M. Dethloff[6], and Donald E. Tillitt[1]

Abstract

This project examined and analyzed 560 fish representing eight species collected from 16 stations in the Columbia River Basin (CRB) from September 1997 to April 1998. Ten of the 16 sampling locations were historical National Contaminant Biomonitoring Program (NCBP) sites where organochlorine and elemental contaminants in fish had been monitored from 1969 through 1986. Five sites were co-located at U.S. Geological Survey (USGS)-National Stream Quantity Accounting Network (NASQAN) stations at which water quality is monitored. The sampling location at Marine Park in Vancouver, Washington did not correspond to either of the established monitoring programs. Eight of the sampling locations were located on the Columbia River; three were on the Snake River, two were on the Willamette River, and one site was on each of the Yakima, Salmon and Flathead Rivers.

Common carp (*Cyprinus carpio*), black bass (*Micropterus* sp.), and largescale sucker (*Catostomus macrocheilus*) together accounted for 80% of the fish sampled during the study. Fish were weighed and measured then field-examined for external and internal lesions, and liver, spleen, and gonads were weighed to compute somatic indices. Selected tissues and fluids were obtained and preserved for analysis of fish health and reproductive biomarkers. Composite samples of whole fish from each station were grouped by species and gender and analyzed for persistent organic and inorganic contaminants and for dioxin-like activity using the H4IIE rat hepatoma cell bioassay.

Several contaminants were measured at concentrations that exceeded wildlife guidelines or thresholds and have been previously identified as chemicals of concern in the CRB. Concentrations of lead (>0.4 µg/g ww) in the upper Columbia River, selenium (>0.6 µg/g ww) in the lower Salmon and middle Columbia Rivers, and mercury (>0.1 µg/g ww) throughout the basin exceeded one or more wildlife criteria in composite fish samples. One or more fish samples from all stations except those in the upper CRB had concentrations of total DDT (>0.15 µg/g ww) that could be potentially harmful to piscivorous wildlife. Other organochlorine pesticide concentrations did not exceed criteria or were isolated to fish samples from a single sampling location. Concentrations of total PCBs (>0.11 µg/g ww) and TCDD-EQs (>5 pg/g) exceeded wildlife guidelines in fish samples from the middle and lower Columbia sub-basins, and ethoxyresorufin *O*-deethylase (EROD) activity was also elevated in fish samples at many of the same stations. However, trend analysis reflected decreasing or stable concentrations of total PCBs, *p,p'*-DDE, mercury, selenium, and lead in fish samples at stations where historical data were available.

Geographic differences for the biomarkers support that fish in the CRB were exposed to contaminants although spatial trends were not apparent. The variation in biomarker results, including spleen and liver size, concentrations of vitellogenin, and presence of ovotestes, demonstrates the necessity to evaluate multiple species. Several male bass collected near Lewiston, Idaho and Warrendale, Oregon were identified as having ovotestes, a condition that may be caused by many factors including exposure to environmental contaminants. Male bass, carp, and sucker containing low concentrations of vtg

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were common in the CRB, but comparatively high concentrations were measured only in males from Creston, Montana, Grand Coulee, Washington, and Pasco, Washington. Results of this study indicate that some organochlorines and metals remain at concentrations of concern for CRB fish, and biomarker responses are consistent with contaminant exposure in fish at specific locations within the CRB.

Introduction

The Columbia River, including major tributaries, is the most important economic driver in the Pacific Northwest. This region which utilizes the river for transportation, irrigation, food, electrical power, recreation, and more. The Columbia River system also supports numerous extractive industries including mining, timber, rangelands, and commercial fishing. These uses and demands on the river have affected water and habitat quality and have resulted in listings of impaired waters, fish consumption advisories, and threatened species. Although numerous federal and state programs have investigated contaminants and water quality throughout the Columbia River Basin (CRB), adverse impacts from environmental contaminants to fish within this system are poorly understood (Schneider, 2002). Grazing, logging, mining, agriculture, irrigation, and industrial and urban land uses have all been associated with degraded water quality in the CRB (Joy and Patterson, 1997; Rinella and others, 1993; Schneider, 2002; Wentz and others, 1998; Williamson and others, 1998).

We studied the Columbia River and several of its largest tributaries during fall 1997 and early spring 1998 as part of the Biomonitoring of Environmental Status and Trends (BEST) Program's large river monitoring activities. The BEST Program is unique among national monitoring programs with its emphasis on characterizing the effects of environmental contaminants on the health of the fish and their supporting habitat. BEST accomplishes this through the application of both chemical concentration measurements and by evaluating the physiological, morphological, and histopathological responses of contaminant exposure by the organism. The primary objective of our study was to document the occurrence and distribution of contaminants and their effects on fish in the CRB, and to evaluate the potential risk represented by these contaminants to other biota. Secondary objectives were to compare biomonitoring results from the CRB to other major river systems in the U.S., and to further define benchmarks for the quantification of long-term trends and interpretation of biomarker results. These latter objectives were achieved by building on the results of similar investigations conducted in the Mississippi River Basin (MRB) in 1995 (Schmitt, 2002a) and the Rio Grande Basin (RGB) in 1997 (Schmitt and others, 2004). Together, the 1997 projects were also designed to evaluate the compatibility of the BEST large rivers component with the USGS National Stream Quantity Accounting Network (NASQAN) program, which monitors concentrations of dissolved pesticides and other constituents in the waters of large U.S. rivers (Hooper and others, 2001). In addition, 1997 fish concentrations were compared to historical and contemporaneous data sets from the basin (Lower Columbia River Estuary Partnership (LCREP), 1991; Maccoy, 2001; Schmitt and others, 1999b; Tetra Tech Inc., 1996; U.S. Environmental Protection Agency (USEPA), 2002a).

Data for the 1997 CRB study are reported in this document and have been incorporated into an interactive national database at: <*www.cerc.usgs.gov/data/best/search/index.htm*>. Results from this study, together with those from similar investigations conducted in other river basins, will help resource managers and scientists assess contaminant impacts on fish and wildlife and human consumers of those fish, and will identify areas within the CRB that warrant further investigation of contaminant threats.

Columbia River Basin Overview

Hydrology and Environmental Setting

The Columbia River is the largest river of the Pacific Northwest and the fourth largest river in the U.S. The CRB was formed during the last ice age 12,000-19,000 years ago when ice dams repeatedly failed, forming the general route of the present day river. The river originates at Columbia Lake in the Rocky Mountains of British Columbia, flows for 1,214 miles (mi), and drains approximately 259,000 square miles (mi^2). Fifteen percent (39,000 mi^2) of the CRB is located within Canada. The average annual runoff at the mouth of the Columbia River is 198 million acre-feet with average year round flows of 275,000 cubic feet per second, second only to the Missouri-Mississippi River system.

The major tributaries of the Columbia River in the U.S. include the Snake, Pend Oreille, Bitterroot, Clark Fork, Willamette, Deschutes, Kootenai, Yakima, Flathead, Salmon, and Spokane Rivers (Fig. 1). The Snake River is the largest tributary of the Columbia River, flowing 1,038 mi from its headwaters in Yellowstone National Park in Wyoming to its confluence with the Columbia in southern Washington. The Willamette, the second largest CRB tributary, is the 13th largest river in the contiguous U.S. in terms of stream flow (Kammerer, 1990) and provides approximately 15% of the Columbia's annual discharge (Bastasch, 2002). There are numerous agricultural waterways and natural streams that drain agricultural lands of central Washington, although the Yakima River is one of the dominant agricultural systems. The lower Columbia River has salt water intrusion 23 mi upstream from the mouth, and tidal influences can extend 146 mi upstream to the Bonneville Dam.

The CRB has a diverse ecology that ranges from temperate rain forest to arid steppes and has a complex matrix

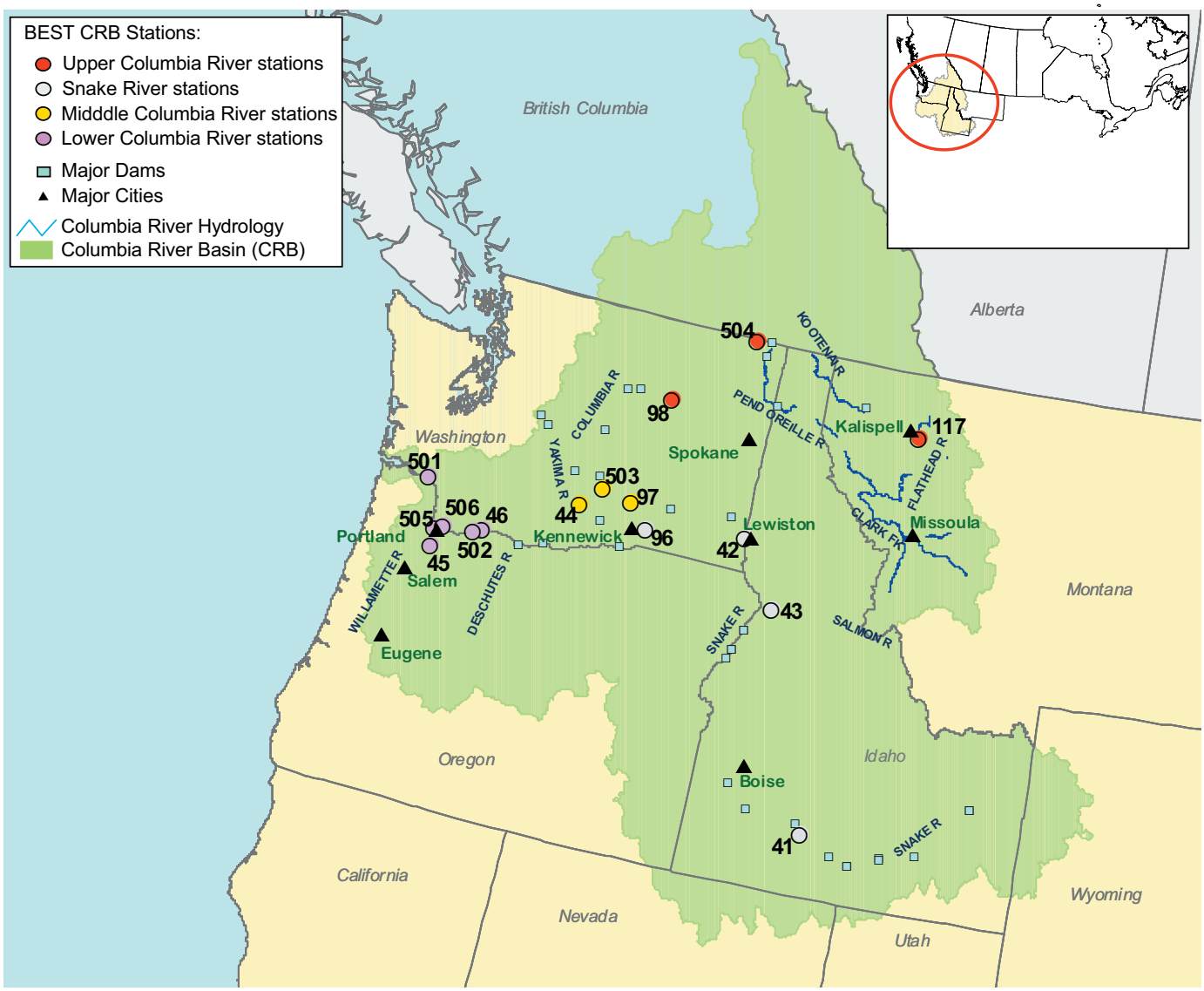

Figure 1. Map of the Columbia River Basin including state boundaries, major cities, major rivers and tributaries, and sites sampled in 1997 (March/April 1998 for Vancouver, Washington (506) and Beaver Army Terminal, Oregon (501)). See Table 3 for station descriptions.

of mountains, high plateaus, deserts, river valleys, and deep gorges. There are nine ecological provinces located within the CRB (Bailey, 1995). The Intermountain Semi-Desert Province is the largest ecoregion which includes the plains and plateaus of the Columbia and Snake Rivers and the Wyoming Basin and is characterized as semiarid with cool temperatures. The average annual precipitation ranges from <10-20 inches (in), and the average annual temperature is approximately 50°F. The chief vegetation in this ecoregion has historically been sagebrush with short grasses (Bailey, 1995). The second largest province is the Middle Rocky Mountain Steppes followed by the Cascade mixed/Coniferous Forest Province, and the Southern and Northern Rocky Mountain Steppes. These provinces are generally characterized as mixed evergreen-deciduous forest with much colder temperatures and greater amounts of precipitation. The remaining ecoregions, including the Sierran Steppe, the Pacific Lowlands, and the Great Plains-Palouse Dry Steppes, only have a portion of their area located within the CRB (Bailey, 1995).

Three distinct air mass types including moist marine air from the west, dry continental air from the east and south, and dry, cold artic air from the north influence the CRB (Ferguson, 1999; Quigley and others, 1997). Most precipitation occurs during the winter except in the far eastern and southern areas of the basin, which receive the most of their precipitation during the summer (Ferguson, 1999). Temperature and precipitation varies throughout the basin depending on the elevation and location of mountain ranges. Precipitation ranges from 6 in per year in the arid and semi-arid regions to 150 in per year in the eastern Cascade Mountains. Most of the basin is influenced by a rain shadow effect from the Cascade Mountains. One exception is Columbia Gorge area, which allows moist air to pass through. Arctic air is blocked by mountain ranges in British Columbia; however, some artic air masses

enter the basin through the Columbia, Okanogan, and Pend Oreille valleys which results in spring and summer precipitation (Ferguson, 1999). The Columbia Plateau and Snake River valleys are usually the driest areas of the CRB. Water from rainfall or snowmelt is slowly absorbed by the arid soils which often results in significant runoff (Ferguson, 1999).

Land Ownership

In the U.S. portion of the CRB, the federal government owns >52% of the land with private land ownership at 39%, and the remainder of ownership is partitioned among Native American lands and state and local government lands (Fig. 2) (Quigley, 1997). The U.S. Forest Service (USFS) and the U.S. Bureau of Land Management (USBLM) own and manage most of the federal lands. Approximately 24% of the USFS land and 10% of the USBLM lands are located in the CRB (Quigley, 1997). In general, USFS and USBLM administered lands are located in the high desert and mountainous regions of the basin whereas private lands are predominately located in river valleys and plateaus. Most private lands in the basin are located in the Willamette Valley, the Columbia Plateau, Yakima River Basin, and the Snake River Basin (Fig. 2).

Urban and Metropolitan Areas

The CRB covers approximately 8% of the U.S. land area and contains about 1.2% of the U.S. population (Quigley, 1997). Thirty-one percent of the CRB population lives in urban areas compared to the U.S. average of 78% (Quigley, 1997). Population density within the basin is one-third of the U.S. average (Quigley, 1997). The largest city in the CRB

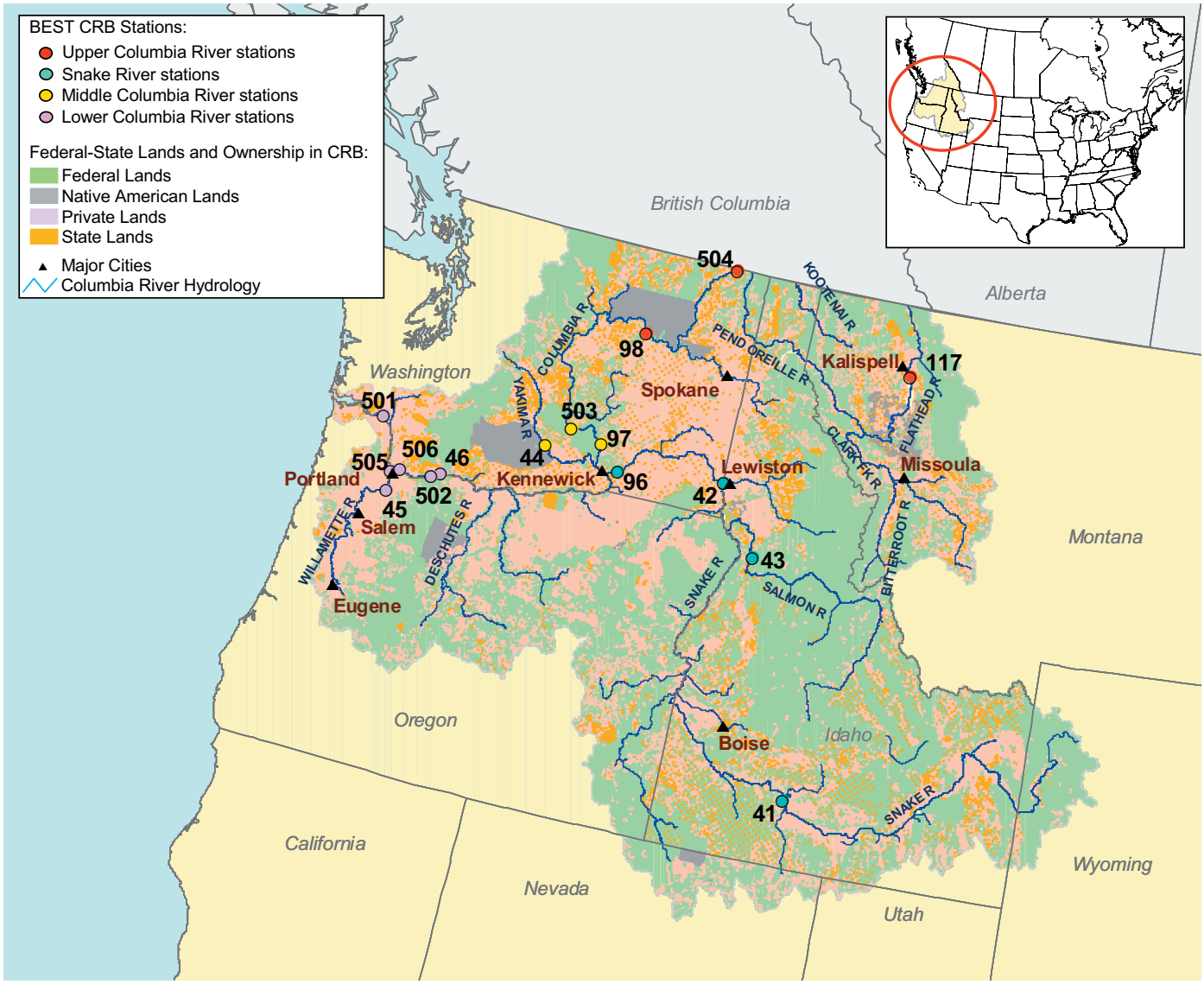

Figure 2. Map of land ownership in the Columbia River Basin including government and private land and sites sampled in 1997.

is Portland, with a population >500,000. Four other cities including Spokane, Salem, Eugene, and Boise have populations >100,000. The largest metropolitan area is the Portland-Vancouver-Beaverton metropolitan area. Other metropolitan areas include Boise, Eugene-Springfield, Richland-Kennewick-Pasco, Spokane, Yakima, and Pocatello. The Canadian portion of the basin does not have any large urban or metropolitan areas; most towns have populations <10,000.

Hydroelectric Power and Dams

The CRB is often cited as the most hydroelectrically developed river system of the world. Development of the major dams and storage reservoirs within the CRB took place from the early 1900s through the 1970s for irrigation, water storage, electrical power, and river transportation. There are >150 hydroelectric projects in the basin including 18 mainstem dams on the Columbia and Snake Rivers, representing 40% of the total hydropower production in the U.S. (Dietrich, 1995). The U.S. Army Corps of Engineers operates nine of ten federal projects on the Columbia and Snake Rivers (Fig. 1). Most federal dams on the lower Columbia and lower Snake Rivers are run-of-river dams that are primarily operated for power generation and navigation. Four federal dams (Bonneville, The Dalles, John Day, and McNary) have navigation locks that allow boats and barges to move upstream as far as Richland, Washington and Lewiston, Idaho. Five of the federal dams are storage dams of which the Grand Coulee is the largest.

The U.S. Bureau of Reclamation (USBOR) has been operating in the CRB since 1904. The USBOR has been involved with >39 projects, including 72 dams, dikes, and diversions and >4,700 mi of canals (Bonneville Power Administration (BPA), 2001). USBOR delivers water to 175 irrigation districts within the Pacific Northwest region, which includes approximately 2.9 million acres of irrigated crops with an estimated annual crop value of $2.2 billion (BPA, 2001). The largest of these projects is known as the USBOR Columbia River Project, which diverts 2.7 million acre-feet of water to irrigate 672,000 acres of land mainly within the Columbia Plateau (BPA, 2001). The key structure of the Columbia Project is the Grand Coulee Dam which is located on the main stem of the Columbia River. Extensive irrigation including 300 mi of main canals, approximately 2,000 mi of laterals, and 3,500 mi of drains and wasteways extend southward from the Columbia Plateau to Pasco and Richland, Washington (BPA, 2001; Schneider, 2002).

The Yakima Project, another large USBOR irrigation project, irrigates approximately 464,000 acres for growing grains, alfalfa hay, silage, dry beans, fruits, sugar beets, potatoes, sweet corn, and many specialty crops (BPA, 2001). Releases from both the Columbia and Yakima projects are made in July and August to ensure adequate water in the lower Columbia River for fish migration (BPA, 2001). Other smaller irrigation projects in the CRB are the Boise Project in Idaho and Oregon, the Mindoka Project in Idaho, the Deschutes Project in Oregon, and the Palisades Project in Idaho and Wyoming (Bastasch, 2002; BPA, 2001; Schneider, 2002). Much of the water diverted for irrigation is routed back to the river as irrigation return flows, which introduce nutrients and contaminants into streams and rivers. Several large-scale programs (Bi-State Water Quality Program, National Water Quality Assessment (NAWQA), and NASQAN) and focused studies in the CRB have cited agriculture and agriculture return flows as contributing to degraded water quality; however, the extent of the degradation is not well understood (Schneider, 2002).

Dams on the Columbia and Snake Rivers are noted for blocking anadromous fish migration and are contributors to degraded water quality (Schneider, 2002). Most often these dams affect water temperature, increase dissolved gases (mostly nitrogen), modify flow regimes, and are associated with industrial spills. Both water releases and periodic dredging allows for the navigation of barges up and down the rivers. Dredging operations have also contributed to degraded water quality by releasing contaminants from sediment (Schneider, 2002).

Water Quality

Impairments

Waters (rivers, streams, lakes) that do not meet defined water quality standards are listed as impaired. Section 303(d) of the Clean Water Act requires each state to assess all surface waters and list those that are impaired. There are hundreds of water bodies throughout the CRB on the 1998 303(d) list, and most are located on small tributaries and are included for temperature, dissolved gas, and flow modifications impairments. Other common impairments include dissolved oxygen, bacteria, pathogens, sediments, and pH. The review of 1998 303(d) listed waters for this report focused only on those listings associated with rivers or reservoirs related to the Columbia River and its major tributaries. The lower Columbia River has numerous impairments due to DDT (2,2-bis (*p*-chlorophenyl)-1,1,1-trichloroethane), DDE (2,2-bis (*p*-chlorophenyl)-1,1-dichloroethylene), dieldrin, phthalates, and PCB (polychlorinated biphenyl) (USEPA, 2002b). DDT and DDE are also noted for impairing reaches throughout the Yakima, lower Willamette, lower Snake, Walla Walla, and Pudding Rivers, and numerous creeks and reservoirs that are predominantly in agricultural areas. Dieldrin impairments are also common in agriculture areas in the lower Columbia River, middle and lower Willamette River, Yakima River, Owyhee River, Palouse River, and many creeks (USEPA, 2002b). Impairments due to PCBs occur in the lower Columbia (mouth to Bonneville Dam), Lower Willamette, Yakima, and lower Spokane Rivers (USEPA, 2002b). Nutrient impairments, which include

nitrates and phosphorus, are widely distributed throughout the CRB usually in smaller watersheds and on larger rivers including the lower Willamette, Clark Fork, Spokane, Umatilla, and the Malheur Rivers (USEPA, 2002b). A single dioxin impairment for the Columbia Slough near the Willamette River in Portland is listed for the CRB (Oregon Department of Environmental Quality (ODEQ), 2000). Most metal impairments are associated with mining activities and urban areas such as Portland and Spokane (USEPA, 2002b). Arsenic (As) impairments occur from the mouth of the Columbia River to McNary Dam (USEPA, 2002b), and mercury (Hg) impairments occur on the Yakima, Owyhee, Columbia (Roosevelt Lake to the international border), and Snake Rivers (Washington border to the Salmon River) (USEPA, 2002b).

Fish Consumption Advisories

Fish consumption advisories are designed to protect human health and are also good indicators of water quality because most advisories are issued after assessing results from fish tissues. The USEPA National Listing of Fish and Wildlife Advisories (NLFWA) database was queried for all the states associated with the CRB (USEPA, 2003a). There were >30 fish consumption advisories in the CRB during the early 1990s through 1998. The advisory review for this report only included those associated with rivers or reservoirs of the major tributaries. Mercury, dioxins, and PCBs were the most common contaminants associated with these advisories.

The mainstem of the Columbia River is associated with two fish consumption advisories. The first advisory for DDT, dioxins, and PCBs for all freshwater fish is located from the mouth of the Columbia River to Bonneville Dam (USEPA, 2003a). The second advisory, issued in 2000 for PCBs in shellfish and crayfish, is located above Bonneville Dam at river mile 147 (USEPA, 2003a) and is associated with the Bradford Landfill. Public health officials investigated contamination possibilities at this site in the early 1990s (Schneider, 2002), and it was determined that electrical equipment buried at the site contaminated soil and sediments in a localized area.

The Willamette River has several advisories for As, creosote, pentachlorophenol (near a wood treatment site located in Portland), Hg, and PCBs (USEPA, 2003a). The source of the Hg is thought to come from natural volcanic and mineral sources in the headwaters of the river and from a number of point sources along the river (Bastasch, 2002). The Willamette River advisories were revised in 2000 to include all fish for PCBs, organoclorinated pesticides, and dioxins (USEPA, 2003a). The Snake River is under a Hg advisory for all fish by the state of Oregon (USEPA, 2003a). This advisory extends from the Oregon/Washington border to the point at which the river leaves Idaho below the town of Adrian. An advisory for the Yakima River was issued for DDT and DDE in all bottom-dwelling fish. This advisory includes the Yakima River and all its tributaries and agricultural drains between the city of Yakima and its confluence with the Columbia River (USEPA, 2003a). The Spokane River is under fish advisories for lead (Pb) and PCBs (USEPA, 2003a).

There are two mainstem reservoirs with advisories. The advisory for Brownlee, located on the Snake River, was issued in 1994 because of Hg in common carp (*Cyprinus carpio*, henceforth carp) and game fish (USEPA, 2003a). Two advisories are listed for Lake Roosevelt. The first advisory, issued in 1994 for dioxins in whitefish (*Coregonus clupeaformis*) (USEPA, 2003a), has been attributed to a pulp mill in British Columbia (Schneider, 2002). A Hg advisory was issued for walleye (*Stizostedion vitreum*) in 2002 after high concentrations were reported in fish from Lake Roosevelt (Munn, 2000; Munn and Short, 1997).

U.S. Department of the Interior (DOI) Resources at Risk from Contaminants in the CRB

Thirty National Wildlife Refuges (NWRs) managed by the USFWS are located in the CRB. BEST sampling sites were located within 30 km of seven NWRs (Table 1). Multiple species within the CRB have been designated as having special status (that is, threatened, endangered, sensitive), although this designation is complicated by federal and state authorities using a variety of status listings. Hundreds of plant and animal species within the CRB have been listed by a variety of agencies, and several species are commonly recognized (Table 2) (USFWS, 2004).

Extant Sources of Information on Contaminants in the CRB

National Contaminant Biomonitoring Program

The National Contaminant Biomonitoring Program (NCBP), formally the National Pesticide Monitoring Program (NPMP), was maintained by the USFWS from the late 1960s through the 1980s. The main objective of this program was to document temporal and spatial trends of organochlorine and elemental concentrations in fish (Schmitt and others, 1999b). By the mid-1980s, the program reported concentrations of many persistent contaminants such as organochlorine pesticides, PCBs, and Hg were decreasing in whole body fish samples. Historical concentration data are available for fish samples, including carp, largescale sucker (*Catostomus macrocheilus*), bass (*Micropterus* sp.), and northern pikeminnow (*Ptychochelius oregonesis*), collected at 10 CRB sites (Stations 117, 98, 41, 43, 42, 96, 97, 44, 46, and 45; Table 3) from 1969 through 1986 (Schmitt and others, 1999b). These historical data were compared to our 1997 data to examine temporal trends in fish sample concentrations.

Table 1. National Wildlife Refuges (NWRs) located in the Columbia River Basin. BEST sampling sites located within 30 km of a NWR are listed.

NWR Name	BEST Site within 30 km of NWR
Ankeny NWR	
Baskett Slough NWR	
Camas NWR	
Cold Springs NWR	
Columbia NWR	
Conboy Lake NWR	
Deer Flat NWR	
Grays Lake NWR	
Julia Butler Hansen NWR for the Columbian Whitetail Deer Kootenai NWR	Station 501
Lee Metcalf NWR	
Lewis and Clark NWR	
Little Pend Oreille NWR	
McKay Creek NWR	
McNary NWR	Station 96
Minidoka NWR	
National Bison Range	
National Elk Refuge	
Nine-Pipe NWR	
Pablo NWR	
Ridgefield NWR	Stations 505 and 506
Saddle Mountain NWR	Station 503
Steigerwald Lake NWR	Stations 502 and 506
Swan River NWR	
Toppenish NWR	Station 44
Tualatin River NWR	Station 505
Turnbull NWR	
Umatilla NWR	
William L. Finley NWR	

National Estuary Program

The USEPA administers the National Estuary Program (NEP), which was established in 1987 by amendments to the Clean Water Act and places responsibility for protecting estuaries to the local level. Public and private stakeholders work through committees to identify problems, determine actions, and develop implementation plans to protect estuaries and their natural resources. The lower Columbia River Estuary Plan (Plan) focused on the 146 mi of tidally influenced section of the river below the Bonneville Dam. The Plan identified toxic contaminants as an issue of concern for the overall health of the Columbia River estuary citing pesticides in water, dioxin and metals in some sediment samples, and a host of organic and inorganic contaminants in the tissues of fish and wildlife (LCREP, 1991).

Columbia River Basin Fish Contaminant Survey

This study was undertaken in 1996-1998 to evaluate the risks posed to members of the tribes comprising the Columbia River Intertribal Fish Commission (CRITFC) (USEPA, 2002a). Sampling locations were selected based upon input from tribal members, and analytes were chosen based on resulsts from other studies in the CRB. Eleven species including anadromous and resident fish were collected. Whole body, fillet (skin off except for sturgeon samples), and egg samples (n=281) were collected, and composite fish tissues except for sturgeon samples were analyzed for a suite of 132 contaminants including 51 semi-volatile chemicals, 26 pesticides, 18 metals, seven PCBs, 20 dioxins, and 10 furans. More specifically, seven Aroclors®, 13 dioxin-like PCB congeners, seven chlorinated dioxins, and 10 chlorinated furan congeners were included in the analysis. Many contaminants including various semi-volatile chemicals, pesticides, metals, and PCBs were not detected although analytical methods may have resulted in high detection limits for some PAHs and semi-volatile chemicals. Hexachlorobenzene, chlordane (and related compounds), and DDT and its metabolites were the most frequently detected pesticides. Of the seven PCB analyzed, Aroclor® 1254 and 1260 were the most frequently detected, and four were never detected. Chlorinated dioxins and furans were widely detected; white sturgeon (*Acipenser transmontanus)* had the greatest concentrations. Antimony and silver (Ag) were the only inorganic contaminants of the sixteen analyzed that were not detected.

Contaminant Load Contributions to the Lower Columbia River (LCR)

Rosetta and Borys (1996) estimated the contaminant load contributions to the LCR (Columbia River below Bonneville Dam) based on discharge volumes and concentrations reported by permitted point sources and extrapolating from instantaneous analytical and flow measurements. The segment of the LCR proximal to and downstream from Portland received the highest organic and metal loads. Approximately 52% of the waste water volume discharged to the LCR came from sewage treatment plants, 39% from paper and allied product manufacturers, and 8% from chemical and primary metal production. While contributing only 39% of the total flows, paper and allied product manufacturers added 71% of the suspended sediment load to the LCR. The study also identified 147 facilities that were likely to contribute dioxins and furans to the river, 98 of which were discharged to either the Willamette or lower Columbia Rivers.

Table 2. Selected protected species identified as having special status by various agencies within the Columbia River Basin. [1]Quigley and others, 1997. [2]USFWS Threatened and Endangered Species System (TESS) webpage. <*https://ecos.fws.gov/ecos/sec/species.do*> (accessed 1/6/04)

Common Name	Scientific Name	Designation
White Sturgeon[1]	*Acipenser transontanus*	Endangered – USFWS, State of Idaho Sensitive – BLM
Pacific Lamprey[1]	*Lampetra tridentate*	Endangered – Idaho Dept of Fish and Game
Sockeye Salmon[1]	*Oncorynchus nerka*	Endangered – USFWS (Upper Snake River in Idaho)
Chum Salmon[1]	*Oncorhynchus keta*	Sensitive – Oregon
Coho Salmon[1]	*Oncorhynchus kisutch*	Endangered – NMFS (petitioned)
Costal Cutthroat Trout[1]	*Oncorhynchus clarki clarki*	Threatened – NMFS Critical Species – Oregon Dept of Fish and Wildlife
Pygmy Whitefish[1]	*Prosopium coulteri*	Monitor Species – Washington
Burbot[1]	*Lota lota*	Threatened – Idaho Sensitive – Region 1 USFS
Sand Roller[1]	*Percopis transmontana*	Special Concern – Idaho Monitor Species – Washington
Borax Lake chub[2]	*Gila boraxobius*	Endangered – USFWS
Brown pelican[2]	*Pelecanus occidentalis*	Endangered – USFWS
Bruneau Hot springsnail[2]	*Pyrgulopsis bruneauensis*	Endangered – USFWS
Columbian white-tailed deer[2]	*Odocoileus virginianus leucurus*	Endangered – USFWS
Lost River sucker[2]	*Deltistes luxatus*	Endangered – USFWS
Mountain yellow-legged frog[2]	*Rana muscosa*	Endangered – USFWS
Oregon chub[2]	*Oregonichthys crameri*	Endangered – USFWS
Canada Lynx[2]	*Lynx Canadensis*	Threatened – USFWS
Lahontan cutthroat trout[2]	*Oncorhynchus clarki henshawi*	Threatened – USFWS
Northern spotted owl[2]	*Strix occidentalis caurina*	Threatened – USFWS
Piping Plover[2]	*Charadrius melodus*	Threatened – USFWS
Steller sea-lion[2]	*Eumetopias jubatus*	Threatened – USFWS
Western snowy plover[2]	*Charadrius alexandrinus nivosu*	Threatened – USFWS

Bi-State Water Quality Program

The legislatures of Oregon and Washington along with contributions from port authorities and industry funded a four year initiative titled the Lower Columbia River Bi-State Water Quality Program (Tetra Tech Inc., 1996). The Bi-State Program focused on evaluating water quality in the Columbia River from the Bonneville Dam to the Pacific Ocean. One of the Bi-State Program initiatives was to evaluate the health of the river (Tetra Tech Inc., 1996). The evaluation concluded that there was strong evidence that many of the contaminants present in the LCR had the potential to have negative effects on wildlife. Sediments in select locations contained heavy metals, organochlorine pesticides, dioxins, furans, and other organic compounds at concentrations capable of harming wildlife.

USGS National Water Quality Assessment (NAWQA) Program

The NAWQA Program has conducted numerous assessments in five study units within the CRB. These study units include the Central Columbia Plateau (Washington and Idaho), upper Snake River Basin (Idaho and Wyoming), Willamette River Basin (Oregon), Yakima River Basin (Washington), and the Northern Rockies Intermontaine Basins (Washington, Idaho, and Montana). Pesticides were frequently detected below drinking water standards in ground water in the Central Columbia Plateau. Dieldrin, 1,2-dibromoethane (EDB), and 1,2-dichloropropane (1,2-DCP) were found to exceed drinking water standards in only 2% of the wells (Williamson and others, 1998), whereas the herbicide atrazine and its breakdown products were detected most often in ground water. Commonly used pesticides in the Palouse subunit of the Central Columbia Plateau were not detected in ground water, but 10 pesticides were detected in surface water. Nutrients have stimulated plant growth in streams which have contributed to dissolved oxygen levels below requirements by some fish species. Erosion has degraded habitat and mobilized sediment contaminated with persistent pesticides or total PCBs resulting in guidelines being exceeded at 22% of the sites sampled. The waterborne concentrations of agricultural pesticides (that is, currently used organophosphate insecticides) occasionally exceeded criteria for the protection of aquatic life in some streams.

Concentrations of nitrate in surface water in the upper Snake River Basin did not exceed the drinking water standard but were highest downstream from agricultural areas (Clark and others, 1998). Pesticides were generally detected in sur-

face water in the spring and early summer following seasonal applications; however, some pesticides were detected at low concentrations throughout the year. Detected pesticides in surface water did not exceed established water quality criteria. Excessive aquatic vegetation, low dissolved oxygen, and high water temperatures due to a combination of nutrient and sediment inputs and reduced stream flows characterize the middle Snake River. Pollution sources in the middle Snake River include discharges from fish hatcheries and municipal wastewater and agriculture irrigation returns.

Nutrients in surface water and ground water have degraded water quality in the Willamette Valley (Wentz and others, 1998). Total phosphorus concentrations exceeded values recommended to prevent nuisance plant growth in nearly half of the streams sampled. Elevated nitrate concentrations were associated with irrigated agricultural areas. Total dioxin and furan concentrations in stream and lake sediments exceeded the USEPA guideline for risks to fish at two sites located downstream of Portland and Corvallis, Oregon, although tissue concentrations did not exceed the threshold for risks to predator fish. Banned organochlorine pesticides and PCBs persisted in sediment and aquatic biota from streams and lakes. Sediment concentrations of organochlorine pesticides exceeded USEPA guidelines for protection of aquatic life at 10 of 47 sites with chlordane, DDT, and their related constituents accounting for most exceedances. Fish tissue concentrations of these chemicals collected at 17 sites did not exceed criteria for protection of fish-eating wildlife. Chromium (Cr) and nickel (Ni) in sediment commonly exceeded guidelines. The highest measured sediment concentrations of cadmium (Cd), Pb, Ag, and zinc (Zn) were found in urban streams. Mercury concentrations in bed sediment were found to be the highest downstream from the abandoned Black Butte Mine located south of Eugene, Oregon. Elevated concentrations of Hg in fish have resulted in consumption advisories in some streams and reservoirs.

Numerous studies in the Yakima River Basin have detected pesticides associated with irrigation drainwater throughout the basin (Ebbert and Embrey, 2002; Rinella and others, 1993; 1999). Pesticide studies conducted in 1999 and 2000 detected at least 20 pesticides basin wide (Ebbert and Embrey, 2002). The most frequently detected herbicide was atrazine, whereas azinphos-methyl was the most widely detected insecticide. Maximum concentrations of azinphos-methyl, carbaryl, diazinon, lindane, and *p*,*p*'-DDE have exceeded USEPA chronic-toxicity guidelines for the protection of aquatic life. The highest detection frequencies and concentrations of pesticides generally occurred during irrigation season and in the lower reaches of the Yakima (Ebbert and Embrey, 2002; Rinella and others, 1999).

Water quality issues with the northern Rocky Mountains Intermontane Basins study unit are mainly associated with mining activities and other extractive industries than from municipal and industrial wastes. Mining waste and tailings have affected surface and ground water in the watersheds of both the Clark Fork-Pend Oreille and Spokane Rivers (Beckwith, 2002; Maret and Skinner, 2000). Mine tailings in the study unit typically contain high concentrations of the trace metals such as As, Cd, copper (Cu), Pb, and Zn. Several fish kills in the Clark Fork River since 1984 have been attributed to the toxic effects of these trace metals (Maret and Skinner, 2000). Other water quality issues include high concentrations of PCBs in fish tissues. Concentrations of PCBs in sportfish fillets collected from the Spokane River exceeded the human consumption criterion for edible fish tissue while concentrations of total PCBs in most rainbow trout (*Oncorhynchus mykiss*; whole body and fillets) and largescale sucker (whole body) samples exceeded the criterion for fish-eating wildlife (Maccoy, 2001). Concentrations of PCBs in fish from the Spokane River have remained 10 times higher than protective criteria for more than six years (Maccoy, 2001).

NAWQA also assessed the occurrence and distribution of organochlorine pesticides and PCBs in aquatic biota as part of a national water quality assessment program from 1992-1995 (Wong and others, 2000). Whole body freshwater fish were collected from 234 sites across the U.S. in the early 1990s. Wong and others (2000) concluded that organochlorine pesticides were high in agricultural regions and urban areas.

Major Sources of Contaminants to the Columbia River Basin

Air Pollution Patterns

Air pollution patterns are typically influenced by weather fronts and geography. The most common patterns are temperature inversions which trap pollutants near the ground, wind patterns moving pollutants through the mountain passes, and rains depositing pollutants (Ferguson, 1999). Schoettle and others (1999) identified numerous pollutants of concern for the interior CRB including sulfur oxides, nitrogen oxides, ozone, small airborne particles, radionuclides, and numerous hazardous pollutants such as Hg, PCBs, and dioxins. Schoettle and others (1999) were able to generalize geographic distributions of air pollutant concentrations after assessing snowpack chemistry patterns and monitoring data. Areas west of Yellowstone National Park in Wyoming and a small area within Montana had the greatest concentrations of air pollutants (mostly sulfate, nitrates, and acidity) in the CRB. Collection sites at lower elevations had greater concentrations of these pollutants than high elevation snowpack sites, a pattern that was attributed to seasonal precipitation. Greater concentrations of air pollutants were measured in the summer rather than the winter when snow accumulation is greater.

Agriculture

The main agriculture centers of the CRB are along the lower Columbia River, the Willamette Valley, valleys and plateaus of the Snake River, and the Columbia Plateau. Approximately 7.3 million acres (using 6% of the total annual flow) are irrigated in the CRB, and the majority of the irrigated acreage (7.1 million acres) is in the U.S. Major crops include alfalfa, potatoes, mint, beets, beans, fruits, and grapes. The counties with the largest number of farms operating are located in the Willamette and Yakima sub-basins according to the U.S. Department of Agriculture (USDA) 1997 Agriculture census (USDA, 1997). Basins with the largest acreage in orchard crops were the Yakima, Willamette, and Hood River Basins. In 1997, 73% (80,000 acres) of orchards in Yakima County were treated with chemicals to control insects and diseases (USDA, 1997).

The NAWQA and NASQAN programs have investigated pesticides and other agricultural related contaminants in surface water and ground water throughout the CRB. Toxic chemicals were common in water, sediments, and fish tissues, and concentrations of these chemicals were greater than anticipated (Schneider, 2002). Most pesticides were detected in fish tissues at least once (Schneider, 2002) and found in complex mixtures (Clark and others, 1998; Wentz and others, 1998; Williamson and others, 1998). Exceedences of DDT and its byproducts, PCBs, and other pesticides and herbicides were measured in many basins; however, the Yakima basin had fish with some of the highest concentrations of DDT measured in the U.S. (Rinella and others, 1993). Persistent pesticide loads from irrigated agricultural areas of the lower Yakima River Basin have long been recognized as serious impairments to water quality, and data indicate that piscivorous wildlife are still likely at risk from exposure to DDT, dieldrin, and other pesticides in Yakima River fish (Joy and Patterson, 1997). Fish communities studied in the NAWQA basins were routinely degraded at urban and agriculturally influenced sites (Clark and others, 1998; Wentz and others, 1998; Williamson and others, 1998).

Mining and Extractive Industries

Mining was an important historical activity throughout the CRB. Today, most of the mining in the CRB is focused on metals (gold, Ag, iron (Fe), Hg, Cu, and Zn) and industrial minerals such as phosphate, limestone, dolomite, and perlite (Quigley, 1997). Aggregate mining (extraction of sand and gravel) is distributed throughout the basin often occurring near towns and waterways. Mining for metallic minerals and phosphates are limited to relatively small specific locations in the basin but are important on a national scale (Quigley, 1997). Phosphate deposits primarily located in the Snake River headwaters accounts for 4% of the world's production and 12% of the U.S. output. Gold production in Washington, Montana, and Idaho accounts for 11% of the total national output, and Ag production in Idaho and Montana contributes 30% of the national output. There are numerous small heap leach fields throughout the basin located on or near floodplains with the potential of contaminating streams and rivers (Quigley, 1997). Other metals commonly mined in the CRB are molybdenum and magnesium. Twenty counties within the CRB contributed >90% of the non-fuel mineral production and accounted for <25% of the mining economy during 1980 to 1992 (Quigley, 1997). The U.S. Bureau of Mines estimated that approximately 14,000 mines were inactive or abandoned in the CRB, and 190 of these sites were classified as potentially hazardous to the environment (Quigley, 1997). The NAWQA study units have all reported trace metal contamination from mining impacts (Clark and others, 1998; Wentz and others, 1998; Williamson and others, 1998).

There are several specific mining areas that are important in the upper CRB. The Coeur d'Alene (CDA) River is a tributary of the Spokane River in northern Idaho. The CDA River and surrounding basin have been heavily contaminated by tailings from a century of Pb mining and related activities in the area around Kellogg, Idaho. Farag and others (1998) reported juvenile perch (*Perca flavescans*) from the CDA River basin have bioaccumulated metals, and metals could bioaccumulate to concentrations that cause physiological effects in indigenous fish (Farag and others, 1995). In another study, laboratory cutthroat trout (*Oncorhynchus clarki*) were fed benthic macroinvertebrates from the CDA River which resulted in reduced feeding activity, histological changes, and metallothionein induction (Farag and others, 1999). Mining activities in the CDA River basin have also resulted in Pb-related problems in multiple bird species (Henny and others, 1994; 2000). The upper Clark Fork River basin in western Montana contains one of the largest ore deposits of Cu, Cd, Pb, manganese (Mn), and Zn and has received mining waste from Butte and Anaconda since 1880 (Woodward and others, 1994). Laboratory studies have reported tissue metal accumulation, physiological changes, and decreased survival and growth in rainbow trout fed a metal-contaminated invertebrate diet from the Clark Fork River (Farag and others, 1994; Woodward and others, 1994).

Industrial and Municipal Sources

The distribution, magnitude, and types of contaminants released in the CRB by industrial and municipal point and non-point sources exert both proximal and basin-wide impacts. To better understand these impacts and to support a more comprehensive analysis of our findings, records describing the location and types/amounts of contaminants released to the air (fugitive emissions) and surface waters of the CRB from 1990 to 1997 were reviewed. Location and discharge data for permitted facilities were derived from the USEPA's Better Assessment Science Integrating Point and Nonpoint Sources (BASINS ver 3.0) analysis system (USEPA, 2001) and through the USEPA Envirofacts Toxic Release Inventory

(TRI) (USEPA, 2003b) and Permit Compliance System (PCS) (USEPA, 2003c). Information on the Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) sites, a database to archive information on hazardous waste and remediation efforts at Superfund sites, was accessed through BASINS for 1997 (USEPA, 2003d). Unique CERCLIS identification numbers were used to query the Envirofacts CERCLIS database for Record of Decisions or for site documentation. Summaries of point-source discharges were derived from BASINS data.

The primary wastewater discharges in British Columbia include a Pb-Zn smelter at Trail and a pulp mill at Castlegar. The smelter has historically released significant quantities of As, Cd, Cu, Cr, Pb, Hg and Zn (Erwin and Munn, 1997; Schmitt and others, 2002a). The pulp mill typically releases organic compounds including furans, dioxins, chlorophenols, resin, and fatty acids (Serdar, 1997). In addition, the cities of Castlegar and Trail discharge treated municipal waste into the Columbia River.

Industrial discharges in the U.S. portion of the basin cluster in and near major population centers. Facilities discharging under the National Pollution Elimination Discharge System (NPDES) into the Spokane River and its tributaries in and near Spokane, Washington include two municipal wastewater treatment works and aluminum, paper, and chemical production facilities. Spokane is also host to >50 industrial facilities including food preparation, wood and paper product manufacture, paint and coating operations, plastic, metal and electronics manufacturing operations. Several food-related facilities located 30 mi upstream of Twin Falls, Idaho discharged >400,000 pounds (lbs) of nitrates and ammonia into the Snake River. The Boise River upstream of its confluence with the Snake River, received >700,000 lbs of nitrates from a food-processing facility and ammonia from an aquaculture operation. The Snake River, after its confluence with the Boise River, received an additional load (160,000 lbs in 1996) of nitrate compounds from a third food-related facility. Private and publicly owned hatchery operations are distributed throughout the basin, and the largest of these operations may produce one million pounds of fish annually. The largest impact of hatchery operations is phosphorus loading, which has contributed to the growth of aquatic vegetation, decreased oxygen, and increased temperature in the middle Snake watershed. Other discharges into the Snake River from 1995-1997 include Zn (>6,000 lbs), methanol (300,000 lbs), and formaldehyde (>5,000 lbs) from a pulp and paper mill near Lewiston, Idaho. Facilities in the Tri-Cities of Kennewick, Richland, and Pasco, Washington area include food-related, chemical, mill, and metal operations and waste water treatment facilities. The U.S. Department of Energy (USDOE) Hanford site has three sites discharging to surface waters under NPDES permits.

The Portland area hosts the largest and most diverse array of manufacturing and production facilities in the basin operating under TRI or NPDES. The Willamette Valley has >170 facilities operating with PCS permits including wastewater treatment, paper, chemical, metal, lumber, and food production facilities. The types of TRI facilities in the Portland area include >250 operations, comprising food, textile, mill works, cabinet, pulp and paper chemical printing, plastics, glass, ferrous and non-ferrous metal products, electroplating, machine parts, electronic and computer, motor vehicles, and surgical and optical manufacturing facilities. The Willamette River received discharges from a number of industrial facilities, including ship building operations, semi conductor manufacturers, and several paper mills which contributed Cu (16,000 lbs), manganese (43,000 lbs), nitrate chemicals (>2.8 million lbs), and Zn (51,000 lbs) from 1995-1997. Facilities in the Willamette Valley, discharging >5,000 lbs of individual contaminants to the Willamette River include two non-ferrous smelter/rolling plant, three paper/pulp mills, and two wood products manufacturers. Industrial facilities in this area cluster in the urban centers of Eugene, Corvallis, Albany, and Salem. In the upper CRB, a paper and pulp mill discharged nitrate compounds (>200,000 lbs) to the Pend Oreille River, and an aluminum producing facility released fibrous aluminum oxide (>11,000 lbs) in 1997.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA - Superfund) Site Summary

The CRB has 102 CERCLIS sites with national priority list (NPL) sites located in multiple states including Idaho (4), Montana (2), Oregon (8), and Washington (27). The majority of these sites are clustered in three areas including Central Washington, Eastern Washington/Western Idaho, and the Portland metropolitan area. With the exception of the Hanford site, the CERCLIS sites were combined and summarized according to the geographic clusters.

The Hanford site is composed of four administrative units (Areas 100, 200, 300, and 1100). These NPL sites are part of a USDOE complex 35 mi north of Richland, Washington. Radioactive waste, heavy metals, PCBs, and volatile organic compounds (VOCs) have contaminated ground water, soil, sludges, and/or surface water at this site.

Eleven CERCLIS sites including eight NPL sites are clustered in Central Washington (northeast of Wenatchee and southwest of Grande Coulee). This cluster includes industrial (2), landfill (4), national defense (3), and mining (2) sites. Most sites involve ground water, soil, and sludge contamination.

Fourteen CERCLIS sites including industrial (7), disposal (3), mining (3), and U.S. Army Corps of Engineers are located in Eastern Washington/Western Idaho. Five of the 14 sites are included on the NPL. Ground water, soil, sludge, and mining wastes are contaminated with a variety of organic and heavy metals.

The Portland metropolitan area cluster (including Vancover, Washington) contains 33 CERCLIS sites (primarily industrial) including 11 NPL sites. These sites involve con-

Table 3. Location, program of origin, and collection dates of sampling stations in the Columbia River Basin (CRB). Stations are grouped by sub-basin and ordered upstream to downstream.

River	Station number	Location	Program (NASQAN station ID)	Collection date(s)	Latitude, Longitude
Upper Columbia River (UCR)					
Flathead	117	Creston, MT	NCBP	10/31/97-11/1/97	48°09'01.09"N, 114°11'29.71"W
Columbia	504	Northport, WA	NASQAN (12400520)	11/3/97-11/4/97	48°58'21.70"N, 117°38'48.92"W
Columbia	98	Grand Coulee, WA	NCBP	11/6/97-11/7/97	47°57'44.85"N, 118°58'53.84"W
Snake River (SR)					
Snake	41	Hagerman, ID	NCBP	10/2/97	42°47'36.21"N, 114°56'18.10"W
Salmon	43	Riggins, ID	NCBP	9/30/97	45°35'43.42"N, 116°16'55.00"W
Snake	42	Lewiston, ID	NCBP	9/24/97-9/25/97	46°24'54.28"N, 117°02'03.49"W
Snake	96	Ice Harbor Dam, WA	NCBP	10/8/97-10/9/97	46°41'51.68"N, 118°53'07.88"W
Middle Columbia River (MCR)					
Columbia	503	Vernita Bridge, WA	NASQAN (12472900)	10/13/97-10/14/97	46°37'28.40"N, 119°51'31.45"W
Columbia	97	Pasco, WA	NCBP	10/10/97-10/11/97	46°31'49.22"N, 119°16'42.07"W
Yakima	44	Granger, WA	NCBP	10/15/97-10/16/97	46°20'49.31"N, 120°12'27.03"W
Lower Columbia River (LCR)					
Columbia	46	Cascade Locks, OR	NCBP	11/18/97-11/20/97	45°41'23.11"N, 121°51'00.41"W
Columbia	502	Warrendale, OR	NASQAN (14128910)	11/25/97-11/26/97	45°38'00.82"N, 121°58'42.57"W
Columbia	506	Vancouver, WA	--	4/2/98	45°35'44.21"N, 122°32'13.61"W
Willamette	45	Oregon City, OR	NCBP	11/21/97-11/24/97	45°19'03.47"N, 122°39'57.50"W
Willamette	505	Portland, OR	NASQAN (14211720)	11/14/97-11/17-97	45°33'04.51"N, 122°41'43.74"W
Columbia	501	Beaver Army Terminal, OR	NASQAN (14246900)	3/31/98-4/1/98	46°10'57.86"N, 123°04'13.87"W

tamination of ground water, soil, and sludge with a variety of metals (Cr, Ni, Cu, and Pb), cyanide, fluoride, VOCs, PCBs, polycyclic aromatic hydrocarbons and trichloroethane (TCE). In addition to the industrial sites, two well fields for the city of Vancouver, Washington are contaminated with TCE.

Materials and Methods

Collection Sites

Site selection for the 1997 BEST CRB study incorporated sites from previous investigations including NCBP and NASQAN. The overlap of sites allowed for comparison of fish tissue contaminant concentrations among studies. Fish were collected at sixteen sites in the CRB (Fig. 1; Table 3). Eight of the 16 sites were located on the Columbia River, two sites were on the Willamette River, three sites were on the Snake River, and one site was on each of the Yakima, Salmon, and Flathead Rivers. Seven sites were located in Washington, five sites were in Oregon, three sites were in Idaho, and one site was in Montana. Stations were grouped into four subbasins including the upper Columbia River (UCR), Snake River (SR), middle Columbia River (MCR), and lower Columbia River (LCR). These groups are not based on hydrology but rather geography to aid the reader in the physical location and distribution of sampling locations. The LCR had the most number of stations (Fig. 1). Ten sites corresponded to historical NCBP sampling stations, and five other sites represented NASQAN stations. Most fish were collected between early September and November 1997, but Stations 501 and 506 were not sampled until April 1998 (Table 3). Sampling at each site was completed during one visit spanning 1-4 days.

Target Species and Sampling Strategy

This study was designed to retain comparability with historical NCBP data (Schmitt and others, 1999b) and other investigations based on composite samples of whole fish while also accommodating the biological measurements incorporated into the overall investigation (Schmitt and Dethloff, 2000). Many of the biological instruments are gender-specific and require live or freshly killed individual fish. It was desirable to collect the same species at each site in a basin to standardize fish health and biomarker results. In previous NCBP collections (Schmitt and others, 1999b), the most prevalent bottom-dwelling species was carp, and the most prevalent predator species was the largemouth bass (*Micropterus salmoide*). These were also the targeted species in other BEST projects (Schmitt, 2002a; Schmitt and others, 2004). These species have a widespread distribution, abundant extant contaminant data, and thorough biological endpoint data. Therefore, carp and largemouth bass were the preferred taxa at all CRB sites. Alternate species were permitted if these taxa could not be obtained. Preferred alternate species included sucker (Catostomidae) as alternate benthivores, and other black bass (*Micropterus* sp., henceforth bass) as piscivores. The collection target at each site was 10 (each) adult male and female of each taxon for a total of 40 fish per site. Collectors were instructed to obtain adult carp and bass of a size representative of those believed to be present based on extant information and to avoid extremely large or small fish. More than two species were collected at sites with incomplete quotas for the target or preferred alternate taxa could not be obtained.

Monitoring Methods Overview

A suite of chemical and biological methods was used to characterize the exposure of fish to contaminants and the effects of exposure (Schmitt and Dethloff, 2000). The suite included reproductive biomarkers, measures of cytochrome P450 enzyme induction, fish health assessments, and chemical analyses of fish carcasses (Table 4). Additional information on these methods is available elsewhere (see Schmitt, 2002a; Schmitt and Dethloff, 2000; Whyte and others, 2000; 2004). Concurrent determination of tissue residue concentrations along with the suite of fish health, immune system responses, and reproductive assessments supports the interpretation of relationships between exposure and biological responses.

Table 5 identifies the organochlorine chemical and elemental contaminants measured in the fish carcass composite samples. These analytes were selected to provide the maximum amount of information on accumulative contaminants of interest at minimal cost and to maintain continuity with the historical NCBP database. Instrumental analyses of specific planar halogenated hydrocarbons (PHHs), such as PCB, polychlorinated dibenzo-*p*-dioxin (PCDD), and polychlorinated dibenzofuran (PCDF) congeners, were not included due to their high analysis cost. Instead, extracts of the composite samples were screened with the H4IIE rat hepatoma cell bioassay (Tillitt and others, 1991; Whyte and others, 2004), which responds to planar PHHs (Table 6). In addition, the livers of the individual fish were assayed for ethoxyresorufin *O*-deethylase (EROD) activity, which indicates recent exposure to exogenous AhR ligands including PHHs and planar aromatic hydrocarbons (PAHs) (Kennedy and Jones, 1994; Pohl and Fouts, 1980; Whyte and others, 2000). Together these assays and analyses allow for the estimation of the relative concentrations of potential biological effects of PHHs and PAHs without the expense of instrumental analyses for these compounds (Table 6).

Measurement of fish health at various levels of biological organization, immune system responses, and reproductive status were included in the suite of indicators to address potential impacts from non-accumulative contaminants and contaminant mixtures (Table 4). Measures of fish health included:

Table 4. Methods incorporated into the Columbia River Basin in 1997.

Method	Description	Tissue(s) examined	Sensitivity	Primary reference(s)
Histopathology	Microscopic examination for the presence of lesions; can provide early indication of chemical exposure	Liver, gill, gonads, spleen, and kidney	Overall organism health and contaminants	Hinton and others (1992); Hinton (1993); Goodbred and others (1997)
Ethoxyresorufin *O*-deethylase (EROD) activity	Enzyme induction by planar hydrocarbons	Liver	PCBs; chlorinated , dioxins, and furans; PAHs	Pohl and Fouts (1980); Kennedy and Jones (1994); Whyte and others (2000)
Macrophage aggregate analysis	Macrophages are important in the immune system, serving as a first line of defense for the organism and as an antigen processing cell	Spleen	Multiple contaminants including PAHs and metals	Blazer and others (1994; 1997)
H4IIE bioassay	A screening tool to determine the presence of certain classes of planar halogenated compounds	Whole fish (composite samples)	PCBs; chlorinated dioxins and furans	Tillitt and others (1991); Whyte and others (2004)
Vitellogenin	A precursor of egg yolk, normally synthesized in the liver of female fish	Blood plasma	Endocrine-modulating substances	Denslow and others (1999)
Chemical analyses	Organochlorine chemical residues and elemental contaminants	Whole fish (composite samples)	Specific analytes	Schmitt and others (1999a)
Somatic indices	The relative mass of some organs is often indicative of chemical exposure	Gonads, spleen, liver	Overall organism health	Grady and others (1992)
Necropsy-based fish health assessment	Visual assessment of external/internal anomalies (for example, lesions, parasites, tumors), which may indicate contaminant-related stress	All	Overall organism health	Goede (1988, 1996); Adams and others (1993); Adams (1990)

1) gross observations for abnormalities; 2) condition and organosomatic indices; and 3) histopathological examination (Goodbred and others, 1997; Hinton, 1993; Hinton and others, 1992). Gross observations and determination of indices based on relative fish and organ sizes such as condition factor (CF), hepatosomatic index (HSI), and splenosomatic index (SSI) are relatively simple and indicative of cumulative, organism-level changes (Grady and others, 1992). However, they are non-specific in terms of causal mechanisms which may reflect early, subtle alterations and may foreshadow subsequent effects at the individual- or population-level.

In addition to being an indicator of overall organism health, the SSI is also a measure of immune system stress. Other immune system indicators included the measurement of macrophage aggregates (MA) in preserved spleen tissue samples (Table 4). Macrophage aggregates, also known as melanomacrophage centers, are discrete aggregations of pigment-bearing macrophages found in the spleen, kidney, and sometimes liver of advanced teleosts (Agius, 1980). These specialized cells are thought to be responsible for centralizing foreign material and debris for destruction, detoxification or reuse, storing waste products, contributing to immune response, and storing/recycling iron (Ellis and others, 1976; Ferguson, 1976). Although they may be affected by a variety of factors, MA measurements have responded to contaminant exposure in both field and laboratory studies (Blazer and others, 1997; Wolke, 1992).

Measures of reproductive condition included plasma vitellogenin (vtg) concentrations, gonadosomatic index (GSI), and gonadal histopathology (Table 4). Contaminants, particularly estrogen mimics, have been shown to impact reproduction in laboratory and field studies although reproductive condition in fish can be influenced by many factors (for example, gender, age, reproductive stage, season, water temperature)

Table 5. Organochlorine chemical and elemental contaminants measured in whole body fish composite samples.—Continued

Contaminant class and analyte	Chemical name(s) or atomic symbol	Principal uses and sources to aquatic ecosystems
Organochlorine chemicals		
p,p'-DDE	2,2-bis (*p*-chlorophenyl)-1,1-dichloroethylene	DDT-metabolite
p,p'-DDD (TDE)	2,2-bis (*p*-chlorophenyl)-1,1-dichloroethane	Insecticide; DDT-metabolite
p,p'-DDT	2,2-bis (*p*-chlorophenyl)-1,1,1-trichloroethane	Insecticide
o,p'-DDE	2-(*o*-chlorophenyl)-2-(*p*-chlorophenyl)-1,1-dichloroethylene	*o,p'*-DDT metabolite
o,p'-DDD (TDE)	2-(*o*-chlorophenyl)-2-(*p*-chlorophenyl)-1,1-dichloroethane	*o,p'*-DDT metabolite
o,p'-DDT	2-(*o*-chlorophenyl)-2-(*p*-chlorophenyl)-1,1,1-trichloroethane	*p,p'*-DDT impurity
Total polychlorinated biphenyls (PCBs)	Mixture containing as many as 209 mono- through octa-chloro-substituted biphenyl congeners.	Dielectric, hydraulic, and transformer fluids; lubricants; extenders; de-dusting agents; carbonless copy paper
Dieldrin	1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,8,8a-hexahydro-1,4-endnnno-exo-5,8-dimethanonaphthalene	Insecticide; aldrin metabolite
Endrin	1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahdyro-1,4- endo-endo-5,8-dimethanonaphthalene	Insecticide; isodrin metabolite
Heptachlor epoxide	1,4,5,6,7,8,8-heptachloro-2,3-epoxy-3a,4,7,7a-tetrahydro-4,7-methano-1H-indene	Heptachlor metabolite; technical chlordane constituent/metabolite
cis-Chlordane	1,2,4,5,6,7,8,8-octachloro-2,3,3a,4,7,7a-hexahydro-4,7-methano-1H-indene (1-α,2-α,3a-α,4-β,7-β,7a-α)	Insecticide; technical chlordane constituent
trans-Chlordane	1,2,4,5,6,7,8,8-octachloro-2,3,3a,4,7,7a- hexahydro-4,7-methano-1H-indene(1-α,2-β,3a-α,4-β, 7-β,7a-α)	Technical chlordane constituent
cis-Nonachlor	1,2,3,4,5,6,7,8,8-nonachloro-2,3,3a,4,7,7a- hexahydro-4,7-methano-1H-indene (1-α,2-α, 3-α, 3a-α, 4-β, 7-β, 7a-α)	Technical chlordane constituent
trans-Nonachlor	1,2,3,4,5,6,7,8,8-nonachloro-2,3,3a,4,7,7a- hexahydro-4,7-methano-1H-indene(1-α,2-β,3-α, 3a-α,4-β,7-β,7a-α)	Technical chlordane constituent
Oxychlordane (octachlor epoxide)	2,3,4,5,6,6a,7,7-octachloro-1a,1b,5,5a,6, 6a-hexahydro-2,5-methano-2H-indeno(1,2-b)oxirene (1a-α,1b-β,2-α,5-α,5a-β,6-β,6a-α)	*cis*-Chlordane metabolite
Toxaphene	Chlorinated camphene mixture averaging 62% chlorine by weight	Insecticide; herbicide
α-Hexachlorocyclohexane (HCH)	1,2,3,4,5,6-hexachlorocyclohexane	Constituent of insecticide mixture containing various HCH isomers; also know as α-benzene hexachloride (BHC)

Table 5. Organochlorine chemical and elemental contaminants measured in whole body fish composite samples.—Continued

Contaminant class and analyte	Chemical name(s) or atomic symbol	Principal uses and sources to aquatic ecosystems
β-HCH	1,2,3,4,5,6-hexachlorocyclohexane	Technical HCH (BHC) constituent
δ-HCH	1,2,3,4,5,6-hexachlorocyclohexane	Technical HCH (BHC) constituent
γ-HCH (Lindane)	1,2,3,4,5,6-hexachlorocyclohexane	Insecticide; technical HCH (BHC) constituent
Hexachlorobenzene (HCB)	Perchlorobenzene	Fungicide; industrial intermediate
Mirex	1,1a,2,2,3,3a,4,5,5,5a,5b,6-dodecachloro- octahydro-1,3,4-metheno-1H-cyclobuta(cd)pentalene	Insecticide; fire retardant
Elemental contaminants		
Arsenic	As	Industrial sources; herbicides; defoliants
Cadmium	Cd	Mining, smelting and other industrial sources; urban runoff; sewage discharges
Chromium	Cr	Mining, tanning, and other refractory and chemical industrial sources
Copper	Cu	Mining, smelting and other industrial sources
Lead	Pb	Mining, smelting and other industrial sources; urban runoff; atmospheric pollution; fishing sinkers; lead shot
Mercury	Hg	Herbicides; fungicides; pulp, paper, and textile effluents; open-cycle chloralkali cells; landfills; mining; atmospheric pollution
Nickel	Ni	Mining, smelting, and other industrial sources
Selenium	Se	Coal-fired powerplants; irrigation return flows
Zinc	Zn	Mining, smelting and other industrial sources; urban runoff

Table 6. Monitoring and assessment strategy for polycyclic aromatic and polyhalogenated hydrocarbons (PAHs and PHHs). [a] Total PCBs were determined by gas chromatography with electron-capture detection. [b] 7-ethoxyresorufin *O*-deethylase. [c] H4IIE bioassay was performed after reactive cleanup to remove AhR-active PAHs. [d] And other planar organic compounds. + responds; – does not respond; *AhR-active isomers and congeners only.

Endpoint	Contaminants		
	PCBs	PCDDs & PCDFs	PAHs [d]
GC-ECD [a] (carcass)	+	-	-
EROD activity [b] (liver)	*	*	*
H4IIE bioassay [c] (carcass)	*	*	-

(Allen and others, 1999; Gimeno and others, 1998). Estrogen mimics are capable of stimulating the production of vtg, a precursor of yolk protein, in the livers of oviparous vertebrates, and a number of endocrine disrupting compounds have been shown to induce abnormal vitellogenesis (Servos, 1999; Tyler and others, 1998). Vitellogenin production is normally associated with female fish; however, it can be produced in males if estrogen or an estrogen-like chemical is present. The detection of levels typical of early- to mid-vitellogenic females in male fish has been associated with exposure to exogenous estrogens (Bowman and others, 2002; Denslow and others, 1999; Folmar and others, 1996; 2000; 2001). Vitellogenin was measured in both male and female fish to document these and other possible alterations and to establish baseline concentrations. The GSI and gonadal histopathology [stage, presence of atretic oocytes, and intersex conditions (presence of female reproductive tissue in males or *vice-versa*)] were also assessed as measures of reproductive health and status. The GSI relates the proportional size of the gonad to the body size and may reflect changes resulting from a variety of physiological factors such as reproductive stage and environmental factors, including exposure to contaminants. Elevated occurrence of atretic (unfertilized and/or reabsorbed) eggs has been noted in fish exposed to contaminants (Cross and Hose, 1988; Johnson and others, 1988), although other factors may also be involved. Feminization of male fish (that is, intersex condition) has been reported in laboratory and field studies of contaminants (Allen and others, 1999; Gimeno and others, 1997; 1998; Jobling and others, 1998).

Field Procedures

Fish Collection

Fish were collected by electrofishing from a boat along the shoreline or backwater areas of the river being sampled. All specimens of the target species were collected, irrespective of size, although electrofishing tends to be biased toward larger fish (Reynolds, 1983). More than 10 fish of a given species and gender were processed at some sites. Global Positioning System (GPS) coordinates were obtained for the upstream and downstream extents of the area from which fish were collected. Fish were held in on-board live wells and transported to shore for processing, usually within a few hours of collection. Fish at certain stations were held alive overnight in tanks or net pens containing ambient river water following night collections.

Sample Processing

The methods used to process the fish have been fully described (Table 4) (Schmitt and Dethloff, 2000). Briefly, a live fish was selected and identified to species. A blood sample was collected from the posterior caudal artery and vein with a heparinized needle and syringe and placed on [wet] ice. Plasma from this blood sample was later obtained for determination of the vtg concentration. The fish was weighed, measured, and subdued. Observations of external features were recorded, and tissue anomalies were removed by dissection and preserved in 10% neutral buffered formalin for histopathological analysis. The abdominal cavity of the fish was dissected open and the liver (in species with a discrete liver), spleen, and gonads were removed and weighed. Liver weights for carp and sucker were not determined because these species have a dispersed hepatic organ. The liver, gall bladder, posterior and anterior kidneys, gonads, mesenteric fat (in certain species), and spleen were examined, and the gender of the fish was determined. Pieces of liver collected for EROD activity analysis were immediately flash-frozen in a dry ice-ethanol slush, then transferred to a liquid nitrogen dry-shipper for storage and shipment. Samples of gonad, kidney, spleen, and additional pieces of liver were collected and preserved in 10% neutral buffered formalin for histopathological examination, gender confirmation (gonad), and macrophage aggregate analysis (spleen). Scales were collected for age determination upon completion of the internal examination and dissection. Remaining tissues (those not frozen or fixed) were placed back into the body cavity and the entire fish was wrapped in aluminum foil. The wrapped carcass was labeled and placed in a polyethylene bag with other carcasses of the same species and gender. These samples were chilled and later frozen for analysis of organochlorine chemical and elemental contaminants and dioxin-like activity (with the H4IIE bioassay). The

entire field procedure was typically conducted in 15-20 min (per fish), and tissue samples, especially liver for EROD analysis, were collected and frozen as rapidly as possible. Blood samples were centrifuged and the plasma was aspirated and frozen in dry ice following the processing of the fish.

Laboratory Analyses

Composite fish samples were shipped frozen in dry ice to laboratories managed by the Patuxent Analytical Control Facility (PACF) of the USFWS where they were prepared and analyzed for organic and elemental contaminants. These laboratories also prepared the composite samples for H4IIE bioassay analyses, which were conducted by the USGS (United States Geological Survey) CERC (Columbia Environmental Research Center). PACF oversaw quality assurance (QA) and quality control (QC) associated with these procedures. Recovery of spiked materials in the samples were evaluated to assess the quality of the procedures but were not used to adjust the concentration of the reported analytes. Additional information on sample preparation and chemical methods are presented by Schmitt and others (2002b). Cryogenically frozen liver samples for EROD analysis were also shipped to CERC for analysis. Cryogenically frozen plasma samples were similarly shipped to the Protein Chemistry Research Laboratory of the University of Florida for analysis of vtg. All preserved tissue samples were shipped to the National Fish Health Laboratory of the USGS Leetown Science Center (LSC) for histopathological analysis. Information on these latter procedures are given by Blazer and others (2002) and McDonald and others (2002). Scales were processed for age determination as described by Jearld (1983), with age (years) estimated from the number of completed annuli.

Composite Sample Preparation

Carcass samples were stored frozen (-20°C) at the lead analytical laboratory (Lab 1) until they were processed. Carcasses were composited by gender and species from each sampling station (for example, Station 42 female carp), and total number of individual fish in the composite sample varied. The carcass of each individual fish was sawed into pieces for processing, and the pieces were then mixed and homogenized in a commercial meat grinder. One sub-sample (100 g) of the composite was re-frozen (-20°C) and shipped frozen to Lab 2 for analysis of moisture content and elemental contaminants. A 10-g subsample was extracted with methylene chloride, subjected to the reactive cleanup procedure described in following sections, ampulated, and shipped to CERC for use in the H4IIE bioassay. Another 10-g subsample was retained by Lab 1 for analysis of organochlorine chemicals by gas chromatography with electron capture detection (GC-ECD) and gravimetric determination of lipid content.

Elemental Analysis and Moisture Content

The 100-g sub-samples were freeze-dried and moisture loss was determined by weight loss during lyophilization at Lab 2. Freeze-dried fish (25-50 g) were digested in nitric acid. Concentrations of total As, Pb, and selenium (Se) in the digestates were determined by graphite furnace atomic absorption spectroscopy (AA). Concentrations of Hg were determined by cold vapor AA. Concentrations of aluminum (Al), barium (Ba), beryllium (Be), boron (B), Cd, Cr, cobalt (Co), Cu, Fe, magnesium (Mg), Mn, molybdenum (Mo), Ni, Ag, strontium (Sr), thallium (Th), vanadium (Va), and Zn were determined by inductively coupled plasma emission spectroscopy (ICPES) without pre-concentration. Quality assurance measures for elemental analyses included the analysis of reagent blanks, duplicate samples, certified reference materials, and fortified samples (Table 7). Results for the other measures were typical for the elements reported here and indicate that the analytical results accurately reflect true concentrations in the samples. Dry-weight (dw) limits of detection (LOD) were determined individually for each analyte in each sample, but were nominally 5 µg/g for Al; 15 µg/g for Fe and Mg; 0.19 µg/g for Be, Cd, and Hg; 0.3 µg/g for Sr; 0.4 µg/g for Pb; 0.9 µg/g for As, Ba, Cr, Cu, Mo, Ni, Se, and V; 2 µg/g for B; 1.5 µg/g for Zn; and 0.5 µg/g for Mn (Table 7). These values, as well as the analytical results, were converted to wet-weight (ww) concentrations for statistical analysis and reporting. Additional information on the analyses of samples for elemental contaminants has been reported elsewhere (Schmitt and others, 2002b).

Organochlorine Chemical Analysis and Lipid Content

At Lab 1, one 10-g subsample of each ground composite sample was mixed with anhydrous sodium sulfate and Soxhlet-extracted with hexane, concentrated by rotary evaporation, and dried to constant weight for gravimetric lipid determination. Tissue extracts were re-dissolved in petroleum ether and fractionated on Florisil® in two fractions. A fraction containing relatively polar organochlorine insecticides, was concentrated for quantification of residues by dual megabore-column GC-ECD. Another fraction further processed by column chromatography on silicic acid to separate HCB (hexachlorobenzene), mirex, PCBs, and hydrophobic organochlorine pesticides. Each of the resultant fractions were concentrated and analyzed by megabore-column GC-ECD. Precision and accuracy of these determinations were ascertained through included analyses of duplicates and fortified samples (n=5), and residue identities were confirmed in selected samples. Recovery efficiency ranged from 88.6% for α-BHC to 99.2% for mirex, but averaged 80-95% for most analytes (Table 8). Based on these results, the analyses were determined to accurately represent the true residue concentrations in the samples. The nominal LOD for individual compounds was 0.01 µg/g ww and the

Table 7. Nominal limits of detection (LOD) and results of quality assurance (QA) for elemental contaminants (µg dry-weight) analyzed in whole body fish composites from the Columbia River Basin. [a] Sample size equals 5 for all contaminants except for Hg where *n*=6. [b] Maximum concentration of elemental contaminants in reagent blanks on a wet-weight basis assuming 75% moisture. [c] Reference material was NRCC TORT-2 (Lobster hepatopancreas).

	n	Element								
		As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Reagent blanks [a] (µg dw)	5									
Min.		0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.00
Max.		0.06	0.02	0.06	0.10	0.00	0.07	0.05	0.07	0.12
Mean		0.02	0.01	0.03	0.06	0.00	0.04	0.02	0.04	0.07
Max.[b] (µg/g ww)		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Duplicate sample analyses (% difference)	5									
Min.		1.57	0.26	2.64	1.80	1.93	1.44	1.57	1.34	2.75
Max.		32.9	16.7	57.5	26.4	26.0	71.8	6.04	21.6	9.22
Mean		9.01	6.31	22.9	9.48	10.2	18.8	3.86	7.87	6.47
Reference materials [c] (% recovery)	5									
Min.		86.6	101	96.8	87.9	93.2	93.0	86.7	99.1	88.6
Max.		106	109	128	93.9	103	97.6	112	107	98.6
Mean		92.9	105	120	92.1	99.3	95.5	105	103	95.3
Cert. conc. (µg/g dw)		21.6	26.7	0.77	106	0.27	2.50	0.35	5.6	180
Fortified spiked sample (% recovery)	5									
Min.		88.2	97.6	96.2	94.1	88.4	99.2	100	94.9	81.3
Max.		108	110	109	103	96.9	109	106	110	114
Mean		99.7	104	104	100	93.3	104	103	101	102
Nominal LOD (µg/g dw)		1.0	0.2	0.5	0.5	0.2	1.0	0.4	1.0	2.0

LOD was 0.03 µg/g ww multi-component chemicals (toxaphene and PCBs) (Table 8). Chemical concentrations were not adjusted for recovery efficiency. Additional information on the organic analyses has been reported elsewhere (Schmitt, 2002b).

H4IIE Rat Hepatoma Cell Bioassay

The 10-g sub-samples for H4IIE analysis were kept frozen at Lab 1 until the initiation of sample processing. Full details of processing have been previously described (Schmitt and others, 2002b). Briefly, samples were thawed, homogenized, and column extracted with methylene chloride. Percent lipid was determined gravimetrically on a 1% portion of the extract. The remainder was concentrated and cleaned up by two-stage column chromatography. Extracts were evaporated, re-dissolved with isooctane, ampulated, and shipped to CERC for analysis. Matrix QC samples (blanks and spikes) prepared at Lab 1 and at CERC included ground tissues from laboratory-raised bluegill (*Lepomis macrochirus*) and samples of a CERC standard positive control tissue (carp from Saginaw Bay, Michigan). These QC samples were processed concurrently with the 1997 samples.

The H4IIE bioassay was performed on the composite sample extracts according to the method of Tillitt and others (1991) as modified for 96-well microtiter plates (Tysklind and others, 1994). The H4IIE cells were seeded at 7000 cells/well in 300 µL of D-MEM culture media (Tillitt and others, 1991) and were dosed with sample extracts or standards in isooctane after a 24 hour (h) incubation (Schmitt and others, 2002b; Whyte and others, 2004). 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) was the standard and at least three TCDD standard curves were analyzed each day. A linear regression was performed on the data from each well to determine an EROD rate (pmol/min). The amount of protein in each well was determined by the fluorescamine assay (Lorenzen and Kennedy, 1993) and used to normalize the dose to each well and EROD activity. The doses of each sample (g-equivalents/mg cellular protein) or TCDD standard (pg TCDD/mg cellular

Table 8. Nominal limits of detection (LOD) and results of quality assurance (QA) for organochlorine chemicals (µg wet-weight) analyzed in whole body fish composites collected from the Columbia River Basin. Minimum, maximum, and mean fortified spike recovery percentages and duplicate sample difference percentages are presented unless otherwise indicated (ND, not determined). [a] Toxaphene- and PCB-fortified samples were not analyzed because multicomponent analytes interfered with the spike analyses. [b] All toxaphene and total PCB samples had an LOD of 0.03 µg/g except sample 506B which had a LOD of 0.05 µg/g.

	Fortified spike recoveries			Duplicate sample differences			LOD (µg/g)
Analyte	Min.	Max.	Mean	Min.	Max.	Mean	
Lipid	ND	ND	ND	1.9	10.8	4.7	ND
Moisture	ND	ND	ND	0	3.3	1.5	ND
o,p'-DDD	93.5	105	99.0	0	0	0	0.01
o,p'-DDE	90.0	99.0	95.1	0	0	0	0.01
o,p'-DDT	85.0	97.0	91.3	0	0	0	0.01
p,p'-DDD	83.5	99.0	91.0	0	12.5	2.5	0.01
p,p'-DDE	84.5	97.0	91.4	0	9.2	5.8	0.01
p,p'-DDT	87.5	102	91.9	0	0	0	0.01
cis-Chlordane	88.5	104	96.5	0	0	0	0.01
trans Chlordane	87.5	100	94.7	0	0	0	0.01
cis-Nonachlor	88.0	102	95.0	0	0	0	0.01
trans-Nonachlor	90.0	98.5	94.5	0	9.5	2.6	0.01
Oxychlordane	85.0	100	93.5	0	0	0	0.01
Heptachlor epoxide	86.5	98.0	93.8	0	0	0	0.01
Dieldrin	90.5	100	96.1	0	16.7	3.3	0.01
Endrin	94.0	104	99.0	0	0	0	0.01
HCB	73.5	93.5	84.1	0	0	0	0.01
Mirex	95.0	102	99.2	0	0	0	0.01
α-BHC	78.0	94.0	88.6	0	0	0	0.01
β-BHC	86.5	98.0	94.0	0	0	0	0.01
γ-BHC	84.0	97.5	90.9	0	0	0	0.01
δ-BHC	81.0	95.0	90.3	0	0	0	0.01
Toxaphene [a]	ND	ND	ND	0	0	0	0.03/0.05 [b]
Total PCBs [a]	ND	ND	ND	0	20.3	6.5	0.03/0.05 [b]

protein) were plotted against EROD activity (pmol/min/mg cellular protein, hereafter pmol/min/mg) to develop dose-response curves. The linear portions of these curves were used to compare the relative potencies of the samples to the TCDD standard. TCDD-equivalents (TCDD-EQ) were determined by a slope-ratio assay (Finney, 1980) as described by Ankley and others (1991). Variance estimates were based on an additive model of variance (Finney, 1980) and were calculated as previously described (Ankley and others, 1991; Tillitt and others, 1991).

Quality assurance procedures and results are documented by Birke and Tillitt (2000a). Samplese were analyzed in blocks of approximately 40. LOD and limit of quantitation (LOQ) were computed separately for each block. LODs ranged from 0-1 pg/g and LOQs were 1 pg/g (rounded to the nearest whole number). The results of the QA program indicated that the bioassays accurately reflected the dioxin-like potency of the extracts (Birke and Tillitt, 2000a).

EROD Activity

Cryogenically frozen liver samples were stored at –80°C by CERC until the preparation of microsomal fractions which were used the day they were prepared. The kinetic microsomal assays were conducted in 96-well microtiter plates (Birke and Tillitt, 2000b; Whyte and others, 2000). Briefly, triplicate determinations of EROD activity were performed on 5-µL portions of each microsomal preparation, and mean EROD activity was reported. Protein content was determined using the fluorescamine protein assay (Lorenzen and Kennedy, 1993) in the same 96-well microtiter plate as the EROD analyses. A positive control material [liver microsomes from laboratory-raised channel catfish (*Ictalurus punctatus*) injected with 10 mg/kg of benzo(*a*)pyrene] and an additional reference material [liver microsomes of wild flathead catfish (*Pylodictis olivaris*) obtained from the Missouri River near Easley, Missouri] were also analyzed. A linear regression was performed on the data from each well to determine an EROD rate (pmol/min) along with its associated estimate of variance. The amount of protein was used to normalize EROD activity (pmol/min/mg) in each well. A rigorous QA program was followed for the EROD assays as described in Birke and Tillitt (2000b). LODs ranged from 0–0.15 pmol/min/mg while LOQs ranged from 0-0.35 pmol/min/mg. The results of this QA program indicated that the results of the bioassay accurately reflected the hepatic EROD rates of the samples analyzed.

Fish Health Indicators

General Histopathological Analyses

Tissues (liver, kidney, spleen, gill, gonad, and grossly visible lesions) preserved in 10% neutral buffered formalin (NBF) were shipped to the LSC and prepared for routine histopathological analysis (Blazer and others, 2002). Paraffin-embedded tissue sections (6-µm) mounted on glass slides were stained with hematoxylin and eosin (H & E) for microscopic examination.

Quantitative Organism-Level Indicators

The prevalence of gross external pathological disorders was determined with a rating of present (1) or not present (0) deduced from the field data. The gross pathologies were selected for consistency with other monitoring programs that have used this type of assessment (Fournie and others, 1996). Gross abnormalities included grossly visible disorders of the eye (exophthalmia, hemorrhage, opacity, emboli, missing), opercles, (shortening, deformities, parasites), and body surface (ulcers, parasites, discolored areas or tumors). In addition, disorders of the fins (hemorrhage, fraying, and so forth) and skeleton (curvature) were also included. Numerical values were assigned to internal and external observations of lesions recorded in the field, and a necropsy-based fish health assessment (HAI) score was calculated for each fish by summing these values for all organs (Blazer and others, 2002). An index was only computed for a fish if there was a complete assessment.

Body and organ weights measured in the field were used to calculate condition and organosomatic indices. Condition factor was computed as body weight/length^3. The hepatosomatic index was calculated as HSI = liver weight/(total body weight – gonad weight) X 100. Similarly, the splenosomatic index was calculated as SSI = spleen weight/(total body weight – gonad weight) X 100. The weight of the gonads was subtracted from the body weight in the computation of HSI and SSI to minimize the effect of the reproductive cycle on these indices (Schmitt and Dethloff, 2000). Gonadosomatic index was calculated as GSI = gonad weight/total body weight X 100. Additional information on these indices is given by Schmitt and Dethloff (2000) and Blazer and others (2002).

Macrophage Aggregates

Macrophage aggregates (MA) and MA pigments in spleen sections were visualized through a staining procedure called the Perl's method (Luna, 1992). Using this method, melanin, a melanosome pigment derived from tyrosine metabolism, stains black; hemosiderin, a protein-bound iron pigment, stains blue; and ceroid/lipofuscin, lipogenic pigments arising from the oxidation of unsaturated lipids, stains yellow-tan. All MA measurements were made with a computer-based image analysis system, and included the number of aggregates in 2 mm^2 of tissue (MAMM) and the area occupied by aggregates. The percentage of tissue occupied by MAs (TISSOC) and mean area of the MAs (MEANAREA) were computed from these measurements (Blazer and others, 2002).

Reproductive Indicators

Gonadal Histopathology

The posterior tip of the gonad was dissected in the field and fixed immediately in 10% NBF. Transverse sections were processed for routine light microscopy (embedded in paraffin, sectioned at 6 µm, and stained with H & E).

Female gonadal tissue was staged using developmental stages (designated 0-5) to classify each section (Blazer, 2002; Nagahama, 1983; McDonald and others, 2000; Rodriguez and others, 1995; Treasurer and Holliday, 1981). Carp and bass ovaries typically contain oocytes in several develop-

mental stages and were classified according to the maturity of the predominant stage of oogenesis of each tissue sample. Ovaries containing only previtellogenic chromatin nucleoli and perinuclear oocytes, which were identified by cytoplasm that stained basophilic with H & E, were assigned to stage 0. Samples containing many oocytes with cortical alveoli in addition to the previtellogenic chromatin nucleoli and perinuclear oocytes characteristic of stage 0 were assigned to stage 1. Ovaries containing primarily oocytes with cortical alveoli and yolk globules filing the cytoplasm were classified as stage 2 (early vitellogenic). Those containing larger oocytes in which the cortical alveoli were pushed to the periphery of the cell, yolk globules filled the center, and the chorion of the developing oocytes were thicker than in earlier stages were designated as stage 3 (mid-vitellogenic). Ovaries containing oocytes with fused yolk globules that appear as a homogeneous mass were designated as stage 4 (mature). Ovaries containing post-ovulatory follicles, which can be observed for some time after ovulation, are typically assigned to stage 5 (spent). After the ovarian tissues were staged they were further examined by light microscopy for atresia and other pathologies. One hundred oocytes in each sample were counted when possible to determine atresia. Those showing morphological evidence of resorption or necrosis were quantified and the percent of atretic oocytes were calculated.

Analogous to the procedure used to stage ovaries, male gonadal tissue was classified into five developmental stages (0-4) according to the maturity of the predominant stage of spermatogenesis of each tissue sample (Blazer, 2002; Nagahama, 1983). Immature, undeveloped, or regressed testes containing only spermatogonia were classified as stage 0 (immature) whereas those containing primarily spermatocytes and spermatids were designated as stage 1 (early spermatogenic). Stage-2 (mid-spermatogenic) testes contain approximately equal proportions of spermatocytes, spermatids, and spermatozoa, and testes containing primarily mature spermatozoa were identified as stage 3 (late spermatogenic). Stage-4 gonadal tissue is post-spawning or spent. Testicular tissue was also examined microscopically for any abnormalities such as intersex and other pathologies. Male fish were classified as intersex when individual or small foci of undeveloped oocytes were observed within testicular tissue (that is, when an ovotestis condition was detected).

Vitellogenin

A sandwich ELISA was used to determine concentrations of vtg in plasma samples obtained from bass, carp, and largescale sucker (Denslow and others, 1999). Monoclonal antibodies (mAb) developed specifically against bass (3G2) or carp (2D4) vtg were utilized. Wells of a microtiter plate were saturated with 10 µg/mL of species-specific mAb in phosphate-buffered saline (50 µL/well). Plates were incubated overnight, then washed with Tris-buffered saline-Tween (TBST). Blocking reagent (10% BSA in TBST, 360 µL/well) was added to each well and allowed to incubate for 2 h. Plates were washed with TBST and 50 µL of standard or samples were added and incubated overnight. Unknown plasma samples were diluted from 1:10,000 (bass) to 1:1000,000 (carp) in 1% BSA-TBST containing 10 kIU/mL of Aprotinin as protease inhibitor. Standard curves were prepared by diluting purified vtg in diluted plasma from control male fish of the same species tested. After overnight incubation, plates were washed with TBST and 50 µL of 1:1000 rabbit polyclonal antiserum in 1% BSA-TBST was added to each well. After a 2 h incubation, plates were washed and 50 µL of goat anti-rabbit F(ab)2 alkaline phosphatase conjugate in 1% BSA-TBST was added to each well as the secondary antibody. The plates were incubated for another 2 h, then washed and 100 µL of p-nitrophenyl phosphate in carbonate buffer was added to each well and incubated for 30 min. The reaction was stopped by addition of 50 µL/well of 3N NaOH. Plates were read at 405 nm in an automated microtiter plate reader (Spectromax Pro, Applied Biosystems). Concentrations of the unknowns were determined from the standard curves.

Concentrations of plasma vtg were determined by direct ELISA using the monoclonal antibody, 2C11 (HL 1689) for the largescale sucker ELISA. The plasma samples were diluted 1:200, 1:10,000, 1:100,000, and 1:1,000,000 with 10mM phosphate, 150mM NaCl, 0.02% azide, 10 KIU/mL Aprotinin, pH 7.6 (PBSZ-AP). Vitellogenin standards (0, 0.005, 0.01, 0.02, 0.04, 0.06, 0.08, 0.1, 0.2, 0.4, 0.6, 0.8, 1.0 µg/mL) containing 1:200, 10k, 100k, and 1000k male white sucker (*Catostomus commersoni*) plasma (in PBSZ-AP) were added to account for matrix effect (Denslow and others, 1999). Samples and standards were loaded onto a 96-well ELISA plate (NUNC) in triplicate and stored overnight at 4ºC in a humidified container. The following day the plates were washed four times with PBSZ and then blocked with 1% BSA in 10mM tris, 150mM NaCl, 0.05% tween, 0.02% azide, 10 KIU/mL Aprotinin, pH 7.6 (1% BSA/TBSTZ-AP) for 2 h at room temperature. The plates were rewashed with PBSZ (4 times) and the monoclonal, loaded to each plate. The lowest dilution (1:200) was probed with 3 µg/mL of the mAb and dilutions of 10k and higher with 1.0 µg/mL. After the addition of the mAb, the plates were stored at 4ºC overnight in the humidified container. The following day the plates were washed and the biotinylated secondary antibody (goat anti mouse IgG-biotin) was added to each well at 1:1000 dilution in 1% BSA/TBSTZ-AP and incubated at room temperature for 2 h. The plates were washed, and strepavidin-alkaline phosphatase was added at 1:1000 dilution in 1% BSA/TBSTZ-AP and incubated for 2 h at room temperature. After washing the plates for the final time, the color was developed by adding 1 mg/mL p-nitro-phenyl phosphate in carbonate buffer (0.03M carbonate, 2mM $MgCl_2$, pH 9.6) and measuring the color using an ELISA plate reader (SpectraMax Plus384, Applied Biosystems) at 405 nm. Concentrations of the unknowns were determined from the standard curves.

The LOD was 0.0005 mg/mL of plasma for sucker vtg direct ELISA, 0.002 mg/mL for bass vtg sandwich ELISA,

and 0.005 mg/mL for carp vtg sandwich ELISA. All assays were performed in triplicate and reported as the mean of the three measurements. The coefficient of variation was <10% for all samples analyzed. Inter-assay variability was routinely measured by analyzing controls on several plates and was found to be <10%.

Data Set Composition and Statistical Analyses

Species were grouped into larger taxon groupings for analysis. These included common carp, largescale sucker, bass (largemouth and smallmouth bass), longnose sucker (*Catostomus catostomus*), northern pikeminnow, rainbow trout and walleye. For indicators based on individual fish (that is, biomarkers and demographic endpoints), data are discussed in terms of the magnitudes of the means or medians for combined stages or each stage within a gender for different species or taxon grouping. Data were summarized graphically with boxplots presenting the range, median, mean, and 25th and 75th percentiles. Whiskers are 10th and 90th percentiles overlain by a scatter plot of individual fish data (Sigma Plot 7.0 2001, Microsoft, Inc.). Some biomarkers including EROD, vtg, and HAI were also analyzed more rigorously (see following sections). Transformations for statistical testing were applied as necessary to achieve the normality and homogeneity of variance required for the application of parametric statistical methods. The transformations were the same as those used in the analysis of the more extensive 1995 MRB data set including log transformation of EROD and vtg and rank transformation of HAI because the 1997 data set is relatively small (Schmitt, 2002a). Concentrations of contaminants and TCDD-EQ in composite samples were also log-transformed. Transformations were not applied to the other variables analyzed. Raw data from this study can be obtained at <*http://www.cerc.usgs.gov/data/best/search/*>.

Descriptive statistics (arithmetic mean, minimum, maximum, and standard error) were computed for length, weight, and age data for species and taxon groupings at each station. Fish for which only regenerated scales were collected (42 fish; 25 carp, 1 largemouth bass, 7 largescale sucker, 9 northern pikeminnow) were reported as ND (not determined) and excluded from interpretation of age data and all analyses that included age as a factor. Fish for which the field gender identification could not be verified histologically (including four individuals from targeted species) were reported as NG (no gonad) and likewise excluded from analyses that included gender as a factor. Data for bass, carp, and largescale sucker are presented in tabular form and discussed. Because of the influence of fish size on concentrations of Hg in predatory fish, length and weights were also analyzed statistically (see next section). Length and weight data for all other species are presented only in tabular form.

Composite samples (n=64) from 16 stations were analyzed for organochlorine chemical residues, elemental contaminants, and TCDD-EQ by the H4IIE bioassay. Seventeen samples (26.5%) from nine stations were carp, 17 samples (26.5%) from nine stations were largescale sucker, and 21 (33%) samples from 11 stations were bass. The remaining nine samples (14%) were comprised of northern pikeminnow (six samples at five stations), rainbow trout (two samples at one station), and walleye (one sample at one station). All results for composite samples were converted to, analyzed statistically as, and reported as ww concentrations. A value of one-half the LOD was substituted for censored values in the computation of un-weighted geometric station means and for statistical analyses (Schmitt and others, 1999b). A value of one-half the LOD was also substituted for censored values in all graphs.

Concentrations of many contaminants in 1997 composite samples were <LOD, which limited the extent and rigor of statistical analyses that could be performed. All data for composite samples (tissue concentrations and H4IIE results) are presented graphically and as tabular summaries. For *p,p'*-DDE, PCBs, As, Cd, Cu, Hg, Pb, Se, and Zn, temporal and geographic differences were also examined statistically using ANOVA. Log-transformed concentrations of these analytes in carp, bass, largescale sucker, and northern pikeminnow were combined with historical NCBP data for these taxa (Schmitt and others, 1999b) at the 10 sites in the CRB (Stations 41, 42, 43, 44, 45, 46, 96, 97, 98, and 117). These data were analyzed as a one-way ANOVA in which samples representing stations, collection years, and taxa were separated into 325 unique combinations ("treatments"). Selected pair-wise comparisons of least-squares treatment means representing 1997 concentrations contrasted against previous years within each station-taxon combination were then conducted using Fischer's protected LSD. Treatments representing the 1997 station-taxon means were also compared as part of this analysis. These single degree-of-freedom, non-orthogonal contrasts are essentially a series of t-tests using a pooled error mean-square (MS_e) that evaluate differences between- or among-samples of the same taxon. A nominal α-level of 0.01 was used in these comparisons to protect against experiment-wide error. Concentrations of Hg in predatory fish were log-transformed and length-adjusted (HgL) and weight-adjusted (HgW) concentrations due to the influence of size and age (Wiener and others, 2002). The adjusted Hg values were computed by dividing the measured concentration in each composite sample by the mean length (m) and weight (kg) of the individual fish comprised by the sample (Brumbaugh and others, 2001). Mean age of the composite samples from some stations could not be estimated due to the large number of fish having re-generated scales; therefore, age-adjustment of the concentrations of Hg could not be performed. In addition, the NCBP fish collected historically were not aged.

Many biomarkers differ among species, gender, and reproductive stages (Schmitt, 2002b; Schmitt and Dethloff, 2000). Accordingly, a series of linear ANOVA models were fit to the individual fish data for bass, carp, and largescale sucker to determine the influence of selected factors on biomarker

responses in these taxa. Station and gender were treated as class variables while age and stage were considered continuous variables in these models, and the models included both main effects and interactions. The results of these analyses were reported as *F*-values and significance levels and were used to guide the graphical presentation and discussion of the findings. Most means were not adjusted for the factors in the models because of the complexity of the models relative to the small size of the data set. The exception was the MA variables because of the known increase in MA density (MAMM) over time (Blazer and others, 2002). The MA data were re-analyzed with a model that included age as a class variable, and age-adjusted station means for MA parameters in bass, carp, and largescale sucker were estimated. There was no evidence that age was associated with MA data in carp and largescale sucker. Results are generally presented and discussed in terms of the magnitudes of the means or medians for combined genders or each gender within a species or taxon grouping and at different stations within a species or taxon grouping.

Correlations between biomarker results and concentrations of selected contaminants in carp, bass, and largescale sucker were also examined. For these analyses, mean biomarker responses in the individual fish comprised by each composite sample were compared to contaminant data. Spearman rank correlations were computed for samples representing male and female bass, carp and largescale sucker (combined within taxon).

Results and Discussion

Geographic Distribution and Demographic Characteristics of the Fish Collected

A total of 560 fish representing eight species from 16 stations were collected in the CRB (Table 9). Bass, carp, and largescale sucker accounted for 80% of the fish collected. Only northern pikeminnow accounted >10% of the total fish count of the four remaining species. Largescale sucker were collected at ten stations, carp and smallmouth bass at nine, largemouth bass at eight, and northern pikeminnow at seven. The remaining three species were found at one or two stations (Table 10). Bass were found at twelve stations total, and alternate predator species (northern pikeminnow, walleye, and rainbow trout) were collected at stations from which bass could not be obtained, with the exception of Station 506. Size and count data for non-target species were summarized but not discussed (Appendix 1).

Total length, weight, and age were examined in bass from the CRB. The mean total length (TL) of bass from the CRB was 339 mm (range 220-522 mm) and mean weight was 728 g (range 114-2,600 g) (Table 11). The mean age for all bass collected was 5.1 y (range 3-12 y). Females outweighed males (808 g vs. 640 g) and were longer (348 mm vs. 329 mm) and older (5.3 y vs. 4.9 y). Male and female bass were generally smallest (mean TL and weight) at Station 42 and largest at Stations 503 and 502, respectively (Table 11). Smallmouth bass were collected at Stations 42, 43, and 503 while a mix of females of largemouth and smallmouth bass were collected at Stations 44, 45, 96, and 97, suggesting that species differences alone did not account for size variation. Mean female age was

Table 9. Fish species collected from the Columbia River Basin in 1997. A total of 560 of fish were collected from 16 stations. Target species are denoted by an asterisk (*).

Species Collected	# of individual collected	# of stations at which collected	Taxon grouping
Common Carp*	157	9	Carp
Largescale sucker	159	10	Sucker
Largemouth bass*	80	8	*Micropterus*
Longnose sucker	15	2	Sucker
Northern pikeminnow	58	7	*Ptychocheilus*
Rainbow trout	20	1	Trouts
Smallmouth bass*	54	9	*Micropterus*
Walleye	17	1	*Stizostedion*

Table 10. Number of fish collected organized by species, station, and gender in the Columbia River Basin in 1997. Stations are grouped by sub-basin and listed upstream to downstream. Station numbers are given in parenthesis. Species totals that include individual(s) of unknown gender are designated by an asterisk (*).—Continued

Sub-basin, Station, and Species	Males	Females	Species total	Station total
Upper Columbia River (UCR)				
Creston, MT (117)				44
Largescale sucker	6	4	10	
Largemouth bass	10	11	21	
Longnose sucker	1	10	13*	
Northport, WA (504)				40
Largescale sucker	10	10	20	
Rainbow trout	2	10	20*	
Grand Coulee, WA (98)				38
Largescale sucker	10	10	20	
Longnose sucker	1	1	2	
Walleye	4	8	16*	
Snake River (SR)				
Hagerman, ID (41)				36
Carp	10	10	20	
Largemouth bass	7	9	16	
Riggins, ID (43)				41
Largescale sucker	9	11	20	
Northern pikeminnow	5	9	14	
Smallmouth bass	4	3	7	
Lewiston, ID (42)				30
Carp	12	5	17	
Smallmouth bass	5	7	13*	
Ice Harbor Dam, WA (96)				28
Carp	11	10	21	
Largemouth bass	1	0	1	
Smallmouth bass	2	4	6	
Middle Columbia River (MCR)				
Vernita Bridge, WA (503)				36
Carp	11	10	21	
Northern pikeminnow	2	8	10	
Smallmouth bass	2	3	5	
Pasco, WA (97)				35
Carp	9	11	20	
Largemouth bass	6	7	13	
Smallmouth bass	0	2	2	
Granger, WA (44)				41
Carp	10	10	20	
Largemouth bass	2	4	6	
Northern pikeminnow	1	5	6	
Smallmouth bass	4	5	9	
Lower Columbia River (LCR)				
Cascade Locks, OR (46)				23
Largescale sucker	9	11	21*	
Northern pikeminnow	0	2	2	

Table 10. Number of fish collected organized by species, station, and gender in the Columbia River Basin in 1997. Stations are grouped by sub-basin and listed upstream to downstream. Station numbers are given in parenthesis. Species totals that include individual(s) of unknown gender are designated by an asterisk (*).—Continued

Sub-basin, Station, and Species	Males	Females	Species total	Station total
Warrendale, OR (502)				38
Carp	10	10	20	
Largescale sucker	0	3	3	
Largemouth bass	0	1	1	
Northern pikeminnow	0	11	11	
Smallmouth bass	3	0	3	
Vancouver, WA (506)				22
Largescale sucker	10	11	21	
Smallmouth bass	1	0	1	
Oregon City, OR (45)				42
Carp	10	4	14	
Largescale sucker	0	6	6	
Largemouth bass	5	8	14*	
Smallmouth bass	1	7	8	
Portland, OR (505)				33
Largescale sucker	10	11	22*	
Largemouth bass	3	5	8	
Northern pikeminnow	0	2	2	
Walleye	0	1	1	
Beaver Army Terminal, OR (501)				33
Carp	4	0	4	
Largescale sucker	5	11	16	
Northern pikeminnow	2	11	13	

lowest at Station 44 and highest at Station 117 whereas male mean age was lowest at Station 43 and highest at Stations 42, 44, and 503. The mean age for females was greater than that for males with the exceptions of Stations 44 and 45. Mean age was not consistently related to mean size; that is, the oldest bass were not necessarily the largest, indicating growth rate differences among stations (Table 11). Overall, the average lengths, weights, and ages of bass from the CRB were similar to those obtained from the MRB in 1995 (Schmitt and others, 2002a). Bass from the RGB also had similar lengths and weights but were younger (1.8 y) compared to bass from the CRB (5.1 y) (Schmitt and others, 2004).

Total length, weight, and age were similar in carp throughout the CRB. The mean TL of carp was 534 mm (range 321-771 mm) and weighed 2,296 g (range 397-8,000 g) (Table 12). The mean age for all carp collected was 4.5 y (range 2-12 y). Females outweighed males (2,739 g vs. 1,963 g) and were longer (555 mm vs. 504 mm), but the average age for both female and male carp was between 4 and 5 y (4.9 y vs. 4.3 y). The largest male and female carp (mean TL and weight) were collected from Stations 45 and 96, and the smallest were collected from Station 41 (Table 12). Mean age was lowest at Station 41 and highest at Station 96 for female fish and Station 501 for male fish. As was true for bass, ranking of stations by mean age did not yield the same order as ranking by TL or weight, indicating differences in growth rates among stations. Overall, the average lengths and weights of carp from the CRB were similar to those obtained from the MRB in 1995 (Schmitt and others, 2002a); however, some CRB carp weighed less than carp of the same age collected in the MRB, indicating slower growth at some sites. Carp collected in the RGB in 1997 had similar lengths and weights but were generally (3.2 y) younger compared to carp in the CRB (4.5 y) (Schmitt and others, 2004), a pattern that was also found in bass.

Some differences in TL, weight, and age existed between male and female largescale sucker from the CRB. Largescale sucker averaged 473 mm in TL (range 310-592 mm) and weighed 1037 g (range 146-2,100 g) (Table 13). The mean age for all largescale sucker collected was 4.4 y (range 3-10 y). Females outweighed males (1,167 g vs. 890 g) and were longer (494 mm vs. 448 mm). The mean ages for females and males were similar (4.5 y vs. 4.3 y). Male and female largescale sucker were generally smallest (mean TL and weight) at Stations 501 and 505 and largest at Station 504 (Table 13). Average weights and lengths for largescale sucker were relatively consistent compared to carp and bass. Mean ages were lowest for male and female largescale sucker at Station 46 and

Table 11. Lengths, weights, and ages of bass collected in the Columbia River Basin in 1997. Stations are grouped by sub-basin and listed upstream to downstream. Station numbers are given in parentheses. Sample size (*n*), arithmetic mean, standard deviation (SD), and range are also given. Fish in which gender could not be determined are identified as having no gonad (NG).

Sub-basin and Station	Gender	Length (mm)				Weight (g)				Age (years)			
		n	Mean	SD	Range	*n*	Mean	SD	Range	*n*	Mean	SD	Range
Entire Basin	All	134	339	72.7	220-522	134	728	578	114-2600	132	5.1	1.63	3-12
	F	76	348	76.1	224-522	76	808	640	147-2600	74	5.3	1.77	3-12
	M	56	329	67.7	220-488	56	640	484	114-2200	56	4.9	1.43	3-8
	NG	2	291	40.3	262-319	2	376	211	226-525	2	6.0	0.00	6
Upper Columbia River (UCR)													
Creston, MT (117)	F	11	412	79.1	279-496	11	1354	757	280-2600	10	7.1	2.91	3-12
	M	10	339	70.5	252-461	10	756	627	114-1880	10	4.8	1.75	3-8
Snake River (SR)													
Hagerman, ID (41)	F	9	365	68.3	257-492	9	891	511	253-2000	9	5.0	1.00	3-6
	M	7	344	33.5	314-397	7	673	210	444-970	7	4.4	0.98	3-6
Riggins, ID (43)	F	3	309	22.5	293-335	3	433	107	310-500	3	4.3	0.58	4-5
	M	4	271	26.9	247-308	4	273	91	140-350	4	4.0	1.15	3-5
Lewiston, ID (42)	F	7	251	21.6	224-269	7	216	55	147-283	7	4.8	1.30	3-6
	M	5	250	21.1	220-289	5	212	57	142-319	5	4.1	0.90	3-6
	NG	1	262	--	--	1	226	--	--	1	6.0	--	--
Ice Harbor Dam, WA (96)	F	4	375	47.3	311-412	4	856	325	425-1150	4	5.3	0.96	4-6
	M	3	388	87.2	330-488	3	1170	904	510-2200	3	5.0	1.00	4-6
Middle Columbia River (MCR)													
Vernita Bridge, WA (503)	F	3	470	9.2	460-478	3	1859	170	1726-2050	3	7.0	1.00	6-8
	M	2	457	26.2	438-475	2	1637	513	1274-2000	2	6.0	0.00	6
Pasco, WA (97)	F	9	338	84.0	251-522	9	783	776	204-2600	9	4.6	1.51	3-7
	M	6	314	87.3	240-440	6	534	476	144-1248	6	4.3	1.51	3-7
Granger, WA (44)	F	9	316	68.9	254-450	9	591	528	212-1803	9	4.0	0.87	3-5
	M	6	353	48.1	285-418	6	700	286	362-1138	6	5.8	0.75	5-7
Lower Columbia River (LCR)													
Warrendale, OR (502)	F	1	497	--	--	1	2550	--	--	0	--	--	--
	M	3	363	35.2	326-396	3	781	250	535-1035	3	4.3	0.58	4-5
Vancouver, WA (506)	F	0	--	--	--	0	--	--	--	0	--	--	--
	M	1	380	--	--	1	897	--	--	1	5.0	--	--
Oregon City, OR (45)	F	15	321	41.1	255-383	15	513	208	235-831	15	5.6	1.18	4-8
	M	6	338	51.6	292-432	6	620	358	382-1306	6	6.5	1.52	4-8
	NG	1	319	--	--	1	525	--	--	1	6.0	--	6
Portland, OR (505)	F	5	328	29.5	280-355	5	571	189	306-758	5	5.4	1.14	4-7
	M	3	286	43.5	255-336	3	373	192	224-590	3	4.3	2.31	3-7

highest at Station 98. Ranking of stations by mean age did not yield similar order to ranking by TL or weight, indicating differences in growth rates among stations for largescale sucker (Table 13).

Table 12. Lengths, weights, and ages of common carp collected in the Columbia River Basin in 1997. Stations are grouped by sub-basin and listed upstream to downstream. Station numbers are given in parentheses. Sample size (*n*), arithmetic mean, standard deviation (SD), and range are also given.

Sub-basin and Station	Gender	Length (mm)				Weight (g)				Age (years)			
		n	Mean	SD	Range	*n*	Mean	SD	Range	*n*	Mean	SD	Range
Entire Basin	All	157	534	93.6	321-771	157	2296	1310	397-8000	133	4.5	1.45	2-12
	F	69	557	102	355-771	69	2739	1603	603-8000	57	4.9	1.75	3-12
	M	87	516	83.7	321-677	87	1963	894	397-4000	75	4.3	1.13	2-8
Snake River (SR)													
Hagerman, ID	F	10	399	38.3	355-464	10	892	255	603-1289	9	3.4	0.53	3-4
(41)	M	10	364	27.4	321-406	10	683	171	397-900	10	3.3	0.48	3-4
Lewiston, ID	F	5	615	21.2	585-639	5	3540	462	2900-4200	3	5.3	0.58	5-6
(42)	M	12	547	50.6	440-601	12	2479	641	1300-3300	8	4.1	0.83	3-5
Ice Harbor	F	10	654	73.7	535-745	11	4219	1743	2150-6738	9	6.3	3.20	3-12
Dam, WA (96)	M	11	595	38.4	560-667	11	2891	579	2200-4000	9	4.9	1.36	3-7
Middle Columbia River (MCR)													
Vernita Bridge,	F	10	607	61.0	475-661	10	3178	961	1376-4550	7	5.4	1.62	4-8
WA (503)	M	11	523	84.2	416-667	11	1853	744	917-2950	11	3.7	0.65	3-5
Pasco, WA (97)	F	11	518	64.4	439-626	11	2041	855	1105-3750	10	5.1	1.79	3-9
	M	9	501	36.5	461-581	9	1473	313	1200-2200	9	4.8	1.39	4-8
Granger, WA	F	10	520	59.2	428-615	10	1818	676	898-3150	8	4.0	0.53	3-5
(44)	M	10	489	43.1	444-590	10	1437	442	1038-2500	7	4.0	1.15	2-5
Lower Columbia River (LCR)													
Warrendale, OR	F	10	572	61.6	500-696	10	2724	972	1670-4500	8	5.0	0.93	4-6
(502)	M	10	514	64.1	383-625	10	1961	699	819-3400	9	4.9	1.05	4-7
Oregon City,	F	4	677	107	562-771	4	5313	2504	2650-8000	4	4.8	0.50	4-5
OR (45)	M	10	563	67.3	465-677	10	2586	910	1351-3800	8	4.6	0.74	4-6
Beaver Army	F	0	--	--	--	0	--	--	--	0	--	--	--
Terminal, OR	M	4	548	64.3	499-642	4	2223	889	1436-3500	4	5.0	1.41	3-6
(501)													

Accumulative contaminants, H4IIE Bioassay, and EROD Activity

Elemental Contaminants

Arsenic

Concentrations of As were >LOD (0.21-0.31 µg/g ww) in 16 samples (25%) from nine stations (Fig. 3). The highest concentrations (0.52-0.56 µg/g ww) were in fish from Stations 96, 504, and 505, with the maximum concentration occurring in male carp from Station 96 (Table 14; Fig. 3). Geometric mean concentrations of As were greatest at Stations 502 (0.31 µg/g ww) and 96 (0.37 µg/g ww) (Table 15).

Among-station differences for concentrations of As were significant in bass and carp but not in northern pikeminnow or largescale sucker (Table 16). Concentrations of As in bass were significantly greater at Stations 502 and 505 than at Station 42, and concentrations of As in carp were significantly greater at Station 96 than at Stations 41, 45, and 503 (Table 16; Fig. 3).

Concentrations of As changed significantly over time at several stations in collections from 1971-1997 (Table 17). Concentrations in carp at Stations 96, 97, 44, and 45, largescale sucker at Stations 98, 46, and 45, and bass at Stations 43 and 44 differed significantly from 1997 values (Table 17). Increasing or decreasing temporal trends were not evident in concentrations at any station with the exception of bass from Station 43 which had increasing concentrations of As (0.13 µg/g ww in 1971 to 0.22 µg/g ww in 1997) (Table 17). NCBP composite concentrations of As did not exceed 0.5 µg/g ww

Table 13. Lengths, weights, and ages of largescale sucker collected in the Columbia River Basin in 1997. Stations are grouped by sub-basin and listed upstream to downstream. Station numbers are given in parenthesis. Sample size (*n*), arithmetic mean, standard deviation (SD), and range are also given. Fish in which gender could not be determined are listed as juvenile (J).

Sub-basin and Station	Gender	Length (mm)				Weight (g)				Age (years)			
		n	Mean	SD	Range	*n*	Mean	SD	Range	*n*	Mean	SD	Range
Entire Basin	All	159	473	56.5	310-592	159	1037	378	146-2100	152	4.4	0.97	3-10
	F	88	494	55.4	370-592	88	1167	384	482-2100	85	4.5	1.05	3-10
	M	69	448	43.5	334-544	69	890	297	331-1754	65	4.3	0.82	3-6
	J	2	393	117	310-476	2	429	400	146-712	2	3.0	0.00	3
Upper Columbia River (UCR)													
Creston, MT	F	4	531	21.5	501-551	4	1479	216	1237-1762	4	4.3	0.50	3-5
(117)	M	6	453	30.1	410-504	6	909	270	597-1306	4	4.3	0.50	4-5
Northport,	F	10	552	23.4	514-592	10	1712	226	1223-2100	10	4.6	0.70	3-5
WA (504)	M	10	511	23.5	472-544	10	1408	177	1115-1754	10	4.8	0.42	4-5
Grand	F	10	552	24.5	517-592	10	1379	215	1156-1865	10	5.4	2.2	3-10
Coulee, WA	M	10	482	15.0	458-507	10	1015	133	732-1183	9	5.2	0.67	4-6
(98)													
Snake River (SR)													
Riggins, ID	F	11	479	24.7	435-516	11	998	146	725-1200	10	4.4	0.52	4-5
(43)	M	9	436	22.3	416-485	9	781	88	700-975	9	3.8	0.83	3-5
Lower Columbia River (LCR)													
Cascade	F	11	544	24.9	508-592	11	1542	189	1264-1892	11	3.6	0.67	3-5
Locks, OR	M	9	462	23.2	418-494	9	982	152	799-1236	9	3.6	0.73	3-5
(46)	J	1	476	--	--	1	712	--	--	1	3.0	--	--
Warrendale,	F	3	472	37.2	441-513	3	964	218	827-1216	3	4.7	0.58	4-5
OR (502)	M	0	--	--	--	0	--	--	--	0	--	--	--
Vancouver,	F	11	469	37.9	395-503	11	1021	264	536-1472	11	5.0	0.45	4-6
WA (506)	M	10	408	32.5	334-442	10	631	134	331-803	10	4.0	0.67	3-5
Oregon City,	F	6	438	23.6	409-469	6	1020	282	812-1570	6	4.7	0.82	4-6
OR (45)	M	0	--	--	--	0	--	--	--	0	--	--	--
Portland, OR	F	11	453	49.1	370-565	11	767	143	482-1032	11	4.5	0.52	4-5
(505)	M	10	409	25.3	375-445	10	645	118	458-866	10	4.4	0.52	4-5
	J	1	310	--	--	1	146	--	--	1	3	--	--
Beaver	F	11	444	47.2	374-515	11	826	250	485-1149	9	4.0	0.87	3-5
Army	M	5	407	7.7	396-414	5	627	41	578-688	4	3.8	0.50	3-4
Terminal													
(501)													

from 1980-1986; concentrations >0.2 µg/g ww were measured in fish samples from Stations 41, 44, 46, 96, and 98 (Schmitt and others, 1999b). The USEPA measured whole body concentrations of As in smallmouth bass and largescale sucker, and concentrations ranged from 0.16-0.17 µg/g ww and 0.074-0.32 µg/g ww, respectively, in the CRB from 1996-1998 (USEPA, 2002b). Concentrations of As in bass and carp were measured in previous BEST projects in the MRB and RGB. Concentrations of As in bass ranged from 0.10-0.57 µg/g ww in the MRB (Schmitt and others, 2002b) and 0.04-0.25 µg/g ww in the RGB (Schmitt and others, 2004). Carp had concentrations of As ranging from 0.12-0.32 µg/g ww in the MRB (Schmitt and others, 2002b) and 0.05-0.55 µg/g ww in RGB (Schmitt and others, 2004), concentrations similar to those measured in the CRB.

Arsenic tends to accumulate in planktivorous clupeids such as gizzard shad (*Dorosoma cepedianum*) and also sculpins (*Cottus* sp.) to a greater degree than in other fishes (Hunter and others, 1981; Schmitt and Brumbaugh, 1990; Wagemann and others, 1978) and can be further accumulated

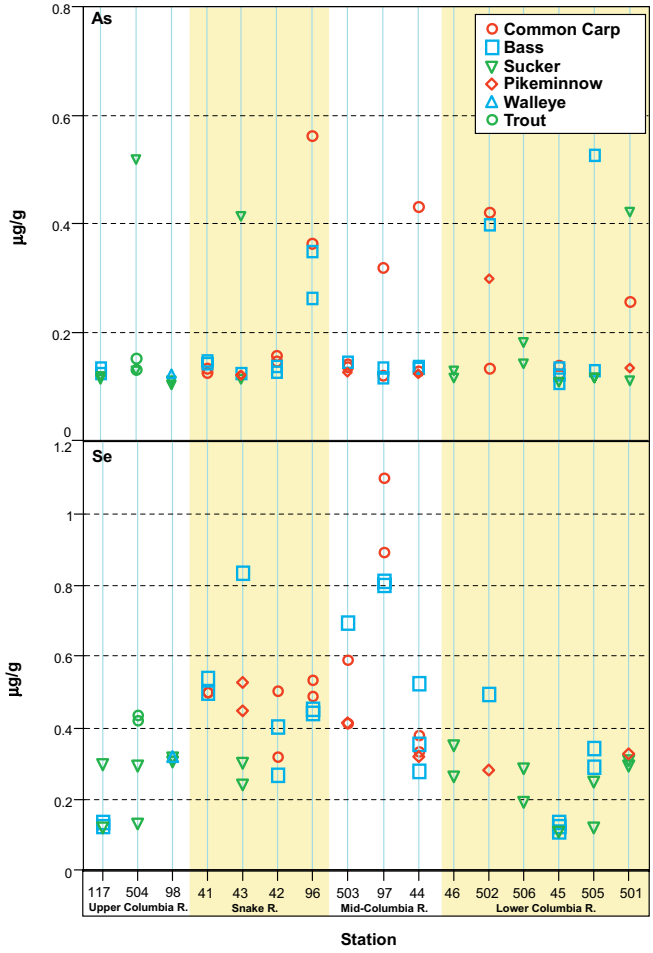

Figure 3. Concentrations (µg/g ww) of arsenic (As) and selenium (Se) by station and taxon in whole body fish composite samples collected in the Columbia River Basin in 1997. Censored values are plotted as one half the LOD. Stations are ordered from upstream to downstream and are grouped by sub-basin. See Table 3 for station descriptions.

by piscivores (Hunter and others, 1981). The occurrence of planktivorous clupeids at some sites and the dynamics of the ecosystems in which they occur may therefore confound trends for As. Schmitt and others (2002b) speculated that the comparatively high concentrations of As in largemouth bass from the southern parts of the MRB, especially in storage impoundments and the river systems containing them, at least partly reflected the presence of gizzard shad and other planktivorous clupeids. Ecosystem and hydrologic differences among stations may also partly explain the varying concentrations in carp and bass from the CRB.

The concentrations of As detected in the freshwater fishes collected from the CRB in 1997 (0.14–0.56 µg/g ww) are not considered a hazard to the fish, piscivorous fishes, or wildlife (USEPA, 1984). A review by Jarvinen and Ankley (1999) included several laboratory studies in which effects of As were evaluated relative to whole body concentrations. For example, concentrations of 8.1-13.5 µg/g ww were associated with loss of equilibrium and 5.4 µg/g ww caused increased mortality in rainbow trout fingerlings (McGreachy and Dixon, 1990; 1992). Adult bluegill experienced reduced survival and growth at 11.6 µg/g ww (Gilderhus, 1966). Concentrations in all fish from the CRB were less than these effect levels.

Selenium

Detectable concentrations of Se (>0.2 µg/g ww) were present at all stations in 55 of 64 composites (86%), with the maximum concentration measured in female carp from Station 97 (Table 14). Concentrations ranged from 0.19-1.10 µg/g ww with concentrations ≥0.5 µg/g ww in composite samples from Stations 41, 42, 43, 44, 96, 97, 502, and 503 (Fig. 3). Concentrations of Se were generally greatest in carp and bass (Fig. 3). The geometric station mean for Se was greatest in fish samples from Station 97 (0.89 µg/g ww) followed by Stations 41 and 503 (Table 15); station means for all other fish samples from were <0.50 µg/g ww.

Among-station differences for concentrations of Se were significant in carp, largescale sucker, and bass but not in northern pikeminnow (Table 16). Concentrations in carp were significantly greater at Stations 45 and 97 than at Stations 41 and 42 (Table 16; Fig. 3), and concentrations at Station 97 were also significantly greater than Station 45. Concentrations of Se in largescale sucker were significantly greater at Stations 43, 46, 98, 501 and 506 than at Station 45 (Table 16; Fig. 3). Concentrations in bass were significantly lower at Stations 45 and 117 than at all other stations, and Stations 43, 97, and 503 had concentrations of Se that were significantly greater than Stations 42, 44, and 505 (Table 16; Fig. 3).

Concentrations of Se changed significantly from 1972-1997 at several stations based on historical NCBP data (Table 17). Concentrations in carp at Stations 42 and 97, largescale sucker at Stations 98, 46, and 45, bass at Station 44, and northern pikeminnow from Station 43 differed significantly from historical concentrations (Table 17). However, clear increasing or decreasing temporal trends were not evident at any of these stations (Table 17). Concentrations in 1997 were generally within the range of 1980-1986 NCBP concentrations (0.1-1.2 µg/g ww), with carp concentrations from Station 97 remaining at approximately 1 µg/g ww (Schmitt and others, 1999b). Walsh and others (1977) found similar concentrations of Se in largescale sucker and northern pikeminnow from the LCR. The USEPA determined whole body concentrations for Se in smallmouth bass and largescale sucker to range from 0.48-0.71 µg/g ww and <0.18-0.50 µg/g ww, respectively, in the CRB from 1996-1998 (USEPA, 2002b). Munn and others (1995) measured concentrations of Se <0.2 µg/g ww in rainbow trout fillets from the UCR. Previous BEST projects measured concentrations of Se in bass and carp. Bass concentrations ranged from 0.20-4.46 µg/g ww in the MRB (Schmitt and others, 2002) and 0.47-1.23 µg/g ww in the RGB (Schmitt and others, 2004). Carp collected in 1995 from the MRB had concentrations of Se ranging from 0.12-4.66 µg/g ww (Schmitt

Table 14. Occurrence (percentages of samples or stations) and censoring concentrations for elemental contaminants in composite samples of whole fish from the Columbia River Basin in 1997. The maximum concentrations and associated sample information (station, species, and gender) from this study are also given. NA, not applicable.

Analyte	Samples (% of 64)	Stations (% of 16)	Censoring range (µg/g)	Maximum 1997 concentration			
				(µg/g)	Station	Gender	Species
Arsenic	25	56	0.21-0.32	0.56	Ice Harbor Dam, WA (96)	M	Carp
Cadmium	42	75	0.04-0.06	0.51	Vernita Bridge, WA (503)	F	Carp
Chromium	100	100	NA	11.20	Vancouver, WA (506)	M	Largescale sucker
Copper	100	100	NA	3.92	Ice Harbor Dam, WA (96)	M	Carp
Lead	23	50	0.09-0.14	9.29	Northport, WA (504)	F	Largescale sucker
Mercury	92	100	0.05-0.06	0.61	Riggins, ID (43)	F	Northern pikeminnow
Nickel	38	81	0.22-0.33	1.18	Vancouver, WA (506)	F	Largescale sucker
Selenium	86	100	0.22-0.27	1.10	Pasco, WA (97)	F	Carp
Zinc	100	100	NA	105.6	Oregon City, OR (45)	F	Carp

and others, 2002b), and concentrations from the RGB ranged from 0.23-1.73 µg/g ww (Schmitt and others, 2004).

Several Se studies were included in a review by Jarvinen and Ankley (1999) on the effects of inorganic chemicals to aquatic organisms. Various studies from this review have shown that whole body concentrations of Se between 8-16 µg/g dw have led to reproductive failure in fathead minnows (*Pimephales promelas*) (Schultz and Hermanutz, 1990) and bluegill (Coyle and others, 1993; Gillespie and Baumann, 1986; Hermanutz and others, 1992). Results from Coyle and others (1993) indicated that concentrations of Se present in the egg stage or at hatch affected larval survival. These results indicate it is essential to examine multiple life stages to correctly assess toxicity/tissue concentration relationships (Jarvinen and Ankley, 1999). Whole body concentrations of Se should not exceed 4 µg/g dw (0.8 µg/g ww assuming 80% moisture) to avoid toxicity to the fish and should not exceed 3 µg/g dw (0.6 µg/g ww assuming 80% moisture) to avoid toxicity to piscivorous wildlife according to the criteria of Lemly (1996). Smallmouth bass at Stations 43 and 503 and carp and largemouth bass at Station 97 exceeded one or both thresholds.

Mercury

Mercury was detected (>0.05 µg/g ww) from all stations in 59 of 64 samples with the maximum concentration (0.61 µg/g ww) measured in female northern pikeminnow from Station 43 (Table 14). Concentrations were >0.25 µg/g ww in samples from Stations 43, 44, 45, 117, 501, 502, 503, and 505 (Fig. 4). The geometric mean was greatest at Station 43 (0.34 µg/g ww) followed by Stations 117 (0.24 µg/g ww) and 44 (0.23 µg/g ww) (Table 15). Concentrations were greatest in predatory fishes (Fig. 4).

Predatory fish (bass, northern pikeminnow) accumulate greater concentrations of Hg than bottom feeding fish (carp, sucker) (Fig. 4) (Schmitt and others, 1999b), and concentrations in predatory fish increase with size (that is, heavier and longer fish have greater concentrations of Hg). Therefore, it becomes necessary to examine concentration of Hg adjusted for weight and length. It is difficult to relate the concentrations of Hg in composite samples to individual length and weight measurements, but overall trends or patterns can be identified. The length or weight adjusted concentrations of Hg in fish were greater (many >0.5 µg/g ww) than the unadjusted concentrations (only one >0.5 µg/g ww) (Fig. 4).

Concentrations of Hg in bass and carp differed significantly among stations (Table 16). Un-adjusted concentrations of Hg in bass were significantly greater at Stations 43, 45, and 117 than at Station 97 in carp (Table 16; Fig. 4). Un-adjusted concentrations of Hg were significantly greater at Stations 42, 44, and 45 than at Stations 41 and 97 (Table 16; Fig. 4). The weight-adjusted (HgW) and length-adjusted (HgL) concentrations of Hg did not differ significantly among stations for northern pikeminnow or largescale sucker; however, differences in bass and carp were significant (Table 16). The

Table 15. Geometric mean, minimum, and maximum concentrations (µg/g, wet-weight) of elemental contaminants in fish collected in the Columbia River Basin in 1997. Censored values were replaced by one-half the value for the LOD for the computation of station means, but only if at least one value exceeded detection limits. The maximum geometric station mean is shown in bold for each contaminant. Stations are grouped by sub-basin and are ordered upstream to downstream.—

Station		Element								
		As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Upper Columbia River (UCR)										
Creston, MT (117)	Mean	<0.28	0.03	0.69	0.62	0.24	<0.27	<0.11	<0.30	19.4
(*n* = 4)	Min.	<0.23	<0.05	0.50	0.40	0.20	<0.22	<0.09	<0.24	16.0
	Max.	<0.28	0.05	1.06	0.96	0.31	<0.27	<0.11	<0.30	23.6
Northport, WA (504)	Mean	0.19	0.10	1.08	**1.71**	0.06	0.31	**1.25**	0.29	31.9
(*n* = 4)	Min.	<0.26	<0.05	0.43	1.10	<0.05	<0.27	0.22	<0.26	19.5
	Max.	0.52	0.42	3.42	3.46	0.15	0.74	9.29	0.43	50.9
Grand Coulee, WA (98)	Mean	<0.25	0.10	0.75	0.83	0.13	0.21	0.23	0.31	22.5
(*n* = 3)	Min.	<0.21	<0.05	0.52	0.53	0.12	<0.25	<0.10	0.30	14.3
	Max.	<0.25	0.46	2.15	1.36	0.15	0.56	1.58	0.32	36.0
Snake River (SR)										
Hagerman, ID (41)	Mean	<0.30	<0.06	1.72	0.81	0.07	0.17	<0.12	0.51	35.7
(*n* = 4)	Min.	<0.25	<0.05	0.91	0.44	<0.05	<0.27	<0.10	0.50	16.5
	Max.	<0.30	<0.06	3.70	1.32	0.24	0.27	<0.12	0.54	77.0
Riggins, ID (43)	Mean	0.15	0.05	0.73	0.87	**0.34**	0.19	0.07	0.48	19.9
(*n* = 5)	Min.	<0.23	<0.05	0.38	0.71	0.15	<0.24	<0.10	0.24	17.3
	Max.	0.41	0.08	2.47	1.01	0.61	0.58	0.17	0.84	24.1
Lewiston, ID (42)	Mean	<0.32	0.04	0.76	0.82	0.18	<0.32	<0.13	0.36	33.3
(*n* = 4)	Min.	<0.26	<0.05	0.69	0.50	0.14	<0.26	<0.10	0.27	15.9
	Max.	<0.32	0.11	0.85	1.07	0.21	<0.32	<0.13	0.50	66.8
Ice Harbor Dam, WA, (96)	Mean	**0.37**	0.07	1.27	1.24	0.12	0.24	<0.14	0.48	28.6
(*n* = 4)	Min.	0.27	<0.05	0.80	0.49	0.10	<0.26	<0.10	0.44	11.6
	Max.	0.56	0.27	3.96	3.92	0.20	0.47	<0.14	0.54	71.4
Middle Columbia River (MCR)										
Vernita Bridge, WA (503)	Mean	0.14	**0.12**	1.51	1.68	0.16	0.29	0.09	0.52	27.5
(*n* = 4)	Min.	<0.26	<0.06	0.50	0.92	0.08	<0.27	<0.10	0.41	14.4
	Max.	<0.30	0.51	3.38	3.32	0.30	0.59	0.33	0.70	75.5
Pasco, WA (97)	Mean	0.16	0.09	1.87	0.90	0.07	0.28	0.07	**0.89**	**38.3**
(*n* = 4)	Min.	<0.24	<0.05	0.66	0.47	<0.05	<0.24	<0.09	0.80	15.1
	Max.	0.32	0.39	3.72	1.55	0.18	0.75	0.14	1.10	104.5
Granger, WA (44)	Mean	0.15	<0.06	1.41	0.89	0.23	0.18	<0.11	0.34	23.4
(*n* = 6)	Min.	<0.25	<0.05	0.53	0.51	0.16	<0.25	<0.10	0.28	14.6
	Max.	0.43	<0.06	3.22	1.65	0.48	0.46	<0.11	0.53	80.9
Lower Columbia River (LCR)										
Cascade Locks, OR (46)	Mean	<0.26	0.08	1.87	1.07	0.11	0.61	0.07	0.30	21.9
(*n* = 2)	Min.	<0.23	0.06	1.25	0.97	0.10	0.53	<0.1	0.26	19.6
	Max.	<0.26	0.10	2.78	1.19	0.13	0.69	0.11	0.35	24.5

Table 15. Geometric mean, minimum, and maximum concentrations (µg/g, wet-weight) of elemental contaminants in fish collected in the Columbia River Basin in 1997. Censored values were replaced by one-half the value for the LOD for the computation of station means, but only if at least one value exceeded detection limits. The maximum geometric station mean is shown in bold for each contaminant. Stations are grouped by sub-basin and are ordered upstream to downstream.—Continued

Station		Element								
		As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Warrendale, OR (502) (n = 4)	Mean	0.31	0.08	0.89	1.07	0.21	<0.27	<0.11	0.40	25.9
	Min.	<0.27	<0.05	0.61	0.58	0.07	<0.27	<0.11	0.28	12.4
	Max.	0.42	0.40	2.09	2.93	0.49	<0.27	<0.11	0.50	94.0
Vancouver, WA (506) (n = 2)	Mean	0.16	0.07	**6.76**	1.38	0.09	**0.97**	0.24	0.23	20.4
	Min.	0.14	0.05	4.08	1.19	0.08	0.80	0.22	0.19	19.5
	Max.	0.18	0.10	11.20	1.60	0.10	1.18	0.27	0.28	21.4
Oregon City, OR (45) (n = 6)	Mean	<0.28	<0.06	0.78	0.82	0.17	0.15	<0.11	<0.27	24.3
	Min.	<0.22	<0.04	0.52	0.53	0.10	<0.22	<0.09	<0.22	14.7
	Max.	<0.28	<0.06	1.23	1.35	0.30	0.29	<0.11	<0.27	105.6
Portland, OR (505) (n = 4)	Mean	0.18	0.02	1.00	0.92	0.16	0.26	0.07	0.23	16.5
	Min.	<0.23	<0.05	0.30	0.34	0.11	<0.26	<0.09	<0.24	14.2
	Max.	0.53	<0.05	2.91	1.46	0.26	0.50	0.21	0.34	20.3
Beaver Army Terminal, OR (501) (n = 4)	Mean	0.20	0.06	1.27	1.15	0.16	0.18	<0.11	0.36	30.2
	Min.	<0.22	<0.05	0.89	0.81	0.09	<0.25	<0.09	0.29	17.6
	Max.	0.42	0.14	1.80	1.40	0.38	0.37	<0.11	0.46	82.0

relative rankings of the stations for bass and northern pikeminnow was similar for Hg, HgL, and HgW (Table 16); however, the magnitude of the among-sample differences at each station were smaller for the adjusted values (Fig. 4), indicating that some of the observed differences were related to fish size. Nevertheless, most relative differences remained after adjusting for fish size, which suggests that spatial differences were not entirely artifacts of fish size.

Concentrations of Hg in fish changed significantly from 1969-1997 at several stations based on historical NCBP collections in the CRB (Table 17). These changes were fairly consistent for Hg, HgL, and HgW (Table 17). The size range of the bass from these stations was smaller than the range by the NAWQA Program's National Hg pilot study (Brumbaugh and others, 2001) in which HgL and HgW were first used to normalize concentrations of Hg relative to fish size. Overall, concentrations of Hg in carp at Stations 42, 96, and 97, largescale sucker at Stations 117, 98, 43, 46, and 45, and northern pikeminnow from Station 43 differed significantly from historical concentrations (Table 17). Increasing or decreasing temporal trends were not evident at any of these stations. In addition, and as noted for the geographic differences, the ordering of the years within taxa was similar for Hg, HgL, and HgW (Table 17). These results indicate that the among-year concentration differences were also not overly influenced by differences in the sizes of the fish comprised by the samples. Concentrations of Hg in 1997 were comparable to those from 1980-1986 when species differences are considered (Schmitt and others, 1999b).

Several other studies have reported concentrations of Hg in the CRB. Walsh and others (1977) found similar concentrations of Hg in largescale sucker and northern pikeminnow from the LCR. Serdar and others (1994) measured concentrations of Hg ranging from 0.12-0.18 µg/g ww in largescale sucker collected near Station 504. The USEPA determined whole body concentrations of Hg in smallmouth bass and largescale sucker to range from 0.22-0.36 µg/g ww and <0.058-0.25 µg/g ww, respectively, in the CRB from 1996-1998 (USEPA, 2002b). Concentrations of Hg ranged from 0.21-0.37 µg/g ww in composite walleye fillets from the UCR in 1994 (Munn and others, 1995). Concentrations of Hg <0.35 µg/g ww were documented in northern pikeminnow collected from Stations 42, 45, and 46 in the CRB from 1969-1981 (Eisler, 1985; Lowe and others, 1985). Previous BEST projects have measured Hg in carp and bass. Concentrations of Hg ranged from 0.04-0.34 µg/g ww in carp and 0.05-0.45 µg/g ww in bass in the MRB in 1995 (Schmitt and others, 2002b). Similar concentrations of Hg were measured in carp (0.03-0.20 µg/g ww) and bass (0.07-0.45 µg/g ww) in the RGB (Schmitt and others, 2004).

Many Hg toxicity studies in adult fish are not associated with environmentally relevant concentrations (Wiener and Spry, 1996). Fish populations are most at risk from Hg at existing exposure levels during embryonic and larval

Table 16. Spatial trends of chemical contaminants in fish collected in the Columbia River Basin in 1997. Least-squares mean concentrations (all in µg/g ww unless otherwise noted) of arsenic (As), cadmium (Cd), copper (Cu), mercury (Hg), length-adjusted Hg (HgL; µg/g/m ww), weight-adjusted Hg (HgW; µg/g/kg ww), lead (Pb), selenium (Se), zinc (Zn), *p,p'*-DDE and PCB. Values within each group of taxon-station means followed by the same letter are not significantly different ($P<0.01$ Fisher's protected LSD). Also shown are ANOVA F-values, degrees-of-freedom (df), and significance levels (*$0.01<P\leq0.05$; **$P\leq0.01$). Stations are listed upstream to downstream within each taxon grouping.—C

Station and species	Contaminant										
	As	Cd	Cu	Hg	HgW	HgL	Pb	Se	Zn	DDE	PCB
Carp											
Hagerman, ID (41)	0.130 a	0.026 a	1.082 ab	0.026 a	0.033 a	0.068 a	0.052 a	0.501 a	73.26	0.155 ab	0.015 a
Lewiston, ID (42)	0.152 ab	0.060 ab	0.959 a	0.190 c	0.064 ab	0.381 c	0.061 a	0.400 a	65.30	0.575 c	0.145 a
Ice Harbor Dam, WA (96)	0.453 b	0.188 c	2.525 c	0.100 bc	0.029 a	0.160 abc	0.062 a	0.512 ab	65.18	0.802 c	0.234 b
Verita Bridge, WA (503)	0.139 a	0.412 c	2.219 bc	0.091 bc	0.038 ab	0.162 abc	0.272 b	0.495 ab	73.36	0.785 c	0.300 b
Pasco, WA (97)	0.197 ab	0.345 c	1.534 abc	0.045 ab	0.026 a	0.089 ab	0.086 a	0.991 c	86.96	0.251 ab	0.029 a
Granger, WA (44)	0.238 ab	0.027 a	1.578 abc	0.163 c	0.101 b	0.323 c	0.054 a	0.355 ab	78.33	0.668 bc	0.077 a
Warrendale, OR (502)	0.238 ab	0.294 c	2.220 bc	0.096 bc	0.042 ab	0.177 bc	0.054 a	0.458 ab	81.84	0.290 abc	0.134 b
Oregon City, OR (45)	0.131 a	0.026 a	1.237 abc	0.117 c	0.032 a	0.189 bc	0.053 a	0.380 b	75.63	0.100 a	0.312 b
Beaver Army Terminal, OR (501)	0.257 ab	0.135 bc	1.402 abc	0.115 bc	0.052 ab	0.210 abc	0.051 a	0.464 ab	81.97	0.510 abc	0.250 b
Largescale sucker											
Creston, MT (117)	0.116	0.033 ab	0.898 a	0.209	0.181	0.427	0.046 a	0.188 ab	22.81 a	0.005 a	0.015 a
Northport, WA (504)	0.260	0.375 c	2.636 b	0.111	0.072	0.209	6.169 e	0.195 ab	48.23 b	0.020 a	0.156 cd
Grand Coulee, WA (98)	0.107	0.376 c	1.299 ab	0.120	0.101	0.232	1.036 d	0.308 b	35.40 b	0.012 a	0.015 ab
Riggins, ID (43)	0.218	0.066 ab	0.873 a	0.171	0.194	0.374	0.130 bc	0.268 b	22.07 a	0.194 bc	0.015 cd
Ice Harbor Dam, WA (46)	0.123	0.076 b	1.071 a	0.115	0.095	0.229	0.073 ab	0.304 b	21.88 a	0.304 bc	0.103 d
Vancouver, WA (506)	0.161	0.069 ab	1.384 ab	0.093	0.115	0.212	0.243 c	0.233 b	20.41 a	0.135 b	0.287 cd
Oregon City, OR (45)	0.108	0.022 ab	1.080 ab	0.118	0.115	0.268	0.043 ab	0.108 a	18.89 a	0.250 bc	0.015 bc
Portland, OR (505)	0.117	0.023 a	1.422 ab	0.118	0.167	0.273	0.098 abc	0.170 ab	18.93 a	0.096 b	0.209 d
Beaver Army Terminal, OR (501)	0.215	0.063 ab	1.343 ab	0.096	0.133	0.225	0.044 a	0.300 b	19.16 a	0.665 c	0.141 cd
Bass											
Creston, MT (117)	0.132 ab	0.027	0.429	0.271 b	0.268 abcd	0.724 abc	0.053	0.132 a	16.45 ab	0.005 a	0.015 a
Hagerman, ID (41)	0.148 ab	0.030	0.612	0.178 ab	0.230 abc	0.504 abc	0.059	0.521 bc	17.41 ab	0.350 bc	0.015 a
Riggins, ID (43)	0.127 ab	0.058	1.007	0.443 b	1.297 e	1.542 c	0.051	0.838 c	17.26 ab	0.200 bc	0.015 a
Lewiston, ID (42)	0.135 a	0.027	0.707	0.172 ab	0.759 de	0.668 abc	0.054	0.330 b	17.01 ab	0.110 b	0.184 b
Ice Harbor Dam, WA (96)	0.306 ab	0.028	0.611	0.141 ab	0.180 abc	0.391 ab	0.057	0.448 bc	12.53 a	0.230 bc	0.026 a
Vernita Bridge, WA (503)	0.147 ab	0.030	0.919	0.153 ab	0.086 a	0.328 ab	0.059	0.698 c	14.44 ab	0.510 bc	0.300 b
Pasco, WA (97)	0.127 ab	0.025	0.534	0.103 a	0.161 ab	0.314 a	0.051	0.808 c	16.83 ab	0.206 b	0.025 a
Granger, WA (44)	0.138 ab	0.028	0.605	0.188 ab	0.340 bcd	0.578 abc	0.055	0.375 b	15.28 b	0.817 c	0.223 b
Warrendale, OR (502)	0.400 b	0.027	0.577	0.192 ab	0.245 abcd	0.528 abc	0.055	0.497 bc	12.44 ab	0.180 bc	0.380 b
Oregon City, OR (45)	0.123 ab	0.025	0.584	0.251 b	0.457 cde	0.766 bc	0.049	0.123 a	15.98 ab	0.186 b	0.020 a
Portland, OR (505)	0.265 b	0.027	0.589	0.230 ab	0.498 cde	0.750 abc	0.053	0.317 b	14.37 ab	0.146 b	0.467 b

Table 16. Spatial trends of chemical contaminants in fish collected in the Columbia River Basin in 1997. Least-squares mean concentrations (all in µg/g ww unless otherwise noted) of arsenic (As), cadmium (Cd), copper (Cu), mercury (Hg), length-adjusted Hg (HgL; µg/g/m ww), weight-adjusted Hg (HgW; µg/g/kg ww), lead (Pb), selenium (Se), zinc (Zn), *p,p'*-DDE and PCB. Values within each group of taxon-station means followed by the same letter are not significantly different ($P<0.01$ Fisher's protected LSD). Also shown are ANOVA F-values, degrees-of-freedom (df), and significance levels (*$0.01<P\leq0.05$; **$P\leq0.01$). Stations are listed upstream to downstream within each taxon grouping.—Continued

Station and species	Contaminant											
	As	Cd	Cu	Hg	HgW	HgL	Pb	Se	Zn	DDE	PCB
Northern pikeminnow												
Riggins, ID (43)	0.122	0.036 ab	0.759 a	0.521	0.831	1.350	0.049	0.484	20.78	0.093 a	0.048 a
Vernita Bridge (503)	0.128	0.135 b	2.321 b	0.302	0.291	0.619	0.051	0.413	19.58	0.280 ab	1.300 c
Granger, WA (44)	0.125	0.025 a	1.035 ab	0.480	0.798	1.162	0.050	0.317	16.05	0.800 b	0.170 b
Warrendale, OR (502)	0.299	0.054 ab	0.949 ab	0.490	0.428	0.953	0.053	0.280	17.14	0.370 ab	0.680 bc
Beaver Army Terminal, OR (501)	0.135	0.027 a	0.806 ab	0.377	0.460	0.853	0.054	0.328	17.57	0.220 ab	0.380 bc
F-value	5.45	12.08	4.44	10.61	11.45	10.90	10.11	9.26	31.49	7.19	9.05
df (model, error)	156,93	156,93	80,56	186,100	186,100	186,100	123,70	156,93	80,56	209,112	93,64

stages partially due to maternal transfer (Wiener and Spry, 1996). Behavioral effects in laboratory studies have been documented in fish containing whole body concentrations of 0.7-5.4 µg/g ww (Kania and O'Hara, 1974; Wiener and Spry, 1996). Grayling (*Thymallus thymallus*) fry with 0.27 µg/g ww of Hg had permanent impairment of their feeding efficiency and competitive ability (Fjeld and others, 1998). Jarvinen and Ankley (1999) reviewed various laboratory studies evaluating the effects of Hg on reproduction in freshwater fish. Included were studies that found reduced reproduction at whole body concentrations of 4.47 µg/g ww in fathead minnows (Snarski and Olson, 1982) and 9.4 µg/g ww in second-generation brook trout (McKim and others, 1976). Concentrations of Hg in the diet of 0.87 µg/g dw increased whole body concentrations of Hg over 10-fold, and suppressed hormone levels and inhibited gonadal development in female fathead minnows (Drevnick and Sandheinrich, 2003). Whole body concentrations associated with behavioral and reproductive effects were approximately 5 µg/g ww for brook trout (*Salvelinus fontinalis*) and 10 µg/g ww for rainbow trout (Wiener and Spry, 1996; Wiener and others, 2002). However, caution should be used with these thresholds because many factors can contribute uncertainty to these critical tissue concentration estimates (Wiener and others, 2002).

Dietary intake of Hg is a concern for piscivorous wildlife because Hg bioaccumulates up the food chain. Dietary concentrations of Hg in wildlife as low as 0.3 µg/g ww have been associated with reproductive impairment in common loons (*Gavia immer*) (Barr, 1986), and reproduction in mallards (*Anas platyrhynchos*) was affected at concentrations as low as 0.1 µg/g ww (Heinz, 1979). Dietary concentrations of Hg at 0.25-1.0 µg/g ww may also be toxic to piscivorous mammals (studies reviewed by Wolfe and others, 1998). Neurotoxicity and mortality occurred in adult mink (*Mustela vison*) after chronic exposure to dietary concentrations of Hg >1 µg/g ww (Dansereau and others, 1999; Wobeser and others, 1976; Wren and others, 1987). Consequently, guidelines for the protection of piscivorous wildlife range from 0.5-1.0 µg/g ww (Eisler, 1987; Thompson, 1996) and values as low as 0.1 µg/g ww for mammals and 0.02 µg/g ww for birds have been derived from water quality criteria and bioaccumulation factors (Yeardley and others, 1998). Selenium affords a degree of protection against Hg toxicity in wildlife by demethylation to inorganic mercury when Se and Hg are in molar ratio of 1:1 (Dietz and others, 1990; Heinz and Hoffman, 1998; Scheuhammer and others, 1998; Wiener and others, 2002). However, studies have shown Se-enhanced Hg embryo toxicity in birds (Heinz and Hoffman, 1998). Reproductive effects may be exacerbated, even though the significant amounts of Se may protect adult birds from the toxic effects of Hg. Concentrations of Hg in largemouth bass at Station 117, smallmouth bass from Station 43, and northern pikeminnow from Stations 43, 44, 501, 502, and 503 exceeded 0.3 µg/g ww, and at least one sample from all stations exceeded 0.1 µg/g ww (Fig. 4). Therefore, our results indicate that Hg is a contaminant of concern in the CRB.

Table 17. Historical trends of chemical contaminants in fish collected from NCBP stations in the Columbia River Basin. Least-squares mean concentrations (all in µg/g ww unless otherwise noted) of arsenic (As), cadmium (Cd), copper (Cu), mercury (Hg), length-adjusted Hg (HgL; µg/g/m ww), weight-adjusted Hg (HgW; µg/g/kg ww), selenium (Se), lead (Pb), zinc (Zn), *p,p'*-DDE, and PCB. Values within each group of taxon-station means followed asterisks differ significantly (*$0.01<P\leq0.05$; **$P\leq0.01$, Fisher's protected LSD) from 1997 means. Also shown are ANOVA F-values, degrees-of-freedom (df), and significance levels. ND, no data/not measured. Stations are listed upstream to downstream within each taxon grouping.—

Station and Species	Year	Contaminant										
		As	Cd	Cu	Hg	HgW	HgL	Se	Pb	Zn	DDE	PCBs
Carp												
Hagerman, ID (41)	1974	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.314	ND
	1997	0.130	0.026	1.082	0.026	0.033	0.068	0.501	0.052	73.26	0.155	0.015
Lewiston, ID (42)	1970	ND	ND	ND	0.250	0.240 **	0.643	ND	ND	ND	0.470	ND
	1971	0.074	0.047	ND	0.300	0.302 **	0.804 *	ND	0.110	ND	0.159 *	ND
	1972	0.140	0.880 **	ND	0.170	0.121	0.391	0.170 **	0.050	ND	1.100	ND
	1973	0.180	0.060	ND	0.060 *	0.049	0.137 *	0.300	0.050	ND	0.310	ND
	1997	0.152	0.060	0.959	0.190	0.064	0.381	0.400	0.061	65.30	0.575	0.145
Ice Harbor Dam, WA (96)	1971	0.106 **	0.074 *	ND	0.214 *	0.294 **	0.660 **	ND	0.074	ND	0.405	ND
	1997	0.453	0.188	2.525	0.100	0.029	0.160	0.512	0.062	65.18	0.802	0.234
Pasco, WA (97)	1970	ND	ND	ND	0.070	0.119 **	0.219 *	ND	ND	ND	1.120 *	ND
	1971	0.039 **	0.098 **	ND	0.075	0.127 **	0.241 **	ND	0.369 **	ND	0.334	ND
	1972	0.120	1.800 **	ND	0.120 *	0.265 **	0.387 **	0.400 **	0.200	ND	0.670	ND
	1973	0.180	0.025 **	ND	0.005 **	0.014	0.016 **	0.668	0.087	ND	0.255	ND
	1974	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.543 **	ND
	1976	0.296	0.050 **	ND	0.020 *	0.063 *	0.068	ND	0.210 *	ND	0.135	0.150 **
	1980	0.069 *	0.049 **	1.374	0.045	0.090 **	0.136	0.832	0.288 **	78.83	0.194	0.224 **
	1997	0.197	0.345	1.534	0.045	0.026	0.089	0.991	0.086	86.96	0.251	0.029
Granger, WA (44)	1970	ND	ND	ND	0.230	0.483 **	0.805 *	ND	ND	ND	1.230	ND
	1971	0.039 **	0.025	ND	0.171	0.329 **	0.567	ND	0.050	ND	1.045	ND
	1972	0.200	0.420 **	ND	0.240	0.661 **	0.900 *	0.400	0.050	ND	2.200	ND
	1973	0.025 **	0.025	ND	0.070	0.129	0.206	0.220	0.050	ND	0.520	ND
	1974	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.612 *	ND
	1978	0.170	0.050	1.187	0.215	0.433 **	0.630	0.542	0.118 *	92.46	1.215	0.524 **
	1997	0.238	0.027	1.578	0.163	0.101	0.323	0.355	0.054	78.33	0.668	0.077
Oregon City, OR (45)	1970	ND	ND	ND	0.170	0.075	0.352	ND	ND	ND	0.340	ND
	1973	0.025 **	0.025	ND	0.150	0.254 **	0.413	0.180	0.050	ND	0.350	ND

Table 17. Historical trends of chemical contaminants in fish collected from NCBP stations in the Columbia River Basin. Least-squares mean concentrations (all in µg/g ww unless otherwise noted) of arsenic (As), cadmium (Cd), copper (Cu), mercury (Hg), length-adjusted Hg (HgL; µg/g/m ww), weight-adjusted Hg (HgW; µg/g/kg ww), selenium (Se), lead (Pb), zinc (Zn), *p,p'*-DDE, and PCB. Values within each group of taxon-station means followed asterisks differ significantly (*$0.01<P\leq0.05$; **$P\leq0.01$, Fisher's protected LSD) from 1997 means. Also shown are ANOVA F-values, degrees-of-freedom (df), and significance levels. ND, no data/not measured. Stations are listed upstream to downstream within each taxon grouping.—Continued

Station and Species	Year	Contaminant										
		As	Cd	Cu	Hg	HgW	HgL	Se	Pb	Zn	DDE	PCBs
	1974	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.880 **	ND
	1997	0.131	0.026	1.237	0.117	0.032	0.189	0.380	0.053	75.63	0.100	0.312
Largescale sucker												
Creston, MT (117)	1980	0.063	0.014 *	0.913	0.099 *	0.169	0.254	0.198	0.100 *	18.21	0.030 **	0.200 **
	1984	0.073	0.020	0.864	0.171	0.165	0.395	0.180	0.063	20.09	0.014	0.173 **
	1986	0.117	0.020	3.143 **	0.176	0.155	0.366	0.172	0.101 *	19.72	0.014	0.075 **
	1997	0.116	0.033	0.898	0.209	0.181	0.427	0.188	0.046	22.81	0.005	0.015
Northport, WA (504)	1971	0.164	0.114 **	ND	0.049 *	0.103	0.145	ND	0.722	ND	0.052 *	ND
	1976	0.300	0.330	ND	0.020 **	0.026 **	0.046 **	ND	2.570 *	ND	0.024	0.495 **
	1978	0.200	0.357	0.849	0.067	0.082	0.152	0.224	1.115	55.39 **	0.040 *	0.474 **
	1980	0.281 *	0.216	0.837	0.125	0.153	0.294	0.195 *	0.653	28.07	0.055 **	0.274 **
	1984	0.137	0.092 **	1.040	0.088	0.205	0.271	0.224	0.253 **	21.05 **	0.024	0.250 **
	1997	0.107	0.376	1.299	0.120	0.101	0.232	0.308	1.036	35.40	0.012	0.015
Riggins, ID (43)	1969	ND	ND	ND	0.230	0.317	0.596	ND	ND	ND	0.140	ND
	1970	ND	ND	ND	0.405 *	0.388	0.908 *	ND	ND	ND	0.110	ND
	1971	0.134	0.072	ND	0.262	0.330	0.662	ND	0.084	ND	0.229	ND
	1972	0.126	0.180 *	ND	0.113	0.200	0.316	0.224	0.141	ND	0.104	ND
	1973	0.200	0.025	ND	0.150	0.184	0.337	0.320	0.050 *	ND	0.120	ND
	1974	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.180	ND
	1976	0.500	0.120	ND	0.190	0.246	0.411	ND	0.230	ND	0.130	0.194 **
	1984	0.114	0.020 **	0.816	0.098	0.206	0.267	0.299	0.154	20.97	0.014 **	0.200 **
	1986	0.110	0.048	0.539	0.125	0.166	0.291	0.261	0.181	19.14	0.014 **	0.075 **
	1997	0.218	0.066	0.873	0.171	0.194	0.374	0.268	0.130	22.07	0.194	0.015
Cascade Locks, OR (46)	1969	ND	ND	ND	0.270	0.298 *	0.644 *	ND	ND	ND	0.360	ND
	1970	ND	ND	ND	0.210	0.231	0.489	ND	ND	ND	0.220	ND
	1971	0.183	0.025 **	ND	0.200	0.245 *	0.492 *	ND	0.145	ND	0.388	ND
	1972	0.025 **	0.160	ND	0.230	0.298 *	0.566 *	0.140 **	0.100	ND	0.470	ND
	1973	0.045 *	0.081	ND	0.320 **	0.381 **	0.714 **	0.088 **	0.353 **	ND	0.248	ND
	1974	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.200	ND

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Station and Species	Year	Contaminant										
		As	Cd	Cu	Hg	HgW	HgL	Se	Pb	Zn	DDE	PCBs
	1976	0.870 **	0.150	ND	0.050	0.138	0.159	ND	0.100	ND	0.127	1.308 **
	1978	0.324 *	0.055	1.209	0.074	0.088	0.173	0.420	0.249 **	22.45	0.284	0.367 *
	1980	0.434 **	0.030 *	0.903	0.071	0.080	0.164	0.258	0.100	18.34	0.535	0.335 *
	1984	0.220	0.040	1.010	0.100	0.105	0.234	0.240	0.090	20.79	0.730	0.550 **
	1997	0.123	0.076	1.071	0.115	0.095	0.229	0.304	0.073	21.88	0.304	0.103
Oregon City, OR (45)	1969	ND	ND	ND	0.180	0.331	0.510	ND	ND	ND	0.150	ND
	1970	ND	ND	ND	0.349 *	0.440 **	0.882 **	ND	ND	ND	0.604	ND
	1971	0.050	0.025	ND	0.299 *	0.367 *	0.744 *	ND	0.050	ND	0.250	ND
	1972	0.059	0.022	ND	0.098	0.180	0.304	0.104	0.100	ND	0.447	ND
	1973	0.025 **	0.025	ND	0.126	0.248	0.449	0.067	0.050	ND	0.255	ND
	1974	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.274	ND
	1980	0.070	0.014	0.913	0.186	0.160	0.262	0.214 *	0.140 *	22.54	0.177	0.917 **
	1997	0.108	0.022	1.080	0.118	0.115	0.268	0.108	0.043	18.89	0.250	0.015
Bass												
Riggins, ID (43)	1971	0.025 **	0.025	ND	0.360	0.794 **	1.254	ND	0.050	ND	0.140	ND
	1972	0.025 **	0.025	ND	0.210	0.772 **	0.861	0.680	0.050	ND	0.360	ND
	1973	0.050	0.025	ND	0.220	0.346 **	0.656	0.830	0.050	ND	0.140	ND
	1974	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.050	ND
	1986	0.015 **	0.006 **	1.182	0.248	0.386	0.730	0.606	0.170 *	12.97	0.060	0.075 *
	1997	0.127	0.058	1.007	0.443	1.297	1.542	0.838	0.051	17.26	0.200	0.015
Lewiston, ID (42)	1969	ND	ND	ND	0.150	1.102	0.844	ND	ND	ND	0.300	ND
	1970	ND	ND	ND	0.210	0.579	0.752	ND	ND	ND	0.330	ND
	1971	0.060	0.025	ND	0.280	0.703	1.021	ND	0.050	ND	0.610 **	ND
	1978	0.050	0.010	0.380	0.190	0.322	0.558	0.440	0.100	15.41	0.280	0.350
	1997	0.135	0.027	0.707	0.172	0.759	0.668	0.330	0.054	17.01	0.110	0.184
Granger, WA (44)	1969	ND	ND	ND	0.140	0.343	0.551	ND	ND	ND	0.940	ND
	1970	ND	ND	ND	0.270	0.425	0.864	ND	ND	ND	1.660	ND
	1973	0.025 **	0.025	ND	0.180	0.233	0.514	0.100 **	0.050	ND	0.770	ND
	1974	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.400	ND

Table 17. Historical trends of chemical contaminants in fish collected from NCBP stations in the Columbia River Basin. Least-squares mean concentrations (all in µg/g ww unless otherwise noted) of arsenic (As), cadmium (Cd), copper (Cu), mercury (Hg), length-adjusted Hg (HgL; µg/g/m ww), weight-adjusted Hg (HgW; µg/g/kg ww), selenium (Se), lead (Pb), zinc (Zn), *p,p'*-DDE, and PCB. Values within each group of taxon-station means followed asterisks differ significantly (*0.01<$P \leq 0.05$; **$P \leq 0.01$, Fisher's protected LSD) from 1997 means. Also shown are ANOVA F-values, degrees-of-freedom (df), and significance levels. ND, no data/not measured. Stations are listed upstream to downstream within each taxon grouping.—Continued

Station and Species	Year	Contaminant										
		As	Cd	Cu	Hg	HgW	HgL	Se	Pb	Zn	DDE	PCBs
	1997	0.138	0.028	0.605	0.188	0.340	0.578	0.375	0.055	15.28	0.817	0.223
Oregon City, OR (45)	1976	0.250	0.050	ND	0.130	0.573	0.556	ND	0.120 *	ND	0.060	0.650 **
	1997	0.123	0.025	0.584	0.251	0.457	0.766	0.123	0.049	15.98	0.186	0.020
Northern pikeminnow												
Riggins, ID (43)	1970	ND	ND	ND	1.700 **	3.748 **	5.109 **	ND	ND	ND	0.740 **	ND
	1971	0.071	0.025	ND	0.710	1.844 *	2.240	ND	0.050	ND	0.312 *	ND
	1972	0.070	0.025	ND	0.180 *	1.323	0.762	0.270 *	0.050	ND	0.220	ND
	1978	0.160	0.010 *	0.640	0.220	0.346	0.574	0.340	0.100	20.51	0.520 *	0.900 **
	1980	0.050	0.020	0.760	0.260	5.732 **	1.551	0.580	0.100	22.12	0.020 *	0.150
	1997	0.122	0.036	0.759	0.521	0.831	1.350	0.484	0.049	20.78	0.093	0.048
Granger, WA (44)	1972	0.100	0.050	ND	0.640	2.822 *	2.333	0.400	0.050	ND	2.700	ND
	1997	0.125	0.025	1.035	0.480	0.798	1.162	0.317	0.050	16.05	0.800	0.170
ANOVA-*F*	--	5.45	12.08	4.44	10.61	11.45	10.90	10.11	9.26	31.49	7.19	9.05
df	--	156,93	156,93	80,56	186,100	186,100	186,100	123,70	156,93	80,56	209,112	93,64

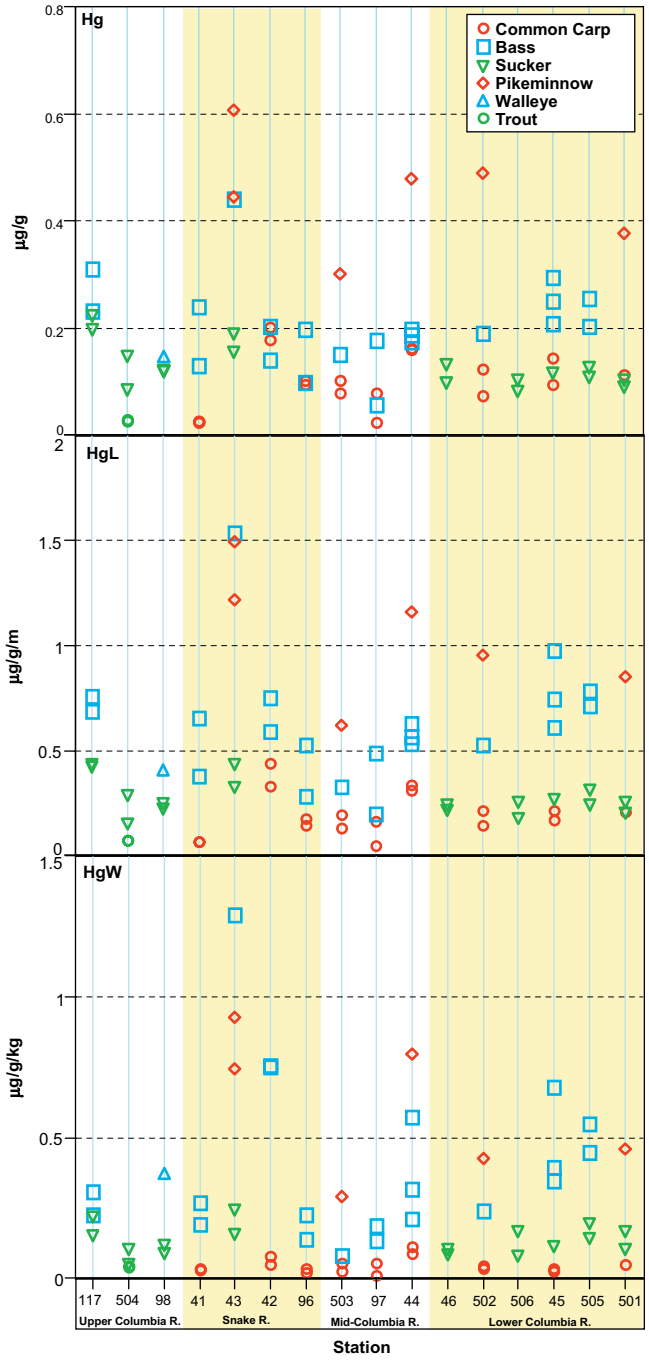


Figure 4. Concentrations (µg/g ww) of mercury (Hg) by station and taxon in whole body fish composite samples collected in the Columbia River Basin in 1997. Unadjusted (Hg), length-adjusted (HgL), and weight-adjusted (HgW) concentrations are shown. Censored values are plotted as one half the LOD. Stations are ordered from upstream to downstream and are grouped by sub-basin. See text for computations and Table 3 for station descriptions

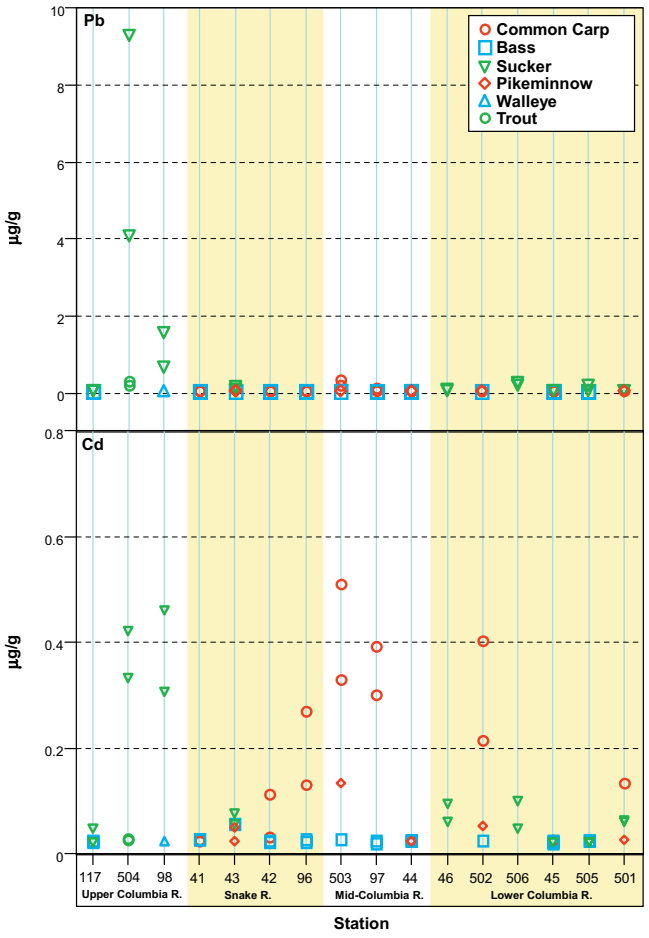


Figure 5. Concentrations (µg/g ww) of lead (Pb) and cadmium (Cd) by station and taxon in whole body fish composite samples collected in the Columbia River Basin in 1997. Censored values are plotted as one half the LOD. Stations are ordered from upstream to downstream and are grouped by sub-basin. See Table 3 for station descriptions.

Lead

Concentrations of Pb in fish from the CRB were >LOD (0.09-0.14 µg/g ww) in 15 of 64 samples (23%) from eight stations (Table 14). Concentrations ranged from 0.10-9.3 µg/g ww with the maximum concentrations measured in female largescale sucker from Station 504. Samples from Stations 98, 503, and 504 had concentrations >0.3 µg/g ww, and Station 504 had the greatest geometric mean (1.25 µg/g ww) (Table 15; Fig. 5); all other station geometric means were <0.24 µg/g ww. Concentrations in bass, northern pikeminnow, and walleye samples were <LOD.

Concentrations of Pb differed spatially in carp and largescale sucker but not in bass and northern pikeminnow (Table 16). Concentrations of Pb in carp were significantly greater at Station 503 than other stations (Table 16; Fig. 5). Concentrations of Pb in largescale sucker were significantly greater at Stations 43, 98, 504, and 506 than at Stations 117 and 501. Concentrations of Pb in largescale sucker at Stations 98 and 504 were the greatest and were significantly different from one another and all other stations (Table 16; Fig. 5).

Concentrations of Pb changed significantly at several stations in collections from 1971-1997 based on historical NCBP

data (Table 17). Concentrations of Pb in carp at Stations 97 and 44, largescale sucker at Stations 117, 98, 43, 46, and 45, and bass at Stations 43 and 45 differed significantly among years (Table 17). In general, a decline in concentrations of Pb in the CRB seen in the 1980s continued (Schmitt and others, 1999b); however, Station 98 had elevated concentrations (>0.35 µg/g ww) in 1980-1986 and 1997. Upstream from Station 98, largescale sucker from Station 504 had concentrations of Pb three to five times greater than in fish from any other station. Station 504 is 31-33 km downstream from a smelting complex located in British Columbia, which historically discharged slag and slurry effluent containing elemental contaminants into the CRB (Bortelson and others, 1994). Schmitt and others (2002a) reported liver concentrations of Pb of 1.34 µg/g ww in largescale sucker collected from Station 504 in 1992. Serdar and others (1994) measured concentrations ranging from 3.0-12.0 µg/g ww in largescale sucker collected near Station 504. Other studies have documented high concentrations of Pb in bottom feeding fish collected near Pb smelters (Schmitt and others, 1993). Concentrations in the northern hog sucker (*Hypentelium nigricans*) and black redhorse (*Moxostoma duduesnii*) of 4.57 µg/g ww and 11.22 µg/g ww, respectively, collected near Pb smelters in Missouri are comparable to concentrations in largescale sucker from Station 504 in 1997. The USEPA determined whole body concentrations for Pb in smallmouth bass and largescale sucker to range from 0.01-0.14 µg/g ww and 0.027-1.10 µg/g ww, respectively, in the CRB from 1996-1998 (USEPA, 2002b). Walsh and others (1977) also found similar concentrations of Pb in largescale sucker, smallmouth bass, and northern pikeminnow from the LCR. Whole body composite concentrations of Pb ranged from 0.01-0.69 µg/g ww in carp and 0.01-0.49 µg/g ww in bass in the MRB (Schmitt and others, 2002b). Another BEST project in the RGB also reported concentrations of Pb in carp (0.07-0.43 µg/g ww) and bass (0.03-0.83 µg/g ww) (Schmitt and others, 2004).

The effects threshold of Pb in fish is ≥0.4 µg/g ww based on whole body concentrations (Holcombe and others, 1976; as reviewed in Jarvinen and Ankley, 1999). Holcombe and others (1976) determined that whole body concentrations of Pb were associated with reduced hatch ability (0.4 µg/g ww) and reduced growth (4.0-8.8 µg/g ww) in third generation brook trout at various life stages. Effects on heme synthesis have been associated with carcass concentrations of Pb >1.0 µg/g ww and varying indirectly with Zn burden (Schmitt and others, 1993). Concentrations in largescale sucker from Stations 98 and 504 exceeded this value and the lowest thresholds of Holcombe and others (1976) but all concentrations in largescale sucker from the CRB were <0.34 µg/g ww in 1997. Most CRB fish did not approach these values although Pb appears to be a potential problem, at least in catostomids, at Stations 98 and 504.

Cadmium

Concentrations of Cd in fish from the CRB were >LOD (0.043-0.063 µg/g ww) in 27 samples (42%) from 12 stations (Table 14). Eleven composite samples yielded concentrations >0.2 µg/g ww (Fig. 5) with the maximum concentration (0.51 µg/g ww) measured in female carp from Station 503. The greatest station geometric mean was calculated for Station 503 (0.12 µg/g ww) (Table 15). Carp and largescale sucker consistently had greater concentrations of Cd at most stations compared to other species collected. Similar patterns were reported the MRB (Schmitt and others, 2002b) and RGB (Schmitt and others, 2004) where carp had concentrations greater than predator species collected concomitantly.

Spatial differences in concentrations of Cd were significant in carp, largescale sucker, and northern pikeminnow but not in bass (Table 16). Concentrations were significantly greater in carp at Stations 96, 97, 501, 502, and 503 than at Stations 41, 44, and 45 (Table 16; Fig. 5). Concentrations of Cd in largescale sucker were significantly greater at Stations 46, 98, 504 than at Station 505; Stations 98 and 504 were also significantly greater than Station 46 (Table 16; Fig. 5). Concentrations of Cd in northern pikeminnow were significantly greater at Station 503 than at Stations 44 and 501 (Table 16; Fig. 5).

Concentrations of Cd in fish from the CRB changed significantly at several stations from 1971-1997 based on historical NCBP data (Table 17). Concentrations in carp at Stations 42, 96, 97, and 44, largescale sucker at Stations 117, 98, 43, and 46, and bass and northern pikeminnow at Station 43 differed significantly among years (Table 17). Increasing or decreasing temporal trends were not clearly evident at any station except carp from Station 97 (Table 17). Composites from NCBP collections (1980-1986) had relatively low concentrations of Cd (<0.1 µg/g ww), with the exception of largescale sucker samples from Station 98 (Schmitt and others, 1999b). Serdar and others (1994) measured whole body concentrations ranging from 0.35-0.48 µg/g ww in largescale sucker collected near Station 504. The USEPA determined whole body concentrations for Cd in smallmouth bass and largescale sucker to range from 0.005-0.019 µg/g ww and 0.013-0.25 µg/g ww, respectively, in the CRB from 1996-1998 (USEPA, 2002b). A 1994 study of the UCR reported concentrations of Cd in fillets of smallmouth bass, walleye, and rainbow trout to be <0.03 µg/g ww (Munn and others, 1995), which are less than whole body concentrations measured in that region in 1997. Previous BEST projects from the MRB and RGB measured Cd in bass and carp. MRB concentrations ranged from 0.03-0.51 µg/g ww in carp and 0.02-0.21 in bass µg/g ww (Schmitt and others, 2002b) while RGB concentrations were 0.02-0.12 µg/g ww in carp and were <LOD in bass (Schmitt and others, 2004).

Birds and mammals are comparatively resistant to Cd; dietary toxicity thresholds were >100 µg/g in the studies reviewed by Eisler (1985). Nevertheless, Eisler (1985) suggested that a Cd concentration of 2 µg/g in fish is evidence of

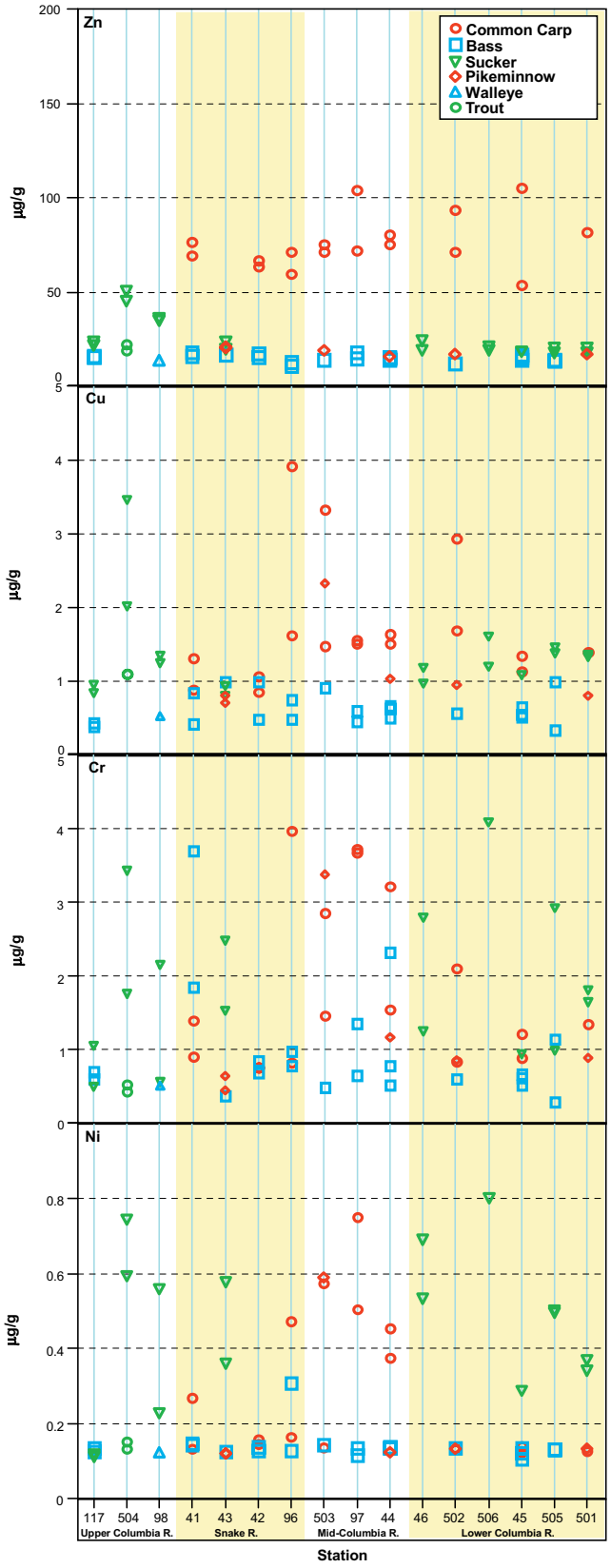


Figure 6. Concentrations (µg/g ww) of zinc (Zn), copper (Cu), chromium (Cr), and nickel (Ni) by station and taxon in whole body fish composite samples collected in the Columbia River Basin in 1997. Censored values are plotted as one half the LOD. Stations are ordered from upstream to downstream and are grouped by sub-basin. See Table 3 for station descriptions.

contamination, that 5 µg/g is potentially life-threatening to the fish, and that 13-15 µg/g is a threat to higher trophic levels. A review by Jarvinen and Ankley (1999) included several laboratory studies in which whole body concentrations of Cd in freshwater fish ranging from 0.12-15.6 µg/g ww resulted in reduced survival and/or growth, and concentrations of 2-8 µg/g ww caused decreased spawning and number of embryos produced in freshwater fish. Concentrations of Cd were well less than these benchmarks even though some 1997 concentrations exceeded historical NCBP concentrations.

Zinc

Concentrations of Zn in fish from the CRB ranged from 11.6-105.6 µg/g ww, with the maximum measured in female carp from Station 45 (Table 14; Fig. 6). All carp samples had concentrations >54 µg/g ww while all other species samples were <51 µg/g ww. All geometric station means were similar (Table 15). Concentrations of Zn differed spatially in largescale sucker and bass but not in carp or northern pikeminnow (Table 16). Concentrations in largescale sucker were significantly greater at Stations 98 and 504 than other stations, similar to patterns in concentrations of Pb in largescale sucker (Table 16; Fig. 6). Concentrations in bass were significantly greater at Station 503 than at Station 43 (Table 16; Fig. 6).

Concentrations of Zn changed significantly at Station 98 in largescale sucker in collections from 1978-1997 based on historical NCBP data (Table 17). Concentrations of Zn from samples collected in 1978-1986 ranged from 13-33 µg/g ww with the exception of two carp samples (75 and 82 µg/g ww) from Station 97 (Schmitt and others, 1999b); carp from the same station in 1997 had concentrations ranging from 72-105 µg/g ww. Historically, largescale sucker concentrations (13.3-28.7 µg/g ww) were less than 1997 concentrations (17.7-50.9 µg/g ww). The USEPA determined whole body concentrations of Zn in smallmouth bass and largescale sucker to range from 15-18 µg/g ww and 16-38 µg/g ww, respectively, in the CRB from 1996-1998 (USEPA, 2002b). Serdar and others (1994) measured concentrations of Zn ranging from 23.1-84.5 µg/g ww in largescale sucker collected near Station 504.

Concentrations of Zn >100 µg/g ww in whole carp have been reported from many locations throughout the Midwest (Schmitt, 2002a; Schmitt and others, 1999a). Sun and Jeng (1998) also reported concentrations of Zn >100 µg/g ww in carp. Common carp partition much of the Zn in their digestive tissue and, in general, have much greater concentrations than other species examined (Sun and Jeng, 1998). The growth and survival of American flagfish (*Jordanella floridae*), a cyprinid, exposed over a life-cycle (larvae-to-adult) were affected at concentrations of 40-64 µg/g ww (Spehar, 1976) as cited by Jarvinen and Ankley (1999). This is well within the range of concentrations normally encountered in carp but lower than levels typical for other fishes in the CRB (Schmitt and Brumbaugh, 1990; Schmitt and others, 1999b). Only concentrations

in carp and largescale sucker exceeded these threshold values in the CRB, so it is unlikely that either fish or higher trophic level organisms are adversely affected by Zn (Eisler, 1993).

Copper

Copper was detected in all samples ranging from 0.34-3.92 µg/g ww, with the maximum concentration measured in male carp from Station 96 (Table 14). Comparatively high concentrations (>1.5 µg/g ww) were measured in carp at Stations 44, 96, 97, 502, and 503, northern pikeminnow at Station 503, and largescale sucker at Stations 504 and 506 (Fig. 6). Stations 503 and 504 had geometric mean values >1.5 µg/g ww (1.68 and 1.71 µg/g ww, respectively) (Table 15).

Concentrations of Cu were statistically different among stations in carp, largescale sucker, and northern pikeminnow but not in bass (Table 16). Concentrations of Cu in carp were significantly greater at Station 96 than at Stations 41 and 42; Stations 502 and 503 also had concentrations significantly greater than Station 42 (Table 16; Fig. 6). Concentrations of Cu in largescale sucker were significantly greater at Station 504 than at Stations 43, 46, and 117 (Table 16; Fig. 6). Concentrations in northern pikeminnow were significantly greater at Station 503 than at Station 43 (Table 16; Fig. 6).

In general, concentrations of Cu in fish collected in 1997 were similar to historical NCBP concentrations (Schmitt and others, 1999b). Concentrations of Cu in largescale sucker changed significantly at Station 117 in collections from 1978-1997 (Table 17). Largescale sucker collected from Stations 41, 44, and 117 had concentrations >3.0 µg/g ww in 1980-1986. Serdar and others (1994) measured concentrations of Cu ranging from 1.2-10.4 µg/g ww in largescale sucker collected near Station 504 in 1992-1993. Largescale sucker were only collected from Station 117 in this study, and concentrations of Cu had decreased to 0.84-0.96 µg/g ww. The USEPA determined whole body concentrations for Cu in smallmouth bass and largescale sucker to range from 0.50-0.56 µg/g ww and 0.80-5.6 µg/g ww, respectively, in the CRB from 1996-1998 (USEPA, 2002b). Concentrations of Cu were reported in whole body composite samples of carp and bass in previous BEST projects. Concentrations of Cu were 0.47-2.68 µg/g ww in carp and 0.35-0.72 µg/g ww in bass in the MRB (Schmitt and others, 2002b). Similar concentrations were measured in carp (0.56-1.8 µg/g ww) and bass (0.36-0.95 µg/g ww) in the RGB (Schmitt and others, 2004).

The ecological relevance of the concentrations of Cu in fish from the CRB is not known. Of the studies reviewed by Jarvinen and Ankley (1999), only the work of Stouthort and others (1996) was relevant; these authors determined that concentrations of 11.1-11.7 µg/g ww were associated with reduced survival of carp larvae, and concentrations of 42 µg/g ww reduced egg survival. However, no tissue-based criteria for Cu are available for the protection of avian and mammalian wildlife (Eisler, 1997).

Chromium and Nickel

Chromium was detected in all samples (0.3-11.2 µg/g ww), with the maximum concentration measured in male largescale sucker from Station 506 (Table 14; Fig. 6). Geometric station means were <1.9 µg/g ww, with the exception of Station 506 (6.76 µg/g ww) (Table 15). The USEPA determined whole body concentrations of Cr in smallmouth bass and largescale sucker to range from 0.11-0.23 µg/g ww and 0.13-0.60 µg/g ww, respectively, collected in the CRB from 1996-1998 (USEPA, 2002b). Eisler (1986) suggested that concentrations of Cr >4 µg/g dw (approximately 1 µg/g ww) in the tissues and organs of fish and wildlife indicate environmental contamination; however, the significance of such a value is unclear. Most 1997 samples and station means had concentrations >1.0 µg/g ww (Fig. 6; Table 15). Concentrations of Cr were not determined by the NCBP (Schmitt and others, 1999b). Although Cr was measured as part of the 1995 MRB BEST project, concentrations were not reported (Schmitt and others, 2002b). Concentrations of Cr in whole body composite samples ranged from 0.38-71.8 µg/g ww in carp and 0.71-70.1 µg/g ww in bass in the RGB (Schmitt and others, 2004). A recent review of the literature (Jarvinen and Ankley, 1999) found no studies linking whole body concentrations of Cr to survival or growth effects in freshwater fishes.

Concentrations of Ni were >LOD (0.22-0.33 µg/g ww) in 24 of 64 samples (38%) from 13 stations (Table 14). Concentrations ranged from 0.23-1.18 µg/g ww, with the maximum occurring female largescale sucker from Station 506 (Table 14; Fig. 6). Geometric station means were <0.31 µg/g ww, with the exception of samples from Stations 46 (0.61 µg/g ww) and 506 (0.97 µg/g ww) (Table 15). Concentrations of Ni were not determined by the NCBP (Schmitt and others, 1999b). Although Ni was measured as part of the 1995 MRB BEST project, concentrations were not reported (Schmitt and others, 2002b). The USEPA determined whole body concentrations of Ni in smallmouth bass and largescale sucker to range from 0.054-0.096 µg/g ww and 0.055-11.0 µg/g ww, respectively, collected in the CRB from 1996-1998 (USEPA, 2002b). The BEST program measured greater concentrations of Ni in carp (0.18-4.21 µg/g ww) and bass (0.23-3.29 µg/g ww) in the RGB compared to the CRB (Schmitt and others, 2004). Like Cu, studies are also lacking for linkages of whole body concentrations to effects for Ni (Jarvinen and Ankley, 1999), and tissue-based criteria for the protection of fishes and piscivorous wildlife are not available for this metal.

Data for additional elements (Al, B, Ba, Be, Fe, Mg, Mn, Mo, Sr, V), along with all other data from this study, are available at <*http://www.cerc.usgs.gov/data/best/search/*>. Of these, B, Be, and Mo were <LOD in all samples.

Table 18. Occurrence (percentages of samples and stations with concentrations >0.01 µg/g ww for individual compounds and >0.03 µg/g ww for toxaphene and total PCBs) of organochlorine chemical residues in composite samples of whole fish in the Columbia River Basin in 1997. The maximum concentrations and associated sample information (station, species, and gender) from this study are also given. ND, not detected. [a] Sum of *cis*- and *trans*-chlordanes and nonachlors; oxychlordane; and heptachlor epoxide, with censored values represented as one half the LOD. [b] 1,1a,2,2,3,3a,4,5,5,5a,5b,6-Dodecachloro-octahydro-1,3,4-metheno-1H-cyclobuta(cd)pentalene. [c] Perchlorobenzene. [d] Sum of α-, β, γ, and δ-hexachlorocyclohexane, with censored values represented as one half the LOD.

Analyte(s)	Samples (% of 64)	Stations (% of 16)	Maximum 1997 concentration			
			µg/g	Station	Gender	Species
p,p'-DDT	20	38	0.310	Granger, WA (44)	M/F	Largemouth bass
p,p'-DDD (TDE)	67	75	0.200	Vernita Bridge, WA (503)	M	Carp
p,p'-DDE	94	94	1.200	Granger, WA (44)	M	Smallmouth bass
Total *p,p'*-homologs	100	100	1.390	Granger, WA (44)	M	Smallmouth bass
o,p'-DDT	8	19	0.043	Vernita Bridge, WA (503)	M	Carp
o,p'-DDD (TDE)	3	6	0.010	Vancouver, WA (506)	M/F	Largescale sucker
o,p'-DDE	3	6	0.010	Vancouver, WA (506)	M/F	Largescale sucker
Dieldrin	20	44	0.029	Lewiston, ID (42)	M	Carp
Endrin	3	6	0.010	Vancouver, WA (506)	M/F	Largescale sucker
cis-Chlordane	6	19	0.020	Portland, OR (505)	F	Largemouth bass
trans-Chlordane	3	6	0.010	Vancouver, WA (506)	M/F	Largescale sucker
cis-Nonachlor	3	6	0.010	Vancouver, WA (506)	M/F	Largescale suck
trans-Nonachlor	23	50	0.100	Lewiston, ID (42)	M	Carp
Oxychlordane	3	6	0.010	Vancouver, WA (506)	M/F	Largescale sucker
Heptachlor epoxide	3	6	0.010	Vancouver, WA (506)	M/F	Largescale sucker
Total chlordane-related residues [a]	100	100	0.125	Lewiston, ID (42)	M	Carp
Toxaphene	3	6	0.050	Vancouver, WA (506)	M/F	Largescale sucker
Mirex [b]	3	6	0.010	Vancouver, WA (506)	M/F	Largescale sucker
Hexachlorobenzene (HCB) [c]	6	13	0.020	Ice Harbor Dam, WA (96)	F	Carp
Total PCBs	67	81	1.300	Vernita Bridge, WA (503)	F	Northern pikeminnow
Hexachlorocylohexane (HCH) [d]	6	13	0.020	Ice Harbor Dam, WA (96)	F	Carp

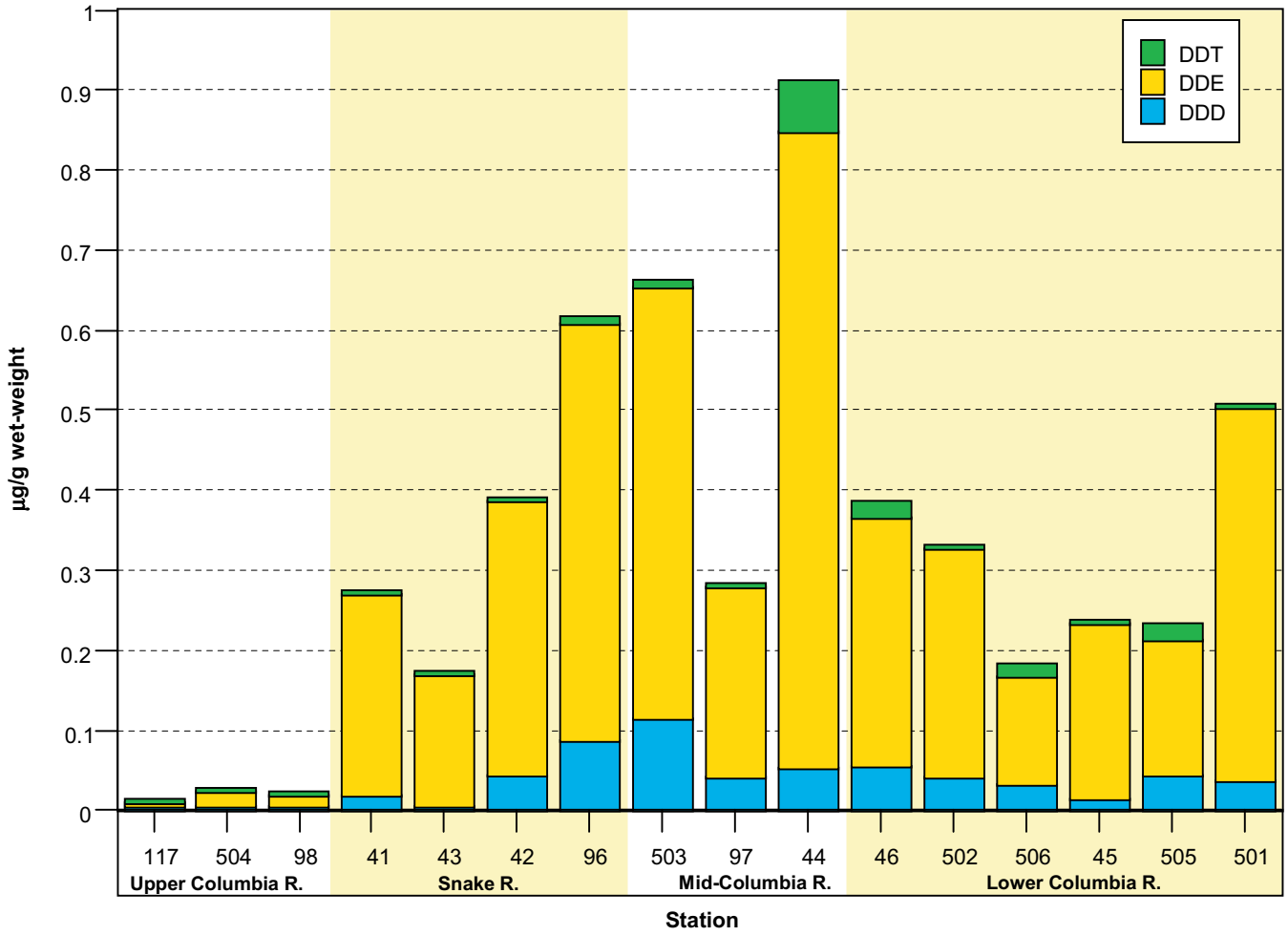


Figure 7. Weighted geometric mean concentrations (µg/g ww) of *p,p'*-DDT, DDE, and DDD by station in whole body fish composite samples collected in the Columbia River Basin in 1997. Censored values are represented by one half the LOD in the computation of means and totals but are not shown in the figure. Stations are ordered from upstream to downstream and are grouped by sub-basin. See Table 3 for station descriptions.

Organochlorine Chemicals

DDT and its primary metabolites

Concentrations of DDT, both *p,p* and *o,p* congeners, were measured in fish in the CRB. Use of DDT was banned in the U.S. in 1972, but concentrations of this persistent organochlorine insecticide and its metabolites remain present in the environment from historical use and as a consequence of atmospheric transport. Elevated concentrations of DDT residues are most common in cotton-growing areas of the U.S. and near former sites of production and formulation, although atmospheric transport from sites where DDT is still used can also deposit these chemicals (Schmitt and others, 2002b). Our study found the parent compound, *p,p'*-DDT, exceeded LOD (>0.01 µg/g ww) in 13 of 64 samples (20%) from six stations (Table 18) and accounted for 3.1% of the total detected DDT (*p,p'*-homologs) in fish sampled in 1997. The greatest concentrations (individual samples and geometric station means) of *p,p'*-DDT and total DDT were from Station 44 (Table 18; Figure 7). Bass from Station 44 had concentrations of *p,p'*-DDT ranging from 0.06-0.31 µg/g ww. Stations 46 and 505 also had samples that were >LOD, and samples from Stations 96, 503, and 506 had trace amounts of *p,p'*-DDT present in the fish (0.01-0.02 µg/g ww).

The major metabolite of *p,p'*-DDT, *p,p'*-DDE, was detected in 60 of 64 fish composites (Table 18) and accounted for 87% of the total detected DDT (Fig. 7). Stations 117, 504, and 98 in the UCR had concentrations <LOD (0.01 µg/g ww) in fish samples (Fig. 8). Composite samples with concentrations >0.5 µg/g ww included carp from Station 42 (0.56 and 0.59 µg/g ww), carp, bass, and northern pikeminnow from Station 44 (0.50-1.2 µg/g ww), carp from Station 96 (0.70-0.92 µg/g ww), carp and largescale sucker from Station 501 (0.51–0.68 µg/g ww), and carp and bass from Station 503 (0.51–1.1 µg/g ww). Geometric station means were greatest at Stations 44, 503, 501, and 96 (Table 19).

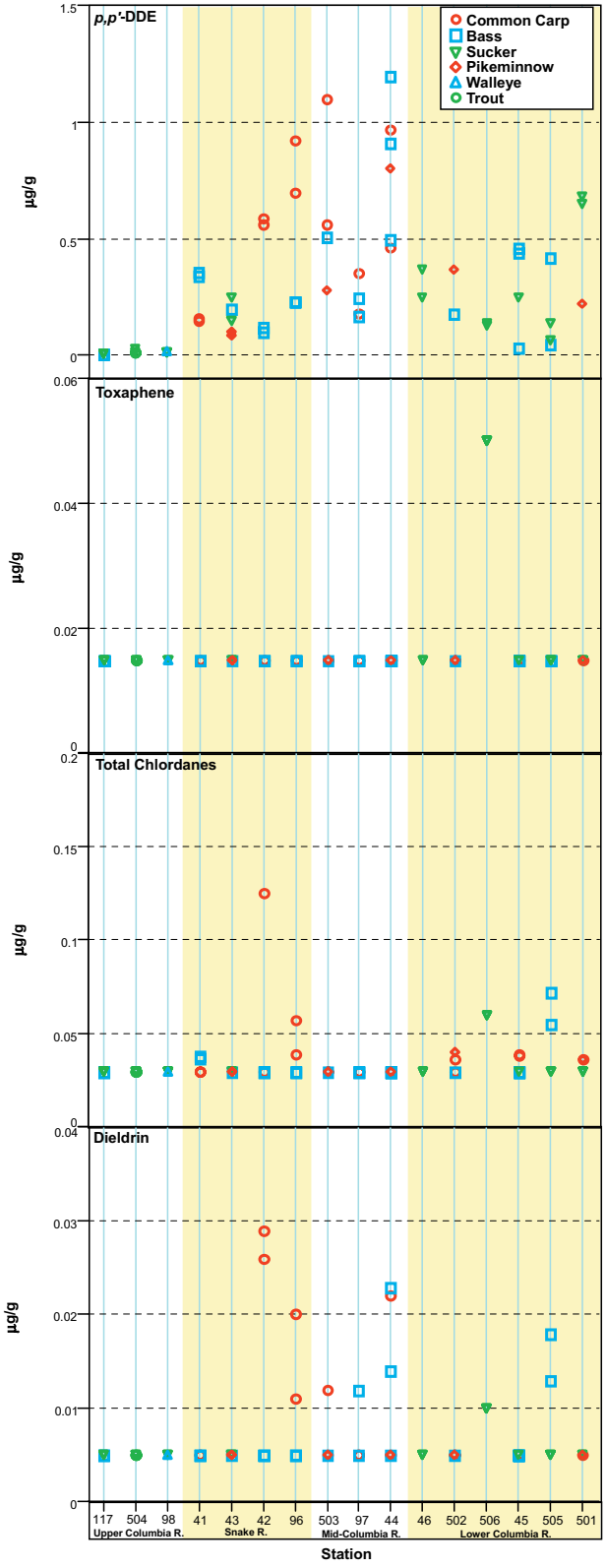


Figure 8. Concentrations (µg/g ww) of *p,p'*-DDE, toxaphene, total chlordanes, and dieldrin by station and taxon in whole body fish composite samples collected in the Columbia River Basin in 1997. Total chlordanes are the sum of *cis*- and *trans*-chlordanes and nonachlors, heptachlor epoxide, and oxychlordane. Censored values are plotted as one half the LOD. Stations are ordered from upstream to downstream and are grouped by sub-basin. See Table 3 for station descriptions.

Among-station differences in concentrations of *p,p'*-DDE were significant in carp, largescale sucker, bass, and northern pikeminnow (Table 16). Concentrations of *p,p'*-DDE were significantly greater in carp at Stations 42, 96, and 503 than at Stations 41, 45, and 97; Station 44 samples also had concentrations of *p,p'*-DDE significantly greater than Station 45 (Table 16; Fig. 8). Concentrations of *p,p'*-DDE in largescale sucker were significantly greater at Station 501 than at Stations 98, 117, 504, 505, and 506; Stations 43, 45, 46, 505, and 506 also had concentrations of *p,p'*-DDE significantly greater than Stations 98, 117, and 504 (Table 16; Fig. 8). Concentrations of *p,p'*-DDE in bass were significantly lower at Station 117 that at all other stations. Station 44 also had concentrations of *p,p'*-DDE in bass that were significantly greater than Stations 42, 45, 97, and 505 (Table 16; Fig. 8). Concentrations of *p,p'*-DDE in northern pikeminnow were significantly greater at Station 44 than at Station 43 (Table 16; Fig. 8).

Concentrations of *p,p'*-DDE changed significantly at several stations from 1969-1997 based on historical NCBP data (Table 17). Concentrations of *p,p'*-DDE in carp at Stations 42, 97, 44, and 45, largescale sucker at Stations 117, 98, 43, 46, and 45, and bass and northern pikeminnow at Station 43 differed significantly among years (Table 17). Decreasing temporal trends were evident in samples at Stations 117 (largescale sucker), 97 (carp), and 43 (northern pikeminnow). Increasing temporal trends were not clearly evident at any station. Johnson and others (1988) reported on the persistence of DDT in the Yakima River drainage (near Station 44) and concluded that irrigation diversions increased concentrations of DDT compounds in the water. Other studies found lower concentrations of *p,p'*-DDE in fish from the LCR compared to our findings (Curtis and others, 1993; ODEQ, 1994; USEPA, 1992). Previous BEST projects measured *p,p'*-DDE in carp and bass. Concentrations of *p,p'*-DDE ranged from 0.01-8.3 µg/g ww in carp and 0.01-0.53 µg/g ww in bass in the MRB (Schmitt and others, 2002b), and concentrations in the RGB were slightly less than the MRB in carp (0.01-0.67 µg/g ww) and bass (0.01-0.40 µg/g ww) (Schmitt and others, 2004). Concentrations of *p,p'*-DDE in carp and bass in the MRB and RGB were generally less than CRB concentrations with the exception of MRB stations in western Mississippi which consistently had carp concentrations >2.0 µg/g ww (Schmitt and others, 2002). Carp and bass from the lower SR and MCR consistently exceeded the 95th percentile (0.33 µg/g ww) for concentrations of *p,p'*-DDE measured in fish collected in a nationwide survey in 1992-1995 (Wong and others, 2000).

Concentrations of *p,p'*-DDD are due to *p,p'*-DDT breakdown and use as an insecticide. This compound accounted for 10.2% of the total detected DDT (≥0.01 µg/g ww) and was detected in 43 of 64 composite samples. Relatively high concentrations (0.1–0.2 µg/g ww) were measured in fish composite samples from Stations 96 and 503. Geometric station means did not exceed 0.06 µg/g ww with the exception of fish samples at Station 503 (0.11 µg/g ww) (Table 19). Wong and others (2000) detected *p,p'*-DDD (≤1.2 µg/g ww) in 42% of fish collected in a nationwide survey in 1992-1995.

Table 19. Unweighted geometric mean, minimum, and maximum concentrations (µg/g ww unless otherwise indicated) of organochlorine chemical contaminant in fish collected from the Columbia River Basin in 1997. Censored values were replaced by one-half of the LOD value for the computation of station means, but only if at least one value exceeded detection limits. Total DDT are the total of *p,p'*-DDT homologs. Total chlordane is the sum of *cis*-chlordane, *trans*-chlordane, *cis*-nonachlor, *trans*-nonachlor, heptachlor epoxide and oxychlordane; heptachlor epoxide and oxychlordane were not detected in any samples but were included in total chlordane at 0.005 µg/g (one half the LOD). The maximum geometric station mean is shown in bold for each contaminant. Stations are grouped by sub-basin and are listed upstream to downstream.—

Station		*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	Total DDT[a]	*cis*-Chlordane	*trans*-Chlordane	*cis*-Nonachlor	*trans*-Nonachlor	Total Chlordane	Dieldrin	Toxaphene	Total PCBs	TCDD-EQ (pg/g)
Upper Columbia River (UCR)														
Creston, MT (117) ($n = 4$)	Mean	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	<0.03	0.40
	Min.	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	<0.03	0.34
	Max.	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	<0.03	0.67
Northport, WA (504) ($n = 4$)	Mean	<0.01	0.02	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	0.11	1.50
	Min.	<0.01	0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	<0.03	1.00
	Max.	<0.01	0.03	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	0.35	5.00
Grand Coulee, WA (98) ($n = 3$)	Mean	<0.01	0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	<0.03	1.19
	Min.	<0.01	0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	<0.03	1.00
	Max.	<0.01	0.02	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	<0.03	2.00
Snake River (SR)														
Hagerman, ID (41) ($n = 4$)	Mean	0.02	0.23	<0.01	0.26	<0.01	<0.01	<0.01	0.01	0.03	<0.01	<0.03	<0.03	1.81
	Min.	0.01	0.15	<0.01	0.17	<0.01	<0.01	<0.01	0.01	0.03	<0.01	<0.03	<0.03	0.67
	Max.	0.03	0.36	<0.01	0.39	<0.01	<0.01	<0.01	0.01	0.04	<0.01	<0.03	<0.03	4.00
Riggins, ID (43) ($n = 5$)	Mean	<0.01	0.15	<0.01	0.16	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	0.02	0.39
	Min.	<0.01	0.09	<0.01	0.10	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	<0.03	0.10
	Max.	<0.01	0.25	<0.01	0.26	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	0.05	2.00
Lewiston, ID (42) ($n = 4$)	Mean	0.02	0.25	<0.01	0.28	<0.01	<0.01	<0.01	**0.01**	0.04	**0.01**	<0.03	0.16	1.41
	Min.	<0.01	0.10	<0.01	0.11	<0.01	<0.01	<0.01	0.01	0.03	<0.01	<0.03	0.05	1.00
	Max.	0.09	0.59	<0.01	0.69	<0.01	<0.01	<0.01	0.10	0.13	0.03	<0.03	0.64	2.00
Ice Harbor Dam, WA (96) ($n = 4$)	Mean	0.06	0.43	0.01	0.50	0.01	<0.01	<0.01	0.01	0.04	0.01	<0.03	0.08	**8.20**
	Min.	0.02	0.23	<0.01	0.26	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	<0.03	3.00
	Max.	0.19	0.92	0.01	1.12	0.02	<0.01	<0.01	0.02	0.06	0.02	<0.03	0.26	43.00
Middle Columbia River (MCR)														
Vernita Bridge, WA (503) ($n = 4$)	Mean	**0.11**	0.48	0.01	0.60	<0.01	<0.01	<0.01	<0.01	0.03	0.01	<0.03	**0.49**	6.29
	Min.	0.07	0.28	<0.01	0.35	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	0.20	6.00
	Max.	0.20	1.10	0.02	1.31	<0.01	<0.01	<0.01	<0.01	0.03	0.01	<0.03	1.30	8.00

Table 19. Unweighted geometric mean, minimum, and maximum concentrations (µg/g ww unless otherwise indicated) of organochlorine chemical contaminant in fish collected from the Columbia River Basin in 1997. Censored values were replaced by one-half of the LOD value for the computation of station means, but only if at least one value exceeded detection limits. Total DDT are the total of *p,p'*-DDT homologs. Total chlordane is the sum of *cis*-chlordane, *trans*-chlordane, *cis*-nonachlor, *trans*-nonachlor, heptachlor epoxide and oxychlordane; heptachlor epoxide and oxychlordane were not detected in any samples but were included in total chlordane at 0.005 µg/g (one half the LOD). The maximum geometric station mean is shown in bold for each contaminant. Stations are grouped by sub-basin and are listed upstream to downstream.—Continued

Station		*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	Total DDT[a]	*cis*-Chlordane	*trans*-Chlordane	*cis*-Nonachlor	*trans*-Nonachlor	Total Chlordane	Dieldrin	Toxaphene	Total PCBs	TCDD-EQ (pg/g)
Pasco, WA (97) ($n = 4$)	Mean	0.04	0.23	<0.01	0.27	<0.01	<0.01	<0.01	<0.01	0.03	0.01	<0.03	0.03	4.82
	Min.	0.02	0.17	<0.01	0.20	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	<0.03	3.00
	Max.	0.07	0.35	<0.01	0.43	<0.01	<0.01	<0.01	<0.01	0.03	0.01	<0.03	0.06	6.00
Granger, WA (44) ($n = 6$)	Mean	0.05	**0.73**	**0.04**	**0.90**	<0.01	<0.01	<0.01	<0.01	0.03	0.01	<0.03	0.15	1.09
	Min.	0.04	0.46	<0.01	0.51	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	0.04	1.00
	Max.	0.08	1.20	0.31	1.39	<0.01	<0.01	<0.01	<0.01	0.03	0.02	<0.03	0.62	2.00
Lower Columbia River (LCR)														
Cascade Locks, OR (46) ($n = 2$)	Mean	0.05	0.30	0.02	0.38	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	0.10	4.47
	Min.	0.04	0.25	0.01	0.30	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	0.08	2.00
	Max.	0.08	0.37	0.03	0.48	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	0.13	10.00
Warrendale, OR (502) ($n = 4$)	Mean	0.04	0.27	<0.01	0.32	<0.01	<0.01	<0.01	0.01	0.03	<0.01	<0.03	0.33	5.03
	Min.	0.03	0.18	<0.01	0.22	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	0.12	3.00
	Max.	0.07	0.40	<0.01	0.47	<0.01	<0.01	<0.01	0.02	0.04	<0.01	<0.03	0.68	8.00
Vancouver, WA (506) ($n = 2$)	Mean	0.03	0.13	0.02	0.18	0.01	**0.01**	**0.01**	0.01	**0.06**	0.01	**0.05**	0.29	2.65
	Min.	0.03	0.13	0.01	0.18	0.01	0.01	0.01	0.01	0.06	0.01	0.05	0.11	1.00
	Max.	0.03	0.14	0.02	0.19	0.01	0.01	0.01	0.01	0.06	0.01	0.05	0.75	7.00
Oregan City, OR (45) ($n = 6$)	Mean	0.01	0.14	<0.01	0.16	<0.01	<0.01	<0.01	0.01	0.03	<0.01	<0.03	0.04	2.20
	Min.	<0.01	0.03	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	<0.03	1.00
	Max.	0.03	0.46	<0.01	0.48	<0.01	<0.01	<0.01	0.01	0.04	<0.01	<0.03	0.36	9.00
Portland, OR (505) ($n = 4$)	Mean	0.04	0.12	0.01	0.17	0.01	<0.01	<0.01	0.01	0.04	0.01	<0.03	0.31	3.81
	Min.	0.01	0.05	<0.01	0.07	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.03	0.19	2.00
	Max.	0.08	0.42	0.07	0.51	0.02	<0.01	<0.01	0.03	0.07	0.02	<0.03	0.52	7.00
Beaver Army Terminal, OR (501) ($n = 4$)	Mean	0.03	0.42	<0.01	0.47	<0.01	<0.01	<0.01	0.01	0.03	<0.01	<0.03	0.24	2.11
	Min.	0.01	0.22	<0.01	0.26	<0.01	<0.01	<0.01	0.01	0.03	<0.01	<0.03	0.06	0.34
	Max.	0.07	0.68	<0.01	0.70	<0.01	<0.01	<0.01	0.01	0.04	<0.01	<0.03	0.38	8.00

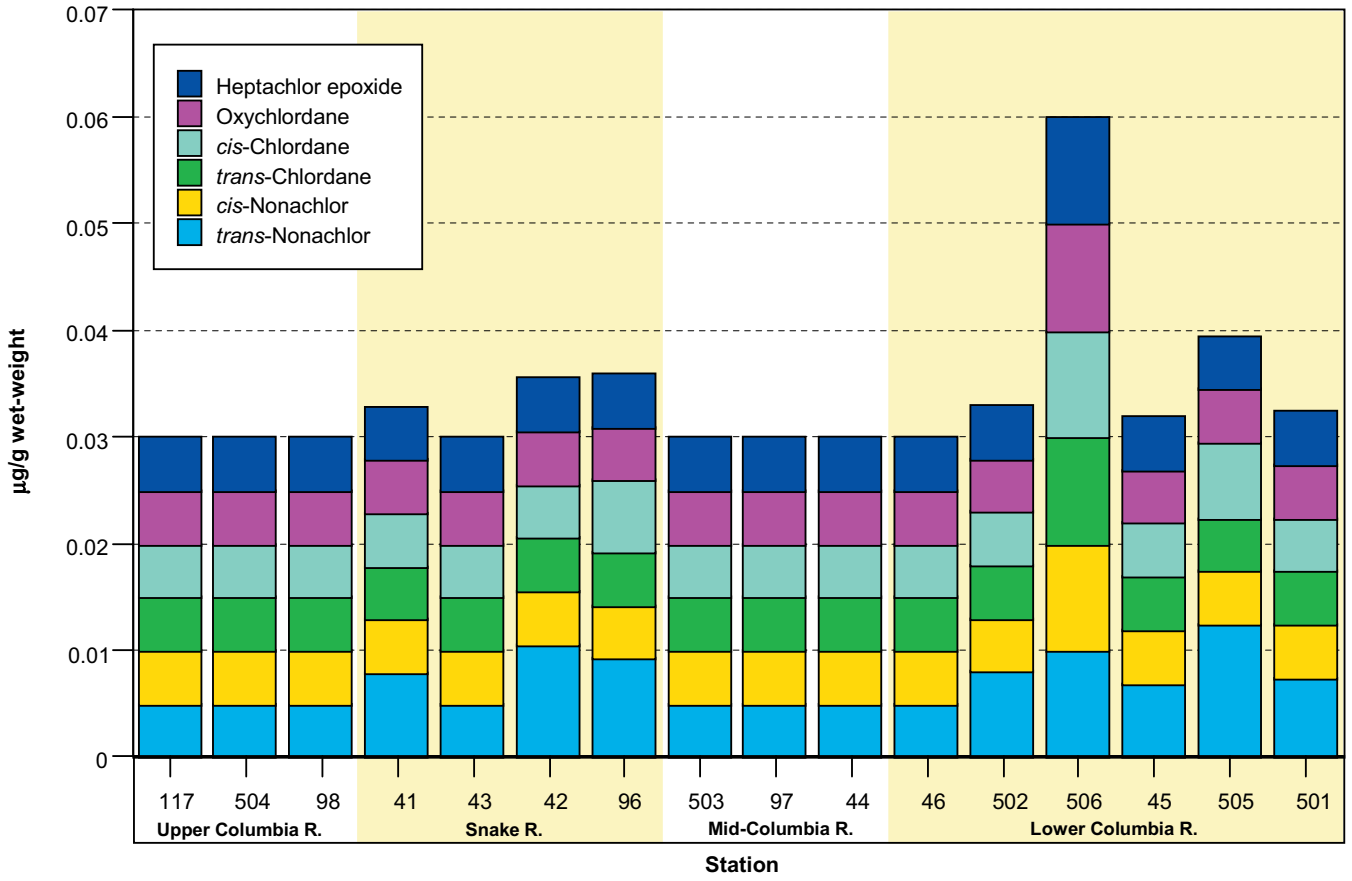


Figure 9. Weighted geometric mean concentrations (µg/g ww) of chlordane-related compounds (*cis*- and *trans*-chlordanes and nonachlors, heptachlor epoxide, and oxychlordane) by station in whole body fish composite samples collected in the Columbia River Basin in 1997. Censored values are represented by one half the LOD in the computation of means and totals but are not shown in the figure. Stations are ordered from upstream to downstream and are grouped by sub-basin. See Table 3 for station descriptions.

Geometric means for total DDT (*p,p'*-homologs) were highest at Stations 44, 503, 501, and 96 (Fig. 7). Stations 98, 117, and 504 were the only stations to have concentrations of total DDT <0.15 µg/g ww in fish samples; however, all stations had samples with concentrations <1 µg/g ww. Historically, low concentrations of total DDT have been recorded in fish at Stations 43, 98, and 117 (Schmitt and others, 1999b). Station 45 had comparatively low concentrations of all three homologs in 1986 fish samples. Station 44 has had fish samples with higher concentrations in the past due to use of DDT in agricultural areas along the Yakima watershed (Schmitt and others, 1990). Relatively high concentrations of total DDT were still present as reported in this other studies (Munn and Gruber, 1997). Mean *p,p'*-DDT homolog concentrations from Stations 44 and 96 exceeded 1986 NCBP concentrations in 1997 (Schmitt and others, 1999a). The USEPA determined whole body concentrations for *p,p'*-DDT and *p,p'*-DDE for a variety of fish species including smallmouth bass and largescale sucker from the CRB in 1996-1998 (USEPA, 2002b). Concentrations in smallmouth bass ranged from 0.97-1.7 µg/g ww for *p,p'*-DDE and 0.044-0.08 µg/g ww for *p,p'*-DDT; concentrations in largescale sucker ranged from 0.028-1.30 µg/g ww for *p,p'*-DDE and <0.001-0.18 µg/g ww for *p,p'*-DDT. Concentrations of total DDT in carp (0.02-0.70 µg/g ww) and bass (0.02-0.43 µg/g ww) in the RGB were similar to those in the CRB (Schmitt and others, 2004).

Multiple studies have suggested criteria to protect wildlife from DDT toxicity. Concentrations of total DDT in fish >0.15 µg/g ww are potentially harmful to the brown pelican (*Pelicanus occidentalis*), a sensitive avian species (Anderson and others, 1975), and wildlife criteria as low as 0.20 µg/g ww has been suggested by Newell and others (1987). According to studies reviewed by Blus (1996), concentrations of 1-3 µg/g ww are potentially hazardous to most piscivorous birds. A review by Jarvinen and Ankley (1999) associated toxic effects to fish with whole body concentrations as low as 0.5 µg/g ww. Reduced survival has been reported with whole body concentrations of total DDT in fry or fingerlings in cutthroat trout (*Oncorhynchus clarki)* (0.57 µg/g ww) (Cuerrier and others, 1967), rainbow trout (1.14-1.42 µg/g ww) (Cuerrier and others, 1967; Hopkins and others, 1969), brook trout (0.46-5.03 µg/g ww) (Cuerrier and others, 1967; Macek, 1968), lake trout (*S. namaycush)* (2.93 µg/g ww) (Burdick and others, 1964), coho salmon *(O. kisutch)* (1.09-2.76 µg/g ww) (Johnson and

Pecor, 1969), and chinook salmon (*O. tshawytscha)* (11.6-21.7 µg/g ww) (Buhler and others, 1969). Reduced survival has been reported with whole body concentrations of total DDT in juvenile and adult green sunfish (*Lepomis cyanellus*) and pumpkinseed (*L. gibbosus*) (24 µg/g ww) (Hamelink and others, 1971), fathead minnows (57-209 µg/g ww) (Jarvinen and others, 1976; 1977), and goldfish (*Carassius auratus)* (200-400 µg/g ww) (Rhead and Perkins, 1984). No station had a geometric mean concentration of total DDT >1.0 µg/g ww (Fig. 7). However, individual samples from Stations 44, 96, and 503 exceeded 1.0 µg/g ww. All stations except those from the UCR (Stations 117, 504, and 98) had individual fish sample concentrations of total DDT >0.15 µg/g ww.

Technical DDT contains *o,p'*-DDT as an impurity, and residues of this compound and its metabolites also remain widespread (Schmitt and others, 1985; 1999b; 2002b). Concentrations of these compounds were not detected in bass or carp in the RGB in 1997 (Schmitt and others, 2004). Comparatively low concentrations of *o,p'*-DDT (0.01–0.043 µg/g ww) were detected in samples from Stations 503, 505, and 506 in the CRB. Largescale sucker from Station 506 had trace concentrations of *o,p'*-DDE and *o,p'*-DDD (0.01 µg/g ww for each). Although the *o,p*' homologs have historically been considered relatively benign, *o,p'*-DDD is weakly estrogenic (Ackerman and others, 2002; Guillette and others, 1996; Toppari and others, 1996), as are many other pesticides and their metabolites (Tyler and others, 1998). Wong and others (2000) reported *o,p'*-DDT (≤0.14 µg/g ww) was detected in only 6% of fish collected in a nationwide survey in 1992-1995. The total risk to fish and wildlife represented by concentrations of *o,p'*-DDT is unknown.

Cyclodiene pesticides:

Chlordane and heptachlor

Chlordane is a mixture of cyclopentadiene-derived compounds that was widely used as a soil insecticide. Concentrations of these compounds are typically greatest in fish from corn-growing regions, urban areas in the "termite belt" or southeastern U.S., and near production and formulation facilities (Schmitt, 2002b; Schmitt and others, 1999b). Six chlordane-related components and metabolites were measured in the 1997 samples: *cis*-chlordane, *trans*-chlordane, *cis*-nonachlor, *trans*-nonachlor, oxychlordane, and heptachlor epoxide (Table 18). Heptachlor epoxide is a metabolite of heptachlor, which is a minor constituent of chlordane and was also used historically as an insecticide. Environmental concentrations of heptachlor epoxide result from both sources. Oxychlordane is a metabolite of *cis*-chlordane. Concentrations of *trans*-chlordane, *cis*-nonachlor, oxychlordane and heptachlor epoxide were <LOD (0.01 µg/g ww) in all samples with the exception of largescale sucker samples from Station 506 (Table 18). *Cis*-chlordane exceeded LOD (0.01 µg/g ww) in samples from Stations 505 (0.02 µg/g ww) and 96 (0.016 µg/g ww) and at LOD in both largescale sucker composites from Station 506 (Table 18; Fig. 9). *Trans*-nonachlor, the most frequently detected chlordane constituent, was detected (0.01 µg/g ww) in 15 of 64 samples (23%) from eight stations (Table 18). Concentrations ranged from 0.01-0.10 µg/g ww, with the maximum concentration measured in male carp from Station 42 (Fig. 8). Male and female largemouth bass samples from Station 505 had concentrations of 0.03 µg/g ww, and samples from Stations 41, 45, 96, 501, 502, and 506 had trace concentrations (0.01-0.02 µg/g ww) (Fig. 8).

NCBP concentrations from samples collected 1980-1986 for all of these compounds except *trans*-nonachlor were either not detected or detected at trace concentrations (0.005 or 0.01 µg/g ww) (Schmitt and others, 1999b). Concentrations of *trans*-nonachlor were 0.03 µg/g ww in largescale sucker and northern pikeminnow samples from Stations 45 and 46 in 1980; all other samples had trace concentrations. Wong and others (2000) reported concentrations of chlordane compounds in fish from a nationwide survey. *Trans*-nonachlor (≤0.12 µg/g ww) was detected in 34%, *cis*-chlordane (≤0.15 µg/g ww) in 24%, *cis*-nonachlor (≤0.05 µg/g ww) in 19%, *trans*-chlordane (≤0.06 µg/g ww) in 17%, oxychlordane (≤0.03 µg/g ww) in 12%, and heptachlor epoxide (≤0.02 µg/g ww) in 6% of the fish samples.

Concentrations of total chlordanes (sum of six compounds) in 1997 ranged from 0.03-0.13 µg/g ww, with the maximum concentrations measured in male carp from Station 42; other samples did not exceed 0.072 µg/g ww (Fig. 8). All geometric station means for total chlordane were ≤0.06 µg/g ww (Table 19). Munn and Gruber (1997) reported similar concentrations of chlordane in largescale sucker and carp from the mid-CRB. A USEPA study (USEPA, 1992) also reported similar concentrations in the LCR. Chlordane residues >0.1 µg/g ww are of concern for the health of predatory fish and fish-eating birds (Eisler, 1990). Total chlordane was measured in the MRB in carp (0.05 to >0.5 µg/g ww) and bass (0.05 to <0.4 µg/g ww) (Schmitt and others, 2002b). Concentrations of total chlordane in the RGB in carp (0.03-0.05 µg/g ww) and bass (0.03-0.06 µg/g ww) were similar to those measured in the CRB (Schmitt and others, 2004).

Dieldrin

Most environmental dieldrin is present due to the breakdown of aldrin, which has not been used since 1974. Concentrations were ≥LOD (0.01 µg/g ww) in the CRB were found in 20% of the samples from seven sites (Table 18). Concentrations were greatest for male and female carp from Station 42, 0.029 and 0.026 µg/g ww, respectively (Fig. 8). Concentrations ranged from 0.014-0.023 µg/g ww for male smallmouth bass, male carp, and female smallmouth bass from Station 44. Trace concentrations (0.01–0.02 µg/g ww) were detected in samples from Stations 96, 97, 503, 505, and 506. All geometric station means were <0.01 µg/g ww (Table 19).

Historically, concentrations of dieldrin in fish samples were ≤LOD (0.01 µg/g ww) at Stations 41, 43, 44, 98 and 117 (Schmitt and others, 1999b). In contrast, concentrations in samples at Stations 42, 45, 96 and 97 were ≥0.2 µg/g ww. Relatively high measured concentrations were measured in fish samples from Station 44 in 1997 but not from 1980-1986. Species differences could account for the differences in accumulation rather than greater inputs to the site. Munn and Gruber (1997) reported similar concentrations in largescale sucker and carp from the mid-CRB. Several other studies found similar concentrations in the LCR (Curtis and others, 1993; ODEQ, 1994; USEPA, 1992). Previous BEST projects from the MRB (Schmitt and others, 2002) and RGB (Schmitt and others, 2004) reported trace concentrations of dieldrin in most carp (0.01-0.25 µg/g ww) and bass (0.01-0.08 µg/g ww). Dieldrin was detected at concentrations of ≤0.26 µg/g ww in 29% of fish sampled in a nationwide survey from 1992-1995 (Wong and others, 2000).

These concentrations probably do not represent a significant threat to either fish or piscivores (Jarvinen and Ankley, 1999; Peakall, 1996). As cited in Jarvinen and Ankley (1999), whole body concentrations in juvenile rainbow trout of 0.36-2.13 µg/g ww were determined to have no effect on survival or growth of juvenile rainbow trout, but concentrations of 5.65 µg/g ww reduced survival (Macek and others, 1970; Shubat and Curtis, 1986).

Endrin

Endrin, one of the most toxic organochlorine pesticides to fish (Johnson and Finley, 1980), was used on comparatively few crops in the past. Concentrations of endrin were ≤LOD (0.01 µg/g ww) in all samples from all locations (Table 18). Only trace levels of endrin (≥0.01 µg/g ww) have been found at the NCBP sites since 1980 (Schmitt and others, 1999b). Other studies reported similar results in the LCR (Curtis and others, 1993; ODEQ, 1994; USEPA, 1992). Previous BEST projects from the MRB (Schmitt and others, 2002b) and RGB (Schmitt and others, 2004) also reported non-detected or trace concentrations (0.01 µg/g ww) of endrin in carp and bass. Endrin was detected at concentrations of ≤0.02 µg/g ww in 2% of fish sampled in a nationwide survey from 1992-1995 (Wong and others, 2000).

Other Organochlorine Compounds

Mirex

Mirex was used as an insecticide to combat red imported fire ants (*Solenopsis wagneri*) in the southern U.S. Elsewhere, mirex was used as a flame retardant and as a polymerizing agent (Kaiser, 1987). Consistent with previous NCBP findings (Schmitt and others, 1999b), concentrations of mirex were ≤LOD (0.01 µg/g ww) in the 1997 CRB samples (Table 18). Other studies reported similar concentrations in the LCR (Curtis and others, 1993; ODEQ, 1994; USEPA, 1992) and other U.S. river basins (Schmitt and others, 2002b; 2004). Mirex was not detected in a 1992-1995 U.S. fish survey (Wong and others, 2000).

Toxaphene

Toxaphene was the most heavily used insecticide in the U.S. following the ban on DDT (Schmitt and Winger, 1980). Use of toxaphene in the U.S. peaked in the late 1970s and the pesticide was subsequently banned. Concentrations of toxaphene in NCBP fish samples peaked in the mid-1970s, reflecting use (Schmitt and others, 1999b). Although toxaphene was used mostly on cotton, this pesticide has been atmospherically transported to remote locations and residues have been detected in fish from the Arctic and the Great Lakes (Muir and others, 1999; Schmitt and others, 1999b). In 1997, toxaphene was detected (>0.03 µg/g ww) in only two largescale sucker samples from Station 506 in the CRB (Fig. 8; Table 18).

Fish from Stations 42, 44, 46, 96, and 98 had concentrations of toxaphene ranging from 0.2-1.0 µg/g ww from 1980-1986 based on historical NCBP data (Schmitt and others, 1999b). Other studies also reported low concentrations in the LCR (Curtis and others, 1993; ODEQ, 1994; USEPA, 1992) and in the RGB (Schmitt and others, 2004). However, concentrations of toxaphene in carp in the MRB (0.05-8.3 µg/g ww) were greater than in the CRB, with concentrations >2.0 µg/g ww in the lower MRB cotton producing region (Schmitt and others, 2004). Toxaphene was detected at concentrations of ≤0.21 µg/g ww in 0.4% of fish sampled in a 1992-1995 nationwide survey (Wong and others, 2000).

Acute and chronic effects of toxaphene on freshwater fish have been reported at whole body concentrations ≥0.4 µg/g ww (Eisler and Jacknow, 1985; Jarvinen and Ankley, 1999). Only male and female largescale sucker samples from Station 506 exceeded this threshold. Jarvinen and Ankley (1999) reviewed multiple laboratory studies on acute and chronic effects of toxaphene. Among these were several by Mayer and others (1975; 1978). These authors reported that adult brook trout containing whole body concentrations of 0.4 µg/g ww produced eggs with reduced viability, and lake trout (*Salvelinus namaycush*) and white sucker containing 0.035-0.203 µg/g ww also produced eggs with reduced viability (Mayer and others, 1975). Survival and growth of freshwater fish (several species) at various life stages were reduced at concentrations >0.90 µg/g ww (Mayer and others, 1975; 1978). It should be noted that the complete composition of the toxaphene components present cannot be determined based on the low-resolution analytical methods used on the 1997 samples (Ribick and others, 1982), and the composition and toxicity of weathered toxaphene can vary greatly (Bidleman and others, 1993; Gooch and Matsumura, 1987; Harder and others, 1983; Ribick and others, 1982).

Hexachlorocyclohexanes (HCH)

Four HCH isomers (α-, β-, δ-, γ-HCH) were measured in the 1997 CRB samples. Although a mixture of isomers was historically used on cotton and other crops in the U.S., only γ-HCH (lindane) is still used in North America for some agricultural and domestic applications. HCH isomers are relatively short-lived. All samples from the CRB had concentrations ≤LOD (0.01 µg/g ww) (Table 18). Concentrations of α- and γ- HCH were ≤LOD (0.01 µg/g ww) in samples collected from NCBP sites from 1980-1986 (Schmitt and others, 1999b) and in other U.S. basins sampled by the BEST program (Schmitt and others, 2002b; 2004). Wong and others (2000) rarely detected (<5% frequency) HCH isomers in a nationwide fish survey from 1992-1995.

Hexachlorobenzene (HCB)

HCB was produced for use as a fungicide and was a by-product of the production of other chlorinated hydrocarbons. This compound is less toxic to fish than many other persistent organochlorines (Schmitt and others, 1999b), but contains toxic impurities. Concentrations of HCB were ≤LOD (0.01 µg/g ww) in all samples with the exception of Station 96. Concentrations in male and female carp from Station 96 were 0.01-0.02 µg/g ww, respectively. Traces of HCB were measured in samples from Station 96 in 1986 (Schmitt and others, 1999b). In general, historical concentrations of HCB from the CRB sites were ≤LOD (0.01 µg/g ww). Previous BEST projects also measured concentrations of HCB ≤0.01 µg/g ww in carp and bass (Schmitt and others, 2002b; 2004). HCB was detected at concentrations of ≤0.03 µg/g ww in 7% of fish sampled in a nationwide survey from 1992-1995 (Wong and others, 2000).

Total PCBs, H4IIE-Derived Dioxin Equivalents, and Ethoxyresorufin *O*-Deethylase (EROD) Activity

Total PCBs

Total PCBs were >LOD (0.03 µg/g ww) in 43 of 64 samples (67%) from 13 stations (Table 18). Concentrations ranged from 0.03-1.3 µg/g ww, with the maximum concentrations measured in female northern pikeminnow from Station 503 (Table 18; Fig. 10). Other samples with concentrations ≥0.5 µg/g ww included male smallmouth bass from Station 42 (0.64 µg/g ww), female smallmouth bass from Station 44 (0.62 µg/g ww), female northern pikeminnow from Station 502 (0.68 µg/g ww), male largemouth bass from Station 505 (0.52 µg/g ww), and female largescale sucker from Station 506 (0.75

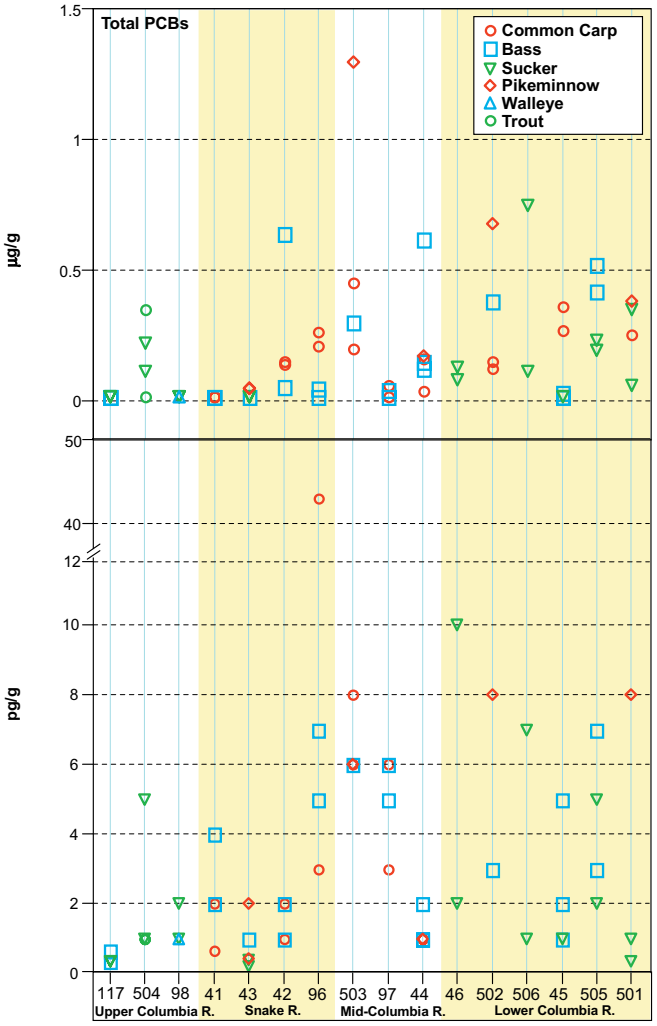


Figure 10. Concentrations of total PCBs (µg/g ww) and H4IIE bioassay-derived TCDD-EQ (pg/g) by station and taxon in whole body fish composite samples collected in the Columbia River Basin in 1997. Stations are ordered from upstream to downstream and are grouped by sub-basin. See Table 3 for station descriptions.

µg/g ww). Geometric station means were greatest (≥0.30 µg/g ww) in samples at Stations 502, 503, and 505 (Table 18).

Like *p,p'*-DDE, among-station differences for concentrations of PCBs were significant in carp, largescale sucker, bass, and northern pikeminnow (Table 16). Concentrations in carp were significantly greater at Stations 45, 96, 501, 502 and 503 than at Stations 41, 42, 44, and 97 (Table 16; Fig. 10). Concentrations of PCBs in largescale sucker were significantly greater at Stations 43, 46, 501, 504, 505, and 506 than at Stations 98 and 117; Stations 46 and 505 also had concentrations of PCBs significantly greater than Station 45 (Table 16; Fig. 10). Concentrations of PCBs in bass were significantly greater at Stations 42, 44, 502, 503, and 505 that Stations 41, 43, 45, 96, 97, and 117 (Table 16; Fig. 10). Concentrations in northern pikeminnow were significantly lower at Station 43 than at all other stations; fish samples at Station 503 also had

concentrations of PCBs that were significantly greater than Station 44 (Table 16; Fig. 10).

Concentrations of PCBs changed significantly at several stations from 1976-1997 (Table 17). Concentrations of PCBs in 1997 were significantly lower than historical NCBP concentrations in carp at Stations 97 and 44, largescale sucker at Stations 117, 98, 43, 46, and 45, bass at Stations 43 and 45, and northern pikeminnow at Station 43 (Table 17).

Similar concentrations of PCBs (0.03-1.3 µg/g ww) were found in other studies in the SR (Clark and Maret, 1998) and CRB (Foster and others, 2001; Tetra Tech Inc., 1996). The USEPA determined whole body concentrations for Aroclor® mixtures (1254 and 1260) in smallmouth bass and largescale sucker to range from 0.046-0.19 µg/g ww and <0.014-0.10 µg/g ww, respectively, in the CRB in 1996-1998 (USEPA, 2002b). Fish composites analyzed for Aroclor® mixtures (1248, 1254, 1260) from 1980-1986 generally contained trace residues (≤0.2 µg/g ww) (Schmitt and others, 1999b). In 1980, northern pikeminnow and largescale sucker samples collected at Stations 45, 46, and 117 contained concentrations between 0.3-0.7 µg/g ww (Schmitt and others, 1999b). Concentrations of PCBs ranged from 0.05-3.3 µg/g ww in carp and 0.05-2.0 µg/g ww in bass in the MRB (Schmitt and others, 2002b) and were not detected in the RGB (Schmitt and others, 2004). Total PCBs were detected in 80% of fish sampled in a nationwide survey from 1992-1995, with concentrations ranging from <0.05-72 µg/g ww (Wong and others, 2000).

The New York State Department of Environmental Conservation (NYSDEC) wildlife guideline for total PCBs in fish is 0.11 µg/g ww (Newell and others, 1987), a concentration exceeded by at least one fish sample from all stations except Stations 43 and 97 (Fig. 10). However, the toxicity of individual PCB congeners ranges over several orders of magnitude (Ahlborg and others, 1994; van den Berg and others, 1998) and varies with the endpoint being considered (Hansen, 1998). Decreased survival of fry at approximately 5 µg/g ww of Aroclor® 1254 has been reported in several laboratory studies (Hansen and others, 1973; Schimmel and others, 1974 as cited in Monosson, 1999). Niimi (1996) as cited in Beyer and others (1996) determined that fish tissue concentrations of 100 µg/g ww can affect reproduction in females or be lethal, and concentrations of 50 µg/g ww can reduce growth and survival in offspring. However, these concentrations may be lower in more sensitive fish species (Niimi, 1996). Mink fed Great Lakes fish or fish products with concentrations of PCBs of 0.48 µg/g ww had inferior reproductive performance and offspring survival (Hornshaw and others, 1983). Concentrations of PCBs in fish are decreasing compared to historical NCBP concentrations but exceed several criteria. Therefore, PCBs remain at levels of concern at some CRB stations.

H4IIE Bioassay

Twenty-one bass samples from eleven stations in the CRB were analyzed for dioxin-like activity. TCDD-EQs in female bass (n=9) ranged from <1.33-7 pg/g, male bass (n=9) ranged from <0.68-7.0 pg/g, and a male and a female bass sample were <LOQ. Three intersex samples had TCDD-EQs ranging from 1–6 pg/g. Individual samples with relatively high total PCBs did not have the highest TCDD-EQ levels (Fig. 10). Overall, TCDD-EQs for bass were relatively low.

The H4IIE bioassay was used to analyze seventeen carp samples from nine stations (Table 18; Fig. 10). The TCDD-EQ in female carp (n=8) ranged from <LOD to 43 pg/g; whereas male carp (n=9) ranged from 1–9 pg/g. Concentraions of PCBs in carp samples did not exceed 0.5 µg/g ww total PCBs suggesting the value of 43 pg/g found in female carp at Station 96 may be caused by other compounds (for example, PCDDs and PCDFs). The other carp and two bass composite samples collected from Station 96 were ≤7 pg/g (Fig. 10).

Seventeen largescale sucker samples from nine stations were analyzed for TCDD-EQs. TCDD-EQ in the female largescale sucker (n=9) ranged from <0.68–10 pg/g; one sample was <LOQ. TCDD-EQ in male largescale sucker (n=8) ranged from <0.35–2 pg/g; three samples were <LOQ. Only two largescale sucker samples (female samples from Station 46 and 506) were >5 pg/g (Fig. 10). Female largescale sucker from Station 506 (7 pg/g) had total PCBs >0.5 µg/g ww. Similar to the bass samples from the CRB, largescale sucker samples had relatively low TCDD-EQs. TCDD-EQs were also relatively low (0-8 pg/g) for rainbow trout, walleye, and northern pikeminnow samples.

Previous studies have examined TCDD-EQ levels in fish. The dietary threshold for toxicity of TCDD is 4.4 pg/g in mammals (Heaton and others, 1995; Tillitt and others, 1996) and 5 pg/g in avian wildlife (Nosek and others, 1992). Most of the TCDD-EQ levels in fish from the CRB are similar to those reported in fish from reference sites in previous studies (Giesy and others, 1995; Schmitt and others, 2002b; 2004; van den Heuvel and others, 1995) and from sites in the LCR (Bonn, 1997). TCDD-EQ values ≥60 pg/g were reported and levels ≥20 pg/g were widespread in fish samples from the MRB (Schmitt and others, 2002b). TCDD-EQ values were low in carp (<1-3 pg/g) and bass (<1-6 pg/g) in the RGB (Schmitt and others, 2004). CRB station means ranged from 0.39-8.0 pg/g (Table 19). Five samples ranged from 8-10 pg/g. One TCDD-EQ value (43 pg/g) in female carp from Station 96 was notably greater than all other samples and approached the threshold for toxic effects in fish (30 pg/g) (Schmitt and others, 2002b and references cited therein; Walker and others, 1996; Whyte and others, 2004).

Ethoxyresorufin *O*-Deethylase (EROD) Activity

EROD activity varies among fish species, between genders, and reproductive stage (Schmitt and others, 2002b; Whyte and others, 2000). A significant ANOVA model for bass containing the factors station, gender, and developmental stage explained 49% of the total variance in EROD activity

Table 20. Results of preliminary analysis-of-variance investigating the effects of various factors on biomarker responses in carp, bass, and largescale sucker in the Columbia River Basin in 1997. Shown are degrees-of-freedom (df), *F*-values with levels of significance (*$0.01<P\leq0.05$; **$P\leq0.01$), and coefficients of determination (R^2).

Variable, source, and (transformation)	Bass			Carp			Largescale sucker		
	df	*F*	R^2	df	*F*	R^2	df	*F*	R^2
EROD (log)									
Model	37	2.41**	0.49	25	7.28**	0.59	22	1.06	0.19
Station	8	1.66		6	1.31		7	0.73	
Gender	1	4.51*		1	0.50		1	1.25	
Station*Gender	6	1.71		2	0.11		0	--	
Stage	1	0.53		1	3.02		1	0.11	
Stage*Station	8	0.87		6	2.46*		7	0.66	
Stage*Gender	1	4.21*		1	2.10		1	1.34	
Stage*Station*Gender	6	1.14		2	0.26		0	--	
Error	92			125			97		
Condition Factor									
Model	38	2.40**	0.50	27	1.37	0.23	28	4.25**	0.48
Station	8	3.95**		7	0.35		9	3.44**	
Gender	1	4.46*		1	0.01		1	0.06	
Station*Gender	6	2.61*		2	0.00		0	--	
Stage	1	2.40		1	0.00		1	0.41	
Stage*Station	8	3.45**		7	0.04		9	2.1*	
Stage*Gender	1	2.53		1	0.01		1	0.18	
Stage*Station*Gender	6	2.23*		2	0.00		0	--	
Error	93			127			128		
Splenosomatic Index									
Model	22	1.45	0.23	16	6.72**	0.43	15	7.64**	0.49
Station	11	1.16		8	6.85**		8	12.02**	
Gender	1	0.05		1	30.1**		1	0.00	
Station*Gender	10	1.38		7	2.29*		6	1.91	
Error	107			140			120		
Hepatosomatic Index									
Model	22	3.66**	0.43	ND	ND	ND	ND	ND	ND
Station	11	4.17**		ND	ND	---	ND	ND	---
Gender	1	1.33		ND	ND	---	ND	ND	---
Station*Gender	10	2.56**		ND	ND	---	ND	ND	---
Error	108			ND			ND		
HAI (rank)									
Model	38	3.76**	0.61	27	1.40	0.23	28	1.25	0.22
Station	8	2.45*		7	0.48		9	0.58	
Gender	1	0.12		1	0.14		1	0.07	
Station*Gender	6	0.22		2	3.12*		0	--	
Stage	1	1.38		1	3.29		1	0.93	
Stage*Station	8	0.75		7	0.66		9	0.89	
Stage*Gender	1	0.12		1	0.03		1	0.06	
Stage*Station*Gender	6	0.29		2	2.03		0	--	
Error	92			127			128		

Table 20. Results of preliminary analysis-of-variance investigating the effects of various factors on biomarker responses in carp, bass, and largescale sucker in the Columbia River Basin in 1997. Shown are degrees-of-freedom (df), *F*-values with levels of significance (*$0.01<P\leq0.05$; **$P\leq0.01$), and coefficients of determination (R^2).—Continued

Variable, source, and (transformation)	Bass			Carp			Largescale sucker		
	df	*F*	R^2	df	*F*	R^2	df	*F*	R^2
TISSOC									
Model	40	7.29**	0.60	33	5.36*	0.37	35	2.50**	0.44
Station	10	1.95*		8	0.81		9	1.58	
Gender	1	3.46		1	0.25		1	2.43	
Station*Gender	8	2.00		7	1.00		7	1.22	
Age	1	12.05**		1	2.58		1	2.80	
Age*Station	10	2.47*		8	0.76		9	2.35*	
Age*Gender	1	4.89*		1	0.24		1	3.06	
Age*Station*Gender	8	2.34*		7	0.91		7	2.04	
Error	80			92			112		
MEANAREA									
Model	40	2.14**	0.52	33	1.24	0.31	35	2.53**	0.44
Station	10	1.21		8	1.00		9	2.07*	
Gender	1	4.48*		1	0.04		1	0.32	
Station*Gender	8	1.84		7	1.26		7	2.65*	
Age	1	5.46*		1	2.75		1	2.49	
Age*Station	10	1.46		8	0.88		9	2.83**	
Age*Gender	1	5.11*		1	0.19		1	0.63	
Age*Station*Gender	8	2.19*		7	1.04		7	3.74**	
Error	80			92			112		
MAMM									
Model	40	2.16**	0.52	33	1.77*	0.39	35	1.12	0.26
Station	10	1.33		8	0.57		9	0.84	
Gender	1	0.74		1	0.19		1	0.77	
Station*Gender	8	0.59		7	0.21		7	0.76	
Age	1	3.03		1	0.84		1	0.08	
Age*Station	10	1.51		8	0.54		9	0.74	
Age*Gender	1	0.40		1	0.56		1	0.56	
Age*Station*Gender	8	0.57		7	0.16		7	0.67	
Error	80			92			112		
Gonadosomatic Index									
Model	38	16.08**	0.87	27	12.95**	0.73	28	12.12**	0.73
Station	8	0.77		7	2.41*		9	5.26**	
Gender	1	0.85		1	2.75		1	3.49	
Station*Gender	6	0.76		2	0.57		0	--	
Stage	1	16.74**		1	2.57		1	14.05**	
Stage*Station	8	1.79		7	1.81		9	10.19**	
Stage*Gender	1	14.07**		1	10.37**		1	0.64	
Stage*Station*Gender	6	1.86		2	1.71		0	--	
Error	92			127			127		

Table 20. Results of preliminary analysis-of-variance investigating the effects of various factors on biomarker responses in carp, bass, and largescale sucker in the Columbia River Basin in 1997. Shown are degrees-of-freedom (df), *F*-values with levels of significance (*$0.01<P\leq0.05$; **$P\leq0.01$), and coefficients of determination (R^2).—Continued

Variable, source, and (transformation)	Bass			Carp			Largescale sucker		
	df	*F*	R^2	df	*F*	R^2	df	*F*	R^2
Vitellogenin (log)									
Model	37	13.44**	0.85	25	79.86**	0.94	22	55.68**	0.93
Station	8	1.13		6	0.99		7	0.33	
Gender	1	0.00		1	6.49*		1	6.02*	
Station*Gender	6	1.44		2	1.33		0	--	
Stage	1	5.97*		1	9.32**		1	0.01	
Stage*Station	8	0.80		6	1.92		7	0.74	
Stage*Gender	1	18.78**		1	12.11**		1	0.15	
Stage*Station*Gender	6	1.26		2	1.53		0	--	
Error	87			125			97		
Atresia									
Model	34	1.33	0.54	20	2.36*	0.57	31	1.36	0.44
Station	6	0.46		1	0.32		2	0.54	
Stage	1	0.10		1	0.24		1	1.38	
Stage*Station	6	0.27		1	0.34		2	0.68	
Age	1	1.66		1	0.30		1	2.26	
Age*Station	6	0.79		1	0.35		2	0.74	
Stage*Age	1	0.17		1	0.28		1	2.19	
Stage*Age*Station	6	0.43		1	0.39		2	0.77	
Error	38			36			53		

(log-transformed), with gender and a stage-gender interaction being significant (Table 20). The ANOVA model for carp was also significant and explained 59% of the total variance, and like bass, EROD activity did not differ significantly among stations after accounting for all other effects. In addition, the interaction of stage and gender was also significant in carp (Table 20). Gender and developmental stage of largescale sucker did not influence EROD activity (Table 20). However, analysis of the larger 1995 MRB BEST data set, which spanned a wider range of EROD values, also indicated that gender was a significant variable (Schmitt and others, 2002b). Therefore, EROD activity was tabulated and evaluated by gender.

EROD in Bass

Mean EROD activity in female bass was greatest (40.4 pmol/min/mg) at Station 505 (*n*=5), ranging from 30.2-57.4 pmol/min/mg (Fig. 11; Table 21). All other geometric station means for female bass were <21.8 pmol/min/mg. Most female bass with EROD levels >20 pmol/min/mg were identified as stage-1 fish, which supports the interaction determined by the ANOVA modeling (Table 20). Adams and others (1994) determined basal EROD activity for female bass to be 0-5 pmol/min/mg, which is less than basal EROD activity (0-16 pmol/min/mg) determined for female bass from the MRB (Schmitt and others, 2002b). Fish from Stations 42, 43, 44, 45, 96, 97, 117, and 505 had EROD activity >16 pmol/min/mg; however, only Stations 45, 117, and 505 had EROD values consistently >16 pmol/min/mg.

EROD activities were similar in male and female bass. Mean EROD activity in male bass was greatest (68.3 pmol/min/mg) at Station 505 (*n*=3), ranging from 47.6-99.4 pmol/min/mg (Fig. 11; Table 21). All other geometric station means for male bass were <18.1 pmol/min/mg with the exceptions of Stations 45 (29.4 pmol/min/mg) and 117 (27.8 pmol/min/mg). Unlike female bass in which stage-1 fish had the greatest EROD activity, most male bass with EROD activity >20 pmol/min/mg were stage 2 and 3, which supports the interaction determined by ANOVA modeling (Table 20).

Other studies have examined EROD activity in bass. Adams and others (1994) determined basal EROD activity for male bass to be 0-17 pmol/min/mg, which is slightly less than basal EROD activity (0-22 pmol/min/mg) determined for male bass from the MRB (Schmitt and others, 2002b). EROD activities in bass at RGB stations ranged from 21.3-108 pmol/min/mg in females and 17.0-75.9 pmol/min/mg in males (Schmitt and others, 2004). Fish from Stations 42, 43, 44, 45, 97, 117, and 505 had EROD activity >22 pmol/min/mg; however, only Stations 45, 117, and 505 had EROD values consistently >22 pmol/min/mg. Two bass in which no gonads were collected

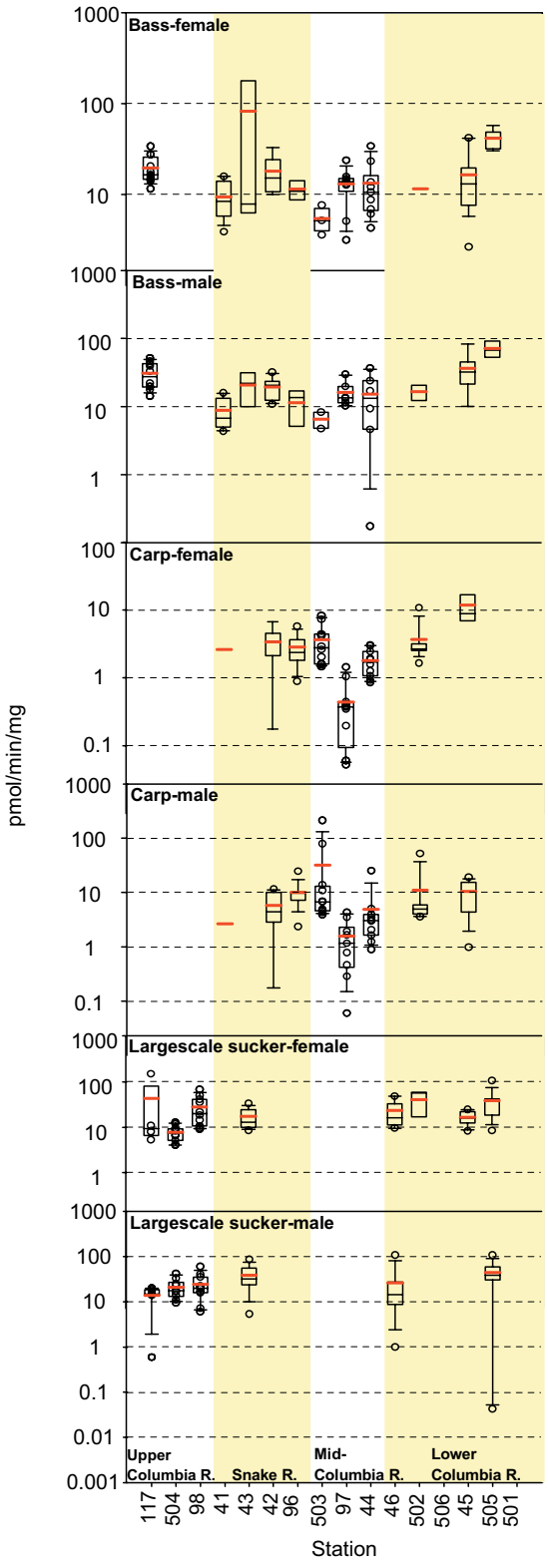


Figure 11. Hepatic microsomal EROD activity (pmol/min/mg) by station in female and male bass (*Micropterus* sp.), carp, and largescale sucker collected in the Columbia River Basin in 1997. Shown for each group are points representing individual fish and the mean (red horizontal line), median (black horizontal line), interquartile range (box), and the 10th and 90th percentiles (whiskers). Stations are ordered from upstream to downstream and are grouped by sub-basin. See Table 3 for station descriptions.

had EROD rates of 43.1 pmol/min/mg (Station 42) and 48.8 pmol/min/mg (Station 45).

EROD in Carp

Mean EROD activity in female carp was greatest (10.3 pmol/min/mg) at Station 45, ranging from 6.54-22.9 pmol/min/mg (Fig. 11; Table 21). All other geometric station means for female carp were <3.17 pmol/min/mg. Schlenk and others (1996) determined basal EROD activity for carp from uncontaminated sites to be 0-5 pmol/min/mg, which is similar to basal EROD activity (0-4 pmol/min/mg) determined for carp from the MRB (Schmitt and others, 2002b). Fish from Stations 41, 42, 45, 96, 502, and 503 had EROD activity greater than these basal levels; however, only Station 45 had female carp with EROD values consistently exceeding basal EROD levels from previous studies.

Mean EROD activity in male carp was greatest (10.6 pmol/min/mg) at Station 503, ranging from 3.88-212 pmol/min/mg (Fig. 11; Table 21). Geometric means for male carp at the other stations ranged from 0.89 pmol/min/mg (Station 97) to 8.76 pmol/min/mg (Station 96). Unlike the female carp, several stations had multiple individual EROD activities that exceeded basal EROD levels in previous studies (Schlenk and others, 1996; Schmitt and others, 2002b), including fish from Stations 42, 45, 96, and 503 with measured EROD levels >10 pmol/min/mg.

Other studies have examined EROD activity in common carp. EROD activities in carp were <10 pmol/min/mg in females but were greater in males (many >20 pmol/min/mg) in the RGB (Schmitt and others, 2004). Several studies have reported juvenile carp in laboratory control groups to have EROD activities ranging from 7.1-25 pmol/min/mg (Kosmala and others, 1998; Marionnet and others, 1997; 1998; Taysee and others, 1998). In studies examining adult carp, EROD activity in laboratory control groups ranged from 2.7-14.3 pmol/min/mg (Deér and others, 1996) and 41.9 pmol/min/mg (Solé and others, 2000). Machala and others (1997) demonstrated that microsomal EROD activity in carp was a very sensitive and specific biomarker of the early effects of PAHs and PCBs.

EROD in Largescale Sucker

Mean EROD activity in female largescale sucker was greatest (30.7 pmol/min/mg) at Station 505, ranging from 8.45-107 pmol/min/mg (Fig. 11; Table 21). All other geometric station means for female largescale sucker were <23.0 pmol/min/mg. Mean EROD activities in male largescale sucker were comparable to females with the greatest activity (30.5 pmol/min/mg) measured at Station 43. All other geometric station means for male largescale sucker were <19.7 pmol/min/mg.

Basal EROD levels for largescale sucker have not been reported previously; however, white sucker and long-

Table 21. Geometric mean and range of microsomal EROD activities (pmol/min/mg protein) in fish collected in the Columbia River Basin in 1997. Censored values were represented by one half the LOQ in the computation of geometric means. Fish in which gender was undetermined or no gonad was obtained are listed as juvenile. The maximum geometric station mean is shown in bold for each taxon. Stations are ordered upstream to downstream.—Conti

Species and Station	Female			Male			Juvenile		
	n	Range	Mean	*n*	Range	Mean	*n*	Range	Mean
Bass									
Upper Columbia River									
Creston, MT (117)	11	11.5-33.8	18.5	10	14.2-51.8	27.8	0	--	--
Snake River									
Hagerman, ID (41)	9	3.89-15.79	8.52	7	4.32-15.9	7.75	0	--	--
Riggins, ID (43)	3	5.68-233	21.8	4	4.82-34.0	16.4	0	--	--
Lewiston, ID (42)	5	10.0-32.9	16.3	7	10.9-31.8	18.1	1	--	43.1
Ice Harbor Dam, WA (96)	4	6.87-17.2	10.9	3	2.3-18.1	8.2	0	--	--
Middle Columbia River									
Vernita Bridge, WA (503)	3	3.60-7.61	5.21	2	4.76-8.27	6.28	0	--	--
Pasco, WA (97)	9	3.15-23.8	11.3	6	10.2-29.7	15.2	0	--	--
Granger, WA (44)	9	4.3-33.9	10.9	6	0.18-36.7	6.9	0	--	--
Lower Columbia River									
Warrendale, OR (502)	1	--	11.6	3	11.0-22.1	15.8	0	--	--
Oregon City, OR (45)	15	2.65-42.2	12.5	5	10.1-82.8	29.4	1	--	48.8
Portland, OR (505)	5	30.2-57.4	**40.4**	3	47.6-99.4	**68.3**	0	--	--
Common Carp									
Snake River									
Hagerman, ID (41)	10	0.58-8.77	2.01	10	1.35-4.66	2.52	0	--	--
Lewiston, ID (42)	5	0.18-6.66	2.11	12	0.18-11.5	3.31	0	--	--
Ice Harbor Dam, WA (96)	10	0.88-5.72	2.44	11	2.35-24.4	8.76	0	--	--
Middle Columbia River									
Vernita Bridge, WA (503)	10	1.45-8.24	3.01	11	3.88-212	**10.6**	0	--	--
Pasco, WA (97)	11	0.05-1.43	0.27	9	0.06-4.32	0.89	0	--	--
Granger, WA (44)	10	0.85-3.02	1.62	10	0.89-25.1	3.00	0	--	--
Lower Columbia River									
Warrendale, OR (502)	10	1.64-10.8	3.17	10	3.60-51.7	6.82	0	--	--
Oregon City, OR (45)	4	6.54-22.9	**10.3**	10	0.98-19.0	7.82	0	--	--
Largescale Sucker									
Upper Columbia River									
Creston, MT (117)	4	5.27-151	16.2	6	0.60-20.0	9.36	0	--	--
Northport, WA (504)	10	4.00-12.8	7.23	10	9.53-42.6	19.5	0	--	--
Grand Coulee, WA (98)	10	9.07-67.8	22.0	10	6.00-59.8	19.7	0	--	--
Snake River									
Riggins, ID (43)	11	8.43-33.5	15.7	9	5.39-86.5	**30.5**	0	--	--
Lower Columbia River									
Cascade Locks, OR (46)	11	9.49-48.7	19.5	9	0.99-108	14.1	1	--	9.31
Warrendale, OR (502)	3	3.50-60.7	23.0	0	--	--	0	--	--
Oregon City, OR (45)	6	8.35-24.8	15.6	0	--	--	0	--	--
Portland, OR (505)	11	8.45-107	**30.7**	10	0.04-107	13.2	2	--	28.2
Longnose sucker									
Upper Columbia River									
Creston, MT (117)	10	2.36-11.0	**5.05**	1	--	**18.0**	2	4.12-6.57	5.20
Grand Coulee, WA (98)	1	--	3.00	1	--	7.34	0	--	--
Northern pikeminnow									
Snake River									
Riggins, ID (43)	9	0.18-4.33	1.31	5	0.18-7.79	2.22	0	--	--
Middle Columbia RIver									
Vernita Bridge, WA (503)	8	2.10-102	10.7	2	2.07-26.1	**7.4**	0	--	--
Granger, WA (44)	5	0.18-3.37	0.78	1	--	0.18	0	--	--
Lower Columbia River									
Cascade Locks, OR (46)	2	3.11-48.1	**12.2**	0	--	--	0	--	--

Table 21. Geometric mean and range of microsomal EROD activities (pmol/min/mg protein) in fish collected in the Columbia River Basin in 1997. Censored values were represented by one half the LOQ in the computation of geometric means. Fish in which gender was undetermined or no gonad was obtained are listed as juvenile. The maximum geometric station mean is shown in bold for each taxon. Stations are ordered upstream to downstream.—Continued

Species and Station	Female			Male			Juvenile		
	n	Range	Mean	*n*	Range	Mean	*n*	Range	Mean
Warrendale, OR (502)	11	0.64-5.53	2.14	0	--	--	0	--	--
Portland, OR (505)	2	1.59-2.44	1.97	0	--	--	0	--	--
Rainbow trout									
Upper Columbia River									
Northport, WA (504)	10	1.19-25.2	9.18	2	6.85-12.0	9.05	8	4.94-41.5	15.1
Walleye									
Upper Columbia River									
Grand Coulee, WA (98)	8	9.45-51.8	24.3	4	16.7-26.3	19.5	4	25.8-30.7	28.3
Lower Columbia River									
Portland, OR (505)	1	--	4.83	0	--	--	0	--	--

nose sucker have reported EROD levels ranging from 5-15 pmol/min/mg (Whyte and others, 2000). Other studies have reported EROD activities to range from 8.5-10 pmol/min/mg in white sucker from reference or uncontaminated sites (Couillard and Hodson, 1996; Schrank and others, 1997). EROD activity in white sucker from a site contaminated by PCBs, PAHs, and heavy metals was determined to be 35.2 pmol/min/mg (Schrank and others, 1997). Stations 43, 45, 46, 98, 117, 502, 504, and 505 had EROD activities >15 pmol/min/mg for male and female fish. Basin-wide means for both males (23.1 pmol/min/mg) and females (18.4 pmol/min/mg) exceeded the basal EROD level. Two juvenile largescale sucker had EROD rates of 9.3 pmol/min/mg (Station 46) and 28.2 pmol/min/mg (Station 505).

EROD in Other Fishes

Hepatic EROD activity was measured in longnose sucker, northern pikeminnow, rainbow trout, and walleye, in addition to the target species (bass, carp, and largescale sucker). EROD activity varies greatly among fishes, and there are relatively few reports of basal activity against which to judge the relative induction associated with many of these results (Whyte and others, 2000). Those for which such comparisons can be made are summarized below.

Longnose sucker were collected from Stations 98 and 117 in the UCR. Only one female and one male were collected from Station 98, and the EROD activity was 3.0 and 7.3 pmol/min/mg, respectively. EROD activity ranged from 2.4-11.0 pmol/min/mg in females, 18.0 pmol/min/mg in a male, and 4.1-6.6 pmol/min/mg in juvenile longnose sucker collected at Station 117. These values are <2-fold lower than previously reported basal activities for this species (Kloepper-Sams and Benton, 1994; Kloepper-Sams and others, 1994; Swanson and others, 1992). Northern pikeminnow were collected from Stations 43, 44, 46, 502, 503, and 505. EROD activities ranged from 0.18-102 pmol/min/mg in females with fish from Stations 46 and 503 having the greatest mean EROD activity. EROD activity in males ranged from 0.18-26.1 pmol/min/mg with Station 503 having the greatest station mean. These levels are similar to those previously reported in fish from the Willamette River in the LCR (Curtis and others, 1993). Rainbow trout, collected exclusively from Station 504, had EROD activities of 1.2-25.2 pmol/min/mg in females, 6.9-12.0 pmol/min/mg in males, and 4.4-41.5 pmol/min/mg in juveniles, and were less than many of the EROD activities in other rainbow trout field studies (many, reviewed by Whyte and others, 2000). Walleye were collected from Stations 98 and 505. Walleye from Station 98 had EROD activities of 9.5-51.8 pmol/min/mg for females, 16.7-26.3 pmol/min/mg for males, and 25.8-30.7 pmol/min/mg for juveniles. These levels are similar to basal activities for this species reported by Williams and others (1997).

Accumulative Contaminants, H4IIE, and EROD Activity: Summary

Concentrations of most contaminants measured in fish from the CRB were low with a few exceptions. Most elemental contaminant concentrations were relatively low; however, Pb, Hg, and Se exceeded protective criteria at multiple stations. Concentrations of Pb >4 µg/g ww were measured in largescale sucker at Stations 98 and 504 in the UCR. These stations are located downstream from a smelting complex. Concentrations of Hg exceeded 0.3 µg/g ww, a threshold value thought to cause reproductive impairment to loons, in predatory fish at various stations throughout the CRB. All samples from Station 97 and bass from Stations 43 and 503 exceeded 0.06 µg/g ww for Se, the threshold toxic to piscivorous wildlife. Comparison of 1997 concentrations with historical NCBP data revealed that most temporal trends for organochlorine and elemental contaminants were decreasing, continuing two-decade trends for accumulative contaminants at these sta-

tions (Table 17). However, concentrations of As, Cd, and Se for select species had increasing concentrations in 1997.

Organochlorines were measured at concentrations of concern at some sites within the CRB. DDT-derived residues (mostly as *p,p'*-DDE) were detected at all stations with the exception of Station 117. Concentrations potentially toxic to fish-eating wildlife (>1.0 µg/g ww) occurred in fish from stations located in the MCR (Stations 44, 97, and 503). However, comparison of 1997 concentrations with historical data revealed decreasing trends for *p,p'*-DDE including Stations 44 and 97 (Table 17). These higher concentrations are most likely due to past DDT use in the agricultural areas in the watersheds. These stations had little or no *p,p'*-DDT detected, indicating the continued weathering of residual DDT rather than the input of new material. Toxaphene and mirex were detected at trace concentrations in largescale sucker from Station 506 in the lower CRB.

Cyclodiene pesticides were present at fewer stations and lower concentrations than DDT. All stations had chlordane residues that were less than the criteria for protecting predatory fish and fish-eating birds (0.1 µg/g ww). Endrin was ≤LOD in fish samples at all stations. Dieldrin was detected at trace concentrations in the lower SR and LCR, and concentrations >0.02 µg/g ww were measured in fish from three stations located in the lower SR and Yakima River. Concentrations of all other organochlorine pesticides were <LOD.

Concentrations of total PCBs were also generally low. PCBs were detected at 81% of the stations; however, only Station 503 had a sample with concentrations >1.0 µg/g ww. Similar to dieldrin, the greatest concentrations occurred in fish from the lower SR and LCR. Concentrations of PCBs were generally lowest in the upper SR and UCR. HCB was only detected in trace quantities at two stations.

Dioxin-like contaminants, as indicated by the H4IIE rat hepatoma cell bioassay, were detected at all stations except Station 117. Based on the potential for reproductive impairment and biomagnification factors, H4IIE bioassay values in fish >5 pg/g may be hazardous to avian and mammalian wildlife which consume fish. Multiple stations throughout the CRB had concentrations >5 pg/g. Female carp from Station 96 had the highest measured TCDD-EQ concentration (43 pg/g) of the study, being four times greater than any other sample. Dioxin-like activity was not well correlated with concentrations of total PCBs, suggesting the presence of one or more other dioxin-like compounds.

EROD activity can be influenced by numerous factors including species (Addison and others, 1991; Segner and others, 1995), fish size and age (Khan and Payne, 2002b; Peters and Livingstone, 1995; Pluta, 1993), nutrition (Ankley and others, 1989), reproductive status (Campbell and others, 1976; Schrek and Hopwood, 1974), water temperature (Khan and Payne, 2002a; Machala and others, 1997), and capture activity (Machala and others, 1997). Results of the EROD assay determined that elevated activities were not consistent among target species. Bass had elevated EROD activity at one station in the UCR and two stations in the lower Willamette River. EROD activity in male carp was elevated in the lower SR and MCR; EROD activity in male and female carp was elevated at one station in the lower Willamette River. Largescale sucker had EROD activity greater than basal levels throughout the CRB. EROD activities did not correlate to either PCBs or TCDD-EQs for bass, carp, or sucker. This suggests that at some stations high EROD activities were caused by exposure of the fish to labile contaminants that did not survive the reactive cleanup used to process the samples for the H4IIE bioassay.

Fish Health Indicators

Organism-Level Indicators

External Gross Lesions

External gross lesions were identified during the fish health examination in the field. The fish health assessment found that 74% of all fish collected from the CRB had external gross lesions (abnormalities). These lesions were categorized by location including lesions on the body surface, eyes, opercles, and fins. The percentage of fish with external lesions ranged from 50% at Station 98 to 100% at Station 44 (Table 22). Statistical analyses found no significant differences between genders for carp, bass, or largescale sucker; therefore, genders were combined for data analysis. The percentage of bass with lesions (67%) was less than the basin-wide percentage for all species (74%). Fish from Stations 42, 43, and 503 had gross lesions on <50% of those surveyed (Table 22). The basin-wide percentage of carp with lesions (83%) was the greatest of all the target species, and greater than carp from other basins sampled by the BEST program (Schmitt and others, 2002b; 2004). All stations except Station 97 had >75% of carp with gross lesions (Table 22). Largescale sucker had lesions on 78% of the fish surveyed and all stations had percent lesions >60% (Table 22). Most the lesions were attributed to eroded, frayed, hemorrhagic, or emboli fins. The percent of lesions for these fish are high and caution needs to be used when interpreting these data. Many lesions identified are not a result of exposure to environmental contaminants but are more likely due to holding time in nets prior to fish processing or normal wear as a fish ages.

Health Assessment Index

The health assessment index (HAI) is a systematic method to identify external and internal lesions for each fish during the field health assessment. A higher HAI score indicates a greater number of lesions were identified on the fish. The HAI may vary depending on gender and gonadal stage.

Table 22. Number and location of external lesions identified on fish collected in the Columbia River Basin in 1997. Body, eyes, opercles, and fins of each fish were examined for the presence of lesions, and the proportion of fish with lesions was calculated. Stations are grouped by sub-basin and ordered upstream to downstream.

Station and Species		Lesion Location					
	n	Body	Eyes	Opercles	Fins	Total no. w/lesions	Proportion
Upper Columbia River (UCR)							
Creston, MT (117)							
All	44	8	0	4	17	24	0.545
Bass	21	2	0	1	12	12	0.571
Largescale sucker	10	3	0	0	3	6	0.600
Longnose sucker	13	3	0	3	2	6	0.462
Northport, WA (504)							
All	40	9	6	2	14	23	0.575
Largescale sucker	20	8	4	2	10	17	0.850
Rainbow trout	20	1	2	0	4	6	0.300
Grand Coulee, WA (98)							
All	38	3	15	0	7	19	0.500
Largescale sucker	21	2	13	0	4	15	0.714
Longnose sucker	1	0	1	0	1	1	1.000
Walleye	16	1	1	0	2	3	0.188
Snake River (SR)							
Hagerman, ID (41)							
All	36	20	3	12	34	34	0.944
Common Carp	20	8	1	5	20	20	1.000
Bass	16	12	2	7	14	14	0.875
Riggins, ID (43)							
All	41	5	5	0	21	26	0.634
Bass	7	1	0	0	3	3	0.429
Largescale sucker	20	2	2	0	11	13	0.650
Northern pikeminnow	14	2	3	0	7	10	0.714
Lewiston, ID (42)							
All	30	7	3	4	12	17	0.567
Common Carp	17	7	2	4	9	13	0.765
Bass	13	0	1	0	3	4	0.308
Ice Harbor Dam, WA (96)							
All	28	8	4	1	16	20	0.714
Common Carp	21	8	4	1	12	16	0.762
Bass	7	0	0	0	4	4	0.571
Middle Columbia River (MCR)							
Vernita Bridge, WA (503)							
All	36	9	7	2	26	28	0.778
Common Carp	21	7	3	1	17	18	0.857
Bass	5	0	1	0	2	2	0.400
Northern pikeminnow	10	2	3	1	7	8	0.800
Pasco, WA (97)							
All	35	3	3	1	13	19	0.543
Common Carp	20	2	2	1	6	10	0.500
Bass	15	1	1	0	7	9	0.600
Granger, WA (44)							
All	41	11	11	3	41	41	1.000
Common Carp	20	6	5	3	20	20	1.000
Bass	15	2	2	0	15	15	1.000
Northern pikeminnow	6	3	4	0	6	6	1.000
Lower Columbia River (LCR)							
Cascade Locks, OR (46)							
All	23	5	3	0	17	18	0.783
Largescale sucker	21	5	3	0	16	17	0.810
Northern pikeminnow	2	0	0	0	1	1	0.500
Warrendale, OR (502)							
All	38	2	11	2	28	32	0.842
Common Carp	20	1	3	1	17	17	0.850
Bass	4	0	1	0	4	4	1.000
Largescale sucker	3	0	0	1	1	2	0.667
Northern pikeminnow	11	1	7	0	6	9	0.818

Table 22. Number and location of external lesions identified on fish collected in the Columbia River Basin in 1997. Body, eyes, opercles, and fins of each fish were examined for the presence of lesions, and the proportion of fish with lesions was calculated. Stations are grouped by sub-basin and ordered upstream to downstream.—Continued

Station and Species	*n*	Lesion Location					
		Body	Eyes	Opercles	Fins	Total no. w/lesions	Proportion
Vancouver, WA (506)							
All	22	9	0	4	12	17	0.773
Bass	1	0	0	1	0	1	1.000
Largescale sucker	21	9	0	3	12	16	0.762
Oregon City, OR (45)							
All	42	14	4	2	28	36	0.857
Common Carp	14	5	1	0	10	13	0.929
Bass	22	5	3	2	13	18	0.818
Largescale sucker	6	4	0	0	5	5	0.833
Portland, OR (505)							
All	33	14	3	0	28	29	0.879
Bass	8	2	1	0	5	6	0.750
Largescale suckers	22	12	1	0	21	21	0.955
Northern pikeminnow	2	0	1	0	2	2	1.000
Walleye	1	0	0	0	0	0	0.000
Beaver Army Terminal, OR (501)							
All	33	15	1	1	22	29	0.879
Common Carp	4	0	0	1	3	4	1.000
Largescale suckers	16	7	1	0	11	13	0.813
Northern pikeminnow	13	8	0	0	8	12	0.923
Basin Total							
All	560	142	79	38	336	412	0.735
Common carp	157	44	21	17	114	131	0.834
Bass	134	25	12	11	82	92	0.687
Largescale sucker	160	52	24	6	94	125	0.781
Northern pikeminnow	58	16	18	1	37	48	0.828
Longnose sucker	14	3	1	3	3	7	0.500
Walleye	17	1	1	0	2	3	0.176
Rainbow trout	20	1	2	0	4	6	0.300

The gender and gonadal stage did not influence HAI in bass, carp, or largescale sucker (Table 20). Therefore, the HAI data for genders were combined for data analysis.

Most HAI values for bass (80%) ranged from 0-100 (Table 23; Fig. 12). Mean HAI values ranged from 30-63 for fish at all stations except Stations 44 (85), 45 (87), and 41 (135) (Fig. 12). Bass with HAI ratings >120 were collected from Stations 41, 44, 45, 503, and 505. Bass collected from Stations 41, 44, and 45 had consistently higher HAI values than bass collected from the other stations (Fig. 12). Blazer and others (2002) determined similar HAI values for bass in the MRB with mean station HAI ranging from 14-130 and a reference station with an HAI score of approximately 50. Other studies have designated HAI values <20 as un-impacted (Schmitt, 2002a).

Most HAI values for carp (82%) ranged from 0-70, indicating most carp were identified as having zero to three lesions (Fig. 12; Table 23). Mean HAI data for fish at all stations ranged from 42-64 with the exception of Station 501 (Fig. 12). Stations that had fish with HAI >110 included Stations 44, 96, 502, and 503, although these data do not indicate that any particular station was notable for numerous abnormalities in carp (Fig. 12). These data are similar to HAI data for carp from the MRB (Blazer and others, 2002), which determined carp to have mean station HAI values of approximately 0-90 for females and 1-95 for males. The RGB BEST study determined most individual carp and bass had HAI values <60 (Schmitt and others, 2004).

Most (95%) of HAI values for largescale sucker were 0-100 (Fig. 12; Table 23), and station mean values ranged from 30-63. Largescale sucker from Stations 43, 117, and 502 had HAI values <70 (Fig. 12). Two or more sucker at the remaining stations had HAI values ≥100. However, HAI among stations did not differ for largescale sucker (Table 20). HAI values ranging from 0-60 for individual fish for largescale sucker from the LCR have been reported by the Bi-State Water Quality Program (Tetra Tech Inc., 1996).

Condition and Organosomatic Indices

These indices are calculated from body and organ weight in individual fish and considered general indicators of the overall health of the fish and alterations of these indices may be indicative of effects resulting from exposure to contaminants (Schmitt and Dethloff, 2000). These indices can vary among species, gender, and developmental stage.

Table 23. Distribution of Health Assessment Index (HAI) scores among bass, common carp, and largescale sucker collected in the Columbia River Basin in 1997. Station totals where HAI scores were not available for all individual fish are noted with an asterisk (*).

Species and station	HAI Score																		
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	Total
Bass																			
Upper Columbia River (UCR)																			
Creston, MT (117)	3	3	0	5	7	1	1	1	0	0	0	0	0	0	0	0	0	0	21
Snake River (SR)																			
Hagerman, ID (41)	0	0	0	0	1	0	0	0	0	2	1	0	0	1	4	0	4	3	16
Riggins, ID (43)	0	0	0	4	2	0	0	1	0	0	0	0	0	0	0	0	0	0	7
Lewiston, ID (42)	3	1	0	4	2	0	3	0	0	0	0	0	0	0	0	0	0	0	13
Ice Harbor Dam, WA (96)	0	0	0	2	3	0	1	1	0	0	0	0	0	0	0	0	0	0	7
Middle Columbia River (MCR)																			
Vernita Bridge, WA (503)	0	0	0	3	1	0	0	0	0	0	0	0	0	1	0	0	0	0	5
Pasco, WA (97)	0	1	0	1	2	0	5	3	0	1	1	0	0	0	0	0	0	0	14*
Granger, WA (44)	0	1	0	2	2	0	0	2	0	0	2	0	0	6	0	0	0	0	15
Lower Columbia River (LCR)																			
Warrendale, OR (502)	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	4
Vancouver, WA (506)	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Oregon City, OR (45)	0	0	0	1	4	0	3	2	0	2	4	0	1	3	0	0	2	0	22
Portland, OR (505)	0	1	0	2	0	0	1	2	0	0	1	0	0	1	0	0	0	0	8
Basin Total	6	7	0	24	27	1	14	14	0	5	9	0	1	12	4	0	6	3	133
Common Carp																			
Snake River (SR)																			
Hagerman, ID (41)	0	0	1	0	8	3	0	4	1	0	3	0	0	0	0	0	0	0	20
Lewiston, ID (42)	2	2	0	4	2	1	0	1	1	0	4	0	0	0	0	0	0	0	17
Ice Harbor Dam, WA (96)	3	0	0	1	5	0	3	5	0	1	1	0	1	0	1	0	0	0	21

Table 23. Distribution of Health Assessment Index (HAI) scores among bass, common carp, and largescale sucker collected in the Columbia River Basin in 1997. Station totals where HAI scores were not available for all individual fish are noted with an asterisk (*).—Continued

Species and station	HAI Score																		
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	Total
Middle Columbia River (MCR)																			
Vernita Bridge, WA (503)	1	3	1	2	5	0	0	5	0	0	2	0	1	0	0	1	0	0	21
Pasco, WA (97)	2	0	0	6	3	1	6	2	0	0	0	0	0	0	0	0	0	0	20
Granger, WA (44)	0	3	0	1	3	0	0	7	2	1	0	1	1	1	0	0	0	0	20
Lower Columbia River (LCR)																			
Warrendale, OR (502)	0	3	0	2	6	0	1	4	0	2	0	1	0	1	0	0	0	0	20
Oregon City, OR (45)	0	2	0	1	2	0	1	6	0	2	0	0	0	0	0	0	0	0	14
Beaver Army Terminal, OR (501)	0	3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	4
Basin Total	8	16	2	17	34	5	12	34	4	6	10	2	3	2	1	1	0	0	157
Largescale sucker																			
Upper Columbia River (UCR)																			
Creston, MT (117)	1	3	0	3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	10
Northport, WA (504)	1	1	0	3	2	0	3	4	1	3	0	1	0	0	0	1	0	0	20
Grand Coulee, WA (98)	2	0	0	5	0	0	4	3	0	3	0	0	2	0	0	1	0	0	20
Snake River (SR)																			
Riggins, ID (43)	0	1	0	7	8	0	3	1	0	0	0	0	0	0	0	0	0	0	20
Lower Columbia River (LCR)																			
Cascade Locks, OR (46)	1	4	0	2	8	0	2	2	0	0	1	0	0	1	0	0	0	0	21
Warrendale, OR (502)	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3
Vancouver, WA (506)	2	1	1	4	4	1	2	1	1	1	2	0	0	1	0	0	0	0	21
Oregon City, OR (45)	0	1	0	1	0	0	0	2	0	0	2	0	0	0	0	0	0	0	6
Portland, OR (505)	0	2	0	1	8	0	0	7	0	0	3	0	1	0	0	0	0	0	22
Beaver Army Terminal, OR (501)	1	2	0	3	3	0	1	3	0	0	3	0	0	0	0	0	0	0	16
Basin Total	8	16	1	30	33	1	19	23	2	7	11	1	3	2	0	2	0	0	159

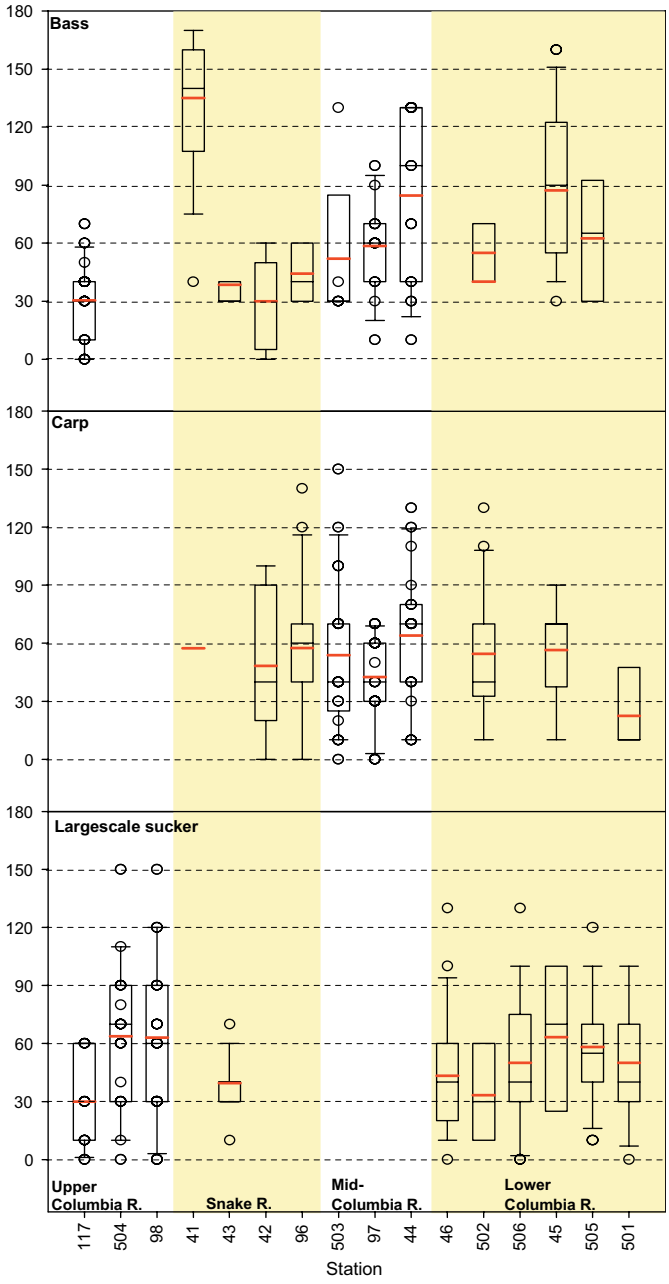


Figure 12. Health assessment index (HAI) score by station in bass (*Micropterus* sp.), carp, and largescale sucker collected in the Columbia River Basin in 1997. Shown for each group are points representing individual fish and the mean (red horizontal line), median (black horizontal line), interquartile range (box), and the 10th and 90th percentiles (whiskers). Stations are ordered from upstream to downstream and are grouped by sub-basin. See Table 3 for station descriptions.

Condition and Organosomatic Indices in Bass

The gender and/or developmental stage influenced condition factor and organosomatic indices in bass (Table 20). Therefore, the data for male and female bass were examined separately for CF and HSI so as not to confound the potential effects other variables may have on the fish health indicators with the effects caused by gender or developmental stage. The basin-wide mean CF for female bass was 1.6, and station means ranged from 1.3 at Station 42 to 1.8 at Station 503 (Table 24; Fig. 13). Female bass from Station 502 (n=1) had a CF of 2.1. Stations 41, 44, 97, 117, 502, and 503 had fish with a CF >1.9. Across all stations, 91% of bass had CF between 1.1-1.9 (Fig. 13), the range of CF in small- and largemouth bass in a nationwide survey (Carlander, 1977). These data are similar to a more recent study which determined female largemouth bass in a laboratory control group to have CF between 1.2 and 1.3 (Sepúlveda and others, 2001). Female bass had mean station CF that ranged from approximately 1.0-2.0 in the MRB (Blazer and others, 2002) and approximately 1.5 in the RGB (Schmitt and others, 2004). CF for female bass varied significantly among stations in the CRB (Table 20).

Male bass had a basin-wide mean CF of 1.5 with station means ranging from 1.3 at Station 42 to 1.7 at Station 96 (Table 24). Stations 41, 43, 96, and 117 had fish with a CF >1.9; Stations 43, 97, and 117 had fish with a CF <1.0. Most (86%) male bass had CF between 1.1-1.9 (Fig. 13). Sepúlveda and others (2001) determined male largemouth bass in a laboratory control group to have CF between 1.1-1.3. CF for male bass did vary among stations in the CRB (Table 20). The mean station CF values in the CRB were similar to those found in male bass from the MRB (Blazer and others, 2002), RGB (Schmitt and others, 2004), and other locations across the U.S. (Carlander, 1977).

Of the three target species, only bass have discrete livers. Thus, HSI was only calculated for bass. The mean HSI for female bass in the basin was 1.4%, and station means ranged from 1.0% at Station 502 to 2.3% at Station 503 (Table 25). With the exception of Station 503, all station means were <1.7% for CF. Indices >2.1% were calculated for fish at Stations 43, 45, 97, and 503; however, most female bass (90%) had HSI between 0.9-2.4% (Fig. 13). Station 503 was the only station that consistently had female bass with HSI >2.0%, while Station 502 (n=1) had the minimum HSI. These data were similar to previous studies. Female bass had HSI station means ranging from 0.6-2.0% in the MRB (Blazer and others, 2002) and were approximately 1.0% in the RGB (Schmitt and others, 2004). Gingerich (1982) determined a comparative range for normal liver weight in fish to be 1-3% of the total body weight. In other studies, HSI in female bass from a control group ranged from 0.9-1.8% (Sepúlveda and others, 2001; 2003).

The mean basin-wide HSI for male bass was 1.4%. Station means ranged from 1.0% at Station 97 to 2.0% at Station 43 for male bass (Table 25). Station means did not exceed 1.7% with the exception of fish at Station 43. Indices >2.2% were calculated for male bass at Stations 43, 44, and 117; however, most male bass (90%) had HSI between 0.8-2.2% (Fig. 13). Several laboratory studies determined male largemouth bass to have HSI ranging from 0.7-1.7% (Sepúlveda and others, 2001; 2003). HSI in male bass varied among stations in the CRB (Table 20). HSI calculated for male bass in

Table 24. Arithmetic mean of condition factor (CF) by station, number of samples (*n*), minimum (min.), maximum (max.), and standard error (SE) in the target species collected in the Columbia River Basin in 1997. Stations are grouped by taxon and sub-basin and ordered upstream to downstream. The maximum station mean for each taxon is shown in bold.—Continued

Taxon and Station	*n*	Mean	Min.	Max.	SE
Bass - female					
Basin total	74	1.57	1.21	2.15	0.03
Upper Columbia River (UCR)					
Creston, MT (117)	11	1.67	1.29	2.13	0.08
Snake River (SR)					
Hagerman, ID (41)	9	1.67	1.45	1.92	0.06
Riggins, ID (43)	3	1.46	1.23	1.81	0.18
Lewiston, ID (42)	5	1.34	1.23	1.45	0.04
Ice Harbor Dam, ID (96)	4	1.55	1.41	1.64	0.05
Middle Columbia River (MCR)					
Vernita Bridge, WA (503)	3	1.79	1.58	1.95	0.11
Pasco, WA (97)	9	1.59	1.29	2.15	0.09
Granger, WA (44)	9	1.53	1.21	1.98	0.08
Lower Columbia River (LCR)					
Warrendale, OR (502)	1	**2.08**	--	--	--
Oregon City, OR (45)	15	1.46	1.29	1.68	0.03
Portland, OR (505)	5	1.56	1.39	1.80	0.08
Bass - male					
Basin total	60	1.51	0.59	2.21	0.04
Upper Columbia River (UCR)					
Creston, MT (117)	10	1.54	0.71	2.21	0.13
Snake River (SR)					
Hagerman, ID (41)	7	1.61	1.42	1.97	0.07
Riggins, ID (43)	4	1.38	0.83	1.99	0.24
Lewiston, ID (42)	7	1.33	1.22	1.49	0.03
Ice Harbor Dam, ID (96)	3	**1.75**	1.42	1.95	0.17
Middle Columbia River (MCR)					
Vernita Bridge, WA (503)	2	1.69	1.52	1.87	0.17
Pasco, WA (97)	6	1.45	0.59	1.81	0.18
Granger, WA (44)	6	1.52	1.37	1.60	0.03
Lower Columbia River (LCR)					
Warrendale, OR (502)	3	1.59	1.54	1.67	0.04
Vancouver, WA (506)	1	1.63	--	--	--
Oregon City, OR (45)	6	1.48	1.33	1.62	0.05
Portland, OR (505)	3	1.50	1.35	1.59	0.07
Carp					
Basin total	157	1.36	0.91	1.91	0.01
Snake River (SR)					
Hagerman, ID (41)	20	1.38	1.18	1.63	0.03
Lewiston, ID (42)	7	1.12	1.04	1.23	0.07
Ice Harbor Dam, ID (96)	21	1.39	0.91	1.91	0.04
Middle Columbia River (MCR)					
Vernita Bridge, WA (503)	21	1.32	0.99	1.82	0.04
Pasco, WA (97)	20	1.29	0.93	1.53	0.03
Granger, WA (44)	20	1.23	1.01	1.53	0.03
Lower Columbia River (LCR)					
Warrendale, OR (502)	20	1.39	1.16	1.66	0.03
Oregon City, OR (45)	14	**1.46**	1.21	1.75	0.04
Beaver Army Terminal, OR (501)	4	1.30	1.16	1.41	0.05

Table 24. Arithmetic mean of condition factor (CF) by station, number of samples (*n*), minimum (min.), maximum (max.), and standard error (SE) in the target species collected in the Columbia River Basin in 1997. Stations are grouped by taxon and sub-basin and ordered upstream to downstream. The maximum station mean for each taxon is shown in bold.—Continued

Taxon and Station	*n*	Mean	Min.	Max.	SE
Largescale Sucker					
Basin total	158	0.94	0.45	1.67	0.01
Upper Columbia River (UCR)					
Creston, MT (117)	10	0.97	0.67	1.16	0.04
Northport, WA (504)	19	1.04	0.90	1.23	0.02
Grand Coulee, WA (98)	20	0.86	0.70	1.06	0.02
Snake River (SR)					
Riggins, ID (43)	20	0.92	0.84	1.04	0.01
Lower Columbia River (LCR)					
Cascade Locks, OR (46)	21	0.96	0.66	1.13	0.02
Warrendale, OR (502)	3	0.91	0.84	0.99	0.04
Vancouver, WA (506)	21	0.95	0.80	1.25	0.02
Oregon City, OR (45)	6	**1.20**	0.97	1.67	0.10
Portland, OR (505)	22	0.87	0.45	1.07	0.04
Beaver Army Terminal, OR (501)	16	0.92	0.78	1.06	0.02

the CRB were similar to previous studies (Blazer and others, 2002; Gingerich, 1982), but greater than male bass in the RGB (Schmitt and others, 2004).

Overall, none of the CRB stations had consistently elevated SSI values. The basin-wide mean for SSI in bass was 0.15%, and station means ranged from 0.10% at Station 96 to 0.25% at Station 42 (Table 26). Stations 42 and 505 had fish with SSI >0.60%; however the majority (95%) of fish SSI were 0.06-0.34% (Fig. 13). The SSI in bass did not vary significantly among stations (Table 20). In previous studies, bass from the MRB had similar SSI to those found in the CRB with station mean SSI ranging from 0.09-0.24% (Blazer and others, 2002). Similar results were reported by Schmitt and others (2004) for bass in the RGB with station means ranging from approximately 0.1-0.2%.

Condition and Organosomatic Indices in Carp

The gender and/or developmental stage influenced CF but not SSI in carp (Table 20). The data for male and female carp were also examined separately for SSI, but combined for CF. The basin-wide mean CF was 1.4 for carp, and station means ranged from 1.2 at Station 44 to 1.9 at Station 42 (Table 24). All individual fish had CF values ranging from 0.9-1.9 (Fig. 14). CF did not vary significantly among stations for carp (Table 20). CF data from the CRB were similar to data from previous studies. CF station means in carp ranged from 1.1-1.5 in the MRB (Blazer and others, 2002) and 1.2-1.5 in the RGB (Schmitt and others, 2004). Carlander (1969) performed a survey of carp across the U.S. and determined the mean CF range from 1.2 to >2.0.

The basin-wide mean for SSI in female carp was 0.24% (Table 26). Station means for female carp ranged from 0.15% at Station 42 to 0.39% at Station 45, and all other station means were 0.2-0.3% (Table 26). Station 42 had three fish with SSI <0.01%, and Stations 45 and 97 had one individual fish each with an SSI >0.5% (Fig. 14). SSI for female carp increased upstream to downstream in CRB, supporting that SSI did vary significantly among stations (Table 20). Female carp from the MRB had slightly greater SSI than carp from the CRB, with station means ranging from 0.09-0.87% (Blazer and others, 2002), but station means in female carp from the RGB (approximately 0.1-0.3%) were similar to SSI in the CRB (Schmitt and others, 2004).

Male carp had greater SSI values compared to female carp having a basin-wide mean of 0.34%, and station means ranged from 0.22% at Station 41 to 0.47% at Station 45 (Table 26). Multiple fish from Stations 42, 45, 501, and 502 had SSI >0.60% (Fig. 14). Stations 45 and 502 consistently had male carp with SSI values >0.3%, recalling Station 45 was previously noted for relatively high SSI for female carp. Similar to female carp, SSI in male carp varied significantly among stations increasing upstream to downstream (Fig. 14; Table 20). SSI station means in male carp from the MRB ranged from 0.04-0.50% (Blazer and others, 2002), which is less than the SSI for carp from the CRB. Male carp from the RGB had SSI that ranged from 0.1-0.4% which is similar to those measured in the CRB (Schmitt and others, 2004).

Condition and Organosomatic Indices in Largescale Sucker

Gender and/or developmental stage did not influence fish health indicators in largescale sucker (Table 20), so the data for males and females were combined for data analysis.

The basin-wide mean for largescale sucker CF was 0.9. The mean CF was greatest (1.2) in largescale sucker at Station 45, while all other station means were <1.0 (Table 24). All fish had CF values <1.3 with the exception of one fish from Station 45 (Fig. 15). Certain largescale sucker had greater CF

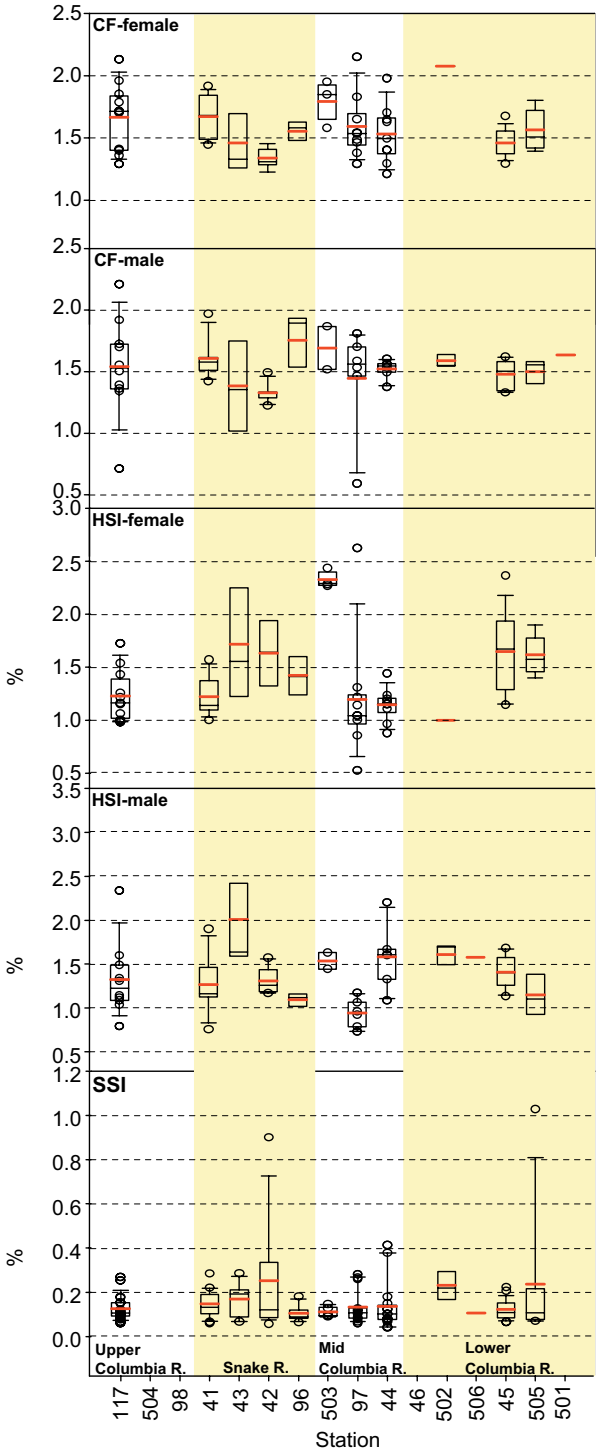


Figure 13. Fish health indicators by station in female and male bass (*Micropterus* sp.) collected in the Columbia River Basin in 1997. Indicators include condition factor (CF), hepatosomatic index (HSI), and splenosomatic index (SSI). Females and males were plotted separately when analysis-of-variance modeling determined gender was a significant factor. Shown for each group are points representing individual fish and the mean (red horizontal line), median (black horizontal line), interquartile range (box), and the 10th and 90th percentiles (whiskers). Stations are ordered from upstream to downstream and are grouped by sub-basin. See Table 3 for station descriptions.

values, but CF values did not differ significantly among stations (Table 20). Previous studies examining CF in sucker are limited. The state of Minnesota set standards that considered white sucker with CF <1.0 to be in poor condition (Carlander, 1969).

Mean SSI values were similar among CRB stations although some individual values increased the variability of the data. The basin-wide mean SSI for largescale sucker was 0.25% and station means ranged from 0.17% at Station 501 to 0.37% at Station 117 (Table 26). Spleen weights were not available for largescale sucker from Station 43. Two fish from Station 117 and one fish from Station 504 had SSI >0.6%, and largescale sucker at Station 117 had the greatest variability (SE±0.06) in SSI data. SSI <0.1% were calculated for fish from Stations 46, 501, and 506. Most values (91%) were between 0.12-0.43% (Fig. 15). Mean station SSI in largescale sucker decreased upstream to downstream in CRB, supporting that SSI did vary significantly among stations (Table 20). Previous studies on SSI in largescale sucker have not been documented. Fish health indicators for non-target species are located in Appendix 2.

Cellular and Histopathological Indicators

Macrophage aggregates (MA) are believed to house endogenous and exogenous waste products and are active in the immune responses to these materials (Schmitt and Dethloff, 2000). Three macrophage aggregate parameters, density or number of aggregates per mm^2 (MAMM), mean size of aggregates in μm^2 (MEANAREA), and percent of tissue occupied by macrophage aggregates (TISSOC) were analyzed for carp, bass, and largescale sucker in this study. Gender and age influenced macrophage aggregate parameters in bass, carp, and largescale sucker (Table 20). The MA data were examined separately, where appropriate, so as not to confound the potential effects other variables may have on the immune biomarkers with the effects caused by gender or age.

MAMM

Gender and age did not influence MAMM in bass, carp, and largescale sucker (Table 20); therefore, genders were combined for data analysis. The basin-wide mean MAMM for bass was 6.3 MA/mm^2, and station means ranged from 4.1 MA/mm^2 at Station 502 to 9.5 MA/mm^2 at Station 43 in bass (Table 27). Individual MAMM in bass ranged from 0.6-19.4 MA/mm^2 (Fig. 16). MAMM values >15 MA/mm^2 were measured in bass at Stations 41 and 117. Most (90%) of bass had MAMM of 1.8–12.4 MA/mm^2; Stations 41, 42, 43, 44, and 117 had fish with MAMM >12.4 MA/mm^2. MAMM did not differ significantly among stations (Table 20). Age-adjusted MAMM values were computed because age was a significant variable for other MA parameters in bass (Tables 20 and 28). Age-adjusted station order was similar to non-adjusted station

Table 25. Arithmetic mean of hepatosomatic index (HSI; %) by station, number of samples (*n*), minimum (min.), maximum (max.), and standard error (SE) in bass collected in the Columbia River Basin in 1997. Stations are grouped by gender and sub-basin and ordered upstream to downstream. The maximum station mean for each gender is shown in bold.

Taxon and Station	*n*	Mean	Min.	Max.	SE
Bass - female					
Basin total	73	1.42	0.53	2.62	0.05
Upper Columbia River (UCR)					
Creston, MT (117)	11	1.23	0.98	1.72	0.07
Snake River (SR)					
Riggins, ID (43)	3	1.72	1.11	2.48	0.40
Lewiston, ID (42)	4	1.63	1.21	2.04	0.19
Ice Harbor Dam, ID (96)	4	1.42	1.15	1.71	0.12
Middle Columbia River (MCR)					
Vernita Bridge, WA (503)	3	**2.33**	2.27	2.44	0.05
Pasco, WA (97)	9	1.20	0.53	2.62	0.19
Granger, WA (44)	9	1.15	0.88	1.44	0.05
Lower Columbia River (LCR)					
Warrendale, OR (502)	1	1.00	--	--	
Oregon City, OR (45)	15	1.65	1.15	2.37	0.10
Portland, OR (505)	5	1.62	1.40	1.90	0.09
Bass - male					
Basin total	60	1.36	0.73	3.17	0.05
Upper Columbia River (UCR)					
Creston, MT (117)	10	1.32	0.79	2.33	0.13
Snake River (SR)					
Hagerman, ID (41)	7	1.27	0.76	1.90	0.14
Riggins, ID (43)	4	**2.00**	1.57	3.17	0.39
Lewiston, ID (42)	7	1.31	1.17	1.57	0.06
Ice Harbor Dam, ID (96)	3	1.09	0.99	1.17	0.06
Middle Columbia River (MCR)					
Vernita Bridge, WA (503)	2	1.54	1.44	1.63	0.09
Pasco, WA (97)	6	0.94	0.73	1.17	0.07
Granger, WA (44)	6	1.58	1.08	2.20	0.15
Lower Columbia River (LCR)					
Warrendale, OR (502)	3	1.61	1.42	1.71	0.09
Vancouver, WA (506)	1	1.58	--	--	
Oregon City, OR (45)	6	1.41	1.13	1.68	0.09
Portland, OR (505)	3	1.15	0.87	1.48	0.18

order with Stations 502 and 505 having the lowest and Station 43 having the greatest MAMM. Age-adjusted station means for bass (genders combined) ranged from 4.28 MA/mm^2 at Station 502 to 10.41 MA/mm^2 at Station 43, and these differences were significant (Table 28). These data are similar to MAMM station means in bass from the MRB (2.2-11.2 MA/mm^2) (Blazer and others, 2002) and RGB (approximately 4-8 MA/mm^2) (Schmitt and others, 2004).

The mean MAMM for carp in the CRB was 6.7 MA/mm^2. MAMM values for individual fish ranged from 0.6-22.4 MA/mm^2 excluding a carp without MA data from Station 41 (Table 27; Fig. 17). Most values (90%) were 1.2-11.8 MA/mm^2, and Stations 42, 97, and 503 had multiple fish with MAMM values >15 MA/mm^2. Station means for MAMM ranged from 3.0 MA/mm^2 at Station 41 to 10.2 MA/mm^2 at Station 42 for carp (5.8-7.8 MA/mm^2) (Table 27). MAMM in carp did not vary significantly among stations (Table 20). Carp from the MRB had similar MAMM station means (5.1-18.3 MA/mm^2) (Blazer and others, 2002). Stations means for female (approximately 1-16 MA/mm^2) and male (approximately 4-14 MA/mm^2) carp in the RGB were also similar to the CRB (Schmitt and others, 2004).

The basin-wide mean MAMM for largescale sucker was 6.8 MA/mm^2, and station means for MAMM in largescale sucker ranged from 4.9 MA/mm^2 at Station 45 to 8.7 MA/mm^2 at Station 117 (Table 27). Individual MAMM in largescale sucker ranged from 1.8-20.0 MA/mm^2 with most (90%) ranging from 2.9-11.7 MA/mm^2 (Fig. 18). Three fish from

Table 26. Arithmetic mean of splenosomatic index (SSI; %) by station, number of samples (*n*), minimum (min.), maximum (max.), and standard error (SE) in the target species collected in the Columbia River Basin in 1997. Stations are grouped by taxon and sub-basin and ordered upstream to downstream. The maximum station mean for each taxon is shown in bold.

Taxon and Station	*n*	Mean	Min.	Max.	SE
Bass					
Basin total	132	0.15	0.04	1.03	0.01
Upper Columbia River (UCR)					
Creston, MT (117)	21	0.13	0.06	0.27	0.01
Snake River (SR)					
Hagerman, ID (41)	16	0.15	0.06	0.29	0.02
Riggins, ID (43)	7	0.17	0.07	0.29	0.03
Lewiston, ID (42)	12	**0.25**	0.06	0.90	0.08
Ice Harbor Dam, ID (96)	7	0.10	0.06	0.18	0.01
Middle Columbia River (MCR)					
Vernita Bridge, WA (503)	5	0.11	0.09	0.15	0.01
Pasco, WA (97)	14	0.13	0.06	0.28	0.02
Granger, WA (44)	15	0.14	0.04	0.41	0.03
Lower Columbia River (LCR)					
Warrendale, OR (502)	4	0.23	0.15	0.34	0.04
Vancouver, WA (506)	1	0.11	--	--	--
Oregon City, OR (45)	22	0.12	0.07	0.22	0.01
Portland, OR (505)	8	0.24	0.07	1.03	0.12
Carp - female					
Basin total	70	0.24	0.00	0.63	0.01
Snake River (SR)					
Hagerman, ID (41)	10	0.20	0.15	0.28	0.01
Lewiston, ID (42)	5	0.15	0.00	0.41	0.08
Ice Harbor Dam, ID (96)	10	0.27	0.17	0.43	0.02
Middle Columbia River (MCR)					
Vernita Bridge, WA (503)	10	0.23	0.17	0.33	0.02
Pasco, WA (97)	11	0.29	0.19	0.56	0.03
Granger, WA (44)	10	0.20	0.15	0.29	0.02
Lower Columbia River (LCR)					
Warrendale, OR (502)	10	0.26	0.15	0.34	0.02
Oregon City, OR (45)	4	**0.39**	0.23	0.63	0.09
Carp - male					
Basin total	87	0.34	0.01	0.66	0.01
Snake River (SR)					
Hagerman, ID (41)	10	0.22	0.18	0.30	0.01
Lewiston, ID (42)	12	0.30	0.01	0.64	0.04
Ice Harbor Dam, ID (96)	11	0.29	0.14	0.50	0.03
Middle Columbia River (MCR)					
Vernita Bridge, WA (503)	11	0.26	0.17	0.37	0.02
Pasco, WA (97)	9	0.38	0.23	0.57	0.04
Granger, WA (44)	10	0.36	0.14	0.51	0.03
Lower Columbia River (LCR)					
Warrendale, OR (502)	10	0.46	0.31	0.65	0.04
Oregon City, OR (45)	10	**0.47**	0.33	0.66	0.04
Beaver Army Terminal, OR (501)	4	0.33	0.18	0.61	0.10
Largescale sucker					
Basin total	137	0.25	0.08	0.66	0.01
Upper Columbia River (UCR)					
Creston, MT (117)	9	**0.37**	0.14	0.65	0.06
Northport, WA (504)	19	0.36	0.15	0.66	0.03
Grand Coulee, WA (98)	20	0.31	0.21	0.43	0.02
Lower Columbia River (LCR)					
Cascade Locks, OR (46)	21	0.24	0.08	0.36	0.02
Warrendale, OR (502)	3	0.24	0.20	0.31	0.03
Vancouver, WA (506)	21	0.18	0.08	0.28	0.01
Oregon City, OR (45)	6	0.20	0.10	0.29	0.04
Portland, OR (505)	22	0.22	0.12	0.40	0.02
Beaver Army Terminal, OR (501)	16	0.17	0.09	0.27	0.01

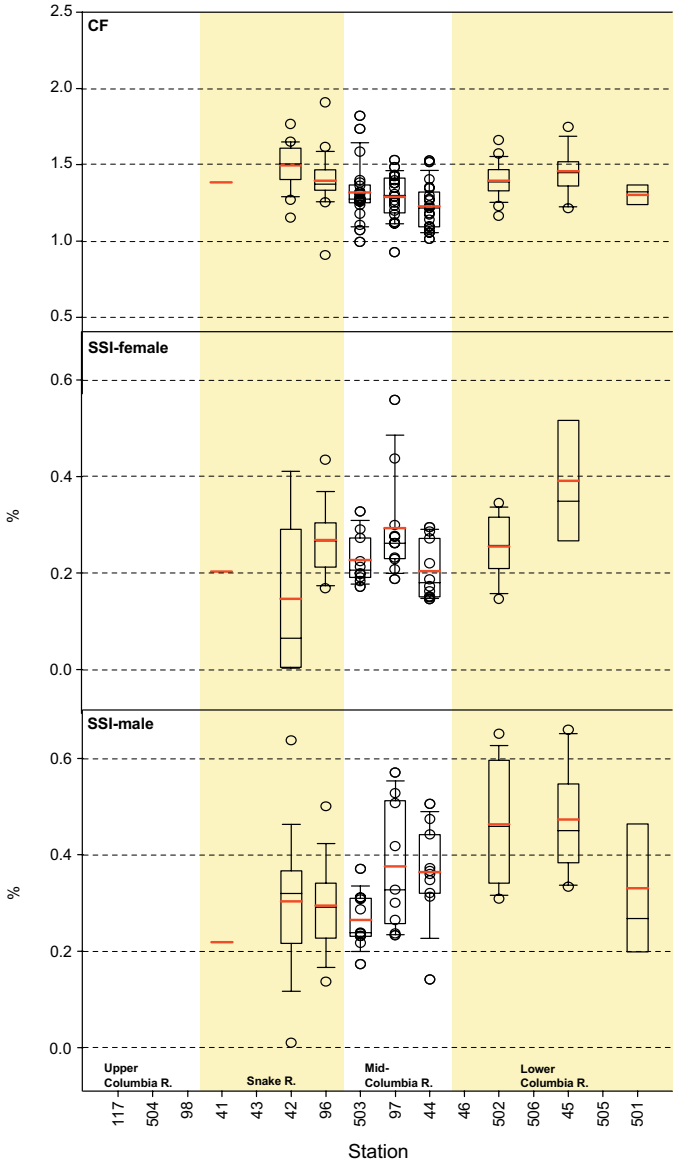


Figure 14. Fish health indicators by station in female and male carp collected in the Columbia River Basin in 1997. Indicators include condition factor (CF) and splenosomatic index (SSI). Females and males were plotted separately when analysis-of-variance modeling determined gender was a significant factor. Shown for each group are points representing individual fish and the mean (red horizontal line), median (black horizontal line), interquartile range (box), and the 10th and 90th percentiles (whiskers). Stations are ordered from upstream to downstream and are grouped by sub-basin. See Table 3 for station descriptions.

Stations 501 and 506 had MAMM values that >15.0 MA/mm^2. As in the carp and bass, MAMMs did not significantly differ among stations for largescale sucker (Table 20). Previous studies on MAMM in largescale sucker have not been documented.

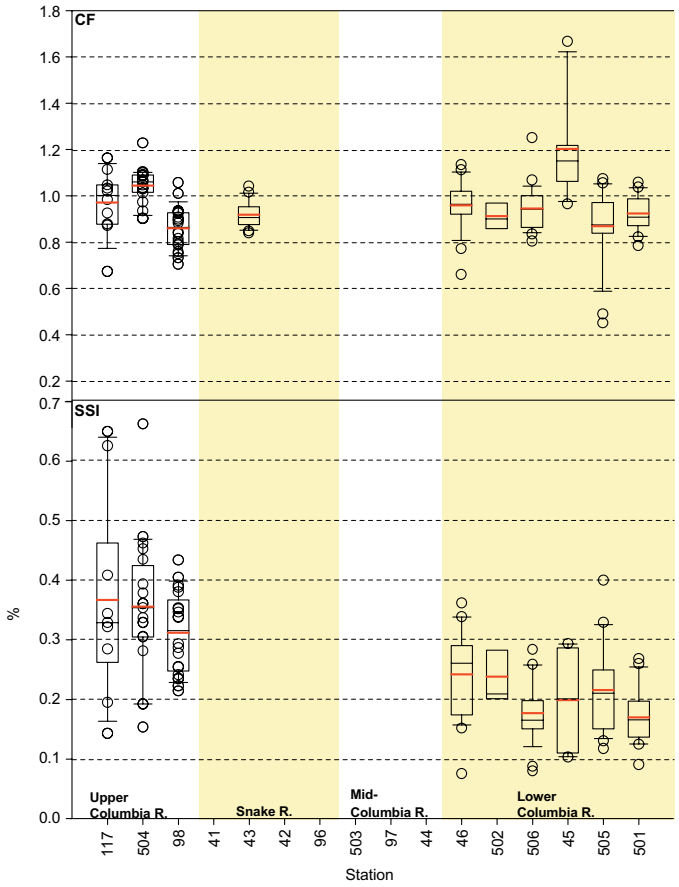


Figure 15. Fish health indicators by station in female and male largescale sucker collected in the Columbia River Basin in 1997. Indicators include condition factor (CF) and splenosomatic index (SSI). Shown for each group are points representing individual fish and the mean (red horizontal line), median (black horizontal line), interquartile range (box), and the 10th and 90th percentiles (whiskers). Stations are ordered from upstream to downstream and are grouped by sub-basin. See Table 3 for station descriptions.

MEANAREA

Gender and age influenced MEANAREA in bass, but not in carp or largescale sucker (Table 20); therefore, genders were examined separately in bass. The MEANAREA station mean in female bass was greatest (5,095 µm^2) at Station 505, ranging from 1,675-8,735 µm^2 (Table 29). All other station means for female bass were <4,670 µm^2. Stations 43, 45, 96, 117 and 505 had bass that had MEANAREA >5,000 µm^2 (Fig. 16). These data did not support that MEANAREA varied significantly among stations for female bass (Table 20). Blazer and others (2002) found MEANAREA station means ranged from 1,049-4,440 µm^2 for bass in the MRB. Schmitt and others (2004) reported similar station means (approximately 3,000-5,000 µm^2) for bass in the RGB.

The MEANAREA station mean for male bass was greatest (5,991 µm^2) at Station 502 (n=3), ranging from 1,820-9,985 µm^2 (Table 29). All other station means for male bass ranged

Table 27. Arithmetic mean of macrophage aggregate density (MAMM) by station, number of samples (*n*), minimum (min.), maximum (max.), and standard error (SE) in the target species collected in the Columbia River Basin in 1997. Stations are grouped by taxon and sub-basin and ordered upstream to downstream. The maximum station mean for each taxon is shown in bold. MAMM are measured in MA/mm2.

Taxon and Station	*n*	Mean	Min.	Max.	SE
Bass					
Basin total	124	6.30	0.59	19.41	0.32
Upper Columbia River (UCR)					
Creston, MT (117)	18	5.82	1.76	19.41	0.93
Snake River (SR)					
Hagerman, ID (41)	15	7.57	2.35	15.29	0.93
Riggins, ID (43)	7	**9.50**	2.94	14.12	1.65
Lewiston, ID (42)	11	7.54	1.18	12.94	1.11
Ice Harbor Dam, WA (96)	7	7.56	4.12	10.59	0.75
Middle Columbia River (MCR)					
Vernita Bridge, WA (503)	5	9.06	5.88	10.59	0.84
Pasco, WA (97)	14	4.45	0.59	12.35	1.17
Granger, WA (44)	13	6.06	0.59	12.94	0.91
Lower Columbia River (LCR)					
Warrendale, OR (502)	4	4.41	1.76	7.06	1.14
Oregon City, OR (45)	22	5.59	2.35	10.59	0.50
Portland, OR (505)	8	4.12	1.76	8.24	0.87
Carp					
Basin total	153	6.66	0.00	22.35	0.29
Snake River (SR)					
Hagerman, ID (41)	17	3.04	0.00	8.24	0.47
Lewiston, ID (42)	17	**10.24**	3.53	22.35	1.07
Ice Harbor Dam, ID (96)	21	6.81	4.12	11.76	0.42
Middle Columbia River (MCR)					
Vernita Bridge, WA (503)	20	6.68	0.59	15.29	0.87
Pasco, WA (97)	20	6.91	2.35	15.88	0.65
Granger, WA (44)	20	7.85	2.94	11.76	0.62
Lower Columbia River (LCR)					
Warrendale, OR (502)	20	5.68	1.76	12.35	0.70
Oregon City, OR (45)	14	5.92	1.76	12.35	0.82
Beaver Army Terminal, OR (501)	4	6.32	2.35	12.35	2.14
Largescale sucker					
Basin total	156	6.82	1.76	20.00	0.26
Upper Columbia River (UCR)					
Creston, MT (117)	9	**8.69**	3.53	13.53	1.12
Northport, WA (504)	19	7.37	4.12	12.35	0.55
Grand Coulee, WA (98)	20	5.38	2.35	10.00	0.46
Snake River (SR)					
Riggins, ID (43)	20	6.38	1.76	14.12	0.80
Lower Columbia River (LCR)					
Cascade Locks, OR (46)	21	8.24	2.94	13.53	0.57
Warrendale, OR (502)	3	5.29	4.71	6.47	0.59
Vancouver, WA (506)	1	7.12	1.76	17.65	3.87
Oregon City, OR (45)	6	4.90	2.94	6.47	0.47
Portland, OR (505)	22	5.51	1.76	10.00	0.41
Beaver Army Terminal, OR (501)	16	8.01	1.76	20.00	1.33

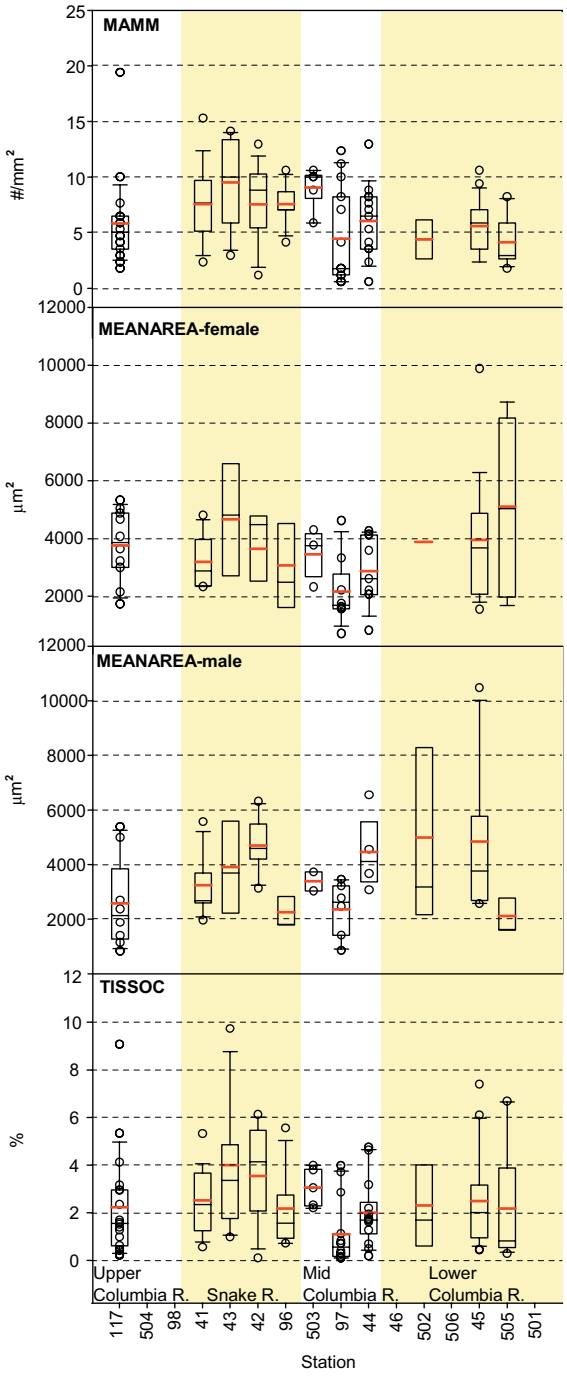


Figure 16. Splenic macrophage aggregate parameters by station in female and male bass (*Micropterus* sp.) collected in the Columbia River Basin in 1997. Parameters include macrophage aggregate density (MAMM), macrophage aggregate area (MEANAREA), and percent of splenic tissues occupied by macrophage aggregates (TISSOC). Females and males were plotted separately when analysis-of-variance modeling determined gender was a significant factor. Shown for each group are points representing individual fish and the mean (red horizontal line), median (black horizontal line), interquartile range (box), and the 10th and 90th percentiles (whiskers). Stations are ordered from upstream to downstream and are grouped by sub-basin. See Table 3 for station descriptions.

from 2,118-4,838 µm² with multiple stations having MEANAREA >5,000 µm² (Fig. 16). As in female bass, these data did not support that MEANAREA significantly differed among stations for male bass (Table 20). The mean size of aggregates in older male bass tended to be larger than younger males.

The ANOVA model indicated that age was a significant variable for MEANAREA in bass (Table 20), thus age-adjusted values were computed (Table 28). Age-adjusted station geometric means for bass (genders combined) ranged from 2,194 µm² at Station 97 to 4,416 µm² at Station 43, and these differences were significant (Table 28).

The MEANAREA station mean in carp was greatest (5,850 µm²) at Station 44, ranging from 2,097-11,911 µm² (Table 29). All other station means for carp were <4,581 µm², and the basin-wide mean was 4,057 µm². Individual carp had MEANAREA ranging from 0 µm² at Station 41 to 11,911 µm² at Station 44 with the majority (90%) of fish having values of 1,400–8,400 µm² (Fig. 17). Carp from Stations 41, 42, 44, 96, 502, and 503 had MEANAREA values >8,000 µm²; however, MEANAREA did not differ significantly among stations (Table 20). Blazer and others (2002) found MEANAREA station means ranged from 1,670-4,684 µm² in carp from the MRB. Station means ranged from approximately 1,500-8,000 µm² in carp from the RGB (Schmitt and others, 2004).

The MEANAREA station mean for largescale sucker was greatest (4,941 µm²) at Station 502 (*n*=3), ranging from 3,506-6,321 µm² (Table 29). All other station means for largescale sucker ranged from 2,821-4,502 µm², and the basin-wide mean was 3,580 µm² (Fig. 18). Individual fish MEANAREA ranged from 716 µm² at Station 43 to 25,066 µm² at Station 46. Multiple stations had fish exceeding 5,000 µm²; however, most largescale sucker (90%) had MEANAREA of 1,450-7,500 µm² (Fig. 18). As in carp and bass, MEANAREA did not vary significantly among stations for largescale sucker (Table 20). There were interactions determined to be significant by the statistical analyses (Table 20); however, no clear trends were identified.

TISSOC

Age influenced TISSOC in bass, but not in carp or largescale sucker (Table 20); therefore, genders were examined separately in bass. Mean TISSOC was greatest (4.0%) in female bass from Station 43, ranging from 1.0-9.7% (Table 30), and all other station means for female bass were <3.6%. Stations 42, 43, 45, 117, and 505 had female bass that had TISSOC >6.0% (Fig. 16), but most fish (84%) had TISSOC between 0.4-5.0%. Age had a positive correlation with TISSOC (Table 20), and the fish with TISSOC >6.0% were also the oldest (>9 years). Age was a significant factor for TISSOC in bass (Table 20); therefore, age-adjusted values were computed (Table 28). Similar to MAMM, age-adjusted station order was similar to non-adjusted station order for TISSOC. Age-adjusted station geometric means for bass (genders combined) ranged from 0.6% at Station 97 to 4.5% at Station 43, and

Table 28. Mean age-adjusted station means for splenic macrophage aggregate (MA) parameters in bass. Arithmetic means for MA density (MAMM) and geometric means for mean MA area (MEANAREA) and percent tissue occupied (TISSOC) adjusted to the basin-wide mean age (5.1 y) using analysis-of-covariance (ANCOVA) are shown. ANCOVA *F*-values and degrees-of-freedom (df) for the analyses (** $P \leq 0.01$; * $0.01 < P \leq 0.05$) are also presented. Means followed by the same letter within each column are not significantly different ($P > 0.05$, Fischer's protected LSD). See text for description of variables and statistical procedures.

Station	MAMM (No./mm²)		MEANAREA (µm)		TISSOC (%)	
Creston, MT (117)	4.84	ab	2374	ab	0.97	ab
Hagerman, ID (41)	7.86	cd	3239	bcd	2.30	cde
Riggins, ID (43)	10.41	d	4404	d	4.45	d
Lewiston, ID (42)	8.11	cd	4206	d	2.97	de
Ice Harbor Dam, ID (96)	7.62	bcd	2368	abc	1.75	bcd
Vernita Bridge, WA (503)	7.85	abcd	2698	abcd	1.88	bcde
Pasco, WA (97)	5.00	ab	2194	a	0.63	a
Granger, WA (44)	6.64	abc	3350	bcd	1.85	cd
Warrendale, OR (502)	4.28	abc	4416	cd	1.67	abcde
Oregon City, OR (45)	5.02	ab	3221	bcd	1.46	bc
Portland Oregon, OR (505)	4.29	a	3255	abcd	1.21	abc
ANCOVA						
Model (df 11,111)	4.50**		4.29**		6.99**	
Station (df 10,111)	3.53**		2.42**		4.18**	
Age (df 1,111)	19.99**		27.00**		38.70**	

these differences were significant (Table 28). TISSOC station means in bass from the MRB ranged from 0.3-3.8%, and a reference station from the study had <1.0% TISSOC (Blazer and others, 2002). The TISSOC station mean was approximately 2-3% in bass in the RGB (Schmitt and others, 2004).

The TISSOC station mean in carp was greatest (4.7%) at Station 44, ranging from 1.0-11.2% (Table 30). All other station means for female carp were <3.6%, and the basin-wide mean for carp was 2.7%. Stations 42, 44, 96 and 503 had fish that had TISSOC >6.0% (Fig. 17); however, most carp (82%) had TISSOC of 0.60-5.0%. As with MAMM and MEANAREA, the lowest values for TISSOC were found in carp from Station 41; only one fish at this station had a TISSOC value >2%. TISSOC did not differ significantly among stations for carp (Table 20). TISSOC station mean in carp was 1.2-6.4% in the MRB (Blazer and others, 2002) and approximately 1-13% in the RGB (Schmitt and others, 2004).

The TISSOC mean for largescale sucker was greatest (3.6%) at Station 46, ranging from 0.9-17.7% (Table 30). All other station means for female largescale sucker were <2.8%. Stations 43, 46, 501, and 504 each had one fish with TISSOC >6.0% (Fig. 18), but most sucker (92%) had TISSOC between 0.50-6.0%. The station mean of Station 46 was 2.9% for largescale sucker when the maximum value (5.6%) was removed. As with both MAMM and MEANAREA for largescale sucker, CRB stations did not vary significantly in TISSOC (Table 20). TISSOC data for largescale sucker have not been previously reported.

Fish Health Indicators: Summary

Fish health indictors for this monitoring effort were selected to evaluate major organ systems and their functions (Schmitt and others, 2002b). The BEST program continued to accumulate information on the target species for comparison with various large river basins and regions throughout the U.S. and for the determination of "normal" ranges for many of these indicators. The fish health indicators can be affected by various factors (that is, age, gender, reproductive status, geographic location) other than contaminants, but were selected to reflect overall organismal health of the fish and their populations.

Species (or genera) were analyzed separately in attempt to eliminate as many confounding factors as possible. Potential effects of gender and age on comparisons among stations were evaluated statistically. Analysis of the data indicated no effect of gender on external lesions, MAMM, TISSOC, HAI in carp, bass, and largescale sucker, CF and MEANAREA in carp and largescale sucker, and SSI in bass and largescale sucker. Of the remaining indicators, CF and MEANAREA in bass and SSI in carp differed between genders; therefore, males and females were evaluated separately for these indicators. HSI in bass was analyzed by gender due to the role of the liver in vitellogenesis (Scott and Pankhurst, 1992). Age is known to significantly influence MA density, at least in some fishes (Brown and George, 1985) including largemouth bass (Blazer and others, 1987). For these reasons age was considered in the statistical model for station comparisons of these parameters.

Most of the endpoints measured in CRB fish were limited to the target species (that is, bass, carp, and largescale sucker) to remain consistent with other portions of the study. However, some endpoints such has external lesions were measured

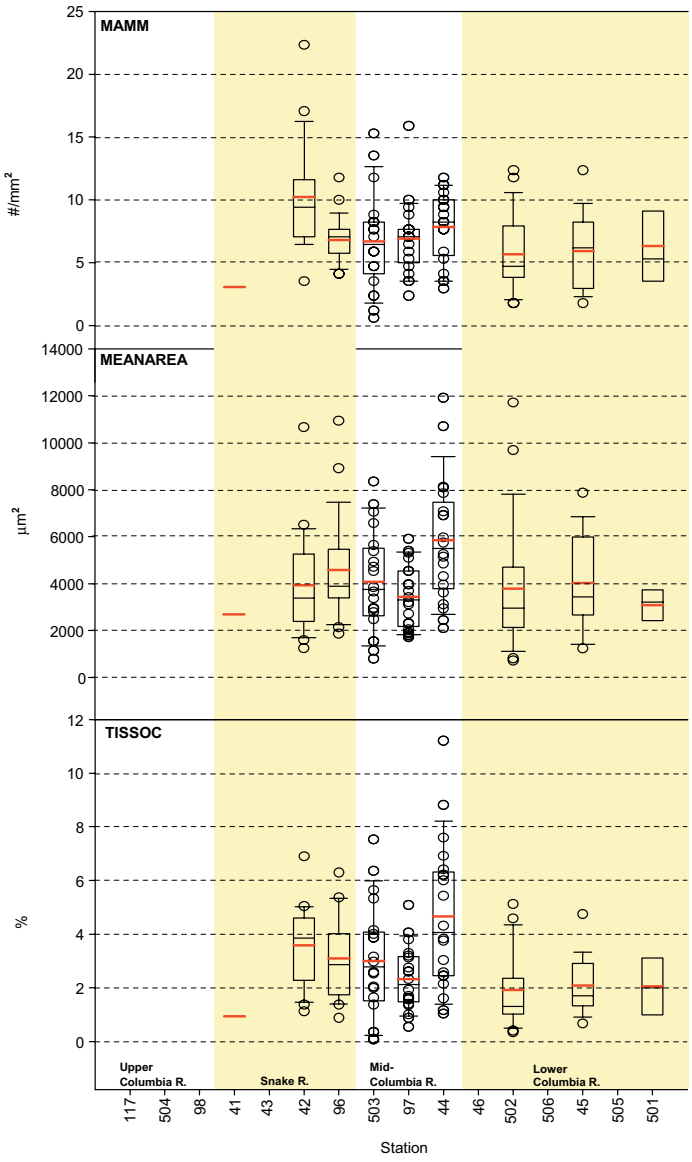


Figure 17. Splenic macrophage aggregate parameters by station in female and male carp collected in the Columbia River Basin in 1997. Parameters include macrophage aggregate density (MAMM), macrophage aggregate area (MEANAREA), and percent of splenic tissues occupied by macrophage aggregates (TISSOC). Females and males were plotted separately when analysis-of-variance modeling determined gender was a significant factor. Shown for each group are points representing individual fish and the mean (red horizontal line), median (black horizontal line), interquartile range (box), and the 10th and 90th percentiles (whiskers). Stations are ordered from upstream to downstream and are grouped by sub-basin. See Table 3 for station descriptions.

in all species. The proportion of fish with disease or anomalies, irrespective of species, is used as a health metric in the Index of Biotic Integrity (IBI) (Karr, 1981; Leonard and Orth, 1986) and the EIB, estuarine biotic integrity index (Deegan and others, 1997). A number of recent studies have compared sites using external anomalies of all fish species collected in estuarine and freshwater systems (Fournie and others, 1996; Sanderson and van den Berg, 1999). Numerous studies have correlated the high prevalence of external anomalies with exposure to anthropogenic stressors (Fournie and others, 1996; McCain and others, 1992; Sindermann, 1979). Fin erosion (Cross, 1985; Lindesjoo and Thulin, 1990; Murchelano and Ziskowski, 1982; Reash and Berra, 1989), skin and liver tumors (Baumann and others, 1991; Malins and others, 1988; Vogelbein and others, 1990), and skeletal deformities (Bengtsson, 1979; Bengtsson and others, 1985; Mehrle and others, 1982) are the anomalies most commonly associated with degraded environments. Other lesions including eye anomalies and skin ulcerations have also been suggested to be results of anthropogenic stress (Hargis and Zwerner, 1988). However, most external lesions identified in CRB fish were frayed or hemorrhagic fins which are not necessarily associated with exposure to contaminants.

The overall proportion of fish with external lesions was 0.74 (of a total of 560 fish examined). Leonard and Orth (1986) found that the proportion of fish with abnormalities in small cool water streams was 0.080-0.344 in "degraded" streams and 0-0.01 for streams only mildly affected. In a study of streams in Ohio, proportions ranged from 0.0004-0.081 for DELT (deformities, erosions, lesions, tumors) anomalies (Sanderson and van den Berg, 1999). Background prevalence of gross abnormalities in estuarine fishes was estimated to be 0.5% in the mid-Atlantic and 0.88% in the Louisiana Providence (Fournie and others, 1996). Caution must be exercised when comparing the CRB results with those of other studies and even in comparing stations with in study for a number of reasons. First, errors in proportion of anomalous fish can result from biased or differential examination of fish, species composition, habitat, and other factors unrelated to environmental degradation are widely recognized (Leonard and Orth, 1986). In the present study, this error could be compounded by the fact that multiple individuals from several offices and organizations were involved in assessing external anomalies. A second confounding factor in comparing the results of various studies is the different anomalies that are considered. All external in the IBI fish health metric signs of disease, parasites, and anomalies are considered (Karr, 1981). In contrast, Fournie and others (1996) examined only the eyes, body surface, fins, and branchial chamber, noting discolorations, raised scales, exophthalmia, white or black spots, ulcers, fin erosion, visible tumors and parasites. Sanders and others (1999) noted only deformities of the fins, head, vertebrae, barbels, and opercles including erosion of the fins, opercles, barbels, and lesions (open sores, ulcerations), but not external parasites. Abnormalities of the body surface, eyes, opercles, and fins, including deformities and parasites were evaluated in this 1997 study.

External lesions were identified on 69% of the 134 bass from 12 stations, on 83% of the 157 carp from nine stations, and on 78% of the 160 largescale sucker from nine stations from fish collected from the CRB in 1997. A greater proportion of carp and largescale sucker had external lesions at 12

Table 29. Arithmetic mean of macrophage aggregate area (MEANAREA) by station, number of samples (*n*), minimum (min.), maximum (max.), and standard error (SE) in the target species collected in the Columbia River Basin in 1997. Stations are grouped by taxon and sub-basin and ordered upstream to downstream. The maximum station mean for each taxon is shown in bold. MEANAREA is measured in μm^2.

Taxon and Station	*n*	Mean	Min.	Max.	SE
Bass - female					
Basin total	70	3519	700	9886	220
Upper Columbia River (UCR)					
Creston, MT (117)	9	3995	2144	5323	358
Snake River (SR)					
Hagerman, ID (41)	8	3191	2333	4804	341
Riggins, ID (43)	3	4670	2004	7192	1499
Lewiston, ID (42)	4	3644	744	4850	974
Ice Harbor Dam, ID (96)	4	3067	1009	6300	1138
Middle Columbia River (MCR)					
Vernita Bridge, WA (503)	3	3457	2318	4296	590
Pasco, WA (97)	8	2171	700	4618	437
Granger, WA (44)	9	2872	822	4258	402
Lower Columbia River (LCR)					
Warrendale, OR (502)	1	3880	--	--	--
Oregon City, OR (45)	15	3955	1545	9886	562
Portland, OR (505)	5	**5095**	1675	8735	1458
Bass - male					
Basin total	52	3521	823	10481	276
Upper Columbia River (UCR)					
Creston, MT (117)	8	2584	823	5379	609
Snake River (SR)					
Hagerman, ID (41)	7	3235	1957	5565	449
Riggins, ID (43)	4	3902	1839	6383	1036
Lewiston, ID (42)	6	4713	3127	6306	452
Ice Harbor Dam, WA (96)	3	2246	1783	3157	456
Middle Columbia River (MCR)					
Vernita Bridge, WA (503)	2	3381	3035	3727	346
Pasco, WA (97)	6	2362	851	3460	421
Granger, WA (44)	4	4463	3071	6549	760
Lower Columbia River (LCR)					
Warrendale, OR (502)	3	**4991**	1820	9985	2527
Oregon City, OR (45)	6	4838	2567	10481	1222
Portland, OR (505)	3	2118	1594	3146	514
Carp					
Basin total	153	4057	0	11911	188
Snake River (SR)					
Hagerman, ID (41)	17	2690	0	8895	475
Lewiston, ID (42)	17	3946	1240	10665	564
Ice Harbor Dam, ID (96)	21	4581	1861	10935	482
Middle Columbia River (MCR)					
Vernita Bridge, WA (503)	20	4079	799	8344	485
Pasco, WA (97)	20	3437	1708	5902	303
Granger, WA (44)	20	**5850**	2097	11911	591
Lower Columbia River (LCR)					
Warrendale, OR (502)	20	3788	715	11716	628
Oregon City, OR (45)	14	4021	1236	7866	550
Beaver Army Terminal, OR (501)	4	3074	1763	4116	489

Table 29. Arithmetic mean of macrophage aggregate area (MEANAREA) by station, number of samples (*n*), minimum (min.), maximum (max.), and standard error (SE) in the target species collected in the Columbia River Basin in 1997. Stations are grouped by taxon and sub-basin and ordered upstream to downstream. The maximum station mean for each taxon is shown in bold. MEANAREA is measured in μm^2.—Continued

Taxon and Station	*n*	Mean	Min.	Max.	SE
Largescale sucker					
Basin total	154	3580	716	25066	206
Upper Columbia River (UCR)					
Creston, MT (117)	9	2821	1535	3935	219
Northport, WA (504)	19	3934	1039	7964	448
Grand Coulee, WA (98)	20	3728	1671	7504	382
Snake River (SR)					
Riggins, ID (43)	20	3210	716	8238	391
Lower Columbia River (LCR)					
Cascade Locks, OR (46)	20	4502	2000	25066	1106
Warrendale, OR (502)	3	**4941**	3506	6321	813
Vancouver, WA (506)	20	3004	1431	8778	378
Oregon City, OR (45)	6	4199	1000	8461	1100
Portland, OR (505)	21	3315	820	9660	426
Beaver Army Terminal, OR (501)	16	3289	1237	13868	738

of the 16 stations where bass and carp or largescale sucker were collected. Fournie and others (1996) reported a higher prevalence of external lesions on demersal fishes compared to pelagic fishes from the Gulf of Mexico. These findings were also similar to the finding of Sanders and others (1999), who used external anomalies to characterize biological integrity of seven Ohio streams. Of the 2,624 carp they collected, 28.5% had external anomalies versus only 2.9% of 5,037 bass (largemouth, spotted, and smallmouth). Schmitt and others (2002) found that 28% of bass and 20% of carp collected from the MRB had external lesions. Similar proportions of external lesions were reported in bass (27%) and carp (29%) in the RGB (Schmitt and others, 2004). In the CRB, high proportions of bass with external lesions (>75%) were collected from Station 41 in the SR, Station 44 in the MCR, and Stations 45, 502, 505, and 506 in the LCR. However, at Stations 502 and 506 few bass (n<10) were collected. Carp with high proportion of external lesions (>75%) were collected from Stations 41, 42, and 96 of the SR, Stations 44 and 503 of the MCR, and Stations 45, 501, and 502 of the LCR. Largescale sucker with proportions of external lesions >75% were collected from Station 504 of the UCR and Stations 45, 46, 501, 505, and 506 of the LCR. High percentages of external lesions for bass and carp or largescale sucker were found at Stations 41, 44, 45, 502, 505, and 506. Histopathological examinations of external lesions collected by field personnel are summarized in the Geographical Summary section.

The HAI, which is also an assessment of grossly visible lesions, is more comprehensive than the incidence of external lesions accounting for both external and internal abnormalities. The HAI has been used to assess largemouth bass populations, particularly in the Tennessee Valley Authority (TVA) reservoirs in the Southeast. The mean HAI for all TVA reservoirs was 62, the "healthiest" reservoir average 17, and the worst had a mean of 79 in a survey of 28 reservoirs (Adams and others, 1993). The HAI of largemouth bass from PCB-contaminated Hartwell Reservoir ranged from 42 at the reference site to 64 at an intermediate site, and, 74 at the most contaminated site. Station mean HAI scores for largemouth bass averaged 42 and ranged from 18 at minimally impacted sites to 94 at sites with combined stressors from the Catawba River system influenced by industrial and sewage effluents (Coughlin and others, 1996). Therefore, Coughlan and others (1996) suggested that only bass between 250 and 459 mm (TL) be included, because a positive linear relation between fish weight and HAI score was noted. A number of stations in the CRB had individual bass >450 mm. To our knowledge, this methodology has had limited use with carp and largescale sucker. Common carp from the MRB had individual HAI scores ranging from 0-160, with most sub-basin means having scores <40 (Blazer and others, 2002). Most (72%) carp and bass from the RGB had HAI scores between 0-60 (Schmitt and others, 2004). White sucker from the upper MRB had individual HAI scores ranging from 0-90 (BEST Program, unpublished data). The Bi-State Water Quality Program conducted a fish health study in the lower CRB in 1994 (Tetra Tech Inc., 1996). Largescale sucker had generally low HAI scores ranging from 0-60 for individual fish. HAI scores in individual fish from the lower CRB collected in 1997 ranged from 0-130; station means throughout the basin did not exceed 63. None of the station means were <20 for any of the target species. Only bass from three CRB stations (Stations 41, 44, and 45) exceeded the "worst" HAI station mean of 79 in the TVA study (Adams and others, 1993), and only bass from Station 41 exceeded the highest HAI station mean of 94 in the Catawba study (Coughlan and others, 1996).

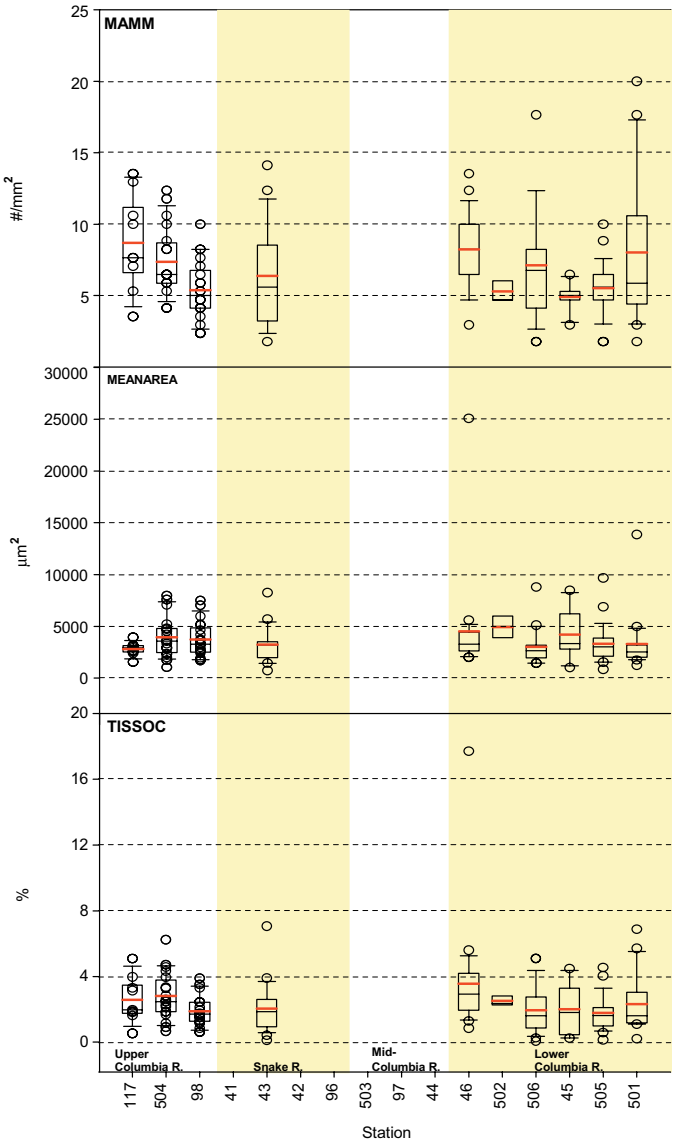


Figure 18. Splenic macrophage aggregate parameters by station in female and male largescale sucker collected in the Columbia River Basin in 1997. Parameters include macrophage aggregate density (MAMM), macrophage aggregate area (MEANAREA), and percent of splenic tissues occupied by macrophage aggregates (TISSOC). Females and males were plotted separately when analysis-of-variance modeling determined gender was a significant factor. Shown for each group are points representing individual fish and the mean (red horizontal line), median (black horizontal line), interquartile range (box), and the 10th and 90th percentiles (whiskers). Stations are ordered from upstream to downstream and are grouped by sub-basin. See Table 3 for station descriptions.

Condition factor may indicate changes at the organism level and is directly affected by nutrition (Tyler and Dunn, 1976), and also by season, sexual maturation, and disease (Adams and others; Denton and Yousef, 1976; 1982; Möller, 1985). Exposure to contaminants such as pulp mill effluent has been linked to elevated CF (Adams and others, 1992; McMaster and others, 1991), whereas diminished CF had been observed after exposure to contaminants such as metals and petroleum (Kiceniuk and Khan, 1987; Miller and others, 1992; Munkittrick and Dixon, 1988). Condition factor can also vary among locations within a species (Doyon and others, 1988; Fisher and others, 1996). A review by Carlander (1969) determined mean CF to range from 1.2 to >2.0 in the U.S. A similar review of largemouth and smallmouth bass found mean CFs of 1.1-1.9 and 1.2-1.9, respectively (Carlander, 1977). Mean CF for bass had greater ranges (1.3-2.1 for females and 1.3-1.8 for males) than other species. Bass with CF >2.0 were found at Stations 97, 117, and 502; CF of <1.0 in individual fish were found in males at Stations 43, 97, and 117. The range of CF station means for carp in the CRB was 1.1-1.4. Individual fish with CFs <1.0 were found in the MCR at Stations 96, 97, and 503; no station was notable for low CF in carp. Largescale sucker had the lowest CF ranging from 0.9-1.2. Individual largescale sucker from Station 505 had the three lowest CF calculated.

The HSI may vary with season (Beamish and others, 1996; Delahunty and de Vlaming, 1980), temperature (Fine and others, 1996), and nutrition (Daniels and Robinson, 1986; Foster and others, 1993) as well as gender and changes in gonadal status (Fabacher and Baumann, 1985; Förlin and Haux, 1990; Grady and others, 1992). It is also the organosomatic index for which changes are most often associated with contaminant exposure (Adams and McLean, 1985). Increased HSI had been reported with exposure of feral fish to organic contaminants, most often PAHs and PCBs, whereas laboratory exposures of fish to metals, crude oil, certain pesticides, and bleached kraft mill effluent have resulted in HSI decreases (Schmitt and Dethloff, 2000). However, two studies found HSI increased in largemouth bass after exposure to bleached/unbleached kraft mill effluents (Sepúlveda and others, 2001, 2003). A comparative range for normal liver weight in fish is 1-3% of body weight, with relative weights >2% being uncommon (Gingerich, 1982). In the CRB, only bass were included in HSI calculations due to the diffuse nature of carp and sucker livers. For female bass, station means ranged from 1.0-2.3% with Stations 45 (in the Willamette River of the LCR) and 503 (in the MCR) having several individuals with HSI >2.0%.

The SSI is measured to determine changes in the relative size of the spleen, a primary hematopoietic organ in fish. The SSI can differ among species, gender, and location and can change over age, size, gonadal development, and season (Krykhtin, 1976; Ruklov, 1979; White and Fletcher, 1985). Studies have also documented changes in relative spleen size with exposure to chemical contaminants. Decreased SSI had been reported in fish exposed to organic contaminants alone or in combination with metals, but increased SSI has rarely been documented with contaminant exposure (Schmitt and Dethloff, 2000). An increase in SSI is considered indicative of disease or immune problems (Goede and Barton, 1990). Capture and holding stress have been reported to alter SSI and HSI in field

Table 30. Arithmetic mean of percent of splenic tissue occupied by macrophage aggregates (TISSOC) by station, number of samples (*n*), minimum (min.), maximum (max.), and standard error (SE) in the target species collected in the Columbia River Basin in 1997. Stations are grouped by taxon and sub-basin and ordered upstream to downstream. The maximum station mean for each taxon is shown in bold. TISSOC is measured as a %.

Taxon and Station	*n*	Mean	Min.	Max.	SE
Bass					
Basin total	124	2.40	0.08	9.73	0.18
Upper Columbia River (UCR)					
Creston, MT (117)	18	1.10	0.20	9.06	0.52
Snake River (SR)					
Hagerman, ID (41)	15	2.51	0.55	5.32	0.37
Riggins, ID (43)	7	**4.00**	0.97	9.73	1.11
Lewiston, ID (42)	11	3.55	0.09	6.12	0.64
Ice Harbor Dam, WA (96)	7	2.17	0.71	5.56	0.64
Middle Columbia River (MCR)					
Vernita Bridge, WA (503)	4	3.06	2.19	3.98	0.41
Pasco, WA (97)	14	1.09	0.08	3.97	0.37
Granger, WA (44)	13	2.00	0.18	4.74	0.39
Lower Columbia River (LCR)					
Warrendale, OR (502)	4	2.31	0.56	5.28	1.11
Oregon City, OR (45)	22	2.49	0.42	7.40	0.43
Portland, OR (505)	8	2.18	0.28	6.68	0.98
Carp					
Basin total	153	2.73	0.00	11.21	0.16
Snake River (SR)					
Hagerman, ID (41)	17	0.94	0.00	4.71	0.26
Lewiston, ID (42)	17	3.58	1.12	6.90	0.37
Ice Harbor Dam, ID (96)	21	3.10	0.88	6.29	0.33
Middle Columbia River (MCR)					
Vernita Bridge, WA (503)	20	3.00	0.07	7.53	0.48
Pasco, WA (97)	20	2.32	0.54	5.08	0.26
Granger, WA (44)	20	**4.65**	1.04	11.21	0.61
Lower Columbia River (LCR)					
Warrendale, OR (502)	20	1.92	0.34	5.13	0.32
Oregon City, OR (45)	14	2.08	0.66	4.75	0.30
Beaver Army Terminal, OR (501)	4	2.05	0.41	3.81	0.72
Largescale sucker					
Basin total	156	2.35	0.06	17.70	0.15
Upper Columbia River (UCR)					
Creston, MT (117)	9	2.60	0.54	5.09	0.47
Northport, WA (504)	19	2.82	0.67	6.23	0.33
Grand Coulee, WA (98)	20	1.90	0.62	3.90	0.20
Snake River (SR)					
Riggins, ID (43)	20	2.06	0.13	7.06	0.35
Lower Columbia River (LCR)					
Cascade Locks, OR (46)	21	**3.57**	0.86	17.70	0.76
Warrendale, OR (502)	3	2.53	2.27	2.97	0.22
Vancouver, WA (506)	20	1.95	0.06	5.10	0.33
Oregon City, OR (45)	6	2.02	0.25	4.48	0.67
Portland, OR (505)	22	1.81	0.14	4.54	0.23
Beaver Army Terminal, OR (501)	16	2.34	0.22	6.88	0.45

studies (Schmitt and Dethloff, 2000).

Stations in the CRB are described as having high or low SSI relative to one another because "normal" ranges are not available for bass, carp, or largescale sucker. For bass, SSI ranged from 0.1-0.3% with Stations 96, 503, and 506 having the lowest stations means. Stations 42, 502, and 505 had the highest mean SSI for bass. Three individual bass from Stations 42 and 505 had SSI values >0.6%. There were multiple bass with low SSI values at multiple stations. For carp, mean station SSI ranged from 0.2-0.4% in females and 0.2-0.5% in males. Low SSI station means in female carp and low individual SSI values occurred in both female and male carp from Station 42 in the SR. The greatest SSI values (>0.5%) in carp occurred in the LCR at multiple stations (Stations 45, 501, 502). SSI in largescale sucker ranged from 0.2-0.4%. Individual fish from stations in the UCR had SSI values >0.5%, whereas fish from the LCR had SSI values <0.1%.

Laboratory investigations and field studies in which fish were collected from specific contaminated sites have generally indicated increases in MA parameters relative to reference sites or groups (Blazer and others, 1994; 1997; Wolke, 1992). MA parameters have been used as bioindicators in other programs such as the USEPA's Environmental Monitoring and Assessment Program (EMAP) of estuaries (Fournie and others, 2001; Summers and others, 1993) and National Oceanic and Atmospheric Administration (NOAA) Status and Trends programs (Chang and others, 1998). Some studies have used splenic MAs whereas others have utilized hepatic MAs. Most of these studies have been performed in marine or estuarine environments. Most previous studies have only evaluated MA density, and even for this parameter, regional baseline information does not exist to establish a "normal" value for any species. To our knowledge, there have not been any studies evaluating carp, bass, or largescale sucker MA and potential effects of contaminant exposure. One study did report an increase in MA in largemouth bass exposed to thermal effluent from a nuclear power plant (Blazer and others, 1987). Numerous studies have reported factors that can affect MAs in other species. The factors include size, nutritional status (Agius, 1979; 1980; Agius and Roberts, 1981; Wolke and others, 1985), age (Blazer and others, 1987; Brown and George, 1985; Couillard and Hodson, 1996), and exposure time (many as reported in Schmitt and Dethloff, 2000).

MA parameters were also evaluated in the CRB in 1997. Station means for MA density in the CRB were 4.1-9.5 MA/mm^2 in bass, 3.0-10.2 MA/mm^2 in carp, and 4.9-8.5 MA/mm^2 in largescale sucker. Statistical analyses of the data suggested there was not a consistent relationship between age and MA density in the target species from the CRB. Fournie and others (2001) suggested than splenic MA densities of >40 MA/mm^2 in at least one fish from a site were correlated with hypoxic stress or high levels of sediment contamination using data collected in the EMAP-Estuaries program for a variety of estuarine fishes and irrespective of age. There is insufficient data to know if this is a reasonable reference number for freshwater fishes or how MA may be correlated with body burdens of various contaminants. However, fish collected from the CRB did not exceed 40 MA/mm^2. Only Station 42 in the SR had an individual carp with >20 MA/mm^2; all individual bass and largescale sucker were <20 MA/mm^2.

Reproductive Biomarkers

Gonadal Histopathology

Gonadal histopathology and gonadosomatic index (GSI) are reproductive indicators that provide structural information about gonadal health and maturational stage. Gonadal histopathology can be affected by season, age, gender, and pollutants (Schmitt and Dethloff, 2000). Reproductive biomarkers were evaluated relative to the stage of gonad development of fish from the CRB. The gender and developmental stage of bass and carp influenced the reproductive biomarkers (Table 20). Therefore, the data for male and female bass and carp were examined separately, so as not to confound the potential effects other variables may have on the reproductive biomarkers with the effects caused by gender and stage of gonad development. Due to the relatively small size of the data set, statistical methods (for example, log transformations) were not used to adjust station means for stage although stage was found to be an important variable for determining GSI and vtg for certain species. Instead, patterns or trends are discussed in the data in relation to fish reproductive stage at each station. Stages of reproductive development are described in Figures 19 and 20.

Female Bass

Examining the stage of gonad development is critical for the interpretation of reproductive biomarkers. Female bass were in stages 0-3 with the majority (55%) identified as stage 1 (Fig. 21). Stage-2 and -3 ovaries represented 22% and 18%, respectively, of female bass collected, while 4% of female bass were identified as stage 0. Fish in stage 0 were present at Stations 42, 44, and 97 (Fig. 22). Females in stage 1 were found at all stations where bass were collected with the exception of Station 506; stage-2 and stage-3 females were each collected from five stations. Stage distributions differed among stations (Fig. 22).

GSI was greatest (2.9%) in female bass at Station 45, ranging from 0.5-7.2% (Table 31), and other station means were <2.4%. Only Station 45 had fish with GSI >4% (Fig. 23). Female bass GSI did not vary significantly among stations although GSI and stage had a significant correlation (Table 20). Stage-3 female bass had the greatest GSI values. GSI station means in female bass were <2% in the MRB (McDonald and others, 2002) and 0.6-0.9% in the RGB (Schmitt and others, 2004). Other laboratory studies deter-

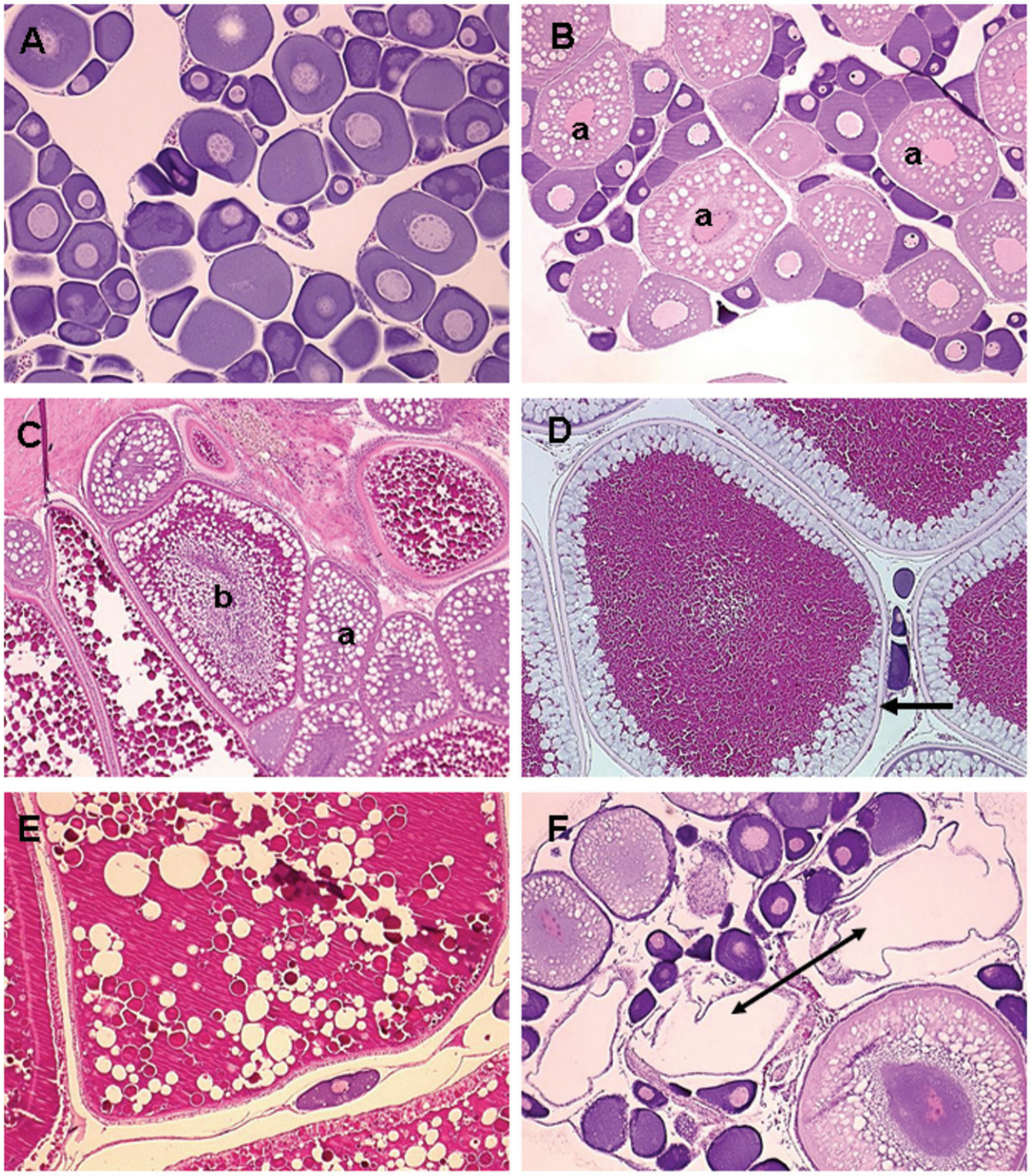


Figure 19. Gonadal stages in female fish species. A. Stage-1 (immature) ovary containing only previtellogenic oocytes. B. Stage-2 (early vitellogenic) containing cortical alveolar (a) and previtellogenic oocytes. C. Early stage-3 ovary containing cortical alveolar (a) and more advanced oocytes (b). Yolk vacuoles are being pushed to the periphery, and yolk globules are filling the central portion of the oocyte. D. Late stage-3 ovary with enlarged oocytes. A thin layer of yolk vacuoles line the periphery, yolk globules fill the cytoplasm, and the chorion (arrow) is thickened. E. Stage-4 (late vitellogenic) ovary containing enlarged oocytes and condensed yolk globules. F. Stage-5 (spent) ovary containing post-ovulatory follicles (shown at the ends of the arrow). H&E stain (X 165).

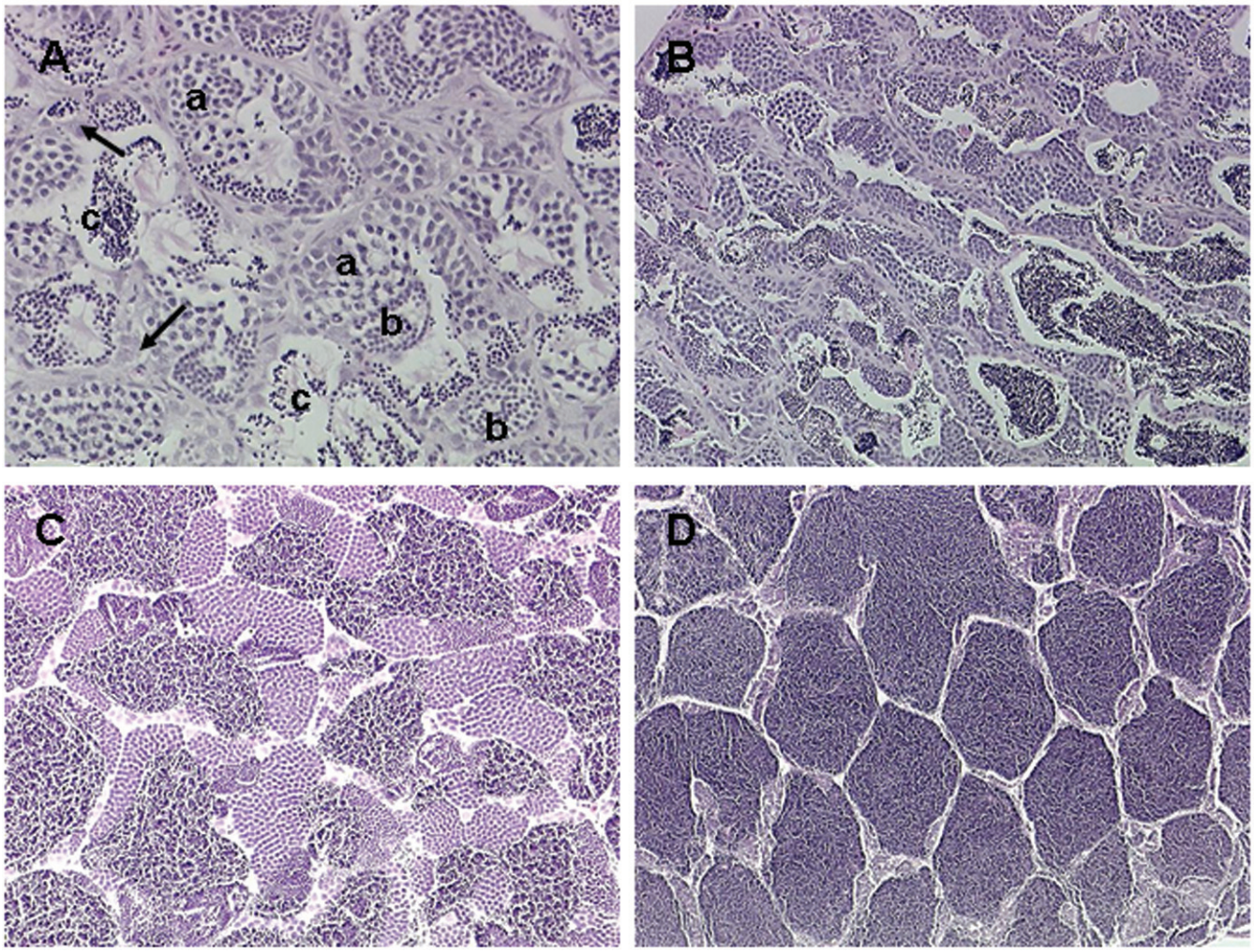


Figure 20. Gonadal stages in male fish species. A. Stage-1 (early spermatogenic) testes can contain all stages of spermatogenesis, spermatogonia (arrows), spermatocytes (a), spermatids (b) and spermatozoa (c). H&E stain (X 824). B. Stage-1 testes in which spermatocytes and spermatids predominate. H&E (X 412). C. Stage-2 (mid-spermatogenic) testes containing approximately equal numbers of spermatocytes, spermatids and spermatozoa. H&E (X 412). D. Stage-3 (late spermatogenic) testes containing primarily mature spermatozoa. H&E (X 412).

mined GSI in female largemouth bass to range from 2.7-4.0% (Sepúlveda and others, 2001; 2003).

The gender and developmental stage of bass influenced concentrations of vtg (Table 20), resulting in females and males being examined separately. Mean vtg in female bass was greatest (14.2 mg/mL) at Station 503, ranging from 12.1-17.7 mg/mL (Table 32). Station 503 consistently had female bass with greater concentrations of vtg. Other station means for female bass ranged from 0.1-7.0 mg/mL, and concentrations of vtg did not vary significantly among stations. Most female bass (75%) had concentrations of vtg between 0.2-3.0 mg/mL (Fig. 23) which were similar to concentrations of vtg found by several other studies (Schmitt and others, 2004; Sepúlveda and others, 2001; 2003). Female bass from Stations 43, 44, 45, 96, 97, and 503 had concentrations of vtg >10.0 mg/mL, although a stage pattern was not apparent for these fish. In general, stage-2 and-3 fish tended to have greater concentrations of vtg than stage-0 and -1. McDonald and others (2002) determined similar stage patterns and concentrations of vtg in female bass from the MRB. Collection date did not appear to influence concentrations of vtg, since low concentrations of vtg were collected on the same date as high concentrations from female bass at the same station.

Mean percent atresia in bass was similar among stations in the CRB. Mean percent atresia was greatest (12%) in female bass at Station 502 (n=1) (Table 33), and all other station means were <7.1%. With the exception of one individual fish from Station 41, all values were <15% (Fig. 23). Overall, station means did not significantly differ for percent atresia, but female bass at Stations 41, 502, and 505 generally had higher values (Fig. 23). Atresia station means in bass ranged from approximately 0-6% in the MRB (McDonald and others,

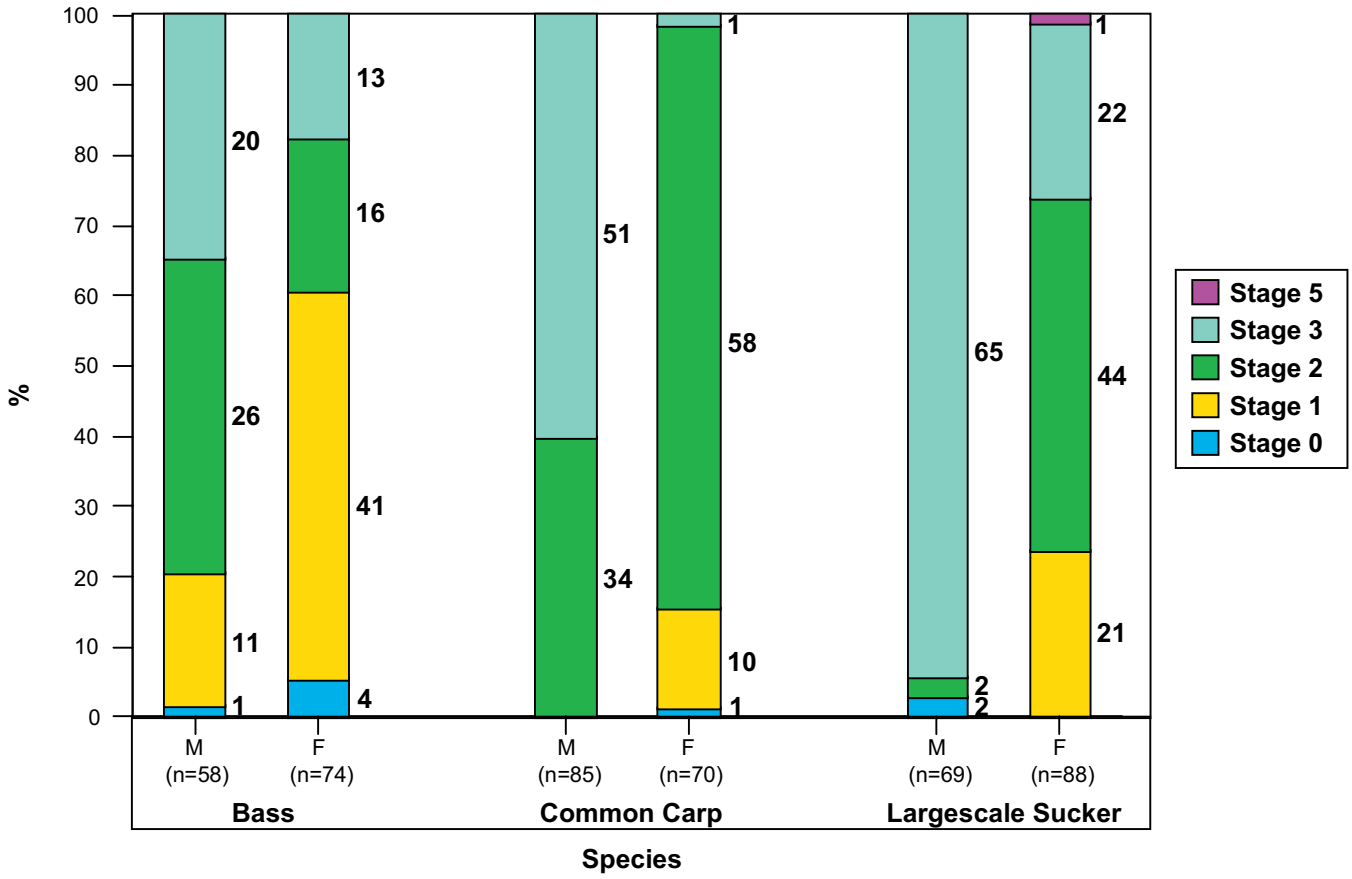


Figure 21. Gonadal stage proportions by taxon and gender in bass, carp, and largescale sucker collected in the Columbia River Basin in 1997. Sample sizes for each stage and gender by taxon are located next to the boxes within the figure.

2002) and 0-30% in the RGB (Schmitt and others, 2004), and a reference station from the MRB had a mean percent atresia of about 3%. Fish from Stations 41, 42, 502, 503, and 505 had mean percent atresia >3%.

Male Bass

Developmental stage of gonads in male bass differed among stations, similar to female bass (Table 20). Male bass were in stages 0-3, and stage-2 testes represented the gonadal stage 45% of male bass collected (Fig. 21). No single stage was present at all stations where male bass were collected, while stage-2 fishes were present at all stations with the exceptions of Stations 502 and 503 (Fig. 23).

Intersex gonads were seen only in male bass in the CRB. Five (smallmouth bass) of 56 male bass had evidence of an ovotestes. Three of seven male bass collected from Station 42 had ovotestis in stage 0, 1, and 2. Two of three male bass from Station 502 had ovotestis in stage 3. Therefore, a relatively high percentage of male bass from these two stations had ovotestes. Other endpoints were examined to investigate possible correlations to these ovotestes males. Age or size relationship was not found at either station. However, ovotestes males from Station 42 had the greatest HSI, GSI, and MA parameters from that station, and ovotestes males from Station 502 had the greatest HSI and MEANAREA from that station. Male bass from Station 42 had high concentrations of PCBs and had the greatest concentration of *trans*-nonachlor for combined composite samples while male bass from Station 502 had high concentrations of As. The only male at Station 42 with a detectable vtg concentration (0.011 mg/mL) was identified as ovotestes and had the greatest HSI (1.57%) of all male bass from that station.

GSI in male bass were similar among CRB stations. GSI in male bass was greatest (0.9%) at Stations 96 and 505 (Table 31), while other station means ranged from 0.2-0.8%. Only Stations 96 and 97 had fish with GSI >1.0% (Fig. 23). Male bass GSI did not vary significantly among stations (Table 20), and GSI and stage were not correlated. GSI station means in male bass ranged from approximately 0.1-0.7% in the MRB (McDonald and others, 2002) and 0.2-0.4% in the RGB (Schmitt and others, 2004). GSI in male largemouth bass from two laboratory studies ranged from <0.5-0.95% (Sepúlveda and others, 2001; 2003).

Concentrations of vtg were also measured in male bass. Most male bass (90%) had concentrations of vtg <LOD (0.002 mg/mL) (Fig. 23). Stations 42, 43, 96, 97, and 117 each

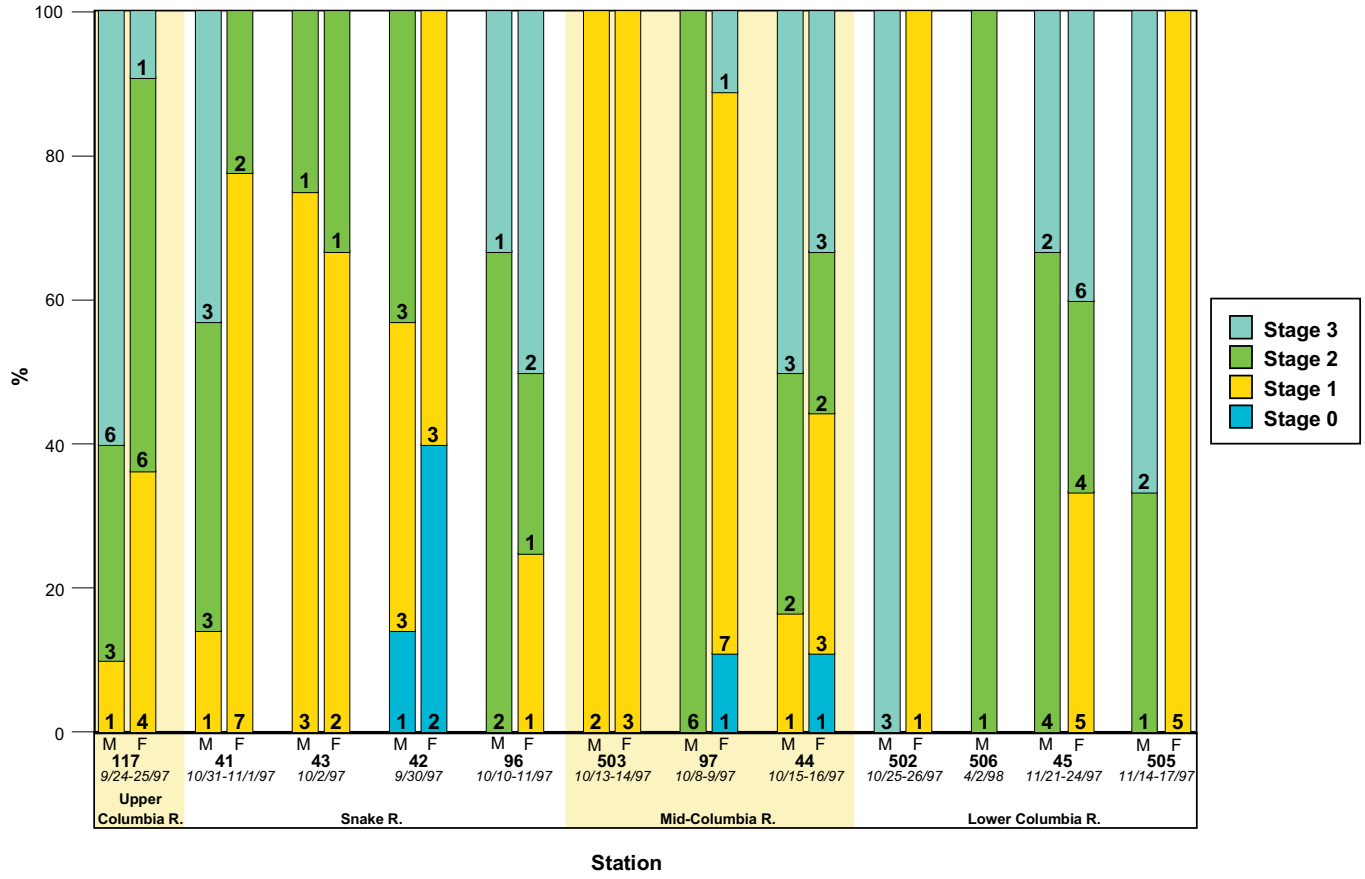


Figure 22. Gonadal stage proportions by station in female and male bass (*Micropterus* sp.) collected in the Columbia River Basin in 1997. Station sample sizes for each stage are located in the boxes within the figure. The collection dates for each station are located below the station number. Stations are ordered from upstream to downstream and are grouped by sub-basin. See Table 3 for station descriptions.

had one male bass with concentrations of vtg >0.01 mg/mL. Concentrations >0.01 mg/mL indicate an estrogenic response in these male bass, but should not be considered a general problem at any of these stations since these concentrations were limited to individual fish. The maximum concentration of vtg in male bass was 0.67 mg/mL at Station 97, a concentration indicative of exposure to endocrine disruption (Fig. 23). These data are similar to concentrations found in male bass from the MRB (McDonald and others, 2002) and RGB (Schmitt and others, 2004). Several laboratory studies determined male largemouth bass concentrations of vtg to range from <LOD (0.001 mg/mL) to 0.32 mg/mL (Sepúlveda and others, 2001; 2003).

Two bass with no preserved gonad were collected from Stations 42 and 45; concentrations of vtg were 0.04 mg/mL and <LOD (0.002 mg/mL), respectively.

Female Carp

Reproductive stage of gonads in female carp differed among stations (Table 20). Most female carp (83%) were identified as stage 2. Stage-0 and -3 each represented 1.5%, and stage-1 ovaries represented 14% (Fig. 21). Females in stage 2 were found at all stations where carp were collected (Fig. 24). Stage-0 females were collected from Station 41, stage-1 females were collected from Stations 41, 44, and 503, and stage-3 females were collected from Stations 501 and 502.

GSI in female carp varied among stations in the CRB. GSI was greatest (14.4%) in female carp at Station 502, ranging from 8.2-20.5% (Table 31). Other station means were >10.0% for female carp with the exception of Station 41. Stations 44, 45, 502 and 503 had fish with GSI >16%, but the majority (86%) of female carp had a GSI <15% (Fig. 25). GSI in female carp varied significantly among stations with an increasing trend upstream to downstream (Fig. 25; Table 20). GSI station means in female carp ranged from approximately 1-18% in the MRB (McDonald and others, 2002) and 5-20% in the RGB (Schmitt and others, 2004).

The gender and developmental stage of carp influenced concentrations of vtg (Table 20), resulting in females and males being examined separately. Mean vtg in female carp was greatest (3.9 mg/mL) at Station 42, ranging from 1.4-7.4 mg/mL (Table 32). All other station means for female carp were <2.2 mg/mL. Most the female carp (86%) had concen-

Table 31. Arithmetic mean of gonadosomatic index (GSI; %) by station, number of samples (*n*), minimum (min.) maximum (max.), and standard error (SE) in the target species collected in the Columbia River Basin in 1997. Stations are grouped by taxon and sub-basin and ordered upstream to downstream. The maximum station mean for each taxon is shown in bold.

Taxon and Station	Female					Male				
	n	Mean	Min.	Max.	SE	*n*	Mean	Min.	Max.	SE
Bass										
Basin total	74	1.7	0.0	7.2	0.2	60	0.46	0.0	1.7	0.0
Upper Columbia River (UCR)										
Creston, MT (117)	11	1.3	0.7	2.3	0.1	10	0.25	0.2	0.4	0.0
Snake River (SR)										
Hagerman, ID (41)	9	1.5	0.2	2.0	0.2	7	0.38	0.2	0.5	0.0
Riggins, ID (43)	3	1.4	1.2	1.6	0.1	4	0.52	0.3	0.9	0.1
Lewiston, ID (42)	5	0.5	0.0	0.9	0.2	7	0.49	0.0	0.7	0.1
Ice Harbor Dam, WA (96)	4	1.9	0.7	3.1	0.6	3	0.91	0.4	1.7	0.4
Middle Columbia River (MCR)										
Vernita Bridge, WA (503)	3	2.1	1.7	2.6	0.3	2	0.85	0.8	0.9	0.0
Pasco, WA (97)	9	1.2	0.4	3.3	0.3	6	0.38	0.0	1.6	0.2
Granger, WA (44)	9	1.5	0.5	2.4	0.2	6	0.55	0.2	0.9	0.1
Lower Columbia River (LCR)										
Warrendale, OR (502)	1	2.4	--	--		3	0.83	0.6	1.0	0.1
Vancouver, WA (506)	0	--	--	--	--	1	**0.95**	--	--	
Oregon City, OR (45)	15	**2.9**	0.5	7.2	0.6	6	0.32	0.2	0.5	0.0
Portland, OR (505)	5	1.4	1.1	1.9	0.1	3	0.26	0.3	0.3	0.0
Carp										
Basin total	70	10.3	0.6	20.5	0.6	87	5.8	0.0	11.0	0.2
Snake River (SR)										
Hagerman, ID (41)	10	2.1	0.6	4.9	0.5	10	4.1	2.8	6.2	0.4
Lewiston, ID (42)	5	10.8	5.9	13.2	1.3	12	4.4	0.0	6.0	0.5
Ice Harbor Dam, ID (96)	10	10.0	4.5	15.2	1.2	11	6.2	4.8	8.2	0.3
Middle Columbia River (MCR)										
Vernita Bridge, WA (503)	10	10.8	3.5	19.5	1.5	11	4.8	1.1	8.8	0.8
Pasco, WA (97)	11	10.1	5.6	13.3	0.7	9	5.2	3.3	7.9	0.5
Granger, WA (44)	10	12.9	8.0	17.7	1.0	10	6.9	3.7	11.0	0.6
Lower Columbia River (LCR)										
Warrendale, OR (502)	10	**14.4**	8.2	20.5	1.2	10	**7.9**	5.4	10.1	0.5
Oregon City, OR (45)	4	14.3	12.1	16.9	1.2	10	6.4	4.8	7.8	0.3
Beaver Army Terminal, OR (501)	0	--	--	--	--	4	7.2	6.1	8.4	0.6
Largescale sucker										
Basin total	88	4.4	0.3	13.4	0.3	70	4.6	0.0	8.3	0.2
Upper Columbia River (UCR)										
Creston, MT (117)	4	4.8	3.6	7.0	0.8	6	3.4	0.0	5.6	1.0
Northport, WA (504)	10	4.3	1.9	5.9	0.3	9	5.2	3.6	6.9	0.4
Grand Coulee, WA (98)	10	2.6	1.1	4.2	0.2	10	4.4	3.5	5.7	0.3
Snake River (SR)										
Riggins, ID (43)	11	2.0	0.3	2.8	0.2	9	4.1	2.9	6.0	0.3
Lower Columbia River (LCR)										
Cascade Locks, OR (46)	11	4.1	2.6	6.2	0.3	9	5.4	4.2	8.0	0.4
Warrendale, OR (502)	3	3.6	2.4	4.2	0.6	0	--	--	--	--
Vancouver, WA (506)	11	6.4	0.5	13.4	1.2	10	4.8	3.9	6.2	0.3
Oregon City, OR (45)	6	3.4	1.9	4.5	0.4	0	--	--	--	--
Portland, OR (505)	11	4.3	3.2	5.5	0.3	10	4.6	3.2	5.7	0.3
Beaver Army Terminal, OR (501)	11	**7.6**	0.9	13.1	1.1	5	**5.7**	4.1	8.3	0.7

trations of vtg between 0.1-3.0 mg/mL (Fig. 25). Only four female carp had concentrations of vtg >3.0 mg/mL, and three of these fish were from Station 42. Vitellogenin did not vary significantly among stations although developmental stage influenced concentrations of vtg in carp (Table 20). The greatest concentrations of fish vtg were found in stage-2 female carp; stage-0, -1, and -3 fish had lower concentrations of vtg although samples were limited to a few individual fish in these stages. A stage-0 female carp (Station 41) and a stage-3 female (Station 502) had concentrations of vtg of 0.01 mg/mL and 0.12 mg/mL, respectively. In another study, female carp from the MRB had mean station concentrations of vtg as great as 2.9 mg/mL (McDonald and others, 2002). Schmitt and others (2004) reported female carp to have station mean concentrations of vtg of approximately 1-25 mg/mL in the RGB. Collection date did not appear to influence concentrations of

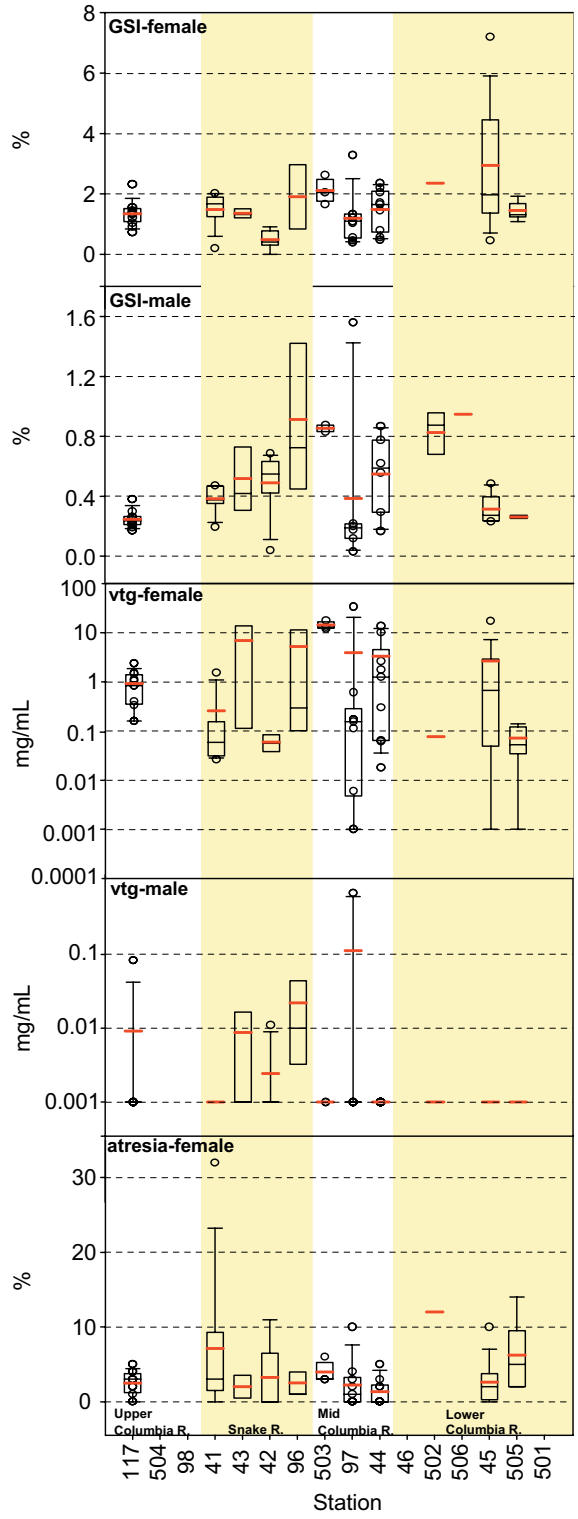


Figure 23. Reproductive health indicators by station in female and male bass (*Micropterus* sp.) collected in the Columbia River Basin in 1997. Indicators include gonadosomatic index (GSI), vitellogenin (vtg), and atresia. Shown for each group are points representing individual fish and the mean (red horizontal line), median (black horizontal line), interquartile range (box), and the 10th and 90th percentiles (whiskers). Stations are ordered from upstream to downstream and are grouped by sub-basin. See Table 3 for station descriptions.

vtg in 1997, since low concentrations of vtg were collected on the same date as high concentrations in female carp from the same station.

Mean percent atresia in carp was similar among CRB stations. Mean percent atresia was greatest (17.6%) in female carp at Station 42, ranging from 3-27% (Table 33). All other station means ranged from 0.2% at Station 41 to 10.9% at Station 96. Stations 42, 96, 97, and 503 had fish with percent atresia >20% although most carp had <20% of eggs that were atretic (Fig. 25). These data did not support a difference in percent atresia among stations for female carp (Table 20). However, a trend of decreasing percent atresia was apparent (Fig. 25). Percent atresia station means in carp from the MRB ranged from approximately 0-25%, and a reference station from the study had <5% mean atresia (Schmitt and others, 2002). Female carp in the RGB had 1-13% atresia (Schmitt and others, 2004). Female carp at Stations 42, 44, 96, 97, and 503 had mean atresia >5% (Table 33).

Male Carp

Two male carp, one from Station 502 and one from Station 503, had histologically identified abnormalities. The abnormal carp tissue from Station 503 was a tumor of multiple cell origin with a leiomyoma, a tumor of smooth muscle, and a seminoma, tumor of germ cell origin. The abnormal carp tissue from Station 502 was a proliferation of fibrous tissue and inflammation.

All male carp were identified as stage 2 (40%) and stage 3 (60%) (Fig. 21). Most male carp from Stations 41, 42, 96, 97, and 503 were stage 2; whereas, fish at Stations 44 and 501 were mostly identified as stage 3 (Fig. 24). All males at Stations 45 and 502 were identified as stage 3.

GSI in male bass varied among CRB stations. GSI was greatest (7.9%) in male carp at Station 502, ranging from 5.4-10.1% (Table 31). Other station means ranged from 4.1-7.2%. Stations 44 and 502 had fish with GSI >9% (Fig. 25). Most (91%) of the male carp had a GSI of 2.5-9.0%. GSI in male carp varied significantly among stations with an increasing trend moving upstream to downstream (Fig. 25; Table 20). GSI station means in male carp ranged from approximately 2-12% in the MRB (McDonald and others, 2002) and 1-13% in the RGB (Schmitt and others, 2004).

Most (87%) male carp had concentrations of vtg <LOD (0.005 mg/mL). All of the detected concentrations of vtg were measured in stage-3 males except in two fish; a stage-2 male at Station 503 (0.02 mg/mL) and a male that could not be staged (no normal gonadal tissue collected) at Station 502 (0.01 mg/mL). Concentrations of vtg in male carp from Stations 45, 96, 502, and 503 were 0.01-0.04 mg/mL (Table 32; Fig. 25). Concentrations of vtg in individual fish from Stations 45, 502, and 503 were >0.01 mg/mL (Table 32), which indicates an estrogenic response in these fish. Most mean station concentrations of vtg in male carp were also near LOD (0.001 mg/mL) in the MRB (McDonald and others, 2002) and RGB (Schmitt and

Table 32. Arithmetic mean of vitellogenin (vtg; mg/mL) by station, number of samples (*n*), minimum (min.), maximum (max.), and standard error (SE) in fish collected in the Columbia River Basin in 1997. Censored values were represented by one half the LOD in the computation of means. The percent of males that had detectable concentrations of vtg are also presented. Stations are grouped by taxon and sub-basin and ordered upstream to downstream. Samples for which gonads were unavailable were not included in this table. The maximum station mean for each taxon is shown in bold.

Taxon and Station	Female					Male					
	n	Mean	Min.	Max.	SE	*n*	%	Mean	Min.	Max.	SE
Bass											
Basin total	69	2.70	0.00	33.67	0.71	58	9	0.016	0.001	0.669	0.012
Upper Columbia River (UCR)											
Creston, MT (117)	11	0.93	0.16	2.36	0.20	10	10	0.008	0.001	0.083	0.008
Snake River (SR)											
Hagerman, ID (41)	9	0.25	0.03	1.54	0.17	7	0	0.001	0.001	0.001	--
Riggins, ID (43)	2	6.95	0.11	13.79	6.84	4	25	0.008	0.001	0.032	0.008
Lewiston, ID (42)	3	0.06	0.03	0.09	0.02	7	14	0.002	0.001	0.011	0.002
Ice Harbor Dam, WA (96)	3	5.16	0.04	15.15	5.00	3	33	0.022	0.001	0.055	0.017
Middle Columbia River (MCR)											
Vernita Bridge, WA (503)	3	**14.29**	12.13	17.67	1.71	2	0	0.001	0.001	0.001	--
Pasco, WA (97)	9	3.88	0.00	33.67	3.72	6	17	**0.112**	0.001	0.669	0.112
Granger, WA (44)	9	3.32	0.02	13.63	1.67	6	0	0.001	0.001	0.001	--
Lower Columbia River (LCR)											
Warrendale, OR (502)	1	0.08	--	--	--	2	0	0.001	0.001	0.001	--
Oregon City, OR (45)	14	2.60	0.001	17.41	1.25	6	0	0.001	0.001	0.001	--
Portland, OR (505)	5	0.07	0.001	0.14	0.03	3	0	0.001	0.001	0.001	--
Carp											
Basin total	70	1.57	0.003	7.37	0.15	83	12	0.002	0.003	0.037	0.001
Snake River (SR)											
Hagerman, ID (41)	10	0.70	0.01	2.81	0.30	10	0	0.003	0.003	0.003	--
Lewiston, ID (42)	5	**3.94**	1.44	7.37	1.04	12	0	0.003	0.003	0.003	--
Ice Harbor Dam, ID (96)	10	2.14	1.46	3.11	0.21	11	9	0.001	0.003	0.009	0.001
Middle Columbia River (MCR)											
Vernita Bridge, WA (503)	10	1.38	0.13	2.33	0.24	11	27	0.006	0.003	0.037	0.004
Pasco, WA (97)	11	2.20	1.36	2.99	0.16	9	0	0.003	0.003	0.003	--
Granger, WA (44)	10	1.84	0.54	2.89	0.23	10	0	0.003	0.003	0.003	--
Lower Columbia River (LCR)											
Warrendale, OR (502)	10	0.36	0.003	1.00	0.10	10	60	**0.008**	0.003	0.035	0.003
Oregon City, OR (45)	4	0.48	0.07	0.99	0.23	10	10	0.001	0.003	0.010	0.001
Largescale sucker											
Basin total	66	38.78	0.09	166.4	4.09	55	9	0.0163	0.0003	0.469	0.010
Upper Columbia River (UCR)											
Creston, MT (117)	4	43.05	0.09	80.80	16.62	6	16	**0.052**	0.0003	0.306	0.051
Northport, WA (504)	10	55.72	27.19	119.1	8.00	9	0	0.0003	0.0003	0.0003	0.000
Grand Coulee, WA (98)	10	14.06	0.10	46.71	5.32	10	20	0.049	0.0003	0.469	0.047
Snake River (SR)											
Riggins, ID (43)	11	31.52	3.55	63.82	6.36	9	0	0.0003	0.0003	0.0003	0.000
Lower Columbia River (LCR)											
Cascade Locks, OR (46)	11	62.82	0.38	128.8	10.27	9	11	0.003	0.0003	0.021	0.002
Warrendale, OR (502)	3	20.25	4.41	34.66	8.76	0	--	--	--	--	--
Oregon City, OR (45)	6	**66.46**	1.26	166.4	22.98	0	--	--	--	--	--
Portland, OR (505)	11	17.46	0.61	31.94	3.14	10	10	0.007	0.0003	0.066	0.007
Longnose sucker											
Upper Columbia River (UCR)											
Creston, MT (117)	10	**16.9**	0.00	63.57	7.51	1	100	**0.006**	--	--	--
Grand Coulee, WA (98)	1	4.06	--	--	--	1	10	0.0003	--	--	--

others, 2004). Villeneuve and others (2002) determined male carp to have concentrations of vtg <0.002 mg/mL in a laboratory study. As in female carp, vtg in male carp did not vary significantly among CRB stations.

Female Largescale Sucker

Female largescale sucker were identified as stage 1 (24%), stage 2 (50%), and stage 3 (25%) with one female in stage 5 at Station 98 (Fig. 21). Stage-2 females were present at all stations where largescale sucker were collected (Fig. 26). Stage-1 and stage-3 fish were each represented at five stations.

Table 33. Arithmetic mean of percent atresia by station, number of samples (*n*), minimum (min.) maximum (max.), and standard error (SE) in female fish collected in the Columbia River Basin in 1997. Stations are grouped by taxon and sub-basin and ordered upstream to downstream. The maximum station mean is shown in bold for each taxon.

Taxon and Station	*n*	Mean	Min.	Max.	SE
Bass					
Basin total	74	3.4	0	32	0.5
Upper Columbia River (UCR)					
Creston, MT (117)	11	2.5	0	5	0.5
Snake River (SR)					
Hagerman, ID (41)	9	7.1	0	32	3.3
Riggins, ID (43)	3	2.0	0	4	1.2
Lewiston, ID (42)	5	3.2	0	11	2.2
Ice Harbor Dam, WA (96)	4	2.5	1	7	1.5
Middle Columbia River (MCR)					
Vernita Bridge, WA (503)	3	4.0	3	6	1.0
Pasco, WA (97)	9	2.2	0	10	1.1
Granger, WA (44)	9	1.3	0	5	0.6
Lower Columbia River (LCR)					
Warrendale, OR (502)	1	**12.0**	--	--	--
Oregon City, OR (45)	15	2.6	0	10	0.7
Portland, OR (505)	5	6.2	2	14	2.2
Carp					
Basin total	70	6.6	0	30	0.9
Snake River (SR)					
Hagerman, ID (41)	10	0.2	0	1	0.1
Lewiston, ID (42)	5	**17.6**	3	27	4.5
Ice Harbor Dam, ID (96)	10	10.9	1	30	3.1
Middle Columbia River (MCR)					
Vernita Bridge, WA (503)	10	8.7	0	27	2.6
Pasco, WA (97)	11	6.6	0	23	2.2
Granger, WA (44)	10	5.9	0	16	1.8
Lower Columbia River (LCR)					
Warrendale, OR (502)	10	3.7	0	15	1.5
Oregon City, OR (45)	4	2.0	1	4	0.7
Largescale sucker					
Basin total	88	2.0	0	16	0.3
Upper Columbia River (UCR)					
Creston, MT (117)	4	1.8	0	4	1.0
Northport, WA (504)	10	1.1	0	7	0.8
Grand Coulee, WA (98)	10	2.5	1	6	0.5
Snake River (SR)					
Riggins, ID (43)	11	1.8	0	9	0.9
Lower Columbia River (LCR)					
Cascade Locks, OR (46)	11	3.7	0	16	1.4
Warrendale, OR (502)	3	0.0	0	0	0
Vancouver, WA (506)	11	0.9	0	6	0.6
Oregon City, OR (45)	6	1.2	0	4	0.7
Portland, OR (505)	11	**4.1**	0	12	1.2
Beaver Army Terminal, OR (501)	11	1.3	0	12	1.1

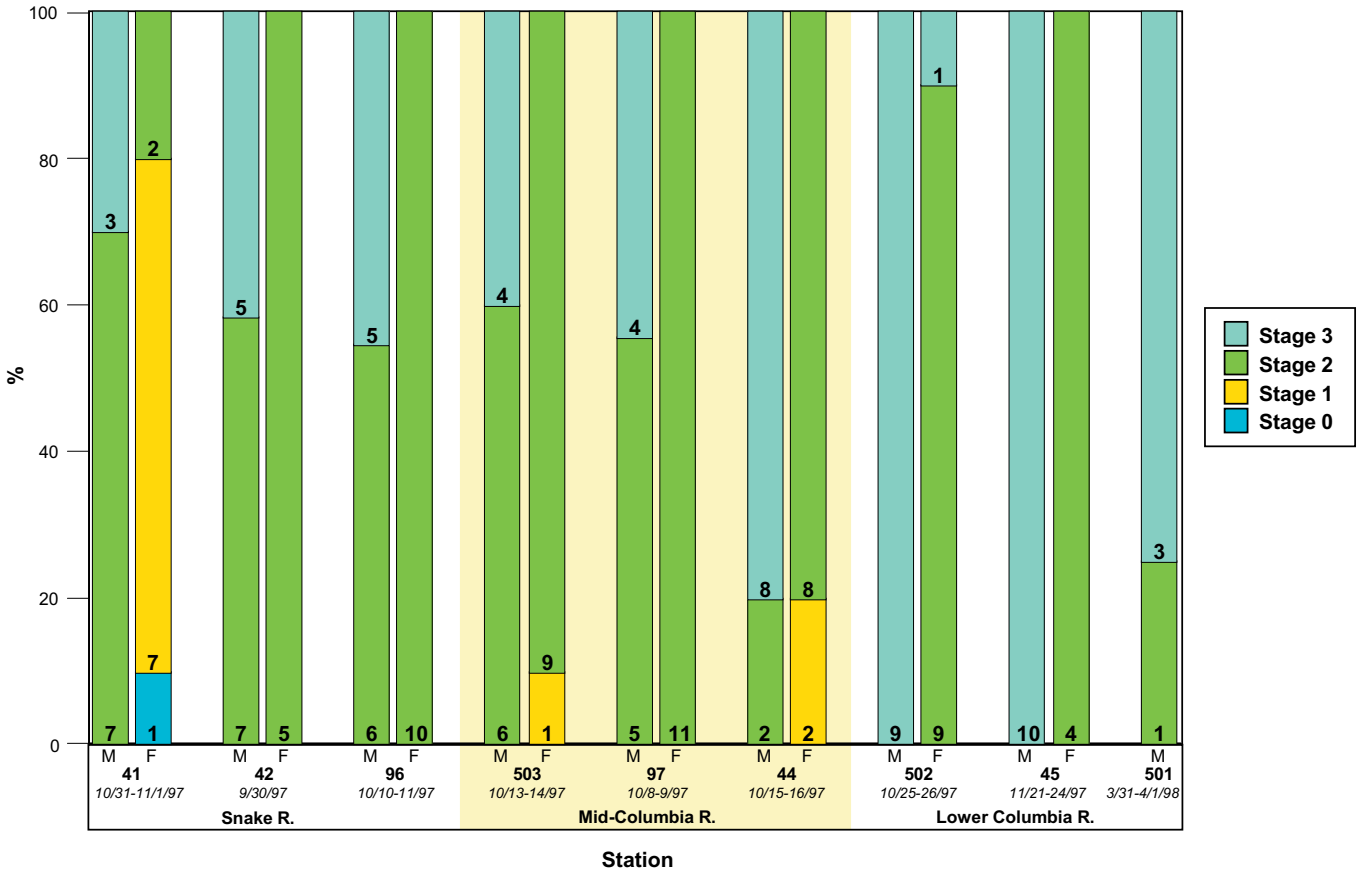


Figure 24. Gonadal stage proportions by station in female and male carp collected in the Columbia River Basin in 1997. Station sample sizes for each stage are located in the boxes within the figure. The collection dates for each station are located below the station number. Stations are ordered from upstream to downstream and are grouped by sub-basin. See Table 3 for station descriptions.

GSI in female largescale sucker varied in the CRB. GSI was greatest (7.6%) in female largescale sucker from Station 501 ranging from 0.9-13.1% (Table 31), and other station means ranged from 2.0-6.4%. GSI >7% were measured in female largescale sucker from Stations 501 and 506 (Fig. 27) although most (90%) values ranging from 1.0-9.0%. GSI varied significantly among stations in female sucker (Table 20), and GSI and stage had a significant correlation. Stage-3 females had the greatest GSI values.

The gender of largescale sucker influenced the reproductive biomarkers (Table 20), resulting in females and males being examined separately. Samples from Stations 501 and 506 were not available for analysis. Mean vtg in female largescale sucker was greatest (66.4 mg/mL) at Station 45, ranging from 1.3-166.4 mg/mL (Table 32). Other station means for female largescale sucker ranged from 14.1-62.8 mg/mL; concentrations of vtg did not vary significantly among stations. All stations had individual fish with high concentrations of vtg. Stations 45, 46, 117 and 504 had numerous largescale sucker with concentrations of vtg >50 mg/mL (Fig. 27). As in female carp and bass, collection date did not appear to influence concentrations of vtg in largescale sucker, since low concentrations of vtg were collected on the same date as high concentrations from the same station. Previous vtg data are not available for largescale sucker. Concentrations of vtg in female longnose sucker from another BEST project with concentrations were <0.001-10.7 mg/mL (Hinck and others, in review).

Atresia in female largescale sucker was examined in the CRB. Mean percent atresia was greatest (4.1%) in largescale sucker at Station 505, ranging from 0-12% (Table 33). All other station means were <3.7%. Atresia in fish from Stations 46, 501 and 505 were >10%, although the majority (97%) of the females had <10% of eggs that were atretic (Fig. 27). Station means did not significantly differ for percent atresia, but Stations 46 and 505 generally had higher values (Fig. 27). Percent atresia data for largescale sucker have not been previously reported.

Male Largescale Sucker

Ninety-four percent of male largescale sucker were identified as stage 3 (Fig. 21). Two males at Station 43 were stage 2, and two males at Station 117 were stage 0 (Fig. 26).

GSI was greatest (5.7%) in male largescale sucker at

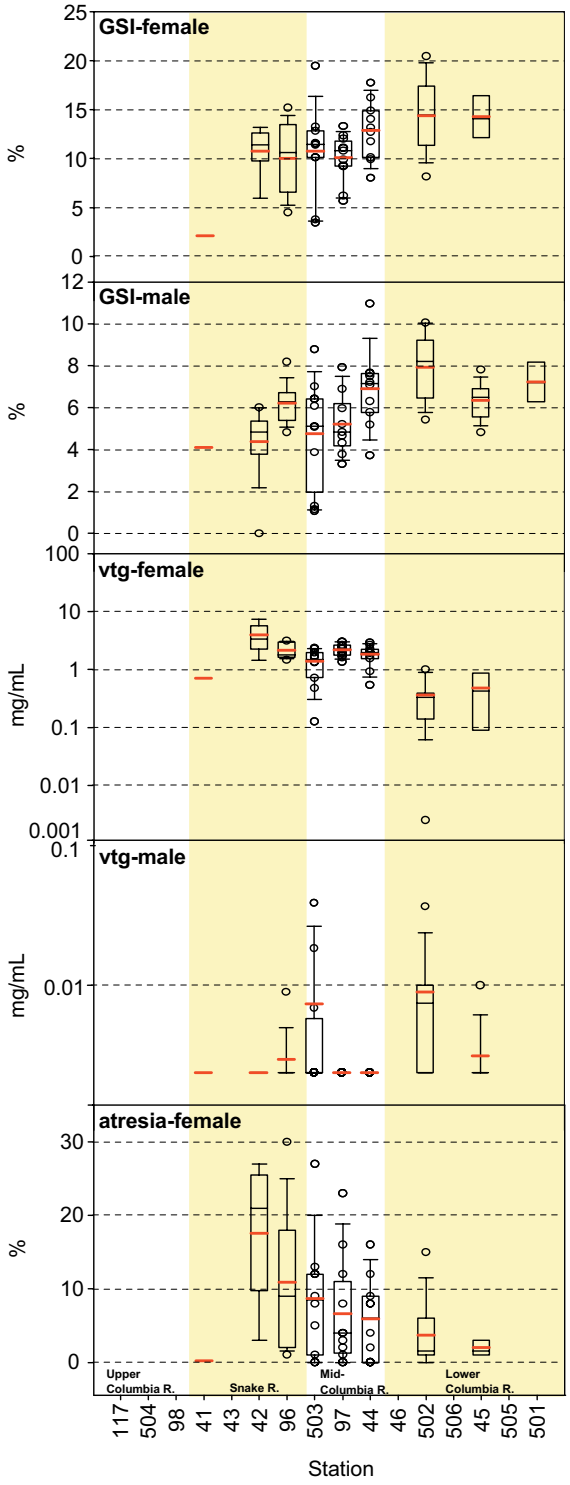


Figure 25. Reproductive health indicators by station in female and male carp collected in the Columbia River Basin in 1997. Indicators include gonadosomatic index (GSI), vitellogenin (vtg), and atresia. Shown for each group are points representing individual fish and the mean (red horizontal line), median (black horizontal line), interquartile range (box), and the 10th and 90th percentiles (whiskers). Stations are ordered from upstream to downstream and are grouped by sub-basin. See Table 3 for station descriptions.

Station 501 (Table 31) ranging from 4.1-8.3%; other station means ranged from 3.4-5.4%. Fish at Stations 46 and 501 had GSI that exceeded 7% with most (93%) values ranged from 2.5-7.0% (Fig. 27). GSI varied significantly among stations in male largescale sucker (Table 20). All male sucker were stage 3 with the exception of four individual fish; therefore, evaluation of stage as a significant variable in predicting GSI was not possible. Previous GSI data are not available for largescale sucker.

Concentrations of vtg in male largescale sucker were <LOD in 46 of 53 (87%) samples. Concentrations >LOD (0.0005 mg/mL) were found in fish at Stations 46, 98, 117, and 505, and detected concentrations of vtg were 0.001-0.47 mg/mL (Table 32; Fig. 27). Male sucker from Stations 46, 98, 117, and 505 had concentrations of vtg >0.01 mg/mL, a concentration that indicates an estrogenic response in these fish. These elevated concentrations were limited to individual fish at Stations 46, 177, and 505, but Station 98 had two fish with concentrations >0.01 mg/mL which may warrant further investigation of endocrine disrupting chemicals at this site. Previous vtg data are not available for largescale sucker. Concentrations of vtg from longnose sucker are available from another BEST project with concentrations ranging from <0.001-0.047 mg/mL (Hinck and others, in review).

Reproductive Biomarker: Summary

The biomarkers used in this study including GSI, gonadal histopathology (used for the analysis of gender, stage, and oocytic atresia) and vtg are the best techniques available for measuring reproductive function as well as the effects of contaminants, whether endocrine disrupting or on reproductive health. The biomarkers are influenced by age, species, water temperature, photoperiod, and other biotic and abiotic factors and can greatly fluctuate during the reproductive cycle. A well-designed study controlling these variables can provide valuable data and important insights into reproductive health. These biomarkers have proven to be valuable measures of reproductive activity and dysfunction in a variety of laboratory studies, as well as several field studies (including this study) designed to monitor the effects of environmental contaminants on the reproductive activity in streams.

The GSI is often used to evaluate reproductive status and health, although interpretations of GSI measurements rely on understanding natural variations among fish of the same age, gender, and species. Environmental influence and behavioral patterns may also confound the data. Considerable gonad size variation has been reported throughout the reproductive cycle of many animal species (de Vlaming and others, 1981). Gonads constituted a substantially greater proportion of the total body mass in carp than in bass as noted in previous studies (for example, McDonald and others, 2002). GSI in largescale sucker were generally between those of carp and bass. Fish from Stations 41 (carp), 42 (male carp), and 43 (large-

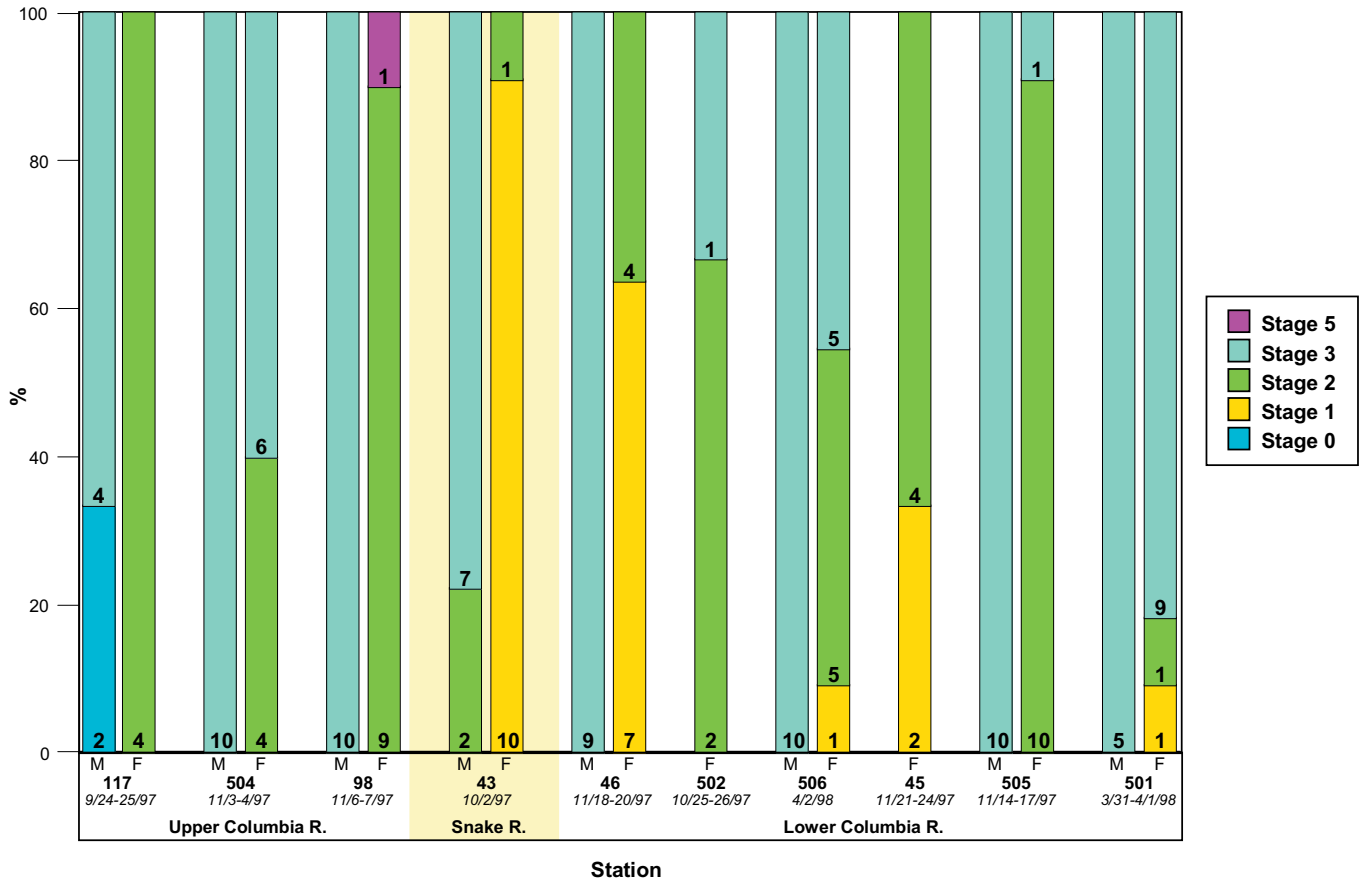


Figure 26. Gonadal stage proportions by station in female and male largescale sucker collected in the Columbia River Basin in 1997. Station sample sizes for each stage are located in the boxes within the figure. The collection dates for each station are located below the station number. Stations are ordered from upstream to downstream and are grouped by sub-basin. See Table 3 for station descriptions.

scale sucker) consistently had relatively low GSI. The GSI in fish from Stations 502 (male carp and bass), 45 (female bass), 501 (female largescale sucker), and 506 (female largescale sucker) were elevated. The GSI was low in individual fish from Stations 42 (bass) and 41 (carp).

Gonadal histopathology was used in this study to confirm gender, assign reproductive stage, and detect anatomical abnormalities such as the presence of ovotestes and excessive oocyte atresia. In general, fish of the same gender/taxon were in similar stages of gonadal maturity, despite differences in sampling times and locations. Males were predominantly in stages 2 and 3, and females were in stages 1 and 2. Because the reproductive biomarkers used in this study are known to vary over the course of the reproductive cycle, stage was given close attention in the interpretation of these data. Those stations at which most fish were outside of the normal range of maturation were identified in the results section, and future efforts should be made to reveal the reason or reasons for either advanced or delayed gonadal development.

Oocyte atresia, as defined by an involution or resorption of vitellogenic oocytes by the ovaries, has been sufficiently validated as a histological biomarker (that is, lesions in laboratory studies have been correlated with chemical exposure) and these same lesions detected in fish from contaminated sites. Although oocyte atresia is a normal physiological event in all fish, it can become a pathological condition following exposure to certain environmental contaminants (Cross and Hose, 1988; 1989; Johnson and others, 1988; Kirubagaran and Joy 1988); however, it is also important to note that other factors may also be involved (June, 1970; 1977). McDonald and others (2002) reported atresia ≥25% for female carp and >10% for female bass may be of concern and were defined as high. The percent atresia was < 20% for female carp, and <10% for female bass and largescale sucker in the CRB. High atresia values in individual fish were found at Station 42 for carp and bass, Stations 41 and 502 for bass, and Stations 46, 501, and 505 for sucker. Carp at Station 42 had a high station mean percent atresia (17.6%).

There was variability in the percent atresia among CRB stations although stations were not significantly different from one another (Tables 20 and 33) However, without a more thorough understanding of normal percentages in healthy individuals it is difficult to reach a conclusion regarding the degree of oocyte atresia that affects reproduction. Other biomark-

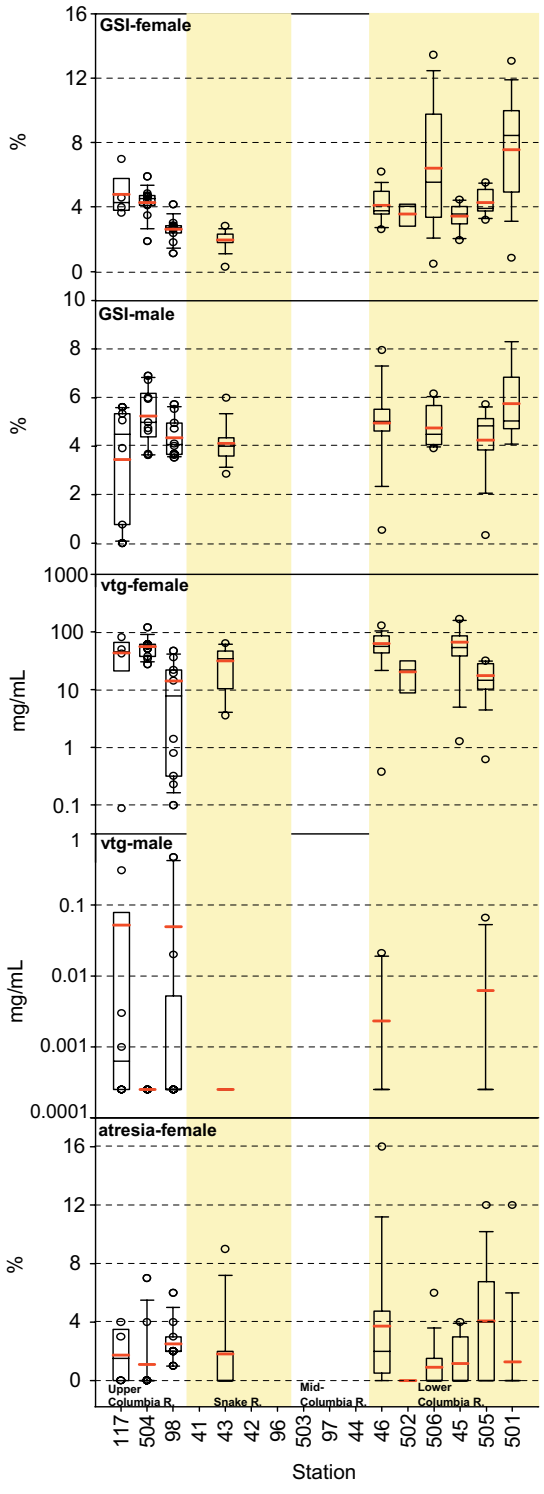


Figure 27. Reproductive health indicators by station in female and male largescale sucker collected in the Columbia River Basin in 1997. Indicators include gonadosomatic index (GSI), vitellogenin (vtg), and atresia. Shown for each group are points representing individual fish and the mean (red horizontal line), median (black horizontal line), interquartile range (box), and the 10th and 90th percentiles (whiskers). Stations are ordered from upstream to downstream and are grouped by sub-basin. See Table 3 for station descriptions.

ers appeared to be normal in female carp from the stations at which mean atresia was high, except MAMM. Basin-wide mean oocyte atresia was less in female bass (3.4%) than female carp (6.6%), and lowest in largescale sucker (2.0%) (Table 33).

Five male smallmouth bass from two stations (Stations 42 and 502) were identified as histologically abnormal and having ovotestes; that is, they were male fish with foci of ovarian tissue. The significance of this is unclear because most of these males had normal GSI and low or undetectable vtg concentrations. To our knowledge, the background occurrence of intersex male bass has not been established. These fish with ovotestes were not functional hermaphrodites. The testes appeared functional and contained later stages of spermatogenesis (that is, having mature sperm), and the oocytes were characterized by only a few previtellogenic, very small oocytes. Other studies have reported high proportions (>40%) of largemouth bass (Schmitt and others, 2004) and smallmouth bass (McDonald and others, 2002) with ovotestes at certain sampling locations in the U.S.

Relatively low concentrations of vtg were recorded for female bass and largescale sucker at Stations 502 and 505 as well as in female carp at Station 502. However, incidences of high concentrations of vtg were not consistent across species/taxon. Concentrations of vtg in female largescale sucker were consistently 15-20 times greater than concentrations in female bass and carp. Individual female bass had high concentrations at Stations 97 and 503, and a male bass at Station 97 had a vtg concentration of 0.67 mg/mL, a level that indicates exposure to endocrine disrupting chemicals. Individual male bass from Stations 42, 43, 96, 97, and 117 had concentrations of vtg >0.01 mg/mL. These results did not indicate a general estrogenic response in male bass at any of these stations. With the exception of two relatively high concentrations in female carp at Station 42, no station was notable for vtg in female carp. Male carp from Stations 45, 502, and 503 had concentrations of vtg >0.01 mg/mL, and multiple male individuals from Stations 502 and 503 exceeded this concentration which indicates an estrogenic response at these two sites. Mean station concentrations of vtg were greatest (>60 mg/mL) for female largescale sucker at Stations 45 and 46. Male largescale sucker from Stations 46, 98, 117, and 505 had concentrations of vtg >0.01 mg/mL. Male sucker from Stations 98 and 117 had very high concentrations of vtg (>0.30 mg/mL), which indicates these fish had estrogenic responses as a result of exposure to environmental conditions at these sites. Recent studies have localized vtg receptors to the testes, muscle, and spermatocytes (Bidwell and Carlson, 1995; Tao and others, 1996).

A 1995 reconnaissance study by Goodbred and others (1997) reported detectable concentrations of vtg in males from the reference site and confirmed that small amounts of vtg can be present in healthy males. Vitellogenin was measured in male bass from Stations 43, 96, 97, and 117, male carp from Stations 45, 96, 502, and 503, and male largescale sucker from Stations 46, 98, 117, and 505. The females from these same

stations did not have elevated concentrations of vtg; therefore, elevated concentrations of vtg were gender specific at CRB stations. Station 502 was the only site with more than three male fish with detectable concentrations of vtg. Concentrations of vtg ranged from 0.007-0.035 mg/mL in male carp from Station 502. Stations 96 and 117 had measured vtg in bass and carp. Stations with vitellogenic males were distributed throughout the CRB, and the SR only had one station where vtg was detected in male fish.

Concentrations of vtg were correlated with stage and differed significantly among stages for female bass from the CRB. Indeed, stage assessments are based in part on the deposition of vitelline granules in the developing oocyte; therefore, it is not surprising that stage and vtg in females are correlated. Although fish were collected in their non-reproductive season, sampling took three months to complete. Therefore, it is reasonable that female fish collected months apart could be in different stages of their respective reproductive cycle. Low or non-detectable concentrations of vtg in fish at Stations 42 and 505 did not seem to be related to sampling time (late September for Station 42 and mid-November for Station 505). At both stations, the females analyzed were almost exclusively in stage 0 and 1. At many of the stations with higher vtg means, such as Stations 43 and 503, fish were also predominantly in stage 1. Both of these stations were also sampled late in the fall. Thus, while sampling over a six-month period is not ideal for assessing any of the reproductive biomarkers, it did not appear to be the reason for differences in stage. However, geographical location is another potentially complicating factor.

Only one female carp in this study had a concentration of vtg <LOD, although several station means were low. Female carp were predominantly stage 2 (83%). Even so, vtg concentrations of stage-2 females ranged from <0.005-7.4 mg/mL. Although the stations (Stations 45 and 502) with the lowest vtg means were also among the latest sites sampled (late November), most female carp (and the only individuals contributing to the station means) were stage 2. Thus, late collection, immature gonads, or both are not reasonable explanations for the variability observed. In addition, the age of the fish collected for the study did not appear to influence the reproductive stage of the gonads.

All female largescale sucker in this study had concentrations of vtg >LOD. Female largescale sucker were predominantly stage 2 (56%) with concentrations ranging from 0.087-166 mg/mL. Stage-1 females were predominantly from Stations 43 and 46 and had vtg concentrations ranging from 0.375-87 mg/mL. Stage-3 females were mainly from Station 504 with concentrations ranging from 27-119 mg/mL. One female from Station 98 was identified as stage 5 with a vtg concentration of 0.225 mg/mL. Neither stage nor age were correlated with vtg and all largescale sucker were collected near the same period of time (late fall).

Spatial patterns in contaminant concentrations and biomarker responses

Geographic Summaries

Geographic station summaries were made to highlight elevated contaminant concentrations and biomarker responses (Table 34). The highlighted findings indicate contaminant concentrations or EROD levels that exceeded known thresholds or were anomalous (that is, high or low) relative to other stations in the CRB. The colors for the reproductive and fish health biomarkers are relative and indicate the number and/or magnitude of the anomalies (including the number of gender-taxon categories in which they occurred) at a station. The summaries are intended only to draw attention to particular stations highlighted in the text, possibly for further investigation. It is important to recognize that increased frequencies of external lesions or elevated health assessment index (HAI) scores, which represent the cumulative total number of grossly visible internal and external lesions, do not necessarily indicate direct contaminant effects. Unfortunately, most of the lesions were not collected for histological examination. The two lesions that were collected exhibited epidermal erosion and inflammation. Many factors other than contaminants can indirectly influence fish health indicators and reproductive biomarkers including nutrients or organic matter and water temperature (see fish health indicator and reproductive biomarkers sections). More studies have determined criteria that assesses risk to fish and piscivorous wildlife associated with bioaccumulative contaminants and EROD than about long- and short-term risks represented by the other biomarkers. Therefore, greater relative risk has been associated with elevated contaminant concentrations and EROD rates than with anomalous fish health or reproductive biomarkers (Table 34).

Upper Columbia River (UCR)

The UCR includes Stations 117, 504, and 98. Male and female largescale sucker were collected from all stations; however, different predator species were collected from each station. Walleye were collected from Station 98, rainbow trout were collected from Station 504, and bass were collected from Station 117. Longnose sucker were also collected from Stations 98 and 117. The UCR stations were sampled in early November 1997. Mercury impairments have been previously reported in the UCR from Roosevelt Lake to the international border (USEPA, 2002b). Fish consumption advisories have been issued for Lake Roosevelt for dioxins in whitefish (USEPA, 2003a), which have been attributed to a pulp mill in British Columbia, Canada (Schneider, 2002).

Table 34. Summary of chemical and biological indicator results, by sub-basin and station. Within each column, colors indicate the severity, incidence, or both of the indicated condition or conditions at each station (green<yellow<red). These designations are relative; see text for explanations. Male and female bass, carp, and largescale sucker were collected from all sites unless otherwise indicated. See Table 3 and Figure 1 for station and sub-basin locations. Bold lettering denotes that threshold criteria was exceeded and/or high incidence of elevated occurrence. DDE, *p*,*p*'-DDE; chlordane, total chlordanes; PCB, polychlorinated biphenyls; TCDD-EQ, dioxin-like activity as determined by H4IIE bioassay; Hg, mercury; Pb, lead; Se, selenium; EROD, ethoxyresorufin *O*-deethylase; SSI, splenosomatic index; HAI, health assessment index; HSI, hepatosomatic index; MA, macrophage aggregates (one or more parameters); vtg, vitellogenin; ovt, ovotestis; b, bass (*Micropterus* sp.); c, carp (*Cyprinus carpio*); s, largescale sucker (*Catostomus macrocheilus*); m, male; f, female. For SSI, - indicates smaller; all others larger.

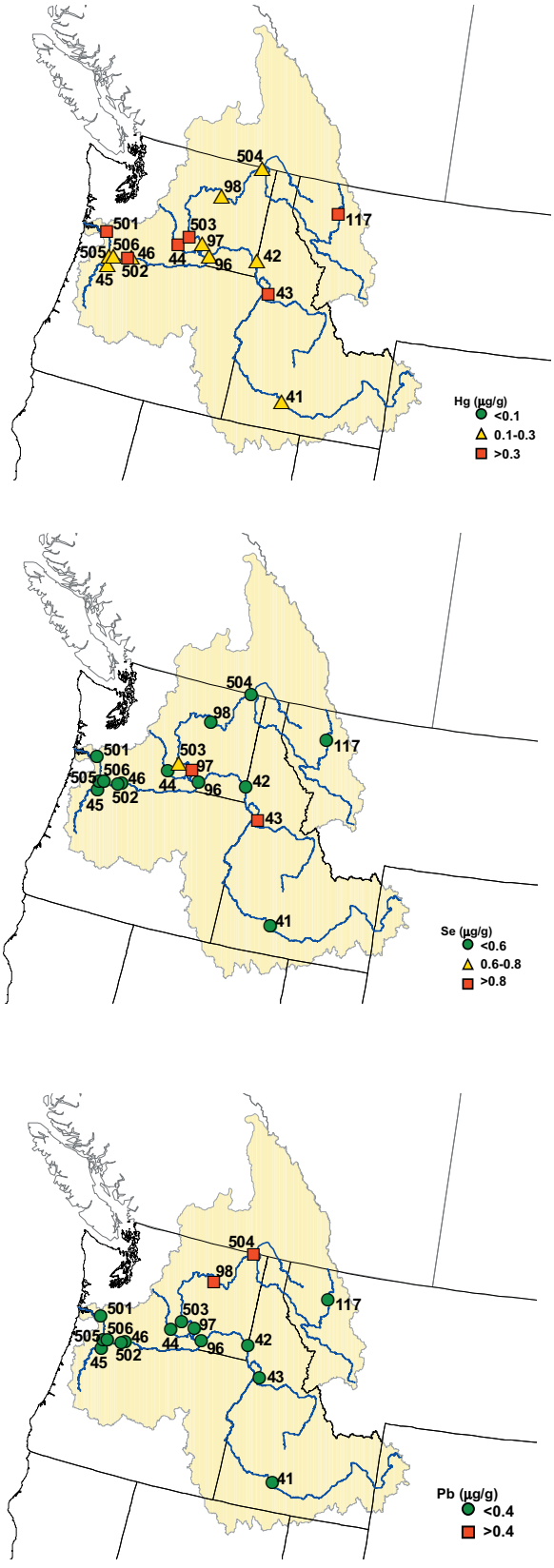
Sub-basin and Station	Contaminants and EROD	Fish Health Indicators	Reproductive Biomarkers
Upper Columbia River (UCR)			
117 (no carp)	Hg (b), EROD (b,s)	SSI (s), Ext. lesions (b,s)	Vtg (ms)
504 (sucker only)	Hg, **Pb**, PCB, TCDD-EQ, EROD	SSI, Ext. lesions	
98 (sucker only)	Hg, Pb, EROD	SSI, Ext. lesions	Vtg (ms)
Snake River (SR)			
41 (no sucker)	Hg (b), EROD (c)	**Ext. lesions** (**c**,b), **HAI** (b)	
43 (no carp)	**Hg** (b), Se (b), EROD (b,s)		
42 (no sucker)	Hg (b,c), DDE (c), **chlordane** (c), PCB (b,c), EROD (b,c)	SSI (fc-), Ext. lesions (c), MA (c)	Ovt (mb)
96 (no sucker)	Hg (b), DDE (c), PCB (c), **TCDD-EQ** (c,b), EROD (b,c)	Ext. lesions (c)	
Mid-Columbia River (MCR)			
503 (no sucker)	Hg (b), Se (b), DDE (c,b), PCB (c,b), TCDD-EQ (c,b), EROD (c)	Ext. lesion (c), HSI (fb)	Vtg (mc)
97 (no sucker)	Hg (b), **Se** (c,b), TCDD-EQ (c,b), EROD (b)		**Vtg** (mb)
44 (no sucker)	Hg (b), **DDE** (c,b), PCB (b), EROD (c,b)	**Ext. lesions (c,b)**, HAI (b)	
Lower Columbia River (LCR)			
46 (sucker only)	Hg, PCB, TCDD-EQ, EROD	Ext. lesions	
502 (no m sucker)	Hg (b,c), PCB (b,c), TCDD-EQ (c), EROD (c,s,b)	**Ext. lesions** (c,**b**)	Vtg (mc), Ovt (mb)
506 (no carp, f bass)	Hg (s), **Toxaphene** (s), **PCB** (s), TCDD-EQ (s)	**Ext. lesions** (s)	
45 (no m sucker)	Hg (b,c,s), PCB (c), TCDD-EQ (c,b), EROD (c,s,b)	Ext. lesions (c,b,s), HAI (b)	
505 (no carp)	Hg (b,s), PCB (b,s), TCDD-EQ (b,s), **EROD** (b,s)	Ext. lesions (b,s)	
501 (no bass, f carp)	DDE (c,s), PCB (c,s)	**Ext. lesions** (**c**,s)	

Station 117 (Creston, Montana)

Several contaminants and biomarkers were highlighted in fish at Station 117 (Table 34). The concentration of Hg in female bass (0.31 µg/g ww) exceeded criteria (0.3 µg/g ww) shown to cause reproductive impairment in loons (Barr, 1986) (Fig. 28). No other inorganic and organic contaminant concentrations exceeded criteria at Station 117. The mean station EROD activity exceeded basal levels set in the BEST 1995 MRB study for male and female bass and female largescale sucker indicating exposure to exogenous AhR agonists (Fig. 29). Largescale sucker from Station 117 had the greatest mean SSI (0.37%) of all CRB stations. External lesions were identified on >50% of the bass and largescale sucker collected from this station. However, most of these lesions were classified as fin abnormalities which could result from factors other than environmental contamination. Vitellogenin was the only reproductive biomarker highlighted at this station. Concentrations of vtg were >0.01 mg/mL in male bass (0.08 mg/mL) and male largescale sucker (0.31 mg/mL), which indicates an estrogenic response to environmental conditions in these individual fish (Table 34; Fig. 30).

Station 504 (Northport, Washington)

Fish at Station 504 exceeded threshold levels for numerous contaminants and several fish health biomarkers (Table 34). The concentration of Hg in male largescale sucker (0.15 µg/g ww) exceeded criteria (0.1 µg/g ww) shown to cause reproductive problems in mallards (Heinz, 1979) (Fig. 28). The concentrations of Pb in male and female largescale sucker were the greatest (>4.0 µg/g ww) in the CRB and exceeded numerous criteria (Fig. 28). Concentrations of PCBs in female largescale sucker and male rainbow trout exceeded the NYSDEC wildlife guideline of 0.11 µg/g ww (Newell and others, 1987). The TCDD-EQ, a measure of dioxin-like activity, for female largescale sucker was 5 pg/g, the dietary threshold



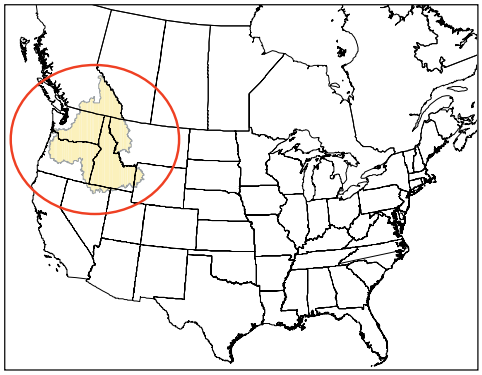
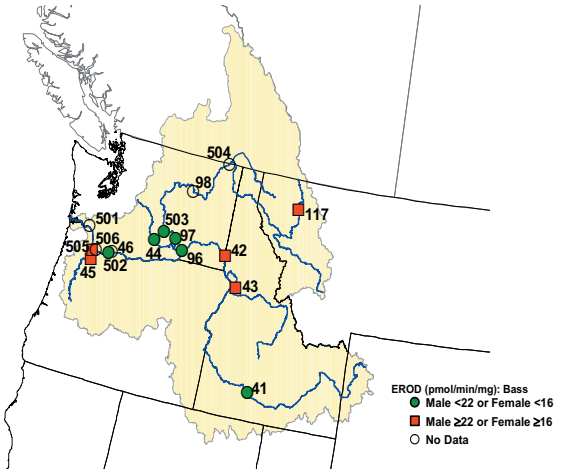


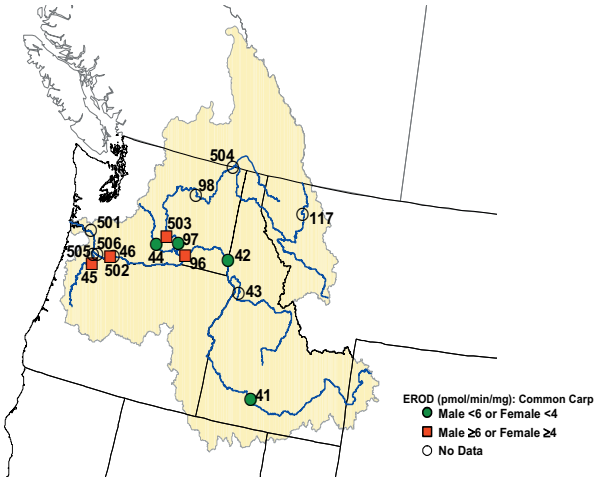
Figure 28. Maximum concentrations (µg/g ww) of mercury (Hg, upper panel), selenium (Se, middle panel), and lead (Pb, lower panel) in composite samples of whole fish. A concentration of Hg of 0.1 µg/g ww in fish has been suggested as a guideline for the protection of piscivorous mammals (Yeardley and others, 1998), and concentrations of 0.3 µg/g ww cause reproductive impairment in the common loon (*Gavia immer*) (Wiener and Spry, 1996; Wiener and others, 2002). For Se, concentrations should be <0.6 µg/g ww to avoid toxicity to piscivorous wildlife and <0.8 µg/g ww to avoid toxicity to fish (Lemly, 1996). Concentrations of Pb of 0.04 µg/g ww have reduced egg hatch ability in brook trout (Holcombe and others, 1976). See Table 3 for station descriptions.

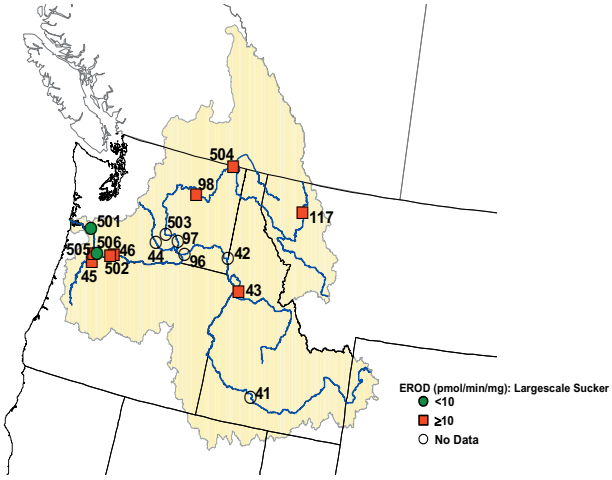
for avian wildlife (Nosek and others, 1992). Station mean EROD activity exceeded 10 pmol/min/mg for male largescale sucker indicating exposure to exogenous AhR agonists (Fig. 29). Fish health indicators highlighted for this station include SSI and external lesions. Station 504 had the second highest mean SSI (0.36%) for largescale sucker throughout the CRB. Eighty-five percent of largescale sucker were identified as having external lesions, mostly located on the body surface and fins. Five of these external lesions were papillomas and two had thickened areas of epithelium with accumulations of pigmented macrophages around vessels in the dermis. One papilloma was an eye lesion composed of chronic granulomatosis inflammation throughout the choroids, iris and, retina. These lesions are similar to those previously described for *Streptococcus* and *Staphylococcus* infections of fish. No reproductive biomarker appeared to be anomalous at this station.

Station 98 (Grand Coulee, Washington)

Multiple contaminant concentrations, fish health indicators, and reproductive biomarkers were highlighted in fish at Station 98 (Table 34). The concentration of Hg in male and female largescale sucker and male walleye exceeded criteria (0.1 µg/g ww) shown to cause reproductive problems in mallards (Heinz, 1979) (Fig. 28). The concentrations of Pb in male and female largescale sucker exceeded criteria for reproduction success in multi-generational brook trout (Holcombe and others, 1976) (Fig. 28). Station mean EROD activity







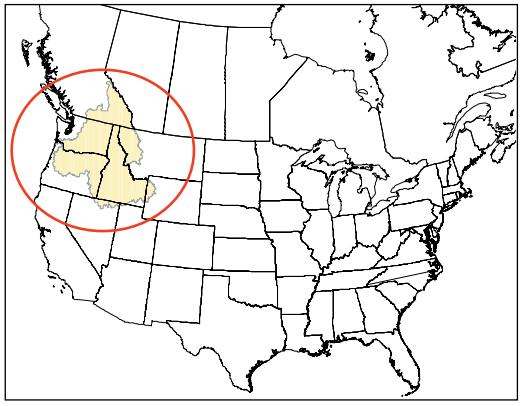
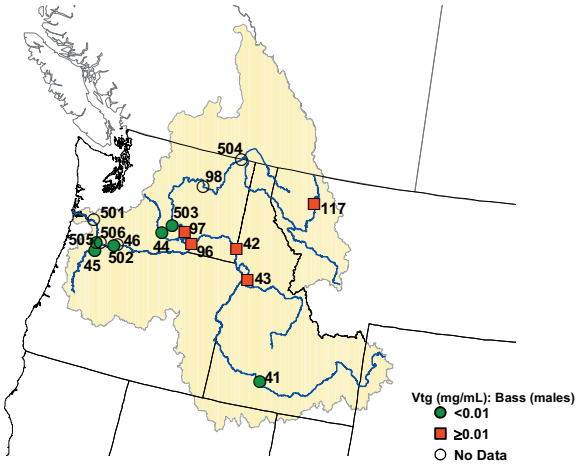


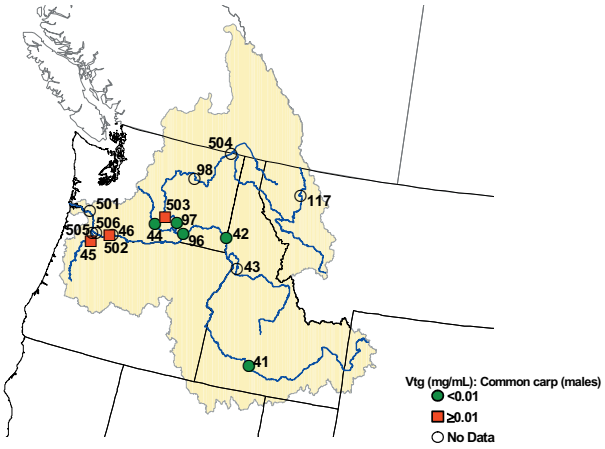
Figure 29. Mean hepatic ethoxyresorufin *O*-deethylase (EROD) activity (pmol/min/mg protein) in bass (upper panel), carp (middle panel), and largescale sucker (lower panel). The thresholds indicated are levels identified in previous studies as indicative of exposure to exogenous Ah-R agonists (Schmitt and others, 2002b). See Table 3 for station descriptions.

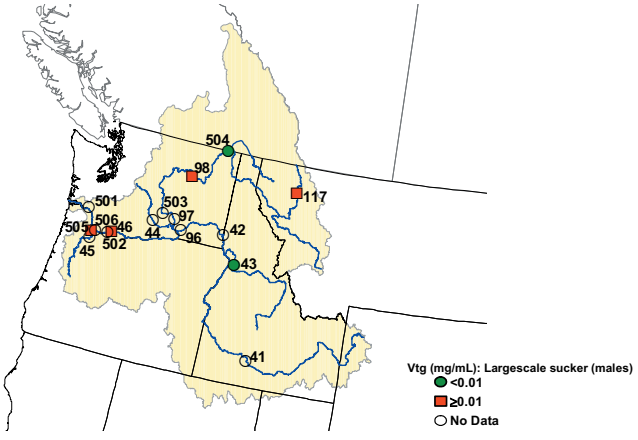
exceeded 10 pmol/min/mg for male and female largescale sucker indicating exposure to exogenous AhR agonists (Fig. 29). External lesions were identified on 71% of the largescale sucker collected from this station. Most of these lesions were classified as eyes that were opaque which could result from factors other than environmental contaminants. Histologically, the eye lesions were composed of chronic granulomatosis inflammation in the choroid gland, cornea, and retina. Concentrations of vtg were >0.01 mm/mL in two male largescale sucker (0.02 mg/mL and 0.47 mg/mL), which indicates that exposure to endocrine disrupting chemicals is a concern at this site (Table 34; Fig. 30).

Snake River (SR)

Stations 41, 43, 42, and 96 were included in the SR. Both male and female bass and carp were collected from all stations except Station 43 where bass, largescale sucker, and northern pikeminnow were collected. The SR stations were sampled from late-September to early October in 1997. Mercury impairments have been previously reported in the SR from the Salmon River to the Washington border (USEPA, 2002b). The SR is under a fish consumption advisory for all fish, beginning at the Oregon/Washington border and terminating below the town of Adrian (USEPA, 2003a). The Brownlee Reservoir, located on the mainstem of SR, was also issued a fish consumption advisory in 1994 because of Hg in carp and game fish (USEPA, 2003a). NAWQA reported pesticides were detected in surface water in spring and early summer following seasonal applications and high nutrient and sediment inputs from fish hatcheries, municipal wastewater, and irrigation returns in the SR (Clark and others, 1998).







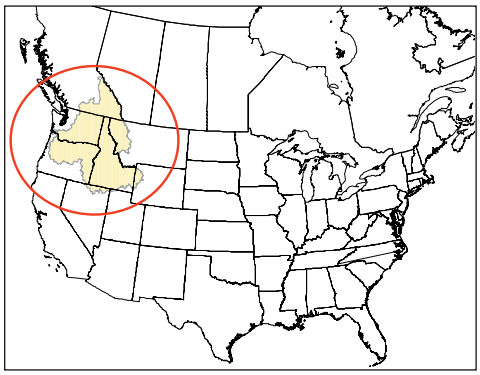


Figure 30. Plasma vitellogenin (vtg) in male bass (upper panel) carp (middle panel), and largescale sucker (lower panel). These thresholds indicate stations where at least one male bass had a detectable concentration of vtg (>0.01 mg/mL). See Table 3 for station descriptions.

Station 41 (Hagerman, Idaho)

Several contaminants and biomarkers were highlighted at Station 41 (Table 34). The concentration of Hg in male and female bass exceeded criteria (0.1 µg/g ww) shown to cause reproductive problems in mallards (Heinz, 1979) (Fig. 28). However, concentrations of Hg in carp were <LOD. No other inorganic or organic contaminant were not measured at concentrations of concern. TCDD-EQs were detected but did not exceed criteria in bass or carp. EROD activity exceeded levels set in the BEST 1995 MRB study for individual female carp, but the station mean (2.01 pmol/min/mg) did not exceed this criteria (Fig. 29). External lesions and HAI were the only fish health indicators highlighted at this station. External lesions were identified in 100% of carp and 88% of bass, the greatest percentages in the CRB. Most of the lesions were categorized as frayed and/or hemorrhagic fins. These are common abnormalities of fish that are not necessarily associated with contaminant influences. These external lesions and liver abnormalities were the main contributors of the inflated HAI scores of bass, which were the greatest in the CRB. The liver, kidney and spleen abnormalities identified during the field examination as white spots, nodules, and discolorations, were histologically identified as large numbers of helminth parasites with a few myxosporidian cysts in the kidney. Most of the skin lesions were proliferations of epidermal cells (mucous and epithelial) and inflammation, also in response to helminth parasites. Four of the fish had nodules of hyperplastic interrenal tissue within the anterior kidney. This could be indicative of chronic stress. No reproductive biomarkers were highlighted in fish at Station 41.

Station 43 (Riggins, Idaho)

Fish at Station 43 had several contaminants and biomarkers that exceeded criteria or were anomalous (Table

34). Concentrations of Hg in the predators species, bass and northern pikeminnow, were the greatest (>0.4 µg/g ww) measured in the CRB and exceeded criteria (0.3 µg/g ww) shown to cause reproductive impairment in loons (Barr, 1986) (Fig. 28). The concentration of Se in bass (0.84 µg/g ww) exceeded guidelines to protect fish and piscivorous wildlife (Lemly, 1996). Organochlorine concentrations did not exceed criteria at this station. Dioxin-like activity as indicated by measurable amounts of TCDD-EQ was detected in female northern pikeminnow and bass but did not exceed criteria. The mean station EROD activity exceeded basal levels set in the BEST 1995 MRB study for female bass (16 pmol/min/mg) and female largescale sucker (10 pmol/min/mg) with the station mean of male sucker (30.5 pmol/min/mg) being the greatest in the CRB (Fig. 29). No fish health indicators and only one reproductive biomarker, vtg, were highlighted at Station 43 (Fig. 30). Vtg was detected in one male bass (0.03 mg/mL); however, general exposure to endocrine disrupting chemicals at this site was not supported.

Station 42 (Lewiston, Idaho)

Multiple contaminants and biomarkers were highlighted in fish at Station 42 (Table 34). All samples had concentrations of Hg that exceeded criteria (0.1 µg/g ww) shown to cause reproductive problems in mallards (Heinz, 1979) (Fig. 28). Concentrations of *p,p'*-DDE in male and female carp (>0.5 µg/g ww) exceeded several wildlife guidelines (Anderson and others, 1975; Jarvinen and Ankley, 1999; Newell and others, 1987). Male carp from Station 42 had the greatest concentration of total chlordane (0.13 µg/g ww) measured in the CRB, but the station mean was less than toxicity thresholds (Fig. 31). Concentrations of PCBs in male and female carp and male bass exceeded the NYSDEC wildlife guideline of 0.11 µg/g ww (Newell and others, 1987). Dieldrin was detected but trace concentrations were less than toxicity threshold to protect predatory fish and fish-eating birds. EROD activity exceeded levels set in the BEST 1995 MRB study for individual carp and bass, but only the station mean (16.3 pmol/min/mg) for female bass approached the criteria (16 pmol/min/mg) (Fig. 29). Several fish health indicators including SSI, external lesions, and macrophage aggregates were noteworthy at this station. Station 42 had the greatest SSI (0.25%) of bass in the CRB, while female carp from this station had lowest SSI (0.15%) of carp in the CRB. More than 50% of the carp were identified as having external lesions, with most occurring on the body surface and fins. Mean station macrophage aggregate density (MAMM) in carp (10.2 MA/mm^2) was the greatest of all CRB stations. Perhaps the most interesting discovery at Station 42 was that three of five male bass had ovotestes, although other reproductive biomarkers (that is, GSI and vtg) for these individuals appeared normal.

Station 96 (Ice Harbor Dam, Washington)

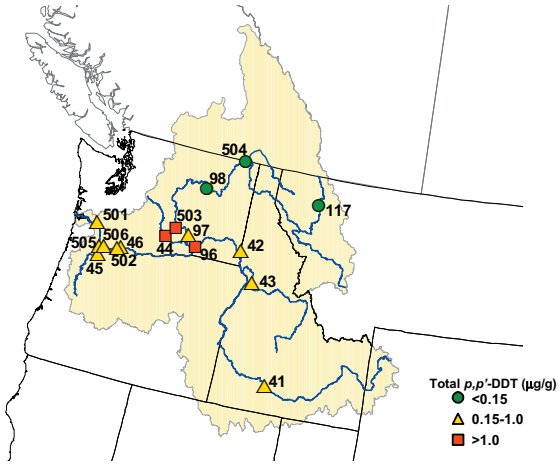
Fish at Station 96 had multiple contaminants and biomarkers that were of concern (Table 34). Carp and bass had concentrations of Hg near 0.1 µg/g ww, the criteria shown to cause reproductive problems in mallards (Heinz, 1979) (Fig. 28). Concentrations of *p,p'*-DDE in male and female carp (>0.7 µg/g ww) exceeded several wildlife guidelines (Anderson and others, 1975; Jarvinen and Ankley, 1999; Newell and others, 1987). A similar pattern of *p,p'*-DDE in carp was identified at Station 42. Concentrations of PCBs in male and female carp (>0.2 µg/g ww) also exceeded criteria at Station 96, but concentrations in bass were ≤LOD (Fig. 32). Dieldrin was detected, but trace concentrations were less than toxicity threshold to protect predatory fish and fish-eating birds. Female carp had the greatest TCDD-EQ (43 pg/g) measured in the CRB, and bass also had dioxin-like activity >5 pg/g (Fig. 32). EROD activity exceeded levels set in the BEST 1995 MRB study for individual male carp and female bass, but only the station mean (8.8 pmol/min/mg) for male carp exceeded the criteria (6 pmol/min/mg) (Fig. 29). More than 50% of the carp and bass were identified as having external lesions, with most occurring on the body surface and fins. However, body and fin abnormalities could result from factors other than environmental contamination. Vitellogenin was the only reproductive biomarker of concern at Station 96 with a single male bass having a concentration of 0.06 mg/mL (Fig. 30).

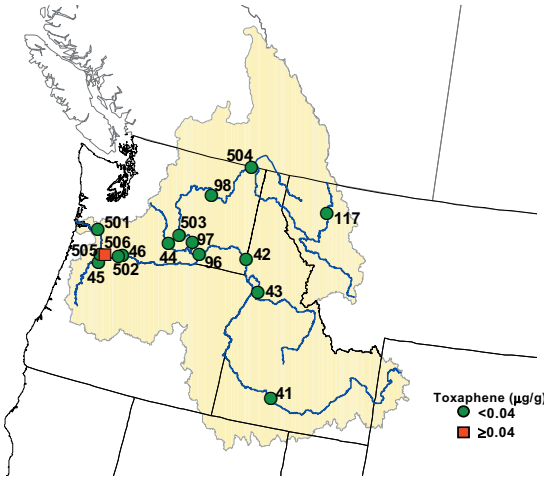
Middle Columbia River (MCR)

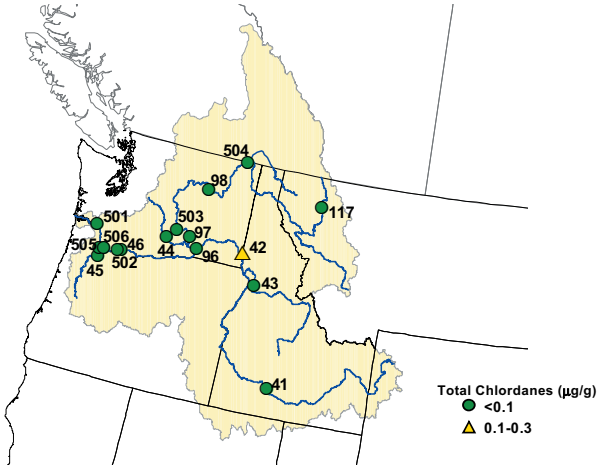
The MCR includes Stations 503, 97, and 44. Male and female bass and carp were collected from all stations; northern pikeminnow were also collected from Stations 44 and 503. The MCR stations were sampled in mid-October in 1997. Water quality impairments for *p,p'*-DDT, *p,p'*-DDE, and dieldrin have been reported for reaches throughout the Yakima River and reservoirs that are located in predominantly agricultural areas, and PCB and Hg impairments have also been reported (USEPA, 2002b). An advisory for *p,p'*-DDT and *p,p'*-DDE in all bottom fish was issued for the Yakima River, all its tributaries, and agricultural drains between the city of Yakima and its confluence with the Columbia River (USEPA, 2003a). The NAWQA program also reported pesticides in surface water and PCBs in sediment were frequently detected in the MCR (Williamson and others, 1998).

Station 503 (Vernita Bridge, Washington)

Several contaminants and biomarkers were at concentrations or levels of concern in fish at Station 503 (Table 34). Concentrations of Hg in bass (0.15 µg/g ww), carp (0.10 µg/g ww), and northern pikeminnow (0.30 µg/g ww) exceeded one or more guidelines to protect wildlife (Barr, 1986; Heinz, 1979) (Fig. 28). The concentration of Se in bass (0.70 µg/g ww) exceeded guidelines to protect fish and piscivorous







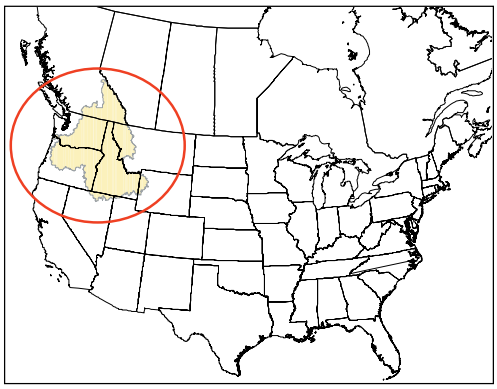
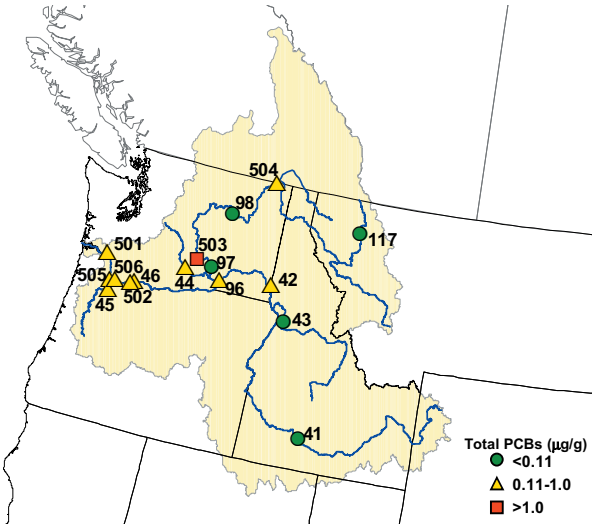


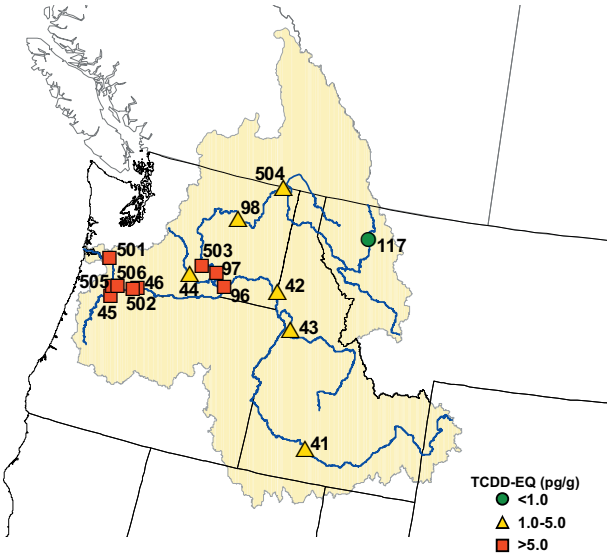
Figure 31. Maximum concentrations (µg/g ww) of total DDT (upper panel, *p,p'*-homologs), toxaphene (middle panel), and total chlordanes (lower panel, sum of six components) in composite samples of whole fish. Concentrations of total DDT of 0.15 µg/g ww are potentially harmful to the brown pelican (Pelicanus occidentalis), the most sensitive avian species (Anderson, 1975), and 1–3 µg/g ww is potentially harmful to other piscivorous birds (Blus, 1996). For toxaphene, reviews by Jarvinen and Ankley (1999) and Eisler and Jacknow (1985) noted acute and chronic effects on freshwater fish at whole-body concentration ≥0.04 µg/g ww. For chlordane, concentrations >0.1 µg/g ww may affect the health of predatory fish and piscivorous birds (Eisler, 1990). See Table 3 for station descriptions and text for explanation of chlordane components.

wildlife (Lemly, 1996). Fish from Station 503 had among the greatest PCB concentrations measured in the CRB with a geometric station mean of 0.49 µg/g ww (Fig. 32). TCDD-EQs in all fish samples were also greater than the dietary threshold for avian wildlife (5 pg/g) (Nosek and others, 1992). Mean EROD activity in male carp (10.9 pmol/min/mg) exceeded criteria from the 1995 BEST MRB project (Schmitt and others, 2002b), while mean EROD activity in the other fish from this site were not of concern (Fig. 29). Two fish health indicators, external lesions and HSI, were anomalous at in fish Station 503. External lesions were identified in 86% of carp and 80% of northern pikeminnow with most abnormalities being attributed to frayed or hemorrhagic fins, conditions that are not necessarily a result of contaminant exposure. The greatest mean HSI (2.33%) in the CRB was measured in female bass. Concentrations of vtg >0.01 mg/mL were measured in two male carp (0.02 mg/mL and 0.04 mg/mL), which is a concentration indicative of an estrogenic response to environmental conditions (Fig. 30). The mean concentration of vtg in female bass (14.3 mg/mL) was at least two times greater than bass from other CRB stations.

Station 97 (Pasco, Washington)

Fish at Station 97 had several contaminants and one





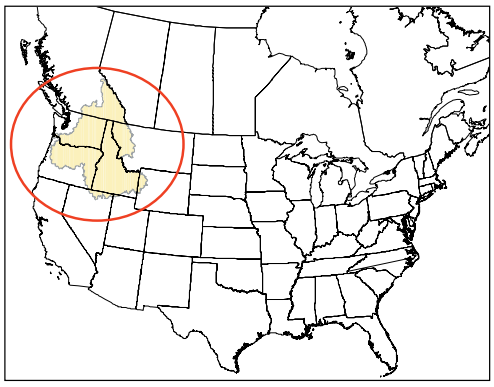


Figure 32. Maximum concentrations of PCBs (µg/g ww, upper panel) and TCDD-EQ (pg/g, lower panel) in composite samples of whole fish. The NYSDEC wildlife guideline for total PCBs is 0.11 µg/g ww (Newell and others, 1987). TCDD-EQ levels >5 pg/g are potentially toxic to piscivorous avian and mammalian consumers wildlife, but the threshold for toxicity to fish is approximately 35 pg/g (Nosek and others, 1992). See Table 3 for station descriptions.

reproductive biomarker highlighted (Table 34). Female bass had a concentration of Hg (0.18 µg/g ww) that exceeded the criteria shown to cause reproductive problems in mallards (Heinz, 1979) (Fig. 28). Concentrations of Se from bass and carp (>0.8 µg/g ww) were the greatest measured in the CRB and exceeding guidelines to protect fish and piscivorous wildlife (Lemly, 1996). The TCDD-EQ for male and female bass and male carp exceeded 5 pg/g, the dietary threshold for avian wildlife (Nosek and others, 1992). EROD activity exceeding levels determined in the BEST 1995 MRB study for individual male and female bass, but the station means did not exceed the criteria (Fig. 29). Fish health indicators appeared normal at Station 97, and vtg was the only anomalous reproductive indicator. The concentration of vtg (0.67 mg/mL) in one male bass greatly exceeded detection limits and indicated that this male had an estrogenic response to environmental conditions at this site (Fig. 30). Both male and female bass had the greatest individual concentrations of vtg measured in the CRB.

Station 44 (Granger, Washington)

Multiple contaminants and several fish health indicators were highlighted in fish at Station 44 (Table 34). Concentrations of Hg in bass (>0.17 µg/g ww), carp (0.16 µg/g ww), and northern pikeminnow (0.48 µg/g ww) exceeded one or more guidelines to protect wildlife (Barr, 1986; Heinz, 1979) (Fig. 28). Fish from Station 44 had some of the greatest concentrations of *p,p'*-DDE including male carp (1.0 µg/g ww), male and female bass (>0.9 µg/g ww), and female northern pikeminnow (0.8 µg/g ww). These concentrations of *p,p'*-DDE exceeded one or more wildlife guidelines (Anderson and others, 1975; Jarvinen and Ankley, 1999; Newell and oth-

ers, 1987). Concentrations of PCBs in male carp (0.16 µg/g ww), male and female bass (0.12-0.62 µg/g ww), and female northern pikeminnow (0.17 µg/g ww) exceeded the NYSDEC wildlife guideline of 0.11 µg/g ww (Newell and others, 1987). Dioxin-like activity was detected in fish samples from Station 44 but did not exceed criteria (5 pg/g) (Nosek and others, 1992). EROD activity exceeded basal levels for individual bass and carp, but the station means did not exceed the criteria (Fig. 29). External lesions and HAI were the only fish health indicators of concern at Station 44. External lesions were identified on 100% of the fish from Station 44 although most of the abnormalities were attributed to frayed or split fins. Other lesions included body surface abnormalities and hemorrhagic eyes. These external lesions, liver abnormalities (nodules and focal discoloration), and kidney abnormalities (granular appearance and white nodules) were the main contributors of the inflated HAI scores (>130) of bass and were a result of helminth parasites and myxosporidian parasites. No reproductive biomarkers were anomalous in fish at Station 44.

Lower Columbia River (LCR)

Stations 46, 502, 506, 45, 505, and 501 were included in the LCR. Male and female largescale sucker were collected from all stations except Stations 45 and 502 where only female fish were collected. Carp were collected from Stations 45 (male and female), 501 (male), and 502 (male and female). Male and female bass were collected from Stations 502, 505, and 45, and Station 506 had a single male bass. Female northern pikeminnow were collected from Station 46, 502, 505, and 501; Station 501 was the only station where male northern pikeminnow were collected. All of the LCR stations were sampled in late November in 1997 except for Station 506 and 501, which were sampled in early April 1998.

Previously, the LCR has been the focus of many contaminant studies. Numerous water quality impairments due to nutrients, metals, *p,p'*-DDT, *p,p'*-DDE, dieldrin, phthalates, and PCBs have been reported in the LCR (ODEQ, 2000; USEPA, 2002b). Fish consumption advisories have been issued for *p,p'*-DDT, dioxins, and PCBs in all freshwater fish and for PCBs in shellfish and crayfish in the LCR. Specifically, the Willamette River has several fish consumption advisories for As, Hg, dioxins, organochlorinated pesticides, creosote, and PCBs (USEPA, 2003a). A previous study determined pesticides in water, dioxin, and metals in some sediment samples, and a host of organic and inorganic contaminants in the tissues of fish and wildlife were of concern from the mouth of the river to Bonneville Dam (LCREP, 1991). The Bi-State Water Quality Program found strong evidence that many of the contaminants present in the LCR had the potential to have negative effects on wildlife and sediments in select locations containing heavy metals, organochlorine pesticides, dioxins and furans and other organic compounds (Tetra Tech Inc., 1996). The NAWQA program also found many contaminants including PCBs, chlordane, *p,p'*-DDT, and Hg were of concern in the LCR (Wentz and others, 1998; Wong and others, 2000).

Station 46 (Cascade Locks, Oregon)

Fish at Station 46 had a minimal number of contaminants and biomarkers of concern (Table 34). The concentration of Hg in female largescale sucker (0.13 µg/g ww) exceeded criteria shown to cause reproductive problems in mallards (Heinz, 1979) (Fig. 28). Female largescale sucker also had concentrations of PCBs (0.13 µg/g ww) that exceeded the NYSDEC wildlife guideline of 0.11 µg/g ww, and a TCDD-EQ of 10 pg/g exceeded the dietary threshold (5 pg/g) for avian wildlife (Nosek and others, 1992). Station mean EROD activity exceeded 10 pmol/min/mg for male (14.1 pmol/min/mg) and female (19.5 pmol/min/mg) largescale sucker indicating exposure to exogenous AhR agonists (Fig. 29). External lesions were identified on 81% of the largescale sucker from Station 46. Most of these abnormalities were attributed to frayed or hemorrhagic fins, which may be an artifact of holding time after capture. Trace concentrations of vtg (0.02 mg/mL) were measured in male largescale sucker from Station 46 (Fig. 30).

Station 502 (Warrendale, Oregon)

Multiple contaminants and biomarkers were of concern in fish at Station 502 (Table 34). Contaminant analyses were not performed on largescale sucker from Station 502. Concentrations of Hg in female carp, male bass, and female northern pikeminnow exceeded criteria (0.1 µg/g ww) shown to cause reproductive problems in mallards (Heinz, 1979) (Fig. 28). Concentrations of PCBs in all fish exceeded the NYSDEC wildlife guideline of 0.11 µg/g ww (Newell and others, 1987). Dioxin-like activity (TCDD-EQ) was detected in all fish samples and exceeded the dietary threshold (5 pg/g) for avian wildlife (Nosek and others, 1992) in female carp and northern pikeminnow. EROD activity exceeded levels determined in the BEST 1995 MRB study for individual bass, carp, and largescale sucker, and the station means exceeded the criteria for male carp and female largescale sucker (Fig. 29). External lesions were the only fish health indicator to be highlighted in fish at Station 502. External lesions were identified on >84% of all fish examined with most lesions being attributed to frayed or hemorrhagic fins. Concentrations of vtg were >0.01 mg/mL in three male carp (0.01-0.04 mg/mL) from Station 502 (Fig. 30). These concentrations indicate that multiple male fish had an estrogenic response to environmental conditions at this station. In addition, two of three male bass had ovotestes, although other reproductive biomarkers (that is, GSI and vtg) for these individual fish appeared normal. The only other fish identified as having ovotestes were male bass from Station 42.

Station 506 (Vancouver, Washington)

Fish at Station 506 had a limited number of contaminants and biomarkers that were of concern (Table 34). The average concentration of Hg in male largescale sucker was 0.1 µg/g ww, a concentration shown to cause reproductive problems in mallards (Heinz, 1979) (Fig. 28). However, female largescale sucker had concentrations of Hg less than the criteria. Largescale sucker from Station 506 were the only samples that had toxaphene (0.05 µg/g ww), mirex (0.01 µg/g ww), and endrin (0.01 µg/g ww). The concentration of PCBs in female largescale sucker exceeded the NYSDEC wildlife guideline of 0.11 µg/g ww (Newell and others, 1987) and was one of the highest concentrations (0.75 µg/g ww) measured in the CRB. The TCDD-EQ value for female largescale sucker also exceeded 5 pg/g, the dietary threshold for avian wildlife (Nosek and others, 1992). External lesions were the only fish health indicator of concern at Station 506. External abnormalities were described in 76% of largescale sucker, with most lesions identified as body surface scars or hemorrhagic or frayed fins. No reproductive biomarkers were anomalous at Station 506.

Station 45 (Oregon City, Oregon)

Several contaminants and biomarkers in fish at Station 45 were at concentrations or levels that were of concern (Table 34). Concentrations of Hg in male and female bass, female carp, and female largescale sucker exceeded criteria (0.1 µg/g ww) shown to cause reproductive problems in mallards (Heinz, 1979) but less than criteria (0.3 µg/g ww) shown to cause reproductive impairment in loons (Barr, 1986) (Fig. 28). Concentrations of PCBs in bass and largescale sucker were less than protective criteria (0.11 µg/g ww), but male and female carp had concentrations >0.27 µg/g ww. Male bass and carp had TCDD-EQs that exceeded the dietary threshold for avian wildlife (5 pg/g) (Nosek and others, 1992). Mean station EROD activity exceeded levels for bass, carp, and largescale sucker (Schmitt and others, 2002b) (Fig. 29). The station mean EROD activity female carp (10.3 pmol/min/mg) was the greatest measured in the CRB. External lesions were identified on 87% of the fish collected from Station 45 with most abnormalities identified as body surface lesions and frayed fins. Bass were also identified as having multiple HAI scores >100. Many of these scores were attributed to abnormalities in the liver (nodules and discoloration), kidneys (nodules), and fins (frayed). The external lesions collected for histology, as well as nodules and discolored areas in the liver and spleen were a result of helminth parasites. Kidney lesions were due to helminth and myxosporidian parasites. Trace concentrations of vtg (0.01 mg/mL) were measured in male carp from Station 45 (Fig. 30).

Station 505 (Portland, Oregon)

Multiple contaminants and biomarkers were highlighted in fish at Station 505 (Table 34). Concentrations of Hg in bass and largescale sucker exceeded criteria (0.1 µg/g ww) known to cause reproductive problems in mallards (Heinz, 1979). Concentrations of PCBs in bass and largescale sucker exceeded the NYSDEC wildlife guideline of 0.11 µg/g ww (Newell and others, 1987). TCDD-EQs in female bass and largescale sucker exceeded 5 pg/g, but male bass and largescale sucker did not exceed the dietary threshold for avian wildlife (Nosek and others, 1992). Bass and largescale sucker from Station 505 had the greatest mean station EROD activities determined in the CRB with individual EROD activities >50 pmol/min/mg. Over 75% of bass and largescale sucker were identified as having external lesions. Most of these abnormalities were defined as body surface lesions and frayed or hemorrhagic fins. These types of lesions are not necessarily indicative of exposure to environmental contaminants. Vitellogenin was the only reproductive biomarker of concern at Station 505 with male largescale sucker having trace concentrations of vtg (Fig. 30).

Station 501 (Beaver Army Terminal, Oregon)

Fish at Station 501 had few contaminants and one fish health indicator of concern (Table 34). All inorganic contaminants were less than criteria set to protect piscivorous fish and other wildlife. Concentrations of *p*,*p'*-DDE in male carp and male and female largescale sucker (>0.5 µg/g ww) exceeded several wildlife guidelines (Anderson and others, 1975; Jarvinen and Ankley, 1999; Newell and others, 1987). Concentrations of PCBs in male carp, male largescale sucker, and female northern pikeminnow exceeded the NYSDEC wildlife guideline of 0.11 µg/g ww (Newell and others, 1987). A female northern pikeminnow was the only sample to have a TCDD-EQ that exceeded 5 pg/g, the dietary threshold for avian wildlife (Nosek and others, 1992). Most carp (100%), largescale sucker (82%), and northern pikeminnow (92%) from Station 501 were identified as having external lesions. These abnormalities were categorized as frayed fins in most fish, a condition that may be associated with holding time prior to fish processing. Reproductive indicators were not at levels or concentrations of concern at Station 501.

Correlations Between Contaminant Concentrations and Biological Endpoints

Spearman Rank correlations were examined to determine if chemical concentrations were related to biomarker responses in the CRB (Table 35). Correlations are reported for each gender and species. Ideally the analysis would only include samples above known levels of concerns for both chemical concentrations and biomarker responses. The limited sample

Table 35. Statistically significant Spearman Rank correlations (P <0.05) between biomarkers and contaminants. See text for biomarker definitions. [1]Black text, positive correlations; red text, negative correlations. [2]Genders were not combined in this analysis because many biomarker differed between males and females. [3]Percent atresia was measured in females only. Samples <LOD and samples sizes <5 were excluded from this analysis. m, male; f, female; b, bass; c, carp; s, largescale sucker.

Biomarker[1, 2]	Total DDT	PCBs	TCDD-EQ	Cd	Cr	Cu	Fe	Hg	Pb	Se	Zn
Age	fc, ms	fs						fb			
Total Length		fc		fs							fs, ms
Weight		fc		mc							fs, ms
Condition Factor		mb		mc							mc
SSI	ms	fc	fb, mb			fb					fc, fs
HSI						mb					
GSI						mb		ms			
MEANAREA						mb	mc		ms	fc	
MAMM			mc				fc, mc				
TISSOC	fc		mc				mc				
Atresia[3]	fc					fb					
HAI	mb		ms	ms	ms		mb	fc	fs		
Vtg							mb, fc				
EROD								fb			

size of the CRB data does not allow for this inclusion. Contaminant and biomarker data <LOD and with sample sizes less than were excluded from the analysis. Multiple biomarker responses were found to be correlated with contaminant concentrations, but few correlations were present in more than one species, genders, or both (Table 35). These correlations are difficult to interpret because many of them cannot be readily explained from a contaminant aspect, and expected correlations (that is, EROD and PCBs or TCDD-EQ) were not significant. This may be due to the limited sample size of this study. In the future, this monitoring program hopes to combine data from all BEST projects and further explore correlations of biomarker responses to contaminant concentrations.

Summary and Conclusions

Overall, fish from the MCR and LCR had greater concentrations of organochlorine contaminants (total *p,p'*-DDT, PCBs) than fish from the UCR. These results are consistent with other studies from the CRB. PCBs and *p,p'*-DDE were the only contaminants where temporal trends could be evaluated. Concentrations of PCBs had declining trends in fish samples at all stations where data were available. This pattern was not reflected for *p,p'*-DDE which remained fairly consistent from 1969 to 1997. Except for Hg, Se, and Pb, concentrations of elemental contaminants were relatively low and stable or declining relative to historical levels in fish samples at most sites. Concentrations of Hg were elevated in bass and northern pikeminnow from the Salmon River at Riggins, Idaho (Station 43) and from several other sites including Granger, Washington (Station 44) and Cascade Locks, Oregon (Station 46). Concentrations of Pb in largescale sucker remained comparable to high historical concentrations near Northport, Washington (Station 504) and Grand Coulee, Washington (Station 98), stations located downstream from a Pb smelter located in British Columbia. Concentrations of Se in fish also remained high enough to constitute a hazard to piscivorous wildlife at Riggins, Idaho (Station 43), Vernita Bridge, Washington (Station 503), and Pasco, Washington (Station 97). Elevated concentrations of Se near Pasco, Washington had been reported previously.

Concentrations of PCBs and TCDD-EQ were low in most CRB samples, but EROD rates in bass, carp, and largescale sucker exceeded threshold levels reported in the 1995 BEST MRB report (Schmitt and others, 2002b) and reflected exposure to exogenous AhR ligands at most sites. These results indicate that fish from some CRB sites were likely exposed to EROD-inducing chemicals other than PCBs, dioxins, and furans. A number of PAHs are known inducers of EROD activity, and some can have increased toxicity following CYP1A metabolism. However, the EROD activities measured in most CRB fish were low relative to levels reported in bass and carp from other river basins in the U.S. (Schmitt and others, 2002b; Whyte and others, 2000).

Discernable spatial patterns of contaminant exposure were not evident in the CRB; however, results at specific stations indicate that fish throughout the CRB were exposed to a variety of contaminants. The enlarged spleens and prevalence of external lesions (excluding fin abnormalities) in the fish from the UCR suggest that the fish were diseased, possibly as a consequence of immune suppression caused by chemical exposure (Anderson and others, 1989; Hutchinson and Manning, 1996), but other factors such as age, size, growth rate, and gonadal development may have been involved (Krykhitin, 1976; Ruklov, 1979). Many of the external lesions were proliferative responses of epidermal or mucous cells in the epidermis or inflammatory responses in the dermis due to parasites or undetermined causes. Many of the internal abnormalities were due to helminth or myxosporidian parasites. Immune suppression could play a role in these infections, however the

presence and density of intermediate hosts in an ecosystem is also an important factor. Enlarged livers were found in female bass at Vernita, Washington (Station 503). The relatively small spleen size of fish from stations throughout the CRB is a condition that has been associated with exposure to a number of different chemicals including petroleum products and metals (Schmitt and Dethloff, 2000). Male bass with ovotestes were found at the Snake River near Lewiston, Idaho (Station 42) and Columbia River near Warrendale, Oregon (Station 502). Similar ovotestes have been induced in males of other species exposed to organochlorine pesticides, natural and synthetic estrogens, and sewage in controlled laboratory and field studies although many factors may be involved (Jobling and others, 1998; Purdom and others, 1994; Wester and Canton, 1986). The incidence of ovotestes may have been underestimated by examining only a small proportion of the gonad of each fish. Male bass, carp, and largescale sucker containing low concentrations of vtg were relatively common, but males with comparatively high concentrations of vtg (that is, levels typical of early- mid-vitellogenic females) were also collected from Creston, Montana (Station 117), Grand Coulee, Washington (Station 98), and Pasco, Washington (Station 97). Biomarkers can be induced in fish by exposure to contaminants although a wide variety factors can cause these conditions (see reviews in Schmitt and Dethloff, 2000).

Multiple species representing various trophic levels should be included in biomonitoring programs. Previous studies have found that chemical accumulation and biomarker patterns are species specific. Bass, carp, and largescale sucker from the CRB varied in contaminant accumulation and levels of effect for biomarkers in the present study. Concentrations of Hg in the CRB accumulated more in bass than in carp and sucker as reported in other studies (Schmitt and others, 2002b; 2004). Conversely, carp and sucker had greater concentrations of Cd, Cu, Cr, and Ni compared to bass, and concentrations of Zn in carp were consistently four to five times greater than other species. Concentrations of pesticides were similar among bass, carp, and largescale sucker. EROD activities in carp were less than in bass and sucker throughout the CRB. Condition factor was greatest in bass and lowest in sucker, whereas SSI was lower bass than carp and sucker. Macrophage aggregate were similar in bass, carp, and sucker in the CRB in 1997. For reproductive indicators, GSI and atresia were greater in carp than in bass and sucker. However, vtg was much greater in sucker than in bass or carp. Results from this study demonstrate that evaluating multiple species from different levels of the food chain allows for a better understanding of how environmental contaminants affect biota. Results from this study also suggest that continued monitoring is warranted in the CRB. Various sites within the basin had concentrations that are potentially problematic to wildlife. Focused investigations are needed to further define contaminants and their effects on fish in the CRB.

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Appendix 1.

Appendix 1. Lengths, weights, and ages of non-target species collected in the Columbia River Basin in 1997. Stations are grouped by sub-basin and listed upstream to downstream. Station numbers are given in parentheses. Sample size (*n*), arithmetic mean, standard deviation (SD), and range are also given. Fish in which gender could not be determined are identified as having no gonad (NG) or juveniles (J).—Continue

Sub-basin and Station	Taxa	Gender	Length (mm)				Weight (g)				Age (years)			
			n	Mean	SD	Range	*n*	Mean	SD	Range	*n*	Mean	SD	Range
Entire Basin	Northern pikeminnow	All	58	444	69.6	322-582	58	829	374	263-1624	49	8.7	2.33	5-14
		F	48	457	68.6	327-582	48	885	379	263-1624	41	9.1	2.19	6-14
		M	10	382	28.7	322-425	10	558	192	300-900	8	6.6	0.92	5-8
	Longnose sucker	All	15	404	65.0	296-505	15	705	323	233-1326	15	4.1	0.70	3-6
		F	11	416	51.6	331-505	11	744	251	361-1176	11	4.1	0.70	3-6
		M	2	443	73.5	391-495	2	938	549	550-1326	2	4.5	0.71	4-5
		NG	2	298	2.8	296-300	2	255	30	233-276	2	3.5	0.71	3-4
	Rainbow trout	All	20	387	104	235-540	20	660	460	125-1576	20	2.2	1.04	1-5
		F	10	375	111	235-533	10	646	529	125-1576	10	2.5	1.18	1-5
		M	2	504	50.9	468-540	2	1084	250	907-1260	2	2.5	0.71	2-3
		NG/J	8	374	92.6	238-490	8	571	380	125-1103	8	1.6	0.74	1-3
	Walleye	All	17	370	49.3	297-505	17	455	282	208-1428	17	2.5	0.80	2-5
		F	9	376	55.8	313-505	9	487	367	208-1428	2.6	2.5	1.01	2-5
		M	4	396	21.4	372-423	4	493	41	444-541	4	2.5	0.58	2-3
		NG/J	4	329	30.5	297-368	4	344	209	214-652	4	2.5	0.58	2-3
Upper Columbia River (UCR)														
Creston, MT (117)	Longnose sucker	F	10	411	52.0	331-505	10	730	260	361-1176	10	4.1	0.74	3-6
		M	1	495	--	--	1	1326	--	--	1	5.0	--	--
		NG	2	298	2.8	296-300	2	255	30	233-276	2	3.5	0.71	3.4
Northport, WA (504)	Rainbow trout	F	10	375	111	235-533	10	646	529	125-1576	10	2.5	1.18	1-5
		M	2	504	50.9	468-540	2	1084	250	907-1260	2	2.5	0.71	2-3
		J	8	374	92.6	238-490	8	571	380	125-1103	8	1.6	0.74	1-3
Grand Coulee, WA (98)	Walleye	F	8	360	29.8	313-407	8	369	106	208-544	8	2.3	0.46	2-3
		M	4	396	21.4	372-423	4	455	41	208-1428	4	2.5	0.58	2-3
		J	4	329	30.5	297-368	4	344	209	214-652	4	2.5	0.58	2-3
	Longnose sucker	F	1	462	--	--	1	889	--	--	1	4.0	--	--
		M	1	391	--	--	1	550	--	--	1	4.0	--	--
Snake River (SR)														
Riggins, ID (43)	Northern pikeminnow	F	9	406	37.7	347-464	9	655	230	275-975	8	7.8	1.28	6-10
		M	5	367	25.3	322-385	5	600	245	300-900	4	6.8	0.96	6-8

Appendix 1. Lengths, weights, and ages of non-target species collected in the Columbia River Basin in 1997. Stations are grouped by sub-basin and listed upstream to downstream. Station numbers are given in parentheses. Sample size (*n*), arithmetic mean, standard deviation (SD), and range are also given. Fish in which gender could not be determined are identified as having no gonad (NG) or juveniles (J).—Continued

Sub-basin and Station	Taxa	Gender	Length (mm)				Weight (g)				Age (years)			
			n	Mean	SD	Range	*n*	Mean	SD	Range	*n*	Mean	SD	Range
Middle Columbia River (MCR)														
Vernita Bridge, WA (503)	Northern pikeminnow	F	8	488	31.6	438-532	8	1039	181	785-1232	8	10.6	1.41	9-13
		M	2	423	3.5	420-425	2	652	49	617-687	2	7.0	0.00	7
Granger, WA (44)	Northern pikeminnow	F	5	413	58.5	327-491	5	601	267	263-1005	5	6.8	1.10	6-8
		M	1	371	--	--	1	419	--	--	1	5.0	--	--
Lower Columbia River (LCR)														
Cascade Locks, OR (46)	Northern pikeminnow	F	2	541	12.0	532-549	2	1479	94	1411-1546	1	8.0	--	--
Warrendale, OR (502)	Northern pikeminnow	F	11	514	39.0	377-582	11	1143	401	432-1624	10	11.0	2.50	6-14
Portland, OR (505)	Northern pikeminnow	F	2	363	17.7	350-375	2	371	46	338-403	0	--	--	--
	Walleye	F	1	505	--	--	1	1428	--	--	1	5.0	--	--
Beaver Army Terminal, OR (501)	Northern pikeminnow	F	11	442	55.1	356-531	11	819	332	325-1386	10	8.7	1.34	7-11
		M	2	384	16.3	372-395	2	430	98	360-499	2	7.0	0.00	7

Appendix 2.

Appendix 2. Fish health indicators for non-target species collected in the Columbia River basin in 1997. Arithmetic mean, number of samples (*n*), minimum (min.), maxiumum (max.), and standard error (SE) are given for gonadosomatic index (GSI; %), splenosomatic index (SSI; %), condition factor (CF), and health assessment index (HAI). Stations are grouped by taxon and ordered upstream to downstream. Fish with undetermined gender from which no gonad was obtained are listed as juvenile.

Taxon and	Female					Male					Juvenile				
Station	*n*	Mean	Min.	Max.	SE	*n*	Mean	Min.	Max.	SE	*n*	Mean	Min.	Max.	SE
Northern pikeminnow															
Riggins, ID (43)															
GSI	9	2.44	1.71	3.42	0.2	5	0.51	0.31	0.82	0.1	0	--	--	--	--
SSI	9	0.11	0.08	0.17	0.0	5	0.10	0.05	0.16	0.0	0	--	--	--	--
CF	9	0.94	0.59	1.04	0.0	5	1.19	0.88	1.67	0.2	0	--	--	--	--
HAI	9	52.2	30	70	4.9	5	64.0	30	120	19.1	0	--	--	--	--
Vernita Bridge, WA (503)															
GSI	8	2.63	2.01	3.46	0.2	2	0.67	0.66	0.67	0.0	0	--	--	--	--
SSI	8	0.16	0.11	0.25	0.0	2	0.19	0.18	0.19	0.0	0	--	--	--	--
CF	8	0.89	0.79	1.00	0.0	2	0.87	0.80	0.93	0.1	0	--	--	--	--
HAI	8	47.5	10	100	9.6	2	30.0	30	30	0.0	0	--	--	--	--
Granger, WA (44)															
GSI	5	1.83	0.66	2.42	0.3	1	0.82	--	--	--	0	--	--	--	--
SSI	5	0.17	0.13	0.26	0.0	1	0.17	--	--	--	0	--	--	--	--
CF	5	0.80	0.75	0.85	0.0	1	0.82	--	--	--	0	--	--	--	--
HAI	5	130.0	100	160	9.5	1	130	--	--	--	0	--	--	--	--
Cascade Locks, OR (46)															
GSI	2	3.23	3.18	3.28	0.1	0	--	--	--	--	0	--	--	--	--
SSI	2	0.31	0.25	0.36	0.1	0	--	--	--	--	0	--	--	--	--
CF	2	0.94	0.85	1.03	0.1	0	--	--	--	--	0	--	--	--	--
HAI	2	5.0	0	10	5.0	0	--	--	--	--	0	--	--	--	--
Warrendale, OR (502)															
GSI	11	3.21	2.02	6.27	0.3	0	--	--	--	--	0	--	--	--	--
SSI	11	0.14	0.09	0.19	0.0	0	--	--	--	--	0	--	--	--	--
CF	11	0.81	0.50	1.01	0.0	0	--	--	--	--	0	--	--	--	--
HAI	11	90.0	10	160	11.7	0	--	--	--	--	0	--	--	--	--
Portland, OR (505)															
GSI	2	1.21	1.07	1.35	0.1	0	--	--	--	--	0	--	--	--	--
SSI	2	0.12	0.11	0.13	0.0	0	--	--	--	--	0	--	--	--	--
CF	2	0.78	0.76	0.79	0.0	0	--	--	--	--	0	--	--	--	--
HAI	2	85.0	70	100	15.0	0	--	--	--	--	0	--	--	--	--
Beaver Army Terminal, OR (501)															
GSI	11	4.14	2.40	6.58	0.4	2	1.43	1.09	1.78	0.3	0	--	--	--	--
SSI	11	0.15	0.10	0.19	0.0	2	0.20	0.18	0.22	0.0	0	--	--	--	--
CF	11	0.89	0.70	0.96	0.0	2	0.75	0.70	0.81	0.1	0	--	--	--	--
HAI	11	66.4	0	130	9.5	2	50.0	30	70	20.0	0	--	--	--	--
Walleye															
Grand Coulee, WA (98)															
HSI	8	0.77	0.61	0.98	0.0	4	0.65	0.46	0.85	0.1	4	0.97	0.44	1.58	0.2
GSI	8	0.36	0.28	0.46	0.0	4	3.47	3.11	3.78	0.1	4	0.04	0.02	0.05	0.0
SSI	8	0.07	0.05	0.09	0.0	4	0.07	0.04	0.09	0.0	4	0.06	0.04	0.08	0.0
CF	8	0.77	0.68	0.84	0.0	4	0.80	0.71	0.86	0.0	4	0.90	0.68	1.31	0.1
HAI	8	18.8	0	60	7.9	4	27.5	0	70	15.5	4	30.0	0	60	12.2
Portland, OR (505)															
HSI	1	1.71	--	--	--	0	--	--	--	--	0	--	--	--	--
GSI	1	0.32	--	--	--	0	--	--	--	--	0	--	--	--	--
SSI	1	0.11	--	--	--	0	--	--	--	--	0	--	--	--	--
CF	1	1.11	--	--	--	0	--	--	--	--	0	--	--	--	--
HAI	1	30	--	--	--	0	--	--	--	--	0	--	--	--	--

Appendix 2. Fish health indicators for non-target species collected in the Columbia River basin in 1997. Arithmetic mean, number of samples (*n*), minimum (min.), maxiumum (max.), and standard error (SE) are given for gonadosomatic index (GSI; %), splenosomatic index (SSI; %), condition factor (CF), and health assessment index (HAI). Stations are grouped by taxon and ordered upstream to downstream. Fish with undetermined gender from which no gonad was obtained are listed as juvenile.—Continued

Taxon and	Female					Male					Juvenile				
Station	*n*	Mean	Min.	Max.	SE	*n*	Mean	Min.	Max.	SE	*n*	Mean	Min.	Max.	SE
Longnose sucker															
Creston, MT (117)											NG				
GSI	10	6.50	0.59	12.40	1.4	1	5.35	--	--	--	2	0.21	0.16	0.25	0.0
SSI	10	0.28	0.14	0.39	0.0	1	0.33	--	--	--	2	0.15	0.02	0.27	0.1
CF	10	1.01	0.91	1.11	0.0	1	1.09	--	--	--	2	0.96	0.90	1.02	0.1
HAI	10	35.0	0	90	10.2	1	30	--	--	--	2	0	0	0	0.0
Grand Coulee, WA (98)															
GSI	1	7.76	--	--	--	1	5.24	--	--	--	0	--	--	--	--
SSI	1	0.27	--	--	--	1	0.36	--	--	--	0	--	--	--	--
CF	1	0.90	--	--	--	1	0.92	--	--	--	0	--	--	--	--
HAI	1	30	--	--	--	1	100	--	--	--	0	--	--	--	--
Rainbow trout															
Northport, WA (504)															
HSI	10	1.02	0.67	1.40	0.1	2	0.86	0.80	0.92	0.1	8	0.80	0.67	0.96	0.0
GSI	10	1.95	0.05	7.10	0.9	2	4.79	4.44	5.14	0.3	8	0.03	0.01	0.07	0.0
SSI	10	0.10	0.02	0.30	0.0	2	0.11	0.10	0.12	0.0	8	0.07	0.05	0.10	0.0
CF	10	0.98	0.86	1.17	0.0	2	0.84	0.80	0.88	0.0	8	0.93	0.72	1.02	0.0
HAI	10	24.0	0	70	9.8	2	45.0	30	60	15.0	8	16.3	0	60	7.8