Executive Summary

Chapter 1. Introduction

The Western Airborne Contaminants Assessment Project (WACAP) was initiated to determine the risk from airborne contaminants to ecosystems and food webs in western national parks of the United States. From 2002 through 2007, WACAP researchers conducted analysis of the concentrations and biological effects of airborne contaminants in air, snow, water, sediments, lichens, conifer needles, and fish in watersheds in each of eight core parks in the western United States, including Alaska (Figure 1):

1. Noatak National Preserve (NOAT)
2. Gates of the Arctic National Park and Preserve (GAAR)
3. Denali National Park and Preserve (DENA)
4. Olympic National Park (OLYM)
5. Mount Rainier National Park (MORA)
6. Glacier National Park (GLAC)
7. Rocky Mountain National Park (ROMO)
8. Sequoia and Kings Canyon National Parks (SEKI)

The parks included 6 west coast and Alaska parks (NOAT, GAAR, DENA, OLYM, MORA, and SEKI) and 2 parks in the Rocky Mountains (ROMO and GLAC). We selected two sites/lakes for sampling in each park—with the exception of NOAT and GAAR, where we sampled one site in each, as the parks are adjacent—for a total of 14 sites.

Semi-volatile organic compounds (SOCs) and heavy metals were the primary focus of the study. The SOCs fall into four general classes: current-use pesticides (CUPs), North American historic-use pesticides (HUPs), industrial/urban use compounds (IUCs), and combustion byproducts. The primary heavy metal of concern is mercury (Hg).

The seven ecosystem components selected for analysis (air, snow, water, sediments, lichens, conifer needles, and fish) were chosen for several reasons. Concentrations of contaminants in air can readily be compared among sites both within this study and with sites from other studies. In many of the high altitude and high latitude sites studied, snow represents a potentially major pathway for input of contaminants to ecosystems. Lake water samples provide an overview of watershed chemical and physical characteristics that help interpret the contaminants data. Lake bottom sediments show historical patterns of change over time in contaminant deposition. Vegetation samples are used to determine spatial gradients of contaminants, and also provide data on direct uptake of contaminants that accumulate in ecosystems through litterfall. Fish bioaccumulate contaminants in their tissues, resulting in toxic effects in the fish themselves, and in birds, animals, and humans who consume the fish.

WACAP researchers evaluated selected contaminant concentrations in samples from multiple ecosystem components specifically to determine the origin of airborne contaminants and whether these sources are local, regional, or global. In addition, air flow patterns to parks were analyzed

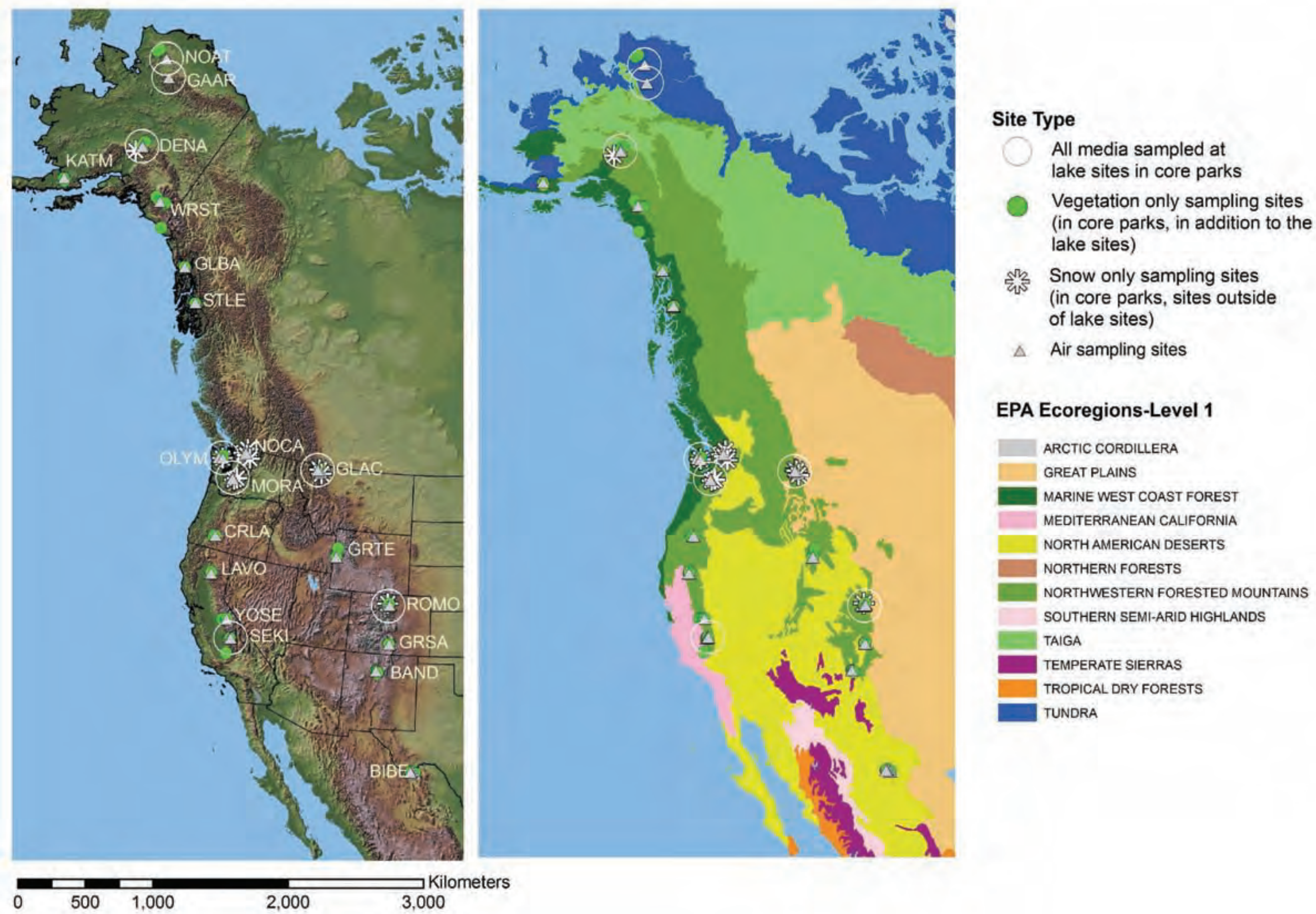


Figure 1. WACAP Sites Mapped on North American Shaded Relief Map and EPA Level 1 Ecoregions (Biomes). See Table 1-4 for key to national park abbreviations. Vegetation-only sampling sites in core parks designate sites used in elevational transect in addition to lake sites. Snow-only sampling sites in core parks designate alternate sampling locations when lake sites could not be reached safely.

through a process known as back-trajectory analysis, to assist in understanding potential sources of contaminants to parks.

The specific objectives that guided the development of WACAP were:

1. Determine if contaminants are present in western national parks.
2. If contaminants are present, determine where they are accumulating (geographically and by elevation).
3. If contaminants are present, determine which ones pose an ecological threat.
4. Determine which indicators appear to be the most useful for assessing contamination.
5. If contaminants are present, determine the source of the air masses most likely to have transported contaminants to the national park sites.

In addition to the 8 core parks sampled, WACAP identified 12 secondary parks (or monuments, preserves, or forests) for expanded spatial and environmental assessment (Figure 1). These locations were identified for collection of samples from three ecosystem components: air, lichens, and conifer needles.

1. Bandelier National Monument (BAND)
2. Big Bend National Park (BIBE)
3. Crater Lake National Park (CRLA)
4. Glacier Bay National Park and Preserve (GLBA)
5. Great Sand Dunes National Park and Preserve (GRSA)
6. Grand Teton National Park (GRTE)
7. Katmai National Park and Preserve (KATM)
8. Lassen Volcanic National Park (LAVO)
9. North Cascades National Park (NOCA)
10. Stikine-LeConte Wilderness, Tongass National Forest (STLE)
11. Wrangell-St.Elias National Park and Preserve (WRST)
12. Yosemite National Park (YOSE)

At all core and secondary parks, vegetation was sampled over an elevational gradient (including core park target watersheds), and passive air sampling devices (PASDs) were deployed for one year.

The WACAP study was designed as a screening study to assess contaminant concentrations across large-scale spatial gradients and temporal scales relevant to western national parks. Future related work, if conducted, might address additional concerns, for example, clarifying the various temporal and spatial dimensions of contaminant pathways and defining and documenting the extent and magnitude of specific ecological effects.

The US Environmental Protection Agency (USEPA), US Geological Survey (USGS), US Forest Service (USFS), Oregon State University, and University of Washington worked in partnership with the National Park Service (NPS) on this assessment. Information acquired through this project is intended to enhance scientific understanding of the global fate, transport, and associated ecological impacts on sensitive ecosystems of airborne contaminants in western parks. It will also help the NPS determine what actions are needed to further understand, mitigate, or communicate impacts of potential effects of contaminants in national parks.

Chapter 2. Park Summaries

Park-specific summaries for the 8 core WACAP parks and the 12 secondary parks provide a quick but in-depth graphical and written overview of the key results from the sites within the parks and show how key variables associated with these sites compare with each other and among results from other parks. Summaries identify key findings specific to each park.

Chapter 3. Contaminants Studied and Methods Used

WACAP researchers measured over 100 different SOCs spanning a wide range of volatility, water solubility, and hydrophobicity, as well as persistence in the environment (Figure 2). Table 3-3 in the body of the report lists the SOCs, including abbreviation, chemical class, and regulatory status. Figure 3-1 provides a summary of the 70 SOCs (excluding PBDEs in fish and sediment) found at detectable levels in WACAP snow, water, vegetation, lake sediment, and/or fish. The SOC physio-chemical properties have been used to interpret the atmospheric transport, deposition, and accumulation of these compounds to the ecosystems assessed in WACAP. Finally, some of the SOCs measured in WACAP have been classified as persistent, bioaccumulative, and toxic (PBT) chemicals by the USEPA. These PBT chemicals include benzo(a)pyrene, aldrin, dieldrin, chlordane, DDT, DDD, DDE, hexachlorobenzene, mirex, and polychlorinated biphenyls (PCBs). As with SOCs, the metals chosen for measurement in WACAP media were selected because they serve as markers for a variety of different sources. These include anthropogenic sources such as coal combustion, petroleum combustion, industrial emissions, agriculture, medical waste, incineration, and automotive sources, as well as natural sources such as sea aerosols, volcanic deposits, and minerals. Mercury is a metal of particular concern because of its detrimental neurological effects, as well as other effects, on humans, fish, and other organisms, and it is classified by USEPA as a PBT chemical.

Because of the remote locations of the WACAP sites, atmospheric transport modeling was an integral part of understanding how the contaminants were transported to the sites. We modeled atmospheric transport via back-trajectory cluster analysis on three different time scales for each of the WACAP core parks. A back-trajectory represents a meteorological calculation of the path that an individual air particle has traveled over a specific time period. By grouping similar trajectories into clusters, we obtained information about the routes of contaminant transport, as well as the climatology for each park.

WACAP researchers assessed snowpack contaminants by sampling the seasonal snowpack from at least 1 site in or near the 14 WACAP core park watersheds during each of the 3 years of the study, in order to analyze inter-annual variability of contaminant loading.

We used PASDs to (1) obtain a measure of SOCs in ambient air by means of a simple, standardized technology to compare loadings between parks and across geographic and elevational gradients, (2) compare PASD and vegetation concentrations, and (3) compare ambient air SOC concentrations in WACAP parks to ambient air concentrations at other national and international locations measured with the same PASD design. In total, 37 PASDs were strategically deployed

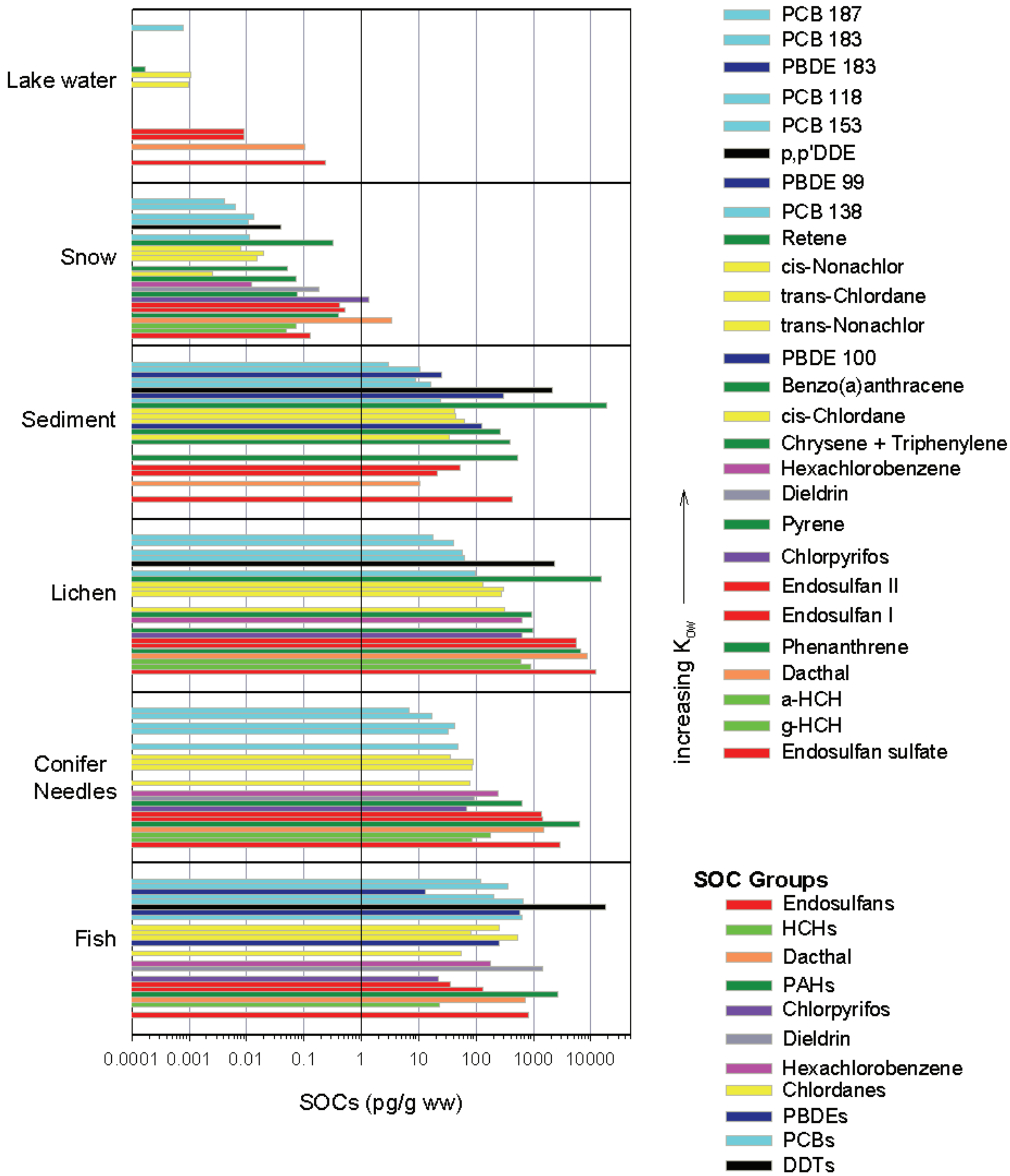


Figure 2. Mean SOC Concentrations (pg/g ww) in Lake Water, Snow, Sediments, Lichens, Conifer Needles, and Fish from Emerald Lake (SEKI). SOCs are ordered by increasing K_{ow}, or decreasing polarity and solubility in water, color-coded by group. SOC concentrations were 3 to 7 orders of magnitude higher in sediments and biota relative to snow and water. SOC concentrations in water, snow, and vegetation, but not sediments and fish, generally decreased with decreasing polarity. Compared to vegetation, fish were better accumulators of PCBs and dieldrin and poorer accumulators of PAHs, endosulfans, HCHs, dacthal, and chlorpyrifos. If no data are shown, all samples were below detection limits; PBDEs were measured in sediments and fish only.

in core and secondary WACAP parks. Multiple PASDs were deployed in the eight core WACAP parks and two of the secondary parks to sample target watersheds and to obtain data along elevational gradients.

We conducted vegetation sampling to (1) determine types and concentrations of SOCs that accumulate in vegetation in each WACAP park, (2) compare individual SOC concentrations within and across parks, especially along latitudinal and elevational gradients, to test for a cold fractionation effect, (3) evaluate metal and nutrient concentrations in lichens in relation to known ranges for lichens at other sites across the western United States, (4) determine the relationship between environmental factors such as geographical location, proximity to urban-industrial and agricultural areas, nitrogen concentrations in ambient particulates, and lichen nitrogen and sulfur content with SOC concentrations in vegetation, and (5) estimate total concentrations of SOCs in conifer needles at WACAP sites as a way of evaluating potential SOC inputs to watersheds via litterfall.

We collected lake water samples from each catchment during the ice-free summer season to characterize the condition of the WACAP lakes by assessing the chemical and physical characteristics of water quality, including trophic state, chemical contamination, and acidification status. Analytes included pH, alkalinity, specific conductance, dissolved organic carbon, dissolved inorganic carbon, chlorophyll-*a*, total nitrogen, total phosphorus, and major cations and anions.

We collected lake sediment cores to provide information about the accumulation and sources of contaminants in the 14 WACAP catchments during the last ~150 years. We dated cores and analyzed sections for SOCs, mercury, metals, total carbon, total organic carbon, and total inorganic carbon. In addition, we assessed spheroidal carbonaceous particles (SCPs) in sediment because they serve as unambiguous indicators of deposition from industrial combustion of fossil fuels, and offer clues as to the source fuel type.

Fish were used as the key bioaccumulators of SOC, Hg, and metal exposure because they are continually immersed in the lake and provide an indication of impacts to the food web. Fish, particularly top predators, are bioindicators of contaminant exposure because they accumulate organic and metal contaminants through their diet. Piscivorous birds and mammals, including humans, bioaccumulate contaminants when they consume fish. Selected biomarkers analyzed for effects on fish condition and health included macrophage aggregates (MA), plasma vitellogenin (Vtg), 11-ketotestosterone, testosterone, estradiol, and gonad, kidney, liver, spleen, and gill histopathology. Contaminant concentrations and fish health analyses were assessed for each fish, allowing a direct correlation of SOC, Hg, and metal concentrations to fish health parameters.

A small number of samples from moose liver and muscle tissue were collected in order to explore the potential for the bioaccumulation of contaminants through the terrestrial food web. Tissues from a total of three moose donated by hunters in Denali National Park and Preserve in 2004 and 2005 were analyzed for mercury, other metals, and SOCs.

Chapter 4. Contaminant Distribution

Spatial patterns of the contaminants found in greatest general abundance within each contaminant category (SOCs, mercury, trace metals, SCPs, nutrients) are as follows.

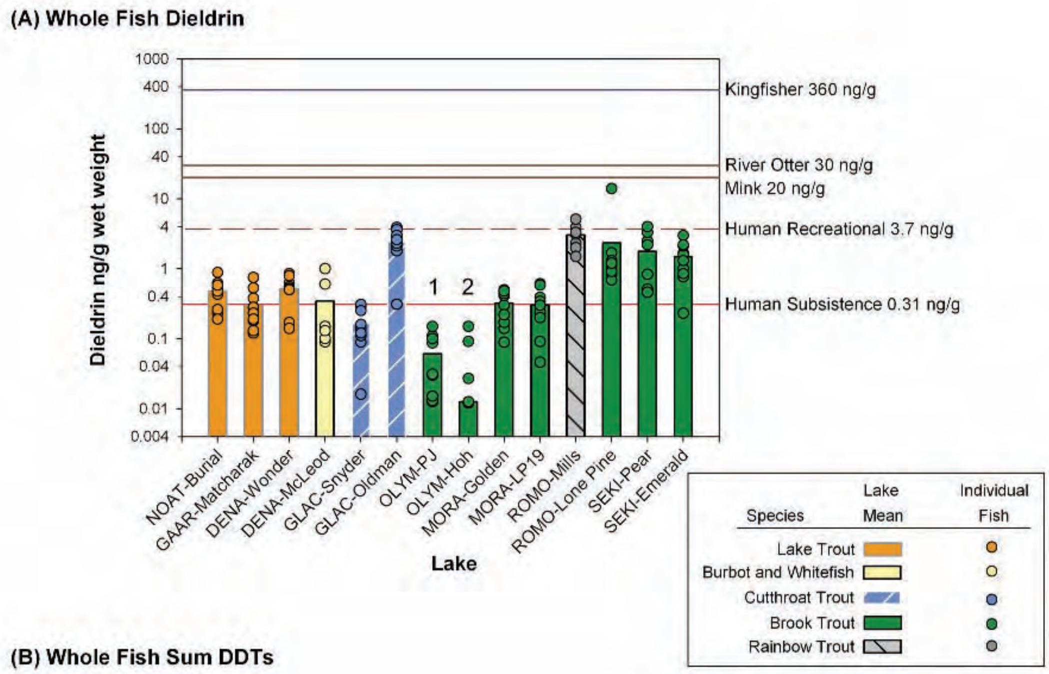
Total SOC concentrations in snow were highest in the Rocky Mountains (GLAC and ROMO) and California (SEKI) parks. This general pattern was often repeated for other ecosystem components. The highest SOC concentrations in vegetation were measured at SEKI, GLAC, YOSE, and GRSA. At parks with the highest SOC concentrations in vegetation, the total SOC concentration was dominated by CUP residues, notably endosulfans and dacthal.

Lichen concentrations of PCBs and many pesticides increased with elevation at most of the WACAP parks for which there were sufficient data, suggesting that these compounds are undergoing cold fractionation. Concentrations of polycyclic aromatic hydrocarbons (PAHs) decreased with increasing elevation at most parks, suggesting an association with wildfires at lower, more heavily wooded elevations. Nitrogen concentrations in lichens from SEKI, GLAC, BAND, and BIBE were elevated, indicating enhanced nitrogen deposition in these parks. Lichen sulfur concentrations indicated enhanced sulfur deposition at SEKI and GLAC.

Fish whole-body lake mean and individual fish concentrations for dieldrin and Sum DDTs (DDT, DDD, and DDE) are shown in Figure 3, along with contaminant health thresholds for humans and piscivorous wildlife. Concentrations of dieldrin in fish (notably at ROMO, SEKI, and GLAC) were significantly elevated compared with those in fish from similar Canadian studies. DDT concentrations in fish from SEKI, GLAC, and ROMO were higher than those reported for many fish elsewhere in the world, including fish from sites in Africa, where DDT is used for mosquito control. Concentrations of the industrial flame retardant compound poly-brominated diphenyl ether (PBDE) in WACAP fish were approximately 3 times higher than concentrations in fish from similar alpine environments in Europe, and concentrations of CUPS in WACAP fish were 2-9 times lower. All WACAP fish had lower PCB, HCH, and HCB concentrations than fish in some recent surveys conducted in other locations of atmospheric contaminants and reported in the literature. Mercury concentrations in fish (Figure 4) from this study were compared with concentrations published in the literature for fish in other areas. In general, mercury concentrations in trout from the parks in this study were lower than those reported for trout in lakes in the Midwest and Northeast United States. However, mercury concentrations were higher in WACAP fish than in some species of fish from northern lakes in Canada and from mountain and sub-Arctic ecosystems in Europe. See Table 5-1 (pages 5-6 through 5-10) in the body of the WACAP report for comparisons of WACAP fish contaminant concentrations to those found in other studies.

At WACAP parks in the conterminous 48 states, strong correlations were found between CUP concentrations in snow and vegetation and percent cropland within 150 km. Concentrations of the CUPs chlordanes, dacthal, and endosulfans in lichens and conifer needles, DDTs in conifer needles, and PAHs in lichens correlated well with agricultural intensity, indicating that most CUP concentrations in these parks are probably attributable to regional agricultural sources. Pesticide deposition in the Alaska parks is attributed to long-range trans-Pacific transport, because there are no significant regional pesticide sources nearby (Figure 5).

Where banned (historic-use) contaminants are found in park ecosystems, concentrations significantly higher than those found in the Alaska parks probably indicate that re-volatilization of persistent compounds is occurring from regional or local soils. Information about probable sources or source areas of atmospherically transported contaminants into parks was assessed from many varied types of data, including atmospheric transport pathways, contaminant spatial patterns, and groupings of types of contaminants.



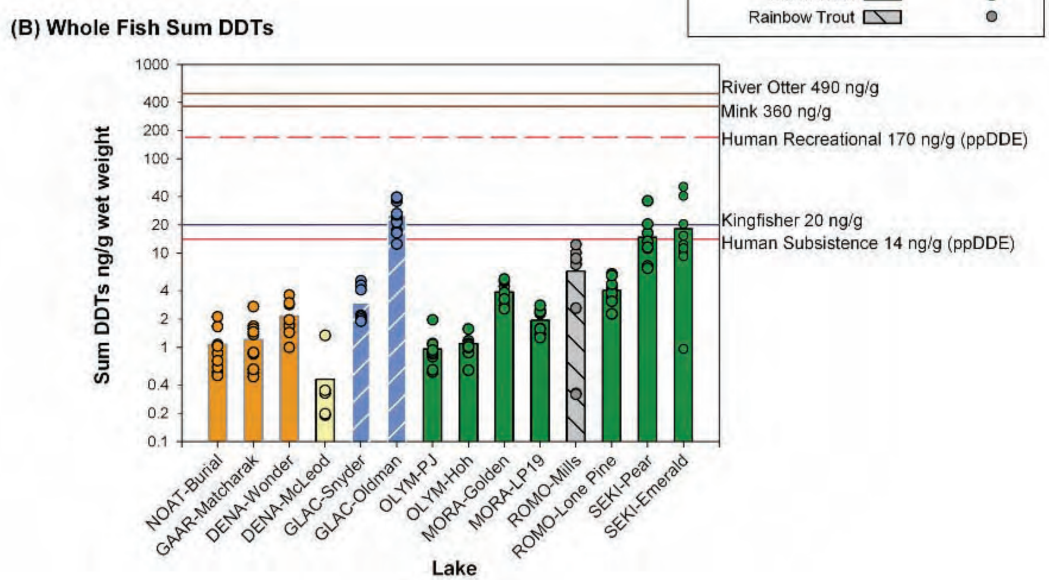


Figure 3. Fish Whole-Body Lake Mean (bars) and Individual Fish (symbols) (A) Dieldrin and (B) Sum DDTs (DDT, DDD, and DDE) Concentrations with Contaminant Health Thresholds for Wildlife and Humans. Mean dieldrin concentrations in fish (A) exceeded human contaminant health thresholds for subsistence fishers in 9 WACAP lakes, and some fish in 4 lakes exceeded the thresholds for recreational fishers; no lakes exceeded health thresholds for piscivorous wildlife. Mean concentrations of sum DDTs (B) in 3 lakes exceeded human contaminant health thresholds for subsistence fishers for p,p,′-DDE, which was the form of DDT most frequently detected in the fish; thresholds for recreational fishers were not exceeded. Some fish in SEKI and the mean concentration of fish in Oldman Lake (GLAC) also exceeded the threshold for kingfishers. If no label is present at the top of a bar, the analyte was detected in at least 70% of the samples. "1" indicates that the analyte was detected in 50-70% of the samples, and "2" indicates that the analyte was detected in less than 50% of the samples. Contaminant health thresholds in piscivorous animals are based on 100% fish in the diet as determined by Lazorchak et al. (2003). See Section 5.4.3 for a description of the human contaminant health thresholds. Data are plotted on a $\log_{10}$ scale and below detection limit values are reported as ½ the EDL.

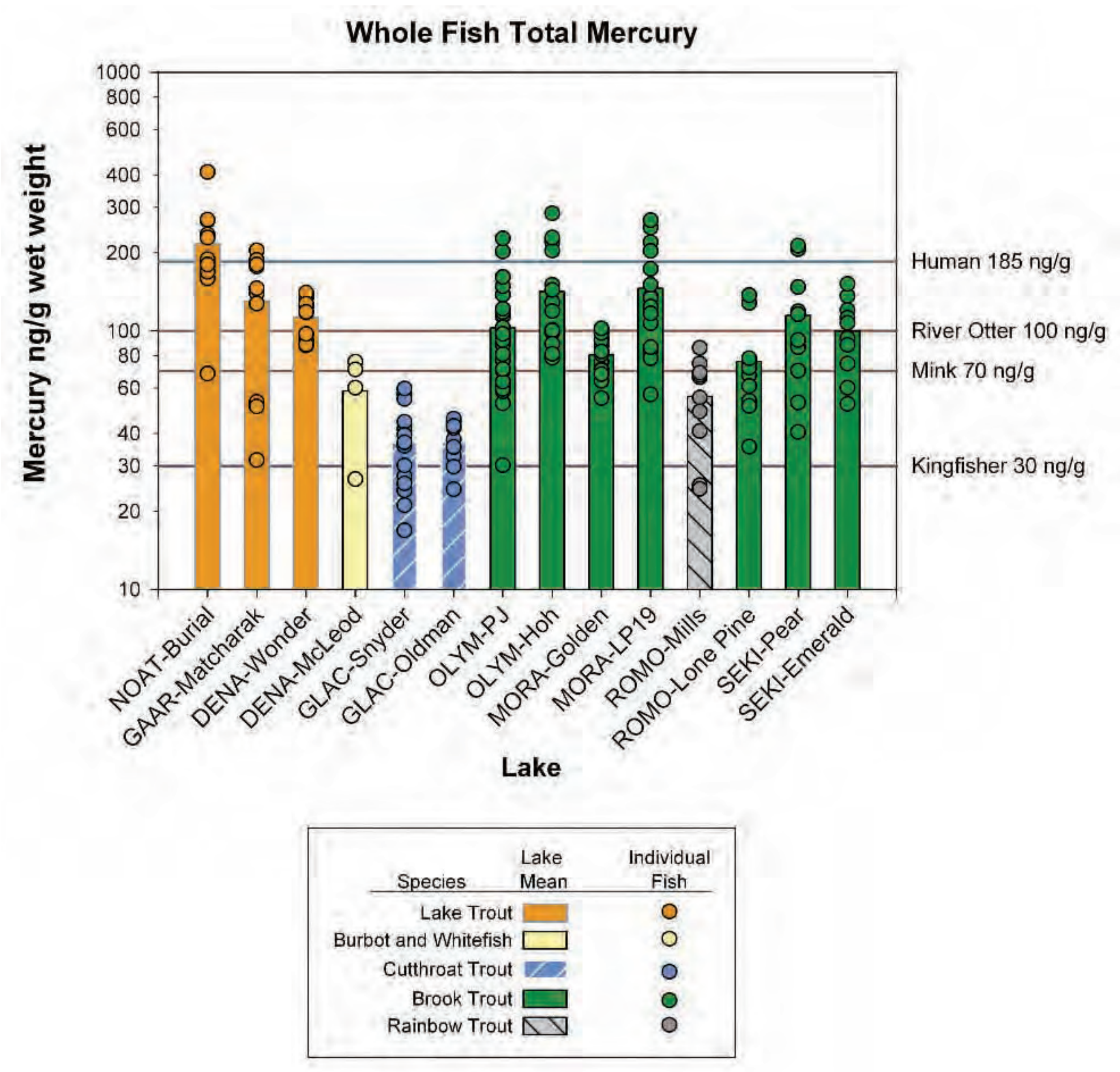


Figure 4. Fish Whole-Body Lake Mean (bars) and Individual Fish (symbols) Total Mercury and Contaminant Health Thresholds for Various Biota. The mean ng/g total Hg in fish at NOAT exceeds the human contaminant threshold, while some fish at Matcharak Lake (GAAR), PJ and Hoh Lakes (OLYM), LP19 (MORA), and Pear Lake (SEKI) exceed the human contaminant threshold. The mean ng/g Hg concentration in fish at all parks exceeds the kingfisher contaminant threshold, and the mean at 7 lakes exceeds all wildlife thresholds—Burial Lake (NOAT), Matcharak Lake (GAAR), Wonder Lake (DENA), PJ and Hoh Lakes (OLYM), LP19 (MORA), and Pear Lake (SEKI). The human threshold is 300 ng/g wet weight (USEPA, 2001), and is based on methyl-Hg in the fillet for a general population of adults with a body weight of 70 kg and 0.0175 kg fish intake per day. 95-100% of Hg in fish is methyl-Hg (Bloom, 1992), and 300 ng/g in the fillet is equivalent to 185 ng/g ww whole body methyl-Hg (Peterson et al., 2007). Contaminant health thresholds in piscivorous animals (wildlife) are based on 100% fish in the diet for whole body total Hg, as determined by Lazorchak et al. (2003). Data are plotted on a $\log_{10}$ scale; the y-axis starts at 10 ng/g.

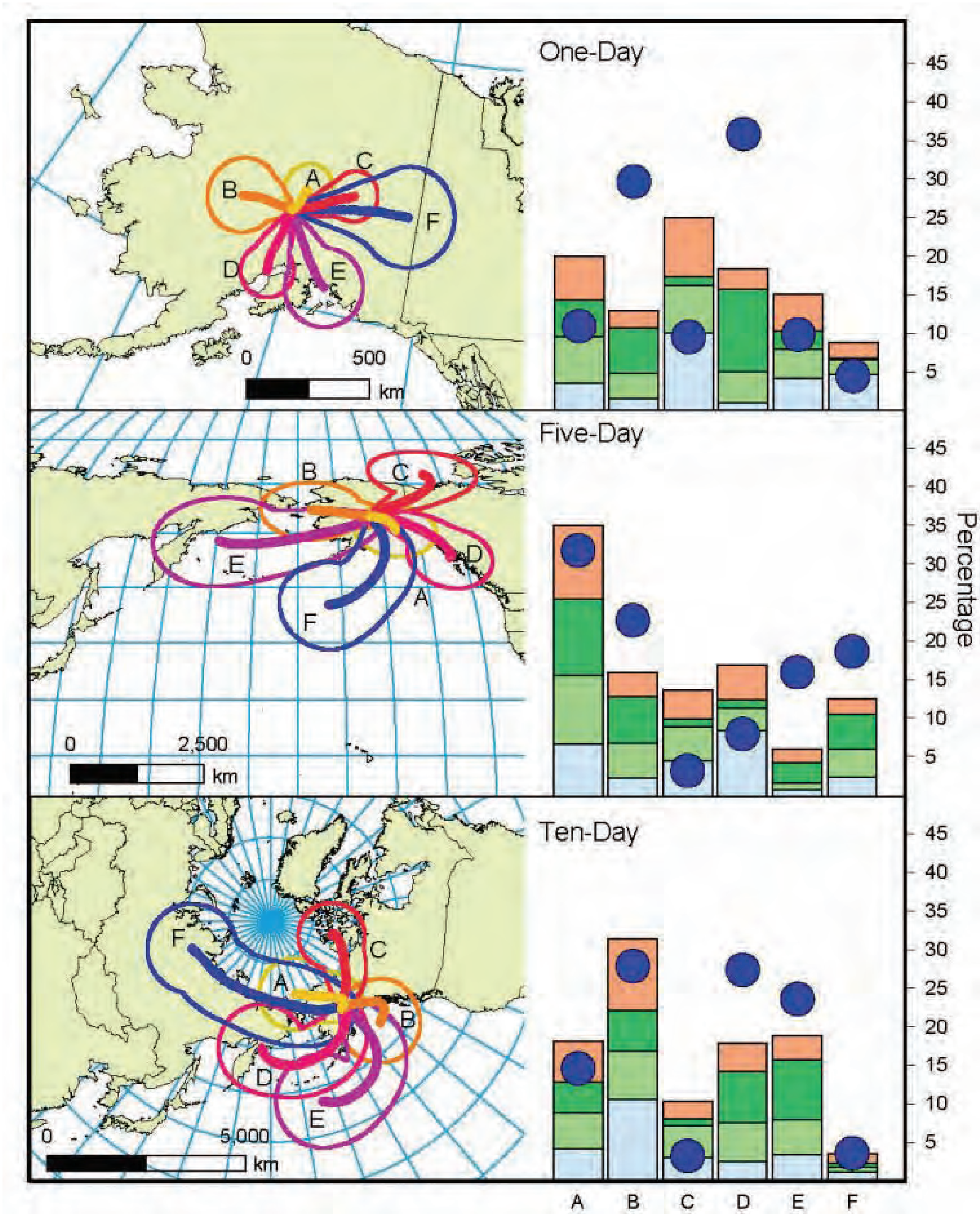


Figure 5. 1-, 5-, and 10-Day Cluster Plots for DENA. Clusters are sorted shortest to longest, A–F. Bars represent the percent of trajectories in each cluster out of 2,922 total (1998-2005). Light blue = winter; light green = spring; dark green = summer; orange = autumn. The dark blue dot is the percent of total precipitation for which each cluster is responsible.

In GLAC, PAH concentrations in snow, sediment, and vegetation in the Snyder Lake watershed were higher than those in the Oldman Lake watershed and 10 to 100 times higher than those in all other WACAP parks. Several lines of evidence point to the aluminum smelter in Columbia Falls, Montana, as the most likely major source of these elevated PAHs to Snyder Lake.

At ROMO, higher SOC and Hg deposition in snow was found in the Mills Lake watershed (on the east side of the Continental Divide), than in Lone Pine Lake (on the west side), possibly because the Continental Divide serves as a topographic barrier for transport of SOCs and Hg from agricultural and populated areas on the east side of ROMO to the west side. SOC concentrations in air (PASDs), conifer needles, and fish show no clear evidence of an east side enhancement.

Sediment cores provide a historical record of contaminant deposition over the past ~150 years. The temporal records from sediment cores indicate that in nearly all parks, Hg deposition increased in the twentieth century because of anthropogenic sources. In many parks, mercury deposition fluxes have declined somewhat, although in other parks the Hg flux appears to still be increasing. This finding reflects a complex array of decreasing regional sources, combined with increasing global contributions and watershed influences on sediment records.

Lead (Pb), cadmium (Cd), and SCPs in sediment indicate regional fossil fuel combustion sources. SCPs clearly show the build-up from industrial sources in lakes in the conterminous 48 states during the late twentieth century. In recent decades, Pb, Cd, and SCPs have declined substantially, reflecting source reductions related to the Clean Air Act and regulation of lead in gasoline. Lead concentrations in lichens at SEKI and MORA have decreased 5- to 6-fold since the 1980s.

In the Alaska lakes, SCPs in sediment were non-detectable and Pb and Cd showed little sign of a twentieth century increase. Only the Hg flux showed a consistent increase in the Alaska lake sediments, reflecting a primary contribution from global sources.

Chapter 5. Biological and Ecological Effects

WACAP assessed the impacts and/or effects of contaminants on biota and ecosystems in a variety of ways. Key results include the following.

Bioaccumulation of SOCs in vegetation appears to occur over time. Second-year needles contained approximately triple the concentrations of contaminants in first-year needles. The amount of contaminant stored in vegetation that eventually contributes to accumulation of SOCs in forest litter-fall and soils is likely to be dependent upon forest productivity (annual above-ground biomass production), tree species, and proximity to contaminant sources.

We observed biomagnification throughout park ecosystems. Concentrations of SOCs were 5 to 7 orders of magnitude higher in fish than in snow, water, and the PASD monitors indicating air concentrations. Concentrations of SOCs were 3 to 5 orders of magnitude higher in fish tissue than in sediments. Vegetation tended to accumulate more PAHs, CUPs, and HCHs, whereas fish accumulated more PCBs, chlordanes, DDTs, and dieldrin. SOCs in vegetation and air (PASD monitors) were expected to show similar patterns; however, this was not the case, possibly because each medium absorbs different types of SOCs with varying efficiencies.

In this study, WACAP researchers assessed both fish-condition biomarkers and concentrations of contaminants in fish tissue. Most fish appeared normal during field necropsies. Macrophage aggregates (MAs; an immune system response, Figure 6) generally increased with mercury concentrations and age in brook, rainbow, and cutthroat trout. Vitellogenin (Vtg) concentrations in male fish are widely used as a biomarker for environmental estrogen exposure. Compounds such as dieldrin, DDT, PDBEs, PCBs, PAHs, endosulfan, and methoxychlor (among others) are known or suspected endocrine disrupting contaminants. Although sample sizes in this study were very small, significant correlations between contaminants in fish tissue and Vtg concentrations in male fish were found in the two core WACAP lakes sampled in ROMO in 2003. Two additional lakes in ROMO, sampled as part of a separate study, contained fish with high concentrations of Vtg; however, contaminants analysis of these fish has not yet been conducted. Two male fish from GLAC and one male fish from MORA also displayed elevated concentrations of Vtg. The fish from Oldman Lake (GLAC) with high Vtg concentrations also contained the highest concentrations of DDT of any of the fish sampled in the project.

Intersex, the presence of both male and female reproductive structures in the same animal, is also a commonly used biomarker of estrogen-like chemical exposure. Intersex fish were found in ROMO and GLAC lakes. In this study, four levels of intersex condition were characterized, both for current samples collected in WACAP, and for historic samples obtained for comparison from museums. The data show that the number of sites with intersex fish has increased since the late 1800s. In the current WACAP samples, 8 of 117 fish in the Rocky Mountains were identified as intersex and none of the 90 samples collected at other parks in the west were intersex. Six of 11 water bodies sampled in ROMO contained intersex fish. Sample size in the project was low, and WACAP was not designed to fully characterize the extent and range of intersex fish in remote sites in the west. However, based on the initial sampling conducted here, it appears that intersex condition in fish from remote areas might be concentrated in the Rocky Mountains. Further investigation is warranted (a variety of potential hypotheses are discussed in the report).

In addition, the severity of abnormalities observed in the intersex fish from ROMO was greater than in any historical samples, displaying category 4 gonad abnormalities, low androgen and estrogen levels, and elevated levels of Vtg. The three intersex fish that were also sampled for contaminants contained high levels of endocrine disrupting contaminants such as dieldrin, DDT, chlordanes, and PCBs. However, whether contaminants are causing the intersex condition in fish cannot be definitively determined with this small dataset.

Mercury concentrations increased with fish age in all fish species up to approximately 15 years of age. Fish older than 15 years had less mercury. Several hypotheses could account for this finding and are discussed in more detail in Chapter 5 of the report. Fish mercury concentrations in WACAP were highest in Burial Lake (NOAT), with the mean Hg concentration exceeding the USEPA contaminant health threshold for human consumption (see Figure 4). The other Arctic lake in this study, Matcharak (GAAR), also contains fish with elevated concentrations, with some fish exceeding human contaminant health thresholds. Because mercury concentrations in snow, sediment, and vegetation were found to be low in these two parks, it is likely that in-lake biological processes, including fish age, Hg methylation rate, watershed biogeochemical characteristics, and food web efficiency influence the higher rates of bioaccumulation in Alaska lakes.

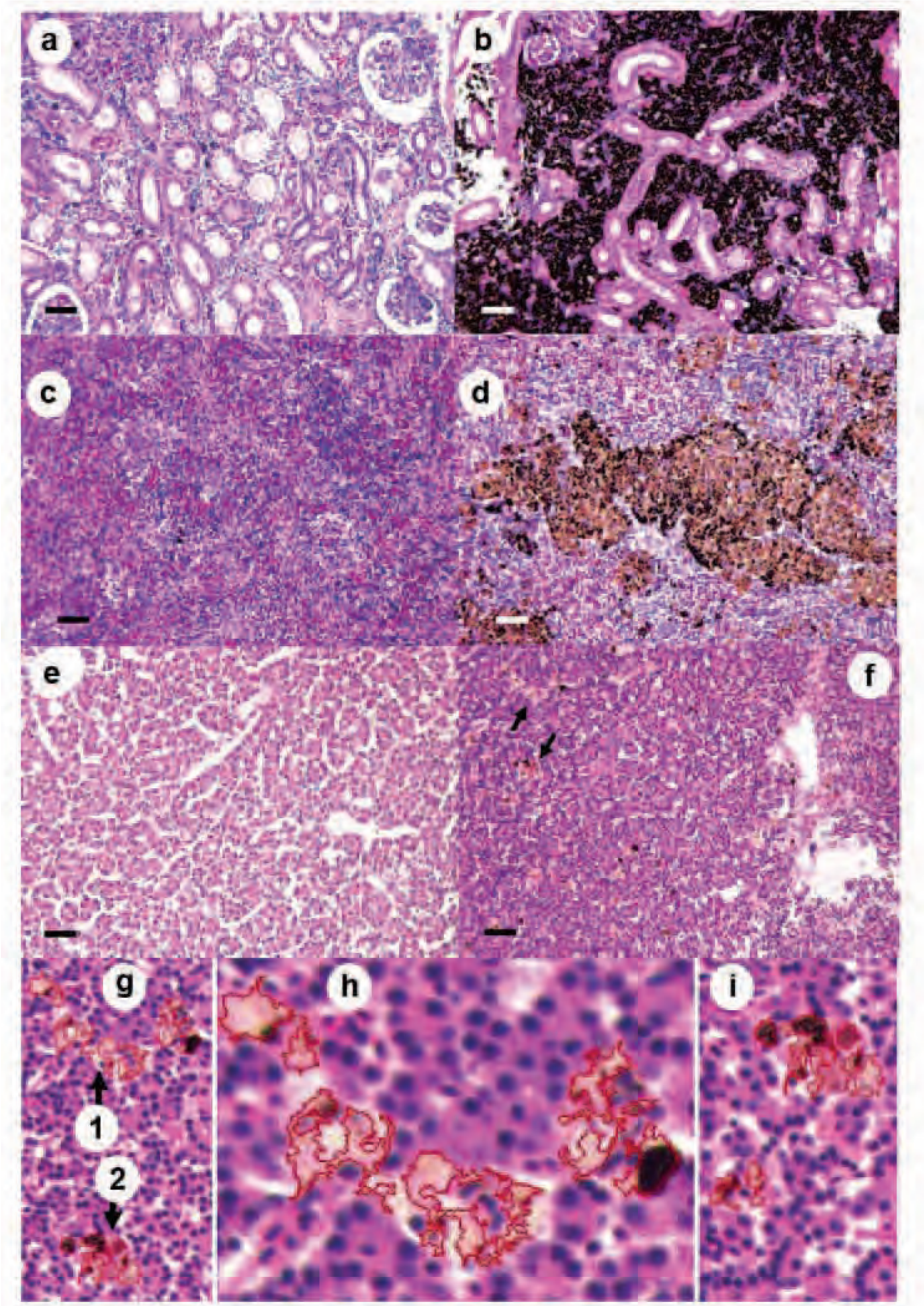


Figure 6. Representative Hematoxylin-Eosin Stained Brook Trout Organs Showing the Relative Difference between Fish with Very Few or No Macrophage Aggregates (MAs) and Extensive Accumulations of MAs (a-f) and Outlined High Magnification Hepatic MAs (g-i). Bars = 50 µm. (a) Kidney with a few MAs; (b) Kidney with extensive MAs; (c) Spleen with a few MAs; (d) Spleen with extensive MAs; (e) Liver with no MAs; (f) Liver with extensive MAs; (g) High magnification of liver MAs corresponding to MAs (arrows) in (f); (h) 2X magnification of the MA corresponding to arrow 1 in (g); (i) 2X magnification of the MA corresponding to arrow 2 in (g). The outlined areas in (g) through (i) are the computer output of delineated MAs in the liver based on pigment selection by the computer program. Modified from Schwindt et al. (2006).

Current contaminant concentrations in 136 fish from 14 lakes in the 8 core WACAP parks were compared to the USEPA's *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories*. The contaminant health threshold is the point at which a 70-kg person who consumes 17.5 g of fish per day (2.3 servings per month; recreational fish consumption) or 142 g per day (19 servings per month; subsistence fish consumption) increases lifetime risk of developing cancer by 1 in 100,000, or significantly increases risk of chronic (non-cancer) disease. Most contaminant concentrations in fish fell below these thresholds. However over half (77 of 136) of the individual fish from 11 of the 14 lakes analyzed carried concentrations of dieldrin and/or p,p,′-DDE that exceeded contaminant health thresholds for subsistence fishing (Figure 3). The lake average fish dieldrin and/or p,p,′-DDE concentrations exceeded subsistence fishing thresholds in nine of the lakes and recreational fishing thresholds in none of the lakes, although five individual fish exceeded dieldrin thresholds for recreational fish consumption in Mills and Lone Pine lakes (ROMO), Pear Lake (SEKI), and Oldman Lake (GLAC). No other SOC concentrations measured in fish from the eight core WACAP parks exceeded human contaminant health thresholds. Of the other compounds detected in >50% of fish (chlorpyrofos, dacthal, endosulfans, methoxychlor, mirex, HCB, a-HCH, g-HCH, chlordanes, heptachlor epoxide, and PBDEs), all were 1 to 7 orders of magnitude below the human contaminant health thresholds.

We assessed impacts of contaminants on aquatic food chains by comparing fish contaminant concentrations with published contaminant health threshold for impacts to mink, river otter, and belted kingfishers. At numerous sites, mean concentrations for mercury in WACAP fish were above thresholds for potential negative health effects on the aforementioned wildlife (Figure 4). Contaminant health thresholds for PCBs for wildlife (banned from production and use in the United States in 1979) were not exceeded. DDT production ceased in the United States in 1972. Some fish at the two sites in SEKI, and the mean concentration of fish in Oldman Lake in GLAC, had concentrations of the sum of DDTs above the threshold for negative health effects for kingfishers (Figure 3B). The concentrations of chlordane, once a broad-use pesticide used to control underground termites, were below thresholds for wildlife, except that one fish in Oldman Lake in GLAC exceeded the threshold for kingfishers. A suspected carcinogen and endocrine disruptor, chlordane was banned in the United States in 1983. The acutely toxic pesticide dieldrin was banned for agricultural use in the United States in 1974 and for most other uses in 1987. The highest dieldrin concentrations in fish in this study were found in ROMO. Dieldrin was produced in nearby Denver, Colorado, from 1952 to 1973. Mean concentrations of dieldrin in fish at all WACAP sites were below the contaminant health thresholds for wildlife (Figure 3A).

We analyzed moose tissue samples for SOCs and metals in Alaska parks with the intent of exploring linkages between the Alaska food web and humans engaging in subsistence hunting. However, tissue samples from only three animals were collected, all in DENA. Few of the target SOC compounds were detected in the moose liver or muscle tissues analyzed. The generally low detection frequencies and the absence of any major patterns among SOC compound groups, among individual moose, or between moose tissue types suggest that these moose were not biomagnifying SOCs to a concentration of concern. Metals concentrations were low, and at the deficiency level for copper, which decrease adsorption of iron in the blood. Compared to the sparse data available from other studies for metals in moose tissue, the WACAP samples were generally lower in cadmium, copper, and zinc.

Chapter 6. Recommendations and Conclusions

The report concludes with recommendations to the National Park Service that respond to the question, “What did you learn in this project that could help guide or focus future work within the NPS on contaminants in parks in the western United States?” These recommendations are specific to the original five project objectives. Also included is a list of additional research questions posed by WACAP scientists. These questions define fertile areas for future research into processes, mechanisms, and ecological interactions of contaminants in western ecosystems. In addition, broad conclusions answering the questions posed by the five project objectives are discussed.

Contaminants were found in all WACAP lakes. In some cases, the concentrations in fish were found to exceed important human and wildlife thresholds. It might be perceived that the two lakes per park that WACAP examined are somehow outliers and that they do not represent the total population of lakes within parks. From a strictly statistical perspective, these lakes are not representative of the population of lakes. However, the lakes were selected to provide “clean” and unambiguous signals of atmospherically deposited contaminants and in no way were they selected to provide the highest or lowest contaminant concentrations. For future work, researchers might choose to consider implementing a robust statistical sampling design for specific parks that would provide a quantitative estimate of the contaminant condition of all lakes in the population.