Forest and Rangeland Ecosystem Science Center

Contaminants in the Klamath Basin: Historical Patterns, Current Distribution, and Data Gap Identification

By Collin A. Eagles-Smith and Branden L. Johnson

Administrative Report

U.S. Department of the Interior
U.S. Geological Survey

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U. S. GEOLOGICAL SURVEY

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Conversion Factors

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
	Area	
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile (mi^2)

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Executive Summary

The Klamath Basin in California and Oregon is a diverse and productive region that supports numerous ecological, economic, and cultural benefits. However, competing uses and major changes to the Basin's hydrology have severely impacted the natural resources of the region. Efforts are underway for major restoration activities within the basin, with the goal of better balancing the diverse use of land and water resources. However, the myriad of ecological stressors on the basin's resources can complicate predicting the trajectory and success of restoration efforts, thus it is important to inventory those stressors and identify critical data gaps prior to implementing actions. The Klamath Basin (approximately 31,000 square kilometers) has a relatively well-documented history of contaminant impacts associated with historical pesticide use on agricultural lands. Agriculture accounts for approximately 6 percent of the land use in the entire basin, most of which exists in the Lost River, Shasta River, and Upper Klamath Lake subbasins (59, 14, and 11 percent, respectively). However, a current inventory of available data on contaminant distribution and sources is lacking. Thus, the goal of this document is to summarize what is currently known about past and current contaminant distribution and impacts of contaminants on the ecological communities throughout the basin. Additionally, we identify key data gaps which, when addressed, will facilitate a more thorough understanding of the factors driving contaminant cycling and ecological exposure so that efforts can be implemented to help minimize the threats.

Based on our extensive data mining efforts on historical contaminant distribution and effects in the basin, we found clear evidence that past organochlorine pesticide use was a major source of avian impacts in the basin, and likely influenced other taxonomic groups as well. The moratorium on organochlorine pesticide use has resulted in a sharp decrease in exposure, greatly reducing the likelihood that these compounds still pose a major threat. However, some compounds have highly recalcitrant degradation products that also are toxic, and may continue to pose a threat to fauna in the region. Specifically, there is some limited evidence that DDE (a degradation product of DDT) may still occur in the Upper Basin at

concentrations that can elicit deleterious effects on avian reproduction. However, limited data over the past 20 years make this difficult to confirm.

Current contaminant threats and impacts to the basin are less clear, primarily due to the fact that robust data to support a more specific assessment are non-existent. Thus, our interpretation of current contaminant threats is necessarily speculative and should be followed by well-designed data collection efforts. Because of the limited monitoring data available, we chose instead to evaluate current threats based on documented use of chemicals in the environment coupled with an evaluation of land use that may be associated with contaminant release and transport. Our efforts identified four key areas where the overlap between use, land management, and species distribution may result in exposure and potential impacts. (1) Pesticide use in the basin: With respect to approximately 68 square kilometers of the Tule Lake Refuge land that are leased by farmers under a Bureau of Reclamation program (hereafter, lease lands), several specific pesticide classes, such as arylphenoxypropionates (herbicide/fungicide), carbamates (insecticide), carboximides (fungicide), chloroacetamide (herbicide), and dithiocarbamates (fumigant) are applied to the lease lands at heavy rates, or their use has increased substantially in recent years. Lack of environmental monitoring precludes an assessment of whether these compounds are migrating into wetland habitats or the Klamath River. Furthermore, a more extensive spectrum of pesticides are applied to agricultural lands outside of refuge boundaries, but are contiguous with important hydrological features of the basin. (2) Methylmercury cycling, bioaccumulation, and effects: Mercury (Hg) has been shown to occur in both the Upper and Lower Basins, and current wetland management efforts may exacerbate the conversion of inorganic mercury to the toxic and bioavailable form, methylmercury. This is a particularly important issue as efforts to restore previously reclaimed wetlands move forward, and as agricultural units are cycled into seasonal wetland habitats. (3) Mining sources in the Lower Basin: More than 2,000 metal mines have been identified in the Lower Basin subbasins that extract a range of mineral resources. Elevated concentrations of chromium and nickel in Klamath Estuary sediments provide limited evidence suggesting that these mining operations may contribute to the metal load to the river, but further investigations should seek to quantify the extent of risk. (4) Arsenic availability and toxicity: Arsenic has been measured at elevated concentration in numerous matrices and across the basin. However, the chemical speciation of arsenic is critical in determining its toxicity and risk. Future work should more thoroughly target identifying arsenic distribution across the basin, and detailed speciation studies should be incorporated into these efforts to better evaluate risk.

In summary, the potential contaminant impacts to the Klamath Basin are numerous, but the lack of current data complicates evaluations of the likelihood that these compounds are affecting ecological health in the region. Future work is needed to better understand the cycling and distribution of several chemical classes, which would facilitate more in depth, targeted efforts to quantify the extent to which ecological health is impaired. Finally, we strongly emphasize that assessments of contaminant effects on the natural resources in the region should be integrated with impacts of other known stressors. Specifically, research should target integrating our understanding of how contaminants stresses interact with factors, such as disease susceptibility, water temperature fluctuations, and flow.

Introduction and Objectives

The Klamath River Basin, located in southern Oregon and northern California, encompasses approximately 31,000 km^2 of land area that is comprised of a diverse range of habitats supporting a rich assemblage of ecological communities and ecosystem functions (National Research Council, 2004). This complexity and diversity supports various cultural, ecological, and agricultural needs that often compete with one another for the limited availability of water resources in the basin. This resource competition has stressed the ecological integrity of the Basin, impacted the economic capacity of the region, and threatened the cultural traditions of the Tribes and their ancestors that have occupied the area for at least the past 11,000 years (National Research Council, 2004). Additionally, alterations to land use, basin hydrology, and human development to exploit these needs have interacted to impair the cumulative functioning of the Klamath River Basin ecosystems and challenge the long-term ecological viability of the Region. As a result, unprecedented agreements were recently reached among Federal and State agencies, Tribes, and other public and private stakeholders to rebuild and restore fisheries and establish reliable water and power supplies for agricultural, community, and National Wildlife Refuge uses.

From an ecological perspective, the center of the current Restoration Agreements focus on addressing availability and quality of both habitat and water, as these are likely the leading limiting factors for successful restoration and rehabilitation of threatened and endangered fishes in the Basin (National Research Council, 2004). However, the Klamath Basin ecosystems also are challenged by past and current land uses, such as agriculture, mining, logging, and development. The stressors associated with these land uses likely will continue to influence the region to some degree even after restoration actions occur, and in some cases, their effects on ecosystem processes could interfere with restoration success. One particular factor that links all of these stressors together is their association with various environmental contaminants, including trace metals and historical and current use pesticides. The Klamath Basin has an extensive and relatively well-documented history of early contaminant impacts and exposure to wildlife dating back many decades. However, limited synthesis of this information and sparse modern data hinder a full understanding of the potential threats these stressors pose. As restoration plans continue and actions are implemented, it will be important to consider the distribution, transport, cycling, fate, and ecological exposure of contaminants in the Klamath Basin as potentially key stressors on healthy ecosystem function. Summarizing past results and identifying current data gaps are a critical first step in formulating a better understanding of contaminant risks in the Basin, as well as targeting future research questions. The goal of this report is to take this first step by providing a comprehensive document that compiles existing contaminant information into one location, and identifies how additional information might facilitate addressing any critical contaminant threats in the basin.

It is important to note that contaminants exist as many classes, each with their own unique chemical properties, environmental mobility, persistence, and toxicity (Newman and Clements, 2008). Additionally, the behavior of many individual compounds can differ substantially when occurring as mixtures with others, thus evaluating the risk or effects of contaminants in systems like the Klamath Basin where there is a wide range of different compounds in the environment can be exceedingly difficult (Baas and others, 2010). Given these facts and the overall paucity of data on the distribution of contaminants in the region, it is well beyond the scope of this document to formally evaluate risk to ecosystem or human health. Instead, we focus on compiling the existing information about contaminant use, occurrence, and distribution in an effort to more efficiently guide future efforts to quantify risk and deleterious effects. Additionally, although we recognize the well-documented threats posed in the basin by algal blooms and associated algal toxins, we specifically exclude evaluation of those issues in this assessment in the interest of focusing on more anthropogenically induced contaminant threats.

Physical Setting, Hydrology, and Land Cover

A thorough review of the physiographic and hydrologic setting of the Klamath Basin is provided by the National Research Council (2004). Thus, we summarize salient details from their report in order to provide context to the contaminant issues within the Basin herein. For a more thorough treatment of the Klamath Basin's structure and hydrology, we refer the reader to the National Research Council's (NRC) work. The underlying geology and tectonic history of the region is largely responsible for the pronounced diversity in habitats across the Klamath Basin (National Research Council, 2004). The basin itself is comprised of a broad mosaic of habitats that is dominated by rugged temperate forests (67 percent of total area) and Mediterranean scrub and grassland, but also holds broad expanses of freshwater marshes and a tidal estuary (fig. 1).

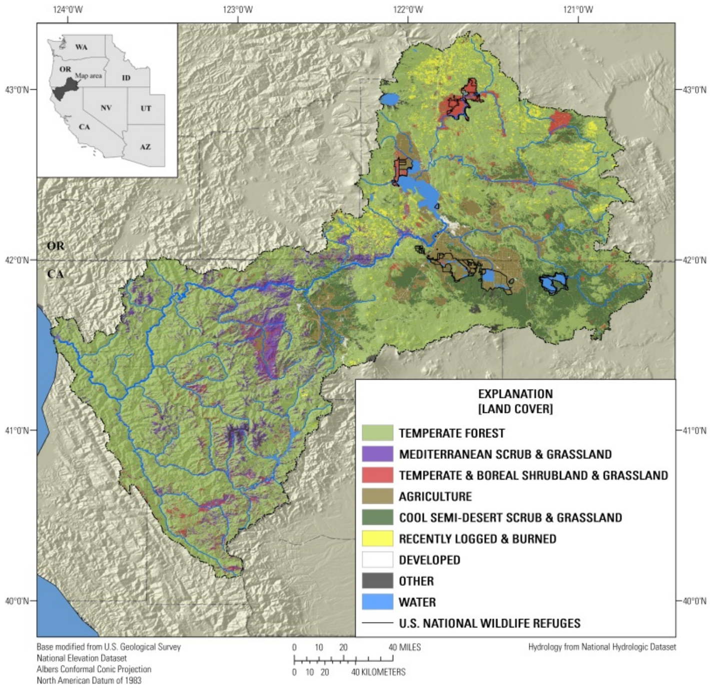


Figure 1. Land cover of the Klamath Basin, Oregon and California. Land cover modified from NatureServe (Cormer and others, 2003).

Average annual precipitation in the basin ranges between as little as 13 cm/yrin the northern arid parts, and as much as 254 cm/yr in the coastal rain forests. The Klamath River itself (downstream of Iron Gate Dam) is the largest coastal river in California and represents a major component of the landscape, spanning nearly the entire extent of the basin from Upper Klamath Lake in the northeast to its estuary 563 river kilometers southwest. The Klamath basin is comprised of 12 distinct subbasins (fig. 2), which contain the primary tributaries to the Klamath River and comprise most of the river's flow.

3).

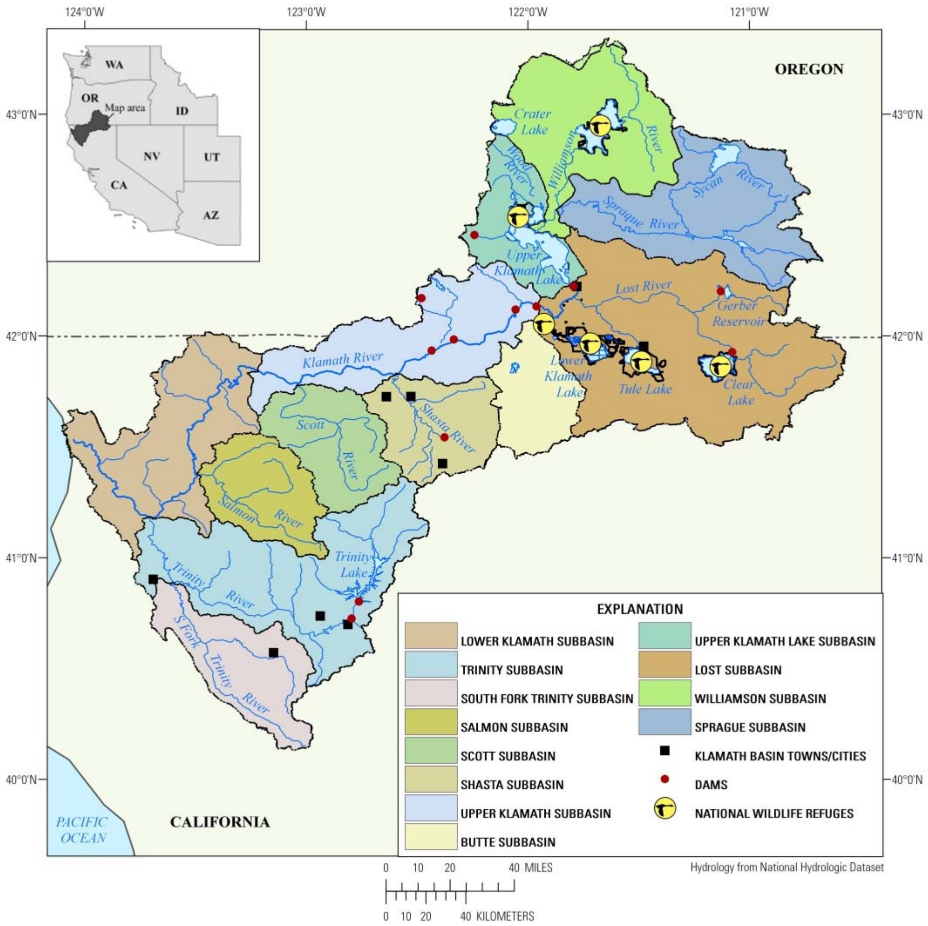


Figure 2. The Klamath Basin drainage basins (8-digit hydrologic units), Oregon and California.

Currently, the flow of the Klamath River is regulated or interrupted by five dams that lie along its path, as well as several others in tributaries (fig. 2). Most of the total land area (62 percent) in the basin is federally owned by the U.S. Forest Service, Bureau of Land Management, Bureau of Reclamation, and U.S. Fish and Wildlife Service Refuge System. However, at least 35 percent of the land in the basin is privately owned, particularly in the Upper Basin and fertile valleys, where agriculture is the predominant land-use category. The remaining 2 percent of the land is either Tribal- (1.4 percent) or State-owned (0.6 percent) (fig. 3).

The Klamath Basin is naturally divided into two distinct sections that are geologically and ecologically distinct, and are separated from one another by the Iron Gate Dam and the boundary between the Shasta and Butte subbasins (see fig. 1). Because these two areas exhibit such pronounced differences in land use, climate, and ecological community structure, we have separated our discussion between them, hereafter referred to the Upper Basin and Lower Basin.

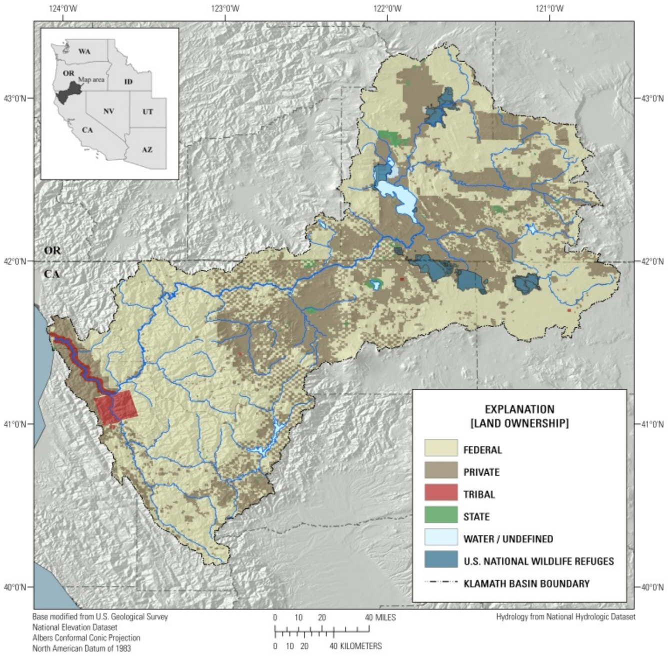
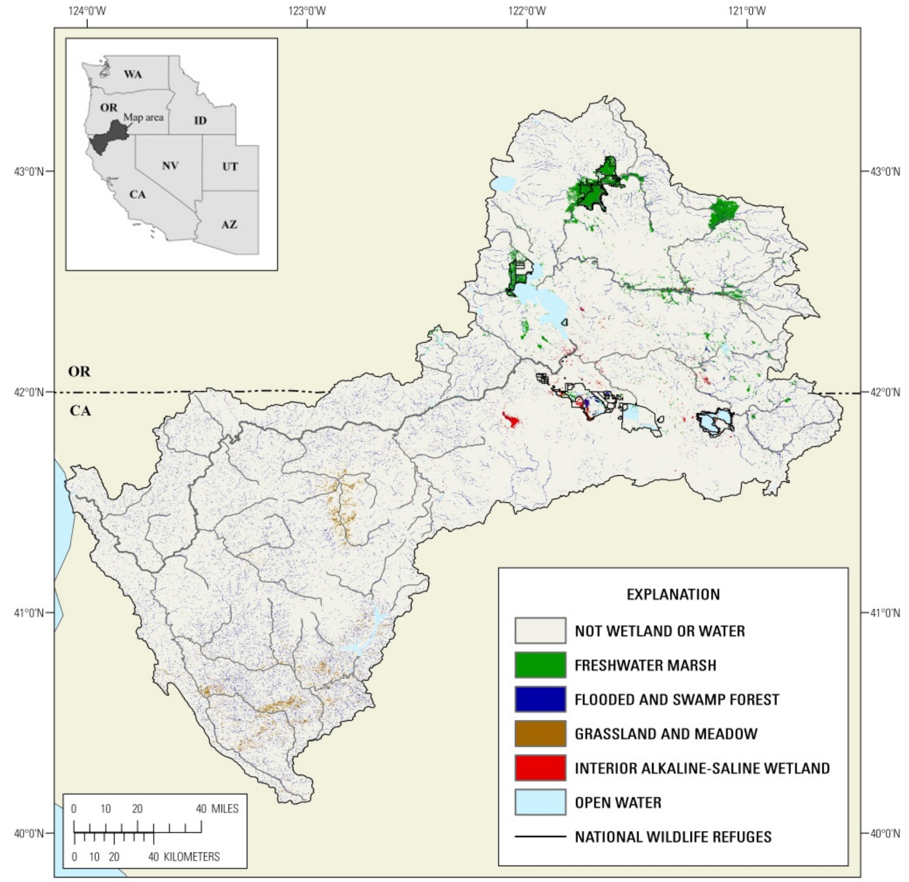


Figure 3. Land ownership of the Klamath Basin, Oregon and California. Land ownership data from Environmental Systems Research Institute, Inc. (ESRI 9.3) and USGS Gap Analysis Program

The Upper Basin

The Upper Basin, which lies north and east of Iron Gate Dam has a dry, high desert climate and is a flat area that extends along the east slope of the Cascade Range. The upper altitudes of the basin also contain abundant temperate forests (57 percent of total basin land area) and have supported a productive timber industry. However, the Upper Basin is perhaps best recognized by its abundance of productive and ecologically important wetlands (Larson and Brush, 2010; fig. 4).



Hydrology from National Hydrologic Dataset

Figure 4. Wetlands of the Klamath Basin, Oregon and California. Salt marsh (0.34 km^2) and bog and fen (4.2kKm^2) categories not included. Wetland categories from NatureServe (Comer and others, 2003).

As an indication of its conservation importance, the Upper Basin contains six National Wildlife Refuges that support more than 1 million migratory and breeding waterbirds, as well as a large wintering population of bald eagles (*Haliaeetus leucocephalus*; Ivey, 2001). Although the Upper Basin has lost a substantial proportion of its historical wetland area (Larson and Brush, 2010), it is still considered among the most important areas for avian conservation along the Pacific Flyway (Fleskes, *in press*). Most of the former wetlands have been converted to irrigated agricultural land, which encompasses more than 9 percent of Upper Basin, much of it in close proximity to (or within the boundaries of) the wildlife refuges. Additionally, two federally listed freshwater fishes, the short-nose sucker (*Chasmistes brevirostris*) and Lost River sucker (*Deltistes luxatus*) also are found only in the Upper Basin waters. The decline in these two fish species has been attributed primarily to water management, habitat alteration, non-native species, and poor water quality (National Research Council, 2004). The recruitment of these species is now restricted to a limited spatial extent within the Upper Basin. Central to the water-quality issues that impact the basin is the rerouting of water flows associated with the Bureau of Reclamation's Klamath Project, and the substantial loss of wetlands in the area. Importantly, the changes in water control have resulted in agricultural drain water sometimes recirculating through irrigated cropland several times before being discharged into the Klamath River. Additionally, the loss of wetlands is thought to have impacted the overall water quality in Upper Klamath Lake, and may have contributed to the severe eutrophication that now affects the Lake. The annual algal blooms in Upper Klamath Lake are thought to also contribute to fish kills in the lake through a reduction in dissolved oxygen, elevated ammonium concentrations, and other water-quality impairments (Bortleson and Fretwell, 1993; National Research Council, 2004). Klamath Falls (population 20,065) has the largest human population in the Upper Basin followed by Tulelake (population 956; U.S. Census Bureau, 2009). These cities are situated along the Klamath River downstream of Upper Klamath Lake and along the Lost River just north of Tule Lake Refuge, respectively.

The Lower Basin

In contrast to the Upper Basin, the Lower Basin which lies south east of Iron Gate Dam, is characterized by the bedrock carved Klamath River and its tributaries, mountainous terrain with rugged and dense coniferous forests, steep tributary streams, and annual rainfall that can exceed 127 cm/yr. More than 75 percent of the total land surface area is comprised of temperate forested habitat, in comparison to 57 percent in the Upper Basin (fig. 1). Additionally, relative to the Upper Basin, the Lower Basin supports substantially less agriculture (433 km^2 versus 1,913 km^2), contains about one-half as much urban and rural development (123 km^2 versus 234 km^2), and has very limited open water and wetland habitat (fig. 4). Because of these ecological, geological, and land-use differences the Lower Basin is characterized by a different suite of contaminant concerns than the Upper Basin. The dense forests and rich mineralogy of the area support numerous mining operations and potential for substantial timber harvest, which both may contribute to the contaminant profiles of the watershed. Human population in the Lower Basin is greatest in the Shasta subbasin where several cities (primarily Yreka, Weed, Montague, Dorris) support approximately 13,000 people situated along the river and associated tributaries (U.S. Census Bureau, 2009). Additionally, smaller rural populations are scattered throughout the lower basin, primarily in the Scott and Trinity basins. The primary anthropogenic impacts to this part of the basin include timber harvest, gold mining (past and present), and flow regulation from the upstream dams (National Research Council, 2004). Managed water flows from the upstream dams on the Klamath River and its tributaries largely control water temperature, flow rate, and sediment transport. The impairment of flows and blockage of upstream spawning habitats are among the most severe threats to the anadromous fishes of the basin.

Summary

The Klamath basin is a unique and ecologically important region facing a wide array of threats due to historical and current land use, landscape alterations, and water management. The ecological crisis in the region is widely acknowledged, motivating a broad stake-holder coalition to initiate major restoration planning efforts to address many of the key issues that threaten ecosystem function, endangered species recovery, and economic vitality in the region. The risks posed by, and effects of, environmental contaminants in the region are still not well-understood, yet any changes in the management and functioning of the system also may alter the cycling, distribution, and fate of contaminants within the Klamath Basin. In the discussion that follows, we summarize the state of knowledge regarding contaminant distribution and impacts in the basin and identify key data gaps that can be addressed through applied research. Cumulatively, our key goal is to facilitate informed decision making in the Basin by ensuring that a broad understanding of contaminant risks are considered, and that key data gaps are addressed. To do this, we first provide a discussion of historical contaminant data and impacts in the Basin, categorized by key contaminant classes. This discussion primarily is based on records from available published literature, and agency reports. We next evaluate more current contaminant threats to the region by discussing what is known about active contaminant sources, the land-use practices that contribute to the Basin's contaminant profile, and any more recent data that are available through unpublished sources. Finally, based on our findings in the first two sections, we identify key unknowns regarding contaminant distribution and effects, and discuss priority research approaches that will help in addressing those knowledge gaps.

Historical Contaminant Review

Documented contaminant impacts within the Klamath Basin date back to at least the 1960s, when wildlife deaths were linked to organochlorine pesticides (such as dichlorodiphenyltrichloroethane [DDT]) that were commonly applied to the National Wildlife Refuges and surrounding agricultural land. Although much of the historical impacts may have limited relevance today, we review them here within the context of the overall history of contaminant-related stress in the Klamath Basin. The section is specifically focused on summarizing available publications and reports specific to the basin.

Organochlorine Pesticides

Organochlorines (OCs) are a class of pesticide introduced in the 1940s that experienced widespread and heavy use through the subsequent 20 to 30 years (Newman and Clements, 2008). Among the most commonly used compounds were: DDT, aldrin, dieldren, toxaphene, chlordane, and heptachlor. These chemicals were popular in part because of their high insect toxicity, relatively low acute mammalian toxicity, and their persistence in the environment (table 1). However, subsequent research on the environmental effects of these compounds revealed that many were highly bioaccumulative, and when coupled with their recalcitrance to degradation, they caused significant impacts to upper trophic level fish, birds, and mammals. Among the most widely noted impacts included the role of DDT (and its derivatives) on population declines of species, such as bald eagles and brown pelicans, due to severe eggshell thinning and reproductive impairment. Organochlorines were banned for most uses in the United States beginning in the 1970s, and were replaced with a series of other pesticide classes, such as organophosphates, carbamates, and pyrethroids, each with their own unique advantages and disadvantages.

Table 1. Chemical properties of major organochlorines and dates of use in the United States.

		Toxicity[a]		Timeframe		Persistence / Mobility[b]					
Organochlorine	Molecular Formula	LC50 Fish A, ppb	LC50 Birds D, ppm	Use Began (USA)	Use Banned (USA)	Sorption Coefficient (Log K_{oc})	Partition Coefficient (Log K_{ow})	Vapor Pressure[c] (mmHg)	Henry's Law[d] (atm-m^3/mol)	Water Solubility[c] (mg/L)	Soil half-life[e] (days)
Aldrin	$C_{12}H_8Cl_6$	2.2-53	6.6 -520	1950s	1974[f]	7.67	6.5	7.5×10^{-5}	4.9×10^{-5}	0.011	365
Chlordane	$C_{10}H_6Cl_8$	0.002-130	331-858	1950	1988	3.49-4.64[g]	5.54[g]	3.9×10^{-6} - 4.5×10^{-5}[h]	4.8×10^{-5}	1.85	350
DDD (p,p')	$C_{14}H_{10}Cl_4$	14-1500	445-4810	1940	1972	5.18	6.02	1.35×10^{-6}	4.0×10^{-6}	0.09	1000
DDE (p,p')	$C_{14}H_8Cl_4$	0.00003	825-3570	1940	1972	4.7	6.54	6.0×10^{-6}	2.1×10^{-5}	0.09	1000
DDT (p,p')	$C_{14}H_9Cl_5$	0.30-9.9	311-1869	1940	1972	5.18	6.91	1.60×10^{-7}	8.3×10^{-6}	0.12	2000
Dieldrin	$C_{12}H_8Cl_6O$	1.2-9.2	37-169	1950s	1974[f]	6.67	6.2	3.1×10^{-6}	5.2×10^{-6}	0.025	1000
Endosulfan	$C_9H_6Cl_6O_3S$	0.09-28	805->3528	1954	slated	3.5	3.55, 3.62	1×10^{-5}	1×10^{-5}	0.060-0.100	50
Endrin	$C_{12}H_8Cl_6O$	0.09-5.6	14-18	1951	1991[i]	4.532	5.45	2.0×10^{-7}	4.0×10^{-7}	0.2	4300
HCB[j]	C_6Cl_6	0.002-0.008	5 -100	1940s	1994[k]	6.08	5.31	1.09×10^{-5}	5.8×10^{-4}	0.006	1000
HCH[l]	$C_6H_6Cl_6$	1.7 -90[r]	490-882[f]	1940s	NB[m]	3.0 - 3.8	3.72 - 4.14	3.6×10^{-7} - 4.5×10^{-5}	2.1×10^{-7}- 6.86×10^{-6}	5 - 17	23 - 184
Heptachlor	$C_{10}H_5Cl_7$	0.85-63	92-480	1952	1983[n]	4.34	6.1	3×10^{-4}	2.94×10^{-4}	0.05	250
HE[o]	$C_{10}H_5Cl_7O$	5.3-23	99-700			3.34 - 4.37	5.4	1.95×10^{-5}[q]	3.2×10^{-5}	0.275	250
Toxaphene	$C_{10}H_{10}Cl_8$	0.53-14	538-828	1940s	1990[p]	3 - 5	3.3 - 6.64	6.69×10^{-6}	6×10^{-6}	0.55	600

[a] Toxicity data from ECOTOX, U.S. Environmental Protection Agency ECOTOXicology database and the National Pesticide Information Center (NPIC). All tested species represented. A, acute (48 – 96 hr duration); D, dietary (8 days duration).

[b] Chemical properties obtained from the Agency for Toxic Substances and Disease Registry (ATSDR), U.S. Department of Health and Human Services.

[c] at 20° or 25° C.

[d] at 2 ° C.

[e] Obtained from the National Pesticide Information Center (NPIC), Oregon State University and the U.S. Environmental Protection Agency.

[f] Banned for all uses except termite control; 1987 banned for all uses.

[g] Pure form of chlordane.

[h] cis- and trans- isomers.

[i] 1979 banned by EPA for some uses, 1986 all uses were voluntarily cancelled except for its use on bird perches which was cancelled in 1991 (USDA 1995).

[j] Hexachlorobenzene, also produced as a byproduct/impurity in the manufacture of chlorinated solvents/compounds including several pesticides currently in use.

[k] Year registration was voluntarily cancelled; most commercial production ended in 1970s.

[l] Hexachlorocycohexane, consists of eight isomers - properties for four of the isomers applicable to pesticide use presented here.

[m] Not banned for use; banned from production, but chemical still imported from other countries. Not permitted for use involving direct aerial application.

[n] Banned for agricultural uses permitted with earlier 1974 ban on most uses. 1988 the sale, distribution, and shipment of existing stocks of all canceled heptachlor products were prohibited. Currently allowed for use in the treatment of fire ants in underground power transformers.

[o] Heptachlor epoxide, an oxidation product of heptachlor and chlordane.

[p] Banned for most uses in 1982 and all registered uses in 1990.

[q] at 30° C.

Organochlorine use in the Upper Basin was widespread from the 1940s to the 1960s, with some applications of a few compounds continuing into the 1970s (Boellstorff and others, 1985). Pesticides containing DDT and toxaphene were among the two most heavily used organochlorine pesticides with 23.9 and 38.8 km^2 within the Tule Lake basin, respectively, treated between 1955 and 1963 (Keith, 1966). The relative use of different organochlorine compounds varied among years, and other commonly applied pesticides included endrin, dieldrin, and heptachlor (Keith, 1966). Importantly, the heavy use of these pesticides, particularly DDT, toxaphene, and dieldren was associated with major toxicity events in waterbirds in the 1960s, when 397 white pelicans *(Pelecanus erythrorhynchos*), 147 great egrets (*Ardea alba*), 448 western grebes (*Aechmophorus occidentalis*), 26 great blue herons (*Ardea Herodias*), and 84 California and ringed-billed gulls (*Larus californicus* and *Larus delawarensis*, respectively) were found dead on Tule Lake and Lower Klamath refuges between 1960 and 1964 (Keith, 1966). Early analyses associated with these mortality events found elevated concentrations of DDT, toxaphene, and in some cases dieldrin in the tissues of many of these species (table 2). In addition to avian tissues, samples of abiotic (water, sediment, suspended particulates) and other biotic (aquatic plants, invertebrates, and fish) matrices were collected between 1960 and 1967 across several locations in the Tule Marsh refuge (Keith and others, 1967; Godsil and Johnson, 1968; table 2). These data indicate an association between with agricultural drainwater and organochlorine bioaccumulation in the Refuge, and also suggest that exposure in the environment varied seasonally with agricultural practices.

The last applications of DDT, toxaphene, and dieldrin reported in the Klamath basin (California side) were in 1971, 1982, and 1976, respectively (Boellstorff and others, 1985). However, dicofol (which commonly contained DDT and DDE as contaminants) was used until 1981 (Boellstorff and others, 1985). Studies conducted after organochlorine pesticide applications ceased in the area indicate that the contaminant profile in waterbirds changed. In 1977, dieldrin concentrations in waterbird eggs were substantially lower than during the years of application, whereas DDE (a highly persistent metabolite of DDT) concentrations in waterbird eggs were still measured at levels associated with reproductive impairment in brown pelicans (*Pelecanus occidentalis*) (table 2). Similarly, both DDT + DDD and Dieldrin concentrations in white pelican eggs declined by about 2-fold between 1969 and 1981, whereas DDE concentrations in pelican eggs did not change over the same time period (Boellstorff and others, 1985). However, both DDE and DDT concentrations were relatively low in pintail (*Anas acuta*) collected from Tule Lake in 1981 (table 2). By 1988, most organochlorine compounds were undetectable or found at very low concentrations in sediment, invertebrates, fish, and bird eggs and carcasses (Sorensen and Schwartzbach, 1991; table 2). However, DDE was still detected in western grebe eggs at concentrations similar to those from the 1960s and DDD was also measured at elevated concentrations in grebe eggs, likely reflecting the long persistence of those compounds. Finally, in a study conducted between 1990 and 1992 (Deleanis and others, 1996), DDE and DDD concentrations in western grebe eggs had decreased to values that generally were less than 1ppm, although a few samples exceeded 2.5 ppm wet weight. Importantly, white-faced ibis (*Plegadis chihi*), which extensively forage on agricultural fields, had a range of organochlorine pesticide compounds detected in their eggs, including dieldrin, endrin, HCB, heptachlor epoxide, t-nonachlor, oxychlordane, DDD, and DDT (table 2). Most of the compounds were detected at relatively low concentrations, but DDE concentrations averaged 4.85 ppm, with 7 of 21 eggs exceeding 8 ppm (Dileanis and others, 1996). Additionally, the authors found a significant negative relationship between DDE concentrations and eggshell thickness in white ibis (*Eudocimus albus*). These results suggest that ibis were either foraging in habitats in the Klamath Basin where residual organochlorine concentrations were more pronounced, such as agricultural fields, or that they were receiving substantial exposure on the wintering grounds or migratory stopovers.

Other Pesticides

As the ecological consequences of using bioaccumulative and persistent organochlorine pesticides became better understood, there was a shift toward the application of more acutely toxic compounds that had limited bioaccumulation potential and underwent comparatively rapid environmental degradation. As a result, two major pesticide classes, organophosphate and carbamate insecticides, emerged as major constituents of post-1960s pest management in agricultural lands of the Klamath Basin. In addition, the use of a suite of herbicides, fungicides, and fumigants began to increase in order to control various pests. Although there is limited information on their distribution and pathways through the Klamath basin ecosystem, several efforts in the 1980s and 1990s made an initial attempt at better understanding the pesticide profiles in drainwater, and potential for ecological exposure.

In 1991–92, 50 of 76 water samples collected from within the Tule Lake Irrigation District contained at least 1 of 47 tested pesticides at measureable concentrations, and detections in agricultural drains occurred at a higher frequency than sites upstream or downstream of Tule Lake (Dileanis and others, 1996). The most commonly detected compounds included four herbicides (simazine [53 percent detection rate], metribuzin [34 percent detection rate], EPTC [32 percent detection rate], metolachlor [30 percent detection rate]), and one insecticide (terbofos [12 percent detection rate]), but none were detected in water at concentrations exceeding acute toxicity criteria. Importantly, 10 of the 16 pesticides detected in the Dileanis and others (1996) study had no documented use on crops in the Tule Lake Irrigation District. This indicates either illegal uses on the refuge lands, or transport from other areas outside of the refuge boundaries. Moreover, examinations of methamidophos pesticide drift in the same study indicated that over-water drift occurred in 25 percent of aerial applications, suggesting that drift may have been an important contributor to pesticide exposure in nearby aquatic habitats.

Although these investigations yielded information on the occurrence and distribution of some of the most heavily used pesticides in the Tule Lake Refuge, there were limited findings relating these detections to toxic effects in aquatic or wildlife species. Static bioassays using site water and *in situ* survival tests indicated some acute toxicity to invertebrates and fish, as well malformations in frog embryos. However, site water quality for those tests generally was considered to be poor overall, and the authors note that pH, ammonia, and hypoxia may have been responsible for the observed mortality, and there was no direct evidence linking pesticide exposure and organism mortality or malformations. Additionally, the study found no evidence of organophosphate or carbamate exposure in ducklings held in cages within the refuge area. Conversely, a separate study of ring-necked pheasants (*Phasianus colchicus*) in agricultural fields of the Lower Klamath and Tule Lake National Wildlife Refuges found that the 68 percent of adult pheasants and 45 percent of savannah sparrows (*Passerculus sandwichensis*) tested exhibited substantial brain acetylcholinesterase inhibition after spraying events (Grove and others, 1998). However, their study also indicated that pesticide-induced mortality was not likely a major factor impacting the pheasant population in the area.

In response to growing concerns about pesticide impacts on refuge lands, a formal pesticide use program was implemented in the mid-1990s, and later refined to include a more quantitative and robust approach to risk assessment. One important component of the program was the requirement for annual reviews and approval of pesticide use on the lease lands. Additionally, the Refuge Integrated Pest Management Program developed a set of best management practices to further reduce risk to pesticides on refuge lands. As a result, prior to any entity applying pesticides on Refuge property, a suite of factors are evaluated to ensure that risk is minimized to the greatest extent possible. Some of the factors considered in the evaluation include: application rates, time periods, methods; modeled environmental transport; toxicity and mode of action; mobility, volatilization, bioaccumulation potential; soil types; and others.

Subsequent to the pesticide use program’s implementation, several studies and evaluations were conducted in an attempt to evaluate the risks of agricultural pesticide use on the Klamath Basin Refuge leased lands. Between 1998 and 2000, there were a series of terrestrial and aquatic field surveys timed around pesticide applications in Lower Klamath and Tule Lake Refuges in order to document any acute impacts of pesticides to the wildlife and aquatic community associated with pesticide use on the refuge (Snyder-Conn and Hawkes, 2004). During the study period, there were a total of 2,612 pesticide applications (fumigants = 0.5 percent; fungicides = 32.6 percent; herbicides = 55.3 percent; insecticides = 11.7 percent) to 581.5 km^2 of land. Over a 3-year period, several wildlife mortalities and fish kills were documented and investigated on the refuge, but with the exception of one incident in which off-refuge use of acrolein caused a fish kill, there was little supporting evidence that implicated pesticides as causative agents in any of the mortality events. However, the results of the study did reveal some evidence of trace wildlife exposure to the herbicides dicamba and 2,4-D and a few cases of limited acetylcholinesterase inhibition in birds, suggesting potential low-level exposure to organophosphate or carbamate insecticides (Snyder-Conn and Hawkes, 2004). In 2002 and 2003, a study was implemented to investigate pesticide exposure and it relationship with reproductive success in European starlings (*Sturnus vulgaris*; Hawkes and Haas, 2005). That study reported that after statistically controlling for the influence of crop type on hatching success there was a significant negative relationship between percent eggs hatched and the number of pesticide applications. Additionally, pesticides were detected in numerous starling dietary samples, with the herbicides dicamba and 2,4-D (both approved for refuge use) the most commonly detected compounds. However, several pesticides that were not approved for refuge use (aldicarb, carbofuran, propazine, simazine, and dichlorprop) also were detected. The authors noted that pesticide concentrations in dietary samples were less than concentrations known to cause adverse effects in birds; however, these thresholds are based on controlled experiments which the test subject(s) is exposed to only one chemical and not repeated exposure periods and/or the combination of chemicals. Finally, collected carcasses and sacrificed starlings nestlings indicated limited exposure to both organophosphate and carbamate pesticides and that overall the percentages of birds exposed to cholinesterase inhibiting pesticides was low. Subsequent to this effort, Cameron (2008) reported monitoring data on pesticide concentrations in Tule Lake NWR, but the reporting limits on the analysis were well above what would be informative for risk evaluation (table 2), so we do not consider those data any further.

To our knowledge, the above-mentioned studies are the only empirical efforts to evaluate pesticide impacts on the biological community in the Klamath Basin after the implementation of the pesticide use program. However, some data modeling and “weight-of-evidence” approaches have shed qualitative light on the likelihood of impacts to threatened and endangered species in the Klamath Basin. Specifically, in 2007 the U.S. Fish and Wildlife Service modeled the risk of multiple pesticides to listed suckers in Tule Lake by incorporating estimates of application rates and subsequent drift or runoff into surface waters and exposure scenarios based on known water usage patterns. When combined with toxicity estimates from test organisms and data on the compounds’ environmental fates, it was determined that

Vapam (a soil fumigant) and Lorsban (an organophosphate insecticide) posed the greatest risk to listed suckers, but that they were not likely to pose substantial risk to either species (Haas, 2007). This determination was based on the estimated pesticide surface-water concentrations in the Tule Lake sumps being below toxicity thresholds for other fish species. Immediately subsequent to the Haas (2007) risk assessment, the U.S. Fish and Wildlife Service (2007) conducted a programmatic Biological Opinion to consider the risks of pesticides to endangered suckers and threatened bald eagles. Based on the limited existing data on pesticide impacts and distribution, pesticide use information, benchmark toxicity values, and habitat use of the threatened and endangered species, the Biological Opinion evaluated impacts from direct exposure to the organisms, indirect effects through pesticide-induced reduction in prey populations, and pesticide-induced reductions in water quality. Although the assessment found that some level of pesticide exposure could occur to listed species, the evidence did not support a determination that the pesticide applications were likely to cause harm to the species considered.

Trace Metals

Mercury

Mercury (Hg) contamination of aquatic ecosystems is increasingly recognized as a widespread issue that poses considerable risks to human and wildlife health (Scheuhammer and others, 2007). A rich ore belt exists in the Coast Range from northern California through southern Oregon, including locations in the Klamath Basin, which contains large deposits of mercury and other metals. Historical mining operations to extract Hg, gold, and other mineral resources has resulted in releases into many streams and rivers within the Klamath Basin (National Research Council, 2004). Additionally, there is strong evidence that Hg concentrations are increasing globally, due in large part to anthropogenic emissions associated with burning fossil fuels, and subsequent atmospheric deposition (Lindberg and others, 2007). Thus, even with reductions in regional mining-associated releases, a substantial reduction in atmospheric Hg loading to aquatic ecosystems is unlikely until global Hg emissions subside. Importantly, Hg is relatively unique in the sense that microbial processes are required to convert inorganic Hg (the most abundant, less toxic form of Hg, which is does not readily bioaccumulate) into methylmercury (MeHg), which is highly toxic and bioaccumulates rapidly through food webs (Eagles-Smith and Ackerman, 2009). These microbial processes require specific environmental conditions to facilitate MeHg production. Therefore, some areas with high Hg deposition may still have relatively low Hg concentrations in biota, whereas if environmental conditions favor conversion of inorganic Hg to MeHg, then other locations with low Hg deposition may have relatively high Hg concentrations in biota. Furthermore, wetlands, floodplains, and other waters with highly seasonal inundation fluctuations (for example, reservoirs), are known habitats that facilitate MeHg production due to their inherent biogeochemical properties (Ulrich and others, 2001). Similarly, densely forested rivers and streams with high precipitation rates have been shown to support elevated Hg loading, and when coupled with tree-litter organic matter cycling, fire regimes, and sediment dynamics, these habitats can be important MeHg sources as well (Sorensen and others, 2009). Thus, with the abundance of productive wetlands in the Upper Basin, and the dominance of dense forested habitat coupled with numerous Hg mines in the Lower Basin, Hg contamination has the potential to be a serious ecological issue throughout the region.

The first documentation of Hg measurements in matrices from within the Klamath Basin was between 1979 and 1982, in a study assessing contaminant concentrations in wintering bald eagles and their prey (Frenzel and Anthony, 1989). Mercury concentrations in dominant prey items, such as mallard ducks (*Anas platyrhynchos*), American wigeon (*Anas americana*), and ruddy ducks (*Oxyura jamaicensis*) generally were low (table 2), but they reported elevated blood Hg concentrations in adult (2.285 ug/g wet weight) and subadult (2.166 ug/g) eagles. These concentrations approach levels in the blood that are known to cause reproductive impairment in other species, but the disconnect between diet and eagle blood concentrations suggests that either: (1) a key prey item was not identified and sampled, (2) the eagles primarily ingested specific organs of prey that had relatively higher concentrations then the homogenized carcass, or (3) Hg concentrations in eagle blood are more reflective of migratory or breeding-ground exposure.

In 1988, Sorenson and Schwarzbach (1991) quantified Hg distribution in abiotic and biotic matrices in the Upper Klamath Basin. Although aqueous concentrations were less than reporting limits, sediment concentrations of total Hg (THg; inorganic + MeHg) were similar to geometric mean values for soils in the Western United States, with the exception of sediments downstream of the Link River Dam, which had concentrations that exceeded the rest of the basin by at least 4-fold. Importantly, there was a consistent trend of biota concentrations across the trophic gradient (pond weed to waterbirds) being considerably higher in Lower Klamath Lake than Tule Lake (table 2). A follow-up study just a few years later found relatively low Hg concentrations in all matrices, with no strong site effects in fish or avian eggs (MacCoy, 1994; Dileanis and others, 1996). However, a simultaneous investigation of an American pelican mortality event in the Great Basin revealed elevated liver mercury concentrations in the two birds sampled from Lower Klamath Lake (Henson and others, 1992). The apparent lack of consistency in Hg measurements in the studies described above highlights the spatial and temporal variability in Hg concentrations in the environment that are strongly connected to the propensity of different habitats to support MeHg production due to the biogeochemical characteristics and wetting and drying patterns. This is particularly true in managed wetland habitats that can undergo major changes in the amount, timing, spatial extent, and duration of flooding as a result of natural precipitation patters and managed water use.

In the Lower Basin, wetlands and marshes are far less common and productive, but the region has been heavily influenced by numerous past and currently active mining operations. There has been limited work on Hg cycling in the Lower Basin, but those few studies suggest that mercury may be a legitimate concern for both ecological and human health. Specifically, work within the Trinity River basin (a tributary to the Klamath River) found that mercury concentrations in eight species of fish often exceeded both human and wildlife health thresholds (May and others, 2005). Mercury concentrations were most elevated in and near Trinity Lake, near a large abandoned mine. However, fish in locations well away from Trinity Lake also exhibited elevated Hg concentrations, suggesting that factors other than point source loading are indeed influencing mercury cycling in the region, and that there may be risk to biota farther downstream. Similarly a recent study on mercury bioaccumulation in lamprey (*Lampetra tridentate*) ammocoetes showed a substantial increase in mercury concentrations with distance away from Trinity Lake (Bettaso and Goodman, 2008). Additionally, the concentrations in ammocoetes were surprisingly high (table 2), approaching and exceeding toxicological thresholds. This has important implications because lamprey are an important native trust species and in addition to causing risk to human health, they may be experiencing deleterious effects from exposure themselves.

Arsenic

Arsenic is a metalloid that occurs naturally in the environment and can be found in high concentrations in association with volcanic activity, hot springs, and sedimentary rocks of marine origin (Eisler, 1988). Anthropogenic sources include industrial processes and wood preservatives (although its use is decreasing), and it was historically used as an anti-fungal pesticide. The environmental toxicity of arsenic strongly depends on its speciation. The most common inorganic forms are arsenite (As (III)) and arsenate (As (V)), with arsenite being substantially more toxic. Arsenic also can exist in various methylated organic forms, which have even lower toxicity than the inorganic compounds. The inorganic speciation (and thus environmental risk) of arsenic is reliant on pH and redox conditions, with As (V) being reduced to As (III) under anoxia.

Sorenson and Schwarzbach (1991) measured arsenic in biota from the Upper Basin at concentrations of environmental concern. However, the measured arsenic was not speciated, so the environmental risks of their findings are unclear. Despite those limitations, arsenic in water was highest (62 µg/L) at Lower Klamath Lake unit 12C (range <1–62 µg/L, median = 7 µg/L, N=18) and arsenic in bottom sediment was highest at Klamath Straits Drain at pumping plant FF (range 0.6–16 µg/g, median = 6.3 µg/g, N=13). Across biological matrices, arsenic concentrations were higher in plants (pond weed, a primary waterfowl food) than any other matrix sampled. Pond weed concentrations ranged from 0.063 µg/g (Lost River) to 25.1 µg/g (Lower Klamath Lake), and were detected in proportion to concentrations measured in water. Arsenic concentrations among aquatic invertebrates ranged from 0.276 to 8.73 µg/g and were highest in clams, mussels, snails, and chironomid larvae. Mean arsenic concentrations in invertebrates among all sampling sites were greater than 0.5 µg/g, which is considered harmful to fish and predators (Sorenson and Schwarzbach, 1991). Arsenic concentrations in fish (<0.20 – 0.67 µg/g) were lower than concentrations shown to adversely affect aquatic species (Eisler, 1988). Arsenic residues in bird livers (coots [*Fulica americana*], mallards, and western grebes: 0.113–1.00 µg/g dry weight) were not observed at acutely toxic concentrations, but concentrations observed in coot eggs (0.324–0.521 µg/g dry weight) may be approaching concentrations harmful to normal embryonic development (Sorenson and Schwarzbach, 1991).

Arsenic was detected in all 11 sediment samples (range = 0.89–5.95 µg/g wet weight; equivalent to geometric mean of 8.8 µg/g dry weight, range = 2.53–25.66 µg/g, Dileanis and others, 1996). Arsenic concentrations were 0.02, 0.07, and 0.06 µg/g wet weight in blue-green algae (*Aphanezomenon flos-aquae*) samples collected in 1991 from Lost River, Tule Lake NWR, and the Klamath Straits Drain, respectively (MacCoy, 1994). Arsenic also was detected in Notonectidae (backswimmers; 2.70 µg/g wet weight) and Corixidae (waterboatman; 0.72 µg/g wet weight) collected from Lower Klamath Lake NWR in 1992, but not in bird egg samples (N=30) (MacCoy, 1994).

Lead

Lead is a ubiquitous heavy metal that enters the environment through mining and smelting, use in industrial and consumer products, paints, combustion of fossil fuels, and through ammunition and fishing tackle. Lead is a highly toxic metal that can cause severe neurological toxicity and permanent kidney damage. It is currently unclear if there are any major lead sources in the Klamath Basin, but some evidence exists for substantial lead exposure in wildlife in the area. Frenzel and Anthony (1989) reported lead concentrations in the prey and in the blood and tissues of bald eagles wintering in the Klamath Basin during 1979–82. Mean lead concentrations in prey species ranged from 0.15 to 4.79 ppm wet weight and were highest in mallards and ruddy ducks. Eagles largely fed on waterfowl (94 percent, N=913) in mid- to late winter, and lead was detected in 95 percent of waterfowl samples. Authors attribute some of the high lead concentrations in prey species to embedded Pb shot fragments in the whole body homogenates (Frenzel and Anthony, 1989). Lead was detected in 41 percent of the bald eagle blood samples (N=17), and the frequency of occurrence and geometric means were greater in subadults (75 percent, 0.129 ppm wet weight, N=4) than adults (31 percent, 0.038 ppm wet weight). Lead was detected in all livers (N=9, range 0.89–27 ppm wet weight) of eagles found dead during 1979–82 (Frenzel and Anthony, 1989).

Summary

As described in the previous sections, the Klamath Basin has a history of contaminant impacts that primarily have been the result of the nexus between land-use practices and important wildlife habitat. Most importantly, past agricultural practices resulted in unintended pesticide bioaccumulation in waterbirds, and subsequent mortality events. The overall magnitude of those impacts on avian populations is unclear. Many of those historical issues have been identified and aggressively addressed and there is now a more rigorous process in place for controlling the use of pesticides on the Refuge lease lands. As a result of changes in pesticide applications and land use, as well as improvements to our understanding of the drivers of contaminant risk, contaminant threats in the region have likely change considerably over the past few decades. In the section that follows, we have compiled available information on more current contaminant distribution and use through the basin to help guide future improvements in our understanding of those risks to ecosystem function.

Table 2. Summary of contaminant concentrations in biota, sediment and water sampled from the Klamath basin reported in studies, 1960 – 2007.

Year	CC[a]	Location[c]	Taxa/Media	Species	Tissue	Contaminant	N	Concentration	Units	Reference
1960	OC	NS	Bird	Great egret	carcass[b]	DDD	1	75	ppm ww	Pillmore 1961
1960	OC	LK	Bird	white pelican	kidney	DDD	3	7 - 12	ppm ww	Pillmore 1961
1960	OC	LK	Bird	white pelican	liver	DDD	3	6 - 15	ppm ww	Pillmore 1961
1960	OC	TL	Bird	Forster's tern	carcass[b]	DDD	1	1	ppm ww	Pillmore 1961
1960	OC	TL	Bird	Multiple	carcass[b]	DDD	3	<0.3 - 0.5	ppm ww	Pillmore 1961
1960	OC	TL	Bird	Western grebe	carcass[b]	DDD	6	5 - 240	ppm ww	Pillmore 1961
1960	OC	TL	Bird	Western grebe	fat	DDD	2	107 - 302	ppm ww	Pillmore 1961
1960	OC	TL	Bird	Multiple	carcass[b]	DDE	3	trace - 2.0	ppm ww	Pillmore 1961
1960	OC	LK	Bird	Redhead duck	carcass[b]	DDE	1	<0.4	ppm ww	Pillmore 1961
1960	OC	NS	Bird	Great egret	carcass[b]	DDT/DDE	1	138	ppm ww	Pillmore 1961
1960	OC	LK	Bird	White pelican	kidney	DDT/DDE	3	ND - 24	ppm ww	Pillmore 1961
1960	OC	LK	Bird	White pelican	liver	DDT/DDE	3	ND - 64	ppm ww	Pillmore 1961
1960	OC	TL	Bird	Heron	carcass[b]	DDT/DDE	1	12	ppm ww	Pillmore 1961
1960	OC	TL	Bird	Black tern	carcass[b]	DDT/DDE	1	3.5	ppm ww	Pillmore 1961
1960	OC	TL	Bird	Forster's tern	carcass[b]	DDT/DDE	1	25	ppm ww	Pillmore 1961
1960	OC	TL	Bird	Great blue heron	carcass[b]	DDT/DDE	1	3	ppm ww	Pillmore 1961
1960	OC	TL	Bird	Western grebe	carcass[b]	DDT/DDE	6	6 - 38	ppm ww	Pillmore 1961
1960	OC	TL	Bird	Western grebe	fat	DDT/DDE	2	162 - 348	ppm ww	Pillmore 1961
1960	OC	TL	Bird	Pintail duck	carcass[b]	DDT	1	1	ppm ww	Pillmore 1961
1960	OC	NS	Bird	Great egret	carcass[b]	Toxaphene	1	17	ppm ww	Pillmore 1961
1960	OC	LK	Bird	White pelican	kidney	Toxaphene	3	4 - 14	ppm ww	Pillmore 1961
1960	OC	LK	Bird	White pelican	liver	Toxaphene	3	7 - 9	ppm ww	Pillmore 1961
1960	OC	NS	Bird	Great blue heron	carcass[b]	Toxaphene	1	10	ppm ww	Pillmore 1961
1960	OC	TL	Bird	Ruddy duck	carcass[b]	Toxaphene	1	0.4	ppm ww	Pillmore 1961
1960	OC	TL	Bird	Western grebe	carcass[b]	Toxaphene	6	ND - 0.8	ppm ww	Pillmore 1961
1960	OC	TL	Bird	Western grebe	fat	Toxaphene	2	24 - 39	ppm ww	Pillmore 1961
1960	OC	LK	Fish	Chubs	composites	DDD	2	0.2	ppm ww	Pillmore 1961
1960	OC	LK	Fish	Chubs	composites	DDD	4	0.03 - 0.06	ppm ww	Pillmore 1961
1960	OC	LK	Fish	Chubs	composites	DDE	2	0.1 - 0.6	ppm ww	Pillmore 1961
1960	OC	LK	Fish	Chubs	composites	DDE	2	0.03 - 0.06	ppm ww	Pillmore 1961
1960	OC	LK	Fish	Chubs	composites	DDT	1	0.03	ppm ww	Pillmore 1961
1960	OC	LK	Fish	Chubs	composites	Toxaphene	2	0.1 and 0.3	ppm ww	Pillmore 1961
1960	OC	LK	Fish	Chubs	composites	Toxaphene	3	<0.05 - 0.2	ppm ww	Pillmore 1961
1960-1961	OC	TL + LK	Invertebrate	NA	Invertebrates	DDT		ND - 6.0		Keith 1966
1960-1961	OC	TL + LK	Invertebrate	NA	Invertebrates	Toxaphene		ND - 0.2		Keith 1966
1960-1961	OC	TL + LK	Plant	NA	Algae	DDT		0.1 - 0.3		Keith 1966
1960-1961	OC	TL + LK	Plant	NA	Pondweed	DDT		ND - 2.1		Keith 1966
1960-1961	OC	TL + LK	Plant	NA	Algae	Toxaphene		ND		Keith 1966
1960-1961	OC	TL + LK	Plant	NA	Pondweed	Toxaphene		ND		Keith 1966
1960-1961	OC	TL + LK	Sediment	NA	Sediment	DDT		ND - 3.8		Keith 1966
1960-1961	OC	TL + LK	Sediment	NA	Sediment	Toxaphene		ND - 0.2		Keith 1966
1960-1962	OC	TL + LK	Bird	Multiple	Multiple	DDT		16.1-102.7	ppm	Keith 1966
1960-1962	OC	TL + LK	Bird	Multiple	Multiple	Dieldren		ND - 3.2		Keith 1966
1960-1962	OC	TL + LK	Bird	Multiple	Multiple	Toxaphene		0.3-10.3	ppm	Keith 1966
1960-1961	OC	TL + LK	Fish	NA	whole body	DDT		ND - 1.6		Keith 1966
1960-1961	OC	TL + LK	Fish	NA	whole body	Toxaphene		ND - 8.0		Keith 1966
1962	OC	TL + LK	Particulate	NA		DDTs		2.8-59.3		Keith 1966
1962	OC	TL + LK	Water	NA	Filtered	DDTs		ND - 0.0001		Keith 1966

Table 2. Continued.

Year	CC[a]	Location[c]	Taxa/Media	Species	Tissue	Contaminant	N	Concentration	Unit	Reference
1965 - 1966	OC	TL	Fish	Chubs	composites	Chlordane	5	ND - 24.0	ppb	Godsil and Johnson 1968
1965 - 1966	OC	TL	Fish	Chubs	composites	DDD/DDT	5	2.5 - 17.0	ppb	Godsil and Johnson 1968
1965 - 1966	OC	TL	Fish	Chubs	composites	DDE	5	2.5 - 45.0	ppb	Godsil and Johnson 1968
1965 - 1966	OC	TL	Fish	Chubs	composites	Endrin	5	4.0 - 198	ppb	Godsil and Johnson 1968
1965 - 1966	OC	TL	Invertebrate	Clams	composites	Chlordane	3	3.0 - 12.0	ppb	Godsil and Johnson 1968
1965 - 1966	OC	TL	Invertebrate	Clams	composites	DDD/DDT	3	3.0 - 4.8	ppb	Godsil and Johnson 1968
1965 - 1966	OC	TL	Invertebrate	Clams	composites	DDE	3	4.0 - 4.8	ppb	Godsil and Johnson 1968
1965 - 1966	OC	TL	Invertebrate	Clams	composites	Endrin	3	2.0 - 34.0	ppb	Godsil and Johnson 1968
1966	OC	TL	Plant	Cladophora spp.	Algae	Chlordane	5	ND - 50.0	ppb	Godsil and Johnson 1968
1966	OC	TL	Plant	Cladophora spp.	Algae	DDD/DDT	5	ND - 3.0	ppb	Godsil and Johnson 1968
1966	OC	TL	Plant	Cladophora spp.	Algae	DDE	5	ND - 2.0	ppb	Godsil and Johnson 1968
1966	OC	TL	Plant	Cladophora spp.	Algae	Endrin	5	ND - 22.3	ppb	Godsil and Johnson 1968
1966	OC	TL	Plant	NA		Chlordane	7	ND - 6.0	ppb	Godsil and Johnson 1968
1966	OC	TL	Plant	NA		DDD/DDT	7	ND - 10.0	ppb	Godsil and Johnson 1968
1966	OC	TL	Plant	NA		DDE	7	ND - 1.0	ppb	Godsil and Johnson 1968
1966	OC	TL	Plant	NA		Endrin	7	ND - 12.5	ppb	Godsil and Johnson 1968
1966 - 1967	OC	TL	Particulate	NA		Chlordane	8	1.5 - 67.0	ppb	Godsil and Johnson 1968
1966 - 1967	OC	TL	Particulate	NA		DDD/DDT	8	ND - 12.0	ppb	Godsil and Johnson 1968
1966 - 1967	OC	TL	Particulate	NA		DDE	8	ND - 6.6	ppb	Godsil and Johnson 1968
1966 - 1967	OC	TL	Particulate	NA		Endrin	8	ND - 57.7	ppb	Godsil and Johnson 1968
1965 - 1967	OC	TL	Water	NA	Water	Chlordane	44	ND - 0.017	ppb	Godsil and Johnson 1968
1965 - 1967	OC	TL	Water	NA	Water	DDD/DDT	44	ND - 0.027	ppb	Godsil and Johnson 1968
1965 - 1967	OC	TL	Water	NA	Water	DDE	44	ND - 0.027	ppb	Godsil and Johnson 1968
1965 - 1967	OC	TL	Water	NA	Water	Endrin	44	ND - 0.069	ppb	Godsil and Johnson 1968
1969	OC	LK + CL	Bird	White pelican	egg	DDE	10	2.34[f]	ppm ww	Boellstorff et al. 1985
1969	OC	TL	Bird	White pelican	egg	DDT+DDD	10	0.76[f]	ppm ww	Boellstorff et al. 1985
1969	OC	LK + CL	Bird	White pelican	egg	Dieldren	10	0.16[f]	ppm ww	Boellstorff et al. 1985
1969	OC	LK + CL	Bird	White pelican	egg	Endrin	1	0.2	ppm ww	Boellstorff et al. 1985
1969	OC	LK	Bird	White pelican	egg	PCBs (total)	4	0.52[f]	ppm ww	Boellstorff et al. 1985
1977	OC	UK	Bird	Heron	egg	DDE	6	3.32	ppm ww	Henny, unpub. data
1977	OC	UK	Bird	Cormorant	egg	DDE	6	4.25	ppm ww	Henny, unpub. data
1977	OC	UK	Bird	great blue heron	egg	DDE	4	2.06	ppm ww	Fitzner etal 1988
1977	OC	UK	Bird	great blue heron	egg	DDE	4	3.31	ppm ww	Henny, unpub. data
1977	OC	UK	Bird	great egret	egg	DDE	5	3.76	ppm ww	Henny, unpub. data
1977	OC	UK	Bird	Western grebe	egg	DDE	6	0.83	ppm ww	Henny, unpub. data
1977	OC	UK	Bird	Multiple	egg	Dieldren	6	0.05	ppm ww	Henny, unpub. data
1977	OC	UK	Bird	cormorant	egg	Dieldren	6	0.14	ppm ww	Henny, unpub. data
1977	OC	UK	Bird	great blue heron	egg	Dieldren	4	0.28	ppm ww	Fitzner etal 1988
1977	OC	UK	Bird	great blue heron	egg	Dieldren	6	0.36	ppm ww	Henny, unpub. data
1977	OC	UK	Bird	great egret	egg	Dieldren	5	0.15	ppm ww	Henny, unpub. data
1977	OC	UK	Bird	Western grebe	egg	Dieldren	4	ND	ppm ww	Henny, unpub. data
1977	OC	UK	Bird	heron	egg	PCBs (total)	6	0.68	ppm ww	Henny, unpub. data
1977	OC	UK	Bird	cormorant	egg	PCBs (total)	6	5.27	ppm ww	Henny, unpub. data
1977	OC	UK	Bird	great blue heron	egg	PCBs (total)	4	3.34	ppm ww	Fitzner etal 1988
1977	OC	UK	Bird	great blue heron	egg	PCBs (total)	6	3.82	ppm ww	Henny, unpub. data
1977	OC	UK	Bird	great egret	egg	PCBs (total)	5	0.13	ppm ww	Henny, unpub. data
1977	OC	UK	Bird	Western grebe	egg	PCBs (total)	4	1.62	ppm ww	Henny, unpub. data

Table 2. Continued.

Year	CC[a]	Location[c]	Taxa/Media	Species	Tissue	Contaminant	N	Concentration	Unit	Reference
1979 - 1982	OC	UK	Bird	California gull	composites	alpha-Chlordane	5	0.023[fg] (0.011 - 0.047)	ppm ww	Frenzel 1985
1979 - 1982	OC	UK	Bird	Eared grebe	composites	alpha-Chlordane	13	<0.01	ppm ww	Frenzel 1985
1979 - 1982	OC	UK	Bird	Ring-billed gull	carcass, composites	alpha-Chlordane	1	<0.01	ppm ww	Frenzel 1985
1979 - 1982	OC	UK	Bird	Western grebe	composites	alpha-Chlordane	13	0.008 [f] (ND - 0.28)	ppm ww	Frenzel 1985
1979-1982	OC	KB	Bird	Bald eagle	carcass	DDD	8	0.380	ppm ww	Frenzel and Anthony 1989
1979 - 1982	OC	UKL	Bird	California gull	composites	DDD	5	<0.01	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Eared grebe	composites	DDD	13	<0.01	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Ring-billed gull	composites	DDD	1	<0.01	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Western grebe	composites	DDD	13	0.452[fg] (0.238 - 0.858)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	American coot	composites	DDE	10	0.037[fg] (0.024 - 0.056)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Am. wigeon	composites	DDE	5	0.008[fh] (ND - 0.02)	ppm ww	Frenzel 1985
1979-1982	OC	KB	Bird	Bald eagle	carcass	DDE	8	4.669	ppm ww	Frenzel and Anthony 1989
1979 - 1982	OC	UKL	Bird	California gull	composites	DDE	5	2.587[fg] (1.978-3.385)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Canada goose	composites	DDE	3	0.006[fh] (ND - 0.01)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	goldeneye	composites	DDE	1	0.06	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Eared grebe	composites	DDE	13	0.056[fg] (0.027 - 0.113)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Gadwall	composites	DDE	1	0.01[fh]	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Goose	composites	DDE	1	<0.01	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Lesser scaup	composites	DDE	8	0.258[fg] (0.108 - 0.615)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Mallard	composites	DDE	5	0.027[fg] (0.007 - 0.106)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Mallard	composites	DDE	7	0.027[fg] (0.011 - 0.068)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Northern pintail	composites	DDE	7	0.059[fg] (0.027 - 0.129)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Ring-billed gull	composites	DDE	1	2.14	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Ross's goose	composites	DDE	7	0.010[fg] (0.007-0.014)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Ruddy duck	composites	DDE	2	0.232[fh] (0.15 - 0.36)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Ruddy duck	composites	DDE	7	0.252 (0.036 - 1.759)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Snow goose	composites	DDE	7	0.011[fg] (0.006 - 0.020)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Western grebe	composites	DDE	13	4.150[fg] (2.794 - 6.164)	ppm ww	Frenzel 1985
1979-1982	OC	KB	Bird	Bald eagle	carcass	Dieldren	8	0.036	ppm ww	Frenzel and Anthony 1989
1979 - 1982	OC	UKL	Bird	goldeneye	composites	Endrin	1	<0.01	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	goose	composites	Endrin	1	0.02	ppm ww	Frenzel 1985

Table 2. Continued.

Year	CC[a]	Location[c]	Taxa/Media	Species	Tissue	Contaminant	N	Concentration	Unit	Reference
1979 - 1982	OC	UKL	Bird	California gull	composites	Heptachlor	5	0.015[fg] (0.009 - 0.024)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Eared grebe	composites	Heptachlor	13	<0.01	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Ring-billed gull	composites	Heptachlor	1	0.21	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Western grebe	composites	Heptachlor	13	0.006[fh] (ND - 0.03)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	American coot	composites	PCBs	10	0.054[fh] (ND - 0.11)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Am. wigeon	composites	PCBs	5	<0.1	ppm ww	Frenzel 1985
1979-1982	OC	KB	Bird	Bald eagle	carcass	PCBs (total)	8	4.588	ppm ww	Frenzel and Anthony 1989
1979 - 1982	OC	UKL	Bird	California gull	composites	PCBs	5	1.839[fg] (1.278 - 2.647)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Canada goose	composites	PCBs	3	<0.1[fh]	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	goldeneye	composites	PCBs	1	0.16	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Eared grebe	composites	PCBs	13	0.067[fh] (ND - 0.34)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Gadwall	composites	PCBs	1	<0.1	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	goose	composites	PCBs	1	<0.1	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Lesser scaup	composites	PCBs	8	0.285[fg] (0.107 - 0.756)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Mallard	composites	PCBs	5	<0.1[f]	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Mallard	composites	PCBs	7	<0.1	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Northern pintail	composites	PCBs	7	0.057[fh] (ND - 0.12)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Ring-billed gull	composites	PCBs	1	1.37	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Ross's goose	composites	PCBs	7	<0.1	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Ruddy duck	composites	PCBs	2	0.126[fh] (ND - 0.32)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Ruddy duck	composites	PCBs	7	0.124[fh] (0.052 - 0.300)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Snow goose	composites	PCBs	7	<0.1	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Western grebe	composites	PCBs	13	3.760[fg] (2.345 - 6.028)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	California gull	composites	cis-Nonachlor	5	<0.01	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Eared grebe	composites	cis-Nonachlor	13	<0.01	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Ring-billed gull	composites	cis-Nonachlor	1	<0.01	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Western grebe	composites	cis-Nonachlor	13	0.059[fg] (0.031 - 0.113)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	California gull	composites	trans-Nonachlor	5	0.081[fg] (0.062 - 0.104)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Eared grebe	composites	trans-Nonachlor	13	<0.01	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Ring-billed gull	composites	trans-Nonachlor	1	0.02	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Bird	Western grebe	composites	trans-Nonachlor	13	0.024[fg] (0.009-0.069)	ppm ww	Frenzel 1985
1980 - 1982	OC	KB	Bird	Bald eagle	carcass	Toxaphene	8	0.002	ppm ww	Frenzel and Anthony 1989
1979 - 1982	OC	UKL	Fish	Blue chub	composites	DDE	15	0.017[fg] (0.013-0.022)	ppm ww	Frenzel 1985

Table 2. Continued.

Year	CC[a]	Location[c]	Taxa/Media	Species	Tissue	Contaminant	N	Concentration	Unit	Reference
1979 - 1982	OC	UKL	Fish	Sucker	composites	DDE	3	0.013[fg] (ND - 0.02)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Fish	Chub	composites	DDE	15	0.015[fg] (0.010-0.023)	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Mammal	ground squirrel	composites	DDE	18	0.006[fh]	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Mammal	jack rabbit	composites	DDE	8	<0.01	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Mammal	Montane vole	composites	DDE	10	<0.01	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Mammal	cottontail	composites	DDE	1	<0.01	ppm ww	Frenzel 1985
1979 - 1982	OC	UKL	Mammal	Montane vole	composites	PCBs	10	<0.1	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	blood	cis-Chlordane	5	ND - 0.018	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	carcass[i]	cis-Chlordane	1	0.09 - 0.30	ppm ww	Frenzel 1985
1980 - 1981	OC	UKL	Bird	Bald eagle	eggs	cis-Chlordane	4	ND - 0.15	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	blood	DDD	24	ND - 0.040	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	blood	DDD	5	ND - 0.029[h]	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	Brain[i]	DDD	1	ND - 0.05	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	Carcass[i]	DDD	1	0.30 - 0.63	ppm ww	Frenzel 1985
1980 - 1981	OC	UKL	Bird	Bald eagle	Eggs	DDD	4	ND - 0.38	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	Blood[i]	DDE	24	0.023[fg] (0.015 - 0.036)	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	blood	DDE	5	0.952[fh] (0.68 - 1.40)	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	blood	DDE	5	0.030[fg] (0.007- 0.126)	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	blood	DDE	16	0.042[fh] (0.028 - 0.064)	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	brain	DDE	1	2.3	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	carcass	DDE	1	1.1	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	Brain[i]	DDE	1	1.1 - 2.4	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	Carcass[i]	DDE	1	9.8 - 34.0	ppm ww	Frenzel 1985
1980 - 1981	OC	UKL	Bird	Bald eagle	Eggs	DDE	4	7.2 - 20.0	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	Carcass[i]	Dieldrin	1	0.06 - 0.17	ppm ww	Frenzel 1985
1980 - 1981	OC	UKL	Bird	Bald eagle	Eggs	Dieldrin	4	ND - 0.10	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	Carcass[i]	HCB	1	ND - 0.15	ppm ww	Frenzel 1985
1980 - 1981	OC	UKL	Bird	Bald eagle	Eggs	HCB	4	ND - 0.03	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	Carcass[i]	Heptachlor	1	ND - 0.28	ppm ww	Frenzel 1985
1980 - 1981	OC	UKL	Bird	Bald eagle	Eggs	Heptachlor	4	ND - 0.03	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	Carcass[i]	cis-Nonachlor	1	0.11 - 0.28	ppm ww	Frenzel 1985
1980 - 1981	OC	UKL	Bird	Bald eagle	eggs	cis-Nonachlor	4	ND - 0.05	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	Blood[i]	trans-Nonachlor	5	ND - 0.02	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	Carcass[i]	trans-Nonachlor	1	0.45 - 0.75	ppm ww	Frenzel 1985
1980 - 1981	OC	UKL	Bird	Bald eagle	Eggs	trans-Nonachlor	4	ND - 0.32	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	Carcass[i]	Oxychlordane	1	0.07 - 0.25	ppm ww	Frenzel 1985
1980 - 1981	OC	UKL	Bird	Bald eagle	Eggs	Oxychlordane	4	ND - 0.10	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	blood	PCBs	5	0.543[fh] (0.40 - 0.71)	ppm ww	Frenzel 1985
1979 - 1983	OC	UKL	Bird	Bald eagle	blood	PCBs	5	0.014[fh] (ND - 0.08)	ppm ww	Frenzel 1985

Table 2. Continued.

Year	CC[a]	Location[c]	Taxa/Media	Species	Tissue	Contaminant	N	Concentration	Unit	Reference
1979 - 1983	OC	UKL	Bird	Bald eagle	blood	PCBs	16	0.018[fg] (0.009 - 0.036)	ppm ww	Frenzel 1985
1981	OC	UK + CL	Bird	White pelican	egg	DDE	35	2.38	ppm ww	Boellstorff et al. 1985
1981	OC	LK	Bird	Northern pintail	carcass	DDE	6	0.143	ppm dw	Mora et al 1987
1981	OC	TL	Bird	Western grebe	egg	DDE	12	1.4[f]	ppm ww	Boellstorff et al. 1985
1981	OC	UK + CL	Bird	White pelican	egg	DDT+DDD	34	0.36[f]	ppm ww	Boellstorff et al. 1985
1981	OC	TL	Bird	Western grebe	egg	DDT+DDD	9	0.18[f]	ppm ww	Boellstorff et al. 1985
1981	OC	LK	Bird	Northern pintail	carcass	DDT	14	0.073	ppm dw	Mora et al 1987
1981	OC	UK + CL	Bird	White pelican	egg	Dieldren	16	0.08[f]	ppm ww	Boellstorff et al. 1985
1981	OC	LK	Bird	Northern pintail	carcass	Dieldren	2	0.027	ppm dw	Mora et al 1987
1981	OC	UK + CL	Bird	White pelican	egg	Endrin	2	ND - 0.18	ppm ww	Boellstorff et al. 1985
1981	OC	UK + CL	Bird	White pelican	egg	PCBs (total)	12	0.37[f]	ppm ww	Boellstorff et al. 1985
1981	OC	TL	Bird	Western grebe	egg	PCBs (total)	11	2.21[f]	ppm ww	Boellstorff et al. 1985
1988	OC	TL	Bird	Mallard	egg	DDD	2	0.02 - 0.03	ppm ww	Sorenson and Schwarzbach 1991
1988	OC	TL	Bird	Western grebe	egg	DDD	3	0.11 - 3.6	ppm ww	Sorenson and Schwarzbach 1991
1988	OC	TL	Bird	American coot	egg	DDE	6	0.01 - 0.06	ppm ww	Sorenson and Schwarzbach 1991
1988	OC	TL	Bird	Mallard	egg	DDE	5	0.0 3- 0.86	ppm ww	Sorenson and Schwarzbach 1991
1988	OC	TL	Bird	Western grebe	egg	DDE	3	1.2 - 2.5	ppm ww	Sorenson and Schwarzbach 1991
1988	OC	LK	Bird	Mallard	egg	DDE	6	0.02 - 0.05	ppm ww	Sorenson and Schwarzbach 1991
1988	OC	TL	Bird	Mallard	egg	DDT	3	0.02 - 0.14	ppm ww	Sorenson and Schwarzbach 1991
1988	OC	TL	Bird	Western grebe	egg	DDT	3	0.01 - 0.03	ppm ww	Sorenson and Schwarzbach 1991
1988	OC	TL	Bird	Mallard	egg	Dieldren	3	0.01 - 0.12	ppm ww	Sorenson and Schwarzbach 1991
1988	OC	TL	Bird	Mallard	egg	Endrin	2	0.05 - 0.06	ppm ww	Sorenson and Schwarzbach 1991
1988	OC	TL	Bird	Western grebe	egg	PCBs	3	0.31 - 0.76	ppm ww	Sorenson and Schwarzbach 1991
1988	OC	LR	Fish	Sucker	whole body	DDE	3	0.02 - 0.05	ppm ww	Sorenson and Schwarzbach 1991
1988	OC	UKL	Fish	Rainbow trout	whole body	DDE	1	0.01	ppm ww	Sorenson and Schwarzbach 1991
1988	OC	TL + UKL	Fish	Chub	whole body	DDE	2	0.01	ppm ww	Sorenson and Schwarzbach 1991
1988	OC	UKB	Sediment	NA	Sediment	DDD	7	0.4 - 2.7	ppb ww	Sorenson and Schwarzbach 1991
1988	OC	TL + LK + LR	Sediment	NA	Sediment	DDE	11	0.2 - 6.6	ppb ww	Sorenson and Schwarzbach 1991
1988	OC	TL + LK + LR	Sediment	NA	Sediment	DDT	1	0.4	ppb ww	Sorenson and Schwarzbach 1991
1990	OC	LK	Bird	White pelican	brain	alpha-Chlordane	2	<0.019	ppm dw	Henson and Schuler 1992

Table 2. Continued.

Year	CC[a]	Location[c]	Taxa/Media	Species	Tissue	Contaminant	N	Concentration	Unit	Reference
1990	OC	LK	Bird	White pelican	brain	Oxychlordane	2	<0.019 - 0.044	ppm dw	Henson and Schuler 1992
1990	OC	LK	Bird	White pelican	brain	DDD	2	0.028 - 0.038	ppm dw	Henson and Schuler 1992
1990	OC	LK	Bird	White pelican	brain	DDE	2	2.5 - 2.7	ppm dw	Henson and Schuler 1992
1990	OC	LK	Bird	White-faced ibis	whole body	DDE	1	0.16	ppm ww	MacCoy 1994
1990	OC	LK	Bird	White pelican	brain	DDT	2	<0.019	ppm dw	Henson and Schuler 1992
1990	OC	LK	Bird	White pelican	brain	Dieldrin	2	0.036 - 0.048	ppm dw	Henson and Schuler 1992
1990	OC	LK	Bird	White pelican	brain	Endrin	2	<0.019 - 0.019	ppm dw	Henson and Schuler 1992
1990	OC	LK	Bird	White pelican	brain	cis-Nonachlor	2	<0.019 - 0.025	ppm dw	Henson and Schuler 1992
1990	OC	LK	Bird	White pelican	brain	trans-Nonachlor	2	<0.019	ppm dw	Henson and Schuler 1992
1990	OC	LK	Bird	White pelican	brain	PCB-1254	2	0.25 - 0.40	ppm dw	Henson and Schuler 1992
1990	OC	TL + LK	Sediment	NA	Sediment	Chlordane	26	ND - 6.0	ppb ww	MacCoy 1994
1990	OC	UKB	Sediment	NA	Sediment	DDD	26	0.97[g] (0.2-4.4)	ppb ww	MacCoy 1994
1990	OC	UKB	Sediment	NA	Sediment	DDE	26	1.22[g] (0.3-4.5)	ppb ww	MacCoy 1994
1990	OC	UKB	Sediment	NA	Sediment	DDT	26	ND - 0.5	ppb ww	MacCoy 1994
1990 - 1992	OC	LK	Bird	White-faced ibis	egg	DDD	21	0.005[f]	ppm ww	MacCoy 1994
1991 - 1992	OC	TL + LK	Bird	Western grebe	egg	DDD	17	0.173[f] (0.02-0.96)	ppm ww	MacCoy 1994
1990 - 1992	OC	LK	Bird	White-faced ibis	egg	DDE	21	2.13[f] (0.29-19.71)	ppm ww	MacCoy 1994
1991 - 1992	OC	TL	Bird	Eared grebe	egg	DDE	4	0.13[f] (0.06-0.19)	ppm ww	MacCoy 1994
1991 - 1992	OC	LK	Bird	Mallard	egg	DDE	1	0.02	ppm ww	MacCoy 1994
1991 - 1992	OC	TL + LK	Bird	Western grebe	egg	DDE	17	0.78[f] (0.35-4.6)	ppm ww	MacCoy 1994
1990 - 1992	OC	LK	Bird	White-faced ibis	egg	DDT	21	0.119[f]	ppm ww	MacCoy 1994
1991 - 1992	OC	TL + LK	Bird	Western grebe	egg	DDT	17	0.004[f]	ppm ww	MacCoy 1994
1990 - 1992	OC	LK	Bird	White-faced ibis	egg	Dieldrin	21	0.026[f]	ppm ww	MacCoy 1994
1991 - 1992	OC	TL + LK	Bird	Western grebe	egg	Dieldrin	17	0.002[f]	ppm ww	MacCoy 1994
1990 - 1992	OC	LK	Bird	White-faced ibis	egg	Endrin	21	0.002[f]	ppm ww	MacCoy 1994
1990 - 1992	OC	LK	Bird	White-faced ibis	egg	Heptachlor	21	0.014[f]	ppm ww	MacCoy 1994
1990 - 1992	OC	LK	Bird	White-faced ibis	egg	HCB	21	0.047[f]	ppm ww	MacCoy 1994
1991 - 1992	OC	TL + LK	Bird	Western grebe	egg	HCB	17	0.003[f]	ppm ww	MacCoy 1994
1990 - 1992	OC	LK	Bird	White-faced ibis	egg	trans-Nonachlor	21	0.021[f]	ppm ww	MacCoy 1994
1991 - 1992	OC	TL + LK	Bird	Western grebe	egg	trans-Nonachlor	17	0.023[f]	ppm ww	MacCoy 1994
1990 - 1992	OC	LK	Bird	White-faced ibis	egg	Oxychlordane	21	0.01[f]	ppm ww	MacCoy 1994
1990 - 1992	OC	LK	Bird	White-faced ibis	egg	PCBs (total)	21	0.004[f]	ppm ww	MacCoy 1994
1991 - 1992	OC	TL + LK	Bird	Western grebe	egg	PCBs (total)	17	0.67[f] (0.2-3.8)	ppm ww	MacCoy 1994
1991 - 1992	OC	TL	Invertebrate	Chironimid	composite	DDD+DDE+DDT	2	<0.01	ppm ww	MacCoy 1994
1991 - 1992	OC	TL	Invertebrate	Leeches	composite	DDD+DDE+DDT	1	<0.01	ppm ww	MacCoy 1994
1991 - 1992	OC	LK	Fish	Fathead minnow	composite	DDD+DDE+DDT	1	<0.01	ppm ww	MacCoy 1994
1991 - 1992	OC	TL + LR	Fish	Chub	composite	DDD+DDE+DDT	13	<0.01 - 0.01		MacCoy 1994
1991 - 1992	OC	UKB	Water	NA	Water	DDE	76	ND - 0.002	ppb	MacCoy 1994
1967	OP	TL	Water	NA	NA	Diazonon	20	10-700	ppt	Keith et al. 1967
1967	OP	TL	Water	NA	NA	Disyston	20	10-700	ppt	Keith et al. 1967
1967	OP	TL	Water	NA	NA	Malathion	20	10-700	ppt	Keith et al. 1967

Table 2. Continued.

Year	CC[a]	Location[c]	Taxa/Media	Species	Tissue	Contaminant	N	Concentration	Unit	Reference
1967	OP	TL	Water	NA	NA	Parathion	20	10-700	ppt	Keith et al. 1967
1967	OP	TL	Water	NA	NA	Systox	20	10-700	ppt	Keith et al. 1967
1991 - 1992	OP	UKB	drift	NA	NA	Methamidophos	9	1004 (624-1247)	ug/m2	MacCoy 1994
1991 - 1992	OP	UKB	Water	NA	NA	Chlorpyrifos	76	0.004 - 0.018	ug/L	MacCoy 1994
1991 - 1992	OP	UKB	Water	NA	NA	Disulfoton	76	0.05	ug/L	MacCoy 1994
1991 - 1992	OP	UKB	Water	NA	NA	Ethoprop	76	0.02-039	ug/L	MacCoy 1994
1991 - 1992	OP	UKB	Water	NA	NA	Malathion	76	0.01-0.013	ug/L	MacCoy 1994
1991 - 1992	OP	UKB	Water	NA	NA	Methyl Parathion	76	0.025 in 1 sample	ug/L	MacCoy 1994
1991 - 1992	OP	UKB	Water	NA	NA	Terbufos	76	0.002-0.007	ug/L	MacCoy 1994
2007	OP	TL + LR	Water	NA	NA	Carbaryl	51	0.47 in 1 sample	ug/L	Cameron 2008
2007	OP	TL + LR	Water	NA	NA	Chlorpyrifos	51	0.11 - 0.26	ug/L	Cameron 2008
1991 - 1992	OT[j]	TL + LR	Water	NA	NA	Metolachlor	76	0.001-0.060	ug/L	MacCoy 1994
1991 - 1992	OT[k]	UKB	Water	NA	NA	Atrazine	76	0.003 and 0.010	ug/L	MacCoy 1994
1991 - 1992	OT[k]	UKB	Water	NA	NA	Simazine	76	0.003 -0.011	ug/L	MacCoy 1994
1991 - 1992	OT[l]	UKB	Water	NA	NA	Metribuzin	76	0.003-0.430	ug/L	MacCoy 1994
1991 - 1992	OT[m]	UKB	Water	NA	NA	Eptam	76	0.001-0.320	ug/L	MacCoy 1994
2002 - 2003	OT[n]	TL + LK	Bird prey	European starling	NA	Dicamba	13	0.053 - 0.360	ppm dw	Hawkes and Haas 2005
2002 - 2003	OT[o]	TL + LK	Bird prey	European starling	NA	Aldicarb	3	0.340 - 0.410	ppm dw	Hawkes and Haas 2005
2002 - 2003	OT[o]	TL + LK	Bird prey	European starling	NA	Carbofuran 3-OH	1	0.272	ppm dw	Hawkes and Haas 2005
2002 - 2003	OT[p]	TL + LK	Bird prey	European starling	NA	2,4-D	11	0.424 - 7.49	ppm dw	Hawkes and Haas 2005
2002 - 2003	OT[p]	TL + LK	Bird prey	European starling	NA	2,4-DB	3	0.248 - 0.642	ppm dw	Hawkes and Haas 2005
2002 - 2003	OT[p]	TL + LK	Bird prey	European starling	NA	Dichlorprop	6	0.060 - 3.81	ppm dw	Hawkes and Haas 2005
2002 - 2003	OT[k]	TL + LK	Bird prey	European starling	NA	Propazine	9	0.376 - 1.25	ppm dw	Hawkes and Haas 2005
2002 - 2003	OT[k]	TL + LK	Bird prey	European starling	NA	Simazine	5	0.427 - 0.699	ppm dw	Hawkes and Haas 2005
2007	OT[q]	TL + LR	Water	NA	NA	Pendimethalin	51	0.070 - 0.082	ug/L	Cameron 2008
2007	OT[r]	TL + LR	Water	NA	NA	Oxyfluorfen	51	0.065 in 1 sample	ug/L	Cameron 2008
2007	OT[p]	TL + LR	Water	NA	NA	2,4-D	51	0.25 in 1 sample	ug/L	Cameron 2008
1979 - 1982	M	UKL	Bird	Canada goose	composites	Lead	2	0.071[fh] (ND - 0.1)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	Lesser scaup	composites	Lead	7	0.959[fg] (0.289 - 3.183)	ppm ww	Frenzel 1985
1979-1982	M	UKL	Bird	American coot	composites	Lead	10	0.452[fg] (0.119 - 1.722)	ppm ww	Frenzel 1985
1979 - 1983	M	UKL	Bird	Bald eagle	blood	Lead	2	ND - 0.25	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	Snow goose	composites	Lead	7	1.220[fg] (0.786 - 1.893)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	Ross's goose	composites	Lead	7	1.172[fg] (0.409 - 3.354)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	Mallard	composites	Lead	7	4.788[fg] (1.890 - 12.13)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	Northern pintail	composites	Lead	7	0.643[fg] (0.198 - 2.085)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	American wigeon	composites	Lead	5	0.197[fg] (0.031 - 1.270)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	Ruddy duck	composites	Lead	7	1.878 (0.439 - 0.559)	ppm ww	Frenzel 1985

Table 2. Continued.

Year	CC[a]	Location[c]	Taxa/Media	Species	Tissue	Contaminant	N	Concentration	Unit	Reference
1979 - 1982	M	UKL	Bird	Montane vole	composites	Lead	10	0.724[fg] (0.235 - 2.225)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	goldeneye	composites	Lead	1	17.60	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	goose	composites	Lead	1	0.72	ppm ww	Frenzel 1985
1979 - 1983	M	UKL	Bird	Bald eagles	blood	Lead	13	0.038[fh] (ND - 0.25)	ppm ww	Frenzel 1985
1979 - 1983	M	UKL	Bird	Bald eagle	blood	Lead	4	0.129[fg] (0.012 - 1.360)	ppm ww	Frenzel 1985
1979 - 1983	M	UKL	Bird	Bald eagle	liver	Lead	1	0.67	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	Canada goose	composites	Mercury	2	<0.01[fh]	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	Lesser scaup	composites	Mercury	7	0.075[fg] (0.055 - 0.102)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	Ruddy duck	composites	Mercury	2	0.024[fh] (0.014 - 0.039)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	American coot	composites	Mercury	10	0.024[fg] (0.014 - 0.039)	ppm ww	Frenzel 1985
1979 - 1983	M	UKL	Bird	Bald eagle	blood	Mercury	4	2.543[fh] (1.10 - 4.80)	ppm ww	Frenzel 1985
1980 - 1981	M	UKL	Bird	Bald eagles	eggs	Mercury	4	0.14 - 0.19	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	Snow goose	composites	Mercury	7	0.006[fh] (ND - 0.01)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	Ross's goose	composites	Mercury	7	0.006[fh] (ND - 0.01)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	Mallard	composites	Mercury	7	0.009[fg] (0.005 - 0.016)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	Northern pintail	composites	Mercury	7	0.012[fg] (0.008 - 0.020)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	Am. wigeon	composites	Mercury	5	0.006[fh] (ND - 0.01)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	Ruddy duck	composites	Mercury	7	0.071 (0.034 - 0.148)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	Montane vole	composites	Mercury	10	0.007[fh] (ND - 0.02)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	goldeneye	composites	Mercury	1	0.05	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Bird	goose	composites	Mercury	1	<0.01	ppm ww	Frenzel 1985
1979 - 1983	M	UKL	Bird	Bald eagles	blood	Mercury	15	2.285 (1.762 - 2.964)	ppm ww	Frenzel 1985
1979 - 1983	M	UKL	Bird	Bald eagles	blood	Mercury	5	2.166[fg] (1.586 - 2.960)	ppm ww	Frenzel 1985
1979 - 1983	M	UKL	Bird	Bald	liver	Mercury	1	1.6	ppm ww	Frenzel 1985
1979 - 1983	M	UKL	Bird	Bald eagle)	liver	Mercury	1	0.97 - 1.6	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Mammal	ground squirrel	composites	Lead	18	2.262[fg] (1.141 - 4.487)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Mammal	jack rabbit	composites	Lead	8	0.146[fg] (0.038 - 0.559)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Mammal	cottontail	composites	Lead	1	<0.1	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Fish	Chub	composites	Lead	15	0.064[fg] (ND - 0.50)	ppm ww	Frenzel 1985

Table 2. Continued.

Year	CC[a]	Location[c]	Taxa/Media	Species	Tissue	Contaminant	N	Concentration	Unit	Reference
1979 - 1982	M	UKL	Fish	Chub	composites	Lead	15	0.076[fg] (ND - 0.22)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Fish	Sucker	composites	Lead	3	0.075[fg] (ND - 0.17)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Fish	Chub	composites	Mercury	15	0.132[fg] (0.110 - 0.158)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Fish	Chub	composites	Mercury	15	0.083[fg] (0.053 - 0.130)	ppm ww	Frenzel 1985
1979 - 1982	M	UKL	Fish	Sucker	composites	Mercury	3	0.119[fg] (0.05 - 0.31)	ppm ww	Frenzel 1985
1988	M	LK	Bird	American coot	egg	Arsenic	6	0.324 - 0.521	ppm ww	Sorenson and Schwarzbach 1991
1988	M	TL	Bird	Mallard	egg	Arsenic	5	0.091 - 0.190	ppm ww	Sorenson and Schwarzbach 1991
1988	M	LK	Bird	Mallard	egg	Arsenic	6	0.08 - 0.262	ppm ww	Sorenson and Schwarzbach 1991
1988	M	TL	Bird	Western grebe	egg	Arsenic	2	0.096 - 0.099	ppm ww	Sorenson and Schwarzbach 1991
1988	M	LK	Bird	American coot	egg	Mercury	6	0.133 - 0.241	ppm ww	Sorenson and Schwarzbach 1991
1988	M	TL	Bird	Mallard	egg	Mercury	3	0.10 - 1.28	ppm ww	Sorenson and Schwarzbach 1991
1988	M	LK	Bird	Mallard	egg	Mercury	6	0.533 - 2.38	ppm ww	Sorenson and Schwarzbach 1991
1988	M	TL	Bird	Western grebe	egg	Mercury	3	0.395 - 0.550	ppm ww	Sorenson and Schwarzbach 1991
1988	M	UKB	Fish	Chub	whole body	Arsenic	7	0.20 - 0.67	ppm ww	Sorenson and Schwarzbach 1991
1988	M	UKB	Fish	Chub	whole body	Mercury	8	0.17 - 0.38	ppm ww	Sorenson and Schwarzbach 1991
1988	M	UKB	Sediment	NA	NA	Arsenic	12	0.6 - 16	ppm ww	Sorenson and Schwarzbach 1991
1988	M	UKB	Sediment	NA	NA	Copper	12	19 - 67	ppm ww	Sorenson and Schwarzbach 1991
1988	M	UKB	Sediment	NA	NA	Lead	12	< - 46	ppm ww	Sorenson and Schwarzbach 1991
1988	M	UKB	Sediment	NA	NA	Mercury	12	<0.02 - 0.22	ppm ww	Sorenson and Schwarzbach 1991
1990	M	LK	Bird	White pelican	liver	Mercury	2	22 - 29	ppm dw	Henson and Schuler 1992
1990	M	TL	Bird	Egret	egg	Mercury	1	0.084	ppm ww	MacCoy 1994
1990 - 1992	M	LK	Bird	Mallard	egg	Mercury	11	<0.025 - 0.330	ppm ww	MacCoy 1994
1990 - 1992	M	LK	Bird	White-faced ibis	egg	Mercury	18	0.14 (0.02-0.331)	ppm ww	MacCoy 1994
1991	M	LK	Bird	American avocet	egg	Mercury	11	0.05 (0.027-0.086)	ppm ww	MacCoy 1994
1991	M	LK	Bird	American coot	egg	Mercury	10	0.12 (0.05 - 0.196)	ppm ww	MacCoy 1994

Table 2. Continued.

Year	CC[a]	Location[c]	Taxa/Media	Species	Tissue	Contaminant	N	Concentration	Unit	Reference
1991	M	TL + LK	Bird	Western grebe	egg	Mercury	25	0.08 0.043 - 0.139)	ppm ww	MacCoy 1994
1992	M	LK	Fish	Fathead minnow	composite	Mercury	3	0.027 - 0.039	ppm ww	MacCoy 1994
1992	M	TL + LR	Fish	Tui Chub	composite	Mercury	20	0.054 (0.017 - 0.098)	ppm ww	MacCoy 1994
1992	M	LK	Invertebrates	mixed	composite	Mercury	2	0.029 and 0.048	ppm ww	MacCoy 1994
1992	M	TL + LK + LR	Sediment	NA	Sediment	Mercury	11	<0.01-0.09	ppm ww	MacCoy 1994
1992	M	LK	Invertebrates	mixed	composite	Arsenic	2	0.72 and 2.70	ppm ww	MacCoy 1994
1992	M	TL + LK + LR	Sediment	NA	Sediment	Arsenic	11	0.89-5.95	ppm ww	MacCoy 1994
2000 - 2001	M	TR	Fish	Rainbow trout	whole body/fillet	Mercury	247	0.080 - 1.810	ppm ww	May et al. 2005
2000 - 2001	M	TR	Fish	Largemouth bass	whole body/fillet	Mercury	32	0.196 - 4.920	ppm ww	May et al. 2005
2000 - 2001	M	TR	Fish	Smallmouth bass	whole body/fillet	Mercury	41	0.214 - 3.840	ppm ww	May et al. 2005
2007	M	TR	Mussel	Pearlshell		Mercury	27	0.030 - 0.036	ppm ww	Bettaso and Goodman 2008
2007	M	TR	Fish	Lamprey	whole body	Mercury	150	0.379 - 0.882	ppm ww	Bettaso and Goodman 2008

Note: ND, not detected; NA, not applicable.

[a] Chemical Class: OC, organochlorine; OP, organophosphate; OT, other; M, metal.

[b] carcass - skinned, feet and bill removed.

[c] NS = Site not specified, LK = Lower Klamath NWR, TL = Tule Lake NWR, CL = Clear Lake NWR, KB = Klamath Basin, UKL = Upper Klamath Lake, LR = Lost River, TRW = Trinity River Watershed .

[d] carcass - skinned, gastrointestianl tracts, bill, wing tips, tarsi/feet removed.

[e] carcass, skinned, gastrointestianl tracts, feet removed.

[f] geometric means

[g] confident intervals

[h] range

[i] adult and subadult found dead.

[j] chloroacetamide

[k] triazine

[l] triazinone

[m] thiocarbamate

[n] benzoic acid

[o] carbamate

[p] phenoxycarboxylic acid

[q] dinitroaniline

[r] diphenyl ether

Current Contaminant Issues

Current Use Pesticides

The importance of agriculture in the Klamath Basin, in combination with the proximity of agricultural activities to National Wildlife Refuges and aquatic habitats that support two endangered fish species and millions of wintering, migrating, and breeding waterbirds, raises questions about the impacts of agricultural activities to those habitats and the organisms they support. The use of numerous pesticides, combined with the active management of irrigation and drain water present the possibility of pesticide exposure in fish and wildlife species through overspray, runoff, and dissolution and transport. As discussed previously, the U.S. Fish and Wildlife Service and Bureau of Reclamation have developed an integrated pest management program to implement these activities responsibly. Although there have been some limited efforts to evaluate potential risk to listed suckers in the Upper Basin, a comprehensive study on the potential for impacts to other taxa, or on endpoints less overt than mortality has not been conducted. Although it is beyond the scope of this review to conduct a risk assessment of the potential impacts of pesticides on the natural resources of the Klamath Basin, below we detail magnitude and spatial and temporal patterns of pesticide use on the lease lands within the Refuge boundaries.

Pesticide use reports (PURs) for the lease lands on U.S. Fish and Wildlife refuge property were obtained from U.S. Fish and Wildlife Service, Klamath Basin National Wildlife Complex, Tulelake, Calif. Material Safety Data sheets (MSDS) were used to identify the active ingredient(s) of each pesticide, the percent active ingredient, and additional physical data (density). Pesticides were grouped by their active ingredient and classified by chemical class according to The Pesticide Manual (Tomlin, 2003). In general, various formulations of the same active ingredient (for example, 2,4-D, glyphosate) were grouped together. Additionally, pesticides were classified by use type (fumigant, fungicide, herbicide, insecticide) according to that identified in the pesticide use reports. PUR data were converted to kilograms active ingredient for summarizing use quantities and patterns from 1998 to 2010. Quantities of pesticides reportedly used were converted to gallons, if applicable, and specific gravity or bulk density was used to convert gallons to pounds. Pounds of pesticide used was converted to kilograms and multiplied by the respective percentage of active ingredient for summarizing pesticide use on the National Wildlife Refuge lease lands. In 2006, five outliers in the PURs were determined to be data entry errors (Marco Buske, U.S. Fish and Wildlife Service, oral commun., May 24, 2011) and thus were not included in the subsequent summaries. The outliers include Quadris Flowable fungicide (2,670 kilograms active ingredient reportedly applied to 0.30 km^2), Manzate flowable (4,504: 0.29) Banvel (5,696: 0.28), Weedar 64 Broadleaf herbicide (5,521: 0.29), and Sencor DF (4,478: 0.30 km^2).

Based on these annual pesticide use reports that are required by the Refuge Pesticide Use Program, in 2009, the most recent year in which water availability allowed for a full growing season, there were 41 different compounds applied to the leased lands, falling into 23 different chemical classes (table 3). Additionally, between 1998 and 2010 a total of 64 different pesticide compounds have been used on Refuge (table 4). We have classified these into 39 different chemical classes, making up four primary use types (fumigant, herbicide, fungicide, and insecticide). To better interpret the chemical class characterizations, we provide the percent each chemical comprises for the various chemical classes (table 5).

Table 3. Number of chemical classes and pesticides reported used on Klamath Basin National Wildlife Refuge Lease Lands, CA, 1998-2010.

Year	Chemical Classes	Pesticides
2010	23[b]	32[b]
2009	28	46
2008	24	39
2007	27	61
2006	24	45
2005	25	41
2004	23	41
2003	25	39
2002	23	40
2001	no data[a]	no data[a]
2000	23	41
1999	22	40
1998	23	43

[a] No water allocated for irrigation in 2001, therefore no pesticides reportedly used on the lease lands.

[b] Insufficient water availability limited irrigation deliveries and agricultural activity on the lease lands.

Table 4. Pesticides and their associated use type, chemical names, and chemical classes reportedly used on the Klamath Basin National Wildlife Refuge lease lands, CA, 1998-2010.

Use Type	Chemical Class[a]	Chemical Name[b]	Pesticide Name[c]
fungicide	aryloxyphenoxypropionate	fenoxaprop-P (+)	Puma 1EC Herbicide
herbicide	aryloxyphenoxypropionate	fluazifop-P-butyl	Fusilade DX Herbicide
herbicide	benzofuran	ethofumesate	Nortron SC Herbicide
herbicide	benzoic acid	diglycolamine salt of dicamba	Clarity Herbicide
herbicide	benzoic acid	dimethylamine salt of dicamba	Banvel
fungicide	biopesticide (bacterium)	*bacillus subtilis*	Serenade ASO
fungicide	biopesticide (bacterium)	*bacillus subtilis*	Serenade MAX
insecticide	biopesticide (bacterium)	*bacillus thuringiensis*	Dipel DF products[d]
insecticide	biopesticide (bacterium)	spinosad A+D	Entrust, Success
insecticide	biopesticide (plant)	azadirachtin	AZA-Direct, Ecozin 3% EC
insecticide	biopesticide (plant)	neem oil	Trilogy
insecticide	biopesticide (plant)	pyrethrins	Pyganic Crop Protection EC 5.0 II
herbicide	bipyridylium	diquat dibromide	Diquat Herbicide, Reglone, Reglone Desiccant
insecticide	carbamate	carbaryl	Sevin products[e]
insecticide	carbamate	oxamyl	Vydate products[f]
fungicide	carboxamide	boscalid	Endura
herbicide	chloroacetamide	S-Dimethenamid	Outlook Herbicide
fungicide	chloronitrile	chlorothalonil	Bravo products[g] , Tatto C Suspension Concentrate[h]
fungicide	chloronitrile	chlorothalonil and mefenoxam	Ridomil Gold Bravo SC
fungicide	cyanoacetamide-oxime (CO)	cymoxanil	Curzate 60DF Fungicide, Curzate 60F
fungicide	CO and oxazolidinedione	cymoxanil and famoxadone	Tanos Fungicide
herbicide	cyclohexanedione derivative	clethodim	Select Max Herbicide with inside Technology
herbicide	cyclohexanedione derivative	tralkoxydim	Achieve Liquid
herbicide	cyclohexanedione oxime	sethoxydim	Poast, Ultima 160 Herbicide
fungicide	dicarboximide	iprodione	Rovral 4 Flowable
herbicide	dinitroaniline	pendimethalin	Prowl H20 Herbicide
herbicide	diphenyl ether	oxyfluorfen	Goal 1.6E Herbicide, Goal 2XL
fungicide	dithiocarbamate	mancozeb	Dithane, Mancozeb, Manzate and Tops products[i]

Table 4. continued.

Use Type	Chemical Class[a]	Chemical Name[b]	Pesticide Name[c]
fungicide	dithiocarbamate	mancozeb and mefenoxam	Ridomil Gold MZ, Ridomil MZ 72 Fungicide
fumigant	dithiocarbamate	metam sodium	Metam 426, Vapam HL Soil Fumigant
herbicide	ethylene generator[j]	ethephon	Cerone Brand Ethephon Plant Regulator
herbicide	glycine derivative	glyphosate	Alecto, Aquaneat, Glypro, Rodeo, Roundup products[k]
fumigant	halocarbon	1,3-dichloropropene (1,3-D)	Telone II CA, Telone II Soil Fumigant
herbicide	imidazolinone	ammonium salt of imazamox	Raptor Herbicide
herbicide	imidazolinone	imazamethabenz methyl ester	Assert Herbicide
herbicide	imidazolinone	imazethapyr	Pursuit DG Herbicide
fungicide	inorganic copper	copper hydroxide	Champion Wettable Powder, Nu-Cop 3L
fungicide	inorganic sulfur	sulfur	Thiolux
insecticide	neonicotinoid	acetamiprid	Assail 70 WP
insecticide	neonicotinoid	imidacloprid	Admire and Provado products[l]
insecticide	organophosphate	chlorpyrifos	Lorsban 15G Granular Insecticide, Lorsban-4E
insecticide	organophosphate	disulfoton	Di-Syston 8 Emulsifiable Systemic Insecticide
insecticide	organophosphate	malathion	Fyfanon, Gowan, Malathion, Wilbur-Ellis products[m]
insecticide	oxadiazine	indoxacarb	Avaunt Insecticide
herbicide	phenoxycarboxylic acid	2,4-D	Clean Crop, Weedar, Weedone products[n]
herbicide	phenoxycarboxylic acid	MCPA, dimethylamine salt	Rhomene MCPA and Riverdale MCPA products[o]
herbicide	phenyl carbamate	phenmedipham and desmedipham	Betamix, Betamix Progress
herbicide	phosphinic acid	glufosinate ammonium	Rely 200 Herbicide
insecticide	pyrethroid	beta-cyfluthrin	Baythroid XL
insecticide	pyrethroid	cyfluthrin	Baythroid 2 Emulsifiable Pyrethroid Insecticide
insecticide	pyrethroid	permethrin	Perm-Up 3.2 EC Insecticide, Pounce 3.2 EC
herbicide	pyridazine[j]	maleic hydrazide	Royal MH-30 SG, Royal MH-30 XTRA
insecticide	selective feeding blocker	pymetrozine	Fulfill
fungicide	strobilurin	azoxystrobin	Quadris Flowable Fungicide
fungicide	strobilurin	pyraclostrobin	Headline Fungicide
herbicide	sulfonylurea	rimsulfuron	Matrix Herbicide, Prism Herbicide
herbicide	sulfonylurea	triflusulfuron methyl	Dupont Upbeet Herbicide

Table 4. continued.

Use Type	Chemical Class[a]	Chemical Name[b]	Pesticide Name[c]
herbicide	thiocarbamate	EPTC	Eptam 7-E Selective Herbicide
herbicide	triazinone	metribuzin	Lexone, Metribuzin, Sencor, Tricor products[p]
fungicide	triazole	propiconazole	Tilt, Tilt SI
fungicide	triazole	tebuconazole	Folicur 3.6 F Foliar Fungicide
herbicide	unclassified herbicide	difenzoquat	Avenge 2ASU, Avenge Wild Oat Herbicide[q]
insecticide	unclassified insecticide	flonicamid	Beleaf 50 SG Insecticide
insecticide	unclassified insecticide	spinetoram	Radiant SC

[a] Classified using The Pesticide Handbook, C.D.S. Tomlin (Ed), thirteenth edition, British Crop Protection Council, 2003.

[b] Chemical names obtained from the Material Safety Data Sheets associated with the pesticide name.

[c] Pesticide name identified in the Pesticide Use Reports provided by U.S. Fish and Wildlife Service, Klamath Basin National Wildlife

[d] Dipel DF Biological Insecticide, Dipel DF Dry Flowable Biological Larvicide.

[e] Sevin products 4F Carbaryl Insecticide, Sevin Brand 4F Carbaryl Insecticide, Sevin Brand XLR Plus Carbaryl Insecticide.

[f] Dupont Vydate C-LV Insecticide/Nematicide, Vydate C-LV Insecticide, Vydate L Insecticide/Nematicide.

[g] Bravo 720, Bravo Ultrex, Bravo Weather Stik, Ridomil Bravo 81W.

[h] Tatto C Suspension Concentrate Fungicide.

[i] Dithane DF Rainshield, Dithane F-45, Dithane M-45 Flowable, Mancozeb Potato Seed Protectant, Manzate Flowable, Manzate Pro-

[j] Plant growth regulator.

[k] Alecto 41 HL, Alecto 41S, Aquaneat Aquatic Herbicide, Glypro, Rodeo Aquatic Herbicide, Roundup Original Max Herbicide,

[l] Admire 2 Flowable, Admire Pro Systemic Protectant, Provado 1.6 Flowable.

[m] Fyfanon 8 lb. Emulsion, Gowan Malathion 8, Malathion 8 Aquamul, Malathion 8EC, Wilbur-Ellis Malathion 8 Spray

[n] Clean Crop Amine 4 2,4-D Weed Killer, Weedar 64 Broadleaf Herbicide, Weedone 638 Broadleaf Herbicide, Weedone L V 4EC

[o] Rhomene MCPA Amine Herbicide, Rhomene MCPA Broadleaf Herbicide, Riverdale MCPA-4 Amine.

[p] Dupont Lexone DF Herbicide, Metribuzin 75, Metribuzin 75DF, Sencor 4 Flowable Herbicide, Sencor DF, Sencor DF 75% Dry

[q] Avenge Wild Oat Herbicide for use in barley.

Table 5. Percent contributions of chemical classes reportedly used on the Klamath Basin National Wildlife Refuge lease lands, CA, 1998-2010.[a]

Chemical Class (CC)	Chemical Name	% of CC
aryloxyphenoxypropionate	fenoxaprop-P (+)	48.6
aryloxyphenoxypropionate	fluazifop-P-butyl	51.4
benzofuran	ethofumesate	100
benzoic acid	diglycolamine salt of dicamba	1.6
benzoic acid	dimethylamine salt of dicamba	98.4
biopesticide_bacterium	*bacillus subtilis*	7.3
biopesticide_bacterium	*bacillus thuringiensis*	17.8
biopesticide_bacterium	spinosad A+D	74.8
biopesticide_plant	azadirachtin	7.0
biopesticide_plant	neem oil	90.6
biopesticide_plant	pyrethrins	2.4
bipyridylium	diquat dibromide	100
carbamate	carbaryl	15.1
carbamate	oxamyl	84.9
carboxamide	boscalid	100
chloroacetamide	S-Dimethenamid	100
chloronitrile	chlorothalonil	75.2
chloronitrile	mefenoxam and chlorothalonil	24.8
cyanoacetamide-oxime (CO)	cymoxanil	100
CO and oxazolidinedione	famoxadone and cymoxanil	100
cyclohexanedione derivative	clethodim	60.6
cyclohexanedione derivative	tralkoxydim	39.4
cyclohexanedione oxime	sethoxydim	100
dicarboximide	iprodione	100
dinitroaniline	pendimethalin	100
diphenyl ether	oxyfluorfen	100
dithiocarbamate	mancozeb	3.9
dithiocarbamate	mefenoxam and mancozeb	1.2
dithiocarbamate	metam sodium	94.9
ethylene generator_PGR	ethephon	100
glycine derivative	glyphosate	100
halocarbon	1,3-dichloropropene (1,3-D)	100
imidazolinone	ammonium salt of imazamox	22.0
imidazolinone	imazamethabenz methyl ester	50.0
imidazolinone	imazethapyr	28.0
inorganic_copper	copper hydroxide	100
inorganic_sulfur	sulfur	100
neonicotinoid	acetamiprid	23.3
neonicotinoid	imidacloprid	76.7

Table 5. continued.

Chemical Class (CC)	Chemical Name	% of CC
organophosphate	chlorpyrifos	16.1
organophosphate	disulfoton	6.7
organophosphate	malathion	77.2
oxadiazine	indoxacarb	100
phenoxycarboxylic acid	2,4-D	87.1
phenoxycarboxylic acid	MCPA, dimethylamine salt	12.9
phenyl carbamate	phenmedipham and desmedipham	100
phosphinic acid	glufosinate ammonium	100
pyrethroid	beta-cyfluthrin	0.2
pyrethroid	cyfluthrin	2.2
pyrethroid	permethrin	97.7
pyridazine_PGR	maleic hydrazide	100
selective feeding blocker	pymetrozine	100
strobilurin	azoxystrobin	99.7
strobilurin	pyraclostrobin	0.3
sulfonylurea	rimsulfuron	72.5
sulfonylurea	triflusulfuron methyl	27.5
thiocarbamate	EPTC	100
triazinone	metribuzin	100
triazole	propiconazole	54.4
triazole	tebuconazole	45.6
unclassified herbicide	difenzoquat	100
unclassified insecticide	flonicamid	1.9
unclassified insecticide	spinetoram	98.1

[a] Pesticide Use Reports provided by US Fish and Wildlife Service, Klamath Basin National Wildlife Refuge, Tulelake, CA.

Pesticide use on the lease lands averages approximately 52,125 kg of active ingredient per year across more than 30.8 km^2 of agricultural land. However, the applications of pesticides on the leased lands vary substantially along both a seasonal and inter-annual basis. When averaged across all years, the seasonal use among categories differs substantially (fig. 5). Fumigant applications dominate early in the season when fields are being prepared for planting, with most applications occurring in March and April. Although the total acreage receiving fumigants is several-fold less than the other use categories, they are applied at very heavy rates. In fact, more than 40,000 kg of active ingredient are applied across the lease lands at peak fumigant use, whereas the highest application rate for the other use classes is less than 2,500 kg of herbicides. Herbicide applications follow two distinct time periods, with the heaviest use occurring in May and June, followed by a subsequent peak in August (fig. 5). Finally, both fungicides and insecticide applications occur primarily in July, with nearly 2,000 kg of fungicide and approximately 700 kg of insecticide active ingredients being applied during that time period.

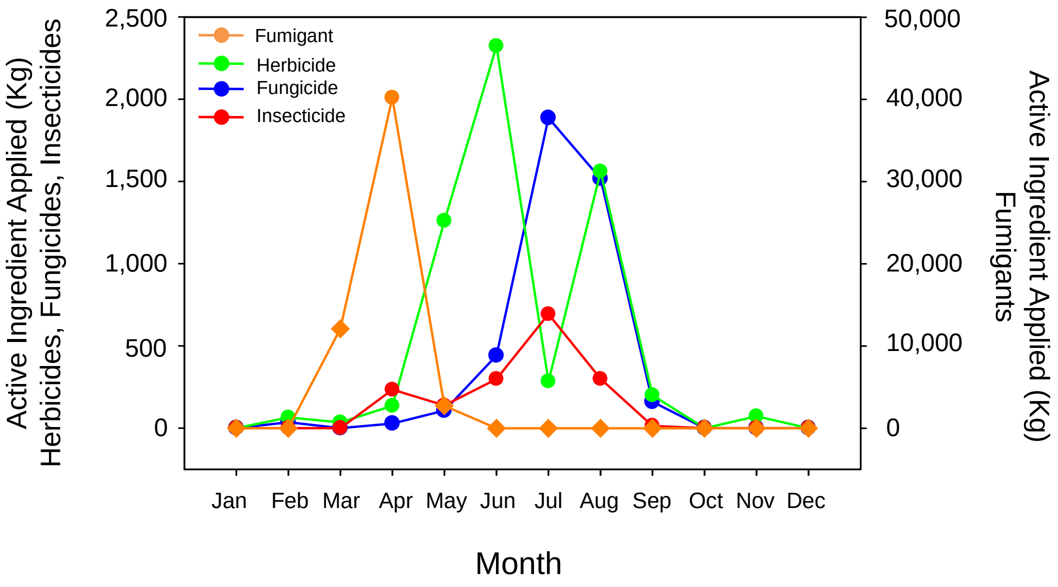


Figure 5. Monthly pesticide applications on the Klamath Basin lease lands as Kg of active ingredient applied by use type (fumigant, herbicide, fungicide, insecticide). Monthly values represent averages from 1998 to 2010.

Annual pesticide use patterns likely reflect a combination of changes in (1) use requirements or restrictions, (2) type of crops grown, (3) pest outbreaks, and (4) water availability. Herbicide and fungicide applications have seen steady decreases since the late 1990s, from 7,000 to 8,000 kg of active ingredient per year to just more than approximately 4,000 kg of active ingredient per year in 2009 (fig. 6). Conversely, fumigant use has increased sharply over that time period from less than 10,000 to more than 90,000 kg of active ingredient per year (fig. 6). Finally, insecticide use has been highly variable, decreasing from 1,800 to 300 kg active ingredient between 1998 and 2006, then increasing again to 2,300 kg active ingredient by 2009 (fig. 6).

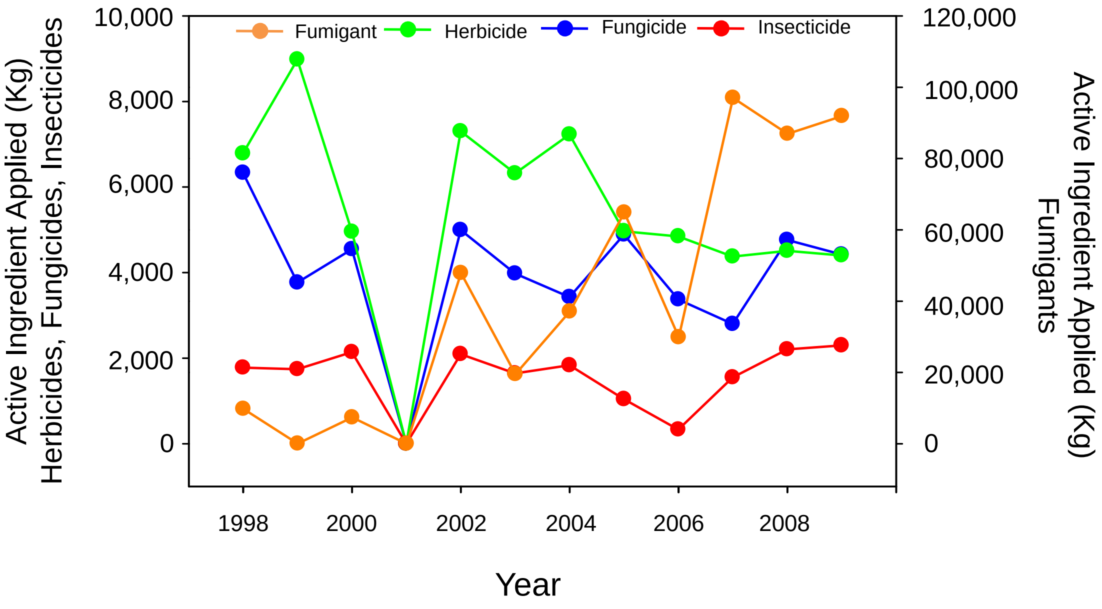


Figure 6. Annual pesticide applications on the Klamath Basin lease lands as Kg of active ingredient applied by use type between 1998 and 2009.

These temporal changes among pesticide use categories can be more thoroughly evaluated by breaking out the associated chemical classes. Some chemical classes, such as chloronitrile (fungicide), organophosphates (insecticides), phenoxycarboxylic acid (herbicide), and triazinone (herbicide) have seen relatively consistent annual use between 1998 and 2009 (fig. 7). Other classes, such as cyanoacetamide oxime (fungicide), cyclohexanedione oxime (herbicide), dicarboximide (fungicide), pyrethroids (insecticide), and pyridazine (herbicide), have undergone a steady decrease in use (fig. 7). Finally, a handful of classes, such as arylphenoxypropionate (herbicide/fungicide), biopesticide bacterium (insecticide), carbamates (insecticide), carboximide (fungicide), chloroacetamide (herbicide), cyclohexidione derivitives (fungicide), dithiocarbamates (fumigant), halocarbons (fumigant), and strobilurin (fungicide) have seen a steady or recent increase in their use (fig. 7).

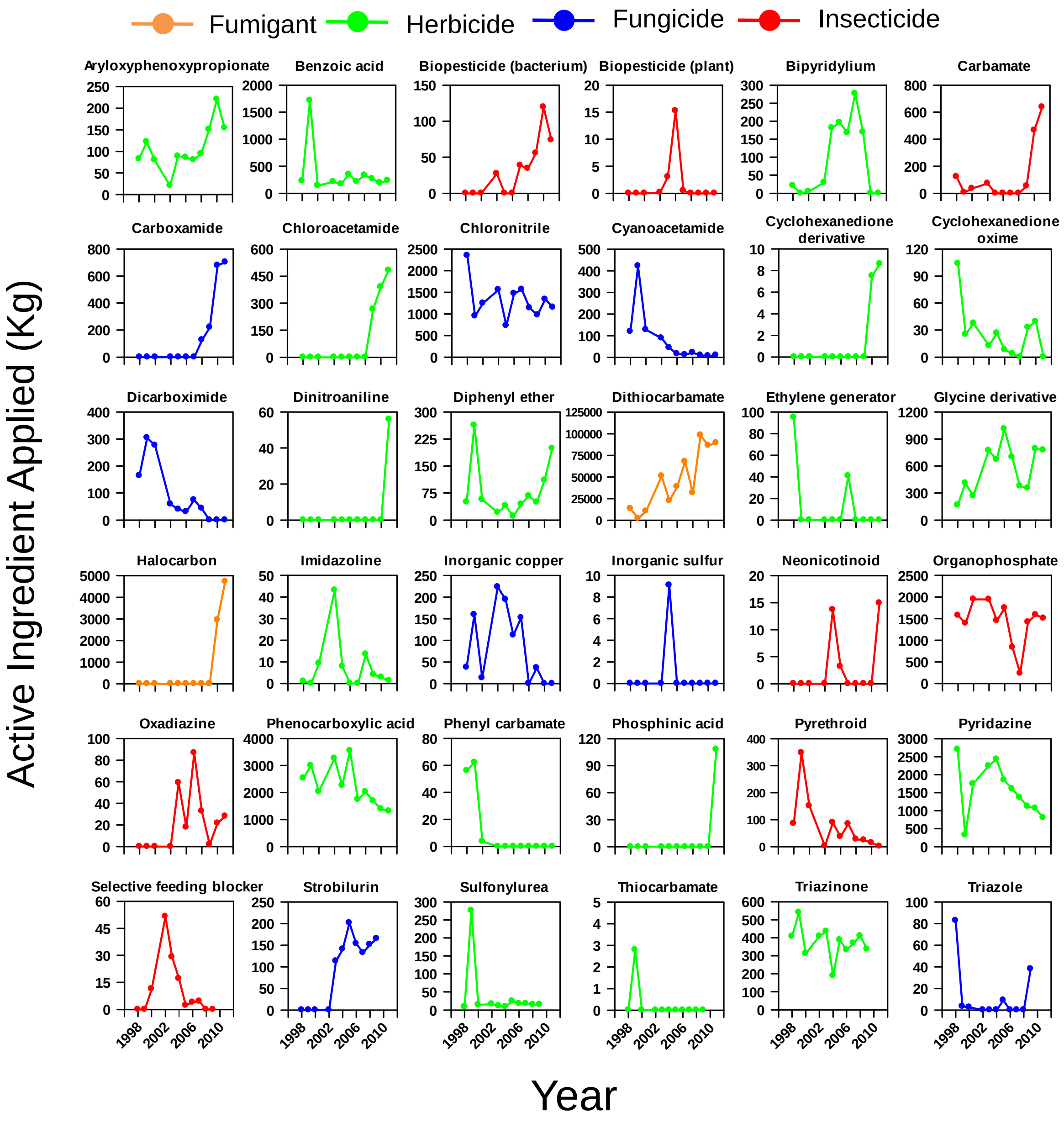


Figure 7. Annual pesticide applications on the Klamath Basin lease lands as Kg of active ingredient applied by chemical class 1998 and 2009.

Spatially, the use of agricultural pesticides on the refuge primarily is limited to the Tule Lake lease lands, with most lease lands in Upper Klamath Refuge dedicated to organic farming. The spatial distribution of pesticide applications are important because even with the implementation of buffer zones, etc., there is still a greater likelihood that applications in closer proximity to wetlands and drains will migrate or drift into aquatic habitats. Thus, we evaluated the total annual use of key pesticide classes within the lease lands by specific agricultural units. Spatial data for lease land plot locations were obtained from the Bureau of Reclamation, Klamath Falls, Oregon. Locations identified in the PURs were linked with spatial location data and ArcMap GIS software (ESRI, Redlands, Calif., USA) was used to produce maps to present spatial and temporal pesticide use trends on the Klamath Basin National Wildlife Refuge lease lands. Data were separated into categories according to that which best characterized a normal distribution. Pesticide use reports included locations (TL-1, 2000 and 2005; TL-2, 2002; Stearns, 2004; Stearns2, 2004; Sump1A, 2004, 2008, 2009) that did not correspond to spatial location data or did not receive pesticide applications (Marco Buske, U.S. Fish and Wildlife Service, oral comm.) and thus were not included in summary maps.

Overall pesticide use has been spread widely across the leased lands in Tule Lake, but application rates began to increase along the northern and western boundaries in 2007 (fig. 8). This appears to be due in large part to the dramatic increase in the use of fumigants (primarily the dithiocarbamate metam sodium; figs. 9 and 10), and to some degree carbamate insecticides (fig. 11) on the refuge. Other key use types and specific compounds show no striking pattern in their spatial distribution in use (figs. 12–17).

All Pesticides

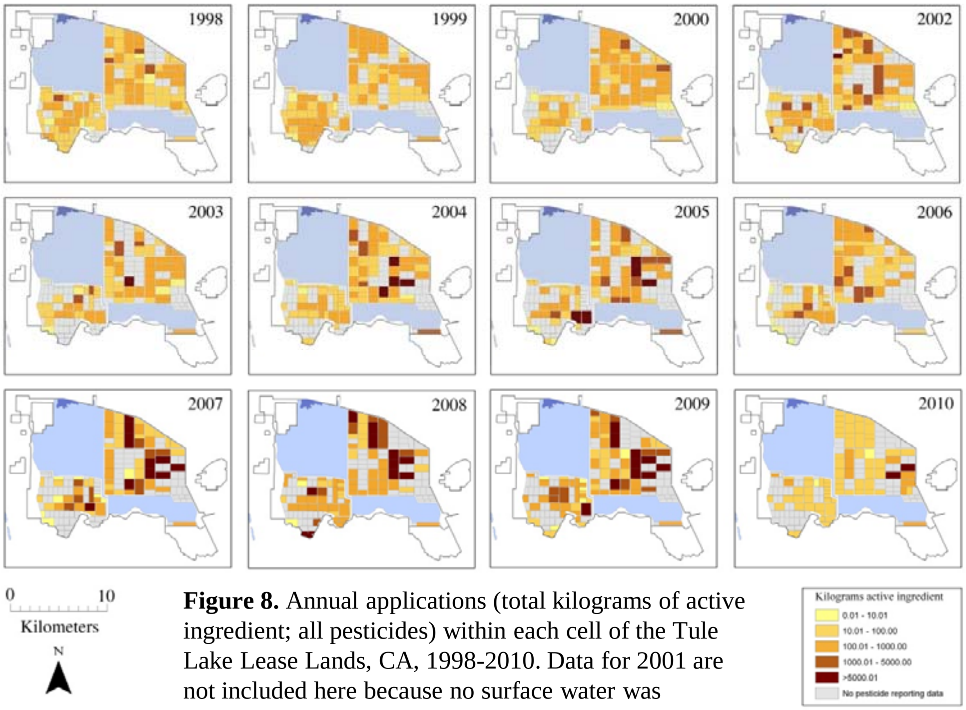


Figure 8. Annual applications (total kilograms of active ingredient; all pesticides) within each cell of the Tule Lake Lease Lands, CA, 1998-2010. Data for 2001 are not included here because no surface water was appropriated for irrigation, thus no pesticides were used or reported.

Fumigants

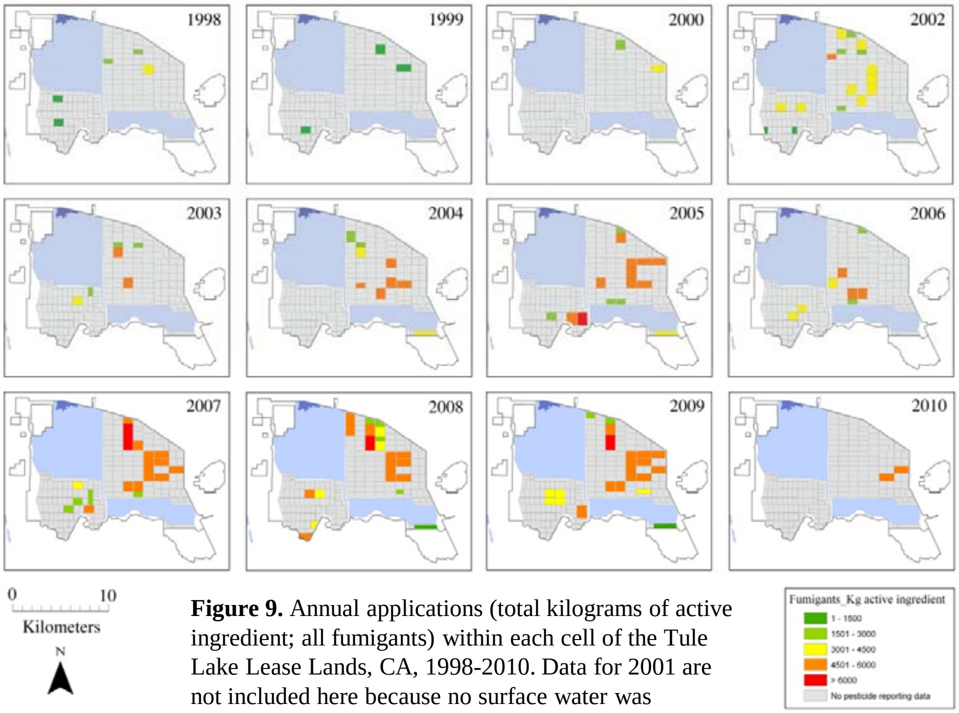


Figure 9. Annual applications (total kilograms of active ingredient; all fumigants) within each cell of the Tule Lake Lease Lands, CA, 1998-2010. Data for 2001 are not included here because no surface water was appropriated for irrigation, thus no pesticides were used or reported.

Dithiocarbamates

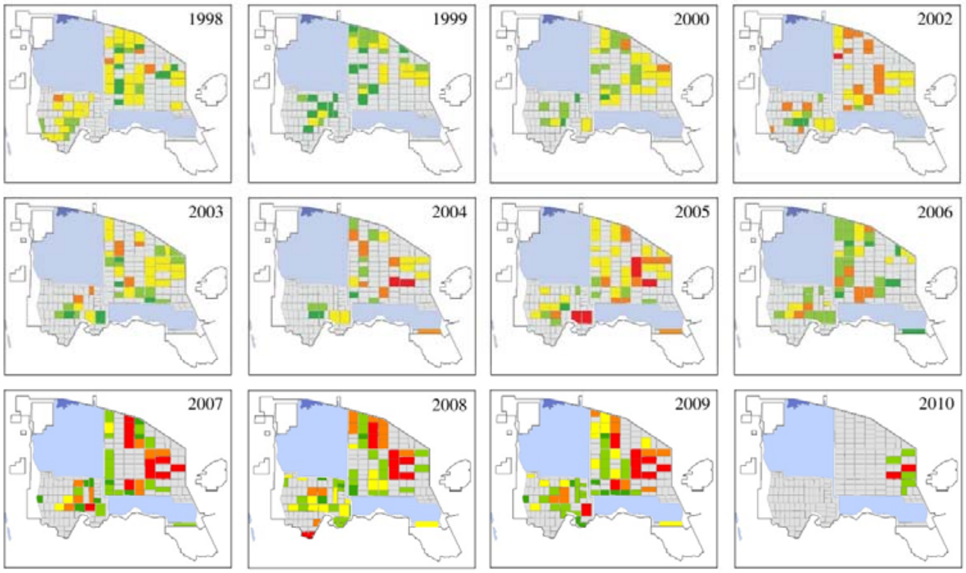


Figure 10. Annual applications (total kilograms of active ingredient; dithiocarbamates) within each cell of the Tule Lake Lease Lands, CA, 1998-2010. Data for 2001 are not included here because no surface water was appropriated for irrigation, thus no pesticides were used or reported.

Insecticides

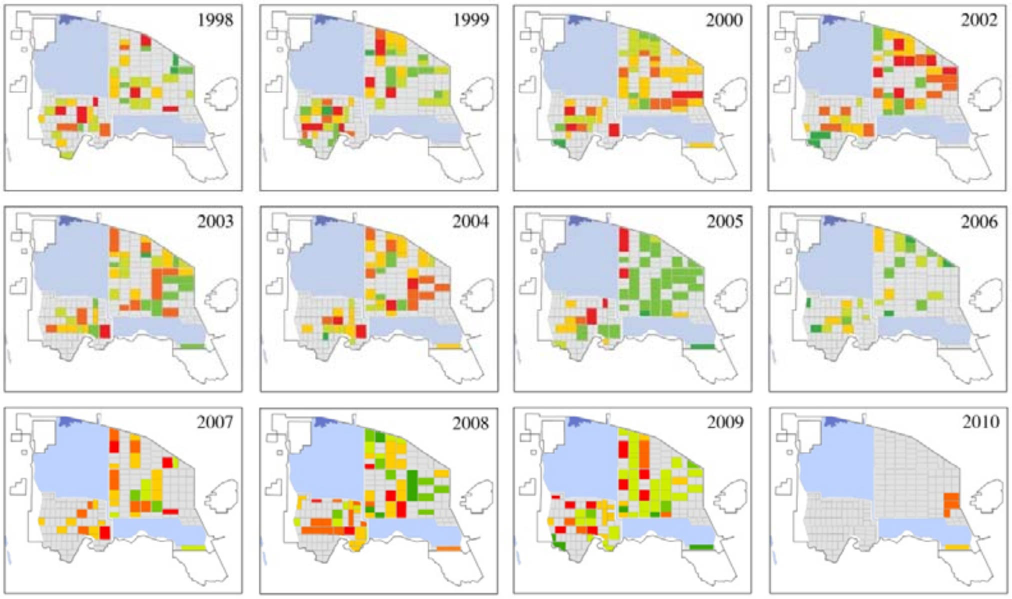


Figure 11. Annual applications (total kilograms of active ingredient; all insecticides) within each cell of the Tule Lake Lease Lands, CA, 1998-2010. Data for 2001 are not included here because no surface water was appropriated for irrigation, thus no pesticides were used or reported.

Fungicides

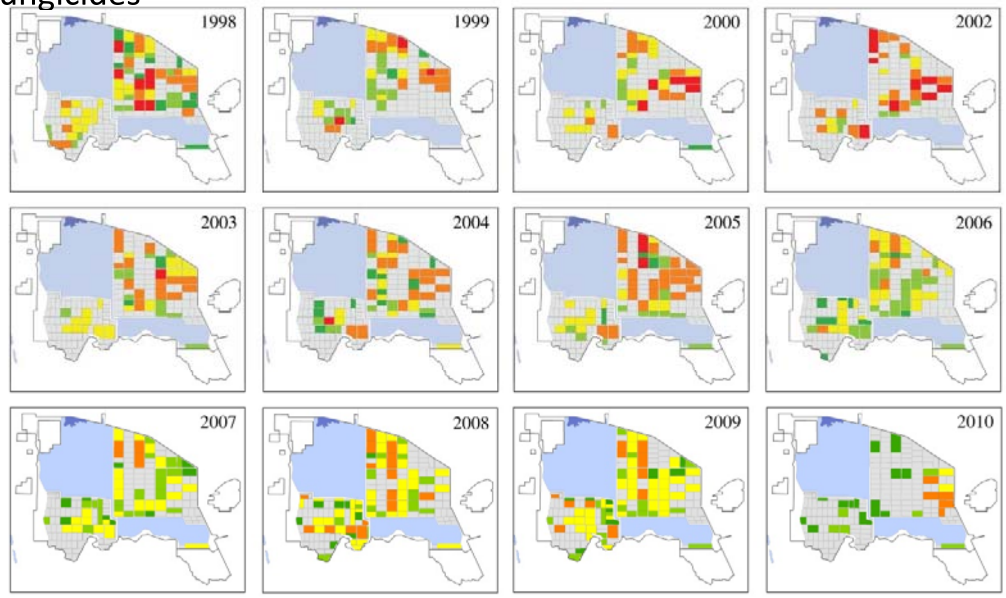


Figure 12. Annual applications (total kilograms of active ingredient; all fungicides) within each cell of the Tule Lake Lease Lands, CA, 1998-2010. Data for 2001 are not included here because no surface water was appropriated for irrigation, thus no pesticides were used or reported.

Herbicides

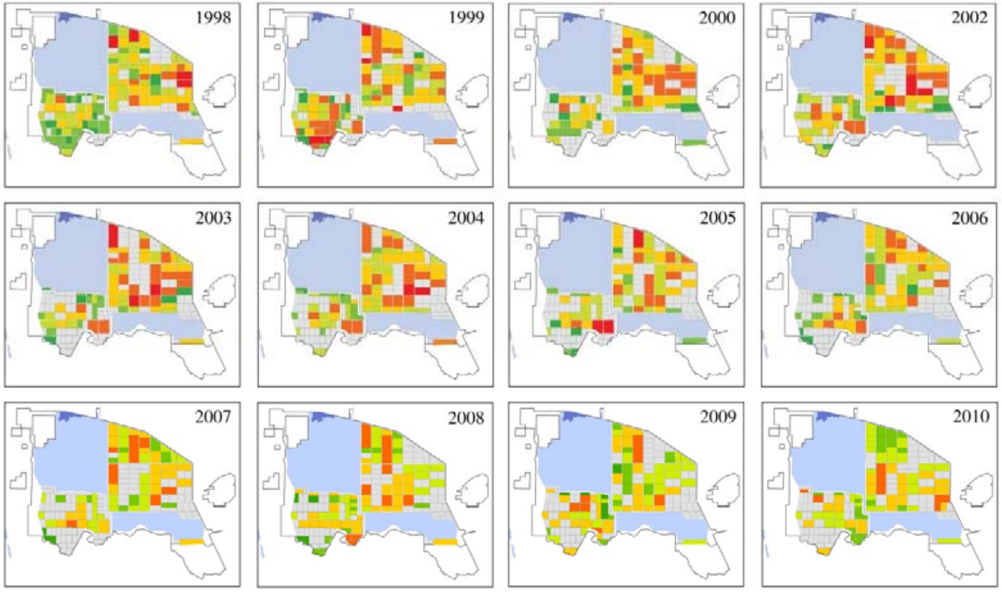


Figure 13. Annual applications (total kilograms of active ingredient; all herbicides) within each cell of the Tule Lake Lease Lands, CA, 1998-2010. Data for 2001 are not included here because no surface water was appropriated for irrigation, thus no pesticides were used or reported.

Organophosphate insecticides

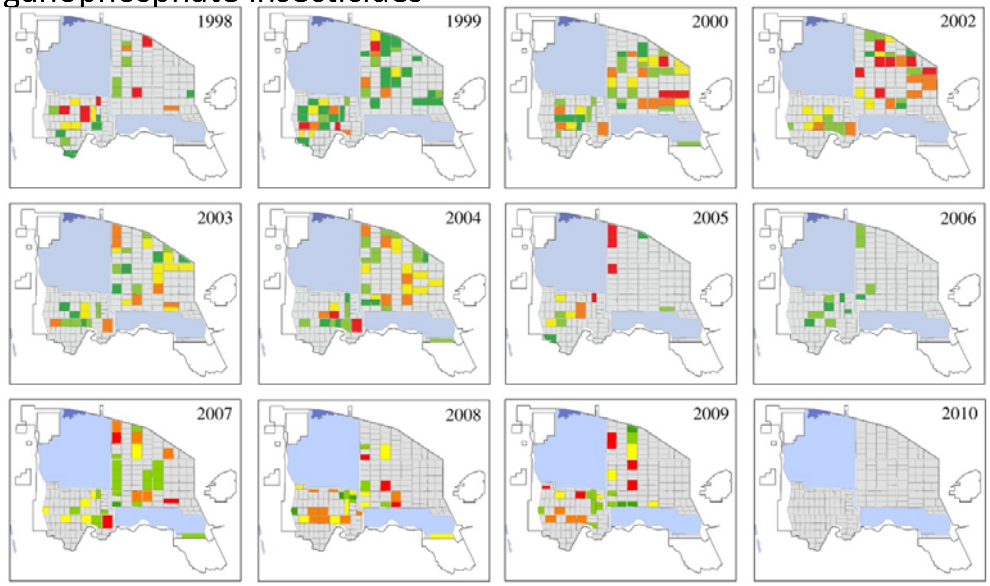


Figure 14. Annual applications (total kilograms of active ingredient; all organophosphate insecticides) within each cell of the Tule Lake Lease Lands, CA, 1998-2010. Data for 2001 are not included here because no surface water was appropriated for irrigation, thus no pesticides were used or reported.

Phenoxycarboxylic acid herbicides

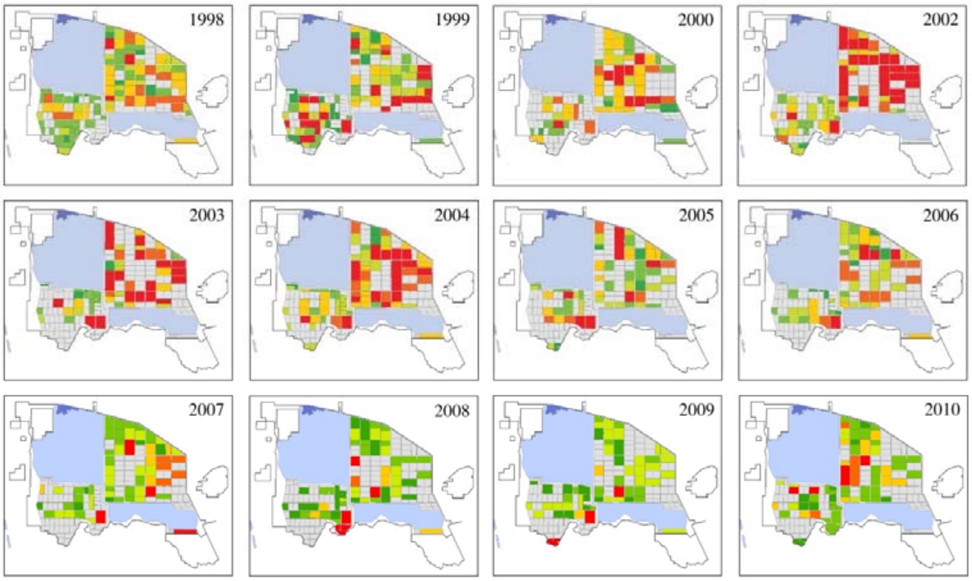


Figure 15. Annual applications (total kilograms of active ingredient; all phenoxycarboxylic acid herbicides) within each cell of the Tule Lake Lease Lands, CA, 1998-2010. Data for 2001 are not included here because no surface water was appropriated for irrigation, thus no pesticides were used or reported.

Chloronitrile fungicides

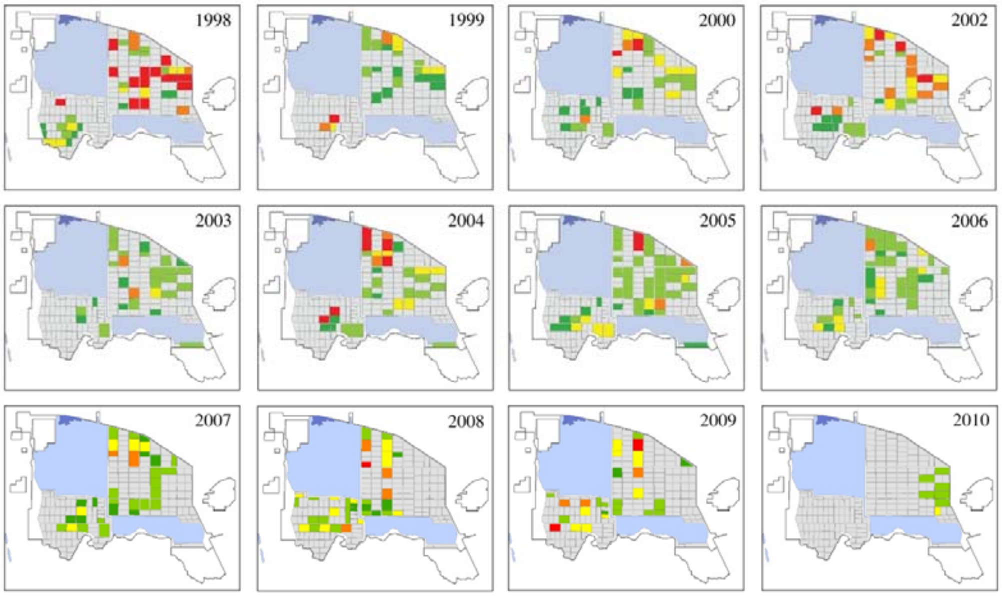


Figure 16. Annual applications (total kilograms of active ingredient; all chloronitrile fungicides) within each cell of the Tule Lake Lease Lands, CA, 1998-2010. Data for 2001 are not included here because no surface water was appropriated for irrigation, thus no pesticides were used or reported.

Strobilurin fungicides

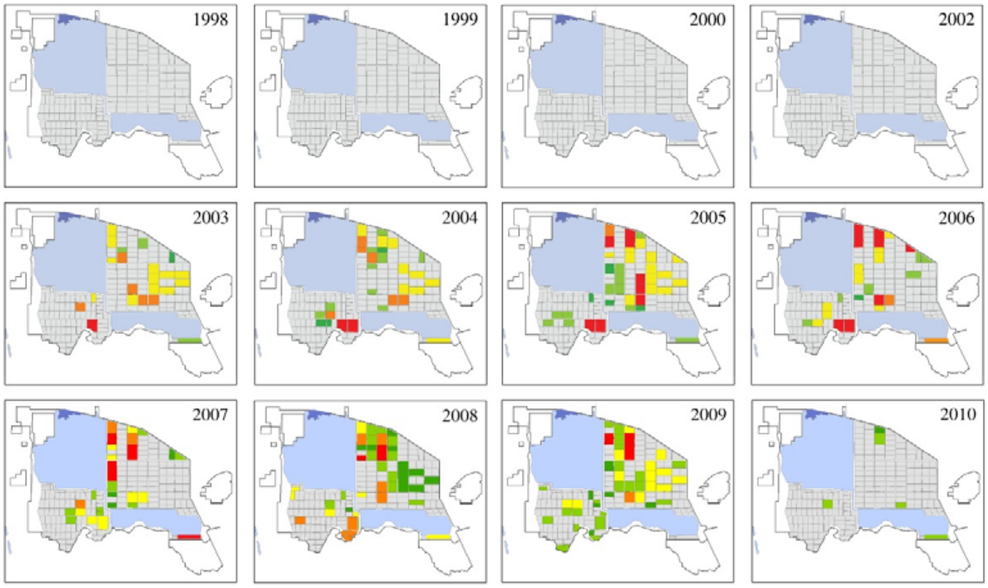


Figure 17. Annual applications (total kilograms of active ingredient; all strobilurin fungicides) within each cell of the Tule Lake Lease Lands, CA, 1998-2010. Data for 2001 are not included here because no surface water was appropriated for irrigation, thus no pesticides were used or reported.

Importantly, the leased lands within the Refuge boundaries represent only a very small proportion of total agricultural activity in the Basin. Within the Upper Basin alone, agriculture accounts for nearly 2,000 km^2 of land area of which 68 km^2 are the lease lands. Moreover, 80 percent of the agriculture in Klamath and Siskiyou Counties and 27 percent of the agriculture in Modoc County occurs within the boundaries of the Klamath Basin. Additionally, much of the irrigated cropland surrounding the refuge is hydrologically connected to the refuge via canals that are part of the Klamath Project (National Research Council, 2004). Farmers within those adjacent and nearby agricultural properties are not restricted in their pesticide use in the same ways as those that use the leased lands. Thus, there exists the possibility for wildlife and fish within the Refuge boundaries to be exposed to chemicals that are not approved for refuge use. In fact, in 2008 and 2009 there were a total of 189 different chemicals reportedly used as pesticide in those three counties, and only 41 of them (22 percent) were approved for refuge use (table 6). Thus, during that time period, there were nearly 150 additional compounds that had some likelihood of resulting in wildlife exposure, but were not regulated on the refuge. Moreover, some of those compounds were either used at exceptionally high rates (for example, methyl bromide), or are particularly toxic (for example, acrolein, diazinon, ethoprop, etc.). Thus, it is important to consider ecological exposure potential for these compounds as well.

Table 6. Total kilograms active ingredient of chemicals reportedly used in the Klamath Basin during 2009 and/or 2008.[a]

Chemicals in bold and italics are those that have no documented use on the lease lands.

		Kilograms of active ingredient[b]				
Chemical Name[c]	Chemical Class[d]	2009 Modoc Co., CA	2009 Siskiyou Co., CA	2008 Klamath Co., OR	2009 Lease Lands, CA	2008 Lease Lands, CA
1,3-D	halocarbon	2172.07	6615.68	79683.01	4730.98	2945.55
2,4-D	phenoxycarboxylic acid	2754.18	5008.92	1555.68	678.47	924.48
abamectin	***avermectin***	***0.18***	***4.27***			
acephate	***organophosphate***	***640.95***	***693.60***	***86.32***		
acetamiprid	neonicotinoid		17.73		3.73	
acetic acid	***organic***			***4.73***		
acrolein	***aldehyde***		***1282.86***	***2658.29***		
ADBAC[e]	***quaternary ammonium compound***			***0.51***		
aluminum phosphide	***inorganic***	***1.39***	***1.35***	***0.82***		
aminopyralid	***pyridinecarboxylic acid***	***95.33***	***148.52***	***29.18***		
ammonium chloride	***quaternary ammonium compound***			***0.77***		
ammonium nitrate	***inorganic***	***2.89***	***6.29***			
ammonium sulfate	***inorganic***	***276.73***	***257.39***			
atrazine	***triazine***		***443.36***			
azoxystrobin	strobin	121.19	244.75	40.72	159.65	148.85
Bacillus sphaericus	***biopesticide***			***12.66***		
Bacillus subtilis	biopesticide	4.54	14.16		17.77	
Bacillus thuringiensis	***biopesticide***	***29.37***	***1.40***	***5.15***		
bentazon	***benzothiadiazinone***	***2047.49***	***415.57***			
benzene	***petroleum derivative***			***125.36***		
bicycloheptene	***dicarboximide***		***0.50***	***0.24***		
bifenazate	***unclassified***		***80.00***	***8.81***		
bifenthrin	***pyrethroid***	***0.06***	***16.22***	***3.14***		
borax	***inorganic***		***493.33***	***327.09***		
boric acid	***inorganic***		***16.28***			
boscalid	carboxamide	835.25	846.40	115.03	668.61	639.78

Table 6. continued.

		Kilograms of active ingredient^b				
Chemical Name^c	Chemical Class^d	2009 Modoc Co., CA	2009 Siskiyou Co., CA	2008 Klamath Co., OR	2009 Lease Lands, CA	2008 Lease Lands, CA
bromacil	***uracil***		***4.35***	***32.84***		
bromoxynil	***hydroxybenzonitrile***	***101.07***	***38.45***	***90.87***		
butanoic acid	***organic***			***133.62***		
captan	***phthalimide***		***2974.91***	***350.35***		
carbaryl	***carbamate***		***704.45***	***20.76***		
carbon	***organic***			***1.54***		
carboxin	***carboxamide***	***134.49***				
carfentrazone-ethyl	***triazolinone***		***1.23***			
chlorfenapyr	***arylpyrrole***		***1.08***			
chloropicrin	***inorganic***		***166631.56***	***78247.13***		
chlorothalonil	chloronitrile	2586.01	3277.25	737.75	889.58	1043.99
chlorpropham	***carbamate***	***744.16***	***815.30***	***1433.48***		
chlorpyrifos	organophosphate	1387.38	1059.93	102.47	415.53	365.73
chlorsulfuron	***sulfonylurea***	***108.52***	***34.81***	***39.69***		
citric acid	***unclassified***	***110.78***	***114.87***			
clethodim	cyclohexanedione derivative	84.14	58.34	8.78	4.81	1.81
clopyralid	***pyridinecarboxylic acid***	***7.90***	***32.47***	***9.40***		
coconut diethanolamide	***unclassified***		***0.06***			
copper	***inorganic***		***2152.91***	***81.32***		
cyfluthrin	pyrethroid	98.47	24.01	6.92	10.85	
cyfluthrin, beta-	pyrethroid	13.88	124.74	11.06	1.35	
cyhalothrin	***pyrethroid***			***3.02***		
cymoxanil	cyanoacetamide-oxime (CO)	68.70	111.53	7.86	9.10	6.00
cypermethrin	***pyrethroid***	***0.01***	***4.96***			
cypermethrin-zeta	***pyrethroid***			***1.34***		
cyprodinil	***anilinopyrimidine***		***154.66***			

Table 6. continued.

		Kilograms of active ingredient[b]				
Chemical Name[c]	Chemical Class[d]	2009 Modoc Co., CA	2009 Siskiyou Co., CA	2008 Klamath Co., OR	2009 Lease Lands, CA	2008 Lease Lands, CA
dazomet	***unclassified***		***367.42***			
deltamethrin	***pyrethroid***	***0.04***	***0.70***			
dialkyl d.a. polynaphthyl amine[f]	***quaternary ammonium compound***	***8.03***	***20.46***			
diazinon	***organophosphate***			***0.58***		
dicamba	benzoic acid	420.24	757.27	4145.31	185.92	156.40
dichlobenil	***benzonitrile***		***15.42***			
dicofol	***organochlorine***		***14.97***			
diflubenzuron	***benzoylurea***		***3.21***			
dimethenamid	chloroacetamide	118.40	81.31	162.49	482.18	374.85
dimethoate	***organophosphate***	***474.29***	***672.75***	***685.61***		
dipropyl isocinchomeronate	***unclassified***			***0.12***		
diquat dibromide	***bipyridylium***	***104.45***	***87.85***	***124.10***		
disodium octaborate tetrahydrate	***inorganic***	***0.73***	***19.72***			
diuron	***urea***	***109.70***	***311.46***	***4212.68***		
EDTA	***chelating agent***		***0.02***			
egg, putrescent whole egg solids	***organic***			***20.75***		
endosulfan	***cyclodiene***		***5.90***	***0.00***		
EPTC	***thiocarbamate***	***122.51***	***26.88***	***342.86***		
esfenvalerate	***pyrethroid***	***1.33***	***1.89***	***11.10***		
ethephon	***ethylene generator***		***3.40***			
ethoprop	***organophosphate***	***253.10***	***743.66***			
famoxadone	***oxazolidinedione***	***65.88***	***70.30***	***7.86***		
famoxadone and cymoxanil	CO and oxazolidinedione				79.17	60.02
fenhexamid	***hydrooxyanilide***		***0.14***	***7.03***		
fenoxaprop-p-ethyl	aryloxyphenoxypropionate	116.98	110.09		76.49	107.83
fenpropathrin	***pyrethroid***		***188.74***			

Table 6. continued.

		Kilograms of active ingredient[b]				
Chemical Name[c]	Chemical Class[d]	2009 Modoc Co., CA	2009 Siskiyou Co., CA	2008 Klamath Co., OR	2009 Lease Lands, CA	2008 Lease Lands, CA
fipronil	***fiprole***	***3.76***	***23.21***			
fluazifop-p-butyl	aryloxyphenoxypropionate	104.30	130.89	31.56	75.88	98.90
fludiozonil	***phenylpyrrole***	***0.01***	***125.79***	***0.11***		
flumioxazin	***N-phenylphthalimide***		***92.28***	***158.69***		
flurozypyr	***pyridinecarboxylic acid***		***12.80***	***0.53***		
flutolanil	***carboxamide***	***4.45***	***81.44***	***199.84***		
fosetyl-al	***phosphonate***	***0.00***	***2050.69***			
glufosinate	phophinic acid	153.53	231.77		97.22	
glyphosate	glycine derivative	1613.04	7735.02	5370.24	762.46	747.23
harpin protein	***biopesticide***		***1.18***			
hexazinone	triazinone	493.63	4157.78	52.42		
hydramethylnon	***trifluoromethyl aminohydrazone***		***0.01***			
hydroprene	***juvenile hormone mimic***		***0.28***			
imazamox	imidazolinone	22.61	42.15	43.36	1.24	2.85
imazapic	***imidazolinone***			***4.03***		
imazapyr	***imidazolinone***		***528.05***			
imazethapry	***imidazolinone***	***8.60***	***11.70***			
imidacloprid	neonicotinoid	144.60	37.88	9.16	10.48	
indoxacarb	oxadiazine	21.61	41.70	5.73	28.00	21.57
iprodione	***dicarboximide***		***79.29***	***13.77***		
iron phosphate	***inorganic***		***0.02***			
isothiocyanate	***unclassified***			***397.50***		
isoxaben	***benzamide***		***15.68***			
lamda-cyhalothrin	***pyrethroid***	***17.06***	***20.62***			
lecithin	***biopesticide***		***271.18***			
lime-sulfur	***inorganic***		***11.22***			

Table 6. continued.

		Kilograms of active ingredient[b]				
Chemical Name[c]	Chemical Class[d]	2009 Modoc Co., CA	2009 Siskiyou Co., CA	2008 Klamath Co., OR	2009 Lease Lands, CA	2008 Lease Lands, CA
malathion	organophosphate	876.34	1846.64	2503.85	1068.23	1173.11
maleic hydrazide	pyridazine	2457.00	1328.02	361.87	762.24	1066.40
mancozeb	dithiocarbamate	2289.07	1732.78	451.70	1775.57	2011.64
MCPA	phenoxycarboxylic acid	740.03	777.21	293.09	502.17	312.99
MCPP	***phenoxycarboxylic acid***		***10.51***			
mefenoxam	***xylylalanine***	***87.96***	***453.01***			
mefenoxam and chlorothalonil	chloronitrile, xylylalanine				235.58	265.09
mefenoxam and mancozeb	dithiocarbamate, xylylalanine				219.39	221.06
metalaxyl	***acylalanine***	***13.03***		***82.25***		
metam sodium	dithiocarbamate	163782.92	131309.21	78713.11	87159.44	78567.79
methamidophos	***organophosphate***	***263.66***	***186.27***	***161.58***		
methomyl	***carbamate***	***690.43***	***93.37***	***11.18***		
methoprene	***juvenile hormone mimic***			***0.24***		
methyl bromide	***halocarbon***		***297716.72***	***120644.93***		
methyl iodide	***halocarbon***			***17.33***		
metolachlor	***chloroacetamide***			***3.24***		
metribuzin	triazinone	1898.58	2571.58	1377.79	283.76	343.59
metsulfuron	***sulfonylurea***			***0.43***		
myclobutanil	***triazole***		***28.74***			
naphthalene	***aromatic hydrocarbon***	***337.61***	***258.23***	***439.44***		
oleic acid	***biopesticide***	***2716.12***	***4378.44***			
oryzalin	***dinitroaniline***		***68.53***			
oxadiazon	***oxadiazole***			***0.23***		
oxamyl	carbamate	1707.07	1319.13	435.45	608.57	465.12
oxyfluorfen	diphenyl ether	185.35	208.49	16.10	197.89	108.19
paraquat dichloride	***paraquat bipyridylium***	***1811.61***	***1987.78***	***1418.39***		

Table 6. continued.

		Kilograms of active ingredient[b]				
Chemical Name[c]	Chemical Class[d]	2009 Modoc Co., CA	2009 Siskiyou Co., CA	2008 Klamath Co., OR	2009 Lease Lands, CA	2008 Lease Lands, CA
parathion	***organophosphate***		***8.96***			
PCNB, quintozene	***organochlorine***		***12.65***			
pendimethalin	dinitroaniline	1549.55	569.21	201.77	42.96	
permethrin	pyrethroid	49.03	4.97	30.56	3.46	
phosphoric acid	***inorganic***	***10.31***	***44.21***			
picloram	***pyridinecarboxylic acid***		***0.67***	***71.15***		
piperonyl butoxide	***unclassified***		***0.41***	***38.87***		
pirimiphos	***organophosphate***			***0.54***		
polyiparamenthene	***unclassified***		***124.91***			
potassium phophite	***inorganic***		***173.54***			
prallethrin	***pyrethroid***			***0.02***		
prodiamine	***dinitroaniline***		***2.51***			
propargite	***sulfite ester***	***1273.78***	***1227.77***	***16.72***		
propiconazole	***triazole***		***34.16***	***0.74***		
propionic acid	***unclassified***		***245.60***	***52.25***		
propyzamide	***benzamide***		***0.00***	***66.61***		
pyraclostrobin	***methoxycarbamate***	***75.77***	***249.49***	***22.53***		
pyraflufen-ethyl	***pyrazolyphenyl***	***0.10***	***0.02***			
pyrasulfotole	***pyrazole***			***10.59***		
pyrethrin	***pyrethrin***		***0.16***	***7.76***		
pyrimethanil	***anilinopyrimidine***	***12.46***	***27.88***			
pyrophosphate	***inorganic***		***0.04***			
rimsulfuron	sulfonylurea	32.22	26.98	20.51	13.26	11.81
sethoxydim	cyclohexanedione oxime			12.51	28.21	
silica gel	***inorganic***		***0.36***			
simazine	***triazine***		***22.45***	***33.37***		

Table 6. continued.

		Kilograms of active ingredient[b]				
Chemical Name[c]	Chemical Class[d]	2009 Modoc Co., CA	2009 Siskiyou Co., CA	2008 Klamath Co., OR	2009 Lease Lands, CA	2008 Lease Lands, CA
sodium carbonate peroxyhydrate	***biopesticide***		***77.11***			
sodium cyanide	***inorganic***			***0.05***		
sodium fluoride	***inorganic***		***12.03***	***20.28***		
sodium hydroxide	***inorganic***		***11.79***			
sodium nitrate	***inorganic***			***2.91***		
spinetoram	unclassified_insecticide	45.04	70.02		55.56	
spinosad A+D	biopesticide	1.60	61.35		53.04	115.61
spirotetramat	***keto-enol***		***1.01***			
strychnine	***biopesticide***	***0.28***	***0.82***	***2.11***		
sulfentrazone	***triazolinone***			***0.51***		
sulfometuron	***sulfonylurea***	***14.78***	***56.58***	***48.74***		
sulfur	***inorganic***		***1013.31***	***3176.11***		
tebuconazole	triazole	403.97	50.49	4.17	28.12	
tebuthiuron	urea	0.18	0.18			
temephos	***organophosphate***			***5.08***		
tetrachlorvinphos	***organophosphate***			***0.36***		
thiabendazole	***benzimidazole***	***49.63***				
thiamethoxam	***neonicotinoid***		***0.04***			
thifensulfuron methyl	***sulfonylurea***			***1.06***		
thiophanate	***benzimidazole precursor***		***302.36***	***3.57***		
thiram	***dithiocarbamate***	***140.89***				
thyme	***biopesticide***		***0.02***			
thymol	***phenol***		***1.65***			
toluamide	***unclassified***			***1.17***		
toluidine	***amine***		***0.04***	***0.04***		
tralkoxydim	cyclohexanedione oxime	14.05	4.61		3.78	5.67

Table 6. continued.

Chemical Name[c]	Chemical Class[d]	Kilograms of active ingredient[b] 2009 Modoc Co., CA	2009 Siskiyou Co., CA	2008 Klamath Co., OR	2009 Lease Lands, CA	2008 Lease Lands, CA
tribenuron-methyl	***sulfonylurea***			***2.65***		
triclopyr	***pyridinecarboxylic acid***		***577.66***	***58.45***		
triethanolamine	***amine***		***0.10***			
trifloxystrobin	***oximinoacetate***		***10.25***	***0.74***		
trifluralin	***dinitroaniline***			***3.07***		
trinexapac-ethyl	***unclassified***		***0.04***			
zinc phosphide	***inorganic***		***43.75***			

[a] The most recent available county data were obtained from the California Department of Pesticide Regulations, Annual Pesticide Use Reports (online; indexed by chemical and county) and from the Oregon Department of Agriculture, Salem, OR; lease land pesticide data were obtained from the U.S. Fish and Wildlife Service, Klamath Basin National Wildlife Refuge, Tulelake, CA.

[b] Reported chemicals totaling less than 0.0005 kg active ingredient are not included the table.

[c] Various formulations of the same chemical were grouped together (e.g., 2,4-D, subspecies of *Bacillus thuringiensis*, etc.)

[d] Classified using The Pesticide Handbook, C.D.S. Tomlin (Ed), thirteenth edition, British Crop Protection Council, Hampshire UK, 2003.

[e] Alkyl dimethyl benzyl ammonium chloride.

[f] Dialkyl dimethyl ammonium polynaphthyl amine.

To facilitate interpreting the potential toxicity profiles of pesticides used in the Basin, we summarized the available data on toxicity test results across a range of taxonomic groups (tables 7a and 7b). ECOTOX, U.S. EPA ECOTOXicology database (U.S. Environmental Protection Agency, 2007) was used to summarize available toxicological data for pesticides used in the Klamath Basin. Studies assessing compounds relative to the Klamath Basin for selected species were considered and various formulations (isomers) of the same chemical and chemical degradates were grouped for summary purposes. Species that were most commonly represented in the database for pesticides used in the Klamath Basin were selected to summarize available toxicity data. Only the most frequently tested organisms were considered to better assess the relative toxicity of pesticides. Several species of some taxa (fish, birds) were commonly tested, but for other taxa (insects) no single species commonly was tested with pesticides used in the Klamath Basin. Minimum, maximum, and median values were reported to represent study results. When applicable, median concentrations were calculated as an average of two middle values. When one of the middle values contained a '>' or '<', the discrete value was reported.

Based on the toxicity data for birds and fish, coupled with reported use information, the following compounds are likely to contribute the greatest direct toxicity threat to natural resources in the Basin: azoxystrobin (99.7 percent of strobilurin class), boscalid (100 percent of carboximide class), chlorothalonil (75.2 percent of chloronitrile class), fenoxaprop-p-ethyl (48.6 percent of arylphenoxypropionate class), malathion (77.2 percent of organophosphate class), metam sodium (95 percent of dithiocarbamate class), oxyfluorfen (100 percent of diphenyl ether class), pendimethalin (100 percent of dinitroaniline class), and tebuconazole (45.6 percent of triazole class). These compounds all exhibit relatively high toxicity to either birds or fish, and are either used at high rates on the lease lands, or the use of their chemical class has shown a substantial trend of increased use over recent years (fig. 7). The risk of these compounds also is strongly tied to their physical properties, environmental mobility, and persistence in the environment. The water solubility and soil half-life of most of these compounds are relatively low, but robust studies of their availability in the surrounding environment are lacking. Similar to the determination made by Haas (2007), metam sodium (a soil fumigant applied in the spring) may pose the greatest threat because of its sheer volume of use, water solubility, and relative mobility in the environment. However, no direct studies in the Basin have evaluated this empirically. Other compounds listed above still warrant attention in order to evaluate any potential impacts, but their ability to migrate out of the agricultural areas is unclear. Additionally, the surfactants used in pesticide formulations (appendix 4) can sometimes exert their own toxic influence. Due to lack of information, we do not include surfactants in our assessment here.

Table 7a. Summary of toxicity data (ECOTOX[a]) for chemicals used in the Klamath Basin for two species of birds. Bold and italicized compounds represent those compounds that have had reported use on Refuge Property

	Testing with *Colinus virginianus* (bobwhite quail) and *Anas platyrhynchos* (mallard duck)[bc]											
	dietary administration				oral gavage or capsule administration				reproductive study, dietary administration			
	LC50[d], concentrations in ppm			Days duration	LD50[e], concentrations in mg/kg			Days duration	LOEL[f], concentrations in ppm			Weeks duration
Chemical Name[gh]	min	max	median	(N tests)	min	max	median	(N tests)	min	max	median	(N tests)
1,3-D	***>1000***	***>10000***	***--***	***8 (2)***	***152***	***--***	***--***	***14 (1)***	***--***	***--***	***--***	***--***
2,4-D	***2019***	***12979***	***>5620***	***8 (43)***	***279***	***>4650***	***1000***	***7-21 (21)***	***>962***	***>962***	***--***	***21 (2)***
abamectin	383	3102	--	8 (2)	85	>2000	--	14 (2)	64	--	--	1G(1)
acephate	1280	>20000	>5000	8-14 (3)	234	734	350	14 (3)	20	80	--	16 (2)
acetamiprid	***5000***	***>5000***	***>5000***	***8 (3)***	***87***	***--***	***--***	***14 (1)***	***60.2***	***250***	***184***	***21-28 (5)***
acrolein	--	--	--	--	9.11	28	19	14-21 (3)	--	--	--	--
ADBAC[i]	>2430	>30000	>5000	8 (14)	0.225	3700	136	14 (6)	--	--	--	--
aluminum phosphide	--	--	--	--	--	--	--	--	--	--	--	--
aminopyralid	>5496	>5556		8 (2)	>292	>2250	--	14 (2)	>2500	>2610	>2623	20 (3)
atrazine	>5000	24450	5760[j]	8 (4)	768	>2000	>2000	12-14 (5)	675	67	--	23 (2)
azadirachtin	***>5620***	***>7000***	***>7000***	***8 (3)***	***>2250***	***16640***	***--***	***14 (2)***	***--***	***--***	***--***	***--***
azoxystrobin	***>5200***	***>5200***	***--***	***8 (2)***	***>250***	***>2000***	***--***	***14 (2)***	***3000***	***3000***	***--***	***22-23 (2)***
Bacillus thuringiensis	--	--	--	--	>5000	--	--	14 (1)	--	--	--	--
bentazon	>5000	11500	>10000	8 (3)	1171	14483	--	14 (2)	>40	>800	75	8-27 (6)
beta Cyfluthrin	--	--	--	--	--	--	--	--	--	--	--	--
bifenazate	656	1862	--	8 (2)	1032	--	--	14 (1)	65	>250	>120	21-26 (3)
bifenthrin	1280	4450	--	8 (2)	1800	>2150	--	21 (2)	>75	>75	--	22-24 (2)
boric acid	>5620	>10000	>7810	8 (4)	>2510	--	--	14 (1)	--	--	--	--
boscalid	***>5000***	***>5000***	***--***	***8 (2)***	***>2000***	***--***	***--***	***14 (1)***	***1000***	***>1000***	***--***	***22 (2)***
bromacil	>10000	>10000	--	8 (2)	355	2250	--	14 (2)	3100	3100	--	21-22 (2)
bromoxynil	1315	5106	2736	8 (9)	170	2350	390	10- 22 (8)	340	>371	--	21 25 (2)
captan	>2400	>5620	>5100	8-240 (6)[k]	>2000	>2150	--	14 (2)	>1000	>1000	--	1G(2)
carbaryl	***>5000***	***>5000***	***--***	***8 (2)***	***>2564***	***--***	***--***	***14 (1)***	***280***	***>3000***	***--***	***24-28 (2)***
carboxin	>4110	>10000	>4820	8 (6)	>2150	6094	--	14 (2)	700	>1000	--	21 (2)
chloropicrin	>5620	>10000	>7810	8 (4)	1316	3352	>2510	14 (4)	--	--	--	--

Table 7a. Continued.

	Testing with *Colinus virginianus* (bobwhite quail) and *Anas platyrhynchos* (mallard duck)[bc]											
	dietary administration				oral gavage or capsule administration				reproductive study, dietary administration			
	LC50[d], concentrations in ppm			Days duration (N tests)	LD50[e], concentrations in mg/kg			Days duration (N tests)	LOEL[f], concentrations in ppm			Weeks duration (N tests)
Chemical Name[gh]	min	max	median		min	max	median		min	max	median	
chlorothalonil	***1746***	***>21500***	***5200[j]***	***8-9 (6)***	***158***	***>4640***	***--***	***14 (2)***	***>50***	***5000***	***437***	***19-22 (5)***
chlorpropham	>5620	--	--	8 (1)	>2000	--	--	14 (1)	--	--	--	--
chlorpyrifos	***136***	***>5620***	***1387.5***	***8 (12)***	***32***	***2126***	***108***	***14 (5)***	***60***	***130***	***125***	***8-29 (5)***
chlorsulfuron	>5000	>5620	--	8 (2)	>5000	>5000	--	14 (2)	928	>987	--	27,1G (2,1)
clethodim	***>3978***	***>4270***	***--***	***8 (2)***	***>2000***	***--***	***--***	***14 (1)***	***833***	***>833***	***--***	***19-22 (2)***
clopyralid	>4640	>5620	>5130	8 (4)	1465	>2000	--	14 (2)	>1000	--	--	20 (1)
copper	***1817***	***>10000***	***>5200***	***8 (27)***	***135***	***>2250***	***1150***	***8-14 (15)***	***<500***	***2500***	***500***	***19-22 (8)***
cyfluthrin	***>5000***	***>5000***	***--***	***8 (2)***	***>2000***	***--***	***--***	***14 (1)***	***>250***	***4000***	***>250***	***5-24 (3)***
cymoxanil	***>5620***	***>5620***	***--***	***8 (2)***	***>2250***	***>2250***	***>2250***	***14 (3)***	***300***	***1200***	***--***	***21 (2)***
cypermethrin	>2634	>5620	>5290	8-16 (5)	>2000	>12085	>10248	14-21 (3)	>50	>50	--	12 (2)
cyprodinil	>5180	>5200	--	8 (2)	>500	>2000	--	14 (2)	>600	--	--	22 (1)
dazomet	1850	>5137	2301[j]	8 (4)	415	424	--	21 (2)	100	1000	--	25-27 (2)
deltamethrin	>4640	>10000	>5620	8 (4)	>2250	--	--	14 (1)	>450	>450	--	22-23(2)
desmedipham	>5000	>10000	>5000	5- 8 (3)	>2000	2480	--	14 (2)	450	2500	--	21 (2)
diazinon	32	>4990	180	5-8 (14)	1.18	>2060	5.1	8-14 (10)	16.33	>32	24.6	6-28 (3)
dicamba	***>2248***	***>10000***	***>5620***	***8 (17)***	***216***	***>4640***	***1980***	***8-14 (10)***	***1600***	***>1600***	***--***	***21 (2)***
dichlobenil	5200	>5200	--	8 (2)	>50	>2000	683	14-15 (3)	146	600	--	21 (2)
dicofol	1651	3010	--	8 (2)	--	--	--	--	>5	>120	40	8-19,NR (3,1)
difenzoquat	***>4640***	***>4640***	***--***	***8 (2)***	***1577***	***--***	***--***	***8 (1)***	***--***	***--***	***--***	***--***
diflubenzuron	>4640	>20000	>12320	8 (4)	>5000	>5000	--	14 (2)	10	1000	>250	13-22 (7)
dimethenamid	***>5620***	***>5620***	***>5620***	***8 (4)***	***1068***	***1908***	***--***	***14 (2)***	***900***	***>1800***	***--***	***20 (2)***
dimethoate	1011	--	--	8 (1)	41.7	63.5	--	14 (2)	10.1	152	30[j]	19-22,1G (4,1)
diquat dibromide	***2932***	***>5000***	***--***	***8 (2)***	***60.6***	***564***	***--***	***14 (2)***	***25***	***215***	***<100***	***8,1G (2,1)***
disulfoton	***46***	***823***	***544***	***8 (9)***	***6.54***	***220***	***28***	***4-14 (11)***	***74***	***80***	***--***	***20-34 (2)***
diuron	1730	>5000	--	8 (2)	>2000	--	--	14 (1)	--	--	--	--

Table 7a. Continued.

	Testing with *Colinus virginianus* (bobwhite quail) and *Anas platyrhynchos* (mallard duck)[bc]											
	dietary administration				oral gavage or capsule administration				reproductive study, dietary administration			
	LC50[d], concentrations in ppm			Days duration (N tests)	LD50[e], concentrations in mg/kg			Days duration (N tests)	LOEL[f], concentrations in ppm			Weeks duration (N tests)
Chemical Name[gh]	min	max	median		min	max	median		min	max	median	
endosulfan	805	>3528	1347.5	8 (4)	28	44	33	14 (5)	<30	>60	60	26 (1)
EPTC[i]	***>2000***	***22000***	***>5620***	***8 (5)***	***>1000***	***>2510***	***>1755***	***14 (4)***	***593***	***1490***	--	***20-26 (2)***
esfenvalerate	4894	>5620	--	8 (2)	381	--	--	14 (1)	--	--	--	--
ethephon	***>5000***	***>10000***	***>7500***	***8 (4)***	***794***	***1998***	***1072***	***14 (3)***	--	--	--	--
ethofumesate	***>5200***	***>10000***	***>7600***	***8 (4)***	***>3445***	***>8743***	--	***NR (2)***	***>3069***	***>3240***	--	***20 (2)***
ethoprop	33	550	186.5	8 (8)[l]	12.6	61	--	8-14 (2)	7.5	40	--	20-24 (2)
famoxadone	>5620	>5620	--	8 (2)	>2250	--	--	14 (1)	252	252	--	20-21 (2)
fenhexamid	>5000	>5469	--	5 - 8 (1)	>2000	--	--	14 (1)	>2074	--	--	23 (1)
fenoxaprop-p-ethyl	--	--	--	--	--	--	--	--	--	--	--	--
fenpropathrin	9026	>10000	--	8 (2)	1089	--	--	14 (1)	>2	500	115	21 (3)
fipronil	48	>5000	114	8-22 (5)	5	>2150	420	14-21 (5)	>10	>1000	--	20-23 (2)
flonicamid	***>4613***	***>5037***	--	***8 (2)***	***>2000***	***>2250***	***>2000***	***14 (3)***	***1030***	***>1030***	--	***20-21 (2)***
fluazifop-p-butyl	***>4850***	***>5230***	--	***8 (2)***	***>3528***	--	--	***14 (1)***	--	--	--	--
fludioxonil	>5200	>5240	--	8-11 (2)	>2000	--	--	14 (1)	303	>714	--	22 (2)
flumioxazin	>5620	>5620	--	8 (2)	>2250	--	--	14 (1)	500	>500	--	21 (2)
flutolanil	>5243	>5243	--	8 (2)	>2000	>2000	--	14 (2)	4800	4800	--	21 (2)
fosetyl-al	>20000	>20000	--	8 (2)	>8000	--	--	14 (1)	--	--	--	--
glufosinate	***>5000***	***>5000***	--	***8 (2)***	***>2000***	***>2000***	--	***14 (2)***	***>400***	***>400***	--	***22 (2)***
glyphosate	***>4640***	***>5200***	***>4920***	***8 (4)***	***>2000***	***>3851***	--	***8-14 (2)***	***>30***	***>1000***	***>1000***	***17,1G (2,1)***
hexazinone	>5000	>10000	>5000	8 (3)	2251	--	--	14 (1)	300	300	--	1G (2)
imazamethabenz	***>5000***	***>5000***	--	***8 (2)***	***>2150***	***>2150***	--	***14 (2)***	--	--	--	--
imazamox	***>5572***	***>5572***	--	***8 (2)***	***>1846***	***>1950***	--	***14 (2)***	***>2000***	***>2000***	--	***21 (2)***
imazapic	>5000	>5000	--	8 (2)	>2150	>2150	--	21 (2)	994	1907	--	22-24 (2)
imazapyr	>5000	5000	5000	8 (4)	>2150	>2150	>2150	21 (3)	>1670	<2000	>1890	18-21 (3)
imazethapyr	***>5000***	***>5000***	--	***8 (2)***	***>2150***	***>2150***	--	***21 (2)***	***585***	***>1084***	--	***20-22 (2)***

Table 7a. Continued.

	Testing with *Colinus virginianus* (bobwhite quail) and *Anas platyrhynchos* (mallard duck)[bc]											
	dietary administration				oral gavage or capsule administration				reproductive study, dietary administration			
	LC50[d], concentrations in ppm			Days duration (N tests)	LD50[e], concentrations in mg/kg			Days duration (N tests)	LOEL[f], concentrations in ppm			Weeks duration (N tests)
Chemical Name[gh]					min	max	median		min	max	median	
imidacloprid	***1536***	***>4797***	***--***	***8 (2)***	***152***	***--***	***--***	***14 (1)***	***<61***	***243***	***234***	***20-21 (2)***
indoxacarb	***808***	***>5620***	***--***	***8-12 (2)***	***98***	***>2250***	***1618[j]***	***12-14 (4)***	***720***	***1000***	***--***	***21-23 (2)***
iprodione	***>5620***	***>20000***	***9200[j]***	***8 (4)***	***930***	***>10437***	***>2000***	***14 (3)***	***1000***	***1000***	***--***	***1G (2)***
isoxaben	>5000	>5000	--	8 (2)	>2000	--	--	14 (1)	1000	>1000	--	24 (2)
lambda-cyhalothrin	>3948	>5300	--	8 (2)	>3950	--	--	14 (1)	>30	>50	--	19-31 (2)
malathion	***3497***	***>5000***	***--***	***8 (2)***	***1485***	***--***	***--***	***14 (1)***	***350***	***2400***	***--***	***20-21 (2)***
maleic hydrazide	***>5620***	***>10000***	***>10000***	***8 (7)***	***>2250***	***>4640***	***>2250***	***8-14 (3)***	***--***	***--***	***--***	
mancozeb	***--***	***--***	***--***	***--***	***--***	***--***	***--***	***--***	***<1000***	***>1000***	***1000***	***18-22 (3)***
MCPA	***>2000***	***>5620***	***>5310***	***8 (6)***	***377***	***>2250***	***478***	***14 (3)***	***>1000***	***--***	***--***	***14 (1)***
MCPP	5000	>30000	>5600	8-14 (7)	>486	>2250	655	14 (4)	--	--	--	--
mefenoxam	>4830	--	--	8 (1)	981	--	--	14 (1)	>900	>900	--	21-24 (2)
metalaxyl	>10000	>10000	--	8 (2)	1466	--	--	14 (1)	300	>900	900	18-23 (4)
metam sodium	***1836***	***>5000***	***>5000***	***8-10 (5)***	***500***	***--***	***--***	***14 (1)***	***--***	***--***	***--***	***--***
methamidophos	42	1650	59	8-9 (7)	8	29.5	9.29	14-21 (4)	<5	>30	>15	23-36,1G (2,1)
methomyl	1100	>5080	3714	8 (7)	15.9	24.2	16.8	14 (3)	150	427	--	17-18 (2)
methoprene	>10000	>10000	--	8 (2)	>2000	--	--	14 (1)	30	30	--	19-20 (2)
methyl bromide	--	--	--	--	73.2	--	--	14 (1)	--	--	--	--
methyl isothiocyanate	--	--	--	--	--	--	--	--	--	--	--	--
metribuzin	***>4000***	***>5000***	***>4000***	***8 (3)***	***164***	***>500***	***--***	***14-21 (2)***	***62***	***>368***	***--***	***20-22 (2)***
myclobutanil	>5000	>5000	--	8 (2)	510	--	--	21 (1)	>60	>260	>160	19-22 (3)
naphthalene	--	--	--	--	2690	--	--	14 (1)	--	--	--	--
oryzalin	>5000	>5000	--	8 (2)	507	--	--	14 (1)	53	>1000	311[j]	22 (2)
oxadiazon	>2500	>6000	>5000	8 (4)	880	6300	>2150	1-21 (3)	1000	>1000	--	20-21 (2)
oxamyl	***225***	***5025***	***1151***	***5-8 (6)***	***3.16***	***39.2***	***10.75***	***14 (3)***	***>50***	***>50***	***--***	***1G (2)***
oxyfluorfen	***>5000***	***>5000***	***--***	***8 (2)***	***>2150***	***>5000***	***--***	***14-21 (2)***	***50***	***751***	***100***	***20-22 (6)***

Table 7a. Continued.

	Testing with *Colinus virginianus* (bobwhite quail) and *Anas platyrhynchos* (mallard duck)[bc]											
	dietary administration				oral gavage or capsule administration				reproductive study, dietary administration			
	LC50[d], concentrations in ppm			Days duration (N tests)	LD50[e], concentrations in mg/kg			Days duration (N tests)	LOEL[f], concentrations in ppm			Weeks duration (N tests)
Chemical Name[gh]	min	max	median		min	max	median		min	max	median	
paraquat dichloride	981	4048	--	8 (2)	176	199	--	8 (2)	--	--	--	--
parathion	28.2	3850	275	8 (11)	0.898	114.7	4.47	14 (10)	>6.27	20	10	12-20,1G (3,2)
PCNB[i]	>5000	>54000	>11699	5-9 (8)	>2150	>2250	--	14-21 (2)	1200	>5500	2500	20-25 (5)
pendimethalin	***4187***	***>4640***	***--***	***8 (2)***	***1421***	***--***	***--***	***8 (1)***	***1410***	***>1410***	***--***	***20-21 (2)***
permethrin	***>5200***	***>23000***	***>10000***	***8 (5)***	***>2000***	***>9869***	***>4640***	***14 (3)***	***>25***	***>500***	***500***	***20 (3)***
phenmedipham	***>5688***	***>10000***	***>7895***	***8 (4)***	***>2100***	***--***	***--***	***14 (1)***	***>1200***	***>1200***	***--***	***22 (2)***
phophoric acid	>5620	--	--	8 (1)	--	--	--	--	--	--	--	--
picloram	>5000	>10000	>10000	8 (9)	>2510	>2250	--	14 (2)	--	--	--	--
piperonyl butoxide	>5620	>5620	--	8 (2)	>2250	--	--	14 (1)	1200	1500	--	22-24 (2)
POE isooctadecanol	>5000	>5000	--	8 (2)	>2000	--	--	14 (1)	--	--	--	--
prodiamine	>10000	>10000	--	8 (2)	>2250	--	--	14 (1)	>1000	>1000	--	20 (1)
propargite	3401	>5020	>4640	8 (3)	>4640	--	--	14 (1)	84.7	288	--	18-20 (2)
propiconazole	***>5620***	***>5620***	***--***	***8 (2)***	***2510***	***2825***	***--***	***14 (2)***	***>1000***	***>4640***	***>1000***	***28 (3)***
propionic acid	>10000	>10000	--	8 (2)	1467	--	--	8 (1)	--	--	--	--
propyzamide	>4000	>10000	>10000	7-8 (3)	>20000	--	--	1 (1)	--	--	--	--
pymetrozine	***>5010***	***>5130***	***--***	***8 (2)***	***>31.25***	***>2000***	***--***	***14 (2)***	***>260***	***300***	***300***	***20-22 (3)***
pyraclostrobin	***>5000***	***>5000***	***--***	***8 (2)***	***>2000***	***>2000***	***--***	***14 (2)***	***>1062***	***>1062***		***22-23 (2)***
pyrethrins	***>5000***	***>5620***	***>5620***	***8 (3)***	***>10000***	***--***	***--***	***1 (1)***	***--***	***--***	***--***	***--***
pyrimethanil	>4828	>5132	--	8 (2)	>2012	--	--	14 (1)	311	>969	--	21-23 (2)
rimsulfuron	***>1339***	***>5620***	***>3499***	***8 (4)***	***>563***	***>2250***	***>2125***	***14 (4)***	***>1250***		***--***	***20 (1)***
sethoxydim	***>5620***	***>5620***	***--***	***8 (2)***	***2510***	***--***	***--***	***14 (1)***	***100***	***>1000***	***--***	***21-22 (2)***
simazine	>2000	32000	10000[j]	7-10,77(5,1)	>4640	--	--	8 (1)	>20	500	450	20-21 (3)
sodium fluoride	>5620	>5620	--	8 (2)	387	--	--	14 (1)	--	--	--	--
spinetoram	***>5640***	***>5790***	***--***	***8-14 (2)***	***>2250***	***>2250***	***--***	***14-17 (2)***	***493***	***>995***	***--***	***21-22 (2)***
spinosad A+D	***>5156***	***>5156***	***--***	***8 (2)***	***>1333***	***>1333***	***--***	***14 (2)***	***1100***	***1100***	***--***	***25-26 (2)***

Table 7a. Continued.

	Testing with *Colinus virginianus* (bobwhite quail) and *Anas platyrhynchos* (mallard duck)[bc]											
	dietary administration				oral gavage or capsule administration				reproductive study, dietary administration			
	LC50[d], concentrations in ppm			Days duration (N tests)	LD50[e], concentrations in mg/kg			Days duration (N tests)	LOEL[f], concentrations in ppm			Weeks duration (N tests)
Chemical Name[gh]	min	max	median		min	max	median		min	max	median	
sulfometuron-methyl	>4600	>5620	--	8 (2)	>5000	--	--	14 (1)	--	--	--	--
sulfur	***>5620***	***--***	***--***	***14 (1)***	***--***	***--***	***--***	***--***	***--***	***--***	***--***	***--***
tebuconazole	***>4816***	***>5000***	***--***	***8-12 (2)***	***1988***	***--***	***--***	***21 (1)***	***75.8***	***611***	***290***[j]	***28-31 (2)***
temephos	92	894	--	8 (2)	27.4	2128	79.4	14 (3)	--	--	--	--
thiabendazole	>5620	>14500	>10000	4-8 (8)	>2250	>4640	>4640	4-14 (6)	>400	>400	--	8-22 (2)
thiophanate-methyl	>4586	>10000	>10000	8 (3)	>4640	>4640	--	8 (2)	>103	>500	>150	20-27 (3)
thiram	3950	5000	--	8 (2)	2.42	>2800	--	NR-14 (2)	50	2500	39.7	23 (3)
tralkoxydim	***>5995***	***>7400***	***--***	***8 (2)***	***>3020***	***--***	***--***	***14 (1)***	***>150***	***>150***	***--***	***23-24 (2)***
tribenuron-methyl	***>5620***	***>5620***	***--***	***8 (2)***	***>2250***	***--***	***--***	***14 (1)***	***180***	***1080***	***--***	***21-23 (2)***
triclopyr	2934	11622	9026[j]	8 (8)	735	3176	1698	8-21 (6)	200	>500	200	19-11 (3)
trifloxystrobin	>5050	>5050	--	8 (2)	>2000	>2250		14 (2)	>320	>500	--	20-21 (2)
trifluralin	>5000	>5000	--	8 (2)	>2000	>2000	--	8-14 (2)	>50	1000	1000[j]	19-20,1G (2,2)
triflusulfuron methyl	>5620	>5620	--	8 (2)	>2250	>2250	--	14 (2)	>40	1250	1250[j]	20-22 (4)
zinc phosphide	469	2885	1067	8 (4)	12.9	67.4	35.7	14 (3)	--	--	--	--
DDT[n]	611	1869	1390	8 (4)	>2240	--	--	14 (1)	--	--	--	--
dieldrin[n]	37	169	153	8 (3)	381	--	--	14 (1)	--	--	--	--
endrin[n]	14	18	--	8 (2)	5.64	--	--	14 (1)	--	--	--	--
toxaphene[n]	538	828	--	8 (2)	30.8	85.5	70.7	14 (3)	--	--	--	--

[a] ECOTOX, U.S. EPA ECOTOXicology database.

[b] -- denotes NA or no available data.

[c] When applicable, median values calculated as an average of two middle numbers.

[d] LC50, lethal concentration at which 50% mortality occurred in test organisms, tests where the toxicant was administered ad libitum in the diet.

[e] LD50, lethal dose at which 50% mortality occurred in test organisms, tests where the toxicant was administered orally.

[f] LOEL, lowest observed effect level for avian reproduction chronic toxicity testing. Tests may include one or several endpoints: growth, embryo and juvenile survival and hatching success. See the Ecotox database and database guidance for additional information.

[g] No toxicity data was available in ECOTOX for chemicals used in the Klamath Basin (see **Table 4**) and not included here.

Table 7a. Continued.

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[h] Various formulations of the same chemical, and chemical degradates were grouped for summarizing ECOTOX toxicity data.

[i] ADBAC, alkyl dimethyl benzyl ammonium chloride; EPTC, ethyl dipropylthiocarbamate; PCNB, pentachloronitrobenzene.

[j] Median values was not calculated by the averaging two middle numbers because one of the middle numbers contained a > or < sign, therefore the discrete value was reported.

[K] 8 days, N=5; 240 days, N=1.

[m] Includes ethoprop/disulfoton mixure.

[n] Two entries reported in pounds of active ingredient: min = 1.0, max = 2.016.

[o] Chemicals banned in the U.S., provided for reference.

Table 7b. Summary of toxicity data (ECOTOX[a]) for chemicals used in the Klamath Basin for four fish species.

	Static, static-renewal and flow through water testing with *Lepomis macrochirus* (bluegill sunfish), *Pimephales promelas* (fathead minnow), *Oncorhynchus mykiss* (rainbow trout), *Cyprinodon variegates* (sheepshead minnow)[bc]							
	LC50[d], concentrations in ppm			Hours duration (N tests)	LOEC[e], concentrations in ppm			Days duration (N tests)
Chemical Name[fg]	min	max	median		min	max	median	
1,3-D	***0.87***	***69.5***	***4.02***	***96 (12)***	***--***	***--***	***--***	***--***
2,4-D	***0.29***	***2840***	***18***	***96 (100)***	***0.114***	***102***	***14.31***	***31-32 (4)***
abamectin	0.0036	260	0.015	96 (5)	9.60E-04	--	--	NR (1)
acephate	>50	>3200	895	24-96 (11)	--	--	--	--
acetamiprid	***>98.1***	***>119.3***	***100***[h]	***96 (4)***	***38.4***	***--***	***--***	***35 (1)***
acrolein	0.022	0.43	<0.073	48-96 (4)	--	--	--	--
ADBAC[i]	0.064	18.5	0.9516	96 (28)	0.0759	--	--	34 (1)
aluminum phosphide	1.26E-04	--	--	96 (1)	--	--	--	--
aminopyralid	>100	>120	>100	96 (3)	>1.36	--	--	36 (1)
atrazine	>1.9	>111	15	96 (15)	0.46 (274D)	2.2 (33D)	0.685	33-274 (4)
azadirachtin	***0.11***	***37***	***4.64***	***96 (4)***	***--***	***--***	***--***	***--***
azoxystrobin	***0.47***	***>150***	***0.8855***	***96 (4)***	***0.193***	***--***	***--***	***28 (1)***
Bacillus thuringiensis	>0.656	>0.656	--	96 (2)	--	--	--	--
bentazon	>100	>1000	>136	96 (7)	--	--	--	--
beta Cyfluthrin	6.80E-05	9.98E-04	2.45E-04	96 (8)	--	--	--	--
bifenazate	0.416	0.76	0.58	96 (3)	--	--	--	--
bifenthrin	1.50E-04	0.0175	3.50E-04	96 (3)	9.60E-05	--	--	368 (1)
boric acid	<100	>1100	>910.5	96 (4)	--	--	--	--
boscalid	***2.7***	***>3.86***	***>3.7***	***96 (3)***	***0.241***	***--***	***--***	***97 (1)***
bromacil	2.6	661	127 [h]	96 (14)	7.2	--	--	90 (1)
bromoxynil	0.029	23	0.15	96 (13)	0.0044	0.0057	--	35-36 (2)
captan	0.065	>126	0.31	96 (13)	0.039	--	--	315 (1)
carbaryl	***0.76***	***290***	***4.25***	***48-96 (22)***	***0.68***	***--***	***--***	***270 (1)***
carboxin	>0.1	11.2	2.9	96 (11)	--	--	--	--
chloropicrin	0.0165	532	0.105 [h]	48-96 (6)	--	--	--	--
chlorothalonil	***0.0179***	***45***	***0.0935***	***24 - 96 (16)***	***0.0065***	***--***	***--***	***168 (1)***

Table 7b. Continued.

	Static, static-renewal and flow through water testing with *Lepomis macrochirus* (bluegill sunfish), *Pimephales promelas* (fathead minnow), *Oncorhynchus mykiss* (rainbow trout), *Cyprinodon variegates* (sheepshead minnow) [bc]							
	LC50[d], concentrations in ppm			Hours duration (N tests)	LOEC[e], concentrations in ppm			Days duration (N tests)
Chemical Name[fg]	min	max	median		min	max	median	
chlorpropham	3.02	6.8	5.7	96 (5)	--	--	--	--
chlorpyrifos	***0.0013***	***0.88***	***31.5***	***96 (18)***	***0.00109***	***0.0048***	***0.0028***	***30-32,200-238 (3,2)***
chlorsulfuron	>250	>980	>300	96 (4)	64.8	--	--	77 (1)
clethodim	***19***	***>33***	***--***	***96 (2)***	***--***	***--***	***--***	***--***
clopyralid	103.5	4686	1968	96 (5)	--	--	--	--
copper	***0.0089***	***>3200***	***1.945***	***24-96 (92)***	***0.00351***	***0.0072***	***0.00604***	***32-164 (3)***
cyfluthrin	***3.00E-04***	***4.05E-03***	***8.70E-04***	***96 (5)***	***1.77E-05***	***6.20E-04***	***1.67E-04***	***28-307 (4)***
cymoxanil	***>0.03***	***<178***	***29*** [h]	***96,504 (7,1)***	***0.0024***	***1.5***	***0.1045***	***21-97 (4)***
cypermethrin	3.40E-04	36.3	0.0022	96 (23)	3.30E-04	--	--	30 (1)
cyprodinil	1.25	3.2	2.295	96 (4)	0.46	--	--	NR (1)
dazomet	0.08	97	2.4	96 (11)	--	--	--	--
deltamethrin	2.50E-04	0.0015	4.90E-04	96 (9)	3.00E-05	3.60E-05	--	36-280 (2)
desmedipham	1.7	6.0	--	96 (2)	--	--	--	--
diazinon	0.09	101.1	0.5	96 (21)	<9.20E05	0.008	0.00182 [h]	25-116 (6)
dicamba	***28***	***>1000***	***144.2***	***96 (18)***	***--***	***--***	***--***	***--***
dichlobenil	4.93	13	6.72	48-96 (5)	<0.33	1.2	--	60 (2)
dicofol	0.124	2.9	0.515	48-96 (10)	0.0079	0.039	0.00896	30-296 (4)
difenzoquat	***46.5***	***711***	***86.6***	***96 (6)***	***--***	***--***	***--***	***--***
diflubenzuron	>0.013	>1000	137.5	96 (20)	>0.1	--	--	300 (1)
dimethenamid	***2.6***	***12***	***6.4***	***96,504 (6,1)***	***0.24***	***--***	***--***	***90 (1)***
dimethoate	6	111	25	24-96 (7)	0.84	--	--	96 (1)
diquat dibromide	***13.9***	***245***	***>100***	***72-96 (7)***	***1.5***	***--***	***--***	***34 (1)***
disulfoton	***0.0082***	***>100***	***1.575***	***48-96 (24)***	***0.0029***	***0.42***	***0.0329***	***33-110 (3)***
diuron	1.95	>300	15.1	96 (10)	0.0618	<0.44	--	38-60 (2)
endosulfan	3.70E-04	0.028	0.0023	96,168 (20,1)	3.00E-05	6.00E-04	0.0004	28-1200 (3)
EPTC[i]	***14***	***>180***	***21***	***96 (11)***	***--***	***--***	***--***	***--***

Table 7b. Continued.

	Static, static-renewal and flow through water testing with *Lepomis macrochirus* (bluegill sunfish), *Pimephales promelas* (fathead minnow), *Oncorhynchus mykiss* (rainbow trout), *Cyprinodon variegates* (sheepshead minnow) [b,c]							
	LC50[d], concentrations in ppm			Hours duration (N tests)	LOEC[e], concentrations in ppm			Days duration (N tests)
Chemical Name[f,g]	min	max	median		min	max	median	
esfenvalerate	7.00E-05	2.30E-04	--	96 (2)	--	--	--	--
ethephon	***97***	***420***	***>180***	***96 (11)***	--	--	--	--
ethofumesate	***0.5***	***>320***	***17.5***	***96 (12)***	***4.17***	--	--	***28 (1)***
ethoprop	0.15[j]	13.8	1.08	96 (15)	0.0037	0.054	0.016	38- 112,NR (3,1)
famoxadone	0.0093	>9	0.013	96 (7)	0.0041	0.0112	--	36-90 (2)
fenhexamid	1.34	11	3.04	96 (4)	0.206	--	--	32 (1)
fenoxaprop-p-ethyl	***0.46***	***317.5***	***0.58***	***96 (4)***	--	--	--	--
fenpropathrin	0.0022	0.015	0.0031	96 (7)	1.30E-05	--	--	260 (1)
fipronil	0.02	0.246	0.061	96 (8)	4.10E-04	0.015	0.0016	32-90 (3)
flonicamid	***>97.9***	***>120***	***>98.8***	***69 (3)***	***20***	--	--	***33 (1)***
fluazifop-p-butyl	--	--	--	--	--	--	--	--
fludioxonil	0.47	1.2	0.735	96 (4)	0.04	0.077	--	30-32 (2)
flumioxazin	2.3	21	3.55	96,504 (3,1)	0.016	--	--	60 (1)
flutolanil	4.8	>6.1	5.4[h]	96 (4)	0.486	--	--	35 (1)
fosetyl-al	75.8	428.1	261.4	96 (4)	--	--	--	--
glufosinate	***12.27***	***>1000***	***26.7***	***96 (7)***	--	--	--	--
glyphosate	***1.3***	***>1000***	***91.5***	***96 (34)***	***>25.7***	--	--	***255 (1)***
hexazinone	>100	<420	238	96 (7)	35.5	--	--	39 (1)
imazamethabenz	***>100***	***420***	***280***	***96 (3)***	***0.83***	--	--	***30 (1)***
imazamox	***>94.2***	***>122***	***>106.6***	***96 (4)***	--	--	--	--
imazapic	>98.7	>100	>100	96 (3)	>96	--	--	32 (1)
imazapyr	>100	>1000	>105	96 (6)	92	>120	>118	28-240 (3)
imazethapyr	***>110***	***423***	***>112***	***96 (5)***	***>97***	--	--	***33 (1)***
imidacloprid	***>83***	***229.1***	***()163***[h]	***96 (4)***	***1.2***	--	--	***98 (1)***
indoxacarb	***0.024***	***>1.3***	***0.65***[h]	***96 (9)***	***0.0417***	***0.25***	--	***32 (2)***
iprodione	***3.7***	***7.8***	***6.3***	***96 (5)***	***0.55***	--	--	***34 (1)***

Table 7b. Continued.

	Static, static-renewal and flow through water testing with *Lepomis macrochirus* (bluegill sunfish), *Pimephales promelas* (fathead minnow), *Oncorhynchus mykiss* (rainbow trout), *Cyprinodon variegates* (sheepshead minnow)[bc]							
	LC50[d], concentrations in ppm			Hours duration (N tests)	LOEC[e], concentrations in ppm			Days duration (N tests)
Chemical Name[fg]	min	max	median		min	max	median	
isoxaben	>0.87	>1.1	--	96 (2)	>0.4	>0.42	--	33-66 (2)
lambda-cyhalothrin	0.106	13	2.8	96 (10)	6.20E-05	3.80E-04	--	300,NR (1,1)
malathion	***0.0041***	***8.65***	***0.0325***	***48,96 (1,7)***	***0.044***	***--***	***--***	***97 (1)***
maleic hydrazide	***>100***	***>1000***	***>102***	***72,96 (1,5)***	***--***	***--***	***--***	***--***
mancozeb	***0.159[k]***	***>502***	***1.425***	***48-96 (20)***	***0.00456***	***--***	***--***	***35 (1)***
MCPA	***1.15***	***635.4***	***>180***	***96 (27)***	***29***	***--***	***--***	***NR (1)***
MCPP	>92	>180	124.8[h]	96 (6)	--	--	--	--
mefenoxam	>121	--	--	96 (1)	--	--	--	--
metalaxyl	18.4	150	131	96 (6)	>9.1	--	--	30 (1)
metam sodium	***0.51***	***34.1***	***--***	***96 (2)***	***--***	***--***	***--***	***--***
methamidophos	1.28	51	34	96 (7)	--	--	--	--
methomyl	0.37	7.7	1.8	96 (19)	0.117	0.49	0.142	28-193 (3)
methoprene	1.01	>50	8.5	96 (9)	--	--	--	--
methyl bromide	--	--	--	--	--	--	--	--
methyl isothiocyanate	0.0512	0.142	0.094	96 (3)	--	--	--	--
metribuzin	***42***	***150***	***85***	***96 (9)***	***3.0***	***--***	***--***	***95 (1)***
myclobutanil	2.4	4.7	4.2	96 (3)	4.0	--	--	NR (1)
naphthalene	2	3.2	--	96 (2)	--	--	--	--
oryzalin	2.88	3.45	3.26[h]	96 (4)	0.43	>0.46	--	34-66 (2)
oxadiazon	0.88	8.2	1.5	96 (9)	0.0017	0.084	--	48-97 (2)
oxamyl	***2.6***	***12.4***	***5.865***	***96 (8)***	***<1***	***1.5***	***1.5***	***2 -61,NR (2,1)***
oxyfluorfen	>0.17	0.41	0.21	96 (5)	0.0024	0.074	--	30-33 (2)
paraquat dichloride	13	156	29	48,96 (1,4)	--	--	--	--
parathion	0.018	161	2.35	24-96 (35)	3.70E-04	0.38	0.08	28-64 (5)
PCNB[i]	0.1	7.9	0.55	96 (13)	0.054	0.32	--	35-95 (2)

Table 7b. Continued.

	Static, static-renewal and flow through water testing with *Lepomis macrochirus* (bluegill sunfish), *Pimephales promelas* (fathead minnow), *Oncorhynchus mykiss* (rainbow trout), *Cyprinodon variegates* (sheepshead minnow) [bc]							
	LC50[d], concentrations in ppm			Hours duration (N tests)	LOEC[e], concentrations in ppm			Days duration (N tests)
Chemical Name[fg]	min	max	median		min	max	median	
pendimethalin	***0.138***	***90.4***	***0.96***	***96 (10)***	***0.0098***	***--***	***--***	***288 (1)***
permethrin	***7.90E-04***	***>0.3***	***0.0098***	***96 (27)***	***4.10E-04***	***0.01***	***--***	***28-246 (2)***
phenmedipham	***1.41***	***3.98***	***--***	***96 (2)***	***--***	***--***	***--***	***--***
phophoric acid	--	--	--	--	--	--	--	--
picloram	3.1	1250	22.75	48-96 (18)	0.88	11.9	--	26-32 (2)
piperonyl butoxide	0.0024	6.2	3.67	96 (12)	0.11	0.48	--	35,NR (1,1)
POE isooctadecanol	98	>300	290	96 (3)	--	--	--	--
prodiamine	>0.45	19.6	>0.829	96 (5)	0.025	--	--	87 (1)
propargite	0.031	0.455	0.1305	96 (6)	0.028	--	--	35 (1)
propiconazole	***0.83***	***506***	***5.35***	***96 (10)***	***0.184***	***0.29***	***0.21***	***100,NR (1,2)***
propionic acid	51	>180	85.3	96 (5)	--	--	--	--
propyzamide	72	100	--	96 (2)	--	--	--	--
pymetrozine	***>117***	***>134***	***>128***	***96 (3)***	***>11.7***	***--***	***--***	***29 (1)***
pyraclostrobin	***0.0062***	***>99.18***	***0.04415***	***96 (4)***	***0.00642***	***0.024***	***0.00837***	***36-98 (3)***
pyrethrins	***0.0032***[l]	***0.10***[l]	***0.018***[l]	***96 (12)***	***0.003***	***--***	***--***	***35 (1)***
pyrimethanil	2.8	26.2	10.14	96 (3)	0.039	2.7	--	21-89 (2)
rimsulfuron	***>110***	***>390***	***>390***	***96 (3)***	***--***	***--***	***--***	***--***
sethoxydim	***1.2***	***265***	***3.5***[h]	***96 (6)***	***>98***	***--***	***--***	***28 (1)***
simazine	>2.5	510	28	24-96 (20)	2.5	2.5	--	120-365 (2)
sodium fluoride	317	830	--	96 (2)	--	--	--	--
spinetoram	***2.69***	***>3.46***	***--***	***96 (2)***	***0.405***	***--***	***--***	***32 (1)***
spinosad A+D	***4.9***	***30***	***6.905***	***96,504 (3,1)***	***0.962***	***2.38***	***--***	***30-32 (2)***
sulfometuron-methyl	>12.5	>150	>45	96 (5)	1.16	--	--	NR (1)
sulfur	***>100***	***>180***	***>180***	***96 (4)***	***--***	***--***	***--***	***--***
tebuconazole	***4.4***	***5.9***	***5.7***	***96 (3)***	***0.025***	***0.047***	***0.043***	***36-203 (3)***

Table 7b. Continued.

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[l] Includes Pyrethrins/Piperonyl butoxide mixture (N = 2), N= 1 for mysid.

[m] Chemicals banned in the U.S., provided for reference.

Metals

The rich mineral resources within the Klamath Basin support widespread mining activities, particularly throughout the Lower Basin. We have identified 3,032 documented mines within the basin that extract a range of resources, including chromium, copper, gold, manganese, mercury, platinum, and silver (fig. 18). Gold is the primary commodity sought by the majority (81 percent; N = 2,440) of documented mines. Although data exists on the operational status of many of the mines in the basin, 39 percent are classified as unknown, indicating that they may be active producers, past producers, or prospects. Of those with known status, 196 (6 percent) are currently producing, 1,485 (49 percent) are past producers, and 178 (6 percent) are prospects (fig. 18). Among mines in which toxic metals are the primary commodity, there are 262 chromium, 100 copper, 33 mercury, 6 lead, 2 nickel, 2 tungsten, 2 arsenic, and 1 zinc mine documented in the basin (fig. 19).

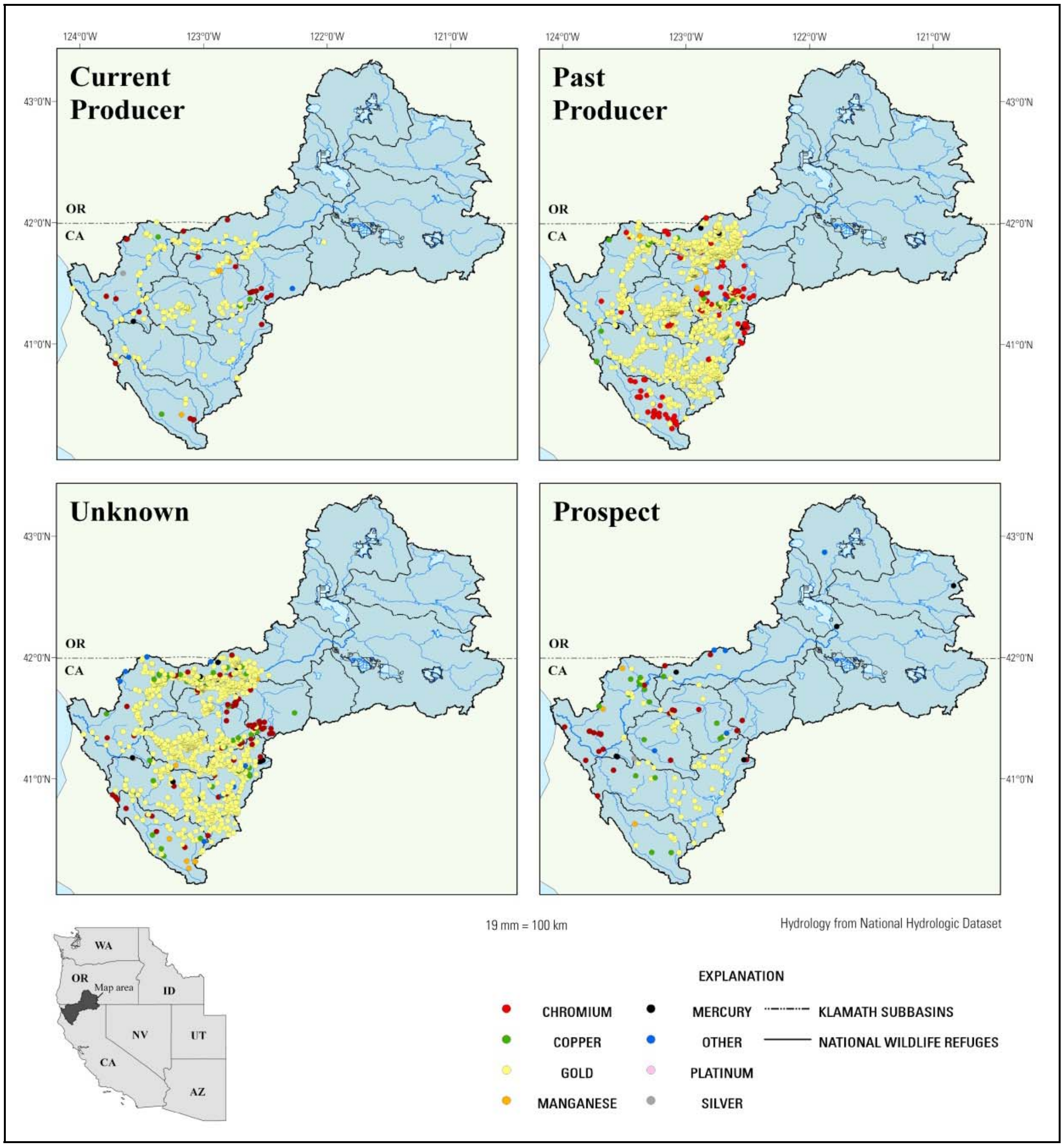

Figure 18. Summary of metallic mines by status and element (only primary commodity shown) in the Klamath Basin, Oregon and California. Other (N=18): antimony, iron, lead, molybdenum, nickel, silica, scandium, titanium, tungsten. Mine data from U.S. Geological Survey (2005).

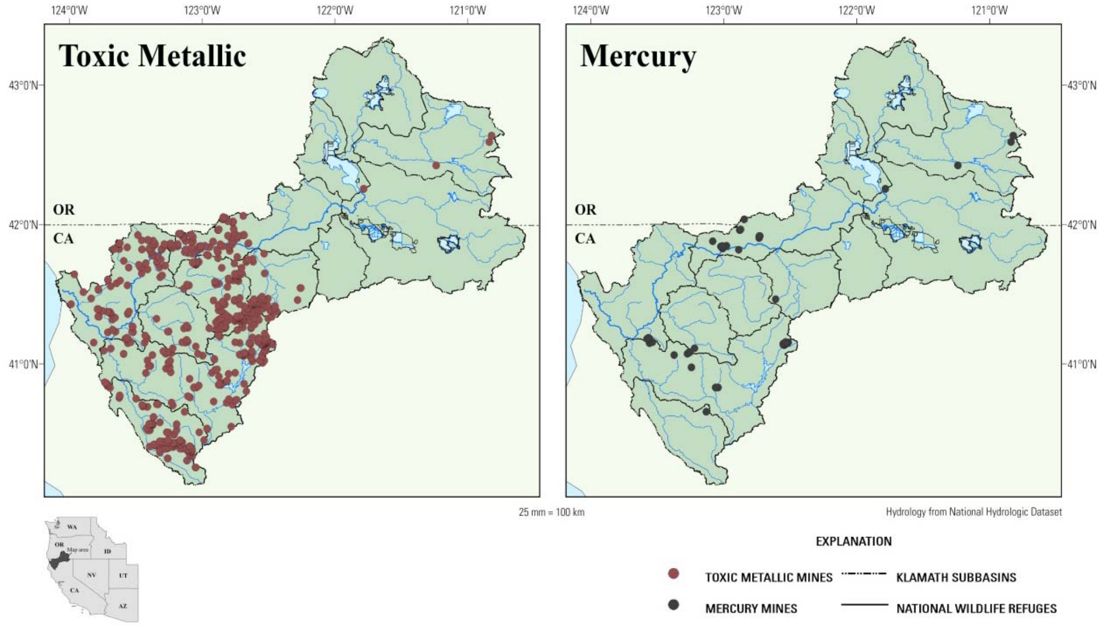

Figure 19. Locations of toxic metallic and mercury mines in the Klamath Basin, Oregon and California. Toxic metallic mines included in map are arsenic, chromium, copper, lead, mercury, nickel, tungsten, uranium, and zinc. Includes, past producer, producer, prospect, and unknown mine locations. Mine data from U.S. Geological Survey (2005).

There is limited information in the region on the impacts that any of these mines might have on water quality and ecosystem health of the Klamath River or its tributaries. Regardless of whether or not the mines release elevated amounts of toxic metals to the watershed, a common threat associated with past mining is the siltation and sedimentation within the streams and rivers, which can alter water chemistry, temperature profiles, and substrate quality. This may be particularly true within the Lower Basin, where the steep hillsides and high precipitation rates likely result in increased sediment transport to streams. Elemental analysis of recent sediment cores taken from the three major upstream reservoirs, and the Klamath Estuary, show relatively low concentrations of chromium and nickel within the reservoir sediments, and substantially more elevated concentrations in the sediments from the Estuary (fig. 20). Conversely, arsenic and lead data in reservoir sediments were substantially more elevated than in the estuary. No additional data exist that support the possibility of mining contributing to these higher values in the estuarine sediments, but given the fact that these sediment concentrations exceed some benchmark levels (CDM 2011), future investigations should address the source of these metals.

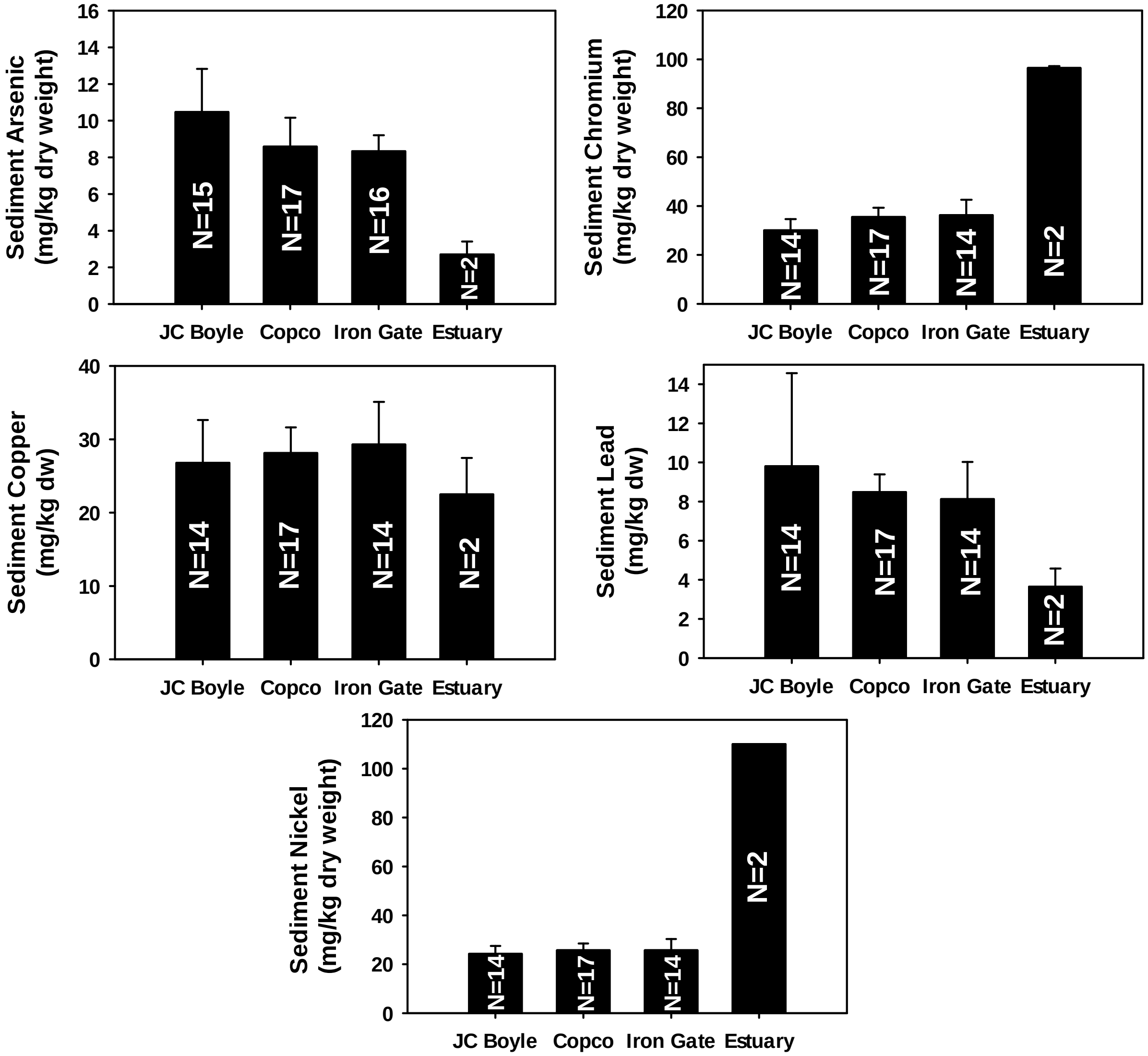

Figure 20. Metal concentrations from sediments in Boyle, Copco, and Iron Gate Reservoirs, and the Klamath River Estuary. Data acquired from the Klamath Restoration Secretarial Study Feasibility (*http://klamathrestoration.gov/keep-me-informed/klamath-river-reservoirs*).

Based solely on the density and types of mines in the region, the fact that ecologically and culturally important fish species (including a federally listed salmonid) are found in these waters, and the dearth of information on metals and metal exposure in the region, subsequent research and monitoring is warranted. This is particularly true in the cases of chromium, copper, and mercury, which account for nearly 97 percent of the mines in which the primary commodity is defined as a toxic metal. It has been well established that copper is toxic to aquatic life and that acute/chronic toxic effects can result in mortality and reductions in survival, reproduction, and growth. With respect to sublethal effects, copper impairs the olfactory nervous system of coho salmon affecting their homing, foraging, and predator avoidance behaviors critical for the migratory success and ultimately survival of the species (Baldwin and others, 2003). Copper concentrations were elevated in all reservoirs and estuary sediments, but levels of dissolved copper in the surface waters are unknown. As discussed above, sediment chromium levels are substantially elevated in the estuary relative to the Upper Basin reservoirs, suggesting that there may be significant sources downstream of Iron Gate Dam. Whether chromium concentrations in the river or estuary pose an ecological risk is still unclear because there has been no evaluation of waterborne chromium concentrations. However, waterborne chromium has been linked to oxidative stress (Vasylkiv and others, 2010) and histopathological abnormalities in fish (Iwasaki and others, 2010). Finally, as discussed previously, Hg may be a widespread concern in both the Upper and Lower Basins, and can be particularly problematic because the risk of Hg impacts stem from both sources and bioavailability of inorganic Hg, as well as the biogeochemical characteristics in the environment that facilitate conversion to MeHg, the bioaccumulative and toxic form. In addition to the 61 documented mercury mines within the Klamath River watershed, Hg also was historically used in the extraction of gold ore. Although there is no readily available information on the amount of Hg used in gold mining activities in the Klamath Basin during the late 1800s, estimates from the Sierra Nevada gold operations indicate that a significant proportion of the Hg used in this fashion was lost to the environment (National Research Council, 2004). Thus, legacy Hg may be a serious issue in some areas within the basin where the environmental conditions support MeHg production. Moreover, legacy Hg that may be sequestered with the fine particles of the river’s substrate may be mobilized and methylated with suction dredge mining, which is growing in popularity. Although there is currently a moratorium on suction dredges in California, Oregon still permits these activities, raising concerns about Hg mobilization in the upper reaches of the Basin. Importantly, recent research by USGS has shown that more Hg is associated with fine-grained sediments than coarser sediments, and that suction dredging mobilizes fine-grained sediments that can be carried downstream (Fleck and others, 2011; Marvin DiPasquale and others, 2011). Thus, a better understanding of Hg distribution and bioaccumulation across the basin could prove valuable in more thoroughly understanding the risks of these activities.

Other Contaminant Sources

There are limited data available on other contaminant sources within the Klamath Basin. However, based on EPA databases, there are at least 2 superfund sites, 8 brownfields, 3 pesticide producers, 3 major NPDES dischargers, and 21 minor NPDES dischargers that are identified within the Basin (fig. 21). These sites are associated with a broad range of contaminants, including: petroleum products, asbestos, volatile organic compounds (VOCs), lead and other heavy metals, dioxins, polyaromatic hydrocarbons (PAHs), and other organic contaminants (fig. 22). The extent to which contaminants from these potential sources reach the surrounding environment is unclear, but there is a possibility that at least some of these sites result in exposure of the Basin's biological resources. Further, human population centers are often situated adjacent to water resources and are frequently associated with various contaminants they may enter the environment, but the specific compounds are not readily documented and potential effects of exposure to biota are not well understood.

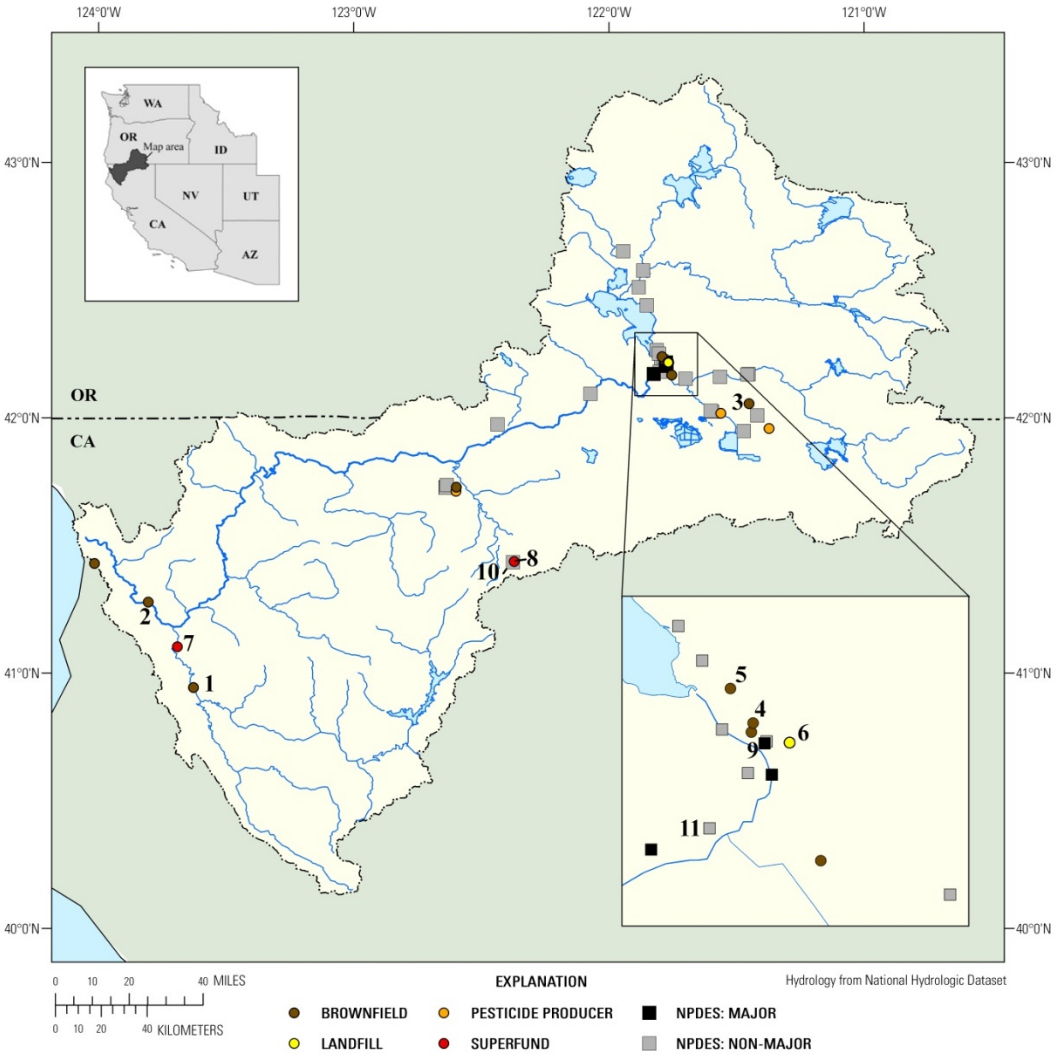

Figure 21. Klamath Basin facilities or sites subject to environmental regulation and/or are of environmental concern with respect to contaminants. Brownfields are "real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant" (US EPA). Pesticide producers identified in the Section Seven Tracking System (SSTS), an automated system EPA uses to track pesticide producing establishments and the amount of pesticides they produce. Superfund sites (National Priorities List, NPL) are sites that are known releases or threatened releases of hazardous substances, pollutants, or contaminants. National Pollutant Discharge Elimination System (NPDES) (major and non-major) is a permit program regulating point source discharges to surface water. Figure numbers correspond to the primary pollutant(s) of concern at specific locations

(symbols not numerically labeled = pollutant(s) unknown and/or undetermined) : (1) petroleum products; (2) petroleum products, other; (3) petroleum products, asbestos, volatile organic compounds (VOCs); (4) petroleum products, asbestos, metals, other; (5) petroleum products, VOCs; (6) lead, other; (7) metals, inorganics; (8) dioxins/dibenzofurans, metals, polycyclic aromatic hydrocarbons (PAHs), pesticides, VOCs, inorganics, organics; (9) sewage treatment facilitiy: violation for metals, coliform, phenols, chlorine, other; (10) lead; (11) toluene, PAHs, benzo(a)anthracene, oil. Data from U.S. Environmental Protection Agency (2011).

Habitat Restoration

Among the most ambitious approaches to restoring the ecological and economic viability of the Klamath Basin is the proposal currently being considered to remove four dams along the Klamath River in order to allow for fish passage to spawning streams, improve water quality in the lakes of the Upper Basin, and restore flow and temperature of the river to regimes that more closely resemble their historical patterns. The benefits of such a large-scale restoration project are clear. However, the agencies involved are currently evaluating the potential unintended negative impacts of these proposed actions. One such consequence is the potential redistribution of contaminants in the sediments that are currently trapped behind the dams. It is well beyond the scope of this effort to evaluate that risk, but a multi-agency assessment to document the potential for contaminant redistribution is currently nearing completion (CDM, 2011).

Other important restoration efforts include the restoration of freshwater wetlands in the Upper Basin. Since the 1980s more than 405 km^2 upstream of Upper Klamath Lake has been converted from irrigated agriculture to artificial wetlands (National Research Council, 2004). Additionally, the Nature Conservancy and other organizations are actively engaging in wetlands restoration in the Upper Basin to increase habitat area and improve habitat quality. These efforts are important contributions for a region that is stressed by water availability and water quality. However, it is important to anticipate other potential consequences associated with these efforts. As discussed above, wetland management and water cycling have a strong influence on MeHg production and bioaccumulation. Thus future restoration efforts should solicit scientific guidance and monitoring expertise to implement restoration efforts while making efforts to reduce their effects on MeHg production.

Data Gaps and Targeted Research Approaches

As we have highlighted throughout this document, the Klamath Basin potentially faces numerous contaminant threats associated with the range of land uses, geology, and hydrology in the region. The goal of the preceding pages was to document the available information on those threats to summarize what is currently known. Perhaps more important is summarizing the critical unknowns in the Basin related to contaminant cycling, and develop a strategy for filling those knowledge gaps. Importantly, our summary and review has highlighted that there was a relative abundance of past information on ecological exposure to various contaminant compounds in the Basin, but current information is lacking. The well-documented data on pesticide use and mining activities suggest that contaminant distribution through the Basin could be widespread, but there is little in the way of modern, robust dataset that support or contend with that hypothesis. Thus, because there is insufficient information on current distribution of contaminants of concern in environmental matrices in the Basin, the data gaps are large. A broad outline of these critical gaps is shown below, as well as some initial suggestions of targeted research and monitoring that would go a long way in substantially improving our understanding of contaminant impacts to the region.

1. ***Contaminant Distribution across the Basin:*** Fundamental to determining risk or impacts of contaminants on the Basin's diverse ecological resources is first evaluating the breadth and magnitude of key contaminants in appropriate matrices across the Basin. This basic task has not occurred on a large scale since the drainwater evaluations of the late 1980s and early 1990s, which were focused almost solely on the lease lands. Updated sampling and analytical techniques have substantially improved the accuracy and precision of such approaches, making this an even more informative action.

   An important consideration in monitoring pesticide distribution and potential exposure is the recognition that regular temporal sampling is critical to appropriately capturing potential exposure pulses. Additionally, passive sampling techniques such as the use of semi-permeable membrane devices (SPMDs) provide an integrated assessment of contaminants in a water body over defined time periods (Springman and others, 2009; Polidoro and others, 2009), allowing for a broader picture of pesticide movement through the wetlands of the Basin. These passive techniques also can be used to better assess the diverse mixtures of compounds that occur in the environment.

   Evaluating Hg distribution in the region may be somewhat more complicated to implement. As stated previously, Hg production is tied to specific biogeochemical parameters that are common in wetlands. However, different types of wetlands and different water management regimes will be important contributors to those processes. Thus, the distribution of Hg contamination in the basin may vary spatially with changes in water management and habitat types. A systematic biosentinel monitoring approach is key to understanding this variability, and efforts towards developing robust biosentinels for mercury bioaccumulation would prove informative over time (Mason and others, 2005). For other contaminants, such as chromium, lead, and arsenic, integrated monitoring of water and resident macroinvertebrates can be used to identify areas of particular concern, as well as guide future studies on potential impacts of those compounds.

Finally, it is important to note that a robust evaluation approach would ensure that biotic matrices span a range of taxonomic groups that utilize the suite of habitats available within the basin. Additionally, biological monitoring should not only focus on concentrations of contaminants within organisms, but also biomarkers of exposure such as acetylcholinesterase inhibition and oxidative stress.

2. ***Contaminant Source Attribution:*** In order to properly address minimizing risk of contaminant concerns identified through monitoring, it will be important to identify key sources of various compounds. In this context, we define sources not only as the physical location or operation for releasing chemicals into the environment, but also those habitats that facilitate conversion of contaminants into more bioavailable and toxic forms, such as MeHg or arsenite.

   Source attribution for pesticides may be particularly difficult given the abundance of uses across the basin and difficulty in determining exactly when and where releases occur. However, this is particularly important for compounds that are not approved for use on refuge lands, yet are detected in abiotic or biotic matrices within the refuge boundaries. Those cases suggest that either the pesticide is migrating from off-refuge, or there is illegal use by farmers on the lease lands. Because the lease lands are public property, managed by Federal agencies, there are unique opportunities to conduct applied research to quantify source attribution that would otherwise be unavailable in a working agricultural setting. Specifically, research with tracer compounds and isotopically labeled pesticides applied within the lease land boundaries can facilitate a better understanding of the proportion of different compounds that migrate from application sites to sensitive aquatic habitats. In addition to distribution via runoff and dissolution, aerial distribution via overspray and dust should be appropriately quantified. The current Pesticide Use Program incorporates atmospheric distribution in their evaluation of use restrictions, but it is important to validate the assumptions and models to characterize that risk with robust research methodology. Moreover, mobilization of pesticides bound to soil dust particles can be an important transport method (Lee and others, 2011) that could be evaluated in the basin.

Source attribution for MeHg in the basin is likely associated as much with habitat management as with actual sources of inorganic Hg. Thus, understanding which habitat characteristics in the basin are associated with elevated mercury concentrations will facilitate subsequent management to minimize Hg risk. Importantly, patterns of flooding and drying in wetlands have been shown to be strong drivers of mercury dynamics in other systems, thus we recommend evaluating those practices in the basin with respect to Hg cycling. In order to quantify the relationship between habitat properties, habitat management, and Hg risk, we suggest implementing replicated, habitat-scale research in which land managers and scientists work collaboratively to test the effects of these variables on MeHg production, bioaccumulation, and risk to ecological communities.

In the Lower Basin, there is limited availability of information on metals or other contaminants within the watershed. The abundant mines in the area do raise the possibility of contamination elsewhere, but with no supporting data, it would be spurious to propose efforts at source attribution. The limited sediment data from the Klamath estuary suggest that some metals, such as chromium and nickel, may be mobilized somewhere within the watershed, but further monitoring to confirm those results are needed first.

3. ***Contaminant Effects to Natural Resources:*** Effects of contaminants on the ecological function of the Klamath Basin may manifest in several ways. Direct mortality events due to elevated exposure to a compound are relatively rare, and somewhat unlikely unless there is a spill, severe acid mine drainage, or wildlife occupying agricultural areas during spray events. More probable are effects such as subtle impacts to metabolic function, behavior, hormone regulation, or immune function, all of which likely differ in sensitivity and impacts on fitness depending on an organism's life stage. Effects also may be indirect in the sense that a specific compound, or mixture of compounds, can influence the abundance or distribution of lower trophic level food resources. These are critical manifestations of exposure that could be studied in depth to better understand the full extent of contaminant impacts in the Klamath Basin. Implementing a robust hybrid field, laboratory, and modeling research program could be used to evaluate these interactions. Important unknowns to address include: the influence of pesticide exposure on diseases susceptibility in wild fish, evaluating the toxicity of complex mixtures of contaminants as opposed to single-compound assessments, and quantifying the relationship between contaminant-induced sublethal stress induction and susceptibility to mortality or reproductive impairment associated with other stressors.

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