Persistent Organic Pollutants (POPs) in Alaska:

What Does Science Tell Us?

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The full report and map are available at our Web site, www.circumpolar.org, thanks to Lars Kullerud, at United Nations Environment Program's GRID-Arendal in Norway, and to the artistry of Kristen Kemerling of Anchorage, Alaska, and Robin Hastey and Iva and Howard of New York.

The map, designed by Encompass Data and Mapping, was created from information in this report, and is based on the summary of data provided in Tables 1, 6, 7, 8, and 9. The numbered symbols included on the map and in the Tables enable the use of a cross-reference system posted on the back of the map.

For further information on contaminants in Alaska, please go to Alaska Community Action on Toxics' Web site at ***www.akaction.net***

Table of Contents

List of Tables

List of Figures

List of Boxes

Executive Summary

For most people in the U.S., few places seem more remote than Alaska, conjuring up images of large expanses of pristine, isolated wilderness. It is unlikely, however, that when most people in the U.S. think about Alaska, they imagine a huge sink for toxic chemicals. These chemicals, though not widely-used in the circumpolar regions, are slowly and inexorably building up there in the fat and tissues of creatures up to the highest levels of the food chain—including men, women, and nursing infants.

Much of the evidence for the accumulation of persistent organic pollutants (POPs) in the Arctic has come from countries other than the U.S. While a substantial body of information has been developed regarding the mechanisms and impacts of pollution in the Canadian Arctic and in Europe, a similar depth of data has not existed about the U.S. Arctic. The purpose of this report is to provide a brief synthesis of what is known about POPs in Alaska. The focus is on the food web which is the basis for the subsistence diet of many Native Alaskan communities, and the human health impacts of the contamination of that web. This includes an overview of the scope of current and ongoing research on contaminants in Alaska and, based on that, the identification of gaps in knowledge about POPs contamination in Alaska.

It is critical to acknowledge that traditional knowledge is key to understanding environmental changes in Alaska. Observations based on traditional environmental knowledge have increasingly noted diseases and abnormalities in species of fish and wildlife relied upon for food by Native peoples. On-line reports of discussions in Native villages in different areas of Alaska are used in this report to supplement and enhance mainstream data sources, which cannot fully encompass the scope and impact of contamination in tables and statistics alone. Published reports identifying and describing the use and significance of traditional foods are also critical in helping determine pathways of exposure and the magnitude of effects of persistent toxic contaminants.

An Overview of POPs

Persistent organic pollutants are a group of chemicals which are defined by certain shared key characteristics. They are man-made organic compounds and highly toxic. They persist in the environment, and bioaccumulate in living organisms, often preferentially in the lipid, or fatty, tissues. They are able to travel long distances around the globe, due in part to their tendency to degrade very slowly, and in part to their ability to evaporate and recondense (called volatilization and revolatilization, or global distillation)—sometimes in repeated cycles—as they travel north. They migrate to northern climates because of strong south-to-north air flows, which transport contaminants from lower latitudes. Most POPs are industrial chemicals or pesticides that were invented for specific uses, but some, such as the dioxins and furans, are by-products of industrial and incineration activities in which chlorinated chemicals are significant constituents.

Twelve POPs have been identified as targets for early global action in the POPs Treaty negotiations currently underway under the aegis of the United Nations Environment Programme (UNEP): aldrin, dieldrin, endrin, chlordane, DDT, heptachlor, mirex, toxaphene, hexachlorobenzene (HCB), polychlorinated biphenyls (PCBs), polychlorinated dibenzodioxins (dioxin), and polychlorinated furans (furans). Also included in this report is hexachlorocyclohexane (HCH), whose gamma (γ) isomer is familiar to many people as the pesticide lindane used for head lice. HCH, while not on the current UNEP POPs list, is widely considered a significant Arctic contaminant.

Why Are POPs in Alaska of Concern?

- Animals at the top of the food chain, high in the food web (e.g., trophic level), are the most exposed to many contaminants. Humans are at the top of the food chain.

- Contaminants in the blubber and tissues of several Arctic wildlife species, such as polar bears, seals, Arctic fox, and beluga whales, have been found in levels equal to or higher than those in experimental lab animals. Marine mammals are a critical part of the subsistence diet in many northern communities. Contaminants have also been found in fish, which constitute 60% of the traditional foods relied upon by Alaska Natives and other Alaskans for subsistence.

- It is unknown whether or not levels of POPs will increase or decrease in the environment in the future, but increases of some chemicals are likely.

- Both infants and adults in initial human epidemiological studies in Alaska have shown concentrations of some POPs contaminants in their blood. Infants from the Yukon-Kuskokwim Delta have the highest levels of DDT metabolites in their blood of any infants in the circumpolar region.

Issues of Arctic contamination are of particular concern to Alaska Natives and other indigenous Arctic peoples for two important reasons. First is a widespread belief that existing, and especially recent, information concerning environmental contaminants has not been widely shared, leading to apprehension among Alaska Natives. Second is the reality that this issue is not merely one of scientific curiosity but is, in fact, of crucial importance because of the safety of traditional foods. These foods are not only a significant part of the diet of many Alaska Natives and a source of important nutrition, but are also pivotal to the cultural and spiritual life of the people.

Why this report?

The intent, therefore, of this report is to bring together in one place a synthesis and review of different repositories of information about contaminants in Alaska to increase the overall understanding of the current state of knowledge. In addition, there is a critical need to develop a more comprehensive and accurate assessment of the impacts of POPs contamination on public health. A solid foundation of data is imperative to inform the public about the magnificent resource represented by the U.S. Arctic and the dangers to it from POPs contamination. A solid foundation of data is also imperative if policy makers are going to make the best decisions and allocate the resources required to accomplish the joint goals of public health and environmental protection.

Everything begins with the food web

In reviewing what is known about POPs in Alaska, the effort has been to build a picture of the food web upon which Alaska Natives rely for their subsistence diet, often referred to as "traditional foods". Information in this report is therefore divided into three main areas, which mirror the path of the bioaccumulation of contaminants up the food chain: contaminants in environmental media (air, water, sediments, soil), contaminants in animals, also called biota or wildlife, (fish, birds, invertebrates, terrestrial and marine mammals), and contaminants in humans. This report also includes tables showing the results of several studies which either included Alaska-specific data or were investigations exclusively devoted to Alaska.

Conclusions

This report demonstrates that there are virtually no areas of research in the Alaskan arctic in which there are no gaps. In a sense, the gaps define the landscape. Fish represent almost 60% of the subsistence diet of most Alaska Natives, particularly salmon, yet there are virtually no studies that have measured the contaminant levels in salmon in the areas where they are most frequently harvested. Levels of POPs contaminants have been found in other fish and shellfish, however. Terrestrial animals contribute significantly to the diets of many Alaska Natives living in the interior, yet there are no studies which have looked in depth at the degree and scope of contamination in these animals. Bald eagles and peregrine falcons have been studied, however, and both have shown effects from pesticide levels in the hatchability of eggs. Finally, although studies of marine mammals including polar bears, whales, seals, and sea lions have been done, all of which have showed contaminants in the blubber of these animals, many questions remain unanswered with regard to trends and effects.

The most significant gap from a public health perspective is the lack of information on to what extent the Alaska Native population has been significantly exposed to POPs and whether health effects have been seen as a result. Three small studies with humans are cited in this report; one important source of on-going research is a project measuring the levels of contaminants in the blood in the umbilical cords of women giving birth in rural Alaska.

Important gaps about environmental contamination also exist. There is a lack of information about the behavior and fate of POPs and other contaminants in the western Arctic ecosystem, extending from Alaska to Russia. There is much to learn about to how to measure these contaminants, information about long-range trends and inputs into the Arctic, and long-range sources of dioxins and furans.

One of the most significant barriers to the development of a coherent body of knowledge regarding the U.S. Arctic has been the lack of a well-organized, centrally coordinated effort to collect existing information, facilitate the development and direction of needed research, and leverage funding.

Recommendations and Priorities

1. **The creation of a strong national Arctic contaminants research and monitoring program in the U.S.** Defining key species for monitoring would be a useful first step in establishing such a program. This would likely be based on potential for bioaccumulation, frequency of use as a food source, and ecological importance. It is also crucial that effective communication about contaminants be provided to citizens and policy-makers in a long-term and comprehensive effort to protect the public's health. This initiative must include funding and resources to assure continuity of projects and excellence in achievement.
2. **Conduct a comprehensive survey and documentation of the main contaminants found in Alaska and identification of their sources.**
3. **Investigate long-term and temporal trends in levels of POPs contaminants**, including loading and interactions between various environmental compartments.
4. **Establish a comprehensive health effects project to evaluate and monitor human health in Alaska populations highly exposed to POPs contaminants.** What are the health effects of POPs contaminants on humans who are most at risk? What are the reproductive, endocrine, immune, developmental and other impacts on these populations? Is there a relationship in humans between body burden levels of POPs and the incidence of diseases?

How do environmental exposures to air, water, snow, and ice increase body burdens of POPs contaminants in humans?

5. **Develop detailed information about food consumption patterns and contaminant intake levels by Alaskans who rely upon traditional and wild foods for subsistence.** Where do the greatest exposures come from and how can they be decreased?
6. **Investigate contaminant exposure patterns and pathways of exposure in humans and wildlife in Alaska.** What are the health effects of POPs contaminants on the animal species most at risk? What are the reproductive, endocrine, immune, developmental and other impacts on these populations? How do environmental exposures to air, water, snow, and ice increase body burdens of POPs contaminants in different species, to what extent, and through what mechanisms?
7. **Reduce and eliminate exposure to persistent chemicals through rigorous, preventive measures at the international, national and local levels.** Such as achieving and ratifying a global, legally binding POPs Treaty; ratifying the Aarhus (POPs) Protocol to the ECE Convention on Long Range Transboundary Air Pollution; and creating a national northern contaminants program, that educates and involves citizens at the state and local level.

These steps should be grounded upon the implementation of the two following basic principles:

The involvement and integration of Alaska Native people in the design and implementation of a comprehensive contaminants research program. This is critical if the full range of environmental, cultural, and public health effects of POPs contamination are to be understood and meaningfully addressed. The observations and theories of indigenous peoples provide a unique and invaluable perspective in the process of hypothesis generation, analysis of conditions, and interpretation of results.

The application of the precautionary principle as the framework for analyzing the outcomes of research initiatives and determining the direction of policy decisions to be implemented. The precautionary principle holds that where there is scientific evidence an activity threatens wildlife, the environment or human health, protective measures should be taken even in the absence of scientific certainty. This shifts the burden of proof and requires a show of no harm as a prerequisite for the production or continued use of any chemical which has the potential for harmful health or environmental impacts.

We do not yet know whether people living in Alaska are being exposed to enough of these chemicals to cause harmful health effects. Greater attention and dedication of resources to the sources and implications of such persistent pollutants could result in a greater ability of Alaska and the U.S. to protect its interests and peoples.

From a spatial viewpoint, the more remote the receptor from the source of contamination, the more gradual the increase in concentration, and the more gradual the decline in concentration once the source is eliminated.[1]

Introduction

For most people in the U.S., few places seem more remote than Alaska, conjuring up images of large expanses of pristine, isolated wilderness. It is unlikely, however, that when most people in the U.S. think about Alaska, they imagine a huge sink for toxic chemicals. These chemicals, though not widely used in the Arctic setting, are slowly and inexorably building up there in the fat and tissues of creatures up to the highest levels of the food chain—including men, women, and nursing infants.

Much of the evidence for the accumulation of persistent organic pollutants (POPs) in the Arctic[a] has come from countries other than the U.S., beginning with a report in 1970 documenting detectable levels of polychlorinated biphenyls (PCBs) and the pesticides DDT and dieldrin in the blubber of ringed seals on Baffin Island in the Canadian Arctic.[2] Since that time, projects such as the Northern Contaminants Program in Canada and the Arctic Monitoring and Assessment Programme (AMAP), an international working group, have been centers for initiating and collating data on the status of POPs contamination in the Arctic environment. While a substantial body of information has been developed regarding the mechanisms and impacts of pollution in the Canadian Arctic and in Europe, a similar depth of data has not existed about the U.S. Arctic. As a result, the first comprehensive report assessing the state of knowledge about the Arctic, published by AMAP in 1997,[3] included significant gaps in information about POPs contamination in Alaska. Today, although many new research efforts have been undertaken since the publication of the 1997 AMAP report, a comprehensive analysis of the levels and impacts of contamination from POPs in Alaska remains elusive.

The purpose of this report is to provide a brief synthesis of what is known about POPs in Alaska (focusing on the food web, which is the basis for the subsistence diet of many northern communities, and on the human health impacts of the contamination of that web). This includes an initial assessment of the scope of current and ongoing research on contaminants in Alaska and, based on this, the identification of some of the remaining gaps in knowledge regarding POPs contamination in Alaska. It is important to note that this report does *not* address other types of environmental stressors that are certainly important, such as heavy metals, including mercury, cadmium, and selenium, as well as radionuclides, UV radiation, and changes in temperature.

Information in the report has been drawn from a variety of sources, including peer-reviewed literature, published and unpublished reports and abstracts, on-line information, and gray

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[a] Defining the boundaries of the Arctic in a way that includes all the areas of science that are relevant has been a difficult issue. Geographically it is defined as the area north of the Arctic Circle (66°32'N). In terms of climate it has been defined as the area north of the line or region which has a mean July temperature of 10°C. Another possible way to define the Arctic is by the treeline, that is, the border between southern forests and northern tundra. As a way of defining the Arctic in a way that is more useful for all the areas of science involved in environmental assessment, the Arctic Monitoring and Assessment Programme (AMAP) has created a guideline about the areas it has included in its work. This guideline sets the boundary generally between 60°N and the Arctic Circle, and with regard to Alaska, sets the Aleutian chain in the Bering Sea as the southern boundary.[4]

literature, including from the Alaska Contaminants and Native Food Database from the Institute of Social and Economic Research at the University of Alaska Anchorage, reports from Alaska Rural and Native Studies, the State of Alaska Section of Epidemiology, the Alaska Native Epidemiology Center, and other sources. The report relies primarily on reports from the last decade, but several earlier sources are also included to help establish temporal trends where possible and to show differences in methods and measurements.

It is critical to acknowledge, as well, that traditional knowledge is key to understanding environmental changes in Alaska. Observations based on traditional environmental knowledge have increasingly noted diseases and abnormalities in species of fish and wildlife relied upon for food by Native peoples. On-line reports of discussions in Native villages[5] in different areas of Alaska are used in this report to supplement and enhance mainstream data sources, which cannot fully encompass the scope and impact of contamination in tables and statistics alone. Published reports identifying and describing the use and significance of traditional foods are also critical in helping determine pathways of exposure and the magnitude of effects of persistent toxic contaminants.[6]

An Overview of POPs

Persistent organic pollutants are a group of chemicals defined by certain shared key characteristics. They are man-made organic compounds and highly toxic. They persist in the environment, and they bioaccumulate in living organisms, often preferentially in the lipid, or fatty, tissues. They are able to travel long distances around the globe, due in part to their tendency to degrade very slowly, and in part to their ability to evaporate and recondense (called volatilization and revolatilization, or global distillation)—sometimes in repeated cycles—as they travel north. They migrate to northern climates because of strong south-to-north air flows, which transport contaminants from lower latitudes.[4] Most POPs are industrial chemicals or pesticides that were invented for specific uses, but some, such as the dioxins and furans, are by-products of industrial and incineration activities in which chlorinated chemicals are significant constituents.

Twelve POPs—all containing chlorine—have been identified as targets for early global action in the POPs Treaty negotiations currently underway under the aegis of the United Nations Environment Programme (UNEP): aldrin, dieldrin, endrin, chlordane, DDT, heptachlor, mirex, toxaphene, hexachlorobenzene (HCB), polychlorinated biphenyls (PCBs), polychlorinated dibenzodioxins (dioxin), and polychlorinated furans (furans). In addition to this list, however, are other chemicals and toxic metals that have also been detected in the environment as well as in the fat and organs of fish and animals in the Arctic. Like POPs, they have also been found in the blood and fat of Alaskan and other Arctic indigenous peoples and their infants. These include mercury, arsenic, cadmium, selenium, and other metals; tributyltin (TBT), used in aquatic settings such as boat hulls, aquaculture pens, and moorings; and hexachlorocyclohexane (HCH), whose gamma (γ) isomer is known to many people as the pesticide lindane, used for head lice. HCH, while not on the current UNEP POPs list, is widely considered a significant Arctic contaminant and will be included in this discussion. Although heavy metals have raised concern, and in some cases are documented in greater detail than some of the organochlorine contaminants, they will not be addressed in this report.

A Thumbnail Sketch of POPs in the Arctic[a]

DDT (dichlorodiphenyltrichloroethane)**.** In the environment, DDT is often identified as one of the break-down products of its two metabolites, DDE (dichlorodiphenyldichloroethylene) and DDD (dichlorodiphenyldichloroethane). Although DDT has long been banned in the U.S., it is still used in many parts of the world for malaria control. In humans, exposure to DDT is also frequently recognized by the presence of its metabolites, or break-down products, such as *p,p'*-DDT, *o,p'*-DDT, *p,p'*-DDD, *o,p'*-DDD, and *p,p'*-DDE. A notation such as "∑DDTs" or "total DDTs," if not explicitly defined in a table or chart, usually refers to the sum (∑) of all the metabolites found in a sample.

DDT has been found in in the air, snow, ice, and soil in the Arctic and in virtually all levels of the Arctic food chain. It has also been found (as DDE) in the blood of infants in the Yukon-Kuskokwin Delta in Alaska in levels which are the highest known for infants in the Arctic.

Health effects in animals include reproductive and developmental failure and possible immune system effects. It causes egg-shell thinning in birds, liver damage in dogs and rats, in whom it has also been linked to decreased thyroid function, impairments in neurological development, and tremors.

Aldrin, Dieldrin, and Endrin. These closely-related chemicals are used as insecticides and rodenticides. Dieldrin is 40 to 50 times more toxic than DDT, and endrin is the most toxic of the three; its metabolites are more toxic than endrin itself.

It has been detected in the Canadian Arctic and has been found in a number of marine organisms.

Health effects include neurological and neurobehavorial problems, kidney damage in rats; aldrin and dieldrin are classified by the U.S. EPA as probable human carcinogens.

Chlordane is an insecticide that is extremely persistent. Used on crops such as citrus and corn, and home lawns and gardens, it has been known to remain in soil for over 20 years.

Chlordane and its metabolites, or what are also called "chlordane-related compounds," such as oxychlordane, *cis*-nonachlor, and *trans*-nonachlor, have been found in the Canadian Arctic in arctic cod, polar bears, and ringed seals.

Health effects include damage to the liver and central nervous system in animals, and neurological effects in humans.

Heptachlor is an insecticide used on fire ants as well as on crops and seed grain, and is also a termiticide. Stored for long periods in fatty tissue, if it is remobilized (through, for example, weight loss) in the body it is capable of producing toxic symptoms long after exposure has ended. Heptaclor breaks down the toxic metabolite heptachlor epoxide, which is carcinogenic.

Heptachlor epoxide has been found in Alaska in the blubber of beluga whales in the Cook Inlet, Northern fur seals in the Aleutian Islands, and ringed seals in the Alaskan Arctic.

Health effects include hyperexcitation of the human central nevous system and liver damage, as well as increase in deaths from cerebrovascular disease. It is classified as a probable carcinogen by U.S. EPA.

HCB (hexachlorobenzene) was used as a fungicide in the U.S. until 1965. It has also been used to make fireworks, ammunition, and synthetic rubber and is formed as a by-product of the production of some chemicals, in some industrial processes, and in the incineration of municipal waste.

HCB has been found in many remote areas, including in the Arctic in snow, seawater, vegetation such as lichen, biota such as caribou, and the air.

Health effects: HCB is a known animal carcinogen. In humans it causes liver toxicity, thyroid damage, and immune suppression.

HCH (hexachlorocyclohexane) is an insecticide that includes the isomer γ-hexachlorocyclohexane, also known as lindane, a widely-used remedy for head lice. (γ is the Greek letter gamma.)

It travels on air currents, is taken up by fish and other marine mammals, and has been found in the organs and blubber of Arctic wildlife.

Health effects include anemia and bone marrow changes, and it is a possible carcinogen.

[a]The information in this section taken from the Canadian Northern Contaminants Program,[2] AMAP,[4] the Alaska Native Epidemiology Center,[12] and the monograph *Persistent Organic Pollutants and Human Health*, by Orris P, Chary LK, Perry K, and Asbury J, published by the World Federation of Public Health Associations' Persistent Organic Pollutants Project, May, 2000.

A Thumbnail Sketch of POPs in the Arctic[a] (Continued)

Mirex is an insecticide that has been used heavily in South America and South Africa. It is highly persistent and, in the presence of sunlight, breaks down into photomirex, which is an even more potent toxin.

It has been found in the Canadian Arctic, where levels in the milk of Inuit from Nunavuk are 10 times higher than those of residents in southern Canada.

Health effects include immune suppression and reproductive effects in rats.

Toxaphene is a generic name for a mixture of chemicals used primarily as an insecticide and acaricide. It was used heavily in the U.S. for maggot control and in cotton fields in the 1980's. The production and use of toxaphene is now banned in the U.S. but it remains in the environment.

According to AMAP, it may be one of the most abundant pesticides in the Arctic, but because it is difficult to measure, it is not well-characterized with regard to exposure and risk. It has been found in high levels in beluga whales off the coast of Alaska, and in extremely high levels in Arctic indigenous women.

Health effects. Chronic exposure in animals has caused disruptive and often toxic effects on the liver, kidney, immune, and neurological systems. It has also caused behavioral and developmental abnormalities in animals. It is not well-studied in humans.

PCBs (polychlorinated biphenyls) are chlorinated chemicals noted for their stability and low volatility, which made them very well-suited to their use as lubricants and coolants in electrical capacitors and transformers, as well as in a variety of other industrial uses, including carbonless copy paper. The term PCBs refers to a group of 209 separate isomers, or *congeners*, each of which is unique with regard to the number and position of chlorine atom substitutions. The placement of the chlorines also affects the persistence of the congener, and the congeners differ greatly in terms of half-lives and elimination rates. Notations using the Greek symbol "∑" sigma, which means "sum," or the letter "s" before PCBs (i.e., ∑PCBs or s-PCBs) usually mean the level given is the sum of all the congeners that were detectable.

Although PCBs have been banned virtually worldwide, it is estimated that close to two-thirds of all PCBs ever produced are still available to the environment, either because they are still being used in electrical equipment, or are buried in landfills or aquatic sediments.

Virtually all people in the U.S. and Canada have PCB in their blood. In Canada, PCB levels in the breast milk of Inuit women are significantly higher than levels in non-aboriginal women living in Quebec. PCBs are in the blubber of many marine mammals in Alaskan waters, including killer whales in which surprisingly high levels were found.

Health effects include reproductive and developmental abnormalities, immune system impairment, liver damage, endothelial cell dysfunction, and endocrine and thyroid disruption. PCBs caused wasting in laboratory animals. Some PCB congeners—particularly those that are called "dioxin-like"—are considered carcinogenic. PCBs may also be related to diabetes and heart disease.

Dioxins and Furans (polychlorinated dibenzo-*para*-dioxins and polychlorinated dibenzofurans) are two structurally similar families of compounds that include mutiple congeners, at least twenty of which are considered extremely toxic. The two have very similar health effects, and will be referred to collectively here as dioxins. Other than for research purposes, these chemicals are not commercially produced, but are by-products of incineration/combustion and industrial processes. 2,3,7,8-TCDD (tetrachlorodibenzo-*p*-dioxin) is one of the most potent and hazardous of the POPs. Dioxins are known to be toxic at extremely low levels.

Health effects: U.S. servicemen exposed to dioxin from Agent Orange in Vietnam have reported a wide variety of symptoms, including reproductive effects and neurological problems. In high level, or acute doses, dioxin may cause a skin disease called chloracne, and a liver disease called porphyria. The dioxins are similar to PCBs in their health effects, and are believed to cause some types of cancer, such as soft-tissue lymphomas.

[a] The information in this section taken from the Canadian Northern Contaminants Program,[2] AMAP,[4] the Alaska Native Epidemiology Center,[12] and the monograph *Persistent Organic Pollutants and Human Health*, by Orris P, Chary LK, Perry K, and Asbury J, published by the World Federation of Public Health Associations' Persistent Organic Pollutants Project, May, 2000.

Why Are POPs in Alaska of Concern?

What do we know about POPs?

Over the past thirty years a body of knowledge regarding contaminants in the Arctic has been developed, but much of that data has been relatively location-specific, and has been focused on the Canadian Arctic and Europe. Whether or not many of the critical findings are also applicable to the U.S. Arctic remains less clear. Some of the conclusions about the Arctic in general, however, are useful to review as a context within which to understand the current status of data regarding Alaska in particular.

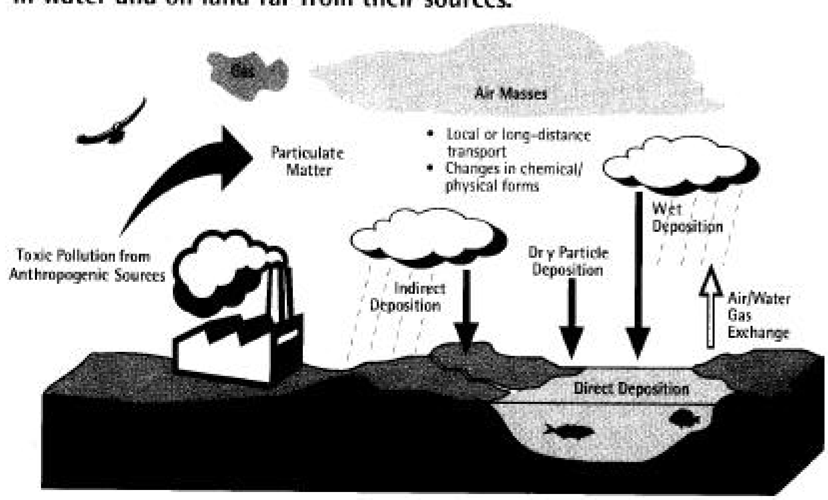
- Due to a constellation of different factors related to atmospheric patterns, the behavior of contaminants in the environment, temperature, and other factors unique to the Arctic setting, there is cause for concern regarding an increase in levels of contaminants in the Arctic ecosystem.[4]

- Long-range transport by air moves potentially destructive contaminants long distances away from their points of origin (see Figure 1). The predominant trend appears to be the transfer of chemicals from south to north, particularly over west Eurasia during winter months, across hemispheres and around the globe. The Arctic, because of its cold temperatures, which inhibit volatilization, ends up becoming a sink for many of these chemicals, which get trapped there. Pesticides and POPs have particular characteristics that seem to facilitate this process, such as their persistence in the environment.[4,7, 8]

- Water is a major storage and transport vehicle for POPs in the Arctic. Oceans play an integral role in the circulation and deposition patterns between air and water, and act as large sinks for deposited contaminants. Sea ice may ease the interaction between sediments and water in transferring POPs between the media. Arctic rivers not only carry contaminants into Arctic seas, but help distribute them throughout estuarine and riverine systems along the way in sediments, run-off, and freeze-melt cycles.[4,7,8]

Figure 1

POPs can be released into the environment, transported, and redeposited in water and on land far from their sources.



SOURCE: *Deposition of air pollutants to the Great Lakes (First Report to Congress).* EPA, 1994.

- Animals at the top of the food chain, high in the food web, are the most exposed to many contaminants. These include marine mammals such as whales, polar bears, walrus, and seals, which are key components of Native Alaskan subsistence diets, along with some important fish species and birds of prey.[5, 6, 9]

- Contaminants in the blubber and tissues of several Arctic wildlife species, such as polar bears, seals, Arctic fox, and beluga whales, have been found in levels equal to or higher than those in experimental lab animals. In the lab, these levels have been associated with effects on the reproductive, neurobehavioral, and immunosuppressive systems. Some field studies of wildlife have also found outcomes suggestive of effects found in experimental animals.[3,9]

- Terrestrial mammals such as caribou and moose do not seem to have contaminant levels as high as have been seen in marine mammals and other wildlife in the Arctic. One explanation for this may be that the terrestrial food chain is shorter and herbivores, favoring lichen and mosses, which tend to have lower contaminant levels, have less opportunity for biomagnification and accumulation of toxics.[10, 11]

Recognizing that an information gap existed between what is known about the behavior and effects of contaminants in the Arctic and what is known about contaminants in Alaska, in 1998 the Alaska Native Epidemiology Center (EpiCenter) sponsored the “Conference on Environmental Contaminants and Disease,” and subsequently published a report based on presentations from the conference called *Alaska Pollution Issues*.[12] Not surprisingly, the report noted that the issues of Arctic contamination were of particular concern to Alaska Natives and other indigenous Arctic peoples for two important reasons. First is a widespread belief that existing, and especially recent, information concerning environmental contaminants has not been widely shared, leading to apprehension among Alaska Natives.[4, 12] Second is the reality that this issue is not merely one of scientific curiosity but is, in fact, of crucial importance because of the safety of traditional foods. These foods not only are a significant part of the diet of many Alaska Natives and a source of important nutrition but also are pivotal to the cultural and spiritual life of the people.

Why this report?

The intent, therefore, of this report is to bring together in one place a synthesis and review of different repositories of information about contaminants in Alaska to increase the overall understanding of the current state of knowledge. This will have many uses. As the authors of the Alaska Contaminants and Native Foods Database have observed, for example, it is important for Native people to have adequate, accurate, and timely information so they can decide for themselves what to do about levels of contamination in Native foods.[13]

Also critical is the need to develop a more comprehensive and accurate assessment of the impacts of POPs contamination on public health, wildlife, and the environment in Alaska.

A solid foundation of data is imperative to inform the public about the magnificent resource represented by the U.S. Arctic and the dangers to it from POPs contamination. A solid foundation of data is imperative if policy makers are going to make the best decisions and allocate the resources required to accomplish the joint goals of public health and environmental protection. One component in this process was the production of the EpiCenter report, which was particularly useful in describing the types, sources, pathways, and effects of contaminants in the Arctic and in Alaska. AMAP documents provided another building block, but did not address the U.S. Arctic in the depth of detail required.

It is the objective of this report to build on the foundation provided by these earlier documents, and to continue with new impetus the drive to move the study and evaluation of the U.S. Arctic forward with increased depth and scope.

Everything begins with the food web

In reviewing what is known about POPs in Alaska, the effort has been to build a picture of the food web upon which Alaska Natives rely for their subsistence diet, often referred to as "traditional food." Information in this report is therefore divided into three main areas, which mirror the path of the bioaccumulation of contaminants up the food chain: contaminants in environmental media (air, water, sediments, soil); contaminants in animals, also called biota (wildlife, fish, birds, and terrestrial and marine mammals); and contaminants in humans. Frequently, what is known in each of these areas derives from investigations of other Arctic areas in the course of which some measurements were taken in Alaska for comparative values, or what has been determined in the context of global research. While a complete survey of all studies ever done was beyond the scope of this report, an effort was made to review and discuss the most representative range of what is available in each of the areas.

This report also includes tables showing the results of several studies that either included Alaska-specific data or were investigations exclusively devoted to Alaska. The map links the table and reported studies with their geographic locations. It is notable that there are few references to atmospheric studies or to investigations of contaminants in Alaskan waters, snow and ice, soils or sediments, or animals at the lowest levels of the food chain (also called the lowest *trophic* levels). The greatest amount of data references animals, primarily marine mammals, and there is just beginning to be a body of data regarding levels of POPs in humans living in Alaska who eat traditional foods. The absence of background and time trend data in so many areas represents a significant gap in the ability to get the full picture of POPS contamination in Alaska today, to establish trends, and to recognize patterns in the progress of this contamination over the past several decades. The intent of this report is to begin to draw the most important contours.

Looking at the Data

Contaminants in air, water, sediments, and other environmental media

Little data is available that exclusively addresses **air and water** contamination in Alaska outside of the context of the Arctic as a whole. If, as AMAP reported in 1997, there is a poor understanding of pathways of transport and deposition in the Arctic overall,[3, 4] the specific conditions related to POPs in the U.S. Arctic is even less well-understood. Documentation of the existence of air deposition of POPs and contamination of Alaskan seawaters has come more from studies of sediments, flora, and biota in the Arctic environment than from studies dedicated to measuring specific levels in the air and water, although Barrie et al reported the levels of toxaphene and other POPs in the atmosphere of the Canadian high Arctic in 1992,[14] and scattered reports of measurements of POPs in air, ice, snow, precipitation and Arctic soils can be found (see, for example, Patton et al,[15] Hargrave et al,[16] Paasivirta et al,[17] and Bright et al[18]).

Understanding Exposure to POPs: What Do the Numbers Mean?

The dose makes the poison.

—Paracelsus, the "father" of modern toxicology (1493-1541)

What Paracelsus never imagined back in the 16th century is that someday technology would be able to detect substances at levels so small they are hard to even imagine. Parts per million, parts per billion, μg/ng, what are these measurements and what do they mean? Technology today has developed very sensitive methods of detecting chemicals at extremely low levels in tissues and in the environment, which is important, because laboratory experiments on animals has shown that some chemicals, such as dioxin, for example, can be very potent at very low levels. **Parts per million (ppm)** is the same thing as μg/g, which reads as "micrograms per gram" ("μ" is the Greek letter "mu," used in scientific notation to mean micrograms and is sometimes written as 10^{-6}). **Parts per billion (ppb)** is the same thing as ng/g, which means nanograms per gram and is sometimes also written as 10^{-9}). A gram is 1/1,000 of a kilogram (kg). So a microgram/gram—or μg/g—is a *really* small number and a nanogram/gram, or ng/g, is even smaller.

ppm = micrograms per gram = mg/g = mg/kg = mg kg^{-1} = 10^{-6}

ppb = nanograms per gram = ng/g = mg/kg = mg kg^{-1} = 10^{-9}

Different studies often report contaminant levels in different measures—some in parts per million, some in parts per billion, some in parts per trillion. In order to compare the levels in studies where the measures are presented in different orders of magnitude, it is possible to convert parts per million to parts per billion by multiplying the values given by 1,000:

2.3 ppm × 1000 = 2300 ppb

All of these terms are measures of concentration—that is, the amount of one material in a larger amount of another material. They are expressed as concentrations rather than total amounts so that different situations can be compared, and so that scientists can measure the concentration in, say, the Bering Sea, by looking at a small sample.[1]

How much is one in a million?

Less than 1 drop of a chemical (1/4 of a milliliter) in a tubful (about 200 liters or 53 gallons) of water

How much is one in a billion?

about one drop of water in nine full water trucks[2]
about one pinch of salt in ten tons of potato chips[1]
about one drop (1/2 milliliter) of a chemical in a 130,000 gallon (500,000 liters) Olympic-sized pool

The levels of POPs in the Alaskan environment, with a few exceptions, such as some Superfund sites and former military sites, have been relatively low, especially compared to other parts of the world. The question is, will they stay that way, and for how long?

[1] See also: "How much is a part per million?" ECOTOXNET: Extension Toxicology Network Toxicology Information Briefs. A project of Cornell University, Oregon State University, the University of Idaho, the University of California at Davis, and Michigan State University. http://ace.orst.edu/info/extoxnet/tibs/partperm.htm. 1993.

Gregor[19] measured concentrations of selected polycyclic aromatic hydrocarbons (PAHs) in the atmosphere of Alert, Canada, and several sites in Alaska (Barrow, Narwhal Island, and Fairbanks) in the late 1970's. The highest levels were in Fairbanks, measured from November, 1976 to April, 1977. In 1996, Chernyek et al[20] published an article describing their findings of various pesticides in the **air, ice, fog, seawater, and surface microlayer** in the Bering and Chukchi Seas in Alaska. This was the first investigation to look at pesticides in these media, and some of the tables from the study are reproduced in Figure 2. More prevalent are studies that have been undertaken to evaluate the contamination of sediments in Alaskan **waters**, both salt and fresh. Wagrowski and Hites[21] used tree bark and soil samples to measure the deposition of dioxins and furans in regions north of the 60th parallel, and Bidleman et al[22] measured levels of POPs residues in air, snow, seawater, zooplankton, and benthic amphipods in the Canadian Arctic.

Gubala et al[23] compared the accumulation of anthropogenic pollutants in the **sediments** of Schrader Lake, an Arctic lake, and Wonder Lake, a subarctic lake, in the winters of 1992 and 1991 respectively. Some of the findings from this study are listed in Table 1, "Contaminants in Sediments and Biota in Selected Alaskan Sites," but according to the authors, the most important observation regarding organochlorine compounds in the sediments of Schrader and Wonder Lakes is that they are present at all. Since these chemicals have no natural sources and were presumably not applied directly into the lakes or watersheds, their presence alone provides evidence to support the hypothesis of transport of these constituents to the lakes through the atmosphere from far-away sources.

Four U.S. Arctic Lakes—Elusive, Schrader, Feniak, and Desperation—in the foothills of the Brooks Range, Alaska, had one sediment core sample each taken in winter over the years of 1991-1993 in a study of chlorinated pesticides and PCBs in sediments and fish in Alaskan fresh waters.[24] The surface sediment from all the lakes contained detectable levels of HCB, *p,p'*-DDE, and PCBs. The results are presented in Table 1.

Figure 2

Evidence of Currently-Used Pesticides in Fog Condensates and Atmospheric Samples in the Bering and Chukchi Seas[a]

TABLE 4

Concentrations (ng l^{-1}) of currently-used pesticides in fog condensates.

Pesticide	F-1 Bristol Bay	F-2 GEOSECS Meteorol. Station	F-3 Southern Bering	F-4 Gulf of Anadyr	F-5 Diomede Islands	F-6 Wrangel Island	F-7 Siberian Coast Chukchi
Chorpyrifos	4.0	<4.0*	<0.9	<2.0	1	5	1
Chlorothalonil	17	17	8	11	13	4	4
Endosulphan I	(3)†	<10	<2.2	<5.0	<1.5	<1.5	<0.5
Metolachlor	51	24	<2.7	<6.0	147	<1.8	2
Terbufos	<3.1	<20	<4.5	<10	<3.0	<3.0	12
Trifluralin	(6)	(25)	(2)	<1.0	<0.3	<0.3	<0.1

*This value is based on the detection limit which is both compound and volume dependent.
†Parentheses indicate some uncertainty in these data as they were detected at less than twice the detection limits.

TABLE 5

Concentrations (pg m^{-3}) of currently-used pesticides in atmospheric samples.

	A-1 Alaska Peninsula	A-2 Central Bering	A-3 Gulf of Anadyr	A-4 Siberian Coastline Chukchi	A-5 Eastern Bering
Atrazine	1.1	<0.29*	<0.31	<0.30	<0.21
Endosulphan II	<0.27	1.0	0.70	(0.5)†	(0.5)

*This value is based on the detection limit which is both compound and volume dependent.
†Parenthesis indicate some uncertainty to these data as they were detected at less than twice the detection limits.

[a] Tables reproduced from Chernyek et al[20]

Table 1
Contaminants in Sediments and Biota in Selected Alaskan Sites

Location	Contaminant	Medium	*N*[a]	Contaminant Level	Collection Date	Reference
				ng/g		
Wonder Lake 64	Total DDTs	Sediments		0.569	1991	Gubala et al[23]
	Total PCBs			30.706		
	Total HCHs			0.810		
	Total chlordanes			0.402		
	Mercury (Hg)			0.03 μg/g[b]		
Schrader Lake 65	Total DDTs	Sediments		0.051	1992	Gubala et al[23]
	Total PCBs			0.172		
	Total HCHs			0.193		
	Total chlordanes			0.035		
	Mercury (Hg)			No enrichment		
76 77 78				**ng/g dry wt. Mean±S.D.**		
Elusive, Schrader, Feniak, and Desperation Lakes 79	HCB	Sediments (top 2 cm)	4	0.17±0.07	1991-1993	Allen-Gil et al[24]
	Sum of PCBs		4	0.12±0.05		
	α-HCH		3	0.04±0.03		
	γ-HCH		4	0.05±0.03		
	γ-Chlordane		ND			
	Heptachlor epoxide		ND			
	Oxychlordane		1	0.01±0.00		
	γ- Chlordane		2	0.03±0.02		
	Sum of DDTs		4	0.15±0.09		
	Sum of *p,p'*-DDTs		ND			
				Range mean±S.D. ng/g dry weight		
Alaska, various sites	Total DDTs[c]	Sediments 70	8	0.17-4.67 1.32±1.47	1993	Valette-Silver et al[27]
		Mollusks	2	1.3-1.86 1.60±0.36		
		Flathead sole (livers)	11	17-247 109±85		
	Total PCBs	Sediments	10	1.63-59 21±17.5		
		Mollusks 68	2	37.5-48.9 42.3±9.4		
NS&T Alaska	Total PCBs	Flathead sole (livers)	11	127-2191 587±586		

[a] *N*=number of samples when known
[b] Estimated value
[c] Total DDTs=total DDTs and its metabolites

Location	Contaminant	Medium	*N*[a]	Contaminant Level	Collection Date	Reference
				Range mean±S.D. ng/g dry weight		
Alaska, various sites	Hexachlor	Sediments	9	0.02-0.73 0.32±0.23	1993	Valette-Silver et al[27]
		Mollusks	2	0.48-0.64 0.56±0.11		
		Flathead sole (livers)	10	1.33-42.6 13.6±12.7		
	Lindane	Sediments	7	0.13-1 0.54±0.36		
		Mollusks	2	1.71-2.39 2.05±0.48		
		Flathead sole (livers)	10	0-4.67 2.81±1.71		
	Mirex	Sediments	1	0.06		
		Mollusks	ND[b]			
		Flathead sole (livers)	10	1.20-3.33 2.02±0.81		
	Total chlordanes	Sediments	2	0.03-0.33 0.16	1993	
		Mollusks	2	1.00-1.94 1.47±0.67		
		Flathead sole (livers)	11	12.7-71.7 40.3±10		
	Total dieldrin	Sediments	ND			
		Mollusks	2	0.36-0.79 0.57±0.31		
		Flathead sole (livers)	10	1.67-15.33 7.65±5.24		
				Range Average±S.D. ng/g dry weight		
West Beaufort Sea	Total DDTs	Sediments (66)	10	0-0.78 0.39±0.3	1993	Valette-Silver et al[27]
		Biota	3	0[c]-1.87 0.74±1.00[d] 3.2[e]		
	Total PCBs	Sediments	10	0.54-2.51 1.04±0.6		
		Biota (67)	3	2.4[f] -31 12.2±8.6[g] 8.0[h]		
	Hexachlor	Sediments	ND			
		Biota	3	0.13[f] -12.99 2.79±3.8[g] 4.92[h]		
	Lindane	Sediments	6	0.6-0.26 0.16±0.8		

[a] *N*=number of samples when known
[b] ND=below detection limits

[c] Maximum-minimum marine invertebrates
[d] Average marine invertebrates
[e] Marine vertebrates

Location	Contaminant	Medium	*N*	Contaminant Level	Collection Date	Reference
				Range Average±S.D. ng/g dry weight		
West Beaufort Sea	Lindane	Biota	6	0.64[f] -3.31 0.17±0.8[g] 0.86[h]	1993	Valette-Silver et al[27]
	Mirex	Sediments	ND			
		Biota	1	0.46[f,,g] ND[h]		
				pg g^{-1} dry weight		
Gulf of Alaska 61	∑DDT	Sediments	1	170	1990	Iwata et al[28]
	p,p'-DDD			54		
	p,p'-DDE			110		
	p,p'-DDT			9.5		
	∑PCBs			2000		
	∑HCH			250		
	α-HCH			160		
	β-HCH			40		
	γ-HCH			48		
	∑Chlordane			55		
	HCB			79		
Bering Sea 62	∑DDT	Sediments	1	6.4		
	p,p'-DDD			1.6		
	p,p'-DDE			3.5		
	p,p'-DDT			1.3		
	∑PCBs			130		
	∑HCH			43		
	α-HCH			36		
	β-HCH			4.0		
	γ-HCH			3.3		
	∑Chlordane			11		
	HCB			61		
Chukchi Sea 63	∑DDT	Sediments	1	8.6		
	p,p'-DDD			3.5		
	p,p'-DDE			3.1		
	p,p'-DDT			2.0		
	∑PCBs			140		
	∑HCH			75		
	α-HCH			50		
	β-HCH			15		
	γ-HCH			10		
	∑Chlordane			13		
	HCB			35		

The National Status and Trends Program (NS&T) is a part of the U.S. National Oceanic and Atmospheric Administration (NOAA), which samples **sediments and bottom-dwelling species** at many fixed sites in U.S. coastal waters. In 1993, researchers from this program followed up on two earlier studies of the area[25, 26] and conducted a one-time survey of the marine sediments of the Beaufort Sea.[27] Sediment samples were analyzed for metals, organic compounds including PCBs, pesticides, and PAHs. Key findings for POPs are reproduced in Table 1. The study concluded that, although it was difficult to compare results for organochlorine chemicals in Arctic **biota** because different studies had analyzed different animal species, average concentrations of dieldrin and total chlordanes in the **invertebrates** in this study were slightly higher compared to previous Alaskan studies.

On the other hand, however, average concentrations of total DDTs and total PCBs were not only lower than the average obtained for the other Alaskan samples taken by the NS&T, but also for the entire U.S. Although the study concluded that this area appeared to have relatively low impacts from man-made pollutants, it emphasized an important caveat, e.g., the observations are few and such studies should be extended to other areas of the Beaufort Sea in order to get a good baseline of contamination levels in the U.S. Arctic. This baseline is critical for future efforts to assess the potential export to the American Arctic of contamination from other Arctic areas, in particular from the Russian Federation.[27]

In another important study, Iwata et al[28] looked at **surface sediments and cores**, and compared trends in organochlorine pollutant levels and rates at different locations in the Gulf of Alaska, the Chukchi Sea, and the Bering Sea. Results from the sediment and core samples are included in Table 1. Temporal trends for sediments in the Gulf of Alaska are shown in Table 2, which is reproduced from the Iwata report. This study also showed that the geographical distributions of POPs show different patterns related to their physical and chemical properties. This confirmed earlier conclusions about the long distance atmospheric transport of HCB[29]. It also showed that lower-chlorinated PCBs increased in sediments from colder waters, and that there were larger fluxes of the lower-chlorinated PCBs between the air and surface seawater in cold oceans, as discussed in earlier investigations.[30, 31, 32, 33]

All of these studies contribute to confirming the hypothesis of the tranfer of contaminants to the north through global transport. In doing so, they also indicate the potential for future contamination, particularly from those chemicals which are still being used, and are still available in the environment.

Contamination of the Alaskan food web

Contamination of the Alaskan **food web** is one of the most critical challenges stemming from the transport of POPs to the north. In order to understand the significance of this in more depth, some

Table 2
Temporal Trends of Organochlorine Accumulation Rates (pb m^2 yr^{-1}) into the Sediments from the Gulf of Alaska

Depth (cm)	Estimated year	HCHs	DDTs	CHLs	PCBs	HCB
0-1	1980-1990	6.1	3.3	0.6	17	2.4
1-2	1970-1980	4.3	4.7	1.1	17	2.8
2-3	1960-1970	0.7	2.1	0.8	9.0	0.9
3-4	1950-1960	0.3	1.0	0.5	4.7	0.5
4-5	1940-1950	<0.2	0.3	0.5	2.6	0.2
5-6	1930-1940	<0.2	0.3	<0.2	2.4	<0.2
6-7	1920-1930	<0.2	<0.2	<0.2	<0.2	<0.2

Reproduced from Iwata et al[28]

knowledge about the role of traditional foods in the diet is critical. Unlike the vast majority of the urban population of the state, many indigenous communities, particularly rural indigenous communities, rely on traditional foods for a significant portion of their caloric and nutrient intake.[6, 34] In 1987-1988, a survey of 351 Alaska Native adults in eleven villages revealed that their traditional subsistence diet provided almost half of key protein intake from fish, meat, and poultry. A later study of 64 Siberian Yupik adults reinforced these findings, with over 50% of their protein, iron, omega-3 fatty acids, and vitamin B_{12} coming from traditional foods.[34] Tables 3-6 show **the importance of traditional food** use in more detail; in particular, Table 5, reproduced from the Traditional Knowledge and Radionuclides Project,[35] gives an idea of the range of wildlife upon which the Native subsistence diet relies.

In addition to the central role traditional foods play in the nutritional well-being of Alaska Natives, there are many other benefits attached to the use of indigenous foods. Cultural and spiritual aspects of life are integrally related not only to the eating of traditional foods, but to the hunting, fishing, and sharing rituals that are a fundamental component of the use of these foods. This was articulated explicitly and clearly in a workshop on the "Uptake and Effects of Contaminants in Alaska Native Foods" conducted under the auspices of the Institute of Social and Economic Research at the University of Alaska Anchorage in 1997, during which the following observations were made:

- In Native Alaska communities, advising against Native food consumption is also to advise against hunting and fishing. *To the extent that aboriginal identity and the collective sense of well-being are based on subsistence as a social system and as an activity, as well as a dietary staple, loss of confidence in Native food undermines confidence in identity and society.*

- Sharing of Native foods is a common practice in Alaska. Harvesting, sharing, processing, and consuming Native foods is an opportunity to practice and teach humility and spirituality.

- The concept of "health" among Native people is holistic. Health is socially and culturally defined. It has spiritual dimensions. Alaska Natives have a strong traditional value of respect for the environment. They see degradation of the environment as a threat to health.

- If Alaska Natives were to stop eating Native foods, they would experience nutrition and protein deficiencies. *Native foods are as important to Native social well-being as they are to physical health*.[36]

[all emphases added]

Table 3
Pounds of Native Foods Harvested Per Capita by Number of Communities

Pounds of Native Foods Range: 52 lbs. – 2,157 lbs.	Number of Communities Total *N* = 165	Percent of Total Communities
<100	16	10%
100-499	105	64%
500-1,000	35	21%
>1,000	9	5%

Source of raw data: Alaska Department of Fish & Game Subsistence Division[35]

Table 4
Percentage of Foods from Traditional Sources

Food Type	Alaska Native Villages *N* = 12	Siberian Yupiks (in Alaska)
Meat, fish , poultry	48%	54%
Fruits (berries)	11%	9%
Vegetables (including seaweed)	<1%	16%
Fats and Oils	12%	28%

Source of Table: Traditional Foods in Alaska[34]

Table 5
Species Harvested in Excess of 20 Pounds Per Capita by at Least One Alaska Native Community

Terrestrial and Riverine Mammals	Fish and Shellfish		Marine Mammals
Beaver	Arctic char	Halibut	Bearded seal
Black bear	Blackfish	Herring/herring roe	Beluga whale
Brown bear	Broad whitefish	Humpback whitefish	Bowhead whale
Caribou	Burbot	Lake trout	Harbor seal
Deer	Char	Pacific tom cod	Ringed seal
Hare	Chinook salmon	Pike	Spotted seal
Moose	Chum salmon	Pink salmon	Steller sea lion
	Cisco	Rockfish	Walrus
	Clams	Round whitefish	
	Cod	Sheefish	
	Coho salmon	Shrimp	
	Dolly varden	Smelt	
	Dungeness crab	Sockeye salmon	
	Eulachon	Trout	
	(hooligan, candlefish)	Whitefish	

Source of data for table: Traditional Knowledge and Radionuclides Project: Progress Report[35]

Fish and shellfish

In the Alaska Native food basket, fish, including shellfish, is the most frequently eaten source of protein, accounting for close to 60% of the Native food harvest.[4,6,35] Salmon is the most common species of fish consumed, and several species of salmon are used, as can be seen in Table 5. Other common fish include burbot, whitefish, trout,[4] Arctic grayling, herring, pike, and cod.[4] The State of Alaska Epidemiology *Bulletin* called *Use of Traditional Foods in a Health Diet in Alaska: Risks in Perspective,*[6] reports that in the Nobmann study of Alaskan villages in 1992, the average daily intake of shellfish and fish for Alaska Natives was more than six times higher than the U.S. national average[a]: 109g (3.82 oz.) compared to 17g (less than one oz.).

In general, information on contaminants in fish, shellfish, and other aquatic organisms in Alaskan waters is extremely limited, particularly with regard to salmon.[6,36,37] A few studies have been published, however, on fish and shellfish in the Aleutian Islands.

Mussels in the Aleutian Islands were studied in 1994-1995 by Reese et al.[38] (See Table 6, "Levels of POPs in Alaskan Snails and Mussels.") Reese collected samples of 30-50 mussels each from 39 sites on 17 islands, including Adak and Amchitka, where Bacon[39] had earlier

[a] As reported in NHANES II, the National Health and Nutrition Examination Survey conducted by the National Center for Health Statistics, which is part of the Centers for Disease Control and Prevention of the U.S. Public Health Service.

Table 6
Levels of POPs in Alaskan Snails and Mussels

Species	Number	Contaminants	Contaminant Level	Location		Collection Date	Reference
			Median Mean±S.D. (ng/g wet weight)	(75) (74) Desperation Lake, Feniak Lake, Schrader Lake, and Elusive Lake (73) (72)			
Snails (*Lymnea* sp.)	6	HCB	0.10 0.15±0.08			1991-1993	Allen-Gil et al[24]
	5	Heptachlor	ND				
	6	*trans*-Nonachlor	0.10 0.12±0.04				
	7	Sum of PCBs	5.60 5.04±1.90				
			μg/kg dry weight	**Alaska**			
Blue Mussels (*Mytilus trossulus*)	1 sample (30-50 mussels)		Soapstone Cove (80)	Southeast Yakobi: Three Hill Island (81)	Inian Island (82)	1996	Reese[38]
		∑PCBs	51	33	39		
		∑DDTs	4.6	4.7	5.3		
		∑HCHs	3.3	3.7	4.4		
		∑Chlordane	3.2	2.9	2.0		
		HCB	0.25	0.42	0.40		
			Glacier Bay (83)	Willoughby: Bartlett Cove (84)		1996	
		∑PCBs	21	23			
		∑DDTs	2.4	3.8			
		∑HCHs	3.1	3.4			
		∑Chlordane	1.5	1.4			
		HCB	0.21	0.32			
				Aleutian Islands:			
			Attu: Abraham Bay (85)	Alaid: West End (86)	Shemya: F&W Site #19 (87)	1996	
		∑PCBs	12	32	14		
		∑DDTs	6.6	13	7.7		
		∑HCHs	7.0	5.5	4.1		
		∑Chlordane	3.5	3.9	3.2		
		HCB	1.1	0.85	0.60		
			Buldir Island (89)	Kiska: Reynard Cove (90)	Kiska: Harbor Pier (91)		
		∑PCBs	39	21	7.9		
		∑DDTs	26	14	8.8		
		∑HCHs	6.5	6.9	9.3		
		∑Chlordane	18	4.2	5.2		
		HCB	1.2	1.1	0.80		
			Amchitka: Kirilof Point (92)	Amchitka: Chitka Point (93)	Ogliuga Island (94)	1996	
		∑PCBs	83	16	12		
		∑DDTs	15	18	7.8		
		∑HCHs	14	6.1	5.3		
		∑Chlordane	11	8.6	5.1		
		HCB	1.3	1.0	1.6		

Species	Number	Contaminants	Contaminant Level	Location		Collection Date	Reference
			Median Mean±S.D. (ng/g d.w.)	**Aleutian Islands**			
Blue Mussels (*Mytilus trossulus*)	1 sample (30-50 mussels)		Tanaga: Cape Anamsik (95)	Tanaga: Hot Spring Bay (96)	Adak: Bay of Islands (97)	1996	Reese[38]
		∑PCBs	14	13	12		
		∑DDTs	4.7	7.9	4.2		
		∑HCHs	8.3	5.6	8.5		
		∑Chlordane	6.4	4.5	4.1		
		HCB	1.1	0.70	1.0		
			Adak: Clam Lagoon (98)	Adak: Sweeper Cove Rocks (99)	Adak: Sweeper Cove Pier (100)	1996	
		∑PCBs	19	430	280		
		∑DDTs	5.6	10	8.3		
		∑HCHs	4.6	7.5	5.8		
		∑Chlordane	4.1	4.5	4.5		
		HCB	0.47	0.86	0.74		
			Adak: Finger Bay #1 (101)	Adak: Finger Bay #2 (102)	Adak: Boot Bay (103)		
		∑PCBs	110	62	9.7		
		∑DDTs	12	7.5	2.9		
		∑HCHs	9.8	6.2	3.4		
		∑Chlordane	6.3	3.9	2.2		
		HCB	1.1	0.93	0.53		
			Great Sitkin: Zaliva Point (104)	Seguam: East Side (105)	Yunaska: Crater Anchorage (106)	1996	
		∑PCBs	12	12	19		
		∑DDTs	6.5	5.3	18		
		∑HCHs	4.6	4.7	13		
		∑Chlordane	4.1	6.8	10		
		HCB	0.72	0.35	1.0		
			Umnak: Anangula (107)	Umnak: Nikolski Bay (108)	Unalaska: Dutch Harbor (109)	1996	
		∑PCBs	8.2	12	2800		
		∑DDTs	2.4	5.1	19		
		∑HCHs	4.3	7.1	5.8		
		∑Chlordane	3.2	4.9	6.9		
		HCB	0.32	0.94	0.52		
			Unalaska: Paso Point (110)	Unalaska: Peacock Point (111)	Unalaska: Chernofski Point (112)		
		∑PCBs	7.4	8.7	8.4		
		∑DDTs	4.7	3.4	4.2		
		∑HCHs	7.6	6.1	5.1		
		∑Chlordane	3.4	2.9	3.0		
		HCB	0.60	0.54	0.47		
			Akutan: Akutan Point (113)	Akutan: Hot Spring Bay (114)			
		∑PCBs	24	14			
		∑DDTs	8.2	4.7			
		∑HCHs	5.9	6.9			
		∑Chlordane	5.5	3.5			
		HCB	0.63	0.65			

collected sea otter samples. Five additional samples were collected in 1996 from five sites in southeastern Alaska, again in the same areas as the sea otter study. Key findings from that study were that PCB concentrations and congener profiles from the majority of Aleutian Islands were not statistically different from those of the southeastern Alaska samples. As Reese points out, because the Aleutian chain is separated from the southeast collection sites by a thousand miles, and because the Aleutians themselves extend for more than one thousand miles, the similar ∑PCB distributions suggest a common source and large-scale transport mechanism (i.e., atmospheric or oceanic) for these PCBs. In contrast, PCB profiles for several sample areas from the areas of Amchitka, Adak, and Unalaska showed noticeably higher levels, and were made up of "heavier" PCB congeners, that is, congeners with more chlorines. This suggests that point source contamination rather than long-range transport may be the cause of the differences, because heavier congeners are less likely to travel long distances. The relationship of these "hot spots" to the highly contaminated areas used by the military over the past 50 years probably means that the higher levels are related to those point sources.

In another preliminary investigation done by the U.S. EPA,[40] twenty samples from several species, including mussels, sea urchins, flounder, and blubber from one sea lion, from Dutch Harbor in Unalaska were analyzed in July, 1999. A Quality Assurance Memorandum from the U.S. EPA on this testing reported that four of the twenty samples contained DDE at low concentrations. One sample contained almost every target chlorinated pesticide except for heptachlor, aldrin, endrin aldehyde, endrin ketone, and toxaphene, and this same sample also had a total DDE level of 2000 ppb. Fifteen of the samples had detectable PCBs, but fourteen of these were characterized as being "low"; the levels were not given. The fifteenth, the same sample as the one with high DDE concentrations, had a total of 2700 ppb of PCBs characterized as Aroclors 1242, 1254, and 1260[a]. This sample was from the blubber of a sea lion, which suggests a high degree of bioaccumulation and biomagnification of organisms near a point source.

From 1994-1996, the U.S. Navy[41] also sampled blue mussels and rock sole fillets at Adak Island. Samples from Sweeper Cove and Kuluk Bay were compared to samples taken from what are described as "background locations" including Bay of Islands, Boot Bay, Cabin Cove, Galas Point, and Laska Cove. Concentrations of PCBs in blue mussels from these background areas ranged from undetected to 0.0018 mg/kg wet weight, which was markedly lower than the reporting limits in Kuluk Bay, where concentrations ranged from undetected to 0.036 mg/kg wet weight. In Sweeper Cove the levels for mussels ranged from 0.027 to 0.78 mg/kg wet weight, substantially higher than in Kuluk Bay and the background locations.

Rock sole fillets in the Navy investigations for PCBs ranged between undetected and 0.341 mg/kg wet weight at Sweeper Cove and between 0.014 and 0.06 mg/kg wet weight at Kuluk Bay. Unlike with the blue mussels, however, there was overlap rather than a differential in PCB levels in the fish in all three areas. In the background area (South Kagalaska Strait), PCB concentrations in rock sole ranged from undetected to 0.162 mg/kg wet weight. A subsequent study by Miles et al,[42] reported by the Navy in its biomonitoring plan, measured organochlorines in the livers of Pacific halibut, gray cod, and rock greenling, collected in 1996. In this investigation, PCBs were expressed both as Aroclor mixtures and as total PCBs, but the Navy reports only Aroclor results. Aroclor 1242 was highest in Pacific halibut from the Bay of Islands, and at similar levels in

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[a] Aroclors® refer to industrial PCB mixtures manufactured by Monsanto Chemical Co. Aroclor® is a trade name which was used to describe different mixtures such as Aroclor 1260, Aroclor 1254, Aroclor 1242, and so forth. The first two numbers of the Aroclors refer to the structure of PCBs as a 12-carbon biphenyl nucleus, and the last two numbers indicate the percent of chlorine in the mixture. As more sophisticated technology has allowed a better analysis of individual congeners, the use of Aroclor mixtures to describe PCB concentration has diminished.

samples from Adak Island at Finger Bay, Kuluk Bay, Sweeper Cove, and Seguam Island. Aroclors 1254 and 1242 were highest in Pacific cod sampled at Buldir Island, and similar in samples of cod from Seguam Island and east and west Adak, except at Sweeper Cove, where cod levels of Aroclor 1260 were elevated. Rock greenling were sampled at Bay of Islands, Finger Bay, Kuluk Bay, and Sweeper Cove. Aroclor 1260 was highest at Sweeper Cove and 1254 was highest at the Bay of Islands. No specific levels were given in the Navy summary.

Although fish such as char, trout, and salmon represent a significant portion of the Native subsistence diet throughout Alaska, published data on POPs contamination of these fish in Alaska are few. Several studies have been done in Canada on fish, however, and some may have relevance to the situation in Alaska in similar locations. Kidd et al,[43] for example, found high levels of toxaphene and other organochlorine contaminants (not specified) in lake trout (*Salvelinus namaychus*) and burbot (*Lota lota*) in a subarctic lake in the Yukon Territory in 1991. Analyses of food chains and contaminants in the biota, water, and sediments showed that the high concentrations in the fish in Lake Leberge resulted entirely from the biomagnification of atmospheric inputs.

Other studies have been done on trout and grayling (*Thymallus arcticus*) in several Alaskan lakes. Two investigations looked these fish in Arctic lakes in the Brooks Range in the North Slope Borough. Wilson et al[44] found a wide range of organochlorine pesticides and PCBs in the muscle tissue and livers of lake trout and Arctic grayling from Schrader Lake. PCBs as a group were the most plentiful contaminant in all tissues, with chlordane-related compounds the secondmost. These results are in Table 7 (“Levels of POPs in Alaskan Fish”). Lake trout showed higher levels of ∑PCBs, chlordane compounds and metabolites, and *p,p'*-DDE than grayling. The authors noted that the concentrations of the contaminants in the lake trout were generally similar to levels in burbot and slightly higher than levels in whitefish from the Mackenzie River Delta in Canada. This is relevant because burbot are also an important subsistence fish in Alaska. This study is important because it showed that some Alaskan fish had levels comparable to those found in Canadian studies, and because the results confirm that long-range transport of these contaminants is occurring to a U.S. Arctic freshwater system.

Allen-Gil et al[24] followed up on this study with an investigation that measured PCBs and organochlorine pesticides in sediments, snails, and the same two fish species, grayling and lake trout, in four Arctic lakes, including Lake Schrader, in the foothills of the Brooks range. Once again, lake trout demonstrated a wider range of compounds and higher concentrations (Table 7) than grayling. Other interesting conclusions are discussed by the authors. First they observe that, in spite of limitations in their data regarding the number and distribution of samples, their investigation suggests that the pattern of contaminant movement reported by Lockhart[45] and Muir[46] (in a northwesterly direction across Canada) may not hold true across the U.S. Arctic. Instead, they believe, pollution from Asia may contribute to higher contaminant levels in the eastern areas of Alaska. Also interesting is that they conclude that the organochlorine levels found in these lakes are in the range of those reported for other Arctic regions, and that differences in levels in different species could be partially explained by differences in their position on the food web. The implications of these findings are highly relevant to concerns about food consumption and contamination levels.

In another study of grayling , the State of Alaska Department of Health and Social Services investigated PCB contamination of fish at the former Umiat Air Force Base.[47] This remote former military site is located in the Colville River Valley north of the Brooks Range in Northern Alaska, approximately 120 miles southwest of Prudhoe Bay. Point source contamination is thought to originate from a landfill at the Umiat facility, and there has been concern that contamination of a seasonal slough inhabited by fish could extend to the Colville River, an important source of fish

Table 7
Levels of POPs in Alaskan Fish

Species	*N*	Tissue	Contaminant(s)	Contaminant Level **Median** **Range** **(ppb wet weight)**	Location	Collection Date	Reference
Whitefish	5	Whole body	"Total" PCBs	7.7 4.1-39.1	Umiat Air Force Base—seasonal slough (54)	1998	State of Alaska [47]
				5.4 2.4-6.0	Colville River Downstream (55)		
				6.4 2.2-8.3	Colville River Upstream (56)		
	5	Whole body	"Total DDTs"	0.7 0.5-2.2	Umiat Air Force Base—seasonal slough		
				0.8 0.7-1.0	Colville River Downstream		
				0.9 0.5-1.3	Colville River Upstream		
Burbot (*Lota lota*)	1	Whole body	"Total PCBs"	3.3	Umiat Air Force Base seasonal slough	1998	State of Alaska [47]
	1	Whole body		18.2			
	1	Liver		270			
	1	Liver		1,060			
	1	Whole body		1.2	Colville River Downstream		
	1	Whole body	"Total" PCBs	8.1	Colville River Downstream		
	1	Whole body					
	1	Liver		256.1			
	1	Liver		680			
	1	Whole body		b.d[a]	Colville River Upstream		
	1			1.2			
	1			1.3			
	1	Liver		119.1			
	1			126			
	1			126			
	1	Whole body	"Total DDTs"	4.1	Umiat Air Force Base seasonal slough (57)		
	1			34.9			
	1	Liver		704.6			
				1,355			
	1			0.7	Colville River Downstream (58)		
	1			4.4			
	1	Liver		174.3			
				722.5			
	1			0.3	Colville River Upstream (59)		
	1			0.3			
	1			0.6			
	1	Liver		73.1			
	1			79.4			
	1			106.9			

[a] b.d. = below detection; detection limit given in parentheses when available

Species	*N*	Tissue	Contaminant(s)	Contaminant Level	Location	Collection Date	Reference
				Mean±S.D. (ng/g wet wt.)			
Lake Trout (*Salvelinus namaycush*)	11	Muscle	∑HCH[a]	1.0±0.6	Schrader Lake	1991-1993	Wilson et al[44]
			HCB	1.0±0.7			
			Dieldrin	0.7±0.5			
			Heptachlor epoxide	0.4±0.2			
			p,p'-DDE	2.8±3.1			
			∑chlordane[b]	0.7±0.5			
			∑PCBs [d]	6.6			
			∑PCBs [d]	22.8			
	N[c]						
Lake Trout (*Salvelinus namaycush*)	34	Muscle	HCB	0.46±0.5	Lakes Elusive, Schrader, Feniak, and Desperation	1991-1993	Allen-Gil et al[24]
	13		Sum of PCBs	3.7±3.54			
	11		α-HCH	0.49±0.43			
	5		γ-HCH	0.19±0.06			
	5		γ-Chlordane	0.06±0.06			
	10		Heptachlor epoxide	0.25±0.16			
	25		Oxychlordane	0.21±0.26			
	23		α- Chlordane	0.25±0.27			
	22		Sum of DDTs	2.69±6.18			
	32		Sum of *p,p'*-DDTs	1.85±4.39			
Lake Trout (*Salvelinus namaycush*)	33	Liver	HCB	1.15±1.2	Lakes Elusive, Schrader, Feniak, and Desperation	1991-1993	Allen-Gil et al[24]
	10		Sum of PCBs	26.3±49.87			
	7		α-HCH	1.19±1.44			
	10		γ-HCH	3.14±2.18			
	3		γ-Chlordane	0.22±0.3			
	0		Heptachlor epoxide	ND			
	16		Oxychlordane	1.03±0.96			
	14		α-Chlordane	2.12±2.18			
	23		Sum of DDTs	7.94±11.09			
	34		Sum of *p,p'*-DDTs	6.75±9.64			

[a] Sum of α-HCH + γ-HCH.

[b] Sum of *cis*-chlordane + *trans*-chlordane.

[c] N=number of samples passing QA in which analyte was detected; ND=not detected; NA=not analyzed. Includes samples in which the analyte was detected, but lower than method detection limit (MDL). These values therefore are estimates. Sum of PCBs; sum of all congeners analyzed. Does not include samples for which one or more congener failed QA.[21]

Species	*N*	Tissue	Contaminant(s)	Contaminant Level	Location	Collection Date	Reference
				Mean±S.D. (ng/g wet weight)			
Grayling (*Thymallus arcticus*)	5	Muscle	∑PCBs[a]	1.3	Lake Schrader (49)	1992	Wilson et al[44]
			∑HCH[b]	0.4±0.1			
			HCB	0.3±0.2			
			Dieldrin	0.3±0.1			
			Heptachlor epoxide	0.2±0.003			
			p,p'-DDE	0.6±0.2			
			∑chlordane[c]	0.2±0.2			
	5	Liver	∑PCBs[b]	3.2			
			∑HCH[c]	1.6±1.5			
			HCB	0.7±0.6			
			Dieldrin	1.9±0.9			
			Hept. epoxide	1.1±0.08			
			p,p'-DDE	1.5±0.8			
			∑chlordane[d]	1.4±0.9			
	N[d]				(50) (51)		
Grayling (*Thymallus arcticus*)	39	Muscle	HCB	0.33±0.3	Lakes Elusive, Schrader, Feniak, and Desperation (52) (53)	1991-1993	Allen-Gil et al[24]
	0		Sum of PCBs	ND			
	26		α-HCH	0.47±0.36			
	1		γ-HCH	0.18			
	4		γ-Chlordane	0.08±0.01			
	14		Heptachlor epoxide	0.11±0.14			
	31		Oxychlordane	0.25±0.27			
	22		α- Chlordane	0.09±0.17			
	33		Sum of DDTs	0.42±0.75			
	51		Sum of *p,p'*-DDTs	0.35±0.56			
	56	Liver	HCB	0.64±058			
	27		Sum of PCBs	4.96±5.62			
	4		α-HCH	0.36±0.2			
	6		γ-HCH	0.84±0.39			
	4		γ-Chlordane	0.61±0.64			
	3		Heptachlor epoxide	0.86±0.33			
	12		Oxychlordane	0.64±0.48			
	8		α- Chlordane	1.19±2.56			
	31		Sum of DDTs	1.92±2.3			
	36		Sum of *p,p'*-DDTs	1.75±2.09			
				Median Range (ppb wet weight)			
Grayling (*Thymallus arcticus*)	7	Whole body	PCBs as Aroclor 1254	b.d.[e] (<10) b.d. (<5.1)-1,400	Umiat Air Force Base—seasonal slough (44)	1997	State of Alaska[47]
	7	Fillet		19 b.d. (<9.9) - 460			

[a]Sum of PCB congeners IUPAC No. 118, 153, 105, 138, 187, 128, 180, 170, 195, 206, 20920

[b] Sum of α-HCH + γ-HCH.

[c] Sum of *cis*-chlordane + *trans*-chlordane.

[d] *N*=number of samples passing QA in which analyte was detected; ND=not detected; NA=not analyzed. Includes samples in which the analyte was detected, but lower than method detection limit (MDL). These values therefore are estimates. Sum of PCBs; sum of all congeners analyzed. Does not include samples for which one or more congener failed QA.[21]

[e] b.d. = below detection; detection limit given in parentheses when available

for both subsistence and recreational users. Sediments there are known to be contaminated, and fish from the slough and upstream and downstream in the river were sampled in August, 1997.

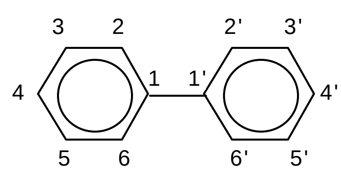
The results showed that fifty sediment samples had PCB concentrations (Aroclor 1254) ranging from non-detectable to 1,300 ppb. Of fourteen Arctic grayling taken from the slough, seven were analyzed as whole fish and seven as fillets. PCBs as Aroclor 1254 were found in three of the whole body samples in amounts ranging from 48 ppb to 1,400 ppb wet weight. Aroclor 1254 was also found in four of the seven fillets, in amounts ranging from 19 ppb to 460 ppb. No PCBs were detected in six Arctic grayling sampled as background from the Colville River about one mile upstream of the slough. Further sampling was done in 1998 in the slough and four miles upstream and downstream in the river. No PCBs or DDTs were found in sediment samples as far as two miles downstream; however, DDTs were found in the sediment ranging from non-detectable to 113 ppb wet weight. Fish sampling consisted of five broad whitefish and “two or three” burbot from each location. Whole body samples of the whitefish were tested, and both whole fish and liver tissue of the burbot were tested. The results of this testing are in Table 7.

The State of Alaska concluded that although some fish were moderately contaminated, the slough did not represent a major threat to public health. At the same time, however, the burbot data suggested that site-related contaminants could be present in some fish species downstream from the site in the Colville River, although again, the state did not consider them to be at levels high enough to provoke concern. It should be pointed out that it continues to be poorly understood exactly how far downstream site-related contaminants can be detected in important prey fish such as burbot. This lack of data represents a serious gap in knowledge about POPs in Alaskan fish, as the pollution level downstream of a known contaminated site is an issue of significant concern in many places throughout Alaska. This includes the downstream village of Nuiqsut, which relies on the Colville River for its fish.

Another noticeable gap in information exists with regard to contaminant levels in Alaskan salmon, one of the most important components of the subsistence diet in many areas of Alaska, including the interior. Only one peer-reviewed study of a single species in Alaskan waters, the sockeye (*Oncorhynchus nerka*), could be found. In contrast, the literature dating as far back as 1971 includes multiple articles on POPs—PCBs and DDT and its metabolites in particular—in various species from elsewhere in the U.S. and Europe, of which the attached references are only a sample.[48, 49, 50, 51, 52, 53, 54, 55]

Isomers and Congeners

Isomers and ***congeners*** are very similar. Many chemical compounds, such as PCBs or HCH, take different forms with different combinations of atoms on the basic molecule. All are members of the same chemical family and all have the same fundamental structure, and the same number of total atoms. But PCBs, for example, have 209 different combinations of chlorine and hydrogen atoms on the molecule. These different combinations are called congeners. Congeners with more chlorines are sometimes called “heavier” and those with fewer chlorines are called “lighter.”



The basic PCB molecule with positions for ten possible chlorine substitutions (all except 1 and 1’)

HCH has three different isomers, designated by the Greek letters α = alpha, β = beta, and γ = gamma. Each PCB congener has a different number, such as 118, 138 or 153, and some are more common in the environment than others. Different congeners or isomers often have different chemical properties which may affect how they behave in the environment and in animals and humans.

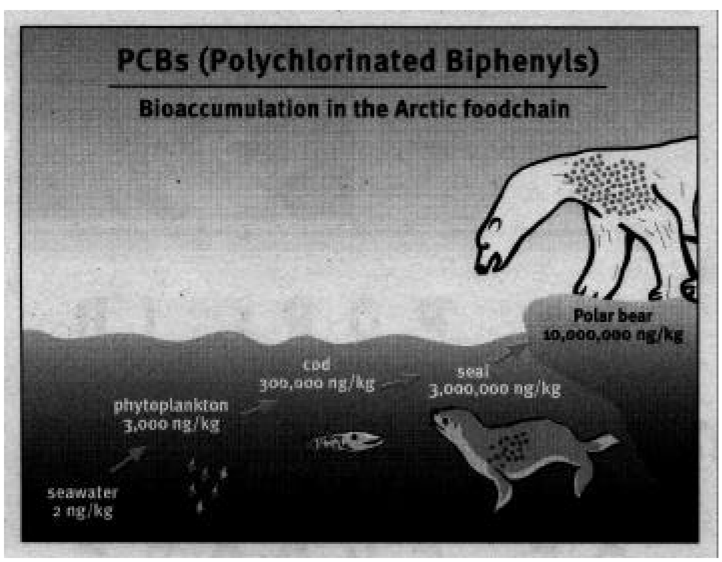
In the summer and fall of 1994, Ewald et al[56] studied migrating sockeye to determine whether the fish themselves, in addition to atmospheric deposition, were a source of organic pollution to the inland lakes to which they migrated, spawned, and died. They followed the salmon from the Gulf of Alaska to Copper Lake, a distance of 410 km (approximately 254 miles). To measure whether the salmon were a source of transport for the organic contaminants, pollutant levels in the arctic grayling, the stationary, resident top aquatic predator in Copper Lake were measured. Grayling in salmon lakes are exposed to contaminants not only through atmospheric deposition, but also through the food chain via their consumption of salmon roe and other trophic organisms in the lake that feed on the degrading salmon carcasses. Grayling in non-salmon lakes are exposed only through atmospheric deposition.

In this study, levels of grayling in salmon lakes were compared to levels in grayling from a comparable lake to which the salmon did not migrate, spawn, or contribute to the nutrient and organic loading of the lake ecosystem. Twenty-three grayling from each of two lakes were caught both before and after the spawning period. Four groups of salmon were also sampled: twenty fish caught up to thirty miles outside the river mouth about to start freshwater migration, sixty-seven fish at different levels of age and growth at sixteen sites along the migration route, twenty

Contaminant Transport by Living Species

from *Alaska Pollution Issues*[8]

Contaminants can be transported long distances from their origins to the Arctic by migratory species and living organisms. Through the process of **bioconcentration**, aquatic organisms, plants, and animals uptake contaminants from the environment. When those plants and animals are eaten by other animals, a process called **bioaccumulation** occurs as the contaminants begin to be accumulated in the tissues of animals up the food chain from both the environment and prey. Some large predator species such as falcons, polar bears, and toothed whales accumulate still higher levels through **biomagnification**—the process of accumulating greater levels as contaminants move up the food chain.



Source: Greenpeace International

Whales, birds, fish, and other marine mammals that overwinter in other areas that are more contaminated transport these contaminants back to Alaska. This is one explanation for why polar bears, who do not migrate, may have very high levels of POPs. Because they are at the top of the food chain with a diet rich in blubber from animals that do migrate, they acquire and biomagnify contaminants to which they may not otherwise be so exposed.

mature fish from about sixteen miles below the spawning lake, and ten spent fish (fish who have already spawned).

The results showed that salmon are important contributors of organic pollutants to the food chain in two ways: first through the levels of chemicals they carry in their own tissues, which increased as they migrated upstream. PCB and DDT levels increased as the distance migrated increased, as the amount of fat in the fish decreased and the contaminants were released into the muscle tissue. In twenty migrating fish, the authors report that the muscle lipid (fat) concentration of PCBs increased from 670 ppb to 2493 ppb and DDTs increased from 221 ppb to 1223 ppb.

The salmon also had high levels after spawning. The PCB level in spent fish muscle fat was 7910 ppb and DDTs were 4863 ppb. The grayling in the salmon-spawning lake also showed significantly higher levels of both PCBs and DDTs than the grayling in the salmon-free lake. At the same time, there were no significant differences in the fallout deposition between the two lakes. These data support the second important conclusion: the salmon, rather than atmospheric deposition, were responsible for the increased contaminant levels in the grayling, and, by deduction, other organisms in the lake's food chain. And yet, Ewald et al stated, "the salmon in this study have concentrations of pollutants far below the levels that have caused concern with regard to human consumption or fish reproduction," and the pollutant levels are lower than those found in salmon in the Baltic Sea and in Lake Ontario in the Great Lakes.

Terrestrial mammals and birds

Virtually no information was available about POPs in terrestrial animals such as **caribou, moose,** or **wolf** in Alaska. Some data is available on caribou in the context of radioisotopes in Canada, but as Thomas et al[57] point out in reference to the Canadian Arctic, the database on organochlorines in terrestrial mammals and birds is very limited. They observe that indications are that the air/plant/animal contaminant pathway is the major route of these compounds into the terrestrial food chain, and they identify HCB and HCH as the most abundant organochlorines in terrestrial herbivores. Gamberg and Braune[58] found low levels of some organochlorines in the livers of wolves in the Yukon Territory, including PCBs, chlorobenzenes, and dieldrin. Braune et al[59] discussed several different species of terrestrial mammals and waterfowl across the Canadian Arctic. They identified PCBs and cadmium as the most prominent contaminants in the species analyzed. They also reported that the relative tissue concentrations of the main organochlorines detected in **lichen**, caribou, and wolves show a clear process of biomagnification of total chlordanes and total PCBs from lichen to caribou to wolf. They also found evidence of transfer of PCBs from **plants** to **lemmings.** Whether any of these findings have relevance to the Alaskan Arctic is unknown, but they appear to be the closest, most recent data available.

In the late 1980's, studies were done in Alaska at the Yukon Delta National Wildlife Refuge at the Cape Romanzof Long Range Radar Site to determine the absence or presence of contaminants at Cape Romanzof.[60] Cape Romanzof is within the Refuge, 540 miles west of Anchorage on a small peninsula that extends into the Bering Sea. The results of this study showed that there were elevated levels of PAHs and organochlorines in fish and wildlife tissue near the Cape. Samples from **vole, fox,** and **fish** showed the highest organochlorine levels, including total PCBs (voles: 0.95-1.14 ppm; fox adipose fat: 0.58 ppm; and fish muscle: 0.16-1.22 ppm). Contamination was also found in sediments at the site. According to U.S.EPA Guidance on food consumption cited in a report by the Natural Resources Defense Council,[61] the highest concentrations in these fish exceed what the U.S. government considers acceptable levels for safe fish consumption by children and adults.

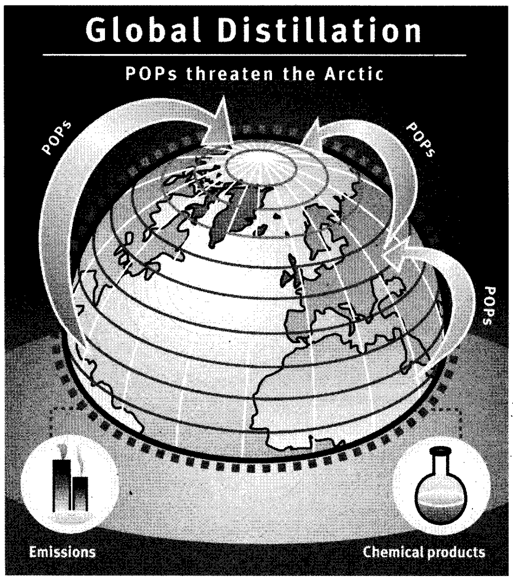
Contaminant Pathways

excerpts from *Alaska Pollution Issues*[8]

Airborne pathways

The most important pathway of contaminants to the Arctic is through air currents. Air transport is enhanced by a unique feature of Arctic meterology called the Arctic high-pressure air mass.

Physical and chemical properties of contaminants dictate the length of time contaminants stay airborne and how far they may be carried. There are two general patterns. Some contaminants stay where they settle out on land, water, or in ice; more volatile contaminants may return to the atmosphere and may take many hops on their way to the Arctic.



Source: Greenpeace International[9]

More volatile contaminants evaporate into the air, condense out, and re-vaporize repeatedly and are referred to as **multi-hop** contaminants. [This is sometimes called the grasshopper effect.] They tend to settle in the Arctic permanently because of the colder weather. These contaminants include the POPs that originate from industrial areas of Europe and Asia as well as agricultural and tropical areas where pesticides are more heavily used.

Waterborne contaminants

Waterborne contaminants enter the Arctic ecosystem through two sources, marine currents from the Pacific and Atlantic oceans and fresh water rivers that empty directly into the Arctic Ocean. The more important of these two is from fresh water rivers.

Rivers from the Russian Federation are an important source of these contaminants. Arctic Ocean currents and pack ice currents distribute contaminants across the Arctic Ocean and tend to concentrate them on either side of Greenland. Arctic pack ice circulation is similar to water patterns. Pack ice rotates clockwise around the Beaufort Gyre and through a wider pattern across the Arctic Ocean from the Chukchi Sea to the straits east of Greenland where it melts or breaks up into icebergs that flow out into the Atlantic.

Ice is an important transport pathway in the Arctic Ocean. Arctic ice picks up contaminants deposited through rain and snow. Ice also picks up contaminants that have settled out on continental shelves, espcially along the north coast of the Russian Federation, which receives runoff from heavily contaminated Russian rivers.

Some data is available for some **bird** species in Alaska, although information in this area represents another significant gap, especially with regard to waterfowl such as ducks and geese. In May, 2000, however, the U.S. Fish and Wildlife Service released their report, *Environmental Contaminants in American and Arctic Peregrine Falcon Eggs in Alaska, 1979-95*.[62] This document includes fifteen years of monitoring and contaminants data in **peregrine falcon** eggs in two subspecies that occur in Northern Alaska, the American peregrine falcon (*Falco peregrius anatum*), which nests south of the Brooks Range, and the arctic peregrine falcon (*F. p. tundrius*), which nests to the north. A summary[63] of this report by the Marine Mammals Management Field office in Anchorage highlighted the following key findings.

Organochlorine contaminants (OCs), including POPs, were measured from 1979-1995. POPs were found to have declined significantly over time, although the trend was weaker for total PCBs than for other OCs. The only significant differences between falcon subspecies were in dieldrin, which was greater in the arctic peregrine compared to the American peregrine, and *p,p'*-DDE, which was lower in the arctic peregrine compared to the American peregrine. For the American peregrine, dieldrin, oxychlordane, and total PCBs were significantly greater in eggs from unsuccessful nests compared to successful nests.[a] **Eggshell thickness**, also used as a meas ure of bald eagle and other avian reproductive success in the Great Lakes, increased in all eggs as *p,p'*-DDE concentrations decreased, but there was no significant increase in eggshell thickness in general over time. The average eggshell thickness from 1991-95 was 12% thinner in the American peregrine and 10.6% thinner in the arctic peregrine than pre-DDT era peregrine eggs.

The Marine Mammals Management Field Office concludes its summary of this report by noting that although concentrations of organochlorines have decreased over time in peregrine eggs from Alaska, evidence for cumulative and single-contaminant effects on reproduction were still found. As a result, contaminant monitoring remains a necessary management tool because peregrine falcons are still recovering from near extinction due to environmental contamination, and because they are top predators that remain vulnerable to persistent and accumulating compounds. Selected tables and figures from the report have been attached to this document as Appendix A.

In another study, Anthony et al[64] studied productivity, diets, and environmental contaminants in nesting **bald eagles** from the western Aleutian Islands during the summers of 1993 and 1994. Elevated levels of PCBs, DDE, mirex, oxychlordane, *trans*-nonachlor, dieldrin, and HCB were found in the eggs from all four islands studied: Adak, Tanaga, Amchitka, and Kiska. Eggshell thickness was not significantly different among the islands, nor did it appear to be related to DDE concentrations. It was, however, negatively correlated to PCB concentrations, that is, as PCB concentrations increased, eggshell thickness decreased. Concentrations of all of these organochlorines except PCBs were higher in eggs from Kiska Island than in the eggs from the other islands. Concentrations of DDE (and mercury) were particularly high in the eggs from Kiska and were associated with lower productivity of breeding pairs. These findings caused the authors to reject their initial hypothesis that bald eagles in the Aleutian Islands were free of organochlorine contamination.

In addition, the investigation discovered that PCB concentrations in bald eagle eggs on Adak, Amchitka, and Kiska Islands were significantly higher than the concentrations on Tanaga. This pattern was attributed to previous military activity on the islands where the PCB concentrations were highest. A second important conclusion the investigators made was that the findings of elevated concentrations of PCBs on all the islands suggested that these contaminants are being transported globally by air and/or sea and deposited into polar regions due to the global distillation effect.

The study presented several hypotheses as to what the sources of these contaminants in bald eagles could be, as they were an unexpected finding. One possibility is that the bald eagles in the Aleutians are getting contaminants from other birds eaten as prey, which migrate to southern latitudes in North America or Asia. This would result in a higher potential for food chain biomagnification than a diet made up only of fish. There is potential independent support for this theory, as one of the bird species mentioned as prey, the glaucous gull, has been shown in to have extremely high PCB levels in colonies on Bear Island, Norway.[65] Also mentioned is that air and/or oceanic transport from Eurasia is a possible source, supported by the fact that DDT is still

[a] Unhatched, addled (that is, spoiled) eggs were collected when nests were first visited to count and band nestlings. The success of a nest was defined as having one or more nestlings, usually between 7 and 28 days old, at the latter nest visit; unsuccessful nests had no chicks present.

used in Japan and Russia, as well as in many other parts of the world. The authors conclude their article by suggesting the possibility of contaminant-related factors in the population declines of sea otters, pinnipeds, and seabirds, and expressing their concern for the health of Aleutian ecosystems given the possible effect of organochlorines on population viability of several top predators. They state that their findings exemplify the need for international controls on the use of contaminants, which know no political or continental bounds and thereby threaten human health as well as wildlife resources.

Marine mammals: whales, seals, sea otter and walrus, and polar bears

POPs contamination in marine mammals, including whales, seals, walrus, and polar bears, has been documented extensively in the Canadian and North European Arctic.[2, 3] Significantly fewer studies have been done in the Alaskan Arctic to confirm or challenge conclusions regarding the observed trend of diminishing levels in many species in an east to westward progression. Few studies focusing exclusively on marine mammals in Alaska have been published; there is little information about walrus and polar bears, for example, even though they are high on the food chain and provide important contributions to the subsistence diet of many Alaskan villages.

In an effort to address this, an on-going monitoring program for contaminants in marine mammals has been underway under the auspices of the Alaska Marine Mammal Tissue Archival Project (AMMAP),[66] which is part of a larger National Biomonitoring Specimen Bank (NBSB). The project involves the Biological Resources Division of the U.S. Geological Survey in Alaska, the National Oceanic and Atmospheric Administration (NOAA), the National Institute of Standards and Technologies (or NIST—part of the U.S. Department of Commerce), which maintains the samples and runs analyses, and local organizations that work with subsistence harvesters to collect species. As of 1997, 595 tissue specimens had been collected from eleven species, seven of which are Arctic species, i.e., **bowhead whale** (*Balaena mysticetus*), **beluga whale** (*Delphinapterus leucas*), **ringed seal** (*Phoca hispida*), **spotted seal** (*P. largha*), **bearded seal** (*Erignathus barbatus*), **Pacific walrus** (*Odobenus rosmarus*), and **polar bear** (*Ursus maritimus*). The majority of specimens have come from three species, bowhead whale (46 animals), beluga whale (45 animals), and ringed seal (46 animals), all of which are important subsistence food resources in the Arctic.

Using samples from the NSSB, Becker et al[67] analyzed blubber from a number of different species from the North Atlantic, North Pacific, and Alaskan waters for chlorinated hydrocarbons. The results of these analyses for Alaskan waters are shown in Table 8, "POPs in Alaskan Marine Mammals." The authors found that **whales** from the North Atlantic had higher concentrations of PCBs, DDT compounds, and *cis*-chlordane than any of the animals from Alaska. They also reported that the PCB and DDT concentrations in the blubber of **beluga** from the Alaskan Arctic were similar to those reported for beluga from the Canadian Arctic and western Greenland, for narwhals, and for polar bears, but an order of magnitude lower than those reported for beluga in the St. Lawrence Estuary in the eastern Canadian province of Quebec.

Beluga from the St. Lawrence River in Quebec have some of the highest levels of PCBs in the world and have been severely stressed by their exposure to these contaminants.[68, 69, 70, 71, 72] To further understand the comparison, levels of total chlordane and toxaphene in Alaska beluga, however, are the same order of magnitude as those in beluga from the St. Lawrence. These levels are also similar to those in beluga and narwhals from the Canadian Arctic, beluga from western Greenland, and polar bears from Canada. Within Alaska, chlorinated hydrocarbon levels in beluga from the Cook Inlet were generally lower than those in beluga in the East Chukchi and Beaufort Seas.

Similar results have been reported elsewhere. Mössner and Ballschmiter[73] analyzed the blubber of beluga whales in the Bering Sea/Arctic Ocean for organochlorine chemicals (Table 8) and compared those data to levels of the same chemicals in Canadian whales in the Atlantic Ocean. Looking at seven PCB congeners, three isomers of HCH, and six metabolites of DDTs, they concluded that whales from the western Canadian Atlantic had levels about 15 times higher than animals from the North Pacific and the Alaskan waters of the Bering Sea/Arctic Ocean. Krahn et al[74] reported on concentrations and patterns of persistent organochlorine contaminants in the blubber of beluga whales from three of the five different Alaskan beluga stocks; the results are shown in Table 8.

The conclusions of this study were that the blubber of these whales contained OCs in concentration ranges similar to those found in the beluga whales from the Canadian Arctic. Cook Inlet beluga stock generally had the lowest and Eastern Beaufort Sea stock the highest concentrations. This study also noted that gender is an important factor in interpreting results. Males of each stock had higher mean concentrations of all contaminant groups than females of the same stock. This difference is attributed to the transfer of some of the mother's body burden to the calf during gestation and lactation.

Two additional studies also reported on the transfer of organochlorines through the placenta and through lactation. Wade et al[75] analyzed samples of blubber from beluga whales[a] for toxaphene, PCBs, DDTs, and chlordane. The levels are shown in Table 8. Toxaphene concentrations were the highest of all contaminants in all samples except the one 6-year-old male, in which PCBs were the highest. The males had higher concentrations than the females, and the older male had higher concentrations than the younger male. In the females, however, concentrations decreased with age, and the fetus had about 10% higher concentration than its mother. The authors concluded that the source of contamination in these mammals was likely global distillation, and that transfer through the placenta and nursing lower the contaminant levels in females. This finding was echoed in unpublished data from Schantz,[76] who measured organochlorine concentrations and PCB congeners in the blubber of a female beluga whale and her near-term fetus in the Cook Inlet, Alaska. This study found that the contaminants were transferred to the fetus before birth. Also, in the case of this animal, chlordane compounds (*trans*-nonachlor, *cis*-chlordane, *cis*-nonachlor) and dieldrin, as well as some of the more highly chlorinated hydrocarbons, were transferred preferentially to the fetus from its mother.

Fewer reports of levels of POPs in tissues are available for other species of whales in Alaskan waters, including **gray whale**, **bowhead**, **narwhal**, and **killer whales.** Varanasi et al[77] reported on contaminants in gray whales (*Eschrichtius robustus*) from tissues taken from animals that had been stranded along the west coast of North America, including Alaska, and these levels can be seen in Table 8. Gray whales are migratory baleen whales. Baleen whales eat organisms at lower trophic levels; they strain large amounts of water to feed on small crustaceans ("krill"), which do not accumulate contaminants at the same levels as species higher on the food chain, such as fish. Baleen whales also swallow large amounts of sediments, however, which may contain contaminants.

Analyses from this study found that chlorinated hydrocarbons (including PCBs, DDTs, HCH, and HCB) in blubber from 22 animals showed no apparent significant differences among stranding sites. Analyses also showed no apparent significant differences between whales stranded in Puget Sound and whales stranded in more pristine areas, including Alaska (Kodiak Island). This study was limited by the inability to compare findings to levels in healthy gray

[a] The gender and estimated age breakdown of this sample were 1 female (16 yrs) with fetus, 3 females (11-19 yrs), and 2 males (6, 13 yrs).

Table 8
POPs in Alaskan Marine Mammals[a]

Equivalents: **mg/g = mg/g = mg g^{-1} = ppm** **ng/g = mg/kg = mg kg^{-1} = mg/kg = mg kg^{-1} = ppb**

Species	Number	Tissue	Contaminant(s)	Contaminant Level	Location	Collection Date	Reference
				Mean ± S.D. ranges ng/g wet weight			
Beluga Whale *(Delphinapterus leucas)*	10 (Female)	blubber	∑PCBs[b]	790 ± 560 190-1,810	Cook Inlet Stock (Site not given) 3	1992-1997	Krahn, MM et al[74]
			∑DDTs[c]	590 ± 450 110-1,410			
			∑Chlordanes[d]	300 ± 220 60-680			
			HCB	150 ± 130 30-460			
			Dieldrin	57 ± 50 11-150			
			Mirex	9.13 ± 3.7 3.7-14			
	10 (Male)		∑PCBs	1,490 ± 700 554-3,090			
			∑DDTs	1,350 ± 730 340-2,910			
			∑Chlordanes	560 ± 250 360-1,110			
			HCB	220 ± 93 78-400			
			Dieldrin	92 ± 47 25-210			
			Mirex	13 ± 5.6 4.0-20			

[a] Measurement presentation differs by study; ranges given where provided, means and S.D. where no ranges provided, individual measurements where applicable.
[b] ∑PCBs is the sum of 17 reported congeners, multiplied by 2 as an estimate of total PCBs [1]
[c] ∑DDTs is the sum of concentrations of six DDT metabolites (o,p'-DDD, p,p'-DDD, o,p'-DDE, p,p'-DDE, o,p'-DDT, and p,p'-DDT)[1]
[d]∑Chlordanes is the sum of concentrations of heptachlor, heptachlor expoxide, cis-chlordane, trans-chlordane, trans-nonachlor, cis-nonachlor, oxychlordane, and nonaclor III.[1]

Species	Number	Tissue	Contaminant(s)	Contaminant Level	Location	Collection Date	
				mean ± S.D. **ranges** **ng/g wet weight**			
Beluga Whale ***(Delphinapterus leucas)***	8 (Females)	blubber	∑PCBs	1,500 ± 1,120 740-4,070	Pt. Lay (4) E. Chukchi Sea stock (5)	1990, 1996	Krahn MM et al[74]
			∑DDTs	930 ± 580 330-4,850			
			∑Chlordanes	790 ± 610 300-2,150			
			HCB	23 ± 280 60-840			
			Dieldrin	120 ± 96 46-320			
			Mirex	22 ± 6.6 15-35			
	2 (Females)	blubber	∑PCBs	2,220 1,800-2,560	(6) Pt. Hope E. Beaufort Sea stock (7)	1989	
			∑DDTs	1,240 1,140-1,330			
			∑Chlordanes	1,300 1,080-1,530			
			HCB	570 230-900			
			Dieldrin	210 140-280			
			Mirex	17 14-20			

Species	Number	Tissue	Contaminant(s)	Contaminant Level	Location	Collection Date	Reference
				ng/g extractable lipids			
Belukha (sic) whale (*Delphinapterus leucas*)	1	blubber	∑PCBs[a]	2,712	North Pacific Arctic Ocean/ Bering Sea 10	1997	Mössner and Ballschmiter[73]
			∑HCHs	372			
			∑DDTs	1,176			
				ng/g wet weight range			
Beluga Whale (*Delphinapterus leucas*)	12	blubber	SPCBs	648-5,233	Point Lay 11	not given	Alaska Contaminants and Native Foods Database[13]
	2	blubber	SPCBs	2,081-2,665	Point Hope 12		
				mean ± S.D.			
Beluga Whale (*Delphinapterus leucas*)	12	blubber	∑PCB[b]	267-1,920 977 ± 484	Cook Inlet 13	not given	Becker PR et al[67]
			∑DDT[c]	133-2350 1050 ± 658			
			4,4'-DDE	65.9-1630 624 ± 484			
			HCB	138-741 368 ± 212			
			α-HCH	26-246 91.2 ± 71.8			
			γ-HCH	na			
			cis-chlordane	5-77 22.5 ± 19.6			
			heptachlor expoxide	1-68 20.8 ± 22.5			
			dieldrin	11-181 105 ± 66.2			

[a] ∑PCB=∑ (7) PCBs x 4 (multiplication factor 4 derives from the assumption that PCB composition in the samples is similar to an Aroclor standard mixtures 1242:1254:1260 (1:1:1))
[b] sum of 33 congeners
[c] sum of 2,4'-DDE, 4,4'-DDE, 2,4'-DDD, 2,4'-DDT, 4,4'-DDT[3]

Species	Number	Tissue	Contaminant(s)	Contaminant Level	Location	Collection Date	Reference
				ng/g wet weight **range** **mean ± S.D.**			
Beluga Whale *(Delphinapterus leucas)*	12	blubber	ΣPCB[a]	648-5230 3670 ± 1380	69 Arctic (Point Lay and Point Hope) 60	not given	Becker et al[67]
			ΣDDT[b]	332-3820 2492 ± 1120			
			4,4'-DDE	142-2230 1415 ± 649			
			HCB	8.9-952 700 ± 264			
			α-HCH	43.9-196 121 ± 47.4			
			γ-HCH	11.5-95.9 49.7 ± 18.3			
			cis-chlordane	19-74.8 37.2 ± 15.8			
			Heptachlor expoxide	19.4-215 145 ± 51.3			
			Dieldrin	45.9-420 290 ± 106			
				μg/g lipid **range**			
Beluga Whale *(Delphinapterus leucas)*	7[c]	blubber	PCBs	0.70-9.42	North Coast near Pt. Lay 14	July, 1992	Wade T et al[75]
			DDTs	0.32-6.83			
			Toxaphene	2.38-15.94			
			Chlordane	0.32-3.88			

[a] sum of 33 congeners
[b] sum of 2,4'-DDE, 4,4'-DDE, 2,4'-DDD, 2,4'-DDT, 4,4'-DDT[3]
[c] Sex and estimated age breakdown of sample: 1 female (16 yrs) with fetus; 3 females (11-19 yrs); 2 males (6, 13 yrs).[4]

Species	Number	Tissue	Contaminant(s)	Contaminant Level	Location	Collection Date	Reference
				å PCB ± S.D.[a] **ng/g wet weight**			
Beluga Whale ***(Delphinapterus leucas)***	10	blubber	∑PCBs	3,808.1 ± 1,496.4	Pt. Lay, Chukchi Sea 25	1990	Schantz et al[113]
Beluga Whale ***(Delphinapterus leucas)***	7	blubber	∑PCBs	680 ± 216 (F=5) 2,986-6,406 (M=2)	Pt. Lay 26	1992	Tarpley[114]
Beluga Whale ***(Delphinapterus leucas)***	12	blubber	SPCB[b]	830-1640 (F=2) 3330 ± 850 (M=10)	Beaufort Sea[c] 71	1983, 1987	Muir et al[115]
Beluga Whale ***(Delphinapterus leucas)***	25	blubber	SPCB	5299 ± 1460 (F=5) 4882±1878 (M=20)	MacKenzie Delta (Canada)[c] 115	unknown	Muir et al[116]
	11	muktuk	SPCB	218 ± 60 (F=5) 317 ± 95 (M=6)	MacKenzie Delta (Canada)[c]	unknown	

[a] Mean value with standard deviation; both actual values listed when n = 2
[b] Summed congeners
[c] Shared population with Canada

Species	Number	Tissue	Contaminant(s)	Contaminant Level	Location	Collection Date	Reference
				range Mean ± S.D. ng/g wet weight			
Gray Whale ***(Eschrictius robustus)***	2	blubber of stranded whales	∑PCBs	150-1,200 680 ± 530	Kodiak Island 9	1989	Varanasi et al[6, 77]
			∑DDE	9-200 100 ± 96			
			∑DDD	1-42 22 ± 21			
			∑DDT	2-88 45 ± 43			
			HCB	16-78 47 ± 31			
			Dieldrin	4-59 32 ± 28			
			∑Chlordanes	13-130 72 ± 59			
	2	liver of stranded whales	∑PCBs	79-880 480 ± 400	Tugidak Island 116	1989	
			∑DDE	7-71 39 ± 32			
			∑DDD	1-22 11 ± 11			
			∑DDT	nd[a]-1 0.6			
			HCB	11-75 43 ± 32			
			Dieldrin	3-34 18 ± 16			
			∑Chlordanes	4-53 28 ± 25			

[a] nd = the analyte was not detected above the limit of detection

Species	Number	Tissue	Contaminant(s)	Contaminant Level	Location	Collection Date	Reference
				Mean & S.D./ ppm lipid weight			
Killer Whale ***(Orcinus orca)***	52 (all residents)	blubber	total PCBs	14.2 ± 14.1	Prince William Sound 39	1998	Matkin et al[82]
	66 (all residents)		total DDTs	14.4 ± 16.8			
	10 (all transients)		total PCBs	237.7 ± 136.1			
			total DDTs	346.0 ± 224.5	1		
Bowhead whale ***(Balaena mysticetus)***	*7*	blubber	PCBs	average 3.6 ppm S.D. ± 0.82	Barrow (5) Kaktovik (2) 2	1979-1980	Overton, Edward et al[79]
				mean ± S.D. ng/g wet weight			
Bowhead whale (*Balaena mysticetus*)	11	blubber	∑PCBs	689 ± 226	Barrow 27	1992	Becker et al[120]
				ng/g extractable lipids			
Bowhead whale (*Balaena mysticetus*)	1	blubber	∑PCBs[a] ∑HCHs ∑DDTs	316 160 71	North Pacific Arctic Ocean /Bering Sea	1997	Mössner and Ballschmiter[73]
				Mean±S.D. median ppb wet weight	8		
Bowhead whale (*Balaena mysticetus*)	26[b]	all blubber	sum PCBs	350.2 ± 202.2 280.0	Barrow 117	1992-1993	O'Hara et al[80]
			sum DDTs	130.1 ± 63.2 110.0			

[a] The sum of seven (7) PCBs x 4 (based on the assumption that the PCB composition in samples is similar to standard Aroclor mixture).
[b] Blubber was taken from 20 whales; this n is not explained in text and is assumed to represent the number of blubber samples analyzed

Species	Number	Tissue	Contaminant(s)	Contaminant Level	Location	Collection Date	Reference
				Mean±S.D. **median** **ppb wet weight**			
Bowhead whale (*Balaena mysticetus*)	26[a]	all blubber[b]	oxychlordane	19.9 ± 13.6 16	Barrow	1992-1993	O'Hara et al[80]
			dieldrin	113.7 ± 57.5 105	118		
			trans-nonachlor	36.3 ±16.3 31.5			
			cis-chlordane	18.5 ± 10.0 16.0			
			heptachlor epoxide	27.2 ± 2 14.0			
	25		lindane	23.8 ± 11.7 22.0			
			HCB	88.7 ± 33.9 80.5			
	11	all liver[c]	sum PCBs	34.4 ± 36.5 23.1			
	20		sum DDTs	5.3 ± 2.5 5.3			
	14		oxychlordane	0.8 ± 0.7 0.7			
	20		dieldrin	3.6 ± 1.4 3.5			
	20		trans-nonachlor	1.5 ± 0.6 1.3			
	17		cis-chlordane	0.7 ± .03 0.7			
	17		heptachlor epoxide	1.1 ± 0.4 1.0			
	16		lindane	1.5 ± 0.6 1.6			
	20		HCB	8.1 ± 2.4 8.5			

[a] Blubber was taken from 20 whales; this n is not explained in text and is assumed to represent the number of blubber samples analyzed
[b] blubber from all whales (male plus female)
[c] liver from all whales (male plus female)

Species	Number	Tissue	Contaminant(s)	Contaminant Level	Location	Collection Date	Reference
				ng/g wet weight range mean			
Northern Fur Seal *(Callorhinus ursinus)*	2	blubber	ΣPCB[aa]	275-590 432	North Pacific 16	not given	Becker PR et al[67]
			ΣDDT[bb]	1,090-1,480 1280			
			α-HCH	na			
			γ-HCH	2.8-2.6 14.4			
			cis-chlordane	<1-4.3			
			heptachlor expoxide	15-34 24.5			
			dieldrin	1.2-26 13.6			
				ng/g extractable lipids			
Northern Fur Seal *(Callorhinus ursinus)*	1	blubber	ΣPCB[c]	2320	North Pacific Arctic Ocean /Bering Sea 15	1997	Mössner and Ballschmiter[c]
			ΣHCHs	402			
			ΣDDTs	3748			
				ng/g wet weight mean ± S.D.			
Northern Fur Seal *(Callorhinus ursinus)*	19	dam blood	Total PCBs	14.5 ± 2.6	St. George Island 22	1996	Beckman KB et al[86]
			p,p'-DDE	1.4 ± 0.9			
			p,p'-DDT	<0.2[d]			
			o,p'-DDT	<0.2[b]			
			p,p'-DDD	<0.2[b]			
			o,p'-DDD	<0.2[b]			
			ΣDDT	1.4 ± 0.9			

[a] Sum of 33 congeners[67]
[b] Sum of 2,4'-DDE, 4,4'-DDE, 2,4'-DDD,2,4'-DDT, 4,4'-DDT[67]
[c] The sum of seven (7) PCBs x 4 (based on the assumption that the PCB composition in samples is similar to standard Aroclor mixture).
[d] All samples below this detection limit[77]

Species	Number	Tissue	Contaminant(s)	Contaminant Level	Location	Collection Date	Reference
				ng/g wet weight mean ± S.D.			
Northern Fur Seal *(Callorhinus ursinus)*	48	pup blood	Total PCBs	20.6 ± 6.9[a]	St. George Island 23	1996	Beckman KB et al[86]
			p,p'-DDE	7.8 ± 9.2[c]			
	43		p,p'-DDT	0.7 ± 0.5			
			o,p'-DDT	<0.2[b]			
	45		p,p'-DDD	1.1 ± 0.6			
			o,p'-DDD	<0.2[b]			
			∑DDT	8.0 ± 9.6[c]			
Northern Fur Seal dams and pups *(Callorhinus ursinus)*	22	milk	Total PCBs	433.4 ± 197.8	St. George Island 21	1996	Beckman KB et al[86]
			p,p'-DDE	757.7 ± 450.7			
			p,p'-DDT	35.3 ± 12.9			
			o,p'-DDT	13.6 ± 6.6			
			p,p'-DDD	43.1 ± 16.2			
			o,p'-DDD	17.0 ± 0.0(20)			
			∑DDT	844.3 ± 471.3			
				mg/kg geometric mean S.D. ± 1			
Northern Fur Seal *(Callorhinus ursinus)*	7	milk	PP-DDE	510 ± 1.5	Arctic (Aleutian Islands) 24	1989	Bacon CE et al[85]
			OP-DDE	<0.5			
			PP-DDT	6.1 ± 2			
			OP-DDT	<0.5			
			PP-DDD	<0.5			
			OP-DDD	3 ± 1.5			

[a] Significantly greater than dam blood at P<0.001.[77]
[b] All samples below this detection limit[77]
[c] Significantly greater than dam blood at P<0.001.[77]

Species	Number	Tissue	Contaminant(s)	Contaminant Level	Location	Collection Date	Reference
				ng/g wet weight			
Northern Fur Seal *(Callorhinus ursinus)* *(continued)*	7	milk	*trans*-Chlordane	<0.5	Arctic (Aleutian Islands)	1981	Bacon CE et al[85]
			Heptachlor epoxide and Oxychlordane	2.2 ± 1.3			
			cis-Chlordane	<0.5			
			Dieldrin	<0.5			
Northern Fur Seal *(Callorhinus ursinus)*	2	blubber	∑PCBs[a]	275-590	St. Paul Island 31	1987	Schantz et al[113]
		liver		18-48			
		kidney		17-87			
		muscle		14-30			
Northern Fur Seal *(Callorhinus ursinus)*	7	blubber	∑PCBs	1,343 ± 522	St. Paul Island 32	1990	Krahn et al[84]
Northern Fur Seal *(Callorhinus ursinus)*	9	blubber	∑PCBs	2,100 ± 1,080	Alaska	1990	Varanasi et al[77]
		liver		150 ± 69			
				mg kg^{-1} wet weight			
Ringed Seal *(Phoca hispida)*	1	blubber	PCB	1.78	Alaska	1972	Galster et al[96]
			∑DDT	0.28			

[a] For all citations from Egeland: ∑PCBs = mean value of summed congeners with standard deviation in parethensis when n > 2 (when available). Both actual values listed with n = 2.

Species	Number	Tissue	Contaminant(s)	Contaminant Level	Location	Collection Date	Reference
				ng/g wet weight			
Ringed Seal							
(Phoca hispida)	2	blubber	∑PCBs[a]	686-686	Barrow	1988	Schantz et al[113]
		liver		18-28	28		
		kidney		10-17			
		blubber		371-415	Nome	1989	
		liver		8-9	29		
				å PCB[b] ± S.D.			
Ringed Seal	8	blubber	∑PCBs	330-363 (F=2)	Bering Sea	1989 & 1994	Krahn et al[84]
(Phoca hispida)				249 ± 75 (M=2)	30	1993-1995	
				mg/g lipid			
Ringed Seal							Becker, P.R.
(Phoca hispida)	4	blubber	∑PCB[c]	371-686	Arctic	1992-1995	et al[67]
			∑DDT[d]	35-1,430	17		
			HCB	125-156[e]			
			α-HCH	na			
			γ-HCH	2.4-633			
			cis-chlordane	0.7-103			
			heptachlor expoxide	34-603			
			dieldrin	0.6-122			
			DDTs	0.32-6.83			
			Chlordane	0.32-3.88			
				ng/g wet weight			
				å PCB[f] ± S.D.			
Harbor Seal	5	blubber	∑PCBs	225-240 (F=2)	Prince William	1993	
(***Phoca vitulina***)				599±143 (M=3)	Sound 34		Krahn et al[84]

[a] For all citations from Egeland: ∑PCBs = mean value of summed congeners with standard deviation in parethensis when n > 2 (when available). Both actual values listed with n = 2

[b] Mean value of summed congeners; actual value when n ≤ 2.[12]

[c] sum of 33 congeners

[d] sum of 2,4'-DDE, 4,4'-DDE, 2,4'-DDD, 2,4'-DDT, 4,4'-DDT[3]

[e] n = 2

[f] Mean value of summed congeners; actual value when n ≤ 2.[12]

Species	Number	Tissue	Contaminant(s)	Contaminant Level	Location	Collection Date	Reference
				ng/g wet weight **å PCB[a] ± S.D.**			
Harbor Seal ***(Phoca vitulina)***	7	blubber	∑PCB	21 ± 6	Alaska	1989-1990	Varanasi et al[77]
	9	liver		340 ± 110			
				mg kg^{-1} wet weight			
Bearded Seal ***(Erignatus barbatus)***	1	blubber	PCB	1.78	Alaska	1992	Galster et al[96]
			∑DDT	0.33			
				ng/g wet weight **å PCB[b] ± S.D.**			
Bearded Seal ***(Erignatus barbatus)***	6	blubber	∑PCB	199 (F=1) 153 ± 110 (M=5)	Bering Sea	1993-1995	Krahn et al[84]
			∑NOPCB[c]	.004 ± .002	36		
			∑PCDD	.001			
				ng/g wet weight **Average ± S.D.**			
Steller Sea Lion ***(Eumatopias jubatus)***	9 (M=8) (F=1)	blubber	Sum of PCBs	1149 ± 762	St. George Island	1994-1996	Krone[92]
			Sum of DDTs	2242 ± 1653	37		
			Sum of chlordanes	1354 ± 969			
	2 (M)	blubber	Sum of PCBs	1363 ± 357	St. Paul Island		
			Sum of DDTs	2255 ± 329			
			Sum of chlordanes	1736 ± 305	38		

[a] Mean value of summed congeners; actual value when n ≤ 2.[12]
[b] Mean value of summed congeners; actual value when n ≤ 2.[12]
[c] total non-*ortho* PCB levels [5]

Species	Number	Tissue	Contaminant(s)	Contaminant Level	Location	Collection Date	Reference
				ng/g wet weight **å PCB[a] ±S.D.**			
Steller Sea Lion ***(Eumatopias jubatus)***	29	blubber	∑PCB	4,346 (F=17) 12,580 (M=12)	Alaska	1976-1978	Lee et al[119]
	28	liver		236 (F=15) 513 (M=13)			
Steller Sea Lion ***(Eumatopias jubatus)***	8	blubber	∑PCB	23,000 ± 37,000	Alaska	1985, 1989, 1990	Varanasi et al[118]
				mg/kg wet weight **Mean ± S.D.**			
Sea Otters ***(Enhydra lutis)***	7	liver tissue	∑PCBs	8 ± 14	Southeast Alaska 18	1988-1992	Bacon CE et al[39]
			∑DDT	1 ± 3			
			∑chlordane	1 ± 1			
			∑NOPCBb	.004 ± .002			
			∑PCDD	.001			
			∑PCDF	ND[b]			
			p,p'-DDE	1 ± 3			
			HCB	1 ± ND			
			β-HCH	6 ± 3			
			Dieldrin	2 ± 4			
Sea Otters ***(Enhydra lutis)***	7	liver tissue	∑PCBs	310±480	Aleutian Islands (Adak and Amchitka) 19 20	1988-1992	Bacon CE et al[39]
			∑DDT	36±500			
			∑chlordane	15±97			
			∑NOPCB[c]	.028±.076			
			∑PCDD	.001±.001			
			∑PCDF	.001±ND			
			p,p'-DDE	36±500			
			HCB	2±4			
			β-HCH	5±16			
			Dieldrin	3 ± 5			

[a] Mean value of summed congeners; actual value when $n \leq 2$.[96]
[b] ND=not detected
[c] total non-*ortho* PCB levels [115]

Species	Number	Tissue	Contaminant(s)	Contaminant Level	Location	Collection Date	Reference
				mg kg^{-1} wet weight Mean			
Pacific walrus *(Odobenus rosmarus divergens)*	4	blubber	PCB	1.78	Alaska	1972	Galster et al[96]
			∑DDT	0.08			
				Mean ± S.D. ppm wet weight			
Pacific walrus *(Odobenus rosmarus divergens)*	53[a]	blubber	Dieldrin	0.05 ± 0.11	Gambell, Savoonga, Little Diomede, Nome, Wales, *Zakharovo*[b]	1981-1984	Hamilton, E.I.[97]
Pacific walrus *(Odobenus rosmarus divergens)*	53[c]	blubber	Oxychlordane	0.04 ± 0.08	Gambell, Savoonga, Little Diomede, Nome, Wales, *Zakharovob*	1981-1984	Hamilton, E.I.[97]
				average ppm range wet weight			
Polar Bear *(Ursus maritimus)*	24		S-PCBs	2.41 0.90-5.06	Beaufort Sea and Chukchi/ Bering Seas	2000	Marine Mammals Management Office[63]
			S-HCH	0.87			

[a] M=44, F=18
[b] The *Zakharovo* was a Soviet ship which collected samples in Soviet waters (near Arakamchechen Island) near Alaska.
[c] M=44, F=18

Species	Number	Tissue	Contaminant(s)	Contaminant Level	Location	Collection Date	Reference
				μg kg^{-1} lipid wt. geometric mean range			
Polar Bear (*Ursus maritimus*)	16 (F)	adipose (blubber)	ΣPCB	5,535 1,001-28,723	Wrangel Island (Russia) Chukchi Sea	1993	Norstrom et al[101]
			DDE	298 46-2,911	124		
			Dieldrin	31 7-217			
			ΣChlordanes	1,016			
Polar Bear (*Ursus maritimus*)	1(M)	adipose (blubber)	ΣPCB	2,849	Wrangel Island (Russia) Chukchi Sea	1993	Norstrom et al[101]
			DDE	120			
			Dieldrin	36			
			ΣChlordanes	923			
Polar Bear (*Ursus maritimus*)	6 (F)	adipose (blubber)	ΣPCB	2,058 1,478-2,883	Bering Sea and Bering Strait south of the Arctic Circle, Chukchi Sea, and Goodhope Bay, Alaska Coast to 155°W	125 126 1988-1990	Norstrom et al[101]
			DDE	91 66-144			
			Dieldrin	42 21-114			
			ΣChlordanes	1,396 839-1,877			

Species	Number	Tissue	Contaminant(s)	Contaminant Level	Location	Collection Date	Reference
				mg kg^{-1} lipid wt. geometric mean 95% C. Limits range			
Polar Bear (*Ursus maritimus*)	3 (M)	adipose (blubber)	∑PCB	2,380 1,999-2,834 2,104-2,958	Bering Sea and Bering Strait south of the Arctic Circle, Chukchi Sea, and Goodhope Bay, Alaska Coast to 155°W	1988-1990	Norstrom et al[101]
			DDE	90 54-151 53-162			
			Dieldrin	51 20-128 16-107			
			∑Chlordanes	1,053 279-3,982 393-5,495			

whales in the same areas, but overall, two conclusions are noteworthy. First, concentrations of these contaminants in stranded whales showed little relation to the levels of the chemical contaminants at the stranding sites. This is assumed to be related to migratory patterns, which means that contaminants can be taken in over the entire range of the whale and that it is not necessarily possible to know from where they came. Second, as may have been expected, concentrations of potentially toxic chemicals in tissues were relatively low when compared with the concentrations of tissues of marine mammals feeding on higher trophic level species.

In later data, unpublished but reported on at a scientific meeting, Tilbury et al[78] reported on concentrations of organochlorines in tissues collected from younger **gray whales** that were harvested for subsistence from their Arctic feeding grounds in the western Bering Sea. They found no differences in the concentrations (based on wet weight of tissue) of contaminants between the female and male subsistence animals. Concentrations of the sum of PCBs from samples taken from young whales found stranded compared to the whales harvested were significantly different, with higher mean concentration in the stranded whales. The authors believe these differences may be due to the whales' feeding and fasting patterns rather than to increased exposure.

Bowhead whales are also baleens with a feeding strategy similar to that of gray whales. Overton et al[79] analyzed tissue samples from seven subsistence bowhead whales harvested in the North Slope Borough in 1979 and 1980. The highest level of contaminants were found in the blubber, with only traces of PCBs in the tissues of other organs. The PCB concentrations reported were very low (see Table 8), near but not as low as the lowest levels reported in whales in other studies in the same time period. Mössner and Ballschmiter[73] looked at bowhead whales in their study of marine mammals and organochlorines, and concluded that there was a clear correlation between the total organochlorine burden of the marine animals they analyzed and the position of those animals in the marine food chain. The levels they reported (see Table 8) for the bowhead were significantly lower than the predatory seals and toothed whales, which reflects the bowhead's position lower on the marine food chain.

O'Hara et al[80] measured organochlorine levels in livers and blubber of bowhead whales collected during the Eskimo subsistence harvest at Barrow (Alaska, USA) in 1992 and 1993. Findings of interest from this study were that the sum of DDTs in the bowhead livers was significantly greater in male whales than in females (see Table 8), and that most of the organochlorines measured were at higher levels in longer (older) than in shorter (younger) males. In female bowhead whales, hexachlorobenzene and lipid levels decreased and other OC levels did not change significantly with increasing length.

In general, the authors concluded that the levels found in these bowhead whales were relatively low, especially as compared to previously reported levels in various species of whales, from studies in other parts of the Arctic.[81] They note that results of their study are consistent with the reduction of chemical body burdens during pregnancy and lactation, as females showed no increase in tissue levels with length (an indicator of age). Based on the findings of this investigation, the authors believe that no adverse effects would be expected in either the whales or in humans who consume them from these contaminant levels, although they commented that chlordane levels in bowhead whale blubber were high enough to suggest monitoring of the amount of blubber eaten on a daily basis. They conclude, however, that more complete investigation of low level chronic exposure effects are necessary to determine with better certainty what the true "no effect" level is.

Levels found in a group of transient **killer whales** (*Orcinus orca*) in Alaska, however, were surprisingly high (Table 8) compared to a similar group of resident killer whales in Prince

William Sound. In this study by Matkin et al,[82] PCB levels averaged fourteen times higher, and DDT levels averaged twenty-two times higher in the transient whales, in concentrations that were comparable to levels found in beluga whales in the Gulf of St. Lawrence in eastern Canada. The authors express concern that contaminants could interfere with the ability of the transient group to thrive and grow. These findings are extremely significant and provide a counterweight to the findings by Becker et al[67] with regard to lower levels in whales in Alaskan waters.

More information is available about **seals** in Alaska. Several reports are available on contaminant levels in **Northern fur seals** (*Callorhinus ursinus*), and levels from these data in addition to data regarding various POPs in **harbor seals** (*Phoca vitulina*), **ringed seals** *(Phoca hispida)*, and **bearded seals** (*Erignatus barbatus)* are included in Table 8. The seal is a particularly important marine animal because it has the potential to contribute contaminants for biomagnification to a number of different species who eat it. In its somewhat central position on food chain, it consumes lower-trophic fish and bioaccumulates contaminants in this way. Then, as prey to animals such as walrus and polar bears, as well as **humans**, for whom seals represent an important subsistence species, it is also a source of contaminant transport. In addition, humans also eat the walrus and polar bears who eat the seals. As can be seen in Table 5, four seal species are on the list as being harvested in greater than 20 pounds per person by at least one Alaska Native community. Information about the amounts and impacts of POPs in seals is therefore of great interest.

In one study of **harbor seals** specifically, Miles et al[83] looked at blubber, kidney, and liver samples taken from twenty-three seals in the Kodiak Archipelago in the Gulf of Alaska. Of the thirteen organochlorine compounds for which analysis was done, only total PCBs, and the pesticides DDT, DDE, and oxychlordane were detected. PCBs were found in 21 of 22 blubber samples, and there was no difference in the concentrations between males and females. DDT was significantly higher in males than in females and was found in 68% of the seals. DDE was found in all samples, and oxychlordane was found in 55% of the samples. DDE and oxychlordane were higher in males than in females. The levels of the contaminants found were relatively low, however, less than 3 ppm, except for PCBs which ranged from undetectable to 6.6 ppm (geometric mean = 2.2 ppm).

More studies of the Northern fur seal were found. Three studies that analyzed PCBs in the blubber, liver, kidney and muscle of Northern fur seals are reported in a chart in Egeland et al.[6] Becker et al[67] included these seals in their report on tissues archived in the NBSB, and Krahn et al[84] analyzed organochlorine contaminants in the blubber of four species of seals in Alaska, including the Northern fur seal. Krahn et al. found that Northern fur seals from the Pribilof Islands (St. Paul Island in the southern Bering Sea) had higher contaminant levels of some organochlorines (∑PCBs, ∑DDTs, ∑chlordanes, HCB and dieldrin; Table 8) than concentrations in harbor seals from Prince William Sound or ringed and bearded seals from the Bering Sea. They suggested that differences in contaminant concentrations among these seals may be explained by differences in feeding habits and migratory patterns, as age or gender did not seem to explain the differences observed. The prey of fur seals comes from the upper levels of fish on the marine food chain (pollock, herring, squid). In addition, fur seals migrate seasonally as far as Japan and down the North American coastline as far south as California, which would allow them to be exposed to higher levels of contaminants. This study also noted that lower blubber concentrations in adult female seals is due to elimination of OCs during lactation.

Bacon et al[85] reported similar findings (Table 8) in their report comparing organochlorine and PCB levels in the milk of five species of pinnipeds: California sea lions, northern elephant seals, Australian sea lions, Antarctic fur seals, and Northern fur seals. Although all samples had detectable levels of DDE and PCBs, the animals from Australian and the Antarctic were the lowest and those from California were the highest (1400 ppb DDE geometric mean in sea lions). The DDEs in fur seals from the Aleutian Islands were only 2.5 to 3 times lower than the California samples, compared to a (geometric) mean of 12 ppb in Antarctic seals. The authors conclude that additional toxicological studies are needed to focus on whether chemicals such as POPs are affecting the abilities of marine mammals to reproduce.

Beckman et al[86] explore this issue in greater detail. They present an important discussion on the question of whether the poor survival of the young in the Northern fur seal population at St. George Island may be related to exposure to environmental organochlorine contaminants detected in fur seal milk and pup tissues. They note that pup production on St. Paul Island experienced a decline of about 7% during the eight years 1975-1983, and on St. George Island pup production declined approximately 4.7% *a year* from 1970 until 1994, and they cite studies on harbor seals in other marine areas which showed various OC-related toxic effects including problems with reproduction and the immune system.

These findings are important because suckling and lactation are the primary route of exposure to POPs for newborns, as well as the major route of elimination of these contaminants in the nursing mother. The authors note that transfer of high concentrations of lipophilic OCs (that is, chemicals that preferentially accumulate in fatty tissue) through the fat-rich fur seal milk could threaten the critical early development of fur seal pups. As several reports have been published documenting the high levels of PCBs and other POPs in the breast milk of Inuit women in the Canadian Arctic,[87, 88, 89] whose diets are similar to those of Alaska Natives, it is clear that this is an issue of concern which has significant implications for human exposures as well.

The levels Beckman et al reported are found in Table 8. Their results showed that firstborn Northern fur seal pups are exposed to milk with higher concentrations of OCs than the pups of dams who have previously given birth, and that firstborn pups had significantly higher organochlorine blood concentrations. They concluded that, based on the levels they found, concentrations of some PCB congeners and DDT metabolites have not only not decreased, but increased, in Northern fur seal milk, lending support to the possibility that PCBs continued to enter the marine environment at least into the mid-1990's. Although not discussed by the authors, one question of continuing concern is whether the relatively lower levels of POPs contaminants now seen in several marine species in Alaska will rise in the coming decades.

The same authors[90] followed up on this research with an investigation into whether immune function or other health effects were correlated with environmental organochlorine contaminant exposure. They wanted to know whether the pups from St. George Island suffered from immune suppression or poor health. Preliminary results indicate that, as newborns, pups with younger dams (and therefore higher levels of OCs in their breast milk) have higher PCB exposure and diminished immune response than pups with older dams and lower PCB exposure.

With regard to harbor seals, a particularly useful document on marine mammals is published by the National Institute of Standards (NIST). A review with annotated bibliography, *Alaska Harbor Seal* (Phoca vitulina*) Contaminants*,[91] this publication includes an excellent synthesis of the information in the literature. It includes background data, helpful explanations about POPs and heavy metals contamination, several useful graphs and tables, and a presentation of levels found in different locations where available. The comprehensive annotated bibliography has 152 references.

Less data is available regarding other species of marine mammals such as **sea otters** (*Enhydra lutris*) and **Steller sea lions** (*Eumatopias jubatus).* POPs contaminants have been found at very high levels in sea otters and Steller sea lions in the Aleutian Islands, compared to levels in comparable populations in other areas (Table 8). Stellar sea lion levels are taken from a table in

Egeland et al[6] and unpublished data from the Environmental Conservation Division of the Northwest Fisheries Science Center at the National Marine Fisheries Service in Seattle, WA, reported in 1997.[92] Contaminant levels in Steller sea lions are of concern because of the decline of these populations in the western Aleutian Islands.[93]

Bacon et al[39] reported that levels of organochlorine pesticides, PCBs, PCDDs (dioxin), and PCDFs (furans) were measured in the livers of sea otters collected between 1988 and 1992. Although levels of summed DDTs were significantly higher in California sea otters than in either Alaskan population, total PCB levels in Aleutian otters were 1.7 times higher than the levels in California otters, and 38 times higher than levels from otters in Southeast Alaska. The authors note that this result was surprising, because of what they characterized as the remote and presumably pristine nature of the western Aleutian Islands. They acknowledge that point sources from military installations may be involved, as otters in the study were selected solely from islands with a history of military presence, and it is unknown what the levels are from otters from non-military sites. It is also believed that atmospheric deposition and transport by oceanic currents contribute to contamination of the area.

Little data has been presented on the status of the **Pacific walrus** *(Odobenus rosmarus divergens)* in Alaska. Wiig et al[94] have recently published a paper on the use of skin biopsies and blubber for assessing levels of OC in walrus, and have found that the correlation between levels in the two types of tissues was significant. Levels from earlier studies[95, 96] have to be taken with some caution because of the changes in methods and technologies since they were reported.

Similarly, while the status of the **polar bear** in other areas of the Arctic has been well-studied, little data has been published on polar bears in Alaska.[3, 97] The polar bear, as a top predator, like humans, may be at increased risk from chronic exposure to PCBs and other POPs in its diet, hence the lack of data for Alaskan bears is of concern. Recent press reports have heightened concern. In September, 2000, it was reported by the BBC News that "scientists on Svalbard have found that more than one in a hundred of the island's polar bears are hermaphroditic."[98] The cause was attributed to exposure to PCBs, which have been known to affect the immune, endocrine, and reproductive systems in laboratory animals. This was not the first report[99] of this problem among polar bears at Svalbard; however, this article reported that 1.2% of the island's 3,000 bears have now been found to be affected.

Just weeks after this report, abnormalities in polar bears were reported in the results of a survey done by the Qikiqtaaluk Wildlife Board and the World Wildlife Fund in Nunavut, Canada.[100] This survey was initiated in 1998 following reports of sick or deformed wildlife in the Baffin Island region of Canada. Abnormalities such as swollen internal organs, wounds, and scars were found in **caribou, seal, walrus, beluga whale, narwhal,** and **polar bear** by thirty-one hunters and elders in four Nunavut communities. Abnormalities in polar bears also included wasting, which has been shown to be correlated with exposure to PCBs in animals. Although this data is considered "anecdotal," it reflects a combined total of nearly 800 years of hunting experience, which is being used in conjunction with mainstream science techniques to analyze the information. Moreover, these reports come from an area where levels of PCBs have been shown to be elevated in the breast milk and blood of Inuit women[87-89] and where harvesting of subsistence species continues to be an important dietary component.

Limited data on polar bears is presented in Table 8, including that from the ongoing study on contaminants being conducted by the Marine Mammals Management Office in Alaska.[63] Levels of PCBs found so far are not high relative to levels found in Hudson Bay, Canada, and Svalbard, Norway, two areas with some of the highest documented levels in polar bears.[3] On the other hand, mean levels of S-HCH[a] for the twenty-four bears recently analyzed were similar to the high levels reported for the Chukchi and Bering Seas. The levels of S-HCH in Chukchi and Bering Sea polar bears are among the highest reported in the Arctic region. Norstrom et al [101] noted that concentrations of ∑PCB, ∑chlordanes, DDE, and dieldrin in the polar bears they studied from the Bering, Chukchi, and western Beaufort Seas—all of which are considered to inhabit Alaskan territory—tended to be among the lowest in the study area. Additional polar bear studies in Alaska are critical for a more accurate picture of actual conditions.

POPs and Human Health: Health Studies in Alaska

Health effects from exposure to POPs have been well-documented in animals and in humans. Body burdens in many regions of the world, including in North America, are at levels at which health effects were seen in animals with lower or comparable levels. POPs have been shown to have neurological and neurodevelopmental effects, particularly in infants whose mothers ate Great Lakes fish contaminated with PCBs; they have been shown to have reproductive effects, immune system effects, and endocrine effects, and many of them either cause cancer or promote potential tumors. While levels in the Alaskan Arctic remain relatively low compared to other areas, it is not known whether there is any actually "safe" level, or threshhold level, below which these contaminants have no effect.

Reports describing high levels of PCBs and other POPs in the meat and blubber of animals that are significant parts of the traditional indigenous diets have raised concerns. A study[102] of the dietary patterns of Baffin Island Inuit women and two communities representing the Sahtu Dene/Metis in the western Canadian Arctic reported that the amounts of traditional foods such as ringed seal, walrus, mattak, narwhal, caribou, whitefish, trout, and duck eaten exceeded Canadian government acceptable daily intake levels. High concentrations of POPs have been found in the blood and breast milk of populations living in the Canadian Arctic.[87-89] The bulk of human health studies—too numerous to detail in this report—on the effects of exposure to POPs have been done in the Great Lakes region of the U.S. and Canada among fisheaters, primarily fishermen and their families, including a cohort of women and infants in Michigan about whom the Jacobsons have written several reports,[103,104,105,106] and among the First Nations and Inuit in Canada.[2]

Similar investigations are very few. In 1996 a preliminary study of maternal and cord blood samples from Alaska native women and infants in the North Slope Borough (NSB) in Barrow and the Yukon-Kuskokwim Delta (YKD) was carried out by the Community Health Service of the Alaska Area Native Health Service (AANHS).[107] Both populations get much of their traditional foods from the ocean, although each is exposed to a different marine ecosystem. The YKD is near the Bering Sea, whose currents are influenced by the Japanese Current. Barrow residents are adjacent to the Arctic Ocean, which has virtually no input from the Japanese Current. Instead, major inputs come from Russian rivers, Atlantic Ocean water, and North American rivers.

Results of the AANHS testing are shown in Table 9, "POPs Concentrations in Human Serum and Cord Blood in Alaska." Mothers and infants from Barrow had different mixtures of compounds in their blood than the infants from the YKD. Some Barrow samples had PCBs and all had HCB and DDE, both of which are wide-spread in the Northern Hemisphere. In contrast, the infants from the upriver area of the YKD had no detectable levels of HCB in their blood. One of the more surprising findings was that the DDE levels for the different groups of infants were

[a] S-HCH=sum of hexachlorocyclohexanes, which include the isomer γ-HCH, more commonly known as lindane.

Table 9
POPs Concentrations in Human Serum and Cord Blood in Alaska

Study Population	Tissue	*N*	Contaminant	Contaminant Level	Location	Collection Date	Reference
				Average ppb			
Alaska Native Infants	Cord blood serum	20	DDE HCB	0.33 0.087	Barrow 127	1996	Berner[107]
		12	DDE HCB	1.40 0.15	Yukon-Kuskokwim Upriver 128		
		38	DDE HCB	1.43 None detected	Yukon-Kuskokwim Coastal 129		
		Not given	DDE	1.18	Canadian Inuit (for comparison)	Not given	
				(mean assumed) in ppb			
Alaska Native Women (mean age = 57)	Serum (blood)	63 breast cancer cases	DDE	6.01	Various areas of Alaska	Mean year of serum collection was 1985	Rubin and Lanier[108-9]
		63 controls	DDE	5.51			
				Mean serum level ± S.D. maximum individual level in ppb			
Alaska Native Women (mean age=57)	Serum (blood)	126	PCB	4.6 ± 4.0 17.7	Various areas of Alaska	Mean year of serum collection was 1985	Rubin and Lanier[108-9]
			p,p'-DDE	6.4 ± 3.3 19.4			
			β-HCH	0.03 ± 0.2			
			γ-HCH (Lindane)	Maximum reported: 0.8			
			Dieldrin	0.01 ± 0.1			

Study Population	Tissue	*N*	Contaminant	Contaminant Level	Location	Collection Date	Reference
				(not lipid-adjusted ppb) Mean ± S.D. Median Range	**Village**		
Alaska Native Adults	Serum	11	Total PCBs	8.4 ± 5.8 5.5 2.8-17.9	Akutan 131	1999	Middaugh et al[110]
		30		14.7 ± 13.5 8.0 0-53.7	Atka 132		
		10		6.0 ± 3.6 8.0 0.9-12.7	Nikolski 133		
		19		7.1 ±7.0 6.6 0-29.6	St. George 134		
		96		5.7 ± 6.9 3.4 0-42.3	St. Paul 135		
Women of Childbearing Age		40		2.9 ± 3.5 2.0 0-14.9	All five villages combined	1999	Middaugh et al[110]
Adult Native Alaskans		51	β-HCH	0.424 ± 0.434 0.260 0-2.059	Three Aleutian villages	1999	Middaugh et al[110]
			Heptachlor epoxide	0.147 ± 0.198 0.000 0-0.740			
			Oxychlordane	0.980 ± 1.058 0.488 0-4.063			
			trans-Nonachlor	2.206 ± 2.642 1.061 0-12.392			
			p,p-DDE	10.622 ± 8.759 7.782 0.543-33.482			
			Dieldrin	0.066 ± 0.113 0 0-0.531			
			p,p-DDT	0.083 ± 0.121 0 0-0.428			
			Mirex	0.143 ± 0.204 0 0-0.795			

different. The levels for the YKD infants were the highest recorded in infants anywhere in the circumpolar region; for comparison, the Canadian average was 1.18 ppb. Because DDT is still used in Southeast Asia, it is hypothesized that DDE could be moving north from the Asian river systems via the Japanese Current. The study of maternal and infant cord blood is ongoing in Barrow and Bethel, and it will be interesting to see future reports.

A pilot study on breast cancer and organochlorines was carried out in 1996[108,109] with 126 Native Alaskan women, 63 of whom had been diagnosed with breast cancer, and 63 of whom did not have cancer but had banked blood samples that could be used for comparison. The levels found are shown in Table 9. PCB levels in the control group were higher than those in the group of women with breast cancer, but as the authors point out, the study had several limitations that must be considered in interpreting the results. The sample was small and included women from selected areas of the state. It was therefore not representative of all Alaska Native women. Also, all the blood used in the study had been collected three to eight years prior to diagnosis and the study did not give any information about whether exposures had increased or decreased over time.

PCBs were not detected in the blood of every participant in the study. They were detected in more of the coastal women than in women from the interior, which makes sense if the greatest exposure pathway is through the consumption of marine mammals and fish. All women in the study had detectable levels of the pesticide metabolite DDE, but not all had DDT. This finding suggests that the exposures may have occurred sometime in the past or that women were being exposed more to metabolized DDT in the environment. It takes DDT seven years to metabolize to DDE. Other POPs reported were β-HCH, γ-HCH (lindane), and dieldrin.

The third Alaskan study was the largest, encompassing five villages in the Aleutian and Pribilof Islands. In 1998, Middaugh et al[110] tested blood from a total of 166 people (see Table 9). They found that the median PCB levels in the Alaskan population were quite similar to the current reference range for the U.S.: 5 to 7 parts per billion.[110] PCB levels were strongly associated with age and were higher among older persons and, in general, higher in men than in women, which, it should be noted, is a similar pattern to that found in several of the marine mammal species. The findings were also compared with an AMAP study of maternal blood PCB levels from six other circumpolar countries. PCB levels in women of childbearing age from the five villages were similar to the levels found in the AMAP study.

Exposure of the Aleutian Island donors to dioxins, furans, and co-planar PCBs (also called “dioxin-like” PCBs) was found to be lower than that of populations in the rest of the United States, not including Hawaii. With regard to pesticides, levels were highest for DDE and were strongly associated with age. Among circumpolar countries, levels of *trans*-nonachlor and oxychlordane were highest in maternal plasma from Greenland and second highest in the Aleutian Island participants. The authors emphasized that although they did compare their findings to median U.S. levels, their results could not be considered characteristic of the Aleutian and Pribilof Islands as a whole and should therefore not be generalized to the greater community. The test group was not a random sample of the entire population. Also, because different laboratories use different methods to measure POPs, it would be difficult to compare the findings from this study to other results using different methods.

Synopsis of Ongoing Research on the U.S. Arctic

When AMAP published its first major report on the status of Arctic pollution in 1997, many were disappointed at the lack of information included about Alaska. Since that time, it has become clear that several research projects encompassing a range of investigation into the contamination of the U.S. Arctic are ongoing. In addition, the Environmental Conservation Division of the National Marine Fisheries Service at NOAA has undertaken the creation of a comprehensive database that will begin in 2001 to collect information about all research on the U.S. Arctic and will format the data in a way that it can be sent to the AMAP Thematic Data Centres.[111] Once this database is operational, it will be a key link in tracking the progress and scope of research in Alaska.

The Interim U.S. AMAP National Implementation Plan, from the summer of 1999, is a central document in terms of presenting an overview of ongoing research in the U.S. Some discussion of the Alaska Marine Mammal Tissue Archival Project occurred earlier in this report; AMMTAP continues as a major center of research. A related project, which will mirror the AMMTAP in purpose and procedure, is the Seabird Tissue Archival and Monitoring Project (STAMP). This project is a partnership between the U.S.G.S., NIST, and the U.S. Fish and Wildlife Service.

The Institute of Social and Economic Research of the University of Alaska Anchorage, in cooperation with the Alaska Native Science Commission, has been compiling a Contaminants and Native Foods Database, funded by the U.S. Environmental Protection Agency. Ongoing consultation and discussion with Alaskan communities to identify local concerns as well as traditional knowledge about the environment and contaminants is an integral aspect of database development. The database itself includes ongoing compilation of scientific data about contaminants in species of interest, collection and presentation of data about the consumption and harvest of subsistence foods by village (Tables 2-5), and discussion of the nutritional value of these foods.

Several other research programs are housed by the University of Alaska, in both Anchorage and Fairbanks, including the Cooperative Institute for Arctic Research in Fairbanks, and the International Union of Circumpolar Health[112] in Anchorage, which includes an Environmental Health Working Group as well as a several other working groups within whose frame of interest the human health effects of POPs will be addressed.

The Bering Sea Ecosystem Research Plan, a joint project of the Alaska Fisheries Science Center, the U.S. Department of the Interior, and the Alaska Department of Fish and Game, is an extensive, coordinated research initiative looking at significant changes in biology and ecology that appear to be occurring in the Bering Sea. Testing and monitoring for contaminants is one of the areas within this larger initiative.

Polar bear studies continue under the auspices of the Marine Mammal Management office in Fairbanks. Other studies planned out of this office include the annual survey of malformed frogs, an effort to look at bill deformities in several bird species, an ongoing project to collect and analyze loon eggs, which revealed high concentrations of organic contaminants, and technical assistance to the Alaska Sea Otter and Steller Sea Lion Commissions.

Health studies are also ongoing in Alaska, although they continue to be few in number. The Alaska Native Tribal Health Consortium has an ongoing study in the North Slope Borough and the Yukon-Kuskokwim Delta to look at maternal and cord blood of mothers and newborn infants, which, as noted earlier, will also be expanded to other coastal areas.

In addition, significant research is continuing internationally to increase the overall body of knowledge with regard to the Arctic; the inclusion of Alaska into many of these projects is certain, as there remains a tremendous deficit of knowledge as to whether earlier findings about the behavior and fate of contaminants in Arctic environments in different areas will also hold true in the Alaskan and western Arctic conditions.

Where Are the Gaps in Our Current Knowledge?

More than anything, it would seem, this review has demonstrated that there are virtually no areas of research in the Alaskan arctic in which there no gaps. In a sense, the gaps define the landscape. Fish represent almost 60% of the subsistence diet of most Alaska Natives, particularly salmon, and there are virtually no studies at all that have comprehensively measured the contaminant levels in salmon in the areas where they are most frequently harvested. Terrestrial animals contribute significantly to the diets of many Alaska Natives living in the interior, and there are no studies that have looked in depth at the degree and scope of contamination in non-marine wildlife. It may be that, as suspected by many researchers, caribou and moose have not been impacted in a significant way by non-point source contamination—that is, from contamination that has been transported via the air or water from far away. It may be that if terrestrial mammals and other animals are impacted, it is from past military or industrial use of chemicals.

There is an enormous gap in the overall assessment of whether the Alaska Native population has been significantly exposed to POPs and whether health effects have been seen in Native populations. This is in dramatic contrast to the degree of investigation that has been undertaken both of the First Nations and the Inuit people in Canada, and of fisheaters throughout the Great Lakes region in the U.S. and Canada. Findings in those populations have provided a solid foundation for hypotheses for investigations in the Alaskan Arctic, and those investigations are overdue.

Another major gap exists regarding the behavior and fate of POPs and other contaminants in the western Arctic ecosystem, extending from Alaska to Russia. The range of many animals encompasses both Russian and U.S. waters, and the impacts of POPs contamination from Russian rivers may have significant effects on Alaskan animal and human populations. The low levels of some contaminants currently seen in the Alaskan Arctic may indicate that the patterns seen in the Canadian Arctic and the North Atlantic in Europe will not be replicated in the west; on the other hand, these low levels may only represent the earliest warnings of increasing future levels.

One of most significant barriers to the development of a coherent body of knowledge regarding the U.S. Arctic has been the lack of a well-organized, centrally coordinated effort to collect existing information, facilitate the development and direction of needed research, and leverage funding. In the U.S., in contrast to the Canadian Northern Contaminants Programme, for example, there is no single program under which all Arctic research activities and data reporting are collated and managed in one place, under the aegis of a single program. Funding and research have never been coordinated to maximize resources and personnel. The lack of dedicated, aggressive, attention and resources directed at Arctic research in the U.S. represents the greatest gap of all. As the federal agencies, Native organizations, and other public interest groups noted unequivocally in the interagency collaborative paper entitled *Contaminants in Alaska: Is America's Arctic at Risk?*:

> **The United States lacks a strong national Arctic contaminant research and monitoring program, thus research and public education lags far behind most other Arctic nations, and we have many unanswered questions regarding the extent and significance of this contamination.**[93]

Conclusion

A picture of POPs contaminants in Alaska is beginning to take shape. The outlines are clear: POPs contamination is ubiquitous throughout the marine areas of the U.S. Arctic, just as it has become in the Great Lakes, the rest of the U.S., and most of the rest of the globe. The **marine food web** has become contaminated, but whether this contamination extends into the interior of Alaska and encompasses terrestrial animals to the same extent is unknown. It is one of many questions that remain to be investigated, and it represents what can be seen as the first of many blank spots that prevent the whole picture from being seen in its desired clarity.

As the AMAP[4] report points out, there is an inadequate understanding not only of the ways long-range global transport of chemicals occur, but of how to measure them. AMAP lists more than a dozen gaps in information regarding the Arctic as a whole, ranging from the need for a better understanding of inputs into the Arctic, to information about long-range trends, to knowledge about combined effects of contaminants on biota and humans at both the ecosystem and individual levels. All of these gaps apply to the U.S. Arctic as well.

The 1997 AMAP Report States Several Important Conclusions Relevant to Alaska

- Outside of the Arctic, sources exist for a number of the persistent organic pollutants (POPs); the main contaminants of concern are organochlorine pesticides and their metabolites from agricultural activities; industrial chemicals (such as PCBs); and anthropogenic and natural combustion products (such as dioxins and furans and polycyclic aromatic hydrocarbons).
- Over much of the Arctic, the levels of POPs cannot be related to known use or releases from sources within the Arctic and can only be explained by long-range transport from lower latitudes.
- Certain Arctic populations are among the most exposed populations in the world to certain environmental contaminants.
- The Arctic is a focus for major atmospheric, riverine, and marine pathways that result in the long-range transport of contamination into and within the Arctic. The Arctic is, therefore, a potential contaminant storage reservoir and/or sink. Various processes remove these contaminants from the atmosphere, oceans and rivers and make them available to plants and animals. Food chains are the major biological pathways for selective uptake, transfer, and sometimes magnification of contaminants by Arctic plants and animals, many of which are subsequently consumed by Arctic peoples.
- Freshwater and marine ecosystems contain higher levels of POPs than terrestrial ecosystems due to longer and/or complex food webs. Biomagnification of POPs is especially important in food webs dominated by organisms with high fat content.
- Contaminant levels in some Arctic birds and mammals exceed some thresholds associated with reproductive, immnosuppressive, and neurobehavioral effects in laboratory animals and some studies wildlife species. Biomagnification is a major factor influencing species exposure, with the long, marine-based food webs being particularly vulnerable. In contrast, migratory birds are vulnerable through overwintering in polluted environments at mid-latitudes and/or from consumption of other contaminated migratory birds.
- Based on the best available information, levels of PCBs and DDT decreased in the subarctic from the 1970's to the 1980's. However, trends for the 1980's and beyond are less clear. Data on trends in the high Arctic are lacking.
- Exposure to POPs, radionuclides, cadmium, and methylmercury are of concern for people living in the Arctic.
- Information for Alaska, like that for Russia, is not adequate to allow for identification of areas of concern within the Arctic.

There are major gaps in information about contamination in all the environmental media in Alaska: **air, water, ice, snow, and soil.** The recent report on long-range air transport of dioxin from North American sources to the Canadian Arctic[120] is one example of the the kind of research that is lacking with regard to the U.S. Arctic. The few studies that exist on environmental impacts of POPs have shown that pesticides are in the **fog and atmosphere** in the Bering and Chukchi Seas,[20] that the **fish and sediments** in some Alaska arctic lakes are contaminated with PCBs and other organochlorine chemicals for which there is no local source,[23, 24] and that marine animals from **mussels** up the food chain to **sea lions** in the Aleutian chain have detectable contaminant levels. **Polar bears, seals**, and **whales** as well, have all been affected.

Many of the studies reviewed in this report have taken care to note that levels found are still relatively low, especially compared to contamination levels observed in the Canadian and European Arctic regions. It is important that these conclusions be understood in the context of the relatively undeveloped body of knowledge that exists about Alaska at the present time. Moreover, POPs that have been banned more recently in the U.S. are likely to continue to accumulate (for example, toxaphene) and those that have not yet been banned in the U.S. (such as lindane) will continue to be a problem into the future. PCBs, although they were banned in many countries over twenty years ago, are yet another problem. Some estimates project that as much as two-thirds of the PCBs ever produced are still potentially available to the environment from landfills, abandoned electrical equipment, former military facilities, and other sources. In addition, there are many POPs that are still in use in other parts of the world, notably DDT and other pesticides, and the production of dioxin and furans continues worldwide with few controls in many areas as the result of incineration and various industrial processes. Low levels at the present do not assure low levels in the future. A strong U.S. role in reducing and eliminating emissions of these substances throughout the world is essential to reduce risks to Alaska over the long term.

In Alaska, as in many other Arctic areas, the implications of the widespread contamination of the food web have serious implications for indigenous populations who rely on traditional foods as dietary staples. Additional research is necessary into levels of contamination in important food sources such as salmon and other fish, waterfowl, caribou, moose, and other animals relied upon. The part of the Alaskan picture that is extremely clear is that Alaska Natives are at particular risk of high exposures to bioaccumulated POPs in the foods they eat. Levels of DDE in infants from the Yukon-Kuskokwim Delta are already the highest recorded in infants anywhere in the circumpolar region. If these levels are due to continued use of DDT in Asia and Africa, there is little likelihood that the levels will fall in the future. Part of the picture that is still missing is a comprehensive assessment of potential health effects from POPs in Alaska Natives.

As the joint statement above[93] from the U.S. government agencies, Alaska Native organizations, and environmental groups emphasized, the U.S. lags far behind the rest of the Arctic world in addressing these issues, and the unanswered questions are pressing. These include:

- What are the main contaminants found in Alaska and what are their sources? Are they predominantly distant or local?
- What are the key vehicles and environmental compartments and receptors (air, water, soils, plants, animals, humans) of POPs in Alaska? Where are the highest concentrations of these chemicals found? Are existing concentrations of contaminants capable of affecting ecosystems, fish, and wildlife species or humans?
- What are the dynamics of the changes in contaminant concentrations, transformations, and interactions that happen within the food chain and between different environmental compartments such as air, land, water, snow, ice, sediments, and biota?

- What have the long-term trends in contaminant levels been in the various compartments?

- What are the exposure patterns and pathways of vulnerable populations in Alaska? Do environmental exposures to air, water, snow, and ice increase body burdens of POPs contaminants?

- What are the health effects of POPs contaminants on humans and the animal species that are most at risk? What are the reproductive, endocrine, immune, developmental, and other impacts on these populations? Is there a relationship in humans between body burden levels of POPs and the incidence of disease?

- There is a need for detailed information on food consumption patterns and contaminant intake levels by the Alaska Native and other populations who rely upon traditional and wild foods for subsistence. From where do the greatest exposures come? How can human exposure to POPs contaminants be decreased?

These questions must define research priorities. To answer them, a coherent, coordinated research and monitoring program on the federal level, with additional resources support at the state and local levels, is necessary. The public must be provided adequate information about contaminants in food, sources of the contaminants, ways to avoid exposure, and ways to eliminate the pollution. All indicators have shown that there is no time to waste in moving forward on this agenda, and that the framework for this work must include two cross-cutting elements.

The first is that it is essential to **involve Alaska Native people in the design and implementation of a comprehensive contaminants research program** if the range of environmental, cultural, and public health effects of POPs contamination is to be fully understood. The value of traditional knowledge is frequently underestimated and devalued in scientific studies that rely on a model of statistical valuation and observer objectivity. What is missed in this model is the enormous depth of contributions made by individuals with the cumulative knowledge of thousands of years of experience with the animals and natural systems being examined. Due to the intense integration of culture with the natural world, the observations and theories of indigenous peoples provide a unique and invaluable perspective in the process of hypothesis generation, analysis of conditions, and interpretation of results.

The second critical element is **the need to apply the precautionary principle as the framework** for analyzing the outcomes of research initiatives and determining the direction of policy decisions to be implemented. The precautionary principle holds that where there is scientific evidence an activity threatens wildlife, the environment, or human health, protective measures should be taken even in the absence of full scientific certainty. This shifts the burden of proof and requires a show of no harm as a prerequisite for the production or continued use of any chemical that has the potential for harmful health or environmental impacts. This is in contrast to the current model for policy development, which demands proof of harm before action can be taken. As has been shown historically, however, from the experiences with POPs in the Great Lakes to the unexpected levels of POPs throughout the Arctic, by the time it is possible to show harm, damage has occurred and the contamination levels cannot be undone.

We do not yet know whether people living in Alaska are being exposed to enough of these chemicals to cause harmful health effects. Greater attention to the sources and implications of such persistent pollutants could result in a greater ability of Alaska and the U.S. to protect their interests and their people.

Appendix A: Selected Figures and Tables from Ambrose et al, *Environmental Contaminants in American and Arctic Peregrine Falcon Eggs in Alaska, 1979-95*[a]

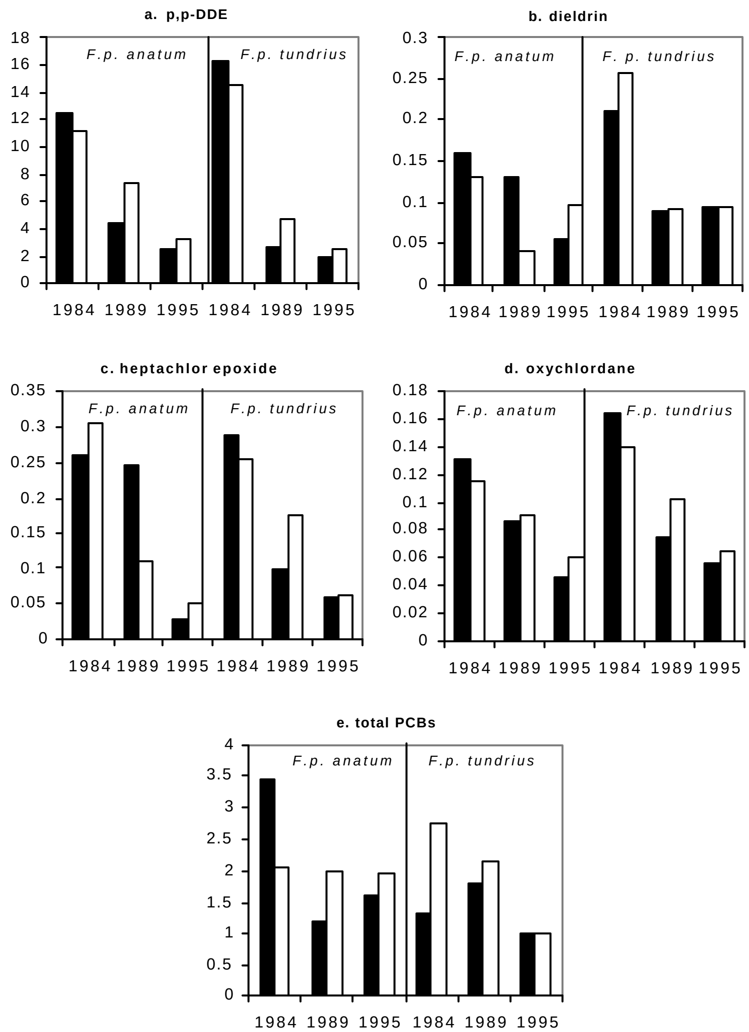


Figure 3
Geometric mean organochlorine (OC) contaminant concentrations (mg/kg, adjusted wet weight) in addled (black bars) and fresh (white bars) American (*F. p. anatum*) and arctic (*F. p. tundrius*) peregrine falcon eggs from Alaska, collected in 1984, 1989, and 1995. There were no significant differences between addled and fresh eggs (two-way MANOVA with time and egg status factors).

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[a] By Robert E. Ambrose, Angela Matz, and Ted Swem of the Fish and Wildlife Service and Peter Bente of the Alaska Department of Fish and Game. Ecological Services Fairbanks, AK, U.S. Fish and Wildlife Service, Technical Report NAES-TR-00-02, May 2000.

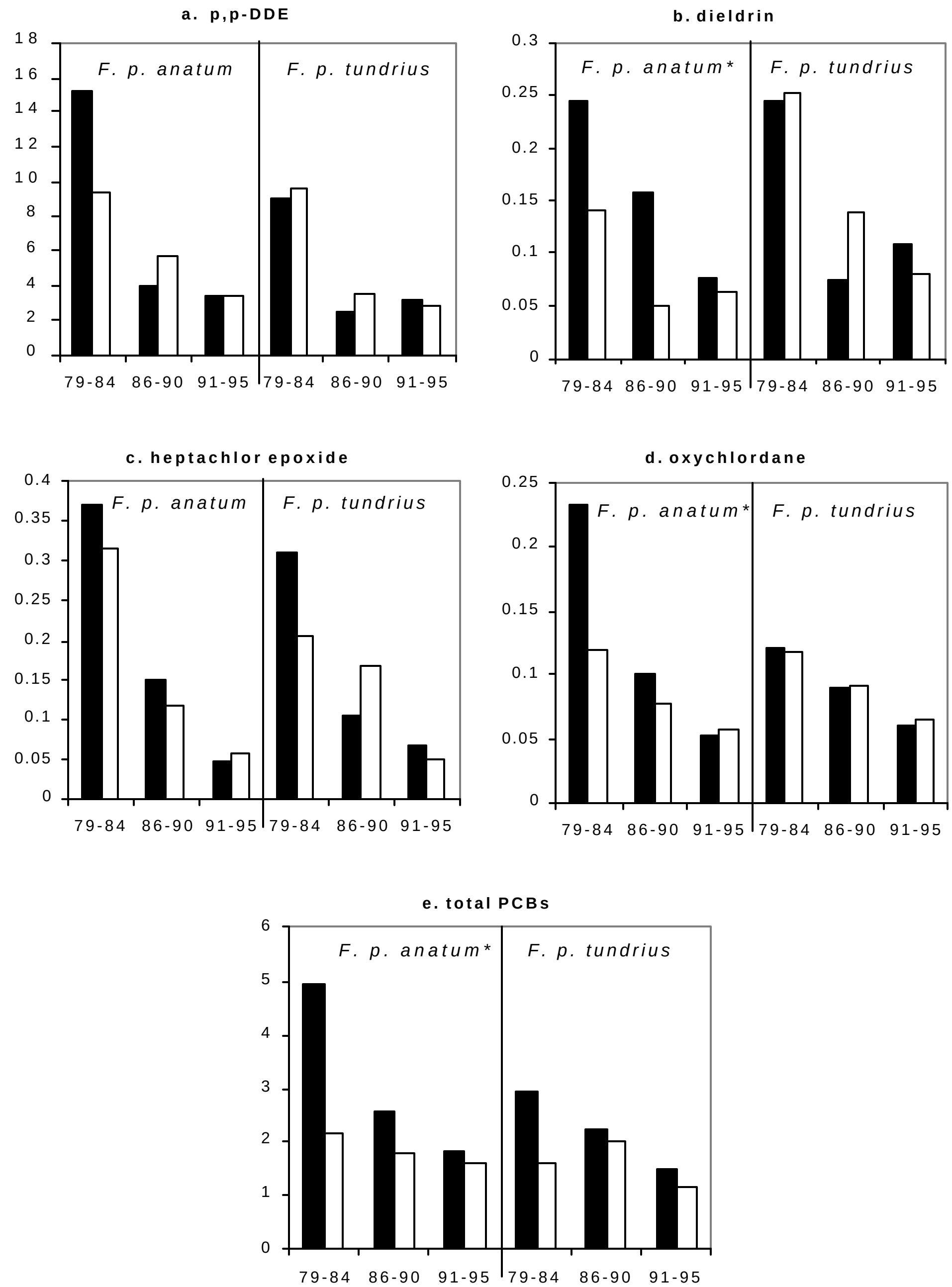

Figure 5
Geometric mean organochlorine (OC) concentrations (mg/kg, adjusted wet weight) in American (*F. p. anatum*) and arctic (*F. p. tundrius*) peregrine falcon eggs from successful (≥ 1 chick at banding; white bars) and unsuccessful (0 chicks at banding; black bars) nests in Alaska, over three time periods. An asterisk following the subspecies label indicates significant differences between eggs from successful and unsuccessful nests (two-way MANOVA with time and success as factors).

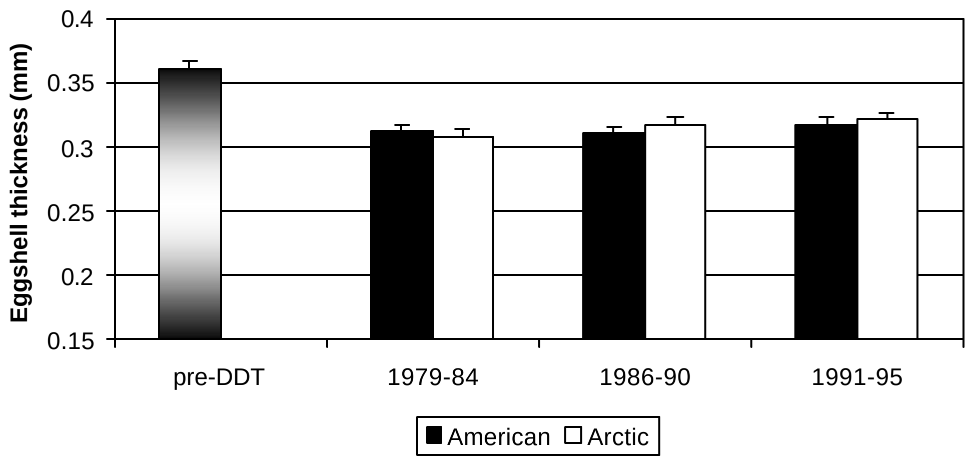

Figure 7
Relationships between eggshell thickness and *p,p'*-DDE in American (*F. p. anatum*) and arctic (*F. p. tundrius*) peregrine falcon eggs from Alaska, 1979-95. Significant negative correlations were noted for each subspecies. Eggshell thickness for both *F. p. anatum* and *F. p. tundrius* increased slightly but not significantly over time Based on a pre-DDT thickness of 0.360 mm for interior and northern Alaska peregrine falcon eggs, thinning in *F. p. anatum* eggs averaged 13.1% (0.313 mm) in 1979-84 (*n* = 31), 13.9% (0.310 mm) in 1988-90 (*n* = 24), and 11.8% (0.317 mm) in 1991-95 (*n* = 32). Thinning in *F. p. tundrius* eggs averaged 14.4% (0.308 mm) in 1979-84 (*n* = 19), 12.0% (0.317 mm) in 1988-90 (*n* = 29), and 10.6% (0.322 mm) in 1990-95 (*n* = 20).

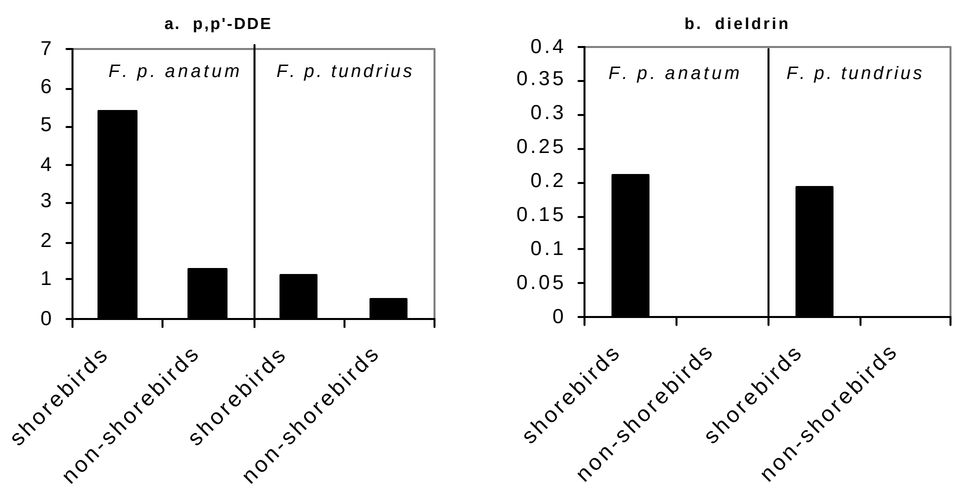

Figure 9
Geometric mean *p,p'*-DDE and dieldrin concentrations (mg/kg, wet weight) in peregrine falcon prey items collected from the breeding ranges of *Falco peregrinus anatum* (Tanana and Yukon rivers) and of *F. p. tundrius* (Colville River) in Alaska, 1984. Concentrations were measured in whole body (minus feathers, beak, feet, and digestive tract) pooled samples of 7-11 birds/species, and 4-9 species/category (shorebirds and non-shorebirds).

Table 8
Environmental contaminant concentrations in American (*Falco peregrinus anatum*) (Females 1-4) and arctic (*F. p. tundrius*) (Female 5) peregrine falcon eggs in Alaska, taken from the same females over time. Decrease or increase indicates whether concentrations were less or greater than concentrations in the egg sampled previously.

			Year			
Female	**1984**	**1988**	**1989**	**1990**	**1991**	**Decrease (¯) or increase (-)**
			***p,p*'-DDE** [1]			
1	22.330		17.011			¯
2		7.937	6.227		6.381	¯, -
3	9.561	8.865				¯
4	21.086		12.583			¯
5				2.870	2.096	¯
			Dieldrin [1]			
1	0.240		0.027			¯
2		0.338	0.073		0.127	¯,-
3	0.096	0.051				¯
4	0.125		0.039			¯
5				0.312	0.193	¯
			Heptachlor epoxide [1]			
1	0.215		0.206			¯
2		0.730	0.356		0.565	¯,-
3	0.261	.				
4	0.414		0.149			¯
5				0.158	0.029	¯
			Oxychlordane [1]			
1	0.103		0.143			-
2		0.230	0.105		0.125	¯, -
3	0.165	0.059				¯
4	0.195		0.157			¯
5				0.100	0.123	-
			Total PCBs [1]			
1	2.147		3.671			-
2		2.689	1.860		1.318	¯, -
3	1.304	2.572				-
4	3.124		2.674			¯
5				4.992	2.228	¯
			Mercury [2]			
2		1.990	1.060		1.336	¯, -

[1] Adjusted for changes associated with development (Stickel et al. 1973), mg/kg wet weight
[2] mg/kg dry weight

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