Atmospheric Pollutants in Banff National Park: Why are Lake Trout from Bow Lake So Contaminated?

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Introduction

Organochlorine compounds such as toxaphene, DDT and PCBs have been found in diverse aquatic ecosystems in locations ranging from Lake Michigan, U.S.A. to Lake Baikal, Russia.

Toxaphene, a complex mix of chlorinated hydrocarbons, has been used not only as an insecticide to protect agricultural crops from nuisance pests, but also in fisheries programs to kill "unwanted" fish in order to prepare lakes for sports fishing. It has been banned or severely restricted in much of the world for about two decades, but many countries in South America, Africa and Asia still use the chemical as a part of their agricultural programs. DDT, a well-known and highly effective pesticide used to remove unwanted insects, has been banned since the 1960s in most countries that formerly used it. PCBs are industrial compounds used primarily in electrical equipment. While they are being phased out gradually, PCBs are still in use in older equipment. All of these organochlorines are persistent, long-lived compounds that are easily transported around the globe through the atmosphere.

In 1991-92, 14 lakes in the Canadian Rocky Mountains were surveyed by Donald et al. (1993) for organochlorine contamination, including toxaphene, DDT and industrial PCB compounds. In Banff National Park, Bow Lake appeared to be unusual because the lake trout there exhibited high concentrations of organochlorines, particularly toxaphene, in their tissues compared to other mountain lake trout populations. The levels of toxaphene in Bow Lake trout were 10-20 times higher than levels found in nearby fish populations.

The research reported here focuses on toxaphene and other organochlorines in Bow Lake fish and invertebrates, and the possibility of contaminant bioaccumulation. "Bioaccumulation" is a general term used to describe the processes by which chemicals accumulate in organisms by exposure to the chemicals, or by consumption of the chemicals in food. Organochlorines easily enter aquatic food webs because of their highly "lipophilic" nature, that is, their tendency to accumulate in adipose tissue (fats and lipids). As the main pathway of organochlorine bioaccumulation is through diet, we studied the biota of Bow Lake and their food web relationships in order to determine the bioaccumulation patterns of organochlorine contaminants.

Bow Lake food web structure and ecology

Lake trout *(Salvelinus namaycush)* and mountain whitefish *(Prosopium williamsoni)* were classified according to their apparent feeding patterns in different zones of the lake. The zones included pelagic (open) water away from the shore, littoral water near the shoreline, and the benthic zone, which is the water-sediment interface along the shoreline. Lake trout had pelagic and littoral feeding sub-groups, plus a group that was "intermediate" between pelagic and littoral. Mountain whitefish had two littoral sub-groupings, which were classified as benthic and "intermediate."

Figure 1 (next page) shows a food web diagram based on the dietary analyses of the two species of fish. There is a littoral food web that is mostly restricted to benthic organisms, such as *Gammarus*, snails and Trichoptera, and a pelagic food web that is based on pelagic zooplankton, including *Hesperodiaptomus arcticus* and *Daphnia* existing in open water. As noted above, mountain whitefish are littoral creatures that depend on benthic invertebrates such as *Gammarus*, snails and fly larvae (Chironomidae and Tipulidae) that exist near the shoreline, whereas lake trout can feed either in the pelagic or littoral zone. Pelagic lake trout prey mostly on zooplankton; littoral lake trout compete with mountain whitefish for benthic invertebrates; and "intermediate" lake trout feed from all parts of the lake. Diatoms (algae) and tiny filter-feeding zooplanktonic rotifers form the base of the food web.

The size of a fish may have direct bearing on its diet composition and its lipid content (Fig. 2). Pelagic and intermediate lake trout are, on the average, larger than the other fish groups. They are able to feed wherever the food source is the richest without the fear of being preyed upon by other fish. Lipid-rich prey such as *H. arcticus* and *Gammarus* are highly sought after. Lipids provide energy for growth, reproduction and overwintering survival. Larger fish are able to eat more lipid-rich foods and so are more likely to succeed. They also have a higher content of lipids in their own tissues. The smaller lake trout may find themselves restricted to the shoreline due to the pressure of predation by the larger fish, but will still feed on *H. arcticus* when the opportunity arises. Littoral lake trout have a lower concentration of lipids in their tissues than pelagic or intermediate lake trout.

In contrast, mountain whitefish are, by nature, benthic feeders, but successful competition for high-lipid benthic invertebrates such as *Gammarus* again would probably depend on fish size. Larger mountain whitefish have a higher percentage of lipids, indicating greater success in feeding on lipid-rich invertebrates.

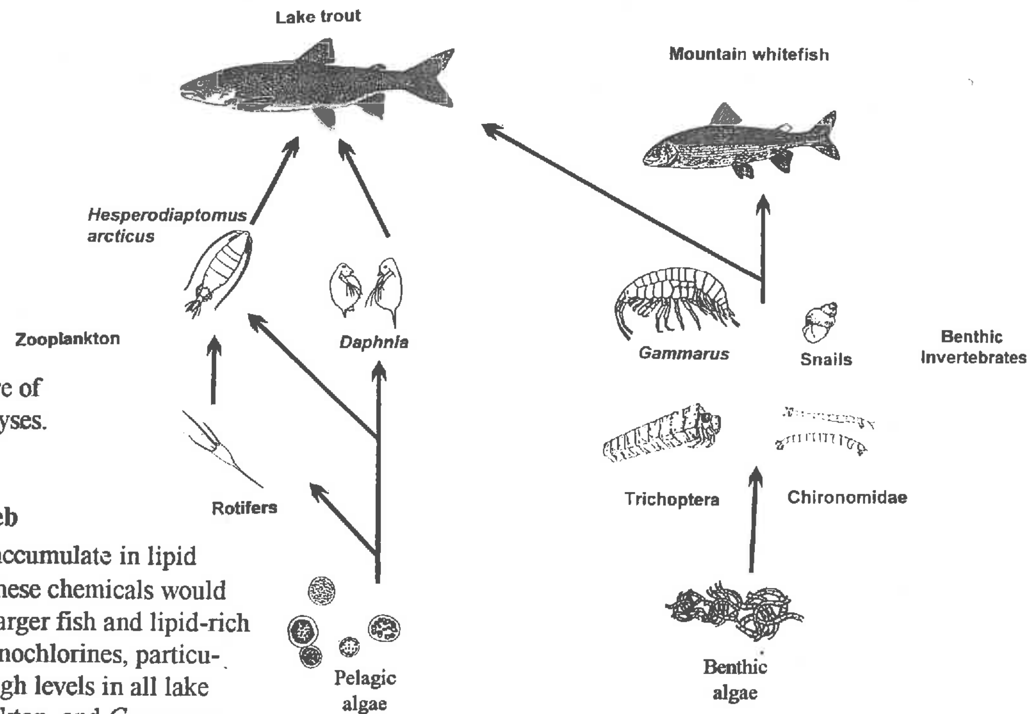

Figure 1. The food web structure of Bow Lake, based on dietary analyses.

Organochlorines in the food web

As organochlorines bioaccumulate in lipid tissue, it was hypothesized that these chemicals would be more highly concentrated in larger fish and lipid-rich invertebrates. In this study, organochlorines, particularly toxaphene, were found at high levels in all lake trout, *H. arcticus*, mixed zooplankton, and *Gammarus*, all organisms with fairly high lipid content (Fig. 3). Notice the similarity of trends between proportion of lipids and organochlorine levels in the organisms. Mountain whitefish, snails and fly larvae (Chironomidae and Tipulidae) had lower concentrations of toxaphene and other organochlorines, which correlates with their lower lipid content. As noted above, *H. arcticus* was found to be high in organochlorine concentrations compared to other zooplankton and benthic invertebrate organisms. In addition, *H. arcticus*, which makes up approximately 60 percent of the zooplankton population, is the main food source for pelagic lake trout. These fish have particularly high levels of organochlorines in their tissues, which would indicate that *H. arcticus* is likely the main source of contaminants in pelagic lake trout. The question is—how does *H. arcticus* accumulate the organochlorine compounds?

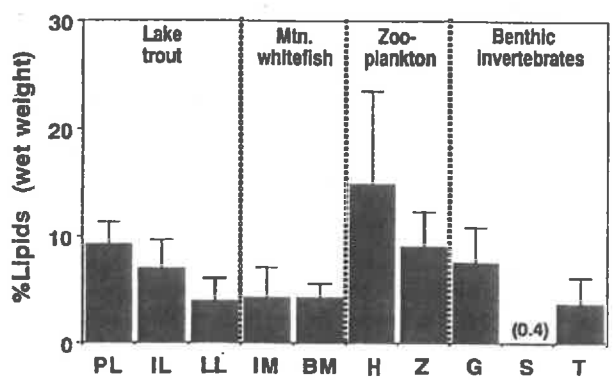

Figure 2. The proportion of lipids in Bow Lake biota. The fish are sorted into feeding sub-groups based on their dietary patterns. (See text)

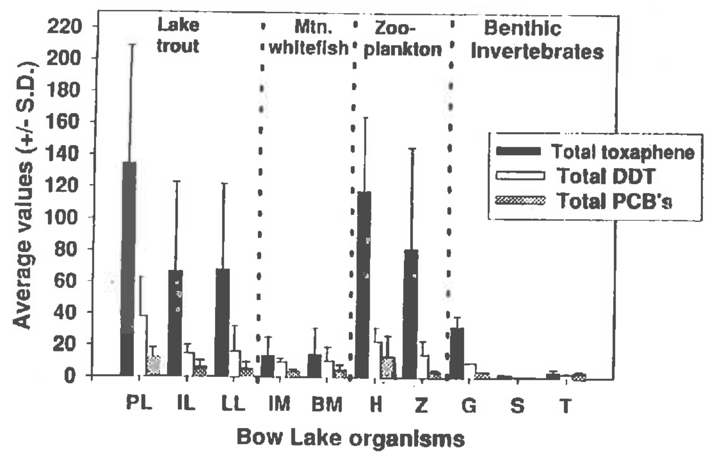

Figure 3. The average concentrations of organochlorines in Bow Lake biota. The fish feeding sub-groups and the invertebrates are same as for the previous graph.

Keys for Figures #2 and #3

Type	Code
Pelagic	PL
"Intermediate" lake trout	IL
Littoral lake trout	LL
"Intermediate" mountain whitefish	IM
Benthic mountain whitefish	BM
Hesperodiaptomus arcticus	H
Mixed zooplankton (all species)	Z
Gammarus lacustris	G
Snails	S
Tipulidae	T

How do organochlorines enter the food web?

A possible source of toxaphene and other organochlorines in Bow Lake may be airborne organochlorine compounds that have been deposited on the Bow Glacier. These contaminants may be entering the lake as the glacier melts. This would mean that contaminants can accumulate over many years, even decades, on the glacier before a particularly warm spring melt flushes the contaminants into the lake. Organochlorines are "hydrophobic," meaning that they do not mix well in water. They will not bind to the ice or the glacial melt-off water, but are likely carried into the lake on dirt and minute rock particles being washed off the glacier. This "rock flour" is extremely fine, and will not immediately settle into the bottom lake sediments. Instead, it is suspended in the water, which gives Bow Lake its intense, blue color on sunny days.

Zooplankton depend on diatoms, rotifers and nauplii (zooplankton offspring) for nutrients. *H. arcticus* and other zooplankton have to ingest high rates of water to obtain enough food, and in the process, large amounts of fine rock flour from the glacier are ingested. In addition, *H. arcticus* is also a predatory organism, so it will feed on other zooplankton, including tiny rotifers that are prolific filter feeders. It is possible that organochlorines on rock flour particles are absorbed into the lipid reserves of the zooplankton before the rock flour passes through in feces. When the gut contents of *H. arcticus* were examined, the guts were found to be fully packed with fine sediment particles in all individuals.

An interesting study carried out at Bow Lake (Smith and Syviski 1980) found that *H. arcticus* drastically affected the find sediment distribution in the lake. The authors expected nearly all of the fine rock flour to be transported out of the lake but instead found a disproportionately large amount deposited within the lake sediments. Upon closer examination, it was found that nearly all deposited fine sediment was in the form of copepod feces, meaning that *H. arcticus* was ingesting most of the suspended rock flour and excreting it within the lake. This zooplankton species was drastically changing the natural distribution of very fine sediment and, at the same time, likely absorbing extraordinarily high levels of contaminants from the glacier rock flour.

Is this an unusual situation for mountain lakes?

Atmospheric contaminants tend to accumulate at higher altitudes (D. Donald, unpublished data) due to climatic and physical factors that will not be detailed here. The question arises, why are lake trout from Bow Lake found to be more contaminated than other mountain fish populations? In an effort to find an answer to this question, Bow Lake was compared to neighboring Hector Lake, which is also fed by the same Wapta Icefields of which the Bow Glacier is a part. Sampled lake trout from Hector Lake showed lower levels of contaminants despite being potentially exposed to the same level of glacier-derived organochlorines as fish in Bow Lake (Fig. 4). The sedimentation concentrations were similar for both Hector and Bow Lakes. The only difference that could be discerned was that the zooplankton biomass in Hector Lake consists mainly of *Diaptomus silicus*, while *H. arcticus* is the major zooplankton in Bow Lake (Fig. 5).

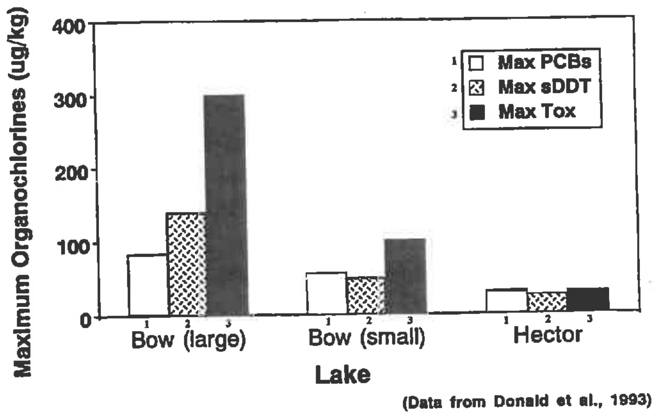

Figure 4. The maximum organochlorine concentrations for lake trout from Bow Lake and Hector Lake. The lake trout from Bow Lake were divided into two size classes, large and small.

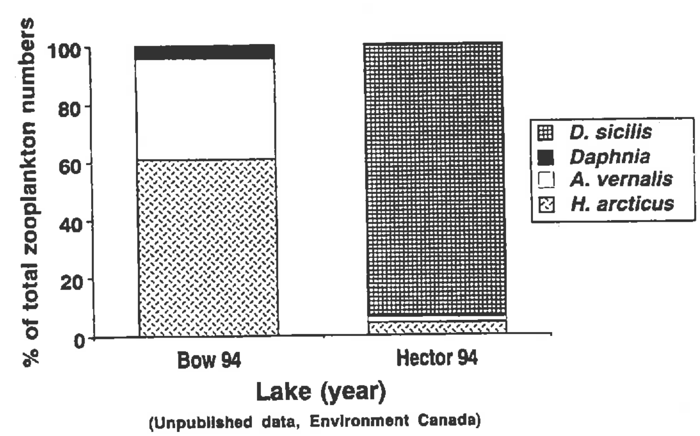

Figure 5. The zooplankton community structure varies between Bow and Hector Lakes.

Very little is known about *D. silicus* compared to *H. arcticus*. These two zooplankton species belong to the same copepod genus[1], but *D. silicus* is smaller than *H. arcticus* and is known to coexist with fish only in large lakes, such as Hector Lake (Donald et al. 1994). Maly

[1]*Hesperodiaptomus* is a sub-genus of *Diaptomus*. *H. arcticus* is in the same genus as *D. silicus*.

and Maly (1974) have suggested that that if two copepods differ greatly in size, they will process food differently. Because of its smaller size, *D. silicus* probably does not directly ingest fine sediment from the water in an effort to obtain nutrients. Also, there is no indication that the copepods in Hector Lake are affecting the sedimentation patterns to the same extent as is occurring in Bow Lake (Smith et al. 1980). It would appear that in order for glacier-derived contaminants to reach high levels in lake trout, a set of unique circumstances has to be present, including the presence of *H. arcticus.*

Conclusions

The pivotal role that *H. arcticus* plays in organochlorine bioaccumulation in lake trout indicates a need for greater understanding of zooplankton ecology in mountain aquatic ecosystems, particularly as it seems lack of this species in the neighboring Hector Lake is the major reason for low toxaphene levels in the fish there. *H. arcticus* and other zooplankton species are just beginning to be studied in depth in mountain lakes, and we are coming to realize the importance of these organisms in mountain aquatic ecosystems (e.g., Parker and Schindler 1995).

A combination of food web dynamics and selective feeding are leading to the high rates of bioaccumulation of contaminants in lake trout in Bow Lake. Lake trout in Bow Lake have higher levels of organochlorines than mountain whitefish there because of their opportunistic feeding habits and their ability to feed on lipid-rich zooplankton, regardless of their assigned feeding group. Mountain whitefish in Bow Lake have higher concentrations of organochlorines than their benthic prey, which shows that bioaccumulation is occurring.

Currently, studies are being planned to compare contaminants in *Gammarus* species between lakes, the distribution patterns of organochlorines in other mountain aquatic food webs, and the atmospheric transport of organochlorines in snow and precipitation. Bow Lake serves as an indicator of what may be happening in other mountain lakes. An ongoing survey of mountain lakes may show that atmospheric contamination at Bow Lake is not an isolated event and that contamination of these lakes may be a more widespread concern in the mountain parks than has previously been recognized.

The Bow Lake study is a part of an interdisciplinary project (University of Alberta, Environment Canada, Department of Fisheries and Oceans) looking at the sources and influences of airborne organochlorines in mountain ecosystems. The project will also provide a means of monitoring the levels present in the mountain environment. The knowledge of how mountain aquatic biota accumulate contaminants will provide information for the management of alpine aquatic resources in Banff National Park.

Acknowledgments:

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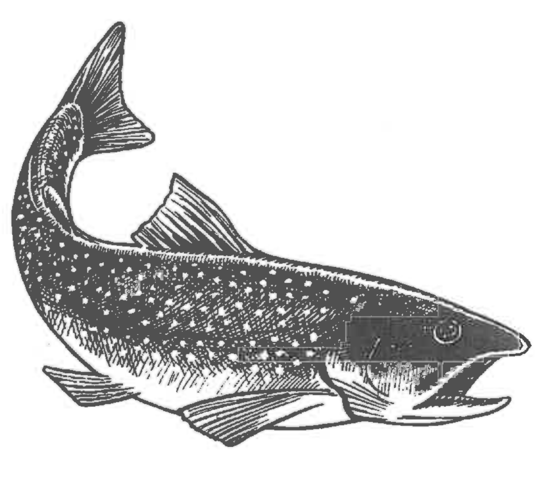

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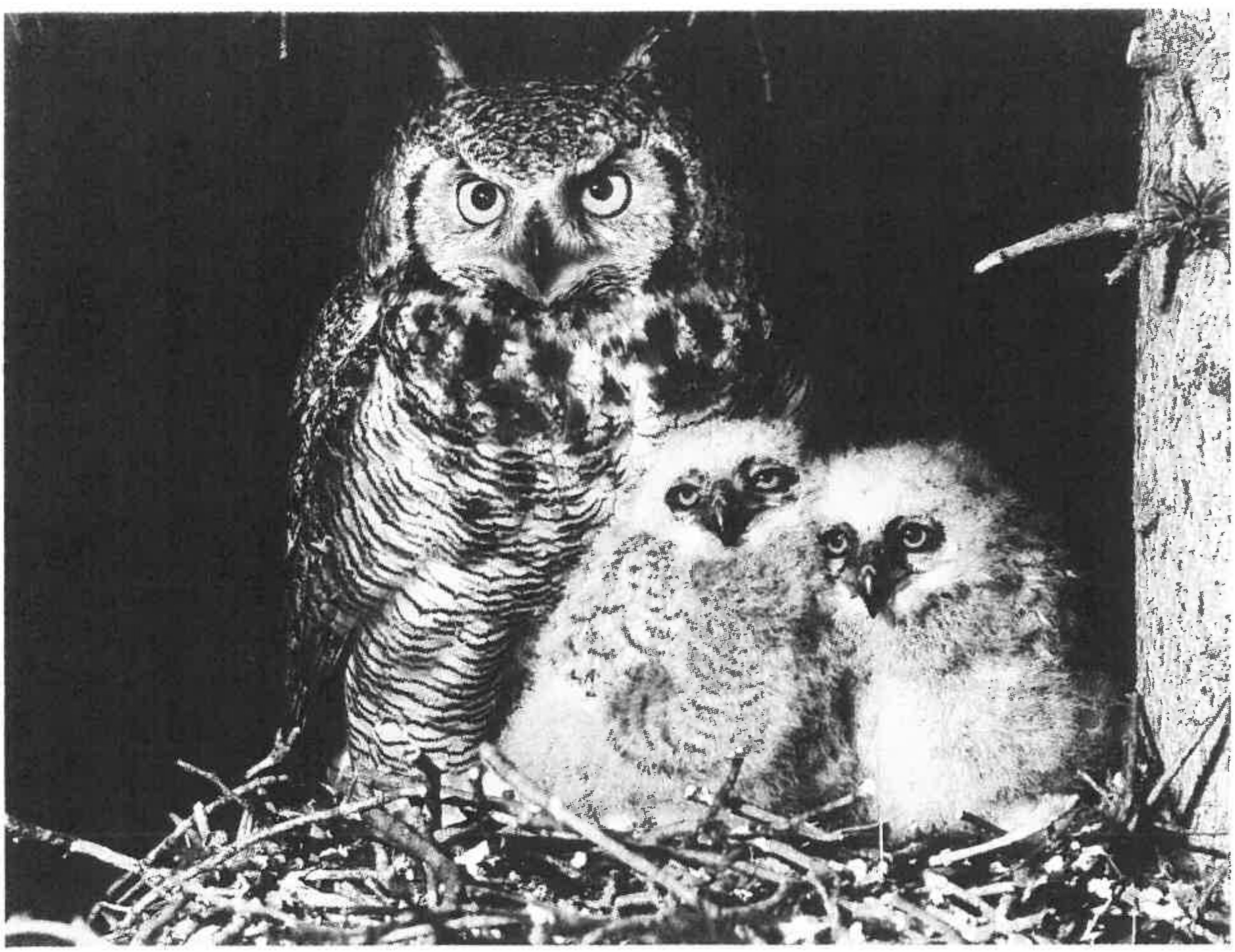

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