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USE OF STABLE NITROGEN ISOTOPE RATIOS TO CHARACTERIZE FOOD WEB STRUCTURE AND ORGANOCHLORINE ACCUMULATION IN SUBARCTIC LAKES IN YUKON TERRITORY

by

KAREN ANN KIDD ©

A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of
DOCTOR OF PHILOSOPHY

in

ENVIRONMENTAL BIOLOGY AND ECOLOGY

DEPARTMENT OF BIOLOGICAL SCIENCES

EDMONTON, ALBERTA

SPRING 1996

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ISBN 0-612-10601-2

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Degree: Doctor of Philosophy

Year this Degree Granted: 1996

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April 17, 1996

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Use of Stable Nitrogen Isotope Ratios to Characterize Food Web Structure and Organochlorine Accumulation in Subarctic Lakes in Yukon Territory submitted by Karen Ann Kidd in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Environmental Biology and Ecology.

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Dated 9 Apr 1996

To my Family

Thank you for your love and support.

ABSTRACT

Unusually high concentrations of persistent organochlorines were found in lake trout muscle and burbot liver from subarctic Lake Laberge, Yukon Territory. As a result of the elevated toxaphene concentrations in these fishes, a health advisory was issued by Health Canada in 1991, and the commercial, sport and subsistence fisheries on the lake were closed. Previous studies on Lake Laberge have revealed that the fish community structure is atypical when compared to other regional lakes, with high biomasses of burbot and longnose sucker and low biomasses of lake trout and lake whitefish. Likewise, the lake trout are known to be faster growing, fattier and strictly fish-eating, unlike other populations from nearby lakes. It was hypothesized that the high concentrations of organochlorines in Laberge fishes were the result of an unusually long food chain in this lake, a factor that has been shown to affect the pollutant concentrations in fish from temperate lakes. To characterize food web structure and examine the biomagnification of organochlorines through the food web of Lake Laberge and two reference lakes, Fox and Kusawa, fishes and invertebrates were analysed for stable nitrogen isotope ratios, to quantify trophic position, and persistent organochlorines. Stable nitrogen isotope ratios were significant predictors of the organochlorine concentrations through these food chains, and in the top predators from these lakes. The slopes of these regressions were greater for the more lipophilic organochlorines when compared to the less lipophilic organochlorines, and appear to directly reflect a pollutant's potential to biomagnify through the food chain. Both within and among species, lipid content was a better predictor of the less lipophilic organochlorines such as hexachlorocyclohexane, while stable nitrogen

isotope ratios were better predictors of the more lipophilic organochlorines such as PCBs and toxaphene. Lake trout and burbot from Lake Laberge fed at a significantly higher trophic position, as determined by stomach content analyses and stable nitrogen isotope ratios, than the same species from Fox and Kusawa lakes. The high concentrations of toxaphene in fishes from Laberge has been attributed to an unusually long food chain and not elevated inputs of this pesticide.

ACKNOWLEDGEMENTS

I am would like to express my sincere thanks to Dr. David W. Schindler for his guidance, enthusiasm and continuous support throughout this thesis project. I would like to thank Dr. Derek C.G. Muir for his suggestion that I conduct this research, support of the organochlorine analyses and insightful discussions. I am grateful to Dr. Bill M. Tonn for his assistance and counsel on the direction of this project. I would like to thank Dr. Raymond H. Hesslein for his support of this project and of the stable isotope analyses, and for his advice.

Many organizations and individuals provided me with invaluable help during my summers in Yukon Territory. I am grateful to the Ta'an Kwach'an First Nation for their assistance throughout this study, and for their guidance and insight. The Department of Fisheries and Oceans, the Department of Indian Affairs and Northern Development, Environment Canada, the Fisheries and Wildlife Branch of the Department of Renewable Resources, Yukon Territorial Government, and the Yukon Contaminants Committee were very generous with their equipment and facilities, and the expertise of their staff was greatly appreciated. Brian and Susan Lendrum, and Mark and Janice Palmer provided me with homes away from home, thank you for your warm hospitality. Al von Finster, Susan Thompson, Rem Ricks, Mark Connor and Paul Sparling provided many of the fishes used in this study, and Nick de Graff and Susan Thompson supplied me with fisheries data. Many thanks these people, and to Joan Eamer and Mark Palmer for their continued support of this project.

This research was generously supported through the Arctic Environmental Strategy Northern Contaminants Program (Department of Indian Affairs and Northern Development), the Boreal Alberta Research Grant from the Canadian Circumpolar Institute (Edmonton), the Lorraine Allison Scholarship from the Arctic Institute of North America (Calgary), the Northern Scientific Training Program Grant (Department of Indian Affairs and Northern Development), the Northern Studies Endowment Fellowship from the Northern Research Institute (Whitehorse), the Department of Fisheries and Oceans (Freshwater Institute, Winnipeg), and an NSERC Operating Grant 89673 to D.W.S.

I am grateful for the financial support that I received from the Province of Alberta Graduate Fellowship program, the University of Alberta Ph.D. Scholarship program, the Tri-Council Eco-Research Doctoral Fellowship program, a J. Gordin Kaplan Graduate Student Award, a Walter H. Johns Graduate Fellowship, and the Department of Biological Sciences (former Department of Zoology) Teaching Assistantship program.

Many thanks to Mehram Alaee, Brian Billeck, Lonnie Chin, Bob Danell, Doug Davidge, Tara Genier, Sebastien Lamontagne, Don Metner, Geraldine Pope, Christine Spencer, and Paul Wilkinson for their assistance with the field work; Rob Currie, Jeff Curtis, Bert Grift, Krystyna Koczanski, Shaliza Mohammed, Pat Ramlal, Bruno Rosenberg, Bev Ross, Alex Salki, and Gary Stern for their assistance with the laboratory analyses and advice; Brian Parker for aging fishes; and Margaret Foxcroft and Brian for their invaluable help with the many bureaucratic aspects of this program. My warmest thanks to my family and peers for their unwavering faith in me.

To Scott, thank you for being a great friend. Your encouragement, patience, understanding and love were appreciated more than words can say.

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I. GENERAL INTRODUCTION

The Northern Lights
    have seen queer sights,
But the queerest they ever did see,
Was the night on the marge
    of Lake Lebarge,
I cremated Sam McGee.

At the turn of this century, Lake Laberge, Yukon Territory was made famous by Robert Service's poem 'The Cremation of Sam McGee' (Service, 1961). Now, nearly a century later, this lake has become infamous for another reason. Unusually high concentrations of PCBs and the pesticides toxaphene and DDT were found in lake trout muscle and burbot liver that were collected in 1989 from Lake Laberge as part of a routine survey. As a result of the high concentrations of toxaphene found in these fish, the Health Protection Branch of Health Canada released the first health advisory ever issued for Yukon on May 8, 1991. It recommended that people limit their consumption of lake trout from Lake Laberge to two meals per month and refrain from eating burbot liver (MacDonald, 1991; Davison, 1991a). As a result, all commercial and sports fisheries on Lake Laberge have been closed, and the Ta'an Kwach'an and Kwanlin Dun First Nations no longer fish in the lake that they once depended heavily upon.

Since the elevated levels of organochlorines were found in Laberge fishes, surveys of many other Yukon lakes have been conducted to determine if Laberge was exceptional in its high fish pollutant levels (Yukon Contaminants Committee, 1996a; 1996b; 1996c; Kidd et al., 1993; Palmer, 1994a). Results have indicated that the burbot liver from Laberge had average wet weight concentrations of toxaphene (2300 ng.g^{-1}), PCBs (1270 ng.g^{-1}), and DDT (3430 ng.g^{-1}) that were substantially higher than the same species from other lakes in Yukon [average toxaphene ranged from 54 to 945 ng.g^{-1}; PCBs ranged from 50 to 579 ng.

g^{-1}; DDT ranged from 21 to 272 $ng.g^{-1}$ for eleven lakes; Department of Indian Affairs and Northern Development (DIAND), 1996]. Lake trout muscle from Laberge was also considerably higher in average toxaphene (560 $ng.g^{-1}$), PCBs (450 $ng.g^{-1}$) and DDT (460 $ng.g^{-1}$) than was found in the same species from other Yukon lakes (average toxaphene ranged from 4.6 to 296 $ng.g^{-1}$; PCBs ranged from 3.5 to 128 $ng.g^{-1}$; DDT ranged from 14 to 403 $ng.g^{-1}$ for twenty lakes; DIAND, 1996). Although lipid content, size or age are known to affect the accumulation of organochlorines in fishes, the high concentrations in Lake Laberge fishes could not simply be explained by these factors (J. Eamer, pers. comm., Canadian Wildlife Service, Whitehorse, Yukon; Kidd et al., 1993).

Considerable research has been conducted examining both the contemporary inputs of organochlorines to the Yukon River system through the analyses of air, snow, rain, and lake and river water samples, and the historical inputs of organochlorines to Lake Laberge and other Yukon lakes using lake sediment core analyses. These studies were conducted to determine whether Lake Laberge received higher inputs of toxaphene, PCBs and DDT from a spill, or through leachates from a dumpsite upstream of the lake, resulting in elevated concentrations of organochlorines in the fishes. Results from these studies are reported elsewhere (Lockhart, 1994; 1993; Alaee and Gregor, 1994; Barrie, 1994; Palmer, 1994b; Gregor and Eamer, 1993).

Surveys conducted by the Yukon Territorial Government have determined that the fish community structure in Laberge was atypical (Table I.1). The lake trout population was unusual when compared to other populations because fish in Laberge grew faster, were fattier, and preyed solely upon other fishes and not a combination of fishes and invertebrates (Thompson, 1996a). I hypothesized that the high concentrations of organochlorines in the fishes from Lake Laberge were the result of a long underlying food chain, a factor that is known to affect the concentrations of organochlorines in top predators from temperate lakes (Rasmussen et al., 1990). This thesis examines the ecological factors underlying the elevated organochlorine concentrations in fishes from Laberge by characterizing food web relationships in this lake and in two reference lakes, Fox and Kusawa.

Traditionally, studies examining the biomagnification (increase in organochlorine concentrations with trophic position) of organochlorines through aquatic food webs categorized organisms into discrete trophic positions. However, fish will vary their diets depending upon the season and availability of prey, making it difficult to group individuals and populations based on generalized feeding habits. Unlike previous studies on freshwater food webs, my research combines food-web measurements of organochlorines with a continuous measure of trophic position, tissue stable nitrogen isotope ratios. The ratios of the heavy (^{15}N) to light (^{14}N) stable isotopes of nitrogen increase in a predator when compared to its prey, thereby providing a continuous measure of trophic position with which to quantify and qualify the transfer of organochlorines up through the food web.

In this chapter, I discuss the study lakes, organochlorines and their historical use in Yukon Territory, transport to the Arctic and biomagnification through aquatic food webs, and the use of stable nitrogen isotope ratios in characterizing food web relationships. Chapter II describes the food web structures in Laberge, Fox and Kusawa lakes using biotic measurements of stable nitrogen isotopes to determine the long-term trophic relationships of fishes and invertebrates. I compared the results of the stable nitrogen isotope analyses to dietary information obtained from fish stomach content analyses to determine if their short-term feeding habits were comparable with their average trophic positioning. Chapter III characterizes the relationship between trophic position, as determined by stable nitrogen isotope ratios, and organochlorine concentrations in the food web from Lake Laberge. Chapter IV examines biotic and abiotic factors underlying the biomagnification of toxaphene through the Laberge, Fox and Kusawa food webs, and elevated concentrations of toxaphene in the top predators from Laberge. Chapter V examines the effects of trophic position, lipid, age and size on the accumulation of organochlorines in several species of fishes from these Yukon lakes. Chapter III has been published in *Science of the Total Environment*, and Chapter IV has been published in *Science*.

Study Site

The Yukon River system drains much of Yukon through Alaska into the Bering Sea, is the largest of the five major drainage basins in the Territory, and is the fifth largest in North America in terms of its land area and average discharge (Todd, 1970). This basin is located within the Interior System and the Western System of the Canadian Cordillera and is composed of volcanic, sedimentary, metamorphic and intrusive rock (Ennis et al., 1984). The locations of the lakes in this study, Laberge (61°11'N 135°12'W), Kusawa (60°20'N 136°22'W) and Fox (61°14'N 135°28'W), are shown in Figure I.1 and their physical and chemical characteristics are given in Chapter II. All three lakes were glaciated during the Late Wisconsin advance of the Pleistocene period which occurred from about 50,000 to 10,000 years before present (Lindsey et al., 1981), and the flow in Kusawa and Laberge is made up, in part, of glacial meltwater and silt from their drainage basins. The climate in this region is subarctic with long cold winters and short warm summers, and a mean annual temperature of -1 °C (Kirkland and Gray, 1986).

Lake Laberge is located 30 km downstream of the City of Whitehorse on the Yukon River system, and receives 75 % of its flow from the upper Yukon River system, 19 % of the flow from Kusawa Lake via the Takhini River (Kirkland and Gray, 1986), and the remainder from its immediate catchment and from Fox Lake through Fox Creek. Due to concerns over hydro-electric development and the growing human population upstream of Laberge, several studies have been conducted on this and other regional lakes. Estimates have been made indicating that additional nutrient input from the City of Whitehorse may increase the total phosphorous (TP) concentration of the Yukon River water flowing into Laberge by 4 ug.L^{-1} during low flow and 1 ug.L^{-1} during periods of high flow (a maximum increase of 10 to 20 % over ambient levels), and ammonia by only 1 to 4 ug.L^{-1} (< 5 % of background dissolved nitrogen; Kirkland and Gray, 1986). This study conducted in 1982 and 1983 indicated that Laberge had higher TP (3.8 to 6.7 ug.L^{-1}), total dissolved nitrogen (TDN; 57 to 118 ug.L^{-1}), and chlorophyll (0.56 mg.m^{-3}) when compared to Atlin, Tagish and Marsh lakes upstream of Whitehorse (TP - 1.9 to 4.5 $ug.L^{-1}$; TDN - 40 to 100 $ug.L^{-1}$; chlorophyll - 0.28 to 0.53 $mg.m^{-3}$), and nutrient levels that were comparable to those measured in Fox Lake (chlorophyll a - 0.62 mg. m^{-3}; TP - 5.6 $ug.L^{-1}$; Shortreed and Stockner, 1985). Similar nutrient levels were found in Laberge between 1977 and 1980 (Godin and Jack, 1984) and in 1992 (Gregor and Eamer, 1993). Although the nutrient levels in Laberge may be higher than those found in upstream lakes, concentrations of phosphorous and chlorophyll indicate that the lake is oligotrophic.

Persistent Organochlorines

This study focused on six major contaminant groups that are commonly found in biota from the Canadian Arctic. These organochlorines are chlordane (CHL), hexachlorocyclohexane (HCH), chlorobenzenes (CBZ), polychlorinated biphenyls (PCBs), dichlorodiphenyl trichloroethane (DDT) and toxaphene (chlorinated bornanes, CHB), and are briefly described below. The physical and chemical properties of these compounds that affect their distribution, fate, and residence time in the abiotic and biotic environment and are shown in Table I.2. These compounds are of concern because they are stable and resistant to biological or chemical degradation. As a result, they are detectable in the environment decades after their direct application (e.g. Keller, 1970; Miskimmin and Schindler, 1995). Of the chemical and physical properties listed, the octanol/water partition coefficient (K_{ow}) is used to determine the relative affinity of organochlorines for lipid versus water, and is most commonly used to predict the environmental fate of the chemicals. Compounds with higher K_{ow}'s (from 10^4 to 10^7), such as those examined in this study, have a high affinity for lipid and, as a result, will accumulate to higher concentrations in aquatic organisms (Mackay, 1982).

Technical chlordane is a complex mixture of 140 compounds, 120 of which have been identified (Dearth and Hites, 1991). It was used as a multipurpose agricultural pesticide to control ants, cutworms, grasshoppers and other insects between 1948 and 1979 in North

America. Between 1979 to 1988 it was registered only for limited applications in termite control. The production of chlordane and its use in the United States was discontinued in 1988, and, up until this period, it was estimated that 70 000 tons were produced globally (Dearth and Hites, 1991). However, chlordane is still used in developing countries (Barrie et al., 1992).

Technical HCH (a 65:7:14 mixture of α, β and γ isomers; Howard, 1991) was used as an insecticide in forestry and agriculture, and in health programs to control diseases carried by the tsetse fly and the *Anopheles* mosquito, from the early 1940s up until 1971 in Canada, and until 1978 in the United States (Voldner and Li, 1995). However, lindane, the purified active ingredient (γ-HCH) from technical HCH, is still being used in the United States, Canada and many other countries worldwide as an insecticide and as a seed treatment in agriculture. The global production of lindane and technical HCH have been estimated at 720 000 and 550 000 metric tonnes respectively (Voldner and Li, 1995).

Chlorobenzenes are manufactured for use as industrial solvents, and as by-products from the synthesis of chlorinated pesticides and other chemicals such as mirex, atrazine and vinyl chloride (U.S. EPA, 1984). They are released into the environment either directly as contaminants in pesticides or indirectly through industrial activities. Hexachlorobenzene was also produced for use as a fungicide starting in 1915, and its estimated annual production in the United States was close to 100 000 tons (Courtney, 1979). Production of all chlorobenzenes in the U.S. in 1980 was estimated to be 200 000 tons (Rapaport and Eisenreich, 1988).

PCBs were once widely used in industrial applications because they were excellent thermal insulators and lubricators, and were resistant to breakdown, nonflammable, and soluble in organic solvents. They were mainly used as plasticizers, in hydraulic fluids and dielectric fluids in electric capacitors and transformers, as flame retardants and in paints (Hutzinger et al., 1974). PCBs were manufactured and used extensively in North America and globally between 1930 and 1970. Because of their persistence in the environment, production in the U.S. was voluntarily reduced and was ultimately curtailed in 1977. Canada imported PCBs from the U.S. until 1980, after which PCBs were prohibited in any machinery manufactured or imported into the country (Environment Canada, 1980). The global production of PCBs has been estimated to range from 500 000 tons (WHO, 1976) to 1.2 million tons, of which, 31 % of which has been estimated to have been released into the environment (Tanabe, 1988).

DDT was heavily used in Canada and the United States as a multipurpose insecticide between the 1940s and 1970s, and the global production to date has been estimated at 1 500 000 metric tonnes (Voldner and Li, 1995). DDT was first used in North America in 1942 after it was tested as an insecticide in World War II. It was used extensively throughout the world in public health and agricultural programs because of its effectiveness and low cost. Although it is still believed to be used in southern Asia, Africa, Central America and South America to control insect-borne diseases such as malaria (Voldner and Ellenton, 1987), production was banned in the U.S. in 1972 (U.S. EPA, 1980) because of the development of DDT-resistance, and the accumulation of its more toxic metabolite DDE in non-target organisms. Canada strictly regulated the use of DDT during this time and it was only imported for limited use as a rodenticide until the early 1980s (Agriculture Canada, 1984).

Toxaphene is a complex mixture of chlorinated camphenes referred to as chlorinated bornanes. It was, on a global scale, the most heavily used insecticide between the 1960s and early 1980s (Saleh, 1991), replacing DDT as a major agricultural pesticide. Toxaphene is also toxic to fishes, and was used in fisheries management practices (Lennon et al., 1970). It was applied directly to lakes at part per billion levels (Miskimmin and Schindler, 1994) to kill unwanted fish species before stocking lakes with trout. This practice was discontinued due to its persistence in treated lakes (Lee et al., 1977) and residual toxicity to aquatic organisms (Webb, 1980; Miskimmin and Schindler, 1994). Toxaphene was mainly used in the United States on cotton and soybean crops until its registration was cancelled in 1982 by the U. S. Environmental Protection Agency (Eisler and Jacknow, 1985). After this time, limited uses of the existing stocks were allowed to continue, with restrictions, up until 1986 (Eisler and Jacknow, 1985). Canada discontinued using toxaphene in 1980 (Saleh, 1991). It has been estimated that between 1950 and 1993, 1 333 000 metric tonnes were used on a global scale. Toxaphene is still not banned or restricted in Mexico, and in parts of South America, Africa, Europe and Asia (Voldner and Li, 1995). Technical toxaphene may be composed of up to 32,768 different compounds (Vetter and Luckas, 1995). The large number of congeners present in toxaphene, and the differences between the technical mixture and what is found in the biotic and abiotic environment (Stern et al., 1992; Bidleman et al., 1995) have made it, up until recently, difficult to quantify. Toxaphene is a predominant organochlorine in arctic biota, and is often found at concentrations that exceed any other pollutant (Lockhart et al., 1992; DIAND, 1996).

Use of Organochlorines in Yukon Territory

After finding high concentrations of organochlorines in fishes from Lake Laberge, a survey of the historical use of organochlorine compounds and other persistent pollutants in Yukon was commissioned (Minister of Indian Affairs and Northern Development, 1993). This report details the known use of persistent organochlorines in Yukon Territory and the findings are discussed below. While the results of this survey indicate that local use and disposal of DDT and PCBs may have resulted in the past contamination of Lake Laberge, no historical use of toxaphene in the Whitehorse area was found.

The most significant use of PCBs in Yukon is believed to have been in electrical transformers and capacitors used in the construction of the Alaska Highway and by industries located in the City of Whitehorse. Up until 1977, uncontrolled disposal of equipment and oil containing PCBs occurred in the region, and elevated PCB levels have been found in soils near dumpsites. Aside from the possible indirect contamination of Lake Laberge from dumpsite leaching and accidental spills of PCBs, it is also possible that PCBs were applied to the lake proper. When steamers were used as the main transportation to Dawson City from Whitehorse, lamp black mixed with oil was applied to the ice surface along the length of Laberge to speed up the spring melt. It is possible that PCB-laden oils were mixed with the lamp black and used for this purpose until the steamers became obsolete in 1956 (see also Davison, 1991b).

Between 1949 and 1969, DDT was used to control mosquitoes and black flies in Yukon through both direct application to water bodies and aerial spraying. It has been estimated that between 1949 and 1963, 35,148 pounds of concentrated DDT were sprayed in and near Whitehorse, and from 1964 to 1969, 4,508 gallons of concentrated DDT were sprayed around Whitehorse and other communities. From 1964 to 1965, Tossit (an encapsulated mixture of DDT and Lindane) was also used as a larvicide on ponds and other stagnant water bodies. It is believed that most of the unused quantities of DDT were taken to local dumps (see also Davison, 1991c) or put into the Yukon River. After 1969 and through to 1985, the organophosphates Abate and Malathion replaced DDT in mosquito control programs, and Vectobac (*Bacillus thuringiensis israeliensis*) is currently being used as a biological control agent.

The only known use of toxaphene in Yukon Territory was to remove unwanted fish species from Hansen Lake, located in central Yukon, in 1963. Rotenone was used more commonly in fisheries management practices though it is known to have only been applied to five lakes and rivers between 1959 and 1966 in Yukon.

Organochlorines in the Arctic

Organochlorines have not had significant use in the Arctic, and long-range atmospheric transport and deposition are believed to be the main sources of pollutants to this region. These compounds volatilize from regions of past or present use, and are carried thousands of kilometers, from as far away as Asia and the former Soviet Union, to the Arctic. Many organochlorines, such as those identified previously, have low water solubilities, are stable both chemically and biologically, and have long atmospheric residence times on particles or as vapour. All of these characteristics favour long-range atmospheric transport to and depostion of these pollutants in the Arctic (Barrie et al., 1992). Persistent organochlorines have been identified in air, snow, rain and water, and on particulates collected from remote arctic locations (Bidleman et al, 1987; 1989; 1995; Gregor and Gummer, 1989; Welch et al., 1991). HCH, chlordane, dieldrin, and PCBs predominate in snow (Gregor and Gummer, 1989), while HCH, chlordane, DDT and toxaphene predominate in air and water (Bidleman et al., 1995). Long-range transport and deposition of toxaphene to the Arctic is mainly dominated by the lower chlorinated compounds, but the more highly chlorinated toxaphene congeners that bioaccumulate to significant levels in biota (Stern et al., 1992) were also found (Bidleman et al., 1995). It has been estimated that 1.5, 3.3 and 32 tonnes of p,p'-DDT, chlordane and toxaphene respectively are deposited on an annual basis to the Arctic through wet and dry particle deposition, and gas flux (Cotham and Bidleman, 1991).

Higher concentrations of the more volatile organochlorines have been found in the polar regions than at temperate latitudes (Iwata et al., 1993). This latitudinal gradient is believed to be a function of the temperature differences between regions. While the warmer southern temperatures volatilize organochlorines from water and soils to the atmosphere for long-range transport, the colder temperatures in the Arctic increase the partitioning of organochlorines from air to water, soil and biota, leading to a greater retention of these compounds in the arctic biosphere (Mackay and Wania, 1995). This movement of organochlorines from warmer to colder climates is known as 'global distillation', 'cold condensation', or the 'grasshopper effect'. Recently, Simonich and Hites (1995) demonstrated that more volatile organochlorines were found in higher proportions in tree bark from northern latitudes when compared to sites near the equator, while the less volatile organochlorines tend to remain near the sites of application or use. Higher concentrations of HCH have been found in arctic waters when compared to samples from more southerly latitudes (Chernyak et al., 1995). Muir et al. (1995) found that the fluxes of DDT to the surface sediments of lakes declined with latitude (49 to 81°N) while fluxes of the more volatile chlorobenzenes increased with latitude. No latitudinal trends were observed for toxaphene, chlordanes, dieldrin and HCHs. Muir et al.'s study also found that while the deposition of DDT was greatest in the 1960s and 1970s for temperate lakes, the maximum deposition of these organochlorines was found at later dates (1980s) in arctic cores, indicating a time lag in the movement of these compounds to northern latitudes.

Few studies have been conducted to examine the long-term depositional trends of organochlorines in the Arctic. Bidleman et al. (1995) found lower concentrations of toxaphene, HCHs and chlordane in air samples collected in 1992 from Resolute Bay, NWT, than were reported for the Canadian High Arctic in 1986/87 (Patton et al., 1989). Oehme et al. (1995) have found a decrease in chlordane and α-HCH concentrations, and a possible increase in γ-HCH, in air samples collected in Norway in 1992 when compared to 1982-84 levels. The high seasonal variability associated with air and precipitation monitoring, and the general lack of data make it difficult to examine long-term trends. However, dated lake and ice cap cores have also been used to examine the depositional history of organochlorines to the Arctic over the past several decades. Gregor et al. (1995) found no long-term decreases between 1964 and 1992 in PCB deposition to the Agassiz Ice Cap on Ellesmere Island. Similarly, Muir et al. (1995) have found that although the deposition of organochlorines to high arctic lakes increased in the 1950s and 1960s, it has not declined since this time.

Several characteristics of the arctic ecosystem may affect the accumulation of organochlorines in biota. Arctic lakes are considered to be unproductive, and are characterized by highly cyclical periods of productivity; highest productivity occurs during the summer months when lake surfaces are ice-free and solar inputs are greatest. Terrestrial vegetation is sparse in arctic lake catchments, and, as a result, organochlorines deposited in the snow may not retained in the drainage basin during spring melt. Colder temperatures and low productivity may also result in reduced revolatilization of organochlorines from arctic lakes, and in slower-growing and longer-living organisms with longer maturation periods. These factors may lead to higher concentrations of organochlorines in the top predators because they prolong an organism's exposure to organochlorines.

Biaccumulation of Organochlorines in Biota

Aquatic organisms accumulate organochlorines either directly from the water, or from a combination of dietary and water sources, and these processes are known as bioconcentration and bioaccumulation respectively (Macek et al., 1979). Organochlorines are lipophilic, and, as a result, they are found at higher concentrations in fattier organisms (Oliver and Niimi, 1988; Mackay, 1982) and tissues (Muir et al., 1990). Although lipid is important, further studies have demonstrated that other biotic and abiotic factors also significantly affect the concentrations of organochlorines in organisms. Laboratory studies have demonstrated that the bioconcentration of organochlorines in fishes is directly dependent upon the concentrations in water (Matsumura, 1977), the lipophilicity or K_{ow} of the compounds (Mackay, 1982; Oliver and Niimi, 1988), temperature (Barron, 1990; Veith et al., 1979), species (Davies and Dobbs, 1984) and fish size (Matsumura, 1977; Davies and Dobbs, 1984). Reductions in the metabolic rates of organisms, which decrease with increasing size of the organism (Adolph, 1949) and decreasing ambient temperature, also reduces the uptake rates of organochlorines in fishes (Tarr et al., 1990; Murphy and Murphy, 1971; Veith et al., 1979). Further, dissolved organic carbon, colloids or particulates in the water will bind organochlorines (McCarthy and Bartell, 1988) and decrease their availability for uptake by aquatic organisms (Servos et al., 1989; Larsson et al., 1992).

For algae and small-bodied organisms such as zooplankton, bioconcentration is the main route of organochlorine uptake (Swackhamer and Skoglund, 1993) because these organisms have high surface area to volume ratios. However, it has been demonstrated that the main source of organochlorines for fishes and other upper-trophic-level organisms is diet. Oliver and Niimi (1988) showed that the concentrations of PCBs in lake trout from Lake Ontario were an order of magnitude higher than expected based on water concentrations alone. The authors concluded that this discrepancy between predicted (based on a compound's lipophilicity) and observed concentrations in fishes was due to significant accumulation of organochlorines from food. Similar discrepancies between have also been observed for fishes from Siskiwit Lake, Isle Royale, Lake Superior (Swackhamer and Hites, 1988).

Rasmussen et al. (1990) and Cabana et al. (1994) grouped temperate lakes into three classes based on the length of the pelagic food chain leading up to lake trout: class 1 lakes had the shortest food chains with no *Mysis* or pelagic forage fish; class 2 lakes had pelagic forage fishes; class 3 lakes had both pelagic forage fishes and *Mysis*. They found that lake trout with the highest and lowest PCB and mercury concentrations were from the longest and shortest food chains respectively, and that PCB concentrations increased 3.5 fold with each increase in lake trout trophic position. Results from this study unequivocally demonstrated that the length of the underlying food chain is a significant predictor of pollutant concentrations in fishes. Similarly, Thomann and Connolly (1984) modelled the concentrations of organochlorines in lake trout from Lake Michigan and found that dietary uptake accounted for almost all (99 %) of their PCB body burdens. The uptake of organochlorines from food, coupled with low metabolism and excretion of these compounds, results in elevated concentrations of organochlorines in top predators, and increasing concentrations in organisms with increasing trophic position (Evans et al., 1991), or biomagnification.

While concentrations of persistent organochlorines appear to have decreased in temperate fishes over the past decades because of the reductions in organochlorine inputs to these systems (e.g. de Vault et al., 1986; Baumann and Whittle, 1988; Miller et al., 1992), data on the long-term trends of organochlorines in arctic biota are scarce. Changes in analytical methodology, and the inherent variability in fish organochlorine data have made such temporal comparisons difficult. Reinke et al. (1972) was the first to report the presence of organochlorines in fishes from the Canadian Arctic. Since this time, other monitoring studies have been conducted and indicate that concentrations of DDT in whitefish in Northwest Territories appear to have declined between 1970 and 1986. Reinke et al. (1972) found concentrations of DDT ranging from < 10 to 190 ng.g^{-1} in whitefish from Northwest Territories flesh collected in 1970; Lockhart et al. (1989) reported values in the same species collected in 1986 that were considerably lower, 0.2 to 3.5 ng.g^{-1} wet weight. Significant declines in the toxaphene concentrations in burbot liver from Great Slave Lake have also been found over the past decade (DIAND, 1996).

As was observed for the above-mentioned lake core data, latitudinal trends in organochlorine concentrations have also been observed for biota. Andersson et al. (1988) found that the concentrations of PCBs and DDT in seals and raptorial birds decreased with latitude while no such trend was observed for toxaphene. Muir et al. (1990) found that concentrations of the less volatile organochlorines including DDT, PCBs (hepta- to nonachlorinated PCBs), dieldrin and mirex were highest in burbot liver from more southerly latitudes when compared to fish from the arctic, while concentrations of the more volatile compounds (HCH, tri- and tetrachlorinated PCBs, and toxaphene) did not decline with latitude.

The presence of organochlorines in arctic biota is of concern for the aboriginal people because a large proportion of their diet traditionally consists of healthful country foods (Kinloch et al., 1992; Wein et al., 1991). Higher concentrations of organochlorines have been found in the blood and breast milk of aboriginal people (Dewailly et al., 1994) when compared to people from southern latitudes, indicating that aboriginals are chronically exposed to higher levels of these pollutants through their diet. However, alternative food sources are not an option for many northerners as the costs are prohibitive.

Use of Stable Nitrogen Isotope Ratios in Food Web Studies

The element nitrogen exists in two stable forms, ^{14}N and ^{15}N, which are present in the environment at average abundances of 99.63 and 0.37 % respectively (Rundel et al., 1988). Due to the difficulty in measuring the absolute isotopic composition of materials and the precision required for such analyses, the nitrogen isotopic composition of a sample is always expressed in terms of its difference from a standard reference material. The reference material used for nitrogen isotope analyses is N_2 in air which has an accepted average ^{15}N to ^{14}N ratio of 0.0036765 (Rundel et al., 1988). The difference between the isotopic composition of a sample and standard is expressed in delta (δ) notation and is calculated as

$$\delta^{15}N = [(R_{sample}/R_{standard})-1] \times 1000$$

where R equals $^{15}N/^{14}N$. Values are multiplied by 1000 in order to express this difference on a parts per thousand or per mil (‰) basis.

Stable isotope ratios are of particular interest in ecological studies because they can be used to provide information on sources if no fractionation of the isotopes occurs, or process information if the heavier isotope is enriched or depleted during biological, chemical or biogeochemical reactions. Isotope ratios of carbon ($^{13}C/^{12}C$) or sulfur ($^{34}S/^{32}S$) in organisms generally reflect the isotopic composition of their diet, thereby providing information on the original source of carbon or sulfur to the food web (Peterson and Fry, 1987). Unlike these elements, the heavier isotope of nitrogen is consistently enriched from primary producers to primary consumers, from primary consumers to secondary consumers, and so on up through the food web (Hesslein et al., 1991; Hobson and Welch, 1995), and provide a continuous measure of an organism's trophic positioning. Stable $\delta^{15}N$ measurements are particularly useful for elucidating food web relationships for organisms whose dietary habits cannot be determined or observed using conventional techniques, or change seasonally, and in locations where year-round sampling is logistically difficult or impossible. While conventional stomach content analyses provide short-term information on dietary habits, $\delta^{15}N$ is an integrated signal of what is digested and assimilated into an organism from it's diet over longer periods of time, possibly months to years in slow growing populations (Hesslein et al., 1993). Therefore, muscle or whole-body $\delta^{15}N$ is a measure of the long-term average energy sources for biota.

The isotopic enrichment of an organism's protein versus its dietary protein is due to mass-induced differences in the metabolism of ^{15}N and ^{14}N. Steele and Daniel (1978) conducted experiments using diets with similar ^{15}N concentrations (0.6 and 0.7 ‰) and different protein levels and found that, relative to its diet, a cow's milk, blood and feces were enriched in ^{15}N, while urine was depleted in ^{15}N, and that isotope ratio inputs balance outputs. These enrichments were comparable despite the variable levels of protein indicating that metabolic processes, and not variations in the availability of nitrogen, causes the fractionation. In dietary studies using rats, Gaebler et al. (1966) found a consistent enrichment of ^{15}N in liver and muscle tissues over the diet and this enrichment was due to the metabolic fractionation of essential and non-essential amino acids. This fractionation is also independent of age and the form of nitrogen excreted by organisms (Minagawa and Wada, 1984; Kiriluk et al., 1996; Hobson and Welch, 1995). The specific mechanism of metabolic nitrogen isotope fractionation has not yet been determined.

Analyses of a wide range of plants and animals have demonstrated that the trophic enrichment of ^{15}N is comparable across a variety of organisms and habitats. Fry (1991) found an average enrichment of 2 to 3 ‰ per trophic level in his survey of plants, algae, herbivores, omnivores and predators from freshwater lakes and streams. Similarly, Minagawa and Wada (1984) and Peterson and Fry (1987) calculated average prey and predator $\delta^{15}N$ enrichments of 3.4 ± 1.1 ‰ (mean ± SD) and 3.2 ‰ respectively for a large number of terrestrial, marine and freshwater organisms from both field studies and laboratory experiments. Cabana and Rasmussen (1994) found an average increase in $\delta^{15}N$ of 3.46 ‰ with each step through the pelagic food web of Lake Ontario, and that $\delta^{15}N$ in lake trout from several temperate lakes covaried with the length of the underlying food chain. Comparable enrichments of $\delta^{15}N$ have been observed for arctic freshwater biota. A stepwise enrichment of $\delta^{15}N$ was found in Toolik Lake, Alaska, with particulate organic matter (POM) having $\delta^{15}N$ values of 3 ‰, copepods averaging close to 7 ‰, and fish measuring 10 ‰ (Fry, 1991). Zooplankton were enriched in $\delta^{15}N$ by an average of 3.5 and 3.2 ‰ over POM in Smith Lake, Alaska (Gu et al., 1994), and in several arctic lakes (Kling et al., 1992) respectively. Also, feeding studies with broad whitefish (*Coregonus nasus*) revealed enrichments of 3.0 and 3.8 ‰ for fish fed two different diets (Hesslein et al., 1993).

$\delta^{15}N$ is appealing to use in ecological studies because it quantifies trophic positions of organisms from food webs varying in species composition (Cabana and Rasmussen, 1994). Moreover, it is useful for among-site comparisons of one species because individuals may vary considerably in their trophic positions due to differences in resource availability and intra- or interspecific competition. For example, Kling et al. (1992) compared the trophic position of the herbivorous copepod *Diaptomus* with the predaceous *Heterocope* they found that the latter species functioned as a herbivore, omnivore or predator within different food webs.

When conducting among-site comparisons it must be considered that an organism's $\delta^{15}N$ is a function not only of its trophic position, but also of the $\delta^{15}N$ of primary producers at the base of the food web. The isotopic composition of algae varies with the productivity of a system as shown by Minagawa and Wada (1984). Algal $\delta^{15}N$ signals from the oligotrophic East China Sea were close to 0 ‰, while phytoplankton samples from the eutrophic Bering Sea and Lake Ashinkoko were around 5 ‰. The fish from these systems had isotopic compositions reflecting this difference in algal $\delta^{15}N$. Similar relationships were observed in Fry (1991); the highest $\delta^{15}N$ values for top predators were found in systems with the highest basal $\delta^{15}N$ signal.

When algae grow in an environment that is not nitrogen limited, they will preferentially incorporate the lighter isotope (^{14}N) into their cellular proteins (Wada and Hattori, 1976), otherwise algal $\delta^{15}N$ will reflect the inorganic $\delta^{15}N$ signal because no fractionation will occur. Peterson et al. (1993) found that the fertilization of an arctic river system with phosphorous and nitrogen (100 ug N $.L^{-1}$ at 0 ‰) resulted in algae (-6.3 ‰) that were 9 ‰ lighter than the algae from the non-fertilized section of the river, and a corresponding decrease in invertebrate and fish $\delta^{15}N$ from the former site. The isotopic composition of inorganic nitrogen being used at the base of the food web also affects the $\delta^{15}N$ signal through the food web. Kline et al. (1990) revealed that the heavier nitrogen from spawning salmon (11.2 ‰) was incorporated into the biota from the stream, increasing their tissue $\delta^{15}N$ by 5 ‰ when compared to the same species from non-spawning sites. Estep and Vigg (1985) found that the inorganic nitrogen downstream of a sewage treatment plant was enriched by almost 9 ‰ when compared to samples from upstream sites (-1 to 1 ‰); the organic effluent had isotopic values of 1 ‰. Algae in the canal and reservoir receiving this effluent had $\delta^{15}N$ values of 7.0 to 8.6 ‰, indicating a reliance upon this isotopically enriched inorganic nitrogen source. Cabana and Rasmussen (1996) have also observed that the $\delta^{15}N$ of primary consumers increases with the human population density in the watershed, and covaries with the $\delta^{15}N$ of perch and walleye from these lakes. Because the $\delta^{15}N$ signal in primary producers depends both upon the availability and $\delta^{15}N$ of inorganic nitrogen in the system, site-specific considerations need to be made when comparing the isotopic composition of consumers from various locations.

The complexity of trophic interactions make it difficult to accurately determine an organism's food web position and, therefore, quantify the in situ biomagnification of organochlorines. Researchers have traditionally assigned species to discrete trophic positions (primary through tertiary consumers) based on the results from other studies, despite the fact that these generalizations may not be applicable to the site of interest (Oliver and Niimi, 1988; Evans et al., 1991; Rasmussen et al., 1990). Unlike traditional food web classifications, $\delta^{15}N$ is a numerical measure of an organism's trophic niche, and it is assumed that the magnitude of the difference in $\delta^{15}N$ between individuals reflects differences in their trophic positioning. By providing a trophic continuum, $\delta^{15}N$ eliminates the need to use discrete trophic assignments and is a quantitative method for examining biomagnification through the food web. For this reason, I chose to use $\delta^{15}N$ to determine if the food web structure in Lake Laberge was unusual when compared to other regional lakes, and was a factor underlying the elevated contaminant concentrations in these fishes.

References

Adolph, E.F. (1949) Quantitative relations in the physiological constitutions of mammals. Science 109:579-585.

Agriculture Canada (1984) Compendium of pest control products registered in Canada. Registered Pest Control Products. Volume RP, Pesticides Division, Plant Health and Plant Products Directorate, Ottawa. Publ. No. 1654 RP/84.

Alaee, M and D., Gregor (1994) A study of the sources and fate of organochlorine contaminants in the Yukon River basin. P.p. 152-161 in: Synopsis of Research Conducted Under the 1993/94 Northern Contaminants Program, J.L. Murray and R.G. Shearer (eds.). Environmental Studies No. 72. Indian and Northern Affairs Canada, Ottawa. 459 pp.

Andersson, O., C-E. Linder, M. Olsson, L. Reutergardh, U-B. Uvemo and U. Wideqvist (1988) Spatial differences and temporal trends of organochlorine compounds in biota from the northwestern hemisphere. Arch. Environ. Contam. Toxicol. 17:755-765.

Barrie, L.A., D. Gregor, B. Hargrave, R. Lake, D. Muir, R. Shearer, B. Tracey and T. Bidleman (1992) Arctic contaminants: sources, occurrence and pathways. Sci. Total Environ. 122:1-74.

Barrie, L. (1994) Northern contaminants air monitoring. P.p. 20-27 in: Synopsis of Research Conducted Under the 1993/94 Northern Contaminants Program, J.L. Murray and R.G. Shearer (eds.). Environmental Studies No. 72. Indian and Northern Affairs Canada, Ottawa. 459 pp.

Barron, M.G. (1990) Bioconcentration. Environ. Sci. Technol. 24(11):1612-1618.

Baumann, P.C. and D.M. Whittle (1988) The status of selected organics in the Laurentian Great Lakes: an overview of DDT, PCBs, dioxins, furans, and aromatic hydrocarbons. Aquatic Toxicol. 11:241-257.

Bidleman, T.F., U. Wideqvist, B. Jansson and R. Soderlund (1987) Organochlorine pesticides and polychlorinated biphenyls in the atmosphere of southern Sweden. Atmos. Environ. 21:641-654.

Bidleman, R.F., G.W. Patton, M.D. Walla, B.T. Hargrave, W.P. Vass, P.E. Erickson, B.R. Fowler, V. Scott and D.J. Gregor (1989) Toxaphene and other organochlorines in Arctic Ocean fauna: evidence for atmospheric delivery. Arctic 42:155-162.

Bidleman, T.F., R.L. Falconer and M.D. Walla (1995) Toxaphene and other organochlorine compounds in air and water at Resolute Bay, NWT, Canada. Sci. Total Environ. 160/161:55-63.

Callahan, M.A., M.W. Slimak, N.W. Gabel, I.P. May, C.F. Fowler, J.R. Freed, P. Jennings, R.L. Durfee, F.C. Whitmore, B. Maestri, W.R. Mabey, B.R. Holt and C. Gould (1979) Water-related environmental fate of 129 priority pollutants, Vol. I. Office of Water Planning and Standards, U.S. Environmental Protection Agency. EPA-440/4-79-029a.

Cabana, G., A. Tremblay, J. Kalff and J.B. Rasmussen (1994) Pelagic food chain structure in Ontario lakes: a determinant of mercury levels in lake trout (*Salvelinus namaycush*). Can. J. Fish. Aquat. Sci. 51:381-389.

Cabana, G. and J.B. Rasmussen (1994) Modelling food chain structure and contaminant bioaccumulation using stable nitrogen isotopes. Nature 372:255-257.

Cabana, G. and J.B. Rasmussen (1996) Modelling food chain structure with N-isotopes: adjusting for anthropogenic shift in isotopic signatures. Unpublished manuscript.

Chernyak, S.M., L.L. McConnell and C.P. Rice (1995) Fate of some chlorinated hydrocarbons in arctic and far eastern ecosystems in the Russian Federation. Sci. Total Environ. 160/161:75-85.

Cotham, W.E. and T.F. Bidleman (1991) Estimating the atmospheric deposition of organochlorine contaminants to the Arctic. Chemosphere 22:165-188.

Courtney, K.D. (1979) Hexachlorobenzene (HCB): a review. Environ. Res. 20:225-266.

Davies, R.P. and A.J. Dobbs (1984) Prediction of bioconcentration in fish. Water Res. 18(10):1253-1262.

Davison, S. (1991a) Lake Laberge fish subject of strong health warning. The Whitehorse Star, May 9, p. 1.

Davison, S. (1991b) Pollution probe:Lake Laberge. The Whitehorse Star, May 17, p. 6.

Davison, S. (1991c) The Range Road dump. The Whitehorse Star, May 10, p. 6.

Dearth, M.A. and R.A. Hites (1991) Complete analysis of technical chlordane using negative ionization mass spectrometry. Environ. Sci. Technol. 25:245-254.

de Graff, N. and L. Mychasiw (1994) Lake trout recovery and contaminant management program in Lake Laberge, Yukon Territory. P.p. 301-304 in: Synopsis of Research Conducted Under the 1993/94 Northern Contaminants Program, J.L. Murray and R.G. Shearer (eds.). Environmental Studies No. 72. Indian and Northern Affairs Canada, Ottawa. 459 pp.

de Bruijn, J. F. Bussers, W. Seinen and J.L.M. Hermens (1989) Determination of octanol/water partition coefficients for hydrophobic organic chemicals with the "slow-stirring" method. Environ. Toxicol. Chem. 8:499-512.

Department of Indian Affairs and Northern Development (1996) Canadian Arctic Contaminants Assessment Report. Chapter III: Ecosystem uptake and effects. D.C.G. Muir (ed.), Department of Indian Affairs and Northern Development, in preparation.

de Vault, D.S., W.A. Willford, R.J. Hesselberg, D.A. Nortrupt, E.G.S. Rundberg, A.K. Alwan and C. Bautista (1986) Contaminant trends in lake trout (*Salvelinus* *namaycush*) from the upper Great Lakes. Arch. Environ. Contam. Toxicol. 15:349-356.

Dewailley, E., P. Ayotte, C. Laliberte, D.C.G. Muir and R.J. Norstrom (1994) Human exposure to polychlorinated biphenyls through the aquatic food chain in the Arctic. Environmental Health Perspectives 101:618-629.

Eisler, R. and J. Jacknow (1985) Toxaphene hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep. 85(1.4). 26 pp.

Ennis, G.L., R.A.C. Johnston, M. Whately, D. Reynolds, T. Pendray and D. Davies (1984) Yukon River basin study: fisheries work group program report. Vancouver, B.C.

Environment Canada (1980) Environmental Contaminants Act. Chlorobiphenyl Regulations No. 1, Amendment. The Canada Gazette Part II. Vol. 114(3):2272-2274. Queen's Printer for Canada, Ottawa.

Estep, M.L. and S. Vigg (1985) Stable carbon and nitrogen isotope tracers of trophic dynamics in natural populations and fisheries of the Lahontan Lake system, Nevada. Can. J. Fish. Aquat. Sci. 42:1712-1719.

Evans, M.S., G.E. Noguchi, and C.P. Rice (1991) The biomagnification of polychlorinated biphenyls, toxaphene, and DDT compounds in a Lake Michigan offshore food web. Arch. Environ. Contam. Toxicol. 20:87-93.

Fry, B. (1991) Stable isotope diagrams of freshwater food webs. Ecology 72(6):2293-2297.

Gaebler, O.H., T.G. Vitti and R. Vukmirovich (1966) Isotope effects in metabolism of ^{14}N and ^{15}N from unlabeled dietary proteins. Can. J. Biochem. 44:1249-1257.

Godin, B. and M. Jack (1984) Environmental quality of Lake Laberge, Yukon. Regional Program Report No. 84-03, Environmental Protection Service, Environment Canada, 201 pp.

Gregor, D. and J.E. Eamer (1993) Base flow water quality and contaminant levels in the upper Yukon River system. P.p. 69-77 in: Synopsis of Research Conducted Under the 1992/93 Northern Contaminants Program, J.L. Murray and R.G. Shearer (eds.). Environmental Studies No. 70. Indian and Northern Affairs Canada, Ottawa. 285 pp.

Gregor, D.J. and W.D. Gummer (1989) Evidence of atmospheric transport and deposition of organochlorine pesticides and polychlorinated biphenyls in Canadian arctic snow. Environ. Sci. Technol. 23:561-565.

Gregor, D.J., A.J. Peters, C. Teixeira, N. Jones and C. Spencer (1995) The historical residue trend of PCBs in the Agassiz Ice Cap, Ellesmere Island, Canada. Sci. Total Environ. 160/161:117-126.

Gu, B., D.M. Schell and V. Alexander (1994) Stable carbon and nitrogen isotopic analysis of the plankton food web in a subarctic lake. Can. J. Fish. Aquat. Sci. 51:1338-1344.

Hesslein, R.H., M.J. Capel, D.E. Fox and K.A. Hallard (1991) Stable isotopes of sulfur, carbon, and nitrogen as indicators of trophic level and fish migration in the lower Mackenzie River basin, Canada. Can. J. Fish. Aquat. Sci. 48(11):2258-2265.

Hesslein, R.H., K.A. Hallard and P. Ramlal (1993) Replacement of sulfur, carbon, and nitrogen in tissue of growing broad whitefish (*Coregonus nasus*) in response to a change in diet traced by $\delta^{34}S$, $\delta^{13}C$, and $\delta^{15}N$. Can. J. Fish. Aquat. Sci. 50:2071-2076.

Hinckley, D.A., R.F. Bidleman, W.T. Foreman and J.R. Tuschall (1990) Determination of vapour pressures for non-polar and semi polar organic compounds from gas chromatographic retention data. J. Chem. Eng. Data 35:232-237.

Hobson, K.A. and H.E. Welch (1995) Cannibalism and trophic structure in a high Arctic lake: insights from stable-isotope analysis. Can. J. Fish. Aquat. Sci. 52:1195-1201.

Howard, P.H. (1991) Handbook of environmental fate and exposure data for organic chemicals. Volume III, Lewis Publishers, Michigan, 684 p.

Hutzinger, O., S. Safe and V. Zitko (1974) The chemistry of PCBs. CRC Press, Cleveland, Ohio.

Iwata, H., S. Tanabe, N. Sakal and R. Tatsukawa (1993) Distribution of persistent organochlorines in the oceanic air and surface seawater and the role of the ocean in their global transport and fate. Environ. Sci. Technol. 27:1080-1098.

Keller, E. (1970) The DDT story. Chemistry 43:8-12.

Kidd, K.A., J.E. Eamer and D.C.G. Muir (1993) Spatial variability of chlorinated bornanes (toxaphene) in fishes from Yukon lakes. Chemosphere 27(10):1975-1986.

Kinloch, D., Kuhnlein, H. and D.C.G. Muir (1992) Inuit foods and diet: a preliminary assessment of benefits and risks. Sci. Total Environ. 122:247-278.

Kiriluk, R.M., M.R. Servos and D.M. Whittle (1996) Using ratios of stable nitrogen and carbon isotopes to characterize the biomagnification of DDE, Mirex and PCB in a Lake Ontario pelagic food web. Can. J. Fish. Aquat. Sci., in press.

Kirkland, R.A. and C.B.J. Gray (1986) Reconnaissance of the chemical and biological limnology in four large lakes of the Yukon River basin. NHRI Paper No. 33, IWD Scientific Series No. 153, Environment Canada, 23 pp.

Kline, T.C., J.J. Goering, O.A. Mathisen and P.H. Poe (1990) Recycling of elements transported upstream by runs of pacific salmon: I. $\delta^{15}N$ and $\delta^{13}C$ evidence in Sashin Creek, southeastern Alaska. Can. J. Fish. Aquat. Sci. 47:136-144.

Kling, G.W., B. Fry and W.J. O'Brien (1992) Stable isotope and planktonic trophic structure in arctic lakes. Ecology 73(2):561-566.

Korte, F.I., I. Scheonert and H. Parlar (1979) Toxaphene (camphechlor), a special report. Int. Union Pure Appl. Chem. 51:1561-1583.

Larsson, P., L. Collvin, L. Okla and G. Meyer (1992) Lake productivity and water chemistry as governors of the uptake of persistent pollutants in fish. Environ. Sci. Technol. 26(2):346-352.

Lee, G., R. Hughes and G. Veith (1977) Evidence for partial degradation of toxaphene in the aquatic environment. Water Air Soil Pollut. 8:479-484.

Lennon, R.E., J.B. Hunn, R.A. Schnick and R.M. Burress (1970) Reclamation of ponds, lakes, and streams, with fish toxicants: a review. FAO Fisheries Tech. Paper 100, Food Agric. Org. U.N., Rome. 99 pp. Reprinted by U.S. Fish Wild. Serv., 1971.

Lindsey, C.C., K. Patalas, R.A. Bodaly and C.P. Archibald (1981) Glaciation and the physical, chemical and biological limnology of Yukon lakes. Can. Tech. Report Fish. Aquat. Sci. No. 966, 37 pp.

Lockhart, W.L., D.A. Metner, D.A.J. Murray, R.W. Danell, B.N. Billeck, C.L. Baron, D.C.G. Muir and K. Chang-Kue (1989) Studies to determine whether the condition of fish from the lower Mackenzie river is related to hydrocarbon exposure. Environmental Studies No. 61, Department of Indian Affairs and Northern Development, Ottawa, 84 pp.

Lockhart, W.L., R.Wagemann, B. Tracey, D. Sutherland and D.J. Thomas (1992) Presence and implications of chemical contaminants in the freshwaters of the Canadian Arctic. Sci. Total Environ. 122:165-243.

Lockhart, W.L. (1993) Depositional trends - lake and marine sediments. P.p. 46-56 in: Synopsis of Research Conducted Under the 1992/93 Northern Contaminants Program, J.L. Murray and R.G. Shearer (eds.). Environmental Studies No. 70. Indian and Northern Affairs Canada, Ottawa. 285 pp.

Lockhart, W.L. (1994) Depositional trends - lake and marine sediments P.p. 138-151 in: Synopsis of Research Conducted Under the 1993/94 Northern Contaminants Program, J.L. Murray and R.G. Shearer (eds.). Environmental Studies No. 72. Indian and Northern Affairs Canada, Ottawa. 459 pp.

MacDonald, S. (1991) Yukon Government News Release, #093, May 8.

Macek, K.J. S.R. Petrocelli and B.H. Sleight (1979) Consideration in assessing the potential for, and significance of biomagnification of chemical residues in aquatic food chains. In: Marking L.L., Kimerle, R.A. (eds) Aquatic Toxicology. American Society for Testing and Materials. pp 251-268.

Mackay, D., W. Ying Shiu and K. Ching Ma (1992) Illustrated handbook of physical-chemical properties and environmental fate for organic chemicals, Volume I, Lewis Publishers, Inc., Michigan, 697 pp.

Mackay, D. and F. Wania (1995) Transport of contaminants to the Arctic: partitioning, processes and models. Sci. Total Environ. 160/161:25-38.

Mackay, D. (1982) Correlation of bioconcentration factors. Environ. Sci. Technol. 16:274-276.

Matsumura, F. (1977) Absorption, accumulation, and elimination of pesticides by aquatic organisms. Environ. Sci. Res. 10:77.

McCarthy, J.F. and S.M. Bartell (1988) How the trophic status of a community can alter the bioavailability and toxic effects of contaminants. in: Functional Testing of Aquatic Biota for Estimating Hazards of Chemicals. ASTM STP 988 (eds) J. Cairns and J.R. Pratt. American Society for Testing and Materials, Philadelphia, pp. 3-16.

Miller, M.A., C.P. Madenjian and R.G. Masnado (1992) Patterns of organochlorine contamination in lake trout from Wisconsin waters of the Great Lakes. J. Great Lakes Res. 18(4):742-754.

Minagawa and Wada (1984) Stepwise enrichment of ^{15}N along food chains: Further evidence and the relation between $\delta^{15}N$ and animal age. Geochim. Cosmochim. Acta 48:1135-1140.

Minister of Indian Affairs and Northern Development, (1993) Use, disposal and transportation of selected contaminants in Yukon. 50 pp.

Miskimmin, B.M. and D.W. Schindler (1994) Long-term invertebrate community response to toxaphene treatment in two lakes: 50-yr records reconstructed from lake sediments. Can. J. Fish. Aquat. Sci. 51:923-932.

Miskimmin, B.M., D.C.G. Muir, D.W. Schindler, G.A. Stern and N.P. Grift (1995) Chlorobornanes in sediments and fish 30 years after toxaphene treatment of lakes. Environ. Sci. Technol. 29:2490-2495.

Muir, D.C.G., C.A. Ford, N.P. Grift, D.A. Metner and W.L. Lockhart (1990) Geographic variation of chlorinated hydrocarbons in burbot (*Lota lota*) from remote lakes and rivers in Canada. Arch. Environ. Contam. Toxicol. 19:530-542.

Murphy, P.G. and J.V. Murphy (1971) Correlations between respiration and direct uptake of DDT in the mosquito fish *Gambusia affinis*. Bull. Environ. Contam. Toxicol. 6:581-588.

Oehme, M., J-E. Haugen and M. Schlabach (1995) Ambient air levels of persistent organochlorines in spring 1992 at Spitsbergen and the Norwegian mainland:comparison with 1984 results and quality control measures. Sci. Total Environ. 160/161:139-152.

Oliver, B.G. and A.J. Niimi (1988) Trophodynamic analysis of polychlorinated biphenyl congeners and other chlorinated hydrocarbons in the Lake Ontario ecosystem. Environ. Sci. Technol. 22:388-397.

Palmer, M. (1994a) Sources, pathways and levels of contaminants in fish from Yukon waters. P.p. 272-275 in: Synopsis of Research Conducted Under the 1993/94 Northern Contaminants Program, J.L. Murray and R.G. Shearer (eds.). Environmental Studies No. 72. Indian and Northern Affairs Canada, Ottawa. 459 pp.

Palmer, M. (1994b) Current contaminant deposition in snow in the Yukon Territory. P.p. 91-103 in: Synopsis of Research Conducted Under the 1993/94 Northern Contaminants Program, J.L. Murray and R.G. Shearer (eds.). Environmental Studies No. 72. Indian and Northern Affairs Canada, Ottawa. 459 pp.

Patton, G.W., D.A. Hinckley, M.D. Walla, T.F. Bidleman and B.T. Hargrave (1989) Airborne organochlorines in the Canadian High Arctic. Tellus 41B:243-255.

Peterson, B., B. Fry and L. Deegan (1993) The trophic significance of epilithic algal production in a fertilized tundra river ecosystem. Limnol. Oceanog. 38:872-878.

Peterson, B.J. and B. Fry (1987) Stable isotopes in ecosystem studies. Ann. Rev. Ecol. Syst. 18:293-320.

Rapaport, R.A. and S.J. Eisenreich (1988) Historical atmospheric inputs of high molecular weight chlorinated hydrocarbons to eastern North America. Environ. Sci. Technol. 22:931-941.

Rasmussen, J.B., D.J. Rowan, D.R.S. Lean and J.H. Carey (1990) Food chain structure in Ontario lakes determines PCB levels in lake trout (Salvelinus namaycush) and other pelagic fish. Can. J. Fish. Aquat. Sci. 47:2030-2038.

Reinke, J., J.F. Uthe and D. Jamieson (1972) Organochlorine pesticide residues in commercially caught fish in Canada - 1970. Pestic. Monit. J. 6:43-49.

Rowan, D.J. and J.B. Rasmussen (1992) Why don't great lakes fish reflect environmental concentrations of organic contaminants? - An analysis of between-lake variability in the ecological partitioning of PCBs and DDT. J. Great Lakes Res. 18(4):724-741.

Rundel, P.W., J.R. Ehleringer and K.A. Nagy (1988) Stable isotopes in ecological research. Springer Verlag, New York, New York, USA.

Saleh, M.A. (1991) Toxaphene: Chemistry, biochemistry, toxicity and environmental fate. Rev. Environ. Contam. Toxicol. 118:1-85

Sanborn, J.R., R.L. Metcalfe, W.N. Bruce and P.Y. Lu (1976) The fate of chlordane and toxaphene in a terrestrial aquatic model ecosystem. Environ. Entomol. 5:533-538.

Service, R. (1961) Collected Poems of Robert Service, Dodd Mead, New York, pp. 33-36.

Servos, M.R., D.C.G. Muir and G.R.B. Webster (1989) Effect of particulate and dissolved organic carbon on the bioavailability of polychlorinated dioxins. Aquatic Toxicol. 14:169-184.

Shortreed, K.S. and J.G. Stockner (1986) Trophic status of 19 subarctic lakes in the Yukon Territory. Can. J. Fish. Aquat. Sci. 43:797-805.

Simonich, S.L. and R.A. Hites (1995) Global distribution of persistent organochlorine compounds. Science 269:1851-1854.

Sparling, P.D. and M.J. Connor (1996) Lake Laberge index fishery and toxicology study 1993 data report. Yukon Territorial Government, in press.

Steele, K.W. and R.M. Daniel (1978) Fractionation of nitrogen isotopes by animals: a further complication to the use of variations in the natural abundance of ^{15}N for tracer studies. J. Agric. Sci. 90:7-9.

Stern, G.A., D.C.G. Muir, C.A. Ford, N.P. Grift, E. Dewailly, T.F. Bidleman and M.D. Walla (1992) Isolation and identification of two major recalcitrant toxaphene congeners in aquatic biota. Environ. Sci. Technol. 1838-1840.

Swackhamer, D.L. and R.A. Hites (1988) Occurrence and bioaccumulation of organochlorine compounds in fishes from Siskiwit Lake, Isle Royale, Lake Superior. Environ. Sci. Technol. 22:543-548.

Swackhamer, D.L. and R.S.Skoglund (1993) Bioaccumulation of PCBs by algae: kinetics versus equilibrium. Environ. Toxicol Chem. 12(5):831-838.

Tanabe, S. (1988) PCB problems in the future:foresight from current knowledge. Environ. Pollut. 50:5-28.

Tarr, B.D., M.G. Barron, and W.L. Hayton (1990) Effect of body size on the uptake and bioconcentration of di-2-ethylhexyl phthalate in rainbow trout. Environ. Toxicol. Chem. 9:989-995.

Thomann, R.V. and J.P. Connolly (1984) Model of PCB in the Lake Michigan lake trout food chain. Environ. Sci. Technol. 18(2):65-71.

Thompson, S. (1996a) Fish stock assessment of Kusawa, Laberge and Teslin lakes, 1993, 1991, 1992. Fish and Wildlife Branch, Yukon Department of Renewable Resources, Whitehorse, Yukon, Y1A 4N6, in press.

Thompson, S. (1996b) Fish stock assessment of Marsh and Tagish lakes, 1993. Fish and Wildlife Branch, Yukon Department of Renewable Resources, Whitehorse, Yukon, Y1A 4N6, in press.

Todd, D.K. (1970) The water encyclopaedia. Water Information Centre, Port Washington, New York. 559 p.

U.S. EPA (1980) Ambient water quality criteria for DDT. Office of Water Regulations and Standards Criteria, Criteria and Standards Division, U.S. Environmental Protection Agency, Washington, D.C. EPA 440/5-80-038.

U.S. EPA (1984) Health assessment for chlorinated benzenes. Environmental Criteria and Assessment Office, Cincinnati, Ohio, U.S. EPA 600/8-84-015a.

Veith, G.D., D.L. DeFoe and B.V. Bergstedt (1979) Measuring and estimating the bioconcentration factor of chemicals in fish. J. Fish. Res. Board Can. 36:1040-1048.

Vetter, W. and B. Luckas (1995) Theoretical aspects of polychlorinated bornanes and the composition of toxaphene in technical mixtures and environmental samples. Sci. Total Environ. 160/161:505-510.

Voldner, E.C. and G. Ellenton (1987) Production, usage and atmospheric emissions of priority toxic chemicals with emphasis on North America. Report ARD-88-4 prepared for the International Joint Commission. Atmospheric Environment Service, Downsview, Ontario, Canada M3H 5T4.

Voldner, E.C. and Y-F. Li (1995) Global usage of selected persistent organochlorines. Sci. Total Environ. 160/161:201-210.

Wada, E. and A. Hattori (1976) Natural abundance of ^{15}N in particulate organic matter in North Pacific Ocean. Geochim. Cosmochim. Acta 40:249-251.

Webb, D.W. (1980) The effects of toxaphene piscicide on benthic macroinvertebrates. J. Kans. Entomol. Soc. 53(4):731-744.

Wein, E.E., Henderson-Sabry, J. and F.T. Evers (1991) Food consumption patterns and use of country foods by Native Canadians near Wood Buffalo Park, Canada. Arctic 44(3):196.

Welch, H.E., D.C.G. Muir, B.N. Billeck, W.L. Lockhart, G.J. Brunskill, H.J. Kling, M.P. Olson and R.M. Lemoine (1991) Brown snow: a long-range transport event in the Canadian Arctic. Environ. Sci. Technol. 25:280-286.

WHO (1976) Polychlorinated biphenyls and terphenyls. Environmental Health Criteria 2, World Health Organization, Geneva.

Yukon Contaminants Committee (1996a) Levels of contaminants found in fish from Yukon lakes, 1991-1992. Yukon Contaminants Committee, Whitehorse, Yukon, in press.

Yukon Contaminants Committee (1996b) Levels of contaminants found in fish from Yukon lakes, 1992-1993. Yukon Contaminants Committee, Whitehorse, Yukon, in press.

Yukon Contaminants Committee (1996c) Levels of contaminants found in fish from Yukon lakes, 1993-1994. Yukon Contaminants Committee, Whitehorse, Yukon, in press.

Table I.1: Catch composition (% of total biomass) of fishes from index netting programs in Yukon Territory (de Graff and Mychasiw, 1994; Sparling and Connor, 1996; Thompson, 1996a; Thompson, 1996b).

	Lake							
Fish Species	Bennett	Teslin	Tagish	Frances	Kluane	Marsh	Kusawa	Laberge[1]
Salvelinus namaycush	32.0	18.5	50.8	31.5	30.3	11.5	44.6	7.4
Coregonus clupeaformis	27.1	22.3	44.0	47.5	58.8	44.3	21.9	16.4
Coregonus nasus	-	24.6	-	-	-	-	9.3	2.1
Prosopium cylindraceum	10.5	2.3	3.9	1.0	0.8	4.9	1.8	0.9
Catostomus catostomus	29.7	1.1	0.7	13.3	8.9	28.4	21.3	50.2
Lota lota	0.2	17	0.2	0.6	0.1	-	-	11.8
Stenodus leucichthys	-	-	-	-	1.0	-	-	0.6
Coregonus sardinella	0.1	7.4	0.1	-	-	<0.1	-	3.1
Thymallus arcticus	0.4	0.4	0.4	0.2	-	-	1.1	0.2
Esox lucius	-	6.4	-	5.4	-	10.8	-	7.5

[1] Data are averages from index netting surveys conducted in 1991 and 1993.

Table I.2: Physical and chemical characteristics of the major contaminant groups examined in this study.

	Empirical Formula	Average Molecular Weight (g mol^{-1})	Log K_{ow}[1]	Water Solubility (g m^{-3})	Henry's law constant (Pa m^{3} mol^{-1})
HCH[2]	$C_6H_6Cl_6$	290.9	3.7-3.8[3]	0.025	0.30
CBZ[4]	$C_6H_2Cl_4$ C_6HCl_5 C_6Cl_6	215.9 250.3 284.8	4.5 5.0 5.5	1.3-7.8 0.65 0.005	122-144 85 131
CHL[5]	$C_{10}H_6Cl_8$	409.8	5.54	0.1	4.91
DDT[6]	$C_{14}H_8Cl_4$	318	6.95	0.04	6.89
CHB[7]	$C_{10}H_{10}Cl_8$	414	6.44	0.4	0.17
PCBs[8]					
Monochloro	$C_{12}H_9Cl$	188.7	4.3-4.6	1.21-5.50	42.56-75.55
Dichloro	$C_{12}H_9Cl_2$	223.1	4.9-5.3	0.060-2.0	17.0-92.21
Trichloro	$C_{12}H_9Cl_3$	257.5	5.5-5.9	0.015-0.40	24.29-92.21
Tetrachloro	$C_{12}H_9Cl_4$	292.0	5.6-6.5	0.0043-0.010	1.72-47.59
Pentachloro	$C_{12}H_9Cl_5$	326.4	6.2-6.5	0.004-0.020	24.8-151.4
Hexachloro	$C_{12}H_9Cl_6$	360.9	6.7-7.3	0.0004-0.001	11.9-86
Heptachloro	$C_{12}H_9Cl_7$	395.3	6.7-7.0	0.00045-0.002	5.4
Octachloro	$C_{12}H_9Cl_8$	429.8	7.1	0.0002-0.0003	38.08
Nonachloro	$C_{12}H_9Cl_9$	464.2	7.2-8.16	0.000018-0.00012	-
Decachloro	$C_{12}H_9Cl_{10}$	498.7	8.26	0.00076	20.84

[1] Octanol-water partition coefficient. [2] Data taken from Howard (1991) for α and γ HCH, vapour pressure is the average for the two isomers from Hinckley et al. (1990). [3] de Bruijn et al. (1989); [4] Data for tetra- through hexachlorobenzenes from Mackay et al. (1992), data for tetrachlorobenzenes are for the 1,2,3,4- and 1,2,4,5- isomers present in the fish samples from Yukon Territory; [5] Data from Howard (1991) for technical chlordane. [6] Data for DDT is for its major breakdown product p,p'-DDE from de Bruijn (1989) and Callahan et al. (1979). [7] From Saleh (1991), Korte et al. (1979), Sanborn et al. (1976), and Bidleman et al. (1987) [8] PCBs were separated into homologue groups due to the wide range of their physical-chemical properties, data was taken from Mackay et al. (1992).

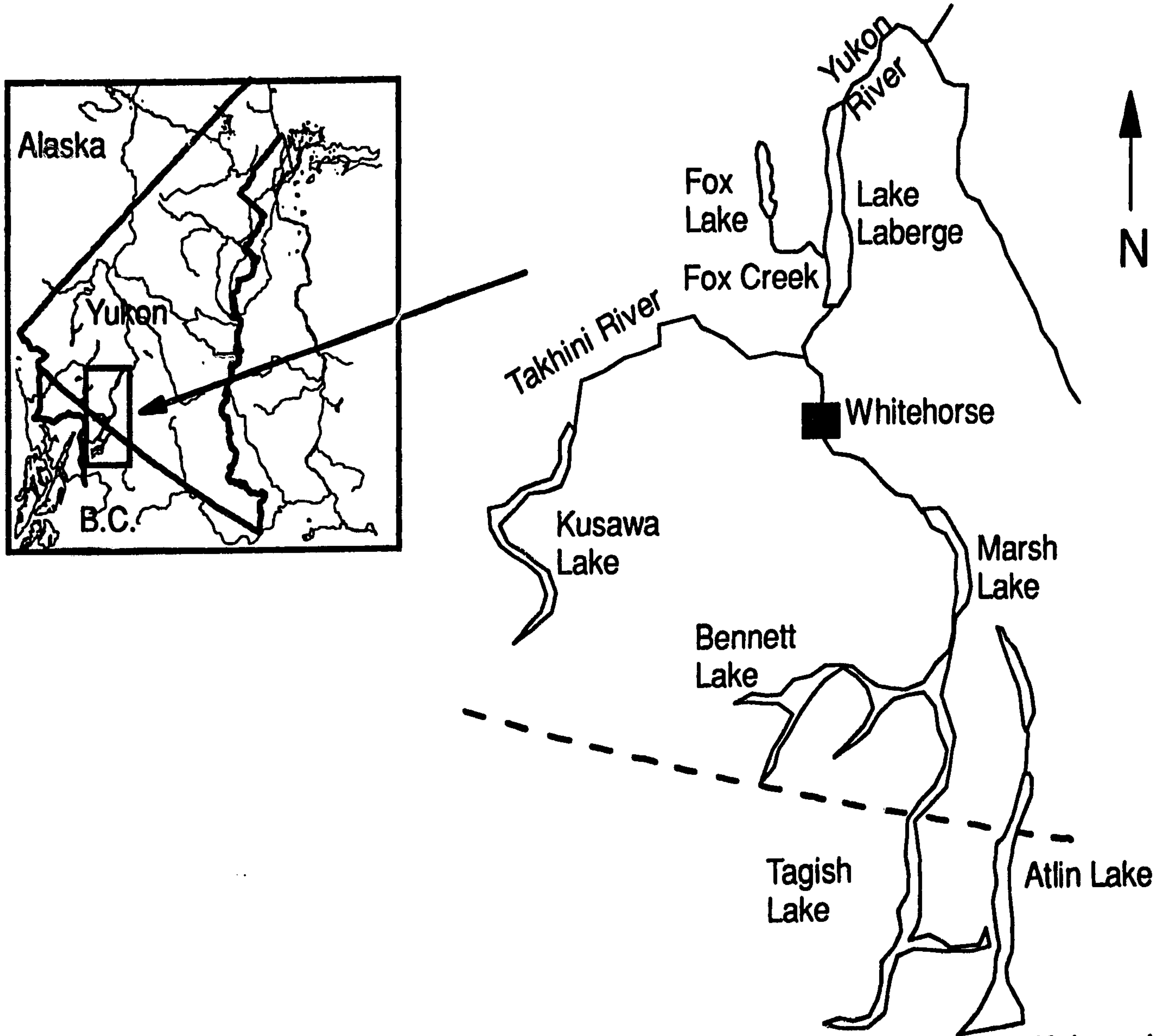

Figure I.1: Location of Laberge, Fox and Kusawa lakes on the Yukon River system (Adapted from Lindsey et al., 1981).

II. TROPHIC RELATIONSHIPS IN SUBARCTIC LAKES: A COMPARISON BETWEEN FISH STOMACH CONTENTS AND STABLE NITROGEN ISOTOPE RATIOS

Introduction

Trophic interactions in freshwater food webs have traditionally been defined using fish stomach content analyses or from the presence/absence of organisms within a system. Measurements of stable isotope ratios are supplementing or replacing stomach content analyses in food web studies because, unlike dietary analyses, they reflect food ingested and assimilated by predators over the period of tissue turnover, and may integrate dietary information over months to years in slow-growing populations (Hesslein et al., 1993), such as those from northern latitudes (Martin, 1951; Miller and Kennedy, 1948). In particular, stable nitrogen isotope ratios ($^{15}N/^{14}N$; $\delta^{15}N$) are being used to examine within and among-species differences in trophic positioning (Peterson and Fry, 1987; Hesslein et al., 1991; Cabana and Rasmussen, 1994; Estep and Vigg, 1985), and provide a quantitative method for comparing food webs that differ in community composition (Cabana and Rasmussen, 1994). The heavier isotope, ^{15}N, is progressively enriched from the primary producer through to the top predators due to the preferential retention of ^{15}N-containing amino acids for protein synthesis (Gaebler et al., 1966). No study to date has compared dietary information obtained from stomach content analyses with tissue $\delta^{15}N$ of fishes to determine if the two methods, representing one-time consumption and long-term dietary assimilation respectively, provide comparable trophic information. If a relationship between the two methods exists, then these results would strengthen the conclusions of studies where only one or the other method was applied. The objective of this paper is to examine the relationship between stomach contents and $\delta^{15}N$ of fishes from subarctic lakes in Yukon Territory.

Our ability to use $\delta^{15}N$ to examine variability in feeding habits and trophic positioning depends upon the degree to which predators' $\delta^{15}N$ reflect their dietary habits and not differences in isotopic fractionation among individuals or species. Field and laboratory studies have found comparable predator to prey enrichments of $\delta^{15}N$, 3 to 5 parts per thousand (‰), for a large number of marine and freshwater taxa (Peterson and Fry, 1987; Minagawa and Wada, 1984). Fishes fed diets of known isotopic composition had trophic $\delta^{15}N$ enrichments of 3.0 to 3.8 (broad whitefish, *Coregonus nasus*; Hesslein et al., 1993), 3.2 (guppies, *Lebistes* sp.; Minagawa and Wada, 1984) and 2.9 to 3.6 ‰ (*Chasmistes cujus*; Estep and Vigg, 1985). Analyses of stomach contents and muscle of arctic grayling (*Thymallus arcticus*; Peterson et al., 1993), anchovy (*Engraulis capensis*) and roundherring (*Etrumeus whiteheadi*; Sholto-Douglas et al., 1991) revealed $\delta^{15}N$ enrichments of 3.1, 4.3 and 4.9 ‰ in the fishes when compared to their diets. Similarly, Kling et al. (1992) and Gu et al. (1994) found average $\delta^{15}N$ enrichments between zooplankton and particulate organic matter from arctic lakes of 3.2 and 3.5 ‰ respectively. Results from these studies demonstrate that the magnitude of ^{15}N enrichment between a food source and its consumer is similar across a large number of species.

In studies of food web interrelationships, results from $\delta^{15}N$ analyses have often been supported by dietary analyses. However, many did not conduct concurrent stomach content analyses but extrapolated either from studies done on the same species at other locations or from those done at the same location during different years and on different individuals (Hesslein et al. 1991; Rau et al., 1992; Estep and Vigg, 1985; Peterson et al., 1993; Cabana and Rasmussen, 1994; Hobson and Welch, 1995). These extrapolations are problematic because of the wide range of feeding habits among individuals and populations for some species. Lake trout, for example, are generalistic predators, and are known to feed upon a large variety of organisms including crustaceans, aquatic and terrestrial insects, mollusks, numerous fish species and mammals (Scott and Crossman, 1973; Martin, 1966). Among fish populations, diets may also vary due to differences in community composition (Lacasse and Magnan, 1992; Trippel and Beamish, 1993) and population growth rates (Trippel and Beamish, 1993), further confounding the use of dietary studies from other locations.

Fish from northern lakes grow mainly during the summer season (Kennedy, 1953) when food is most abundant and metabolic requirements are highest. Because the open-water season is a period of intense feeding and growth for fishes from subarctic and arctic lakes, one would expect that their muscle $\delta^{15}N$ signal would directly reflect their dietary habits during this time. In this study, I used stomach content analyses to examine the trophic interrelationships in these lakes, and compared these results to those resolved through tissue $\delta^{15}N$ analyses. A comparison of these two methods is important for determining whether the short-term dietary habits of individuals and populations reflect their long-term average energy sources.

Study Area and Methods

The three lakes in this study, Laberge, Fox and Kusawa, are located on the Yukon River System in south-central Yukon Territory. Fox and Kusawa lakes drain into Lake Laberge through Fox Creek and the Takhini River respectively. Epilimnetic water samples were collected as part of this study and analysed for phosphorous, nitrogen, dissolved solids and organic carbon, and conductivity. Chemical and physical data for these lakes are given in Table II.1, and the fish species present in each lake are listed in Table II.2. Although all three lakes support some sports and subsistence fishing, the fisheries on Lake Laberge, including commercial catches, were closed in 1991 as a result of unusually high levels of organochlorine pesticides in the lake's top predators (Chapter I).

Fish and Invertebrate Sampling

Lake trout, burbot, northern pike, lake and round whitefish, longnose sucker and least cisco were netted in Laberge and Kusawa lakes in the spring of 1992, and in all three lakes through the summer season of 1992 and 1993 using both overnight gill net sets of multifilament panels (22.9 m long by 2.4 m deep, stretched mesh sizes ranging from 2.54 to 12.7 cm), and beach seines. Broad whitefish from Laberge, and slimy sculpin from the three lakes were also netted and analysed for stable isotopes because they were prey species for the lakes' top predators. Fishes were also obtained through index netting programs conducted in 1993 on Laberge and Kusawa lakes by the Renewable Resources Division of the Yukon Territorial Government, Whitehorse, Yukon Territory (Sparling and Connor, 1996; Thompson, 1996a). Weight (± 25 g for fish > 500 g; ± 1 g for fish < 500 g), length (± 1 mm; total length for burbot and fork length for other fishes) and sex of each fish was recorded; only weight was presented here for comparative purposes. Otoliths for lake trout, burbot, cisco and whitefish, and cleithra for pike were removed and used for age determinations. Ages of longnose sucker were not determined. Data for individual fishes are presented in Appendix A. All samples were frozen shortly after collection and kept at temperatures below -10 °C until they were required for laboratory analyses. Dorsal muscle was removed from the fishes either on site or after partial thawing in the laboratory.

Invertebrates were also collected from several locations within each lake and included most taxa that were common in the fish stomachs. These samples were collected between May and August of 1992 through 1994 using benthic grabs, shore sampling and vertical tows of a 153 μm zooplankton net through the water column. All trichopterans and mollusks, with the exception of Valvatidae/Planorbidae, were removed from their cases or shells on site. Samples were washed with lake water to remove particulates, pooled by major taxa and site, and frozen until required for isotopic analyses. Rocks from the littoral zones of the lakes were scraped to collect samples of epilithic algae. Sediment traps were also deployed at 20 m below the surface in the pelagic zone of each lake for a period of one month to collect particulate organic matter (POM); these samples were considered to be mainly phytoplankton although heterotrophs, terrestrial detritus, zooplankton, and fecal pellets may have also been collected.

Subsamples of invertebrates were preserved for identification purposes. However, these samples were used only as a general indicator of the taxa present and are not considered to be an exhaustive survey of the benthic and planktonic fauna[1]. Three families of gastropods were collected in each lake and included Lymnaeidae (*Lymnaea, Fossaria, Bakerilymnaea, Stagnicola*), Planorbidae (*Gyraulus*) and Valvatidae (*Valvata*). All three families feed primarily upon periphyton and plant material, although *Lymnaea* are considered to be scavengers of both plant and animal material (Pennak, 1953). In Laberge, mollusks from the family Sphaeriidae (*Pisidium*) were also collected. These organisms are also primary consumers and feed upon particulate matter, mainly algae, filtered from the water column (Pennak, 1953). The Trichoptera I collected were from the family Limnephilidae of the genus *Dicosmoecus*, and from the family Limnephilinae including the genera *Asynarchus*, *Grammotaulius*, *Hesperophylax*, *Limnephilus* and *Philarctus*. These trichopterans are herbivorous and feed upon plants, periphyton and detritus (Merritt and Cummins, 1978). Chironomid samples from all three lakes were composed of the subfamilies Tanypodinae (*Procladius*), Prodiamesinae (*Monodiamesa*), and Chironominae (*Stictochironomus*; *Paratanytarsus* - Kusawa and Laberge; *Polypedilum* and *Paracladopelma* - Laberge; *Micropsectra* - Kusawa); in Fox and Kusawa lakes the subfamilies Orthocladiinae and Diamesinae (*Protanypus*) were also found[2]. Of the above subfamilies, only the two genera *Procladius* and *Polypedilum* have been identified as predators, while the remainder are considered to be herbivorous/detritivorous (Merritt and Cummins, 1978). Zooplankton samples that were collected in early August, 1993 indicated that all three lakes contained the cyclopoid Copepoda *Cyclops scutifer* (Sars), and the Cladocera *Daphnia longiremis hyalina microcephala* (Sars) and *Daphnia longiremis* (Sars). The calanoid Copepoda *Diaptomus sicilis* (Forbes) and the cladoceran *Eubosmina longispina* (Leydig) were present in Fox, the cyclopoid Copepoda *Cyclops capillatus* (Sars) were present in Fox and Kusawa, the calanoid Copepoda *Diaptomus pribilofensis* (Juday and Muttkowski) and *Senecella*

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[1] The invertebrate samples, excluding chironomids and zooplankton, were identified by B.M. Miskimmin, Department of Biological Sciences, University of Alberta, Edmonton, AB.

[2] All chironomid samples were identified by P.L. Wong, Freshwater Institute, Winnipeg, MB using Oliver and Roussel (1983).

calanoides (Juday) were present in Laberge and Kusawa, and the Cladocera *Holopedium gibberum* (Zaddach) were present in Kusawa. In each lake the omnivorous *Cyclops scutifer* and a herbivorous cladoceran or calanoid (*Diaptomus sicilis* - Fox; *Daphnia longiremis* - Laberge; *Holopedium gibberum* - Kusawa) were the two dominant species as determined by the number of individuals per litre[3]. The species identified in these samples were comparable to those collected from Fox and Kusawa lakes in 1975 and 1970 respectively (Lindsey et al., 1981). The average density of zooplankton in Laberge over the growing season has been determined to be 11.9 mg dry weight.m^{-3} (110-*um* mesh, not corrected for net efficiency; Kirkland and Gray, 1986), which was considerably less than in Fox Lake (114 mg dry weight.m^{-3}; 100-*um* mesh, not corrected for net efficiency; Shortreed and Stockner, 1987). Comparable data were not available for Kusawa Lake. In addition, the amphipod *Gammarus lacustris* was collected from Fox Lake and is considered to be omnivorous because it feeds on a variety of animal and plant material (Pennak, 1953). Oligochaeta collected from Laberge were not identified.

Stomach Content Analyses

Stomach contents were removed during fish sampling, kept on ice prior to identification and then examined under a dissecting microscope. Order, family or genus of the organisms were recorded and the results tabulated based on the presence/absence of these taxa in the stomachs of each fish species (Hyslop, 1980); individual-fish data are presented in Appendix B. The % of fish from each lake feeding on each taxon were calculated as:
(# of stomachs with taxon/ total # of non-empty stomachs) × 100
Based on the stomach content analyses for each population within each lake, a potential range of δ^{15}N for these fishes were calculated by adding the trophic enrichment value of 3.4

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[3] All zooplankton samples were identified and enumerated by A. Salki, Freshwater Institute, Winnipeg, Manitoba.

‰ to the average $\delta^{15}N$ of the isotopically lightest and heaviest prey they consumed (as identified in Tables II.1a-c). Averages of prey $\delta^{15}N$ were used rather than extreme values because it was assumed that the longer-lived predators would integrate the variability of $\delta^{15}N$ found in their diets. It was also assumed that all species had comparable trophic enrichments of $\delta^{15}N$ (3.4 ‰ between prey and predator), and that all components of the prey organisms (excluding cases and shells) were digested and assimilated into the predators. No information was collected on the relative abundance of each prey (by weight) in individual-fish stomachs, and for this reason fish $\delta^{15}N$ values predicted from their diet could not be corrected for the differences in weight of the prey found. When cannibalism or piscivory upon other piscivorous fishes was found, the lowest measured $\delta^{15}N$ for the prey species was used to calculate potential predator $\delta^{15}N$.

The large number of taxa found in some individuals' stomachs and the high percentage of stomachs containing unidentifiable fishes made it difficult to compare a consumer's $\delta^{15}N$ versus its specific diet. However, no overlap between measured $\delta^{15}N$ of invertebrates and fishes was found in Fox or Kusawa lakes, and only a small amount of overlap (1.2 ‰) existed in Lake Laberge. For these reasons, individual fish were categorized as piscivores (strict fish-eaters), omnivores (fish- and invertebrate-eaters) or zoobenthivores/zooplanktivores (strict invertebrate-eaters) and these generalized feeding habits were then compared to their tissue $\delta^{15}N$.

A subset of the $\delta^{15}N$ data presented in this paper were obtained as part of a study examining organochlorine bioaccumulation through the food webs of these lakes (Chapter III - V). Initial fish collections did not include dietary analyses for some of individuals that were analysed for $\delta^{15}N$. For this reason, comparisons between diet and tissue $\delta^{15}N$ were made both at a population and an individual-fish level.

Stable Isotope Analyses

Skinless dorsal muscle samples from individual fishes were dried in an oven at 60°C. Pooled invertebrate samples were first treated with 1 N HCl to dissolve any remaining shells and surficial carbonates, and then dried. All tissues were ground to a fine powder to homogenize the samples. Samples were analysed initially by vacuum-sealing approximately 15 mg of dried tissue in a Vycor tube with 1 g copper wire, 1 g copper oxide wire, and a 1-mm^2 piece of silver foil. These tubes were then combusted at 850°C for 4 h and at 600°C for 2 h. Nitrogen gas was cryogenically separated from CO_2, trapped in a molecular sieve, and analysed on a dual inlet isotope ratio mass spectrometer (VG Micromass 602E). However, most tissue samples were analysed using the following fully automated method. Dried samples of 8-12 mg were combusted in a Carlo Erba NA1500 elemental analyzer. Sample gases were introduced into a VG Optima automated mass spectrometer with helium carrier gas, and water and CO_2 were cryogenically removed using magnesium perchlorate and an Ascarite® column respectively. $\delta^{15}N$ in samples was standardized against N_2 in air as follows:

$$\delta N‰ = [(R_{sample}/R_{standard})-1] \times 1000$$

where $R = {}^{15}N/{}^{14}N$. A laboratory working standard of Pharmamedium was run with every 10 samples. Precision of these instruments for nitrogen isotope analysis over several years of use has been 0.4 ‰ (2 SD). Duplicate analyses of samples (n = 35) resulted in an average absolute deviation about the mean of 0.22 ‰. Results of the $\delta^{15}N$ analyses were presented here as means ± SD (see Appendix A for individual-fish data). Analyses of carbon isotope ratios, which do not fractionate from prey to predator and therefore indicate food source (e.g. Hesslein et al., 1991), were also conducted on all invertebrates and fishes. Though the data were not presented in this study, they were used to support the food web relationships determined from $\delta^{15}N$ data.

Statistical Analyses

All statistical analyses were conducted on Statistical Analysis System (SAS, 1982). Significant differences within species were examined using analysis of variance, followed by Duncan's multiple range tests for comparisons among all three lakes.

Results

The major invertebrate taxa examined in this study had comparable values of $\delta^{15}N$ among lakes (Table II.3). Chironomid samples from these lakes were not significantly different in their $\delta^{15}N$, and had average values of 4.02 to 4.08 ‰. Assuming a 3.4 ‰ fractionation, these values were consistent with a diet composed of the epilithic algae collected from Laberge (-0.23 ‰, $n = 3$) and Kusawa (0.29 ‰, $n = 2$) but not from Fox Lake (-1.07 ‰, $n = 1$). An oligochaete sample from Laberge and *Gammarus* samples from Fox Lake had tissue $\delta^{15}N$ (3.52 and 3.43 ‰ respectively) that were comparable to values found for chironomids. The primary consumers Lymnaeidae and Valvatidae/Planorbidae had average $\delta^{15}N$ values that were not significantly different among lakes, and ranged from 1.42 to 2.05 ‰, and from 1.26 to 1.76 ‰ respectively; Sphaeriidae from Laberge also had similar $\delta^{15}N$ at 2.19 ‰. Trichopteran samples were also not significantly different in their $\delta^{15}N$ among lakes with averages of 2.55, 1.62 and 2.53 ‰ for Laberge, Kusawa and Fox lakes respectively. The $\delta^{15}N$ values found for trichopteran from Fox Lake were consistent with a diet of the epilithic algae collected from this lake (- 1.07 ‰). Unlike the other invertebrate samples, zooplankton from Laberge were significantly higher in $\delta^{15}N$ (4.94 ‰) when compared to Fox (3.56 ‰) or Kusawa lakes (2.85 ‰). The $\delta^{15}N$ values for zooplankton from the latter two lakes indicated that they fed upon organic matter that was isotopically similar to the POM collected for this study. Although only one sediment trap sample was analysed from each lake, POM samples had similar $\delta^{15}N$, with values of 0.31 in Laberge, - 0.01 in Kusawa and 0.18 ‰ in Fox Lake.

Stomach content analyses indicated that most fishes from Lake Laberge were either secondary or tertiary consumers (Table II.4). Longnose sucker and round whitefish from Laberge were strictly zoobenthivorous/zooplanktivorous, with 93 and 82 % of fish containing chironomids respectively, and fewer individuals (< 27 %) containing mollusks, leeches, trichopterans or zooplankton. Least cisco were mainly zooplanktivorous (84 %) and 26 % of individuals also fed upon chironomids. Ninety-four percent of the lake whitefish were also zoobenthivorous/zooplanktivorous; thirty to fifty percent of all their stomachs contained chironomids, *Hydracarina* sp. and Valvatidae/Planorbidae. However, 6 % lake whitefish also fed upon other fishes including cisco, round whitefish and sculpin (Table II.4). This indicates that some lake whitefish occupied a higher trophic level in the Lake Laberge food web than the other forage fishes. All northern pike and burbot, and 85 % of lake trout were tertiary consumers, and preyed upon the same species of forage fishes. Although a large percentage of fish found in their guts were unidentifiable, 35 to 42 % of these predators contained least cisco, 5 to 17 % contained sculpin, and round and lake whitefish, longnose sucker and broad whitefish were found in 1 to 11 % of individuals from each of these populations; some pike and burbot were also cannibalistic. In contrast, 12 and 14 % of the lake trout preyed on unidentified invertebrates and chironomids respectively, as well as ephemeropteran and *Hydracarina* sp. With few exceptions, stomach content analyses revealed that northern pike, burbot and lake trout occupied trophic positions that were higher than and distinct from those found for forage fishes.

The trophic relationships of fishes from Lake Laberge, as determined by $\delta^{15}N$, were generally consistent with those determined from the populations' stomach content analyses (Figure II.1). Round whitefish and longnose sucker had average values of 7.16 and 7.57 ‰ respectively (Table II.5), indicating that their diets were composed strictly of zoobenthos/zooplankton, and that these fish fed mainly upon chironomids ($\delta^{15}N$ of 4.02 ‰, assuming a 3.4 ‰ trophic fractionation, Table II.3). The average $\delta^{15}N$ found for least cisco of 7.87 ‰ was also indicative of a diet composed of invertebrates, and suggests that they fed mainly upon zooplankton (4.94 ‰) and minor proportions of isotopically lighter prey such as chironomids. Lake whitefish had the highest average $\delta^{15}N$ (8.22 ‰) of any forage fishes found in Laberge. Minimum $\delta^{15}N$ values of 5.22 ‰ for this species indicated that some individuals fed upon mollusks (1.26 to 2.19 ‰) and trichopteran (2.55 ‰) as was found in the stomach content analyses. However, the average $\delta^{15}N$ for lake whitefish was consistent with a diet of chironomids and zooplankton, and the highest $\delta^{15}N$ values (up to 10.21 ‰) found in their muscle indicated that some fish consumed mainly other fishes such as sculpin (6.33 ‰, Table II.3). The broad range of prey, from mollusks to fishes, found in the stomachs of lake whitefish corresponded with their large range of $\delta^{15}N$ values (over 5 ‰). Northern pike fom Laberge occupied a higher trophic position than all forage fishes with $\delta^{15}N$ values averaging 9.62 ‰. A diet composed almost entirely of the sculpin (6.33 ‰) found in their stomachs would explain the average $\delta^{15}N$ found for this species. Although gut content analyses of pike indicated that they fed mainly upon least cisco and that some individuals were cannibalistic, pike muscle had $\delta^{15}N$ values that were lower than expected from their diet and a range that overlapped with values found lake whitefish, cisco and longnose sucker. This overlap between the $\delta^{15}N$ of invertebrate-eating forage fishes and northern pike reveals that either the pike were not strict fish eaters as their diets indicated, or that they mainly fed upon forage fishes with lower $\delta^{15}N$ such as sculpin. Unlike pike, burbot and lake trout had $\delta^{15}N$ values that were distinct from those of the lower-trophic-level fishes, and ranged from 10.27 to 13.04 ‰ and from 10.35 to 13.96 ‰ respectively. Their ranges and average $\delta^{15}N$ values indicated that they preyed only upon fish and not the invertebrates that were found in some lake trout stomachs. From their $\delta^{15}N$, least cisco, round whitefish, and longnose sucker were possible prey species for these fishes; however, carbon isotope ratios indicated that lake trout or burbot did not prey upon longnose sucker but that they did feed upon the other two fish species (ranges of $\delta^{13}C$ for lake trout -25.3 to -33.1; burbot -24.5 to -27.7; round whitefish -21.8 to -27.7; least cisco -20.8 to -31.8; longnose sucker -20.4 to -24.2 ‰). The average and maximum $\delta^{15}N$ values observed in lake trout and burbot suggested that they selectively fed upon lake whitefish with higher-than-average $\delta^{15}N$ or were quaternary consumers, feeding upon other piscivorous fishes. Although cannibalism was observed in burbot and explains the higher $\delta^{15}N$ found in this species, no evidence of this feeding behaviour was found for lake trout.

Stomach content analyses of lake trout, and lake and round whitefish from Kusawa revealed more overlap in the dietary habits of the top predator and forage fishes than was found in Laberge (Table II.6). Round whitefish were strict zoobenthivores/zooplanktivores; the most common prey found their stomachs were chironomids (78 %), while mollusks, trichopteran and zooplankton were also found in a minority of fish stomachs. Lake whitefish fed upon similar prey species when compared to round whitefish, including chironomids (60 %), *Hydracarina* sp. (65 %), Sphaeriidae (74 %) and Valvatidae/Planorbidae (83 %). Unlike the same species in Laberge, all lake whitefish from Kusawa were zoobenthivorous/zooplanktivorous (Table II.5) indicating that they occupied a comparable trophic position to round whitefish. In contrast to the forage fishes, 38 % of all lake trout fed strictly upon fishes including sculpin, lake whitefish and the occasional lake trout. However, 41 % of all lake trout stomachs contained invertebrates including chironomids, mollusks, trichopteran and zooplankton, and 21 % of these fish were omnivorous (Table II.5). Their dietary analyses indicated that while some lake trout in Kusawa were tertiary consumers and occupied the top trophic position in this food web, a large percentage of trout fed upon invertebrates and were at a trophic level that was comparable to that of the whitefish.

The long-term average trophic positions of the fishes in Kusawa, as measured by $\delta^{15}N$, were comparable to the results of the populations' stomach content analyses (Figure II.2). The forage fishes, round and lake whitefish, and longnose sucker all had similar $\delta^{15}N$ values (6.03, 6.83 and 6.73 ‰ respectively), indicating that these species occupied comparable trophic positions within this lake (Table II.5). Lake and round whitefish had muscle $\delta^{15}N$ values which were consistent with a diet of chironomids (4.08 ‰) and smaller proportions of mollusks and trichopteran (1.42 to 1.76 ‰), the organisms found in their stomachs. Though stomach contents of longnose sucker were not analysed, their $\delta^{15}N$ values indicate that they also fed mainly upon chironomids. Albeit zooplankton in Kusawa were possible prey ($\delta^{15}N$ values averaging 2.85 ‰), carbon isotope analyses of both invertebrates and fishes indicated that all forage fishes fed mainly upon benthos (average $\delta^{13}C$ for fish -21.9 to -23.4; zooplankton -32.1; benthic invertebrates -17.6 to -25.4 ‰). Average $\delta^{15}N$ for lake trout (9.89 ‰) was 3 to 3.8 ‰ higher than was found for the forages fishes, and indicates that the trout fed mainly upon lake and round whitefish, and longnose sucker. Although trout occupied a higher trophic position, their range of $\delta^{15}N$ values overlapped with those of lake whitefish and longnose sucker (Table II.5). These results were consistent with the dietary analyses which indicated that while some lake trout were strictly piscivorous, other individuals were zoobenthivorous/zooplanktivorous (Table II.6).

Considerable overlap in the dietary habits of forage fishes and top predators was also observed in Fox Lake (Table II.7). Ninety-six percent of lake whitefish and all round whitefish examined were zoobenthivorous/zooplanktivorous, feeding upon similar prey items including leeches, mollusks and trichopteran. The most common prey in lake whitefish stomachs were Sphaeriidae (57 %) and chironomids (55 %), while the latter invertebrates were found in 73 % of all round whitefish. However, when compared to the round whitefish, a larger number of taxa were found in lake whitefish stomachs, a greater proportion individuals fed upon mollusks, and four percent of lake whitefish were omnivorous (Table II.5), containing sculpin and unidentified fishes as well as invertebrates. Limited stomach content analyses for burbot and northern pike indicated that these species fed upon some of the same invertebrates (leeches and *Gammarus)* that were found in whitefish stomachs. Sixty-seven and twenty-five percent of pike and burbot respectively were strictly piscivorous and fed upon sculpin or unidentifiable fishes. Stomachs of lake trout from Fox Lake also contained many prey species that were found in whitefish gut contents. Seventy-two percent of all lake trout were zooplanktivorous/zoobenthivorous and contained chironomids (53 %), *Gammarus* (28 %), trichopteran (15 %), *Hydracarina* (10 %) and zooplankton (8 %). Only twenty-eight percent of individuals contained other fishes or fishes and invertebrates indicating that the majority of trout occupied a trophic niche comparable to that found for lake and round whitefish.

In Fox Lake, average fish $\delta^{15}N$ values supported the information obtained from the populations' stomach content analyses (Figure II.3). Round whitefish had an average tissue $\delta^{15}N$ of 6.40 ‰ (Table II.5) which indicated that their diet consisted of a combination of chironomids (4.06 ‰) and trichopteran (2.55 ‰; Table II.3). Because of their small gape size, it is unlikely that round whitefish preyed upon *Gammarus* (3.43 ‰), and this invertebrate was not found in their stomachs. Lake whitefish had $\delta^{15}N$ values that were approximately 1 ‰ higher than the average $\delta^{15}N$ for round whitefish even though both species fed upon the same types of prey. Their average $\delta^{15}N$ of 7.41 ‰ indicated that this species fed mainly upon chironomids and possibly on some *Gammarus* (3.43 ‰), as was found in their dietary analyses. Carbon isotope analyses indicated that zooplankton were not a main prey species for the fishes from Fox Lake (average $\delta^{13}C$ for fish and benthic inverts -28.4 to -25.6; zooplankton -33.6 ‰). Although the stomach content analyses indicated that northern pike and burbot in Fox Lake were mainly piscivorous, their $\delta^{15}N$ averages were similar to those found for the zoobenthivorous lake trout. Average $\delta^{15}N$ for lake trout, burbot and northern pike ranged from 8.26 to 8.87 ‰, indicating that these species were only a full trophic level above sculpin (5.08 ‰). From the ranges of $\delta^{15}N$ observed, these top predators also preyed upon round whitefish (6.40 ‰) and chironomids (4.06 ‰). $\delta^{15}N$ values for northern pike, burbot and lake trout overlapped considerably with lake whitefish values, indicating that they occupied trophic positions that were not distinct from that of the forage fishes.

Significant among-lake differences in average $\delta^{15}N$ were found for all species of fish examined (Table II.5). For the upper-trophic-level fishes, these differences were related to the general feeding habits (piscivory, omnivory and zoobenthivory/zooplanktivory) of the populations. For lake trout, average $\delta^{15}N$ was highest in Laberge (12.36 ‰) where most individuals were piscivorous (85%), lower in Kusawa (9.89 ‰) where fewer trout fed upon other fish (piscivores - 38%, omnivores - 21%), and lowest in Fox Lake (8.82 ‰) where 72% of the trout examined fed upon zoobenthos/zooplankton (piscivores - 15%, omnivores - 13%). Results for burbot were comparable to those found for lake trout; a significantly higher average δ^{15}N was found for burbot from Laberge than for individuals from Fox Lake, and this difference corresponded to a higher percentage of piscivory in the former lake. All burbot from Laberge were piscivorous, whereas limited stomach content analyses of burbot in Fox Lake indicated that 75 % fed on a combination of fish and zoobenthos, and 25 % were piscivorous. Similarly, northern pike from Laberge had significantly higher tissue δ^{15}N and a larger percentage of individuals that fed strictly on fishes (100%) than was found in Fox Lake (67% were strictly piscivorous). Lake whitefish from Laberge were significantly higher in δ^{15}N than the same species in Fox or Kusawa. These among-lake differences were also related to differences in the populations' general feeding habits. While most whitefish were zoobenthivorous/zooplanktivorous, and a few individuals from Laberge and Fox lakes were also omnivorous, 5% of lake whitefish from Laberge were strict piscivores.

Stomach content analyses were also used to determine the expected ranges of δ^{15}N in each population's muscle tissue, assuming a 3.4 ‰ fractionation from prey to predator. For the lower-trophic-level fishes, the ranges of δ^{15}N predicted from their stomach contents were comparable to their measured values of δ^{15}N (Figure II.4). However, average δ^{15}N for round whitefish from Laberge was significantly higher (Table II.5) and fell closer to the maximum predicted values shown in Figure II.4 than the same species from Kusawa and Fox lakes. Although these fish fed upon similar prey species among lakes, the higher isotopic signal of round whitefish from Laberge indicates that their diet was composed of greater proportions of prey heavier in δ^{15}N, such as chironomids, than isotopically-lighter mollusks or trichopterans. Least cisco and longnose sucker from Laberge also had tissue δ^{15}N closest to the maximum predicted value, indicating that their average energy sources consisted mainly isotopically heavier organisms such as zooplankton and/or chironomids. The range of tissue δ^{15}N in Laberge whitefish extended over 5 ‰ and was greater than the ranges for all other populations of fish. However, δ^{15}N values for lake whitefish from Laberge, as well the populations from Fox and Kusawa lakes, were comparable to values predicted from the stomach content analyses.

More discrepancies between the long-term average trophic position ($\delta^{15}N$) and the $\delta^{15}N$ values predicted from the dietary analyses were found for the top predators in these lakes (Figure II.4). Although the $\delta^{15}N$ values for trout from Kusawa and Fox lakes fell within the ranges predicted from the populations' dietary habits, the average and upper range of $\delta^{15}N$ measured in Laberge trout exceeded the values predicted from their stomach content analyses. The average $\delta^{15}N$ for burbot from Laberge were consistent with their predicted range, while the average $\delta^{15}N$ for burbot from Fox was comparable to the maximum predicted values based on a diet of sculpin. Northern pike from Laberge had values of $\delta^{15}N$ that were closest to the minimum predicted value, while Fox Lake pike had an average $\delta^{15}N$ consistent with a diet composed mainly of the isotopically heavier organisms found in their stomachs.

The dietary habits of individual fishes from the three lakes generally agreed with their long-term trophic positions, but some exceptions were observed (Figures II.5-7). Most piscivorous northern pike, burbot and lake trout from Laberge had values of $\delta^{15}N$ that were greater than would be possible from a diet composed strictly of the invertebrates analysed in this study (Figure II.5). Because of the overlap in $\delta^{15}N$ values for some fishes and invertebrates in Lake Laberge (approximately 1‰), it was not possible to determine whether some northern pike, lake whitefish, least cisco and longnose sucker had $\delta^{15}N$ values that agreed with their dietary habits. However, most of the lake and round whitefish, least cisco, and longnose sucker were zoobenthivorous/zooplanktivorous and had $\delta^{15}N$ values consistent with their observed diets. Also, two whitefish from Laberge had $\delta^{15}N$ values that exceeded the range expected from their zoobenthivorous diets. In Kusawa Lake, the piscivorous lake trout had $\delta^{15}N$ values that were considerably higher and distinct from the zoobenthivorous/zooplanktivorous fishes, including lake and round whitefish and one lake trout (Figure II.6). The zoobenthivorous/zooplanktivorous lake trout had an $\delta^{15}N$ value of 6.98 ‰ while the piscivorous fishes were a full trophic level higher with an average $\delta^{15}N$ of 10.83 ‰. The individual whitefish from Kusawa were strict zoobenthivores/zooplanktivores and had $\delta^{15}N$ values that were consistent with their dietary habits. More differences between an individual's diet and its $\delta^{15}N$ were observed in Fox Lake (Figure II.7). While lake and round whitefish were all classified as zoobenthivorous/zooplanktivorous and had $\delta^{15}N$ values which corresponded to their feeding habits, many piscivorous trout, burbot and northern pike had values of $\delta^{15}N$ that were comparable to the zoobenthivores/zooplanktivores. Similarly, some fishes that fed strictly on invertebrates had $\delta^{15}N$ values that were consistent with a diet of fishes. Zoobenthivorous/zooplanktivorous, omnivorous, and piscivorous lake trout had average $\delta^{15}N$ values of 8.7, 9.32 and 8.94 ‰ respectively, indicating that although they had different feeding habits, their long-term trophic positions were comparable.

Discussion

Among-lake differences in the $\delta^{15}N$ of fishes may be due not only to differences in diet but also to differences in the basal $\delta^{15}N$ of primary producers (Cabana and Rasmussen, 1996). Systems can have variable basal signals of $\delta^{15}N$ due to differences in trophic status (Minagawa and Wada, 1984), additions of fertilizer (Peterson et al., 1993) or sewage (Estep and Vigg, 1985; Cabana and Rasmussen, 1996), or to differences in the isotopic composition of the inorganic nitrogen available to primary producers (Kline et al., 1990). Algae will preferentially incorporate the lighter isotope (^{14}N) into their cellular proteins when growth occurs under non-limiting conditions (Wada and Hattori, 1976). Minagawa and Wada (1984) found that marine and freshwater phytoplankton $\delta^{15}N$ ranged from -2.1 to 7.5 ‰, depending on the trophic status of the system, and was correlated to $\delta^{15}N$ in fishes from each of these systems. A recent study has shown that the $\delta^{15}N$ signal of primary consumers from lakes with heavily populated watersheds was an average of 8 ‰ greater than the same organisms from relatively uninhabited systems (Cabana and Rasmussen, 1996), and that the $\delta^{15}N$ signal in these organisms was correlated with fish muscle $\delta^{15}N$. Although Lake Laberge is located 30 km downstream of the City of Whitehorse, and receives additional nutrient input from the city (see Chapter I), no significant differences in $\delta^{15}N$ of the zoobenthos were found among lakes, indicating that the basal $\delta^{15}N$ signals in these lakes were comparable.

Average $\delta^{15}N$ for zooplankton was significantly higher in Laberge when compared to values found in Kusawa and Fox lakes. Zooplankton from Lake Laberge had $\delta^{15}N$ (3.02 to 6.39 ‰) that were comparable to results obtained by Hobson and Welch (≈ 5 ‰; 1995), Kling et al. (5.3 to 9.9 ‰; POM ranging from 1.6 to 3.2 ‰; 1994) and Gu et al. (2.9 to 8.3 ‰; POM ranging from 0.3 to 4 ‰; 1994) for zooplankton from other oligotrophic arctic lakes. In this study, zooplankton samples were collected in early August and subsequently identified; results indicated that 70, 34 and 40 % of the individuals in the zooplankton samples from Laberge, Kusawa and Fox lakes respectively were the predaceous cyclopoid *Cyclops scutifer*. Unlike Laberge, zooplankton samples from Kusawa and Fox lakes were equally dominated by the herbivorous cladoceran *Holopedium gibberum* or calanoid *Diaptomus sicilis* respectively. The large predaceous cladoceran *Leptodora* has also been found in Laberge (Kirkland and Gray, 1986); however, this zooplankter was not identified in any of the samples collected for this study. The higher $\delta^{15}N$ of zooplankton from Laberge may be related to differences in the dominant zooplankton species among these lakes. Zooplankton may also differ in their dietary habits among lakes resulting in variable $\delta^{15}N$ values within one species. Across several arctic lakes, Kling et al. (1994) found that the copepod *Heterocope* (which the authors believed to be mainly predaceous) was either at a similar or higher trophic position than the herbivorous zooplankter *Diaptomus*. Further analyses of individual species rather than bulk samples would be required to elucidate the trophic relationships of zooplankton in these Yukon lakes.

Consistent with the results of other studies (Hobson and Welch, 1995; Hesslein et al., 1990; Cabana and Rasmussen, 1994; Peterson et al., 1993), biota from these subarctic lakes exhibited a stepwise increase in $\delta^{15}N$ from the primary producers up through to the top predators. Epilithic algae and POM samples from all three lakes were close to 0 ‰. The invertebrates occupied the next trophic level and had $\delta^{15}N$ values from 1.2 to 4.9 ‰, indicating that they fed upon organic matter with $\delta^{15}N$ values ranging from approximately -

2 to 1.5 ‰. Forage fishes occupied a higher trophic level than the invertebrates in these lakes with isotopic signals ranging from 5 to 8 ‰. Lake trout, burbot and northern pike were the top predators and had average $\delta^{15}N$ values from approximately 8 to 12 ‰. The isotopic values found in this study were comparable to results from other arctic lakes. Invertebrates from the Kuparuk River, Alaska had $\delta^{15}N$ values from 1.9 (*Orthocladius)* to 4.6 ‰ (*Brachycentrus*), and the insectivorous grayling occupied a higher trophic position with an average $\delta^{15}N$ of 8.3 ‰. Similarly, mysids, chironomids, trichopteran and zooplankton from Char Lake, NWT had an average $\delta^{15}N$ of 4.2 ‰, and arctic char had tissue $\delta^{15}N$ ranging from 5.7 in insectivorous/detritivorous individuals up to 13.7 ‰ in the quaternary consumers (cannibalistic fish; Hobson and Welch, 1995). Kline et al. (1990) found that periphyton, trichopteran, stoneflies, and small and large rainbow trout (believed to occupy different trophic positions) from Sashin Creek, Alaska, had $\delta^{15}N$ values of 0, 4.8, 5.1, 7.4 and 10 ‰ respectively. Fishes from Travaillant Lake, NWT, (Hesslein et al., 1991) had $\delta^{15}N$ values that overlapped with but were generally higher than the same species from Yukon lakes studied herein. In the Travaillant Lake food web, amphipods had $\delta^{15}N$ of ≈ 5 ‰, the insectivorous white sucker, stickleback, young-of-the-year northern pike, lake whitefish, and least cisco with values ranging from ≈ 7 to 12 ‰, and the piscivorous lake trout and pike with values ranging from ≈ 13 to 14.5 ‰. In general, invertebrates, insectivorous fishes and top predators from arctic sites had similar $\delta^{15}N$ values to the organisms from lakes in the subarctic region of Yukon Territory.

The main purpose of this study was to compare the short-term trophic information obtained from dietary analyses with the fish's long-term average position, as determined by $\delta^{15}N$. The range of $\delta^{15}N$ predicted from the stomach content analyses of forage fishes was consistent with their measured levels (Figure II.4), and most individuals had $\delta^{15}N$ values that agreed with their generalized feeding habits (Figure II.5-7). More discrepancies between feeding habits and measured $\delta^{15}N$ were found for the top predators in these lakes. In particular, lake trout and northern pike from Laberge had higher and lower values of $\delta^{15}N$ respectively than were predicted from their diet (Figure II.4), and individual piscivorous pike had muscle $\delta^{15}N$

values that were comparable to other forage fishes (Figure II.5). Also, one-fifth of all top predators from Fox Lake had dietary habits that were inconsistent with their tissue $\delta^{15}N$ values (Figure II.7). It is possible that some of the differences between the two methods may have been due to the large number of unidentifiable prey (especially fish species) or empty stomachs (see Table II.5). However, these results demonstrated that while stomach contents could be used as a general indicator of food web interactions within a lake, they did not consistently reflect a population's or individual's average trophic position.

Information from stable isotope ratios is invaluable in that it quantifies the trophic positions for those individuals whose stomach contents are unidentifiable, empty, indicate a rare meal or are not representative of what is digested and assimilated by the fish. Many of the top predators were feeding on fishes that were not possible to identify (Table II.4, II.6 and II.7) and up to 70% of the fishes examined within each population had empty stomachs (Table II.5). Stomach content analyses may not accurately reflect the relative importance of prey species because of differences in digestion rates; soft-bodied invertebrates are digested faster than hard-bodied invertebrates (e.g. Kennedy, 1969). Although many lake whitefish stomachs in this study contained mollusks, their muscle $\delta^{15}N$ values indicated that they preferentially fed upon chironomids and other isotopically-heavier prey.

The composition of a fish's diet may change over the open-water season as prey emerge and relative abundances of organisms vary. Unlike the dietary analysis done herein, studies which include the % composition of prey by weight may be more useful for quantitative comparisons of a consumer's feeding habits versus its $\delta^{15}N$. However, because most types of stomach content analyses provide only short-term dietary information, the simple presence/absence of prey species in stomach contents may be useful as an indicator of a fish's predisposition to utilize certain food organisms over a summer season.

Up until 1991, Lake Laberge supported commercial, subsistence and sport fisheries. Possibly as a result of this intensive fishing, the community composition in this lake is different than other regional lakes; the lake contains high biomasses of burbot and longnose sucker and low biomasses of lake trout and lake whitefish (de Graff and Mycasiw, 1994; Chapter I). Also, the lake trout and lake whitefish in Laberge grow faster than other regional populations (Thompson, 1996a; 1996b), which is a characteristic of exploited fish populations (Healey, 1975; 1978). In this study, trout from Laberge were mainly piscivorous and significantly younger at the same weight than the trout from Kusawa and Fox lakes. Reduced intraspecific competition in a smaller population may have enabled Laberge trout to grow faster and switch to a piscivorous diet at a younger age than the populations in Fox and Kusawa lakes (Trippel and Beamish, 1993). Faster growth also reduces their susceptibility to predation (Tonn et al., 1992). Fish that feed at a higher trophic level tend to live longer, grow faster and reach a larger size than individuals that feed at a lower trophic level (Martin, 1966; Trippel and Beamish, 1993). It is through growth, and not through the metabolic replacement of tissues, that an isotopic change in a fish's diet is exemplified in its muscle (Hesslein et al., 1993). In slow-growing populations, it may take many years before trophic-level changes in the dietary habits of fishes are reflected in their tissues. If fishes from Laberge grow faster than the same species from other lakes, their higher $\delta^{15}N$ may be due not only to an earlier shift in diet, but also to a faster change in the $\delta^{15}N$ signal of their tissues.

Analyses of stomach contents often provide specific information on resource utilization or food web interactions that are not discernible from isotopic analyses. Many prey species are similar in their isotopic composition, making it difficult to determine if a fish feeds strictly on one prey such as trichopteran or a combination of prey that averages to the same $\delta^{15}N$ as trichopteran. Although these problems could be overcome to some extent by using multiple isotopes (Hesslein et al., 1991), the integrative nature of isotopes signals would obscure certain food web relationships. Although stable isotopes are indicative of the main pathways of energy flow in a system, additional information on specific food web interactions can only be discerned from stomach content analyses.

Results from this study indicate that the short-term feeding habits of fishes were not always comparable to their long-term average trophic position, as measured by $\delta^{15}N$, particularly for the upper-trophic-level fishes. Because of the temporal limitations of stomach content information, the problems with empty stomachs or unidentifiable prey, and the time-consuming nature of dietary analyses, $\delta^{15}N$ is a more reliable method for examining within- and among-species variability in trophic positioning. However, for studies examining all pathways of energy flow within a system, stomach content analyses provide species-specific information on food web interactions that may not otherwise be discernible from stable isotope analyses.

References

Cabana, G. and J.B. Rasmussen (1994) Modelling food chain structure and contaminant bioaccumulation using stable nitrogen isotopes. Nature 372(17):255-257.

Cabana, G. and J.B. Rasmussen (1996) Modelling food chain structure with nitrogen isotopes: adjusting for anthropogenic shifts in isotopic signatures. Unpublished manuscript.

de Graff, N. and L. Mychasiw (1994) Lake trout recovery and contaminant management program in Lake Laberge, Yukon Territory. P.p. 301-304 in: Synopsis of Research Conducted Under the 1993/94 Northern Contaminants Program, J.L. Murray and R.G. Shearer (eds.). Environmental Studies No. 72. Indian and Northern Affairs Canada, Ottawa. 459 pp.

Estep, M.L.F. and S. Vigg (1985) Stable carbon and nitrogen isotope tracers of trophic dynamics in natural populations and fisheries of the Lahontan Lake System, Nevada. Can. J. Fish. Aquat. Sci. 42:1712-1719.

Gaebler, O.H., T.G. Vitti and R. Vukmirovich (1966) Isotope effects in metabolism of ^{14}N and ^{15}N from unlabeled dietary proteins. Can. J. Biochem. 44:1249-1257.

Gu, B., D.M. Schell and V. Alexander (1994) Stable carbon and nitrogen isotopic analysis of the plankton food web in a subarctic lake. Can. J. Fish. Aquat. Sci. 51:1338-1344.

Healey, M.C. (1975) Dynamics of exploited whitefish populations and their management with special reference to the Northwest Territories. J. Fish. Res. Board Can. 32:427-448.

Healey, M.C. (1978) The dynamics of exploited lake trout populations and implications for management. J. Wildl. Manage. 42(2):307-328.

Hesslein, R.H., M.J. Capel, D.E. Fox and K.A. Hallard (1991) Stable isotopes of sulfur, carbon, and nitrogen as indicators of trophic level and fish migration in the lower Mackenzie River basin, Canada Can. J. Fish. Aquat. Sci. 48(11):2258-2265.

Hesslein, R.H., K.A. Hallard and P. Ramlal (1993) Replacement of sulfur, carbon, and nitrogen in tissue of growing broad whitefish (*Coregonus nasus*) in response to a change in diet traced by $\delta^{34}S$, $\delta^{13}C$, and $\delta^{15}N$. Can. J. Fish. Aquat. Sci. 50:2071-2076.

Hobson, K.A. and H.E. Welch (1995) Cannibalism and trophic structure in a high arctic lake: Insights from stable-isotope analysis. Can. J. Fish. Aquat. Sci. 52:1195-1201.

Hyslop, E.J. (1980) Stomach contents analysis-a review of methods and their application. J. Fish Bio. 17:411-429.

Kennedy, C.R. (1969) Tubificid oligochaetes as food of dace *Leuciscus leuciscus*. J. Fish. Biol. 1:11-15.

Kennedy, W.A. (1953) Growth, maturity, fecundity and mortality in the relatively unexploited whitefish, *Coregonus clupeaformis*, of Great Slave Lake. J. Fish. Res. Board Can. 10:413:441.

Kirkland, R.A. and C.B.J. Gray (1986) Reconnaissance of the chemical and biological limnology in four large lakes of the Yukon River basin. NHRI Paper No. 33, IWD Scientific Series No. 153, Environment Canada, 23 pp.

Kline, T.C., J.J. Goering, O.A. Mathisen and P.H. Poe (1990) Recycling of elements transported upstream by runs of pacific salmon: 1. $\delta^{15}N$ and $\delta^{13}C$ evidence in Sashin Creek, Southeastern Alaska. Can. J. Fish. Aquat. Sci. 47:136-144.

Kling, G.W., B. Fry and W.J. O'Brien (1992) Stable isotopes and planktonic trophic structure in arctic lakes. Ecology 73(2):561-566.

Lacasse, S. and P. Magnan (1992) Biotic and abiotic determinants of the diet of brook trout, *Salvelinus fontinalis*, in lakes of the Laurentian Shield. Can. J. Fish. Aquat. Sci. 49:1001-1009.

Lindsey, C.C., K. Patalas, R.A. Bodaly and C.P. Archibald (1981) Glaciation and the physical, chemical and biological limnology of Yukon lakes. Can. Tech. Report Fish. Aquat. Sci. No. 966, 37 pp.

Martin, N.V. (1951) A study of the lake trout *Salvelinus namaycush* in two Algonquin Park, Ontario, lakes. Trans. Am. Fish. Soc. 81:111-137.

Martin, N.V. (1966) The significance of food habits in the biology, exploitation, and management of Algonquin Park, Ontario, lake trout. Trans. Am. Fish. Soc. 95:415-422.

Merritt, R.W. and K.W. Cummins (1978) An introduction to the aquatic insects of North America. Kendall/Hunt Publishing Company, Iowa, 441 pp.

Miller, R.B. and W.A. Kennedy (1948) Pike (*Esox lucius*) from four northern Canadian lakes. J. Fish. Res. Board Can. 7:190-199.

Minagawa, M. and E. Wada (1984) Stepwise enrichment of ^{15}N along food chains: Further evidence and the relation between $\delta^{15}N$ and animal age. Geochim. Cosmochim. Acta 48:1135-1140.

Oliver, D.R. and M.E. Roussel (1983) The genera of larval midges of Canada, Diptera:Chironomidae. In: The insects and arachnids of Canada Part 11, Agriculture Canada Publication 1746, Minister of Supply and Services Canada, Ottawa.

Pennak, R.W. (1953) Fresh-water invertebrates of the United States. The Ronald Press Company, New York, 769 pp.

Peterson, B.J. and B. Fry (1987) Stable isotopes in ecosystem studies. Ann. Rev. Ecol. Syst.

18:293-320.

Peterson, B., B. Fry, L. Deegan and A. Hershey (1993) The trophic significance of epilithic algal production in a fertilized tundra river ecosystem. Limnol. Oceanog. 38:872-878.

Rau, G.H., D.G. Ainley, J.L. Bengston, J.J. Torres and T.L. Hopkins (1992) $^{15}N/^{14}N$ and $^{13}C/^{12}C$ in Weddell Sea birds, seals and fish: implications for diet and trophic structure. Mar. Ecol. Prog. Ser. 84:1-8.

SAS Institute, Inc. 1985. User's guide: Statistics. SAS Institute, Inc., Cary, North Carolina.

Scott, W.B. and E.J. Crossman. (1973) Freshwater fishes of Canada. Bull. Fish. Res. Board Can. 184, Ottawa, 966 pp.

Sholto-Douglas, A.D., J.G. Field, A.G. James and J.J. van der Merwe (1991) $^{13}C/^{12}C$ and $^{15}N/^{14}N$ isotope ratios in the southern Benguela ecosystem: indicators of food web relationships among different size-classes of plankton and pelagic fish; differences between fish muscle and bone collagen tissues. Mar. Ecol. Prog. Ser. 78:23-31.

Shortreed, K.S. and J.G. Stockner (1986) Trophic status of 19 subarctic lakes in the Yukon Territory. Can. J. Fish. Aquat. Sci. 43:797-805.

Sparling, P.D. and M.J. Connor (1996) Lake Laberge index fishery and toxicology study 1993 data report. Yukon Territorial Government, in press.

Thompson, S. (1996a) Fish stock assessment of Kusawa, Laberge and Teslin lakes,1993, 1991, 1992. Fish and Wildlife Branch, Yukon Department of Renewable Resources, Whitehorse, Yukon, Y1A 4N6, in press.

Thompson, S. (1996b) Fish stock assessment of Marsh and Tagish lakes,1993. Fish and Wildlife Branch, Yukon Department of Renewable Resources, Whitehorse, Yukon, Y1A 4N6, in press.

Tonn, W.M., C.A. Paszkowski and I.J. Holopainen (1992) Piscivory and recruitment:Mechanisms structuring prey populations in small lakes. Ecology 73(3):951-958.

Trippel, E.A. and F.W.H. Beamish (1993) Multiple trophic level structuring in Salvelinus-Coregonus assemblages in boreal forest lakes. Can J. Fish. Aquat. Sci. 50:1442-1455.

Wada, E. and A. Hattori (1976) Natural abundance of ^{15}N in particulate organic matter in North Pacific Ocean. Geochim. Cosmochim. Acta 40:249-251.

Table II.1: Physical and epilimnetic chemical characteristics of Laberge, Fox and Kusawa lakes, Yukon Territory (Lindsey et al., 1991; Kirkland and Gray, 1986; Shortreed and Stockner, 1986; Water Survey of Canada, Whitehorse, Yukon). Unless otherwise noted, the water quality data is from this study and are given as means (ranges).

	Laberge	Fox	Kusawa
Latitude	61°11'N	61°14'N	60°20'N
Longitude	135°12'W	135°28'W	136°22'W
Length (km)	48	17	57
Maximum width (km)	4.2	1.3	2.5
Surface area (km^2)	201	15.9	142
Volume (km^3)	11.1 10.8	0.45	7.72
Maximum depth (m)	146	75	140
Drainage area (km^2)	25385	-	4070
Flushing rate (yr^{-1})	1.06	0.19	-
Conductivity (μmhos cm^{-1})	113 (111-115)	375 (352-403)	74 (41-139)
TDS (mg L^{-1})	62 (54-75)	243 (243-244) 228[2]	25 (19-36)
DOC (mg L^{-1})	2.61 (1.55-6.12)	8.63 (2.85-10.73)	3.37 (1.70-9.36)
TP (ug L^{-1})	5.1 (3.5-8.1) 3.8 - 6.7[1]	7.4 (5.8-9.2) 5.6[2]	3.6 (2.2-5.2)
TDP (ug L^{-1})	2.5 (1.4-6.1) 1.3 - 2.5[1]	4.4 (2.8-6.5)	1.8 (0.9-4.0)
TDN (ug L^{-1})	66.2 (61.4-75.2) 57 - 118[1]	194 (71.6-259) 399[2]	82.5 (72.1-92.6)
NO_3 (ug L^{-1})	16 (3.8-30.0)	4.0 (1.3-13.0) <1[2]	25.1 (18.3-28.8)
NH_3 (ug L^{-1})	15.2 (6.4-20.6)	10 (9.0-12.5)	12 (2.2-19.6)

[1] Kirkland and Gray (1986).

[2] Shortreed and Stockner (1986), taken from under the ice in March, 1983.

Table II.2: Fish species present in Laberge, Fox and Kusawa lakes, Yukon Territory (Lindsey et al., 1981; Sparling and Connor, 1996; Thompson, 1996; pers. obs.).

Fish		Lake		
		Laberge	Fox	Kusawa
Lake trout	*Salvelinus namaycush* (Walbaum)	X	X	X
Lake whitefish	*Coregonus clupeaformis* (Mitchill)	X	X	X
Round whitefish	*Prosopium cylindraceum* (Pallas)	X	X	X
Arctic grayling	*Thymallus arcticus* (Pallas)	X	X	X
Slimy sculpin	*Cottus cognatus* (Richardson)	X	X	X
Burbot	*Lota lota* (Linnaeus)	X	X	
Northern pike	*Esox lucius* (Linnaeus)	X	X	
Longnose sucker	*Catostomus catostomus* (Forster)	X		X
Inconnu	*Stenodus leucichthys* (Güldenstadt)	X		X
Chinook salmon	*Oncorhynchus tshawytscha* (Walbaum)	X		X
Broad whitefish	*Coregonus nasus* (Pallas)	X		X
Least cisco	*Coregonus sardinella* (Valenciennes)	X		X[1]

[1] Least cisco were not netted in a 1993 index netting survey conducted by the Fish and Wildlife Branch, Renewable Resources Department, Yukon Territorial Government, Whitehorse, Yukon.

Table II.3: Mean, SD and range of δ^{15}N (‰) of prey for fishes from Laberge, Kusawa and Fox lakes, Yukon Territory. Different superscripts indicate significant among-lake differences ($P < 0.05$) within each taxon.

Species	Lake	*n*	δ^{15}N (‰) Mean ± SD	δ^{15}N (‰) Range
Broad Whitefish	Laberge	3	6.55±1.10	5.77-7.81
Chironomids	Laberge	8	4.02±1.14^{a}	2.41-5.85
	Kusawa	5	4.08±0.62^{a}	3.58-4.89
	Fox	4	4.06±0.97^{a}	3.01-5.25
Gammarus	Fox	5	3.43±1.44	1.62-4.99
Lymnaeidae	Laberge	6	2.05±1.01^{a}	0.41-3.03
	Kusawa	5	1.42±0.99^{a}	0.29-2.42
	Fox	4	1.95±0.46^{a}	1.34-2.47
Oligochaeta	Laberge	3	3.52±0.29	3.32-3.85
Sculpin[1]	Laberge	1	6.33	
	Kusawa	1	7.44	
	Fox	1	5.08	
Sphaeriidae	Laberge	1	2.19	
Trichoptera	Laberge	9	2.55±1.38^{a}	1.11-5.39
	Kusawa	2	1.62^{a}	0.69, 2.54
	Fox	6	2.53±1.26^{a}	0.70-4.52
Valvatidae/Planorbidae	Laberge	4	1.26±1.39^{a}	-0.61-2.38
	Kusawa	2	1.76^{a}	1.47, 2.05
	Fox	5	1.40±0.31^{a}	0.93-1.83
Zooplankton	Laberge	6	4.94±1.22^{a}	3.02-6.39
	Kusawa	6	2.85±1.04^{b}	1.19-3.86
	Fox	6	3.56±0.56^{b}	2.91-4.32

[1] Each sculpin sample is composed of muscle tissue from several individuals.

Table II.4: Percent occurrence of prey items in fish stomachs from Lake Laberge, Yukon Territory. Numbers with * indicate those organisms used for Figure II.4 to calculate potential maximum and minimum predator $\delta^{15}N$ values.

	Lake Trout	Burbot	Northern Pike	Lake Whitefish	Round Whitefish	Least Cisco	Longnose Sucker
# of stomachs with prey	84	65	38	220	68	19	15
# of empty stomachs	8	15	14	29	22	3	1
Chironomidae	14*	-	-	39	82*	26	93
Coleoptera	-	-	-	2	1	-	-
Ephemeroptera	1	-	-	-	-	-	-
Formicidae	-	-	-	2	1	5	-
Gammarus	-	-	-	1	-	-	-
Hirudinea	-	-	-	-	-	-	27
Hydracarina	2	-	-	30	6	-	-
Lymnaeidae	-	-	-	12*	12*	-	-
Oligochaeta	-	-	-	1	1	-	-
Plecoptera	-	-	-	1	-	-	-
Sphaeriidae	-	-	-	15	6	-	7
Tipulidae	-	-	-	1	-	-	-
Trichoptera	-	-	-	4	12	5*	-
Unidentified Invertebrates	12	-	-	11	7	-	-
Valvatidae/Planorbidae	-	-	-	55	7	-	7*
Zooplankton	-	-	-	11	-	84*	20*
Broad Whitefish	2	2	3	-	-	-	-
Burbot	-	5*[1]	3*[1]	-	-	-	-
Lake Whitefish	1*	5	3	-	-	-	-
Least Cisco	35	37	42	1*	-	-	-
Longnose Sucker	7	2	3	-	-	-	-
Northern Pike	-	-	3	-	-	-	-
Round Whitefish	1	5	11	1	-	-	-
Slimy Sculpin	17	14*	5*	3	-	-	-
Unidentified Fishes	54	62	42	4	-	-	-

[1] The lowest $\delta^{15}N$ value for burbot of 10.27 ‰ was used in calculating potential predator ranges for Figure II.1.

Table II.5: Mean ± SD, and maximum and minimum of ages and weights of fishes, and $\delta^{15}N$ of fish muscle, and summarized stomach content data from Laberge, Kusawa and Fox lakes, Yukon Territory. Significant within-species differences are indicated by different superscripts.

		Stable Isotope Data				Stomach Content Data			
Species	Lake	*n*	Weight (g)	Age (yr)	$\delta^{15}N$ (‰)	*n*	Piscivores	Omnivores	Zoobenthivores/ zooplanktivores
Burbot	Laberge	32	1269±774^{a} 2962,230	11±4^{a} 24,5	12.06±0.59^{a} 13.04,10.27	65	100	-	-
	Fox	14	1350±558^{a} 2500,750	11±3^{a} 16,7	8.87±0.71^{b} 9.77,7.65	4	25	75	-
Lake Trout	Laberge	32	1579±1103^{a} 5900,500	12±4^{a} 25,7	12.36±0.85^{a} 13.96,10.35	84	85	1	14
	Kusawa	14	1743±1234^{a} 3967,26	17±7^{b} 32,4	9.89±0.98^{b} 10.95,6.98	64	38	21	41
	Fox	20	1191±1065^{a} 5000,150	18±7^{b} 35,10	8.82±0.85^{c} 10.36,7.00	40	15	13	72
Northern Pike	Laberge	10	1960±1008^{a} 4000,1000	7±1^{a} 9,6	9.62±0.75^{a} 10.78,8.46	38	100	-	-
	Fox	9	2415±929^{a} 3625,600	7±3^{a} 11,4	8.26±0.64^{b} 9.06,7.23	6	67	33	-
Lake Whitefish	Laberge	36	325±260^{a} 950,14	10±4^{a} 22,2	8.22±1.15^{a} 10.21,5.22	220	5	1	94
	Kusawa	20	600±148^{b} 900,400	12±4^{ab} 21,7	6.83±0.99^{b} 8.58,5.12	124	-	-	100
	Fox	18	855±225^{c} 1300,500	15±9^{b} 39,5	7.41±0.98^{c} 8.79,5.44	110	-	4	96
Round Whitefish	Laberge	8	187±251^{a} 800,50	5±4^{a} 15,3	7.16±0.76^{a} 7.94,5.70	68	-	-	100
	Kusawa	9	68±35^{b} 125,23	4±2^{a} 9,3	6.03±0.62^{b} 6.78,4.99	23	-	-	100
	Fox	8	244±88^{a} 380,165	5±3^{a} 11,3	6.40±0.27^{b} 6.67,5.89	11	-	-	100
Longnose Sucker	Laberge	12	870±96^{a} 1000,700	-	7.57±0.92^{a} 8.82,5.80	15	-	-	100
	Kusawa	12	671±125^{b} 800,500	-	6.73±0.49^{b} 7.19,5.41	-	-	-	-
Least Cisco	Laberge	14	68±31 114,6.4	4±1 5,3	7.87±0.47 8.79,7.30	19	-	-	100

Table II.6: Percent occurrence of prey items in fish stomachs from Kusawa Lake, Yukon Territory. Numbers with * indicate those organisms used in Figure II.4 to calculate potential maximum and minimum predator $\delta^{15}N$ values.

	Lake Trout	Lake Whitefish	Round Whitefish
# of stomachs with prey	64	124	23
# of empty stomachs	14	5	7
Chironomidae	5	60*	78*
Coleoptera	14	2	-
Diptera	19	8	
Ephemeroptera	6	-	-
Formicidae	6	-	4
Hirudinea	-	3	-
Hydracarina	-	65	4
Lymnaeidae	6*	15*	4*
Plecoptera	2	-	9
Sphaeriidae	2	74	4
Trichoptera	14	6	17
Unidentified Invertebrates	25	2	26
Valvatidae/Planorbidae	14	83	-
Zooplankton	2	2	22
Lake Trout	2[1]	-	-
Lake Whitefish	6	-	-
Slimy Sculpin	5*	-	-
Unidentified Fishes	48	-	-

[1] Lake trout $\delta^{15}N$ was not used to calculate maximum potential $\delta^{15}N$ for Figure II.1 because sculpin $\delta^{15}N$ exceeded the lowest value found for lake trout.

Table II.7: Percent occurrence of prey items in fish stomachs from Fox Lake, Yukon Territory. Numbers with * indicate those organisms used in Figure II.4 to calculate potential maximum and minimum predator $\delta^{15}N$ values.

	Lake Trout	Burbot	Northern Pike	Lake Whitefish	Round Whitefish
# of stomachs with prey	40	4	6	110	11
# of empty stomachs	6	9	5	10	1
Chironomidae	53	25	-	55	73*
Coleoptera	3	-	-	1	-
Ephemeroptera	3	-	-	-	9
Formicidae	8	-	-	-	-
Gammarus	28	50*	-	14	-
Hirudinea	3	-	33	5	9
Hydracarina	10	-	-	20	-
Lymnaeidae	-	-	-	10	9*
Oligochaeta	-	-	-	5	-
Plecoptera	3	-	-	-	-
Sphaeriidae	5	-	-	57	-
Trichoptera	15*	-	-	14	36
Unidentified Invertebrates	5	-	-	12	-
Valvatidae/Planorbidae	-	-	-	14*	-
Zooplankton	8	-	-	6	-
Round Whitefish	3*	-	-	-	-
Slimy Sculpin	8	25*	33*	2*	-
Unidentified Fishes	25	75	67	2	-

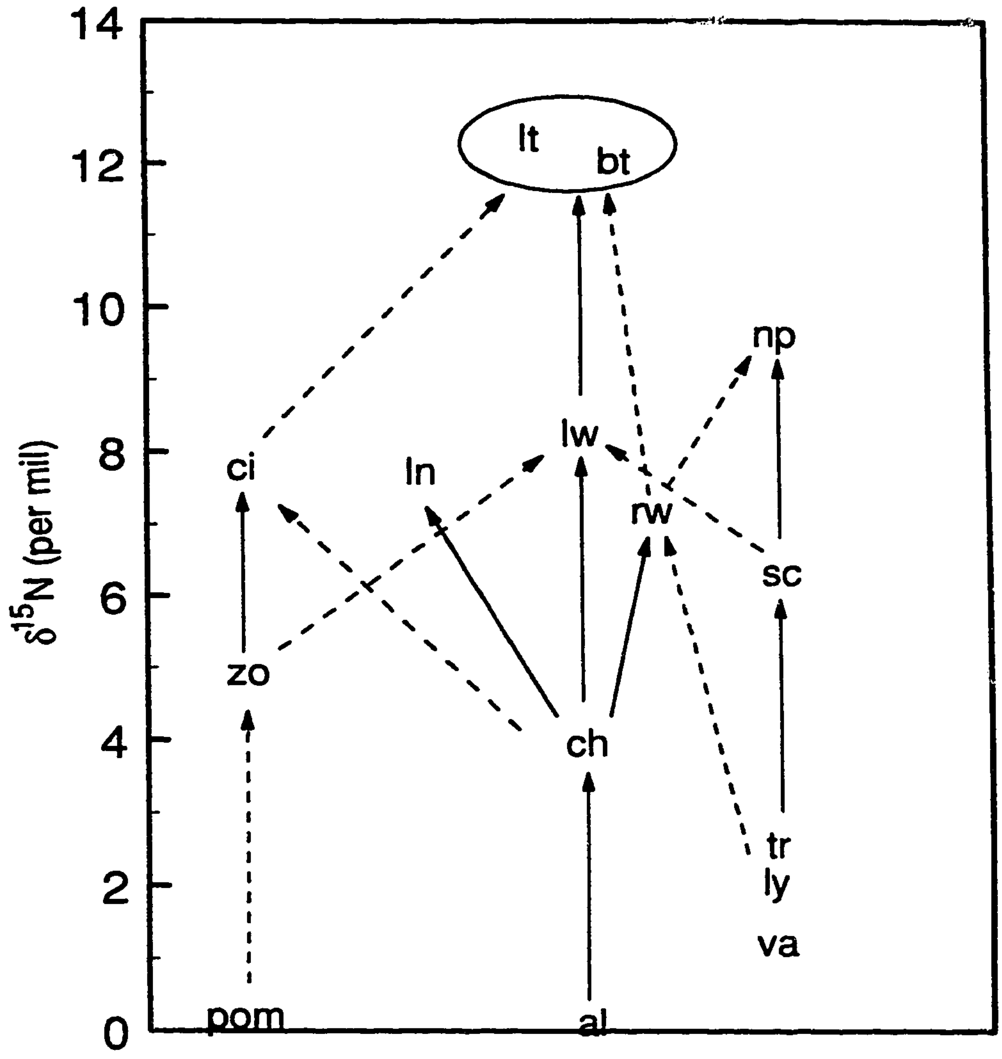

Figure II.1: Food web structure in Lake Laberge, Yukon Territory, based on $\delta^{15}N$ (per mil) of fish muscle and whole invertebrates. Solid arrows designate main prey while dashed arrows are minor prey species. lt - lake trout, bt - burbot, np - northern pike, sc - slimy sculpin, lw - lake whitefish, ln - longnose sucker, rw - round whitefish, ci - least cisco, zo - zooplankton, ch - chironomids, tr - tricopteran, ly - Lymnaeidae, va -Valvatidae/Planorbidae, pom - particulate organic matter from the pelagic zone, al - epilithic algae.

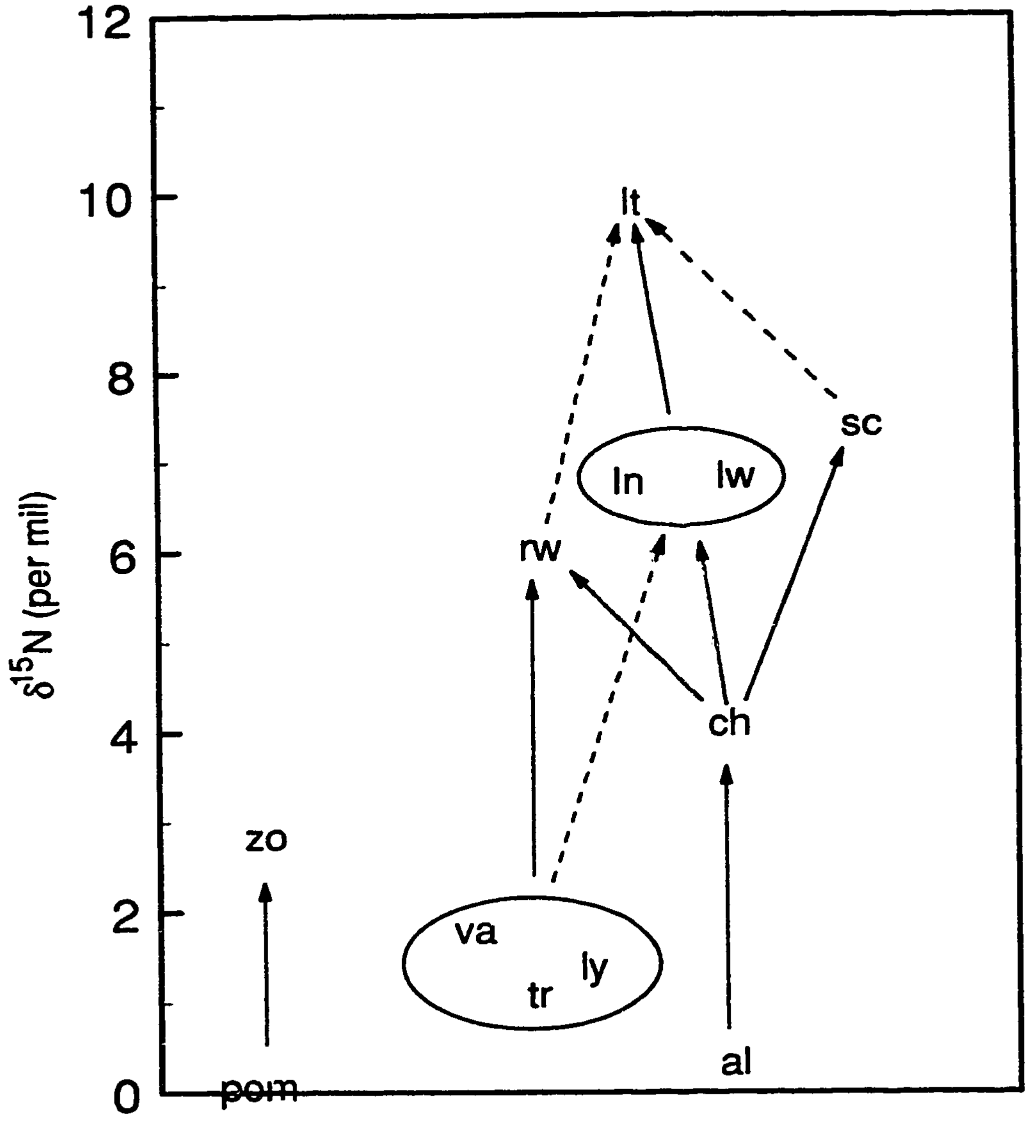

Figure II.2: Food web structure in Kusawa Lake, Yukon Territory based on $\delta^{15}N$ (per mil) of fish muscle and whole invertebrates. Solid arrows designate main prey while dashed arrows are minor prey species. lt - lake trout, sc - slimy sculpin, lw - lake whitefish, ln - longnose sucker, rw - round whitefish, zo - zooplankton, ch - chironomids, tr - tricopteran, ly - Lymnaeidae, va - Valvatidae/Planorbidae, pom - particulate organic matter from the pelagic zone, al - epilithic algae.

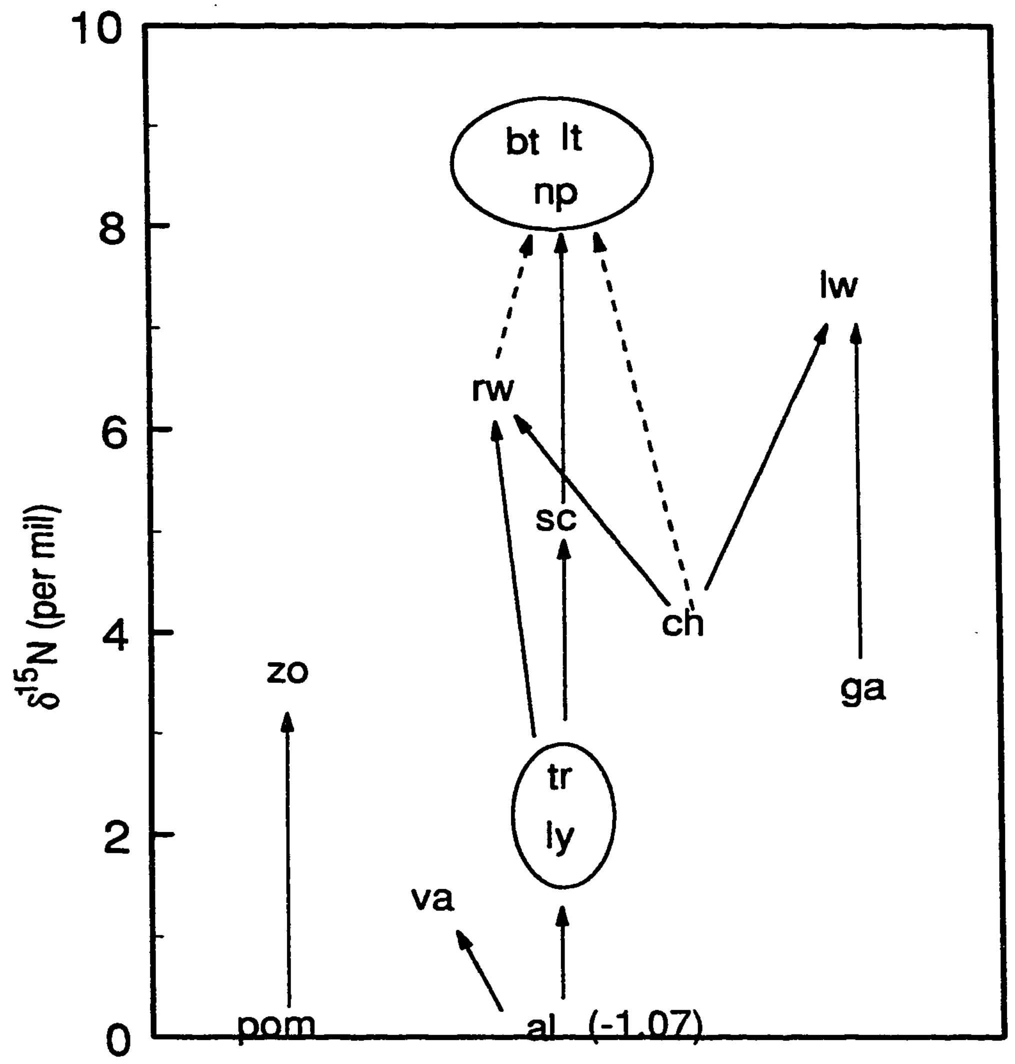

Figure II.3: Food web structure in Fox Lake, Yukon Territory based on $\delta^{15}N$ (per mil) of fish muscle and whole invertebrates. Solid arrows designate main prey while dashed arrows are minor prey species. lt - lake trout, bt - burbot, np - northernpike, sc - slimy sculpin, lw - lake whitefish, ln - longnose sucker, rw - round whitefish, ga - *Gammarus*, zo - zooplankton, ch - chironomids, tr - tricopteran, ly - Lymnaeidae, va - Valvatidae/Planorbidae, pom - particulate organic matter from the pelagic zone, al - epilithic algae.

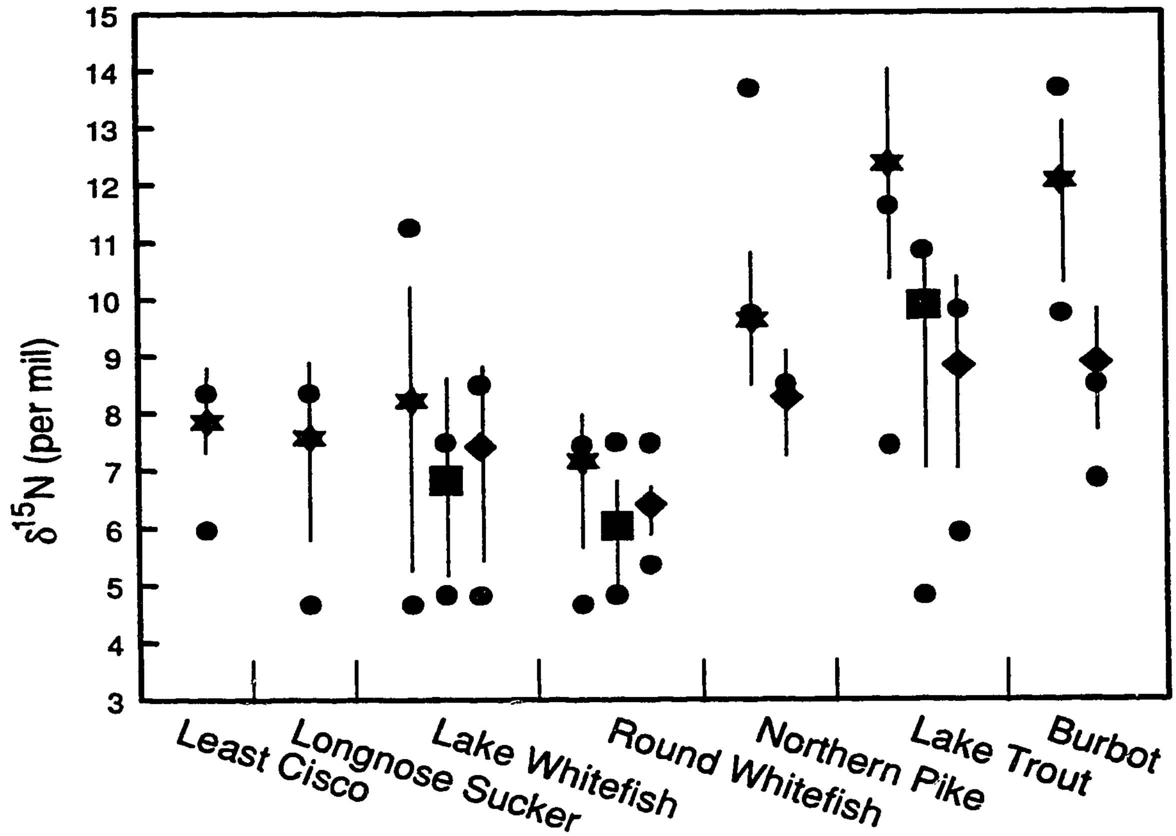

Figure II.4: δ^{15}N and range (solid line) of fish muscle from Laberge (stars), Kusawa (squares), and Fox (diamonds) Lakes, Yukon Territory. Maximum and minimum δ^{15}N fish values were predicted based on stomach content analyses (see text for an explanation) and are shown as closed circles.

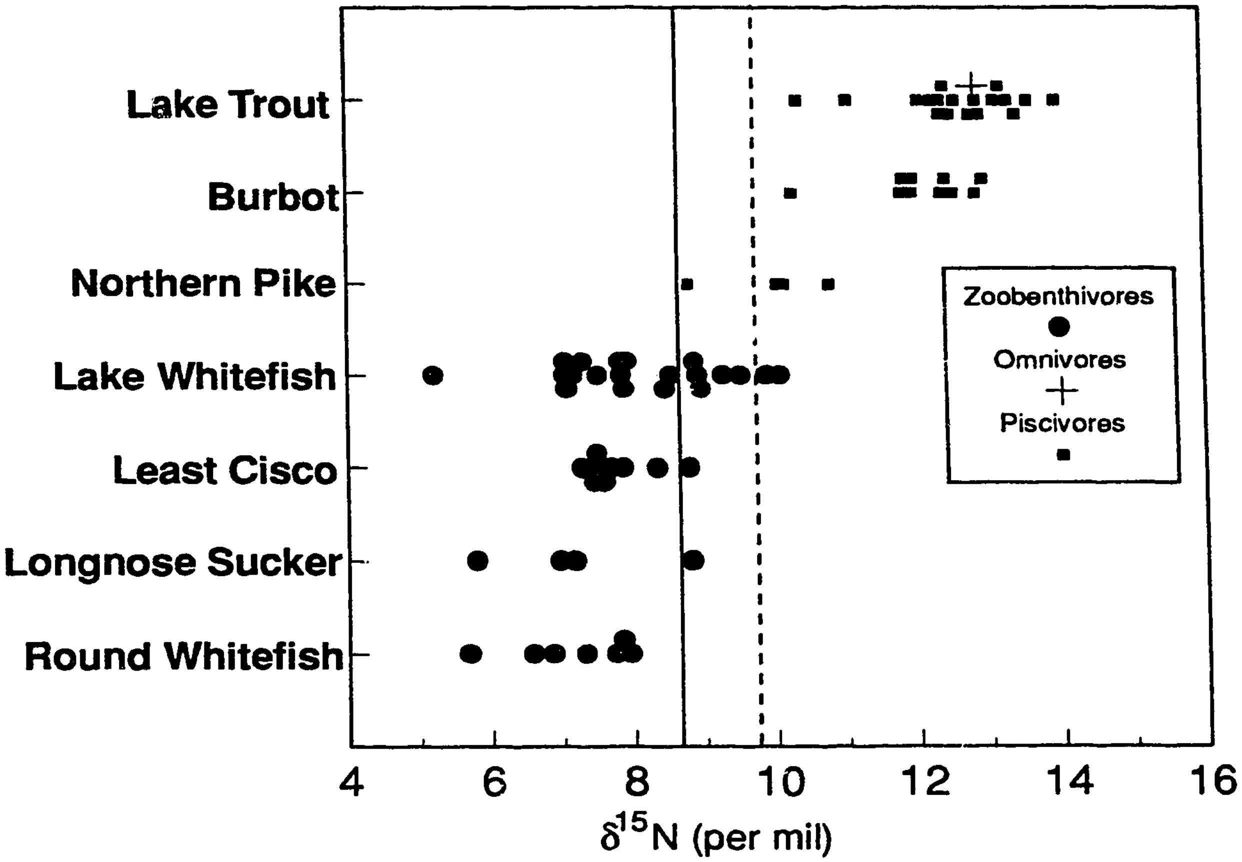

Figure II.5: $\delta^{15}N$ of muscle for individual fishes from Lake Laberge, Yukon Territory that were categorized from their stomach content analyses as zoobenthivores/zooplanktivores (invertebrate-eaters), omnivores (fish- and invertebrate-eaters), or piscivores (fish-eaters). The dashed line represents the maximum possible value of $\delta^{15}N$ for fish feeding on invertebrates (based on the highest measured value for invertebrates plus 3.4 per mil), and the solid line represents the minimum possible value of $\delta^{15}N$ for fish feeding on other fishes (based on the lowest measured value for fishes plus 3.4 per mil).

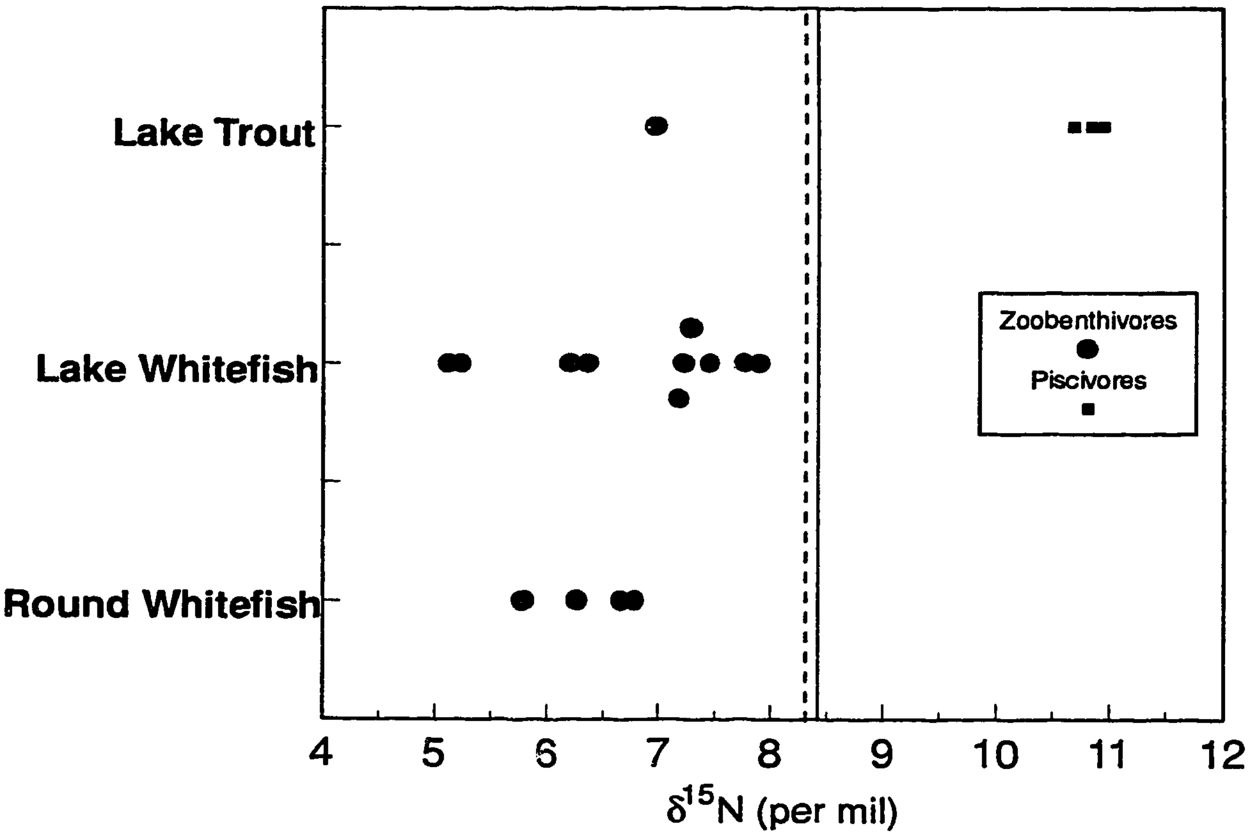

Figure II.6: δ^{15}N of muscle for individual fishes from Kusawa Lake, Yukon Territory that were categorized from their stomach content analyses as zoobenthivores/zooplanktivores (invertebrate-eaters), omnivores (fish- and invertebrate-eaters), or piscivores (fish-eaters). The dashed line represents the maximum possible value of δ^{15}N for fish feeding on invertebrates (based on the highest measured value for invertebrates plus 3.4 per mil), and the solid line represents the minimum possible value of δ^{15}N for fish feeding on other fishes (based on the lowest measured value for fishes plus 3.4 per mil).

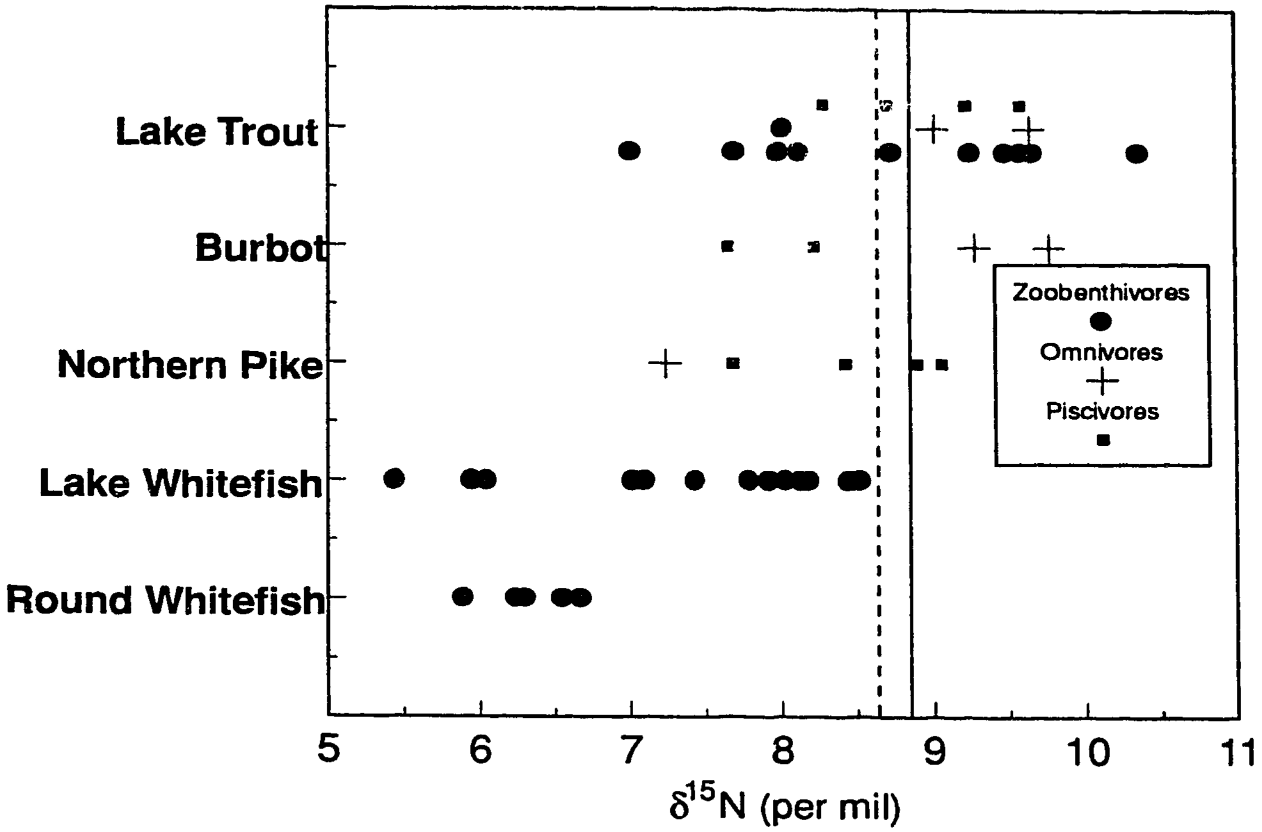

Figure II.7: δ^{15}N of muscle for individual fishes from Fox Lake, Yukon Territory that were categorized from their stomach content analyses as zoobenthivores/zooplanktivores (invertebrate-eaters), omnivores (fish- and invertebrate-eaters), or piscivores (fish-eaters). The dashed line represents the maximum possible value of δ^{15}N for fish feeding on invertebrates (based on the highest measured value for invertebrates plus 3.4 per mil), and the solid line represents the minimum possible enrichment of δ^{15}N for fish feeding on other fishes (based on the lowest measured value for fishes plus 3.4 per mil).

III. CORRELATION BETWEEN STABLE NITROGEN ISOTOPE RATIOS AND CONCENTRATIONS OF ORGANOCHLORINES IN BIOTA FROM A FRESHWATER FOOD WEB[4]

Introduction

Biomagnification, the process of increasing contaminant concentrations in biota with increasing trophic level, has been examined in many temperate freshwater food webs. These studies have estimated the biomagnification of organochlorines from prey to predator using food webs that have been structurally defined from stomach contents or from estimated interspecies relationships (e.g. Oliver and Niimi, 1988; Rasmussen et al., 1990; Evans et al., 1991). However, conclusions reached in these studies are limited by the fact that an organism's diet often consists of prey from several trophic levels, varies seasonally with prey availability, or cannot be determined.

Trophic relationships of marine and freshwater biota are currently being defined using measurements of naturally occurring stable nitrogen isotopes (Fry, 1991; Hesslein et al., 1989; 1991; Kling et al., 1992). The heavier isotope of nitrogen, ^{15}N, is preferentially retained from an organism's diet during metabolic processes (Gaebler et al., 1966). An organism's $^{15}N/^{14}N$ (herein referred to as $\delta^{15}N$) increases on average 3 to 5 parts per thousand (‰) from its source of dietary nitrogen (Peterson and Fry, 1987). Tissue $\delta^{15}N$ can therefore be used as a continuous variable to replace discrete trophic assignments, and, unlike stomach contents, represents what is assimilated into an organism from its diet over the time period of tissue turnover (Hesslein et al., 1993).

Previous studies have examined the relationship between $\delta^{15}N$ and organochlorine

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[4] A version of this chapter has been published. Kidd, Schindler, Hesslein and Muir 1995. Sci. Total Environ. 160/161:381-390.

concentrations in marine food webs (Spies et al., 1989; Broman et al., 1992; Rolff et al., 1993). Broman et al. (1992) and Rolff et al. (1993) found that the toxic equivalents of PCDD/Fs were significantly related to $\delta^{15}N$, indicating that stable nitrogen isotopes had the potential to be used in further studies of organochlorine biomagnification. To mv knowledge, this type of relationship has not previously been examined in freshwa systems.

The following study examines the relationship between the organochlorines hexachlorocyclohexane (HCH), DDT and chlorinated bornanes (toxaphene, CHB) and $\delta^{15}N$ in biota from a subarctic freshwater lake. Lake Laberge is located 30 km downstream of Whitehorse, Yukon Territory on the Yukon River system. The lake trout from Laberge have concentrations of DDT (Muir et al., 1992a) that are comparable to levels found in salmonids from the Great Lakes (DeVault et al., 1986; Oliver and Niimi, 1988; Borgmann and Whittle, 1991). Total CHB concentrations in lake trout and burbot from Lake Laberge are significantly higher than the levels found in the same species from other Yukon lakes (Kidd et al., 1993) and lakes in the Northwest Territories (Muir et al., 1990), and have resulted in the closure of the commercial, sport and native subsistence fisheries. DDT and toxaphene were previously used in the Yukon as a regional insecticide and as a piscicide in one lake, respectively (Sharp, 1952; Walker et al., 1973). However, the contemporary source of HCH, DDT and CHB is believed to be long range atmospheric transport and deposition as is found in the Canadian Arctic (Bidleman et al., 1989; Barrie et al., 1992).

Methods

Sample Collection

Fish and invertebrate samples from Lake Laberge were collected in March, and between June and August, of 1992. Lake trout (*Salvelinus namaycush*), lake whitefish (*Coregonus clupeaformis*), broad whitefish (*Coregonus nasus*), longnose sucker (*Catastomus*

catastomus), least cisco (*Coregonus sardinella*), and burbot (*Lota lota*) were netted in Laberge; length, weight, and sex of the fish were recorded, and aging tissues and stomach contents removed. Only length and weight of the fishes are presented herein. Fishes were either sampled for dorsal muscle on site or frozen whole and subsequently sampled after partial thawing in the laboratory.

The invertebrates collected for this study were those predominant in the stomach contents of the fishes. Chironomids (subfamilies Tanypodinae, Prodiamesinae and Chironominae), snails (Family Limnaeidae) and trichopterans (Families Limnephilidae and Limnephilinae) were sampled using benthic grabs and shore sampling. These invertebrates were washed with lake water to remove any particulate matter, removed from their shells or cases when present and pooled to obtain adequate masses. The zooplankton sample was collected by towing 250 µm net vertically through the top 15 m of the water column. All invertebrate samples were blotted to remove surficial water. All fish and invertebrate samples were kept on ice until they were frozen (within hours of collection) and were kept at a maximum of -10°C until they needed for laboratory analyses.

Stable Isotope Analyses

Skinless dorsal muscle from individual lake trout, burbot, whitefish, cisco and longnose sucker, and pooled whole invertebrate samples (pretreated with 1 N HCl) were dried in an oven at 60°C and homogenized to a fine powder. Methods for stable isotope analyses followed those found in Chapter II. Stable isotope ratios were standardized against air as follows:

$\delta^{15}N$ ‰ $= [(R_{sample}/R_{air}) - 1] \times 1000$ where $R = {}^{15}N/{}^{14}N$

Precision of the instrument for nitrogen isotope analysis over several years of use has been 0.4 ‰ (2 SD).

Organochlorine Analyses

Muscle tissue (including skin for lake trout and lake whitefish; skinless for broad whitefish and longnose sucker) and whole cisco were homogenized with dry ice. After CO_2 sublimation, 5 to 20 g was mixed with anhydrous sodium sulfate (precleaned at 600 °C for 16 h). Blanks were included with every third set of six samples to ensure that solvents and glassware were clean. Internal standards of aldrin (or PCB30) and octachloronaphthalene (OCN) were added to the samples to determine extraction efficiencies. Burbot liver and invertebrate tissues were ball-milled with anhydrous sodium sulfate and hexane for 30 min, and the hexane was decanted after sitting for 4 h. Samples were ball-milled again with hexane for another 30 min, centrifuged at 4000 rpm, and this hexane then decanted and combined with the hexane from the previous extraction. Fish muscle and whole fish were Soxhlet-extracted for 4 hours using hexane:dichloromethane (DCM) 1:1 and left in the Soxhlet overnight. For all fish and invertebrate samples, lipids were determined gravimetrically using 1/10th of the extract. Remaining lipids were removed from the extract using automated gel permeation chromatography on SX-3 Biobeads with DCM:hexane (1:1) as the eluant. The eluant was then separated on Florisil (1.2% deactivated with HPLC-grade water) into three fractions: hexane (F1), hexane:DCM (85:15)(F2), and hexane:DCM (1:1)(F3)(Norstrom and Won, 1985). F1 contained all PCBs and most chlorobenzenes; F2 contained most CHB, HCH, chlordane and DDT congeners; F3 contained dieldrin and heptachlor epoxide.

For this study, ΣHCH (sum of αHCH, βHCH and γHCH), ΣDDT [sum of ΣDDD (o,p'-DDD and p,p'-DDD), ΣDDE (o,p'-DDE and p,p'-DDE) and ΣDDT (o,p'-DDT and p,p'-DDT)] and ΣCHB were quantified in F1 and F2 using a Varian 6000 or 3600 with a ^{63}Ni-electron capture detector (GC-ECD) and a 60 m by 0.25 mm i.d. DB-5 column (film thickness 0.25 μm) with H_2 carrier gas (approximately 1 $mL.min^{-1}$; initial flow of 2.0 $mL.min^{-1}$; constant pressure of 22.5 psi) and N_2 makeup gas. The column temperature started at 100 °C, increased 15 $°C.min^{-1}$ to 150 °C, 3 $°C.min^{-1}$ to 265 °C and then remained at this temperature for the rest of the 57 minute run. OCN had a retention time of 47.7 minutes under these conditions. Samples were quantified against external standards that were obtained from National Research Council of Canada (Halifax, NS), Ultra Scientific (Hope, RI), National Institute of Standards and Technology (Maryland) and Cambridge Isotope Laboratories (Massachusetts). ΣCHB was quantified in the samples using a single response factor based on the areas of 20 peaks in the standard (Muir et al., 1992b). The detection limits for the individual congeners averaged 0.01 ng.g^{-1} and were calculated using a series of blank runs (3x the SD of background). Average recoveries of internal standards for all samples were 80 and 89 % for F1 (PCB30 or aldrin) and F2 (OCN) respectively.

Statistical Analyses

Organochlorine concentrations and lipid were log-transformed to normalize the distribution of the data. Relationships between δ^{15}N, lipid and organochlorine concentrations (wet weight and lipid-normalized) were analysed using the general linear models procedure in SAS (1985), and the residuals were examined graphically to ensure that they were randomly distributed. Slopes of the wet weight regression equations were tested for significant differences using analysis of covariance (ANCOVA) and Tukey tests with the mean square error of the pooled regression equation (Zar, 1984). Student's t test (k=2) was used to test for significant differences between intercepts using the slope and mean square error from the common regression equation (Zar, 1984).

Results

Measurements of biotic δ^{15}N revealed that there were three distinct trophic groups in the food web of Lake Laberge. The primary consumers trichopterans, mollusks, chironomids and zooplankton, occupied the lowest trophic level with δ^{15}N values ranging from 1.3 to 5.0 ‰. The secondary consumers broad and lake whitefish, longnose sucker and cisco occupied the next level in the food web (δ^{15}N 5.8 to 9.9 ‰), while burbot and lake trout were the top predators and had average $\delta^{15}N$ values (11.5 and 11.6 ‰; Figure III.1) that were distinct from the lower-trophic-level organisms.

These trophic relationships, as defined by $\delta^{15}N$, were consistent with observed diets of the fishes (see Chapter II) and indicated that ^{15}N was progressively enriched through the food web. Lake trout and burbot fed upon cisco and lake whitefish and were an average of 3.7 ‰ higher in $\delta^{15}N$ than their prey. Longnose sucker and broad whitefish fed upon chironomids and had tissue $\delta^{15}N$ that were respectively 2.0 and 1.8 ‰ higher than their food source. A $\delta^{15}N$ enrichment of 2.5 ‰ was observed between cisco and their diet of zooplankton. Lake whitefish fed on varying combinations of chironomids, mollusks, trichopterans, zooplankton and occasional small fishes, which resulted in an average $\delta^{15}N$ increase of 5.2 ‰ between the predator and the prey. In general, an average increase in $\delta^{15}N$ of 3.3 ‰ was found between a fish species and its observed food source(s).

Weight and length of all fishes, and % lipid and ΣHCH, ΣDDT and ΣCHB concentrations for all organisms are presented in Table III.1. Mean concentrations of these contaminants in the forage fishes (cisco, lake whitefish, and longnose sucker) were intermediate between the concentrations found for invertebrates and the top predators, while the organochlorine concentrations in broad whitefish were comparable to those found in the invertebrates.

There was a highly significant relationship between the log wet weight concentrations of ΣHCH, ΣDDT and ΣCHB, and $\delta^{15}N$ over the range of trophic levels examined in this study (Figures III.2-4; Table III.2). Trophic position, as measured by $\delta^{15}N$, explained between 67 and 81 percent of the variability in the organochlorine concentrations across species; the coefficients of determination were comparable for ΣDDT and ΣCHB (r^2 of 80 and 81 %), and larger than was found for ΣHCH (r^2 of 67 %). ANCOVA analyses revealed that the slope of log ΣHCH versus $\delta^{15}N$ was significantly different from the slopes found for either log ΣDDT or log ΣCHB and $\delta^{15}N$ through the food web of Lake Laberge. However, no significant differences between either the slopes or the intercepts for ΣDDT and ΣCHB versus $\delta^{15}N$ were found. Lipid (log-transformed) was also a significant predictor of organochlorine concentrations (Table III.3) and the slopes of these relationships were comparable for ΣDDT and ΣCHB, and lowest for ΣHCH. The slopes of all relationships were greater when the burbot liver data were included than when the data were excluded (regressions not shown). After lipid normalization, log ΣHCH, ΣDDT and ΣCHB concentrations were significantly related to $\delta^{15}N$ (Table III.2) and the slopes of these relationships were smaller than those found with wet weight concentrations. Log-lipid was also significantly related to $\delta^{15}N$ through the food web both with (Eqn 1) and without (Eqn 2) burbot liver data.

$$\text{log lipid } (g.g^{-1}\ ww) = 0.11\ (\pm 0.021)\ \delta^{15}N - 0.25\ (\pm 0.18) \tag{1}$$

$$r^2 = 0.49, P < 0.001, SE_{est}=0.39$$

$$\text{log lipid } (g.g^{-1}\ ww) = 0.070\ (\pm 0.019)\ \delta^{15}N - 0.045\ (\pm 0.153) \tag{2}$$

$$r^2 = 0.35, P < 0.001, SE_{est}=0.32$$

Discussion

The wide geographical distribution of burbot (Scott and Crossman, 1973) and the high fat content of their livers make them a suitable choice for studies on the spatial variability of organochlorine concentrations in fishes (Muir et al., 1990; Kidd et al., 1993). However, it is difficult to compare organochlorine concentrations found in burbot liver to pollutant levels in the muscle from other species because of the differences in tissue lipid and organochlorine storage. Muscle samples of burbot from Lake Laberge were low in lipid (0.3 %) and had concentrations of ΣDDT and ΣCHB that were 400 and 700 times lower respectively than liver concentrations, while ΣHCH was below the detection limit (0.1 $ng.g^{-1}$; J. Eamer, Canadian Wildlife Service, Whitehorse, unpublished data). Whole body concentrations of organochlorines would therefore remove the variability associated with the differences in contaminant storage found among species examined herein.

In this study, I used muscle rather than liver tissue of burbot for $\delta^{15}N$ analyses because replicate analyses of $\delta^{15}N$ in liver tissue were much more variable within individuals. This variability may due to the fact that the liver is a site of protein anabolism, and of ammonia synthesis. Both of these processes are believed to be important in the fractionation of $\delta^{15}N$ from prey to predator (Gaebler et al., 1966; Steele and Daniel, 1978).

Significant relationships between the wet weight log-transformed concentrations of ΣHCH, ΣDDT and ΣCHB and trophic positioning, as determined by $\delta^{15}N$, were found in Lake Laberge. The slopes of these relationships were significantly greater for ΣDDT and ΣCHB, than the slope for ΣHCH, indicating that the more lipophilic organochlorines have greater rates of accumulation through this food web. This difference suggests that the slope of the organochlorine-$\delta^{15}N$ relationship directly reflects a compound's potential to biomagnify through the food web.

Percent lipid and trophic position ($\delta^{15}N$) were significantly related through the Lake Laberge food web, and these results were consistent with the findings of Oliver and Niimi (1988) and Rasmussen et al. (1990). Both variables were significantly related to biotic organochlorine concentrations; however, lipid explained more of the variability in ΣHCH concentrations than $\delta^{15}N$ (r^2 of 0.76 for lipid and 0.67 for $\delta^{15}N$), while $\delta^{15}N$ was a better individual predictor of both ΣDDT and ΣCHB concentrations through the food web when compared to the regressions with lipid (r^2 of 0.80 and 0.81 for $\delta^{15}N$; r^2 of 0.67 and 0.58 for lipid). If lipid was the only factor driving biomagnification through this food chain, one would expect that the slopes of the regressions for the lipid-normalized organochlorine concentrations versus $\delta^{15}N$ would be close to zero. Albeit the slopes of the lipid-normalized organochlorine concentrations versus $\delta^{15}N$ were lower than the regressions using wet weight concentrations, significant relationships between these variables were found. With the exception of ΣHCH, the least lipophilic compound, the lipid-normalized regressions also explained a large part of the variability in contaminant concentrations across this food web (r^2 = 0.65 and 0.70). Rasmussen et al. (1990) found that PCB concentrations in lake trout from temperate lakes were significantly predicted both by the underlying length of the food chain (as categorized by the presence/absence of prey species) and fish lipid content. However, they noted that as the trophic position of the lake trout increased, PCB concentrations in these fish increased by a factor of 3.5, while the lipid content of their muscle increased by only a factor of 1.5. The results from this study indicate that while lipid was an important predictor, it did not account for all of the variability in organochlorine concentrations through the Lake Laberge food web, and that $\delta^{15}N$ is a better individual predictor of the more lipophilic organochlorines examined in this study.

Comparisons of organochlorine concentrations versus $\delta^{15}N$ in marine food webs have yielded different conclusions from this study. Broman et al. (1992) and Rolff et al. (1993) found that the toxic equivalents of PCDD/Fs increased exponentially with $\delta^{15}N$ in both a pelagic and a littoral food web of the Baltic Sea. However, total 2,3,7,8-substituted PCDD/Fs (pg.g^{-1} dry wt) decreased with increasing $\delta^{15}N$ through both types of food webs, possibly due to the biotransformation of PCDD/Fs at higher trophic levels (Norstrom et al., 1992). Similarly, Spies et al. (1989) found a negative correlation between $\delta^{15}N$ and ΣDDT and Aroclor 1254 (ng.g^{-1} liver ww) in one fish species that was collected from an area near a marine sewage outfall. The authors speculated that this negative relationship was found because some individuals fed upon an uncontaminated diet higher in $\delta^{15}N$, while others relied upon an isotopically-light sewage-based food source that was higher in its concentrations of ΣDDT and Aroclor 1254. In the latter study, $\delta^{15}N$ was used mainly as an indicator of food source and not as a measure of trophic status through the food web.

Lake whitefish from Laberge had a larger range of $\delta^{15}N$ (almost 4 ‰) than the other species analysed in this study. The $\delta^{15}N$ values within all other taxa from Laberge ranged over less than 2‰, which is consistent the range of $\delta^{15}N$ found for individuals fed the same diet (DeNiro and Schoeninger, 1983). Occasional piscivory has been observed in Lake Laberge lake whitefish (Chapter II) which may explain the greater range of $\delta^{15}N$ in this species and the larger calculated prey to predator enrichment of $\delta^{15}N$ for this species (5.2 ‰). Muscle

$\delta^{15}N$ in broad whitefish and longnose suckers were 1.8 and 2.0 ‰ higher respectively than the average $\delta^{15}N$ of their diet; this fractionation of ^{15}N was lower than typically expected between a predator and its diet, and indicates that these fishes fed mainly upon invertebrates lighter in ^{15}N than those analysed in this study. Also, broad whitefish are a migratory species and, as a result, may be feeding on isotopically-lighter invertebrates elsewhere in the Yukon River system. Differences between the short-term feeding habits of these fishes and their long-term average trophic position, as measured by $\delta^{15}N$, have been observed previously and may also explain this discrepancy (Chapter II).

Age and $\delta^{15}N$ in fishes will be correlated if an individual switches from an insectivorous to piscivorous diet. Although small sample sizes precluded examining this relationship in Lake Laberge, Rau et al. (1981) found a positive correlation between the weight of Dover sole and their $\delta^{15}N$ values which the authors attributed to an increase in trophic positioning of the fish with age. The age at which fish such as lake trout become piscivorous can vary significantly between lakes (Trippel and Beamish, 1993). It may be possible to distinguish these among-lake differences using measurements of $\delta^{15}N$ if one assumes that no changes in the metabolic fractionation of $\delta^{15}N$ occur over an organism's lifespan. Minagawa and Wada (1984) found no relationship between age and $\delta^{15}N$ of two species of marine mussels that maintain constant diets throughout their lifetime, indicating that the magnitude of $\delta^{15}N$ fractionation does not change as an organism ages.

However, a recent study suggests that physiological factors may need to be considered when using $\delta^{15}N$ to interpret an organism's trophic position. Hobson et al. (1993) found that nutritional stress in birds increases their tissue $\delta^{15}N$, possibly due to the internal recycling of proteins. If organisms do not feed over the winter months, their tissue may become isotopically enriched in ^{15}N. This may result in seasonal shifts in $\delta^{15}N$ that will confound the interpretation of stable isotope information if organisms are collected at different times of the year. It is possible that some of the variability found within species is due to factors other than trophic position and needs further consideration.

Furthermore, when examining the within-species variability of $\delta^{15}N$, it must also be considered that among-site differences in the nitrogen isotope signal at the base of the food web affects the $\delta^{15}N$ of the top predators. For example, fish from the East China Sea had lower $\delta^{15}N$ than fish from the Bering Sea, and this difference was correlated to lower $\delta^{15}N$ signals in the algae at the base of the former food web (Minagawa and Wada, 1984). Similarly, Kline et al. (1990) found that nitrogen from anadromous spawning salmon ($\delta^{15}N$ of 11.2 ‰) was recycled in an Alaskan stream food web and resulted in periphyton with $\delta^{15}N$ up to 7 ‰ higher than periphyton from upstream of the spawning site. This shift in $\delta^{15}N$ was also found in the invertebrate and fishes feeding in the ^{15}N-enriched section of the stream. Finally, fertilization of a section of an arctic river resulted in a - 9 ‰ shift in the $\delta^{15}N$ of filamentous green algae, which lowered the $\delta^{15}N$ at all levels of the food web (Peterson et al., 1993). For these reasons, it is important to characterize the basal $\delta^{15}N$ signals in a particular lake using either primary producers or consumers. With this information, the variability of $\delta^{15}N$ in top predators may be better understood and thus more widely applied in future contaminant studies.

In conclusion, the results of the present study indicated that organochlorine concentrations in freshwater biota were significantly related to their trophic position, as determined by $\delta^{15}N$. The slopes of these organochlorine-$\delta^{15}N$ regressions were significantly different, and indicated that ΣHCH did not biomagnify to the same extent as the more lipophilic compounds, ΣDDT and ΣCHB. Thus, it appears that the biomagnification potential of a compound may be represented by the slope of this relationship. $\delta^{15}N$ has significant potential for use in further studies on the biomagnification of organochlorines through aquatic food webs.

References

Barrie, L. A., D. J. Gregor, B. T. Hargrave, R. Lake, D. C. G. Muir, R. Shearer, B. Tracey and T. F. Bidleman (1992) Arctic contaminants: sources, occurrence and pathways. Sci. Total Environ. 122:1-74.

Bidleman, T. F., G. W. Patton, M. D. Walla, B. T. Hargrave, W. P. Vass, P. Erickson, B. Fowler, V. Scott and D. J. Gregor (1989) Toxaphene and other organochlorines in Arctic Ocean fauna: Evidence for atmospheric delivery. Arctic 42(4):307-313.

Borgmann, U. and D. M. Whittle (1991) Contaminant concentration trends in Lake Ontario lake trout (*Salvelinus namaycush*): 1977 to 1988. J. Great Lakes Res. 17(3):368-381.

Broman, D., C. Naf, C. Rolff, Y. Zebuhr, B. Fry and J. Hobbie (1992) Using ratios of stable nitrogen isotopes to estimate bioaccumulation and flux of polychlorinated dibenzo-p-dioxins (PCDDs and dibenzofurans (PCDFs) in two food chains from the northern Baltic. Environ. Toxicol. Chem. 11:331-345.

DeNiro, M. J. and M. J. Schoeninger (1983) Stable carbon and nitrogen isotope ratios of bone collagen: Variations within individuals, between sexes, and within populations raised on monotonous diets. J. Archaeol. Sci. 10(3):199-203.

DeVault, D. S., W. A. Willford, R. J. Hesselberg, D. A. Nortrupt, E. G. S. Rundberg, A. K. Alwan, and C. Bautista (1986) Contaminant trends in lake trout (*Salvelinus namaycush*) from the Upper Great Lakes. Arch. Environ. Contam. Toxicol. 15:349-356.

Evans, M. S., G. E. Noguchi and C. P. Rice (1991) The biomagnification of polychlorinated biphenyls, toxaphene and DDT compounds in a Lake Michigan offshore food web. Arch. Environ. Contam. Toxicol. 20:87-93.

Fry, B. (1991) Stable isotope diagrams of freshwater food webs. Ecology 72(6):2293-2297.

Gaebler, O. H., T. G. Vitti and T. Vumirovich (1966) Isotope effects in metabolism of ^{15}N and ^{14}N from unlabelled dietary proteins. J. Biochem. Phys. 44:1245-1257.

Hesslein, R. H., D. E. Fox and M. J. Capel (1989) Sulfur, carbon, and nitrogen isotopic composition of fish from the Mackenzie River delta region and other Arctic drainages. Can. Data Rep. Fish. Aquat. Sci. 728:iv + 11p.

Hesslein, R. H., M. J. Capel, D. E. Fox and K. A. Hallard 1991. Stable isotopes of sulfur, carbon, and nitrogen as indicators of trophic level in fish migration in the lower Mackenzie [illegible]sin, Canada. Can. J. Fish. Aquat. Sci. 48(11):2258-2265.

Hesslein, R.H., K. [illegible]rd and P. Ramlal (1993) Replacement of sulfur, carbon, and nitrogen in tissue of growing broad whitefish (*Coregonus nasus*) in response to a change in diet traced by δ^{34}S, δ^{13}C, and δ^{15}N. Can. J. Fish. Aquat. Sci. 50:2071-2076.

Hobson, K. A., R. T. Alisauskas and R. G. Clark (1993) Stable-nitrogen isotope enrichment in avian tissues due to fasting and nutritional stress: Implications for isotopic analyses of diet. The Condor 95:388-394.

Kidd, K. A., J. E. Eamer and D. C. G. Muir (1993) Spatial variability of chlorinated bornanes (toxaphene) in fishes from Yukon lakes. Chemosphere 27(10):1975-1986.

Kline, T. C., J. J. Goering, O. A. Mathisen and P. H. Poe (1990) Recycling of elements transported upstream by runs of Pacific salmon: I. δ^{15}N and δ^{13}C evidence in Sashin Creek, southeastern Alaska. Can. J. Fish. Aquat. Sci. 47:136-144.

Kling, G. W., B. Fry and W. J. O'Brien (1992) Stable isotopes and planktonic trophic structure in arctic lakes. Ecology 73(2):561-566.

Minagawa, M. and E. Wada (1984) Stepwise enrichment of ^{15}N along food chains: Further evidence and the relation between ^{15}N and animal age. Geochim. Cosmochim. Acta 48:1135-1140.

Muir, D. C. G., R. J. Norstrom and M. Simon (1988) Organochlorine contaminants in arctic marine food chains: Accumulation of specific polychlorinated biphenyls and chlordane-related compounds. Environ. Sci. Technol. 22:1071-1079.

Muir, D. C. G., C. A. Ford, N. P. Grift, D. A. Metner, and W. L. Lockhart (1990) Geographic variation of chlorinated hydrocarbons in burbot (*Lota lota*) from remote lakes and rivers in Canada. Arch. Environ. Contam. Toxicol. 19:530-542.

Muir, D. C. G., B. Rosenberg and C. A. Ford (1992a) Interim report on organochlorine contaminants in fish from Lake Laberge.

Muir, D. C. G., C. A. Ford, N. P. Grift, R. E. A. Stewart, and T. F. Bidleman (1992b) Organochlorine contamination in narwhal (*Monodon monoceros*) from the Canadian Arctic. Environ. Pollut. 75:306-316.

Norstrom, R. J. and H. J. Won (1985) Long term preservation of egg and tissue homogenates for determination of organochlorine compounds: freezing versus freeze-drying. J. Assoc. Offic. Anal. Chem. 68:130-135.

Norstrom, R. J. , D. C. G. Muir, C. A. Ford, M. Simon, C. R. Macdonald and P. Beland (1992) Indications of P450 monooxygenase activities in beluga (*Delphinapterus leucas*) and narwhal (*Monodon monoceros*). Mar. Environ. Res. 34:267-272.

Oliver, B. G. and A. J. Niimi (1988) Trophodynamic analysis of polychlorinated biphenyl congeners and other chlorinated hydrocarbons in the Lake Ontario ecosystem. Environ. Sci. Technol. 22:388-397.

Peterson, B. J. and B. Fry (1987) Stable isotopes in ecosystem studies. Ann. Rev. Ecol. Syst. 18:293-320.

Peterson, B. J., B. Fry and L. Deegan (1993) The trophic significance of epilithic algal production in a fertilized tundra river ecosystem. Limnol. Oceanogr. 38:872-878.

Rasmussen, J. B., D. J. Rowan, D. R. S. Lean and J. H. Carey (1990) Food chain structure in Ontario lakes determines PCB levels in lake trout (*Salvelinus namaycush*) and other pelagic fish. Can. J. Fish. Aquat. Sci. 2030-2038.

Rau, G. H., R. E. Sweeney, I. R. Kaplan, A. J. Mearns and D. R. Young (1981) Differences in animal C, N and D abundance between a polluted and an unpolluted coastal site: Likely indicators of sewage uptake by a marine food web. Est. Coast. Shelf Science 13:701-707.

Rolff, C., D. Broman, C. Naf and Y. Zebuhr (1993) Potential biomagnification of PCDD/Fs -New possibilities for quantitative assessment using stable isotope trophic position. Chemosphere 27(1-3):461-468.

SAS Institute, Inc. 1985. User's guide: Statistics. SAS Institute, Inc., Cary, North Carolina.

Scott, W. B. and E. J. Crossman 1973. Freshwater fishes of Canada. Bulletin 184. Fish Res. Board Can. Ottawa, 966 p.

Sharp, J. F. (1952) Adult mosquito control by airspray in Northern British Columbia and Yukon. Can. Ent. 84:281-289.

Spies, R. B., H. Kruger, R. Ireland and D. W. Rice (1989) Stable isotope ratios and contaminant concentrations in a sewage-distorted food web. Mar. Ecol. Prog. Ser.

54:157-170.

Steele, K.W. and R.M. Daniel (1978) Fractionation of nitrogen isotopes by animals: a further complication to the use of variations in the natural abundance of ^{15}N for tracer studies. J. Agric. Sci. 90:7-9.

Trippel, E. A. and F. W. H. Beamish (1993) Multiple trophic level structuring in Salvelinus - Coregonus assemblages in boreal forest lakes. Can. J. Fish. Aquat. Sci. 50:1442-1455.

Walker, C. E., J. E. Brown and R. F. Brown (1973) Rainbow trout planting and lake survey program in Yukon Territory 1956 - 1971. PAC/T-73-12. Pacific Region.

Zar, J. H. (1984) Biostatistical analysis. 2nd Edition. Prentice-Hall Inc., New Jersey. pp. 718.

Table III.1: Mean (± SE) length and weight of fishes, and % lipid (g.g^{-1} ww), ΣHCH, ΣDDT and chlorinated bornanes (toxaphene, ΣCHB) concentrations (ng.g^{-1} ww) in burbot liver, lake trout, lake and broad whitefish, cisco and longnose sucker muscle, and whole invertebrates from Lake Laberge, Yukon Territory.

	n	Length (mm)	Weight (g)	% Lipid (g.g^{-1} ww)	ΣHCH (ng.g^{-1} ww)	ΣDDT (ng.g^{-1} ww)	ΣCHB (ng.g^{-1} ww)
Burbot	5	650 ± 42	1998 ± 323	36.3 ± 4.5	30.2 ± 2.8	3430 ± 1130	2820 ± 660
Lake Trout	6	512 ± 21	1626 ± 243	7.5 ± 1.6[1]	4.3 ± 0.7	523 ± 303[1]	382 ± 163[1]
Lake Whitefish	6	375 ± 5	647 ± 64	2.8 ± 0.4	1.7 ± 0.2	73.0 ± 11.8	41.5 ± 8.5
Broad Whitefish	3	434 ± 28	900 ± 152	1.2 ± 0.2	0.6 ± 0.2	6.4 ± 1.6	4.8 ± 0.6
Least Cisco	3	185 ± 11	60 ± 8	6.5 ± 0.8	2.4 ± 0.2	32.7 ± 2.5	76.3 ± 6.5
Longnose Sucker	2	474	900	0.7	0.5	22.5	14.1
Trichopteran[2]	2	-	-	2.3	0.6	1.6	3.3
Chironomids	2	-	-	3.8	0.2	6.6	1.2
Lymnaeidae[2]	2	-	-	0.8	0.3	0.5	2.0
Zooplankton	1	-	-	5.3	2.6	9.3	28.2

[1] one lake trout excluded from mean due to unusually high concentrations ΣDDT - 3010, ΣCHB - 1440 ng.g^{-1} ww, % lipid - 13.1.

[2] shells and cases were removed prior to analyses.

Table III.2: Slopes and intercepts of the regressions between log ΣHCH, ΣDDT and ΣCHB ($ng.g^{-1}$) and $\delta^{15}N$ through the food web of Lake Laberge, Yukon Territory. Significant differences between slopes and intercepts are indicated by different superscripts.

	log Y ($ng.g^{-1}$)	Slope (± SE)	Intercept (± SE)	SE_{est}	r^2	P
wet weight	ΣHCH	0.16 ± 0.02^a	-1.00 ± 0.17	0.41	0.67	< 0.01
	ΣDDT	0.32 ± 0.03^b	-0.72 ± 0.24^a	0.47	0.81	< 0.01
	ΣCHB	0.29 ± 0.03^b	-0.57 ± 0.23^a	0.50	0.80	< 0.01
lipid weight	ΣHCH	0.05 ± 0.02	1.26 ± 0.13	0.29	0.27	< 0.05
	ΣDDT	0.20 ± 0.03	1.54 ± 0.23	0.42	0.65	< 0.01
	ΣCHB	0.18 ± 0.02	1.68 ± 0.18	0.38	0.70	< 0.01

Table III.3: Slopes and intercepts of the regressions between log ΣHCH, ΣDDT and ΣCHB (ng.g^{-1}) and log lipid through the food web of Lake Laberge, Yukon Territory.

	log Y (ng.g^{-1})	Slope (± SE)	Intercept (± SE)	r^2	*P*
wet weight	ΣHCH	1.1 ± 0.11	- 0.39 ± 0.089	0.76	< 0.01
	ΣDDT	1.66 ± 0.26	0.73 ± 0.21	0.57	< 0.01
	ΣCHB	1.68 ± 0.21	0.67 ± 0.17	0.68	< 0.01

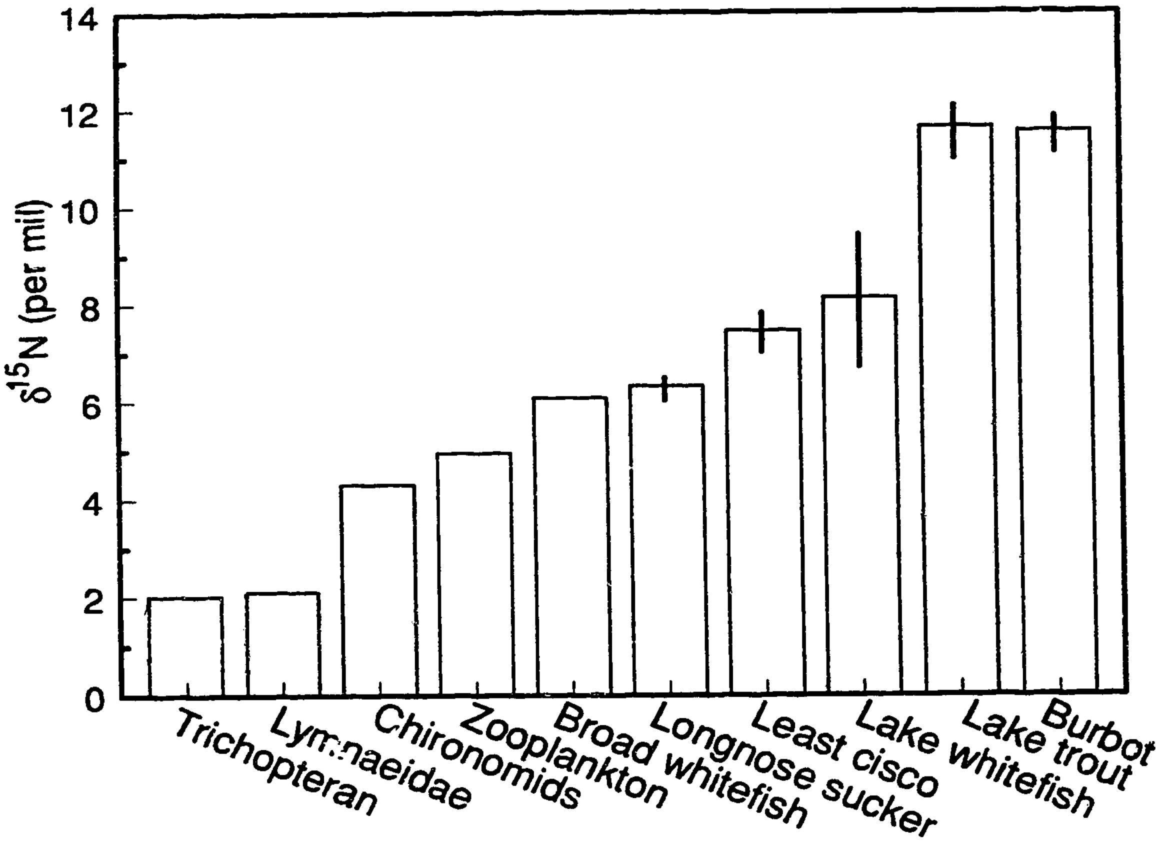

Figure III.1: Mean $\delta^{15}N$ (per mil, ± SD) of whole trichopterans, snails, (Family Lymnaeidae), chironomids and zooplankton, and broad whitefish, longnose sucker, lake whitefish, least cisco, lake trout, and burbot muscle from Lake Laberge, Yukon Territory (*n* given inTable III.1).

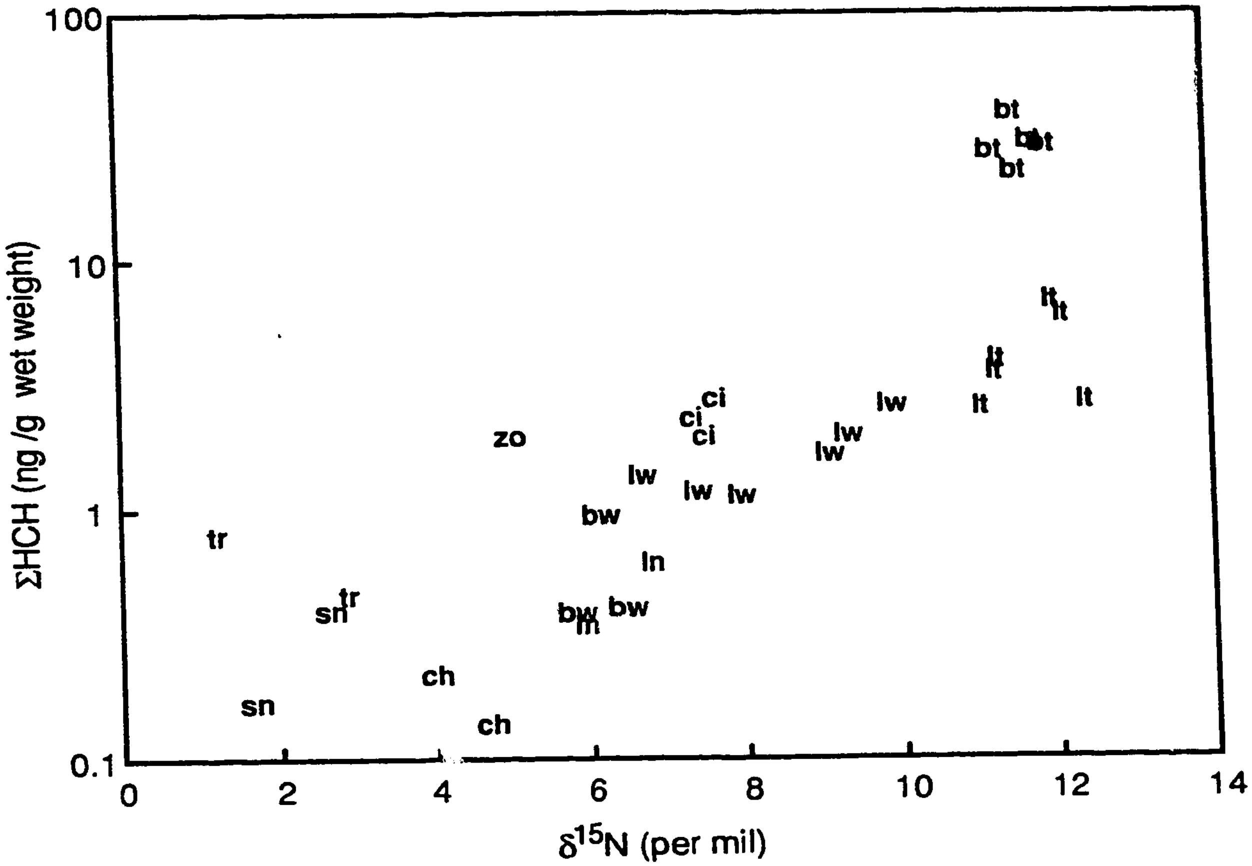

Figure III.2: Relationship between ΣHCH (ng/g wet weight) and $\delta^{15}N$ (per mil) for fishes and invertebrates from Lake Laberge, Yukon Territory (tr - trichopteran, sn - snail (Family Lymnaeidae), ch -chironomid, zo - zooplankton (whole body); bw - broad whitefish, lw - lake whitefish, ln - longnose sucker, ci - cisco and lt - lake trout (muscle); and bt - burbot ($\delta^{15}N$ in muscle, ΣHCH in liver).

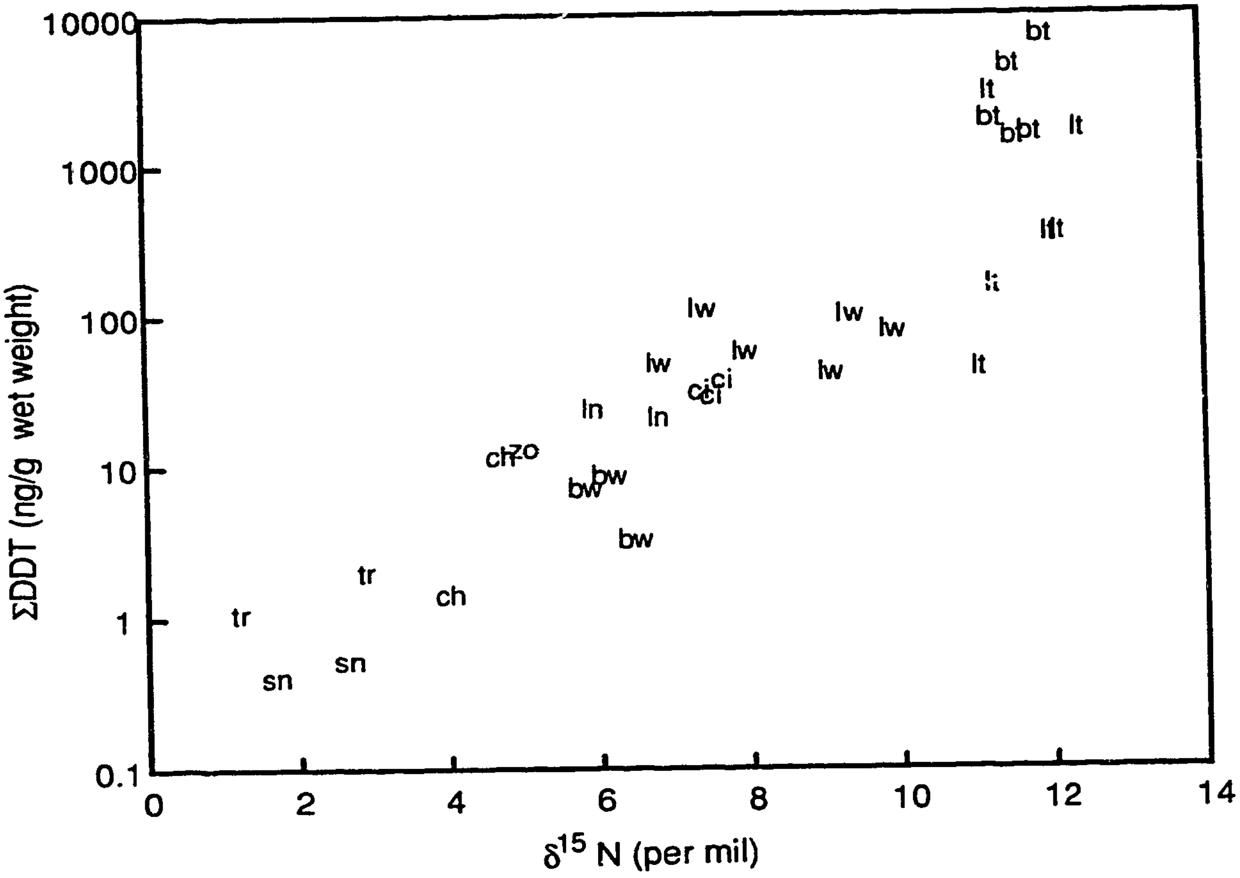

Figure III.3: Relationship between ΣDDT (ng/g wet weight) and $\delta^{15}N$ (per mil) for fishes and invertebrates from Lake Laberge, Yukon Territory (tr - trichopteran, sn - snail (Family Lymnaeidae), ch - chironomid, zo - zooplankton, (whole body); bw - broad whitefish, lw - lake whitefish, ln - longnose sucker, ci - cisco and lt - lake trout (muscle); and bt - burbot ($\delta^{15}N$ in muscle, ΣDDT in liver).

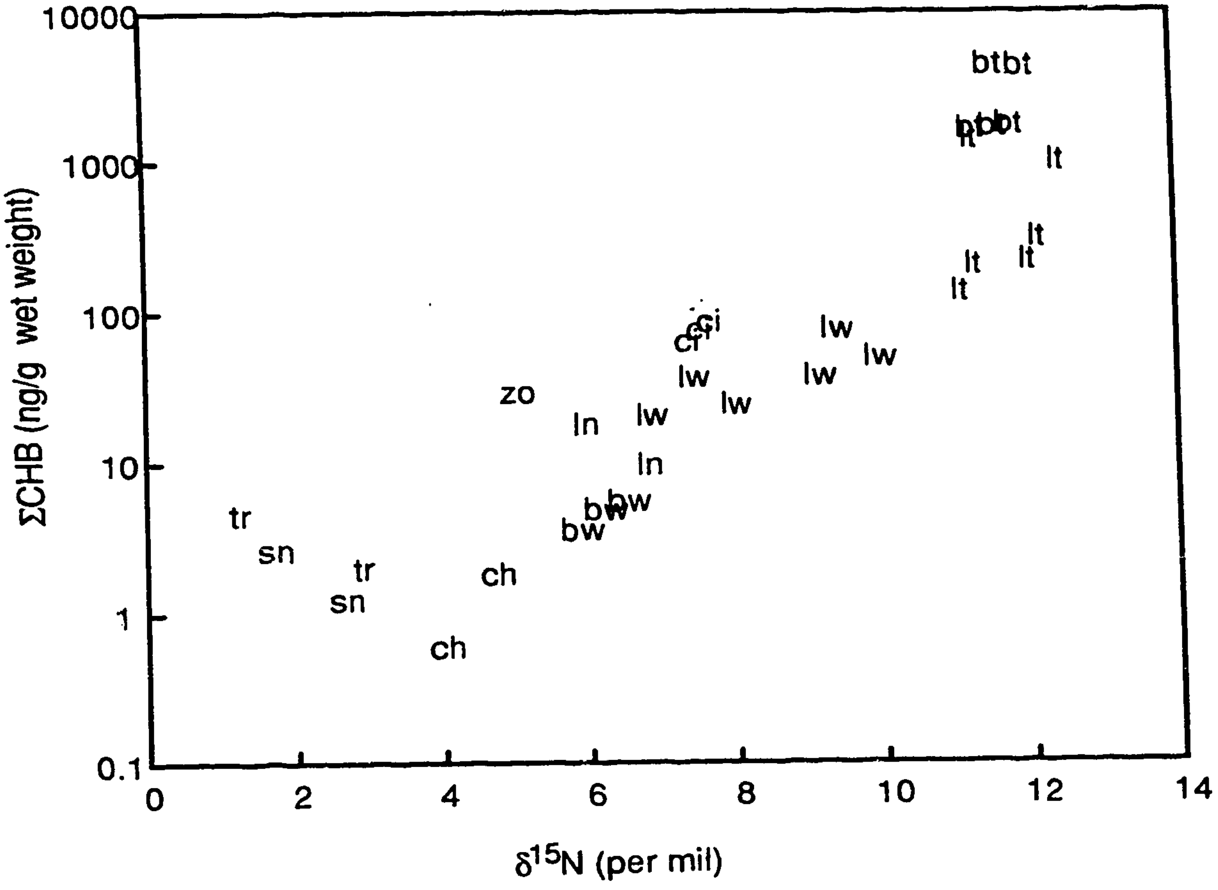

Figure III.4: Relationship between chlorinated bornanes (toxaphene, ΣCHB, ng/g wet weight) and $\delta^{15}N$ (per mil) for fishes and invertebrates from Lake Laberge, Yukon Territory (tr - trichopteran, sn -snail (Family Lymnaeidae, ch - chironomid, zo - zooplankton (whole body); bw - broad whitefish, lw - lake whitefish, ln - longnose sucker, ci - cisco and lt - lake trout (muscle); and bt - burbot ($\delta^{15}N$ in muscle, ΣCHB in liver).

IV. HIGH CONCENTRATIONS OF TOXAPHENE IN FISHES FROM A SUBARCTIC LAKE[5]

Introduction

Lake Laberge (61°11'N, 135°12'W) is located in southern Yukon Territory, Canada. Although the town of Whitehorse has grown along the Yukon River upstream of the lake, Laberge and its watershed are symbols of pristine wilderness for Canadians (Service, 1961).

In 1991, a routine survey of contaminants in fishes from Yukon lakes revealed that lake trout (*Salvelinus namaycush*) and burbot (*Lota lota*) from Lake Laberge were contaminated with toxaphene (mainly chlorinated bornanes in biota, CHB) and other lipophilic contaminants to values several-fold higher than the same species from other subarctic and arctic lakes and rivers (Muir et al., 1990; Kidd et al., 1993). As a result of the high CHB concentrations, fish consumption advisories were issued by Health Canada (MacDonald, 1991), and the commercial, sport, and native subsistence fisheries were closed.

Toxaphene was once used in North America as a piscicide to remove rough fish species, and as an agricultural pesticide (Saleh, 1991). Although Canada and the United States discontinued its use in the early 1980s, it is believed to be currently used in Mexico, parts of Asia, Africa, and South America (Voldner and Li, 1993) and is carried by long range atmospheric transport to subarctic and arctic regions (Barrie et al, 1992; Welch et al., 1991; Bidleman et al., 1989). As a result, elevated concentrations of CHB have been found in upper trophic-level biota from the Arctic (Lockhart et al., 1992) despite their distance from the original source.

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[5] A version of this chapter has been published. Kidd, Schindler, Muir, Lockhart, Hesslein 1995. Science 269:240-242. Data from sediment cores and water samples used in this chapter were kindly provided by D.C.G. Muir, W.L. Lockhart, M. Alaee and G. Stern.

One possible cause for the contamination of fishes in Laberge was surreptitious dumping. It is known that one lake in northern Yukon was treated with technical toxaphene in 1963 (Minister of Indian Affairs and Northern Development, 1993). Alternatively, the elevated levels could be attributed to biomagnification through the food chain because concentrations of persistent organochlorines increase from prey to predator (Oliver and Niimi, 1988; Evans et al., 1991), and are highest in fish from lakes with the longest food chains (Rasmussen et al., 1990). Significant biomagnification of lipophilic contaminants occurs at subarctic and arctic latitudes, where aquatic organisms must survive winters lasting several months (Schindler et al., 1995). Here, I examined food-chain organisms, water and sediments of Yukon lakes for CHB to distinguish between the "surreptitious dumping" and "food-chain length" hypotheses.

Traditional studies of contaminant biomagnification in lacustrine food webs have used discrete trophic classifications based on inferred feeding behaviour or stomach content analyses (Swackhamer and Hites, 1988; Evans et al., 1991; Rasmussen et al., 1990; Oliver and Niimi, 1988). However, interpretation is complicated for species such as lake trout which may be piscivorous, omnivorous, or insectivorous in different lakes, feeding on varying combinations of terrestrial and benthic insects, other fish or plankton (Scott and Crossman, 1973; Nelson and Paetz, 1992; Trippel and Beamish, 1993).

Stable nitrogen isotope ratios ($\delta^{15}N$) have been used as an index of trophic level for freshwater organisms (Peterson and Fry, 1987; Hesslein et al., 1991; Estep and Vigg, 1985; Kidd et al., 1995; Minagawa and Wada, 1984; Cabana and Rasmussen, 1994). $\delta^{15}N$ increases an average of 3 to 5 per mil (*‰*) from prey to predator (Peterson and Fry, 1987). Stable nitrogen values in fish represent the integral of several months of feeding, thereby providing a continuous measure of trophic position (Hesslein et al., 1993). Recently, Cabana and Rasmussen (1994) demonstrated that $\delta^{15}N$ in lake trout muscle is correlated with food-chain length across a large number of lakes. We hypothesized that $\delta^{15}N$ would be directly correlated with contaminant concentrations in individuals varying in trophic position.

Methods

Water Samples

Epilimnetic water samples (89 to 95 L) were collected from Atlin (60°00'N, 133°50'W), Tagish (60°10'N, 134°20'W), Marsh (60°25'N, 134°18'W), Laberge, Fox and Kusawa lakes in February, 1994. Unfiltered water samples were extracted using a Goulden continuous extractor (Foster and Rogerson, 1990; Goulden and Anthony, 1985). Both water and sediment extracts were analysed using high resolution electron-capture negative ion MS using the conditions given in Miskimmin et al. (1995). The instrumental detection limit for total CHB was < 50 pg.uL^{-1} with a mass spectrometric resolution of 15000.

Sediment cores were collected from Laberge, Fox and Kusawa lakes in March of 1992 and 1993 using a KB corer. Cores were sliced at 1-cm increments and kept at 0 to -10 °C both before and after they were freeze-dried. Sediment slices were extracted using the methods given in Muir et al. (1995). Excess ^{210}Pb profiles were log-linear and used to calculate the median age of each slice. Integrals of excess ^{210}Pb ranged between 0.189 and 0.259 Bq cm^{-2} for all three lakes, indicating little among-lake difference in sediment focusing.

Focusing factors were calculated using latitude-specific atmospheric fluxes of ^{210}Pb. Sedimentation rates (g m^{-2} yr^{-1}) were calculated using both a simple linear model (assumes constant ^{210}Pb flux and constant dry-mass sedimentation rate) and Robbins rapid steady-state mixing model [assumes constant ^{210}Pb flux and accumulation rate, and a rapid steady-state mixing only throughout a surface zone of fixed thickness (Robbins, 1978)]. The Robbins model values were used to calculate fluxes of CHB, however, both models calculated comparable sedimentation rates (within ± 10%). Fluxes were calculated as ΣCHB concentration (ng.g^{-1} dry weight) × sedimentation rate ÷ focusing factor.

Biota

Fish and invertebrates were obtained from these three lakes by netting or dredging in June to August of 1992 and 1993. Samples were frozen shortly after collection and kept at a maximum of -10°C until analysed for CHB and $\delta^{15}N$ using the methods given in Chapter III.

Statistical Analyses

Relationships between ΣCHB and $\delta^{15}N$ were examined within lakes using the general linear models procedure of Statistical Analysis Systems (1985). Analysis of covariance (ANCOVA) was conducted to determine if slopes of the regressions were significantly different by examining the Type III significance of the interaction term (lake*$\delta^{15}N$). The *F* and Tukey tests as outlined in Zar (1984) were used to test for significant differences among intercepts. Tukey multiple comparison (lake trout and lake whitefish) and Student's *t* tests (burbot) were also used to test for significant differences among mean $\delta^{15}N$ of the fishes.

Results and Discussion

Large volume water samples from six lakes on the Yukon River system and ^{210}Pb-dated sediment core slices from Laberge, Fox, and Kusawa lakes were used as surrogate measures for CHB inputs from atmospheric or point sources. Total CHB in Laberge water (23 pg.L^{-1}) was within the range found for five other lakes in southern Yukon (12 - 27 pg.L^{-1}). Surface and maximum fluxes of CHB in the sediment cores were comparable in all three lakes, similar to those found in other arctic cores, and orders of magnitude lower than was found in temperate lakes previously treated with toxaphene (Table IV.1). I thus dismissed the hypothesis that Laberge received elevated inputs of toxaphene from point sources.

Concentrations of ΣCHB in biota were significantly related to their trophic position, as established by $\delta^{15}N$ (Figure IV.1). Further, the slopes of ΣCHB versus $\delta^{15}N$ in the three lakes were not significantly different (both with and without burbot liver data), indicating a broad regional similarity in the biomagnification of this contaminant through the food chain. The least-square regression equations of log CHB (ng.g^{-1} wet weight) versus $\delta^{15}N$ (‰) are shown in Table IV.2. There were no significant differences among the regression intercepts ($P < 0.05$) which further supports the sediment and water data of comparable inputs of CHB to these lakes.

Lake trout, burbot and lake whitefish (*Coregonus clupeaformis*) from Laberge were significantly higher in $\delta^{15}N$ than the same species from other Yukon lakes, indicating that they feed at a higher trophic level (Figure IV.2). This observation is consistent with summer stomach analyses of fishes from the three lakes, which revealed that Laberge lake trout, burbot, and occasionally lake whitefish are piscivorous, while those of other nearby lakes fed upon invertebrates and fishes (Chapter II). Because of their higher trophic position, fishes from Laberge accumulated more CHB than the same species from surrounding lakes (see Figure IV.1).

Taken together, the contaminant-$\delta^{15}N$ relations for biota, and contaminant concentrations in water and sediments indicate that a longer-than-normal food chain is the sole reason for the elevated CHB concentrations in fishes from Lake Laberge. I speculate that this difference in food-chain length may be due to sustained heavy fishing pressure on Lake Laberge (see Chapter V).

Fish form a critical food base for many populations of aboriginal North Americans (Lockhart et al., 1992; Kinloch et al., 1992; Wein et al., 1991). Screening the fisheries of northern lakes for organic contaminants would be an expensive and time-consuming undertaking. Our results suggest that highest contaminant levels are found in fishes from lakes with exceptionally long food chains, and that $\delta^{15}N$ might be useful as an initial screening mechanism to identify such lakes.

References

Barrie, L. A., D. J. Gregor, B. T. Hargrave, R. Lake, D. C. G. Muir, R. Shearer, B. Tracey and T. F. Bidleman (1992) Arctic contaminants: sources, occurrence and pathways. Sci. Total Environ. 122:1-74.

Bidleman, T. F., G. W. Patton, M. D. Walla, B. T. Hargrave, W. P. Vass, P. Erickson, B. Fowler, V. Scott and D. J. Gregor (1989) Toxaphene and other organochlorines in Arctic Ocean fauna: Evidence for atmospheric delivery. Arctic 42(4):307-313.

Cabana, G. and J.B. Rasmussen (1994) Modelling food chain structure and contaminant bioaccumulation using stable nitrogen isotopes. Nature 372(17):255-257.

Estep, M.L.F. and S. Vigg (1985) Stable carbon and nitrogen isotope tracers of trophic dynamics in natural populations and fisheries of the Lahontan Lake System, Nevada. Can. J. Fish. Aquat. Sci. 42:1712-1719.

Evans, M. S., G. E. Noguchi and C. P. Rice (1991) The biomagnification of polychlorinated biphenyls, toxaphene and DDT compounds in a Lake Michigan offshore food web. Arch. Environ. Contam. Toxicol. 20:87-93.

Foster, G.D. and P.F. Rogerson (1990) Enhanced preconcentration of pesticides from water using the Goulden large-sample extractor. Intern. J. Environ. Anal. Chem. 41:105-117.

Goulden, P. and D.J.H. Anthony (1985) Design of a large sample extractor for the determination of organics in water. NWRI Contribution No. 85-121 Analytical Methods Division, National Water Research Institute, Burlington, Ontario, 12 p.

Hesslein, R.H., M.J. Capel, D.E. Fox and K.A. Hallard (1991) Stable isotopes of sulfur, carbon, and nitrogen as indicators of trophic level and fish migration in the lower Mackenzie River basin, Canada 48(11):2258-2265.

Hesslein, R.H., K.A. Hallard and P. Ramlal (1993) Replacement of sulfur, carbon, and nitrogen in tissue of growing broad whitefish (*Coregonus nasus*) in response to a change in diet traced by δ^{34}S, δ^{13}C, and δ^{15}N. Can. J. Fish. Aquat. Sci. 50:2071-2076.

Kidd, K.A., J.E. Eamer and D.C.G. Muir (1993) Spatial variability of chlorinated bornanes (toxaphene) in fishes from Yukon lakes. Chemosphere 27(10):1975-1986.

Kinloch, D., Kuhnlein, H. and D.C.G. Muir (1992) Inuit foods and diet: a preliminary assessment of benefits and risks. Sci. Total Environ. 122:247-278.

Lockhart, W.L., R. Wagemann, B. Tracey, D. Sutherland and D. J. Thomas (1992) Presence and implications of chemical contaminants in the freshwaters of the Canadian Arctic. Sci. Total Environ. 122:165-243.

MacDonald, S. (1991) Yukon Government News Release, #093, May 8.

Minagawa, M. and E. Wada (1984) Stepwise enrichment of ^{15}N along food chains: Further evidence and the relation between δ^{15}N and animal age. Geochim. Cosmochim. Acta 48:1135-1140.

Minister of Indian Affairs and Northern Development (1993) Use, Disposal and Transportation of Selected Contaminants in Yukon, Ottawa, Canada, 50 p.

Miskimmin, B.M. and D. W. Schindler (1994) Long-term invertebrate community response to toxaphene treatment in two lakes:50-yr records reconstructed from lake sediments. Can. J. Fish. Aquat. Sci. 51:923-932

Miskimmin, B.M., D.C.G. Muir, D.W. Schindler, G.A. Stern and N.P. Grift (1995) Chlorobornanes in sediments and fish thirty years after toxaphene treatment of lakes. Environ. Sci. Technol. 29:2490-2495.

Muir, D.C.G., C.A. Ford, N.P. Grift, D.A. Metner and W.L. Lockhart (1990) Geographical variation of chlorinated hydrocarbons in burbot (*Lota lota*) from remote lakes and rivers in Canada. Arch. Environ. Contam. Toxciol. 19:530-542.

Muir, D.C.G., N.P. Grift, W.L. Lockhart, P. Wilkinson, B.N. Billeck and G.J. Brunskill (1995) Spatial trends and historical profiles of organochlorine pesticides in arctic lake sediments. Sci. Total Environ. 160/161:447-457.

Nelson, J.S. and M. J. Paetz (1992) *The Fishes of Alberta*, University of Alberta Press, Edmonton, 437 pp.

Oliver, B.G. and A.J. Niimi (1988) Trophodynamic analysis of polychlorinated biphenyl congeners and other chlorinated hydrocarbons in the Lake Ontario ecosystem. Environ. Sci. Technol. 22:388-397.

Peterson, B.J. and B. Fry (1987) Stable isotopes in ecosystem studies. Ann. Rev. Ecol. Syst. 18:293-320.

Rasmussen, J.B., D.J. Rowan, D.R.S. Lean and J.H. Carey (1990) Food chain structure in Ontario lakes determines PCB levels in lake trout (Salvelinus namaycush) and other pelagic fish. Can. J. Fish. Aquat. Sci. 47:2030-2038.

Robbins, J.A. (1978) Geochemical and geophysical applications of radioactive lead. In: Biogeochemistry of Lead in the Environment, Part A, J. O. Nriagu (ed.) Elsevier, Amsterdam, pp. 285-293.

Saleh, M.A. (1991) Toxaphene: Chemistry, biochemistry, toxicity and environmental fate. Rev. Environ. Contam. Toxicol. 118:1-85.

SAS Institute, Inc. (1985) User's guide: Statistics. SAS Institute, Inc., Cary, North Carolina.

Schindler, D.W., K.A. Kidd, D.C.G. Muir and W.L. Lockhart (1995) The effects of ecosystem characteristics on contaminant distribution in northern freshwater lakes. *Sci. Total Environ.* 160/161:1-17.

Scott, W.B. and E.J. Crossman (1973) Freshwater Fishes of Canada. Bulletin 184. Fisheries Research Board of Canada, Ottawa, Ontario. pp.

Service, R. (1961) Collected Poems of Robert Service, Dodd Mead, New York, pp. 33-36.

Swackhamer, D. and R.A. Hites (1988) Occurrence and bioaccumulation of organochlorine compounds in fishes from Siskiwit Lake, Isle Royale, Lake Superior. Environ. Sci. Technol. 22:543-548.

Trippel, E.A. and F.W.H. Beamish (1993) Multiple trophic level structuring in Salvelinus-Coregonus assemblages in boreal forest lakes. Can J. Fish. Aquat. Sci. 50:1442-1455.

Voldner, E.C. and Y.F. Li (1993) Global usage of toxaphene. Chemosphere 27(10):2073-2078.

Welch, H.E. D.C.G. Muir, B.N. Billeck, W.L. Lockhart, G.J. Brunskill, H.J. Kling, M.P. Olson and R.M. Lemoine (1991) Brown snow: A long-range transport event in the

Canadian Arctic. Environ. Sci. Technol. 25(2):280-286.

Wein, E.E., Henderson-Sabry, J. and F.T. Evers (1991) Food consumption patterns and use of country foods by Native Canadians near Wood Buffalo Park, Canada. Arctic 44(3):196.

Zar, J.H. (1984) Biostatistical analysis. 2nd Edition. Prentice-Hall Inc., New Jersey. pp. 718.

Table IV.1: Surface and maximum fluxes of ΣCHB (ng m^{-2} yr^{-1}), and the median dates of slices in sediment cores from lakes in Yukon Territory (YT; this study), and Northwest Territories (NWT; Muir et al., 1995), and two lakes treated with toxaphene in Alberta (AB; Miskimmin et al., 1994; Miskimmin et al., 1995). Peanut and Chatwin fluxes were not corrected for sediment focusing, and mean dates of these slices are given.

	Surface		Maximum	
Lake	Flux	Date	Flux	Date
Laberge-2, YT (61°11'N 135°12'W)	180	1991	270	1978
Laberge-3, YT	32	1991	340	1973
Fox, YT (61°14'N 135°28'W)	180	1992	260	1983
Kusawa, YT (60°20'N 136°22'W)	24	1989	140	1974
Far, NWT (63°42'N 90°40'W)	310	1986	-	-
Hawk, NWT (63°38'N 90°42'W)	500	1985	-	-
Amituk, NWT (75°03'N 93°48'W)	140	1980	-	-
Hazen, NWT (81°45'N 71°30'W)	120	1986	-	-
Peanut, AB (54°01'N 114°21'W)	2.3×10^4	1985	1.0×10^5	1962
Chatwin, AB (54°15'N 110°51'W)	1.7×10^4	1990	5.1×10^5	1962

Table IV.2: Coefficients and intercepts (± SE) from regression analyses of log-transformed ΣCHB versus $\delta^{15}N$ for Laberge, Fox and Kusawa lakes, Yukon Territory.

Lake	Slope	Intercept	Se[illegible]	r^2	*n*	*P*
Laberge	0.23±0.03	-0.33±0.23	0.56	0.62	43	<0.01
Fox	0.19±0.08	-0.70±0.63	0.60	0.25	18	0.03
Kusawa	0.25±0.04	-0.59±0.31	0.39	0.69	23	<0.01

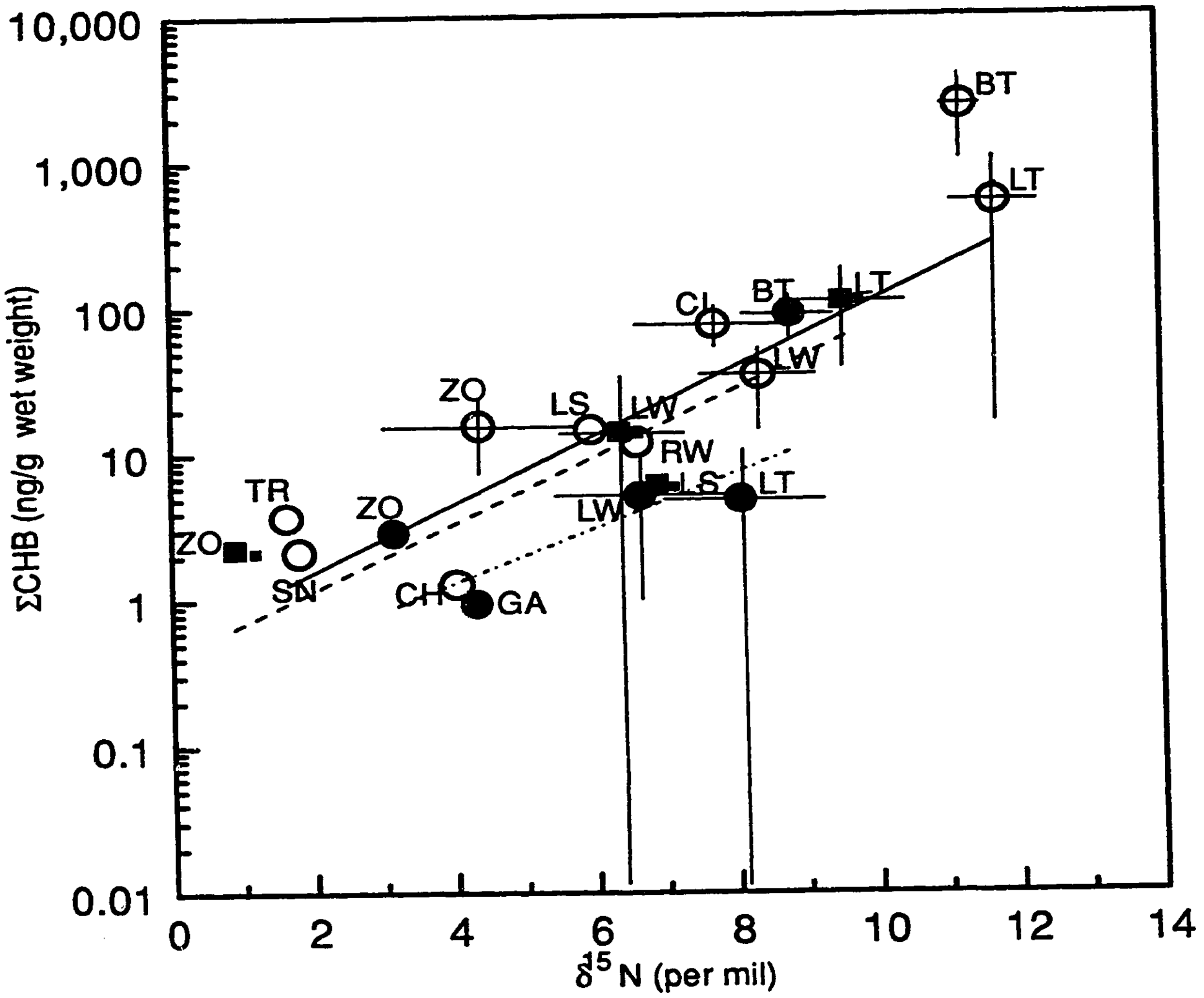

Figure IV.1: ΣCHB (ng/g wet weight) versus δ15 N (per mil; shown here as mean ± SD, *n* = 1 to 14) for whole invertebrates and fish muscle (burbot liver used for CHB analyses) from Laberge(open circles, solid line), Fox (solid circles, dash-dot line), and Kusawa (squares, dashed line) lakes, Yukon Territory. Organisms are identified as follows: LT - lake trout, BT - burbot, LW - lake whitefish, RW - round whitefish, CI - least cisco, LS - longnose sucker, ZO - zooplankton, GA - *Gammarus*, CH - chironomids (Subfamilies Tanypodinae, Prodiamesinae, and Chironominae), SN - snail (Family Lymnaeidae), and TR - trichopteran (Family Limnephilidae and Limnephilinae).

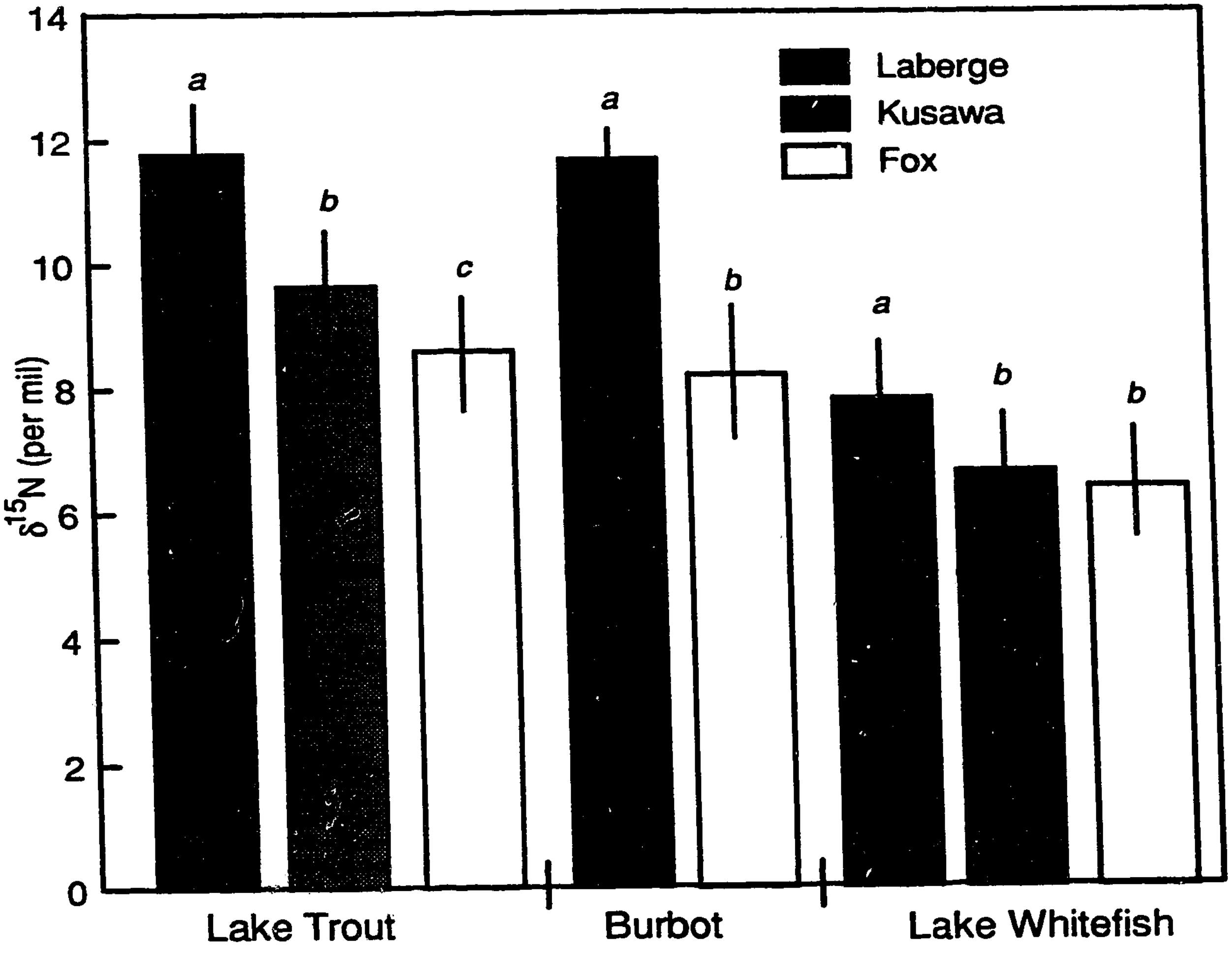

Figure IV.2: Mean δ^{15}N (per mil ± SD, $n = 5$ to 14) for lake trout, burbot and lake whitefish muscle from Laberge, Fox and Kusawa lakes, Yukon Territory. Within species, bars with the same letter were not significantly different ($P < 0.05$).

V. EFFECTS OF TROPHIC POSITION, AS DETERMINED BY STABLE NITROGEN ISOTOPE RATIOS ($\delta^{15}N$), LIPID, SIZE AND AGE ON ORGANOCHLORINE CONCENTRATIONS IN FISHES FROM SUBARCTIC LAKES.

Introduction

Despite production bans or severe restrictions on their use in North America over the past two decades, organochlorines such as toxaphene, PCBs, DDT, chlordane, chlorobenzenes and hexachlorocyclohexane continue to be found in subarctic and arctic regions of Canada. These compounds volatilize from sites of past application and move via long range atmospheric transport from warmer to colder climates (Simonich and Hites, 1995) through the process of global distillation (Mackay and Wania, 1995). Organochlorines are carried in air masses and precipitation (Barrie et al., 1992), and are deposited in remote subarctic and arctic lakes as evidenced by sediment core analyses (Muir et al., 1995). Their recalcitrant and lipophilic nature enables these contaminants to bioaccumulate up through food chains to reach levels in fish that occasionally exceed those considered safe for human consumption (Chapter IV).

Considerable research has examined those factors underlying the individual, temporal and spatial variability of organochlorine concentrations in fishes from temperate lakes (e.g. Rasmussen et al., 1990; Swackhamer and Hites, 1988; Johnson et al., 1988; DeVault et al., 1986; Madenjian et al., 1994). Although abiotic factors such as organochlorine loadings (Johnson et al., 1988), dissolved organic carbon content and trophic status (Larsson et al., 1992; McCarthy and Bartell, 1988) of lakes have been examined, the primary focus has been on fishes and the effects of such factors as life history traits (Hebert and Haffner, 1991), organochlorine absorption and excretion rates (Sijm et al., 1992), body size (Muir and Lockhart, 1995; Rasmussen et al., 1990; Swackhamer and Hites, 1988; Borgmann and Whittle, 1983), growth rates (Hammar et al., 1993; Larsson et al., 1992), sex and reproduction (Larsson et al., 1993), and age (Thomann and Connolly, 1984) on individual and population contaminant burdens.

Few studies have examined the importance of intraspecific factors on organochlorine accumulation in fishes from subarctic and arctic lakes. As in temperate lakes, results from studies on northern lakes indicated that the concentrations of organochlorines in fish were significantly predicted by their lipid content, age and size (Kidd et al., 1993; Muir et al., 1990). The colder temperatures in northern regions can result in slower growth and maturation rates, and longer lifespans of fishes (Healey, 1978). These factors may increase fishes' contaminant burdens by decreasing "biomass dilution" (Hammar et al., 1993) and loss through reproduction (Larsson et al., 1993). For these reasons, fishes from subarctic and arctic lakes may accumulate higher concentrations of organochlorines than the same species from temperate lakes.

Organochlorines accumulate in proportion to the lipid content of organisms (e.g. Oliver and Niimi, 1988; Chapter III). Their accumulation in fish has been ascribed to a simple equilibrium partitioning between water and fish lipid which is directly correlated to the compound's lipophilicity or octanol/water partition coefficient (K_{ow}, Mackay, 1982). However, concentrations of contaminants in fish from field studies exceed levels predicted by this relationship, particularly for fishes occupying upper-trophic-level positions and for those compounds with higher K_{ow} (Oliver and Niimi, 1988; Connolly and Pederson, 1988; Swackhamer and Hites, 1988; Thomann and Connolly, 1984). The importance of food chain structure in determining concentrations of organochlorines in top predators was unequivocally demonstrated in a study by Rasmussen et al. (1990). They used a lake classification system based on the presence/absence of prey species to demonstrate that the concentrations of PCBs in lake trout, the top predator, were directly proportional to the length of the underlying food web, and not simply a function of fish lipid content.

Difficulties in determining an individual's trophic position have often precluded our ability to quantify and qualify the effects of food web structure on fish contaminant concentrations. The trophic positions of fishes have often been estimated based on their observed feeding habits in other systems or from different years (Rasmussen et al., 1990; Oliver and Niimi, 1988; Muir et al., 1990) despite the fact that fish diets often vary between individuals, seasons and sites (e.g. Trippel and Beamish, 1993; Scott and Crossman, 1973). Traditional methods using stomach content analyses to determine the discrete trophic positions of fishes are being supplemented with stable nitrogen isotope ($\delta^{15}N$) analyses. The heavier isotope (^{15}N) increases 3 to 5 parts per thousand from prey to predator (Peterson and Fry, 1987), making it useful as a continuous measure of trophic positioning. Though $\delta^{15}N$ is not a unique method for examining food web relationships, it has only recently been used to interpret contaminant accumulation through freshwater and marine food webs (Broman et al., 1992; Spies et al., 1989; Cabana and Rasmussen, 1994; Chapter III and IV; Kidd et al., 1995a).

In this study I used $\delta^{15}N$ as an indicator of trophic positioning, along with lipid, size and age to examine which factors determine the concentrations of contaminants in several species of fishes. The top predators from these lakes vary significantly in food web positioning (Chapter IV) thereby providing the opportunity to determine the relative importance of lipid and trophic level on concentrations of organochlorines in fishes.

Methods

Methods for fish capture and sampling are detailed in Chapter II. Fishes were collected under ice in the spring of 1992, and over the summer season in Laberge, Fox and Kusawa lakes in 1992 and 1993. Fishes were also obtained from index netting programs conducted in 1993 on Laberge and Kusawa lakes by the Renewable Resources Division of the Yukon Territorial Government, Whitehorse, Yukon Territory (Sparling and Connor, 1996; Thompson, 1996a). Weight, length, sex and age of each fish was determined. Age was not determined for longnose sucker. Fishes were either kept whole or sampled for dorsal muscle on site. All samples were kept on ice and frozen a few hours after their collection. Least cisco from Laberge were analysed because they were a major food item for lake trout, burbot and northern pike (Chapter II). Longnose sucker and least cisco were not present in Fox Lake, and northern pike and burbot were not netted in Kusawa.

Skinless dorsal muscle tissue from individual fishes was dried in an oven at 60°C and ground to a fine powder. Stable isotope analyses were conducted as outlined in Chapter II. All samples were standardized against N_2 in air as follows:

$$\delta N‰ = [(R_{sample}/R_{standard})-1]\times 1000$$

where $R = {}^{15}N/{}^{14}N$. Precision of these instruments for nitrogen isotope analysis over several years of use has been 0.4 ‰ (2 SD).

Whenever possible, a range of fish sizes and an approximately equal number of males and females were chosen for the organochlorine analyses detailed in Chapter III. Fish muscle and whole fish (round whitefish and least cisco) were homogenized with dry ice. For Lake Laberge only, round whitefish were analysed as composite samples of 4 to 6 individuals grouped by weight and location. Internal standards of aldrin (or PCB30) and octachloronaphthalene were added to the samples prior to extraction. Burbot liver tissues were ball-milled with hexane whereas muscle and whole-body samples were Soxhlet-extracted with equal volumes of dichloromethane (DCM) and hexane. Lipids were determined gravimetrically with 1/10th of the extract. After removing the remaining lipids, the extract was separated on Florisil into three fractions: hexane (F1), hexane:DCM (85:15)(F2), and hexane:DCM (1:1)(F3). F1 contained all PCBs, and chlorobenzenes; F2 contained most hexachlorocyclohexane, chlorobornane, chlordane and DDT congeners, F3 contained dieldrin (these data were not presented herein). All fractions were analysed for organochlorines using a Varian 6000 or 3600 with a ^{63}Ni-electron capture detector (GC-ECD) and a 60 m by 0.25 mm i.d. DB-5 column with H_2 carrier gas, and the conditions given in Chapter III.

Results were examined for six major contaminant groups that represented a range of lipophilicities. Hexachlorocyclohexane (ΣHCH) was quantified as the sum of αHCH, βHCH, and γHCH with log K_{ow}'s of 3.7 to 3.8 (de Bruijn et al., 1989). The chlorobenzenes (ΣCBZ) detected in these fishes included 1,2,3,4-tetrachlorobenzene, 1,2,4,5-tetrachlorobenzene, hexachlorobenzene and pentachlorobenzene which have log K_{ow}'s from 4.5 to 5.5 (Mackay et al., 1992). Chlordane (ΣCHL) was quantified as the sum of trans-chlordane, cis-chlordane, oxychlordane, heptachlor epoxide, trans-nonachlor, cis-nonachlor, C, C1A, C1B, C2, C3, U1 and U3 which have an average log K_{ow} of 5.54 (Howard, 1991). ΣDDT congeners included p,p'- and o,p'-DDT, p,p'- and o,p'-DDE, p,p'- and o,p'-DDD which have log K_{ow}'s from 6.2 to 6.9 (for p,p'-DDD, DDE and DDT, de Bruijn et al., 1989). Total PCBs (ΣPCB) were quantified as the sum of all detected congeners, and consisted mainly of penta-, hexa- and heptachlorinated PCBs that range in log K_{ow} from 6.2 to 7.0 (Mackay et al., 1992). Chlorinated bornanes (toxaphene; ΣCHB) were quantified using a single response factor based on the areas of 20 peaks in the standard (Muir et al., 1992). Although CHBs in environmental samples can differ considerably in their patterns of CHBs when compared to technical toxaphene (Stern et al., 1992; Miskimmin et al., 1995), the octanol-water partition coefficients for the environmentally-relevant individual congeners have not yet been determined. For the general comparative purposes of this study, the log K_{ow} of technical toxaphene (6.44) was used (Saleh, 1991). In general, the lipophilicity of the major contaminant groups in this study are as follows: ΣDDT ≈ ΣPCB ≈ ΣCHB > ΣCHL > ΣCBZ > ΣHCH.

Organochlorine data were log-transformed because means were proportional to standard deviations, and transformation reduced the skewness of the data. The Statistical Analysis Systems (SAS, 1985) general linear models (GLM) procedure, and Duncan's Multiple Range or Student's *t* tests were used to determine if significant among-lake differences existed in organochlorine concentrations, weight, length, age, % lipid or $\delta^{15}N$ for each species.

For each species, simple and multiple least squares linear regression analyses were conducted using GLM to examine which variable or combination of variables (lipid, length, weight, $\delta^{15}N$ or age) significantly predicted the concentrations of ΣHCH, ΣCBZ, ΣCHL, ΣDDT, ΣPCB, ΣCHB across all lakes. Weight, length or age were log transformed if transformation reduced the skewness of the data within each species. Percent lipid was not arcsin transformed, as is suggested for percentages or proportions, because this transformation did not improve the distribution of the data. Plots of the residuals were examined for each model to ensure that they were randomly distributed. Multicollinearity of the independent variables was examined using Pearson correlation coefficients (Appendix D). Variables that were highly correlated, such as length and weight, were not included in the same regression analyses. In the multiple regression analyses, variables were retained in the model if they explained a significant proportion of the variability over and above the variability explained by other variables in the model. Multi-variable models with the largest coefficients of determination were considered to be the best predictors of fish organochlorine concentrations. Within species, analysis of covariance (ANCOVA) was used to determine if the slopes of the simple regression relationships were significantly different among groups of organochlorines. If significant differences were found, Tukey tests were conducted to examine specific differences in slopes using the mean square error of the pooled regression equation. When no significant differences among slopes were found, Tukey tests were conducted using a common slope and the mean square error from the common regression equation was used to examine significant differences among intercepts.

Results

There were no significant effects of sex on each species' concentration of ΣPCB, ΣDDT, ΣCHB and ΣCBZ within any of the lakes. However, ΣCHL in female burbot liver (23.2 ± 7.92 ng.g^{-1} ww, $n = 6$) from Fox was significantly higher than in males (15.9 ± 6.19 ng.g^{-1} ww, $n = 8$; $F_{1,12} = 5.42$, $P = 0.038$). ΣHCH was significantly higher in female northern pike (0.12 ± 0.04 ng.g^{-1} ww, $n = 3$) than males (0.08 ± 0.03 ng.g^{-1} ww, $n = 5$; $F_{1,6} = 19.84$, $P = 0.004$) from Fox Lake, and significantly higher in female longnose sucker (0.40 ± 0.07 ng.g^{-1} ww, $n = 3$) from Kusawa Lake when compared to males (0.28 ± 0.03 ng.g^{-1} ww, $n = 3$; $F_{1,4} = 9.25$, $P = 0.038$). These differences were not strictly related to differences in lipid because male burbot and northern pike from Fox had higher average lipid levels than the females, but female longnose sucker from Kusawa had higher average lipid than males. Because there were no consistent differences between concentrations of the major contaminant groups that were attributable to the sex of the fishes, data were combined within lakes for further analyses.

Concentrations of organochlorines were generally highest in Laberge, mid-range in Kusawa and lowest in fishes from Fox Lake (Table V.1) Lake trout, burbot, northern pike and lake whitefish from Lake Laberge occupied a significantly higher trophic position than the same species from Fox and Kusawa lakes as determined by $\delta^{15}N$ (Table V.2 and Chapter II). In general, fishes higher in $\delta^{15}N$ were also higher in percent lipid (Table V.2) and significant within-species correlations between lipid and $\delta^{15}N$ were found for lake trout, burbot and lake whitefish (Appendix D).

Lake Trout (*Salvelinus namaycush*)

Organochlorine concentrations in lake trout muscle were significantly higher and up to two orders of magnitude greater in Laberge than was found in trout from either Fox or Kusawa lakes. When compared to fish from Fox, Kusawa lake trout were significantly higher in all contaminants except ΣHCH (Table V.1). While no among-lake differences in mean fish weight or age were found, trout from Laberge were significantly higher in both % lipid and $\delta^{15}N$ than fish from the other two lakes; in turn, lake trout from Kusawa were significantly higher in % lipid and $\delta^{15}N$, and longer than trout from Fox Lake (Table V.2).

Among lakes, concentrations of all contaminants increased significantly with increasing length, log weight, lipid or $\delta^{15}N$ of the lake trout. Although length and log weight were significant predictors, these factors only explained between 26 and 38 % of the variability in contaminant concentrations (equations not shown). Lipid and $\delta^{15}N$ were better individual predictors of fish contaminant levels than size, and these relationships and their regression equations are shown in Figures V.1 and V.2. ANCOVA analyses showed that the slopes of the organochlorine-lipid regressions were not significantly different among organochlorine groups. However, the intercepts for the regressions of ΣPCB, ΣDDT and ΣCHB were not significantly different from each other, and significantly higher than the intercepts for ΣCHL, ΣHCH and ΣCBZ. Also, the intercept for the regression of ΣCHL versus lipid was significantly higher than the intercepts for ΣHCH and ΣCBZ, and the latter two intercepts were not significantly different from one another (see Figure V.1). Unlike lipid, the slopes of the regressions between the organochlorine concentrations and $\delta^{15}N$ in lake trout muscle increased with the lipophilicity of the compounds and were significantly different among the major contaminant groups. Specifically, the slopes of ΣDDT and ΣCHB versus $\delta^{15}N$ were significantly higher than the slope of ΣHCH versus $\delta^{15}N$ (Figure V.2). For all simple regression analyses, lipid and $\delta^{15}N$ explained from 43 to 66, and from 30 to 51 % of the respective variability in lake trout contaminant concentrations. The coefficients of determination indicated that the concentrations of ΣDDT and the more hydrophilic compounds (ΣCBZ and ΣHCH) were best predicted by % lipid while all remaining organochlorines (ΣPCB, ΣCHL and ΣCHB) were better predicted by $\delta^{15}N$.

Although individual variables were significant predictors of contaminants in lake trout, multiple regression analyses showed that varying combinations of lipid, log weight and $\delta^{15}N$ were better predictors of organochlorine concentrations in fish. For ΣHCH and ΣCBZ, lipid and log weight explained 70 and 69 % of the variability in the lake trout concentrations. ΣCHL, ΣCHB and ΣDDT were significantly predicted by lipid, log weight and $\delta^{15}N$ (r^2= 0.71 to 0.83), and ΣPCB was significantly related to log weight and $\delta^{15}N$ (r^2 = 0.66; Table V.3a). Log weight was replaced by length in the regression analyses to determine if one was a better predictor of organochlorine concentrations than the other; both variables were comparable in the amount of variability in trout organochlorine concentrations that they explained.

Burbot (*Lota lota*)

Mean concentrations of all major contaminant groups were significantly higher in burbot liver from Laberge than the same species from Fox Lake (Table V.1). There were no significant differences in weight, length or age of the fish between lakes, but average $\delta^{15}N$ of burbot muscle and % lipid of their liver were significantly higher in fish from Laberge (Table V.2).

Results of the linear regression analyses indicated that $\delta^{15}N$, but not lipid, age, length or weight, was a significant predictor of all contaminant concentrations in burbot liver across both lakes (r^2=0.48 to 0.85). The linear regressions for organochlorines versus $\delta^{15}N$ and their equations are shown in Figure V.3. The slopes of the organochlorine-$\delta^{15}N$ relationships were significantly different: ΣDDT was greater than ΣCHL, ΣCBZ and ΣHCH; ΣPCB and ΣCHB were not different from one another and greater than ΣCBZ and ΣHCH; ΣCHL was greater than ΣCBZ and ΣHCH. As for lake trout, the more lipophilic contaminants were better predicted by $\delta^{15}N$ than the less lipophilic contaminants, as determined by their r^2 values (Figure V.3).

Multiple regression analyses showed that trophic position ($\delta^{15}N$) and either log age or weight (and lipid for ΣHCH) were highly significant predictors of the concentrations of all contaminants in burbot liver (Table V.3b). Replacing weight with length in the analyses did not improve or reduce the fit of the model. These models explained between 73 and 90 % of the variability in the contaminant concentrations in this species and were better predictors than any one variable was in the simple regression analyses.

Northern Pike (*Esox lucius*)

Northern pike from Laberge had significantly higher concentrations of ΣCHL, ΣPCB, ΣDDT and ΣCHB in their muscle than the same species from Fox, but average ΣCBZ and ΣHCH were not significantly different between sites (Table V.1). While no significant differences were found between lakes for age, length and weight of these fish, northern pike from Laberge were significantly higher in both % lipid and $\delta^{15}N$ than the fish from Fox Lake (Table V.2).

Simple linear regression analyses revealed that all organochlorines but ΣCBZ in northern pike muscle were significantly predicted by $\delta^{15}N$. These regressions explained from 62 to 73 % of the variability in ΣCHL, ΣDDT, ΣPCB and ΣCHB, and 28 % of the variability for ΣHCH (Figure V.4). As for the other top predators, ANCOVA showed that the slopes of these relationships were significantly different. The slopes for the organochlorine-$\delta^{15}N$ relationships were highest for the most lipophilic compounds (ΣDDT, ΣPCB, ΣCHB) and lowest for the least lipophilic group (ΣHCH); the slope for ΣCHL was not significantly different from any other contaminant group. Length or weight were not significant predictors of any organochlorine concentrations, but lipid was a significant variable for ΣDDT and ΣCHL and explained 28 and 31 % of the respective variability (equations not shown).

Concentrations of ΣCHL, ΣDDT and ΣPCB in pike muscle were better predicted by both lipid and $\delta^{15}N$ as shown by multiple regression analyses (r^2=0.80 to 0.83; Table V.3c). Weight, length and age were not significant independent variables for any of the contaminants and no variable measured in this study was a significant predictor of ΣCBZ concentrations in these fish.

Lake Whitefish (*Coregonus clupeaformis*)

Concentrations of ΣCHL, ΣPCB, ΣDDT and ΣCHB for lake whitefish were significantly different among all three sites, with the highest and lowest levels in fish from Laberge and Fox lakes respectively. ΣCBZ and ΣHCH concentrations were not significantly different in lake whitefish from Fox and Kusawa but both lakes had significantly lower concentrations than were found in Laberge fish (Table V.1). Although there were no differences in ages, whitefish from Fox were significantly heavier, and fish from Laberge were significantly shorter, and had greater % lipid and $\delta^{15}N$ than whitefish from the other lakes (Table V.2).

All variables of interest but age were significant predictors of contaminant concentrations in lake whitefish muscle. Length and weight were negatively related to organochlorine concentrations in these fish but only explained a maximum of 22 % of the associated variability (equations not shown). The negative relationships observed for length or weight were due to the fact that the large whitefish from Fox had the lowest concentrations of organochlorines. Although trophic position ($\delta^{15}N$) of the fish was also a significant predictor

(r^2 ranged from 0.12 to 0.30, and its importance increased with lipophilicity of the organochlorine group; Figure V.5), the best predictor of organochlorine concentrations for this species was lipid (r^2=0.25 and 0.63; Figure V.6), and the coefficients of determination were greatest for the less lipophilic groups. Results for the organochlorine-lipid and organochlorine-δ^{15}N ANCOVA analyses were the same; the slopes of these relationships were not significantly different, and the intercepts for ΣPCB, ΣDDT and ΣCHB were not significantly different from each other, and higher than those for ΣCHL, ΣCBZ and ΣHCH. The intercepts for the ΣCHL-lipid and ΣCHL-δ^{15}N relationships were significantly greater than those found for ΣHCH or ΣCBZ; the latter two organochlorine groups did not have significantly different intercepts in either analyses (Figure V.5 and V.6).

No combination of variables significantly predicted ΣHCH and ΣCBZ in the multiple regression analyses. ΣCHL and ΣPCB were significantly related to lipid, weight (or length) and log age (Table V.3d). δ^{15}N, weight (or length) and lipid were significant predictors of ΣCHB, while a combination of these variables and log age predicted ΣDDT concentrations in lake whitefish. These models explained between 55 and 66 % of the variability in the organochlorine data.

Round Whitefish (*Prosopium cylindraceum*)

No significant differences between the concentrations of ΣCBZ and ΣHCH in round whitefish were found among lakes. Concentrations of ΣCHL and ΣCHB in round whitefish from Laberge and Kusawa were not significantly different but were significantly higher than those for fish from Fox Lake. ΣDDT and ΣPCB concentrations were significantly higher in round whitefish from Laberge when compared to the other two sites (Table V.1). There were no differences between % lipid, δ^{15}N, length, weight or age (Fox and Kusawa only) of the round whitefish in this study (Table V.2). Age was not examined for Laberge fishes because samples were analysed as composites.

Lipid was the only significant predictor of ΣCHB, ΣCBZ, ΣCHL and ΣHCH concentrations in round whitefish (r^2=0.28 to 0.42; Figure V.7); no significant predictors of ΣPCB and ΣDDT concentrations were found. As seen previously, the slopes of these organochlorine-lipid relationships were not significantly different and the r^2 values were greatest for the less lipophilic compounds. Also, significant differences between the intercepts were found; the intercept for ΣCHB was significantly greater than ΣHCH, ΣCBZ and ΣCHL while the intercepts for the latter three groups were not significantly different from each other (Figure V.7).

Longnose Sucker (*Catostomus catostomus*)

There were no significant differences for concentrations of all major contaminant groups in longnose sucker between Laberge and Kusawa lakes (Table V.1). Similarly, the average weight, length, % lipid and δ^{15}N of these fish were not significantly different between lakes (Table V.2).

Simple linear regression analyses indicated that ΣHCH, ΣCHL, ΣCBZ and ΣCHB in longnose sucker were all significantly related to lipid (r^2=0.22 to 0.60; Figure V.8). The slopes of these organochlorine-lipid relationships were not significantly different, the intercepts were significantly different (ΣCHB > ΣCHL > ΣCBZ = ΣHCH), and the r^2 values for ΣCBZ and ΣHCH were greater than the same values for ΣCHB and ΣCHL. Concentrations of ΣCHL, ΣPCB, ΣDDT and ΣCHB were significantly related to the length of longnose suckers (r^2=0.28 to 0.38). The slopes for these relationships were also not significantly different but the intercepts for ΣPCB, ΣDDT and ΣCHB were significantly greater than the intercept for ΣCHL (Figure V.9). ΣCHL and ΣCHB were better predicted by length of the fish (r^2=0.31 and 0.38 respectively) than muscle lipid content (r^2 = 0.22 and 0.26 respectively).

A combination of lipid, length and δ^{15}N (ΣCHB only) predicted more of the variability in longnose sucker ΣCHL and ΣCHB concentrations than any one independent variable alone

(Table V.3e). Although weight (in place of length) was also a significant variable in these regression analyses, it did not explain as much of the variability as did length.

Discussion

Differences in fish contaminant concentrations between lakes have been attributed to variable inputs of organochlorines. Macdonald et al. (1993) found higher concentrations of PCBs in fishes from lakes with known point sources of organochlorines when compared to individuals from lakes contaminated solely by atmospheric deposition. Concentrations of organochlorines have been measured in dated sediment cores and large volume water samples from all three of the lakes in this study to determine if Lake Laberge was contaminated by spills or leachates from dumpsites in the City of Whitehorse, upstream from Lake Laberge. Although results of sediment core analyses showed elevated inputs of PCBs and DDT to Laberge before 1970, concentrations after this period are comparable to those found in cores from Fox and Kusawa lakes (Lockhart, 1993). It is not known how long the elevated historical inputs of organochlorines will cycle in northern lakes and influence contemporary concentrations of pollutants in fishes. No evidence of point source contamination of CHB was found for Laberge because maximal and surface fluxes of this contaminant were similar between sites (Chapter IV). Similarly, concentrations of ΣHCH, ΣCBZ and ΣCHL in the sediment cores did not exhibit any temporal trends after 1950 and were comparable among lakes (D. Muir, pers. comm., Department of Fisheries and Oceans, Winnipeg, Manitoba). Concentrations of ΣCBZ, ΣHCH, ΣCHL, ΣCHBs, and ΣPCB in water from Laberge were similar to or lower than levels found in Fox and Kusawa lakes. Only concentrations of ΣDDT in water samples were about 2-fold higher in Laberge than was found in Fox, Kusawa and other sites on the Yukon River system (Alaee and Gregor, 1994). Generally, no evidence of high contemporary inputs of organochlorines to Laberge was found, indicating that the between-lake differences in fish concentrations were not likely the result point source contamination. Although organochlorine concentrations in fishes may be directly related to the magnitude of inputs to a system (Johnson et al., 1988), pollutant levels in biota are also a function of an organism's size and lipid content (Rowan and Rasmussen, 1992; Oliver and Niimi, 1988).

If the higher concentrations of organochlorines in Laberge fishes were the result of elevated contemporary inputs of organochlorines to Lake Laberge, one would expect to see higher contaminant burdens in the invertebrates from Laberge when compared to the same taxa from Fox and Kusawa lakes. Results from the organochlorine analyses of invertebrate samples (zooplankton, chironomids, mollusks and trichopterans) from Laberge, Kusawa and Fox lakes did not reveal any consistent differences among lakes (Kidd et al., 1995b; Appendix E). For all invertebrate taxa, concentrations of ΣHCH were not significantly different among lakes. Concentrations of ΣCBZ were significantly higher in Laberge chironomids than the same invertebrates from Fox and Kusawa, and significantly higher in Limnaeidae from Kusawa when compared to Fox Lake. Chlordane concentrations were not significantly different in any invertebrates except Limnaeidae; the samples from Kusawa were higher than those from Fox. Concentrations of ΣPCB and ΣCHB were not significantly different in chironomids, Valvatidae/Planorbidae, and trichopteran from all three lakes. ΣPCB and ΣCHB were significantly higher in Laberge zooplankton when compared to zooplankton from Kusawa. Zooplankton from Fox Lake had intermediate concentrations of ΣPCB and ΣCHB when compared to Laberge and Kusawa lakes. Concentrations of ΣCHB in Limnaeidae were significantly higher in Kusawa than samples from Laberge, which were in turn, significantly higher than Fox Lake samples. Chironomids were the only invertebrates from Laberge that were significantly higher in ΣDDT when compared to taxa from both Fox and Kusawa lakes. Zooplankton from Laberge and Fox lake were not significantly different in their ΣDDT concentrations but both lakes had significantly higher concentrations than the samples from Kusawa. Whereas higher concentrations of organochlorines in invertebrates have been used as an indicator of point source contamination (e.g. Bright et al., 1995 for PCB contamination from DEW sites), the inconsistent differences found among invertebrates taxa sampled in this study did not allow for any such conclusions.

Results from other studies have shown that size and/or age were important predictors of the levels of contaminants in fishes. Weight, length or age were all significant predictors of organochlorine concentrations in salmonids from Lake Michigan (Stow, 1995), Lake Ontario (Borgmann and Whittle, 1991), Peter Lake, NWT (Muir and Lockhart, 1995), and several temperate lakes in central Ontario (Rasmussen et al., 1990). Also, differences in organochlorine concentrations in rainbow trout and lake trout have been attributed to different lifespans of these two species (Madenjian et al., 1993). Larsson et al. (1993) found that female northern pike had decreasing concentrations of organochlorines with age which the authors attributed to a loss of organochlorines through spawning when these fish mature. Muir et al. (1990) found a significant relationship between the concentrations of organochlorines (ΣPCB, ΣDDT, ΣCHL and ΣCHB) and the age of burbot from northern lakes. In contrast to Muir et al.'s study which analysed lipid-normalized data, I found that age alone was not a significant predictor of organochlorine concentrations in any fish species, but was only significant when included in the multiple regression analyses for burbot and lake whitefish (Table V.5). Similarly, weight or length alone were not significant predictors of organochlorine concentrations in burbot, northern pike and round whitefish, and were poor predictors of contaminant burdens in lake trout and lake whitefish. Also, a negative relationship between organochlorine concentrations and size was found for lake whitefish because the population of whitefish with the lowest organochlorine concentrations were also the biggest fish. With the exception of longnose sucker where ΣCHL and ΣCHB were better predicted by length than lipid, concentrations of organochlorines were best predicted by lipid or $\delta^{15}N$ and not fish size.

Burbot, lake trout and lake whitefish from Fox and Kusawa lakes had concentrations of organochlorines and % lipid that were comparable to the concentrations found in the same species from other northern sites (Table V.4). However, concentrations of the more lipophilic contaminants (ΣCHL, ΣPCB, ΣDDT and ΣCHB) in Laberge fishes were higher than concentrations found elsewhere. The lipid content of fishes from Laberge falls within the range of values found elsewhere, indicating that the elevated organochlorine concentrations were not simply a function of higher lipid levels in Laberge fish tissues.

Previously, I have demonstrated that the food chain in Lake Laberge was unusually long when compared to the other lakes studied herein (Chapter II and IV). Higher-trophic-level feeding is related to elevated concentrations of organochlorines in fishes, and explains much of the between-lake variability in contaminant concentrations in top predators from temperate systems (Rasmussen et al., 1990).

Lake Laberge has previously supported commercial, sport and subsistence fisheries, and, possibly as a result of heavy fishing pressure, has anomalously low biomasses of lake trout and lake whitefish, and a high biomass of burbot when compared to other regional lakes (de Graff and Mychasiw, 1994; Chapter I, Table I.1). Populations of fish from exploited lakes grow faster than those from non-exploited lakes (Healey, 1975; 1978; Hewson, 1955), probably due to reduced intraspecific competition and an increased forage base. Although faster growth has been associated with decreased contaminant concentrations in fishes (Hammar et al., 1993), this was found within a species complex where differences in diet were negligible. Faster-growing lake trout will switch from a diet of invertebrates, sculpin and yellow perch to one consisting mainly of cisco at an earlier age than slower-growing populations (Trippel and Beamish, 1993). In Lake Laberge, trout grow faster, have a higher average condition factor (weight to length ratio; Laberge - 1.26, Kusawa - 1.01, Fox - 1.10), and are mainly piscivorous in comparison to trout from Kusawa and Fox lakes (Chapter II) and other populations on the Yukon River system (Thompson, 1996a, 1996b; Sparling and Connor, 1996). Lake trout and the other top predators in Laberge may have higher concentrations of organochlorines because they began feeding at a higher trophic level, and thus on more contaminated prey, at a younger age. Also, a shift to a diet composed solely of fish also explains the higher average trophic position of Laberge fishes.

Lipid content increases with the trophic position of organisms (this study; Chapter III; Rasmussen et al., 1990; Oliver and Niimi, 1988) making it difficult to distinguish the effects of these two factors on the accumulation of organochlorines in biota. Results from this study generally supported the conclusions of Rasmussen et al., (1990), Rowan and Rasmussen (1992), Thomann (1989), and Macdonald et al. (1993) in that a combination of trophic positioning and lipid best predicted the concentrations of the more lipophilic contaminants in some species (Table V.5). However, the following exceptions were found. Concentrations of all organochlorines but ΣHCH in burbot liver were significantly related to $\delta^{15}N$, and not lipid. In contrast, lipid and not $\delta^{15}N$ was a significant predictor of organochlorine concentrations in the forage fishes longnose sucker and round whitefish. These differences indicate that the importance of trophic positioning and lipid in the accumulation of organochlorines varies between species, and that trophic positioning becomes progressively more important in top predators.

The accumulation of persistent organochlorines in fishes is believed to be dependent upon the lipophilicity of the compounds. Mackay (1982) demonstrated that the bioconcentration factor (ratio of organochlorine concentrations in fish lipid to organochlorine concentrations in water, calculated from laboratory studies of water-borne chemicals) increased with log K_{ow} of the organochlorines. Similar relationships between bioaccumulation factors and log K_{ow} have been observed in field studies, although the concentrations of the more lipophilic organochlorines (log K_{ow} between 4 and 7) exceeded those predicted by equilibrium partitioning with lipid alone (Oliver and Niimi, 1988) due to an increased importance of food chain effects on contaminant accumulation in the upper-trophic-level fishes (Thomann, 1989). Within each species examined herein, the slopes of the relationships between organochlorine concentrations and lipid were not significantly different, indicating that more lipophilic compounds do not accumulate at a greater rate per unit lipid than the less lipophilic compounds. However, the intercepts of the organochlorine-lipid regressions were significantly greater for ΣPCB, ΣDDT and ΣCHB than the intercepts for ΣHCH, ΣCHL and ΣCBZ, indicating that the concentrations of these organochlorines in fishes were affected by inputs and not by the preferential accumulation of the more lipophilic contaminants with increasing lipid content.

Unlike the above-mentioned relationships, the slopes of the regressions between organochlorines and $\delta^{15}N$ were significantly higher for the more lipophilic than less lipophilc contaminants: the slopes of ΣDDT and ΣCHB were significantly higher than ΣHCH for lake trout; the slopes of ΣDDT, ΣPCB and ΣCHB were significantly higher than ΣHCH and ΣCBZ in burbot; the slopes of ΣDDT, ΣPCB and ΣCHB were significantly higher than ΣHCH in northern pike. Unlike these top predators, no significant differences in the slopes of organochlorines versus $\delta^{15}N$ were found for lake whitefish. In the top predators, the differences in the organochlorine-$\delta^{15}N$ slopes indicates that trophic position affected the accumulation of the more lipophilic contaminants to a greater extent than the less lipophilic contaminants. The fact that this relationship was not observed for lower-trophic-level species further substantiates the theory that trophic position is a more important factor in determining organochlorine concentrations in top predators. Similarly, although Rasmussen et al. (1990) could not separate the effects of trophic position and lipid on ΣPCB concentrations in lake trout, they noted that lipid increased 1.5 fold with increasing food chain length leading up to lake trout (generalized by the presence/absence of prey species) while PCBs increased by 3.5 fold. Similar relationships between lipophilicity and $\delta^{15}N$ have been observed among species; the slopes of ΣDDT and ΣCHB versus $\delta^{15}N$ were significantly greater than the slope of ΣHCH versus $\delta^{15}N$ in the Lake Laberge food web (Chapter III). The analysis of this relationship for individual congeners would allow further testing of the hypothesis that the organochlorine-$\delta^{15}N$ slopes increase with increasing lipophilicity of the pollutants.

Northern pike from Laberge and Fox lakes had considerably lower concentrations of organochlorines than the other top predators lake trout and burbot. These differences among species may be due to the varying maturation rates; lake trout and burbot from Yukon lakes mature at age 9 or 10, while northern pike mature at age 5 (Thompson 1996a; 1996b; de Graff, 1992). Mature fishes will lose a certain percentage of their body burden of organochlorines through reproduction (Larsson et al., 1993; Sijm et al., 1992), and a younger-age-to-maturation may explain the differences in the organochlorine burdens of the top predators in this study.

In conclusion, although lipid content was a significant predictor of the contaminant concentrations in fishes from these lakes, trophic position as determined by $\delta^{15}N$ was more important for the upper-trophic-level fishes. Within species, $\delta^{15}N$ is a better individual predictor (greater r^2 value) of the more lipophilic contaminants than the less lipophilic contaminants, and lipid is a better predictor of the less lipophilic contaminants than the more lipophilic contaminants.

References

Alaee, M. and D. Gregor (1994) A study of the sources and fate of organochlorine contaminants in the Yukon River basin. P.p. 152-161 in: Synopsis of Research Conducted Under the 1993/94 Northern Contaminants Program, J.L. Murray and R.G. Shearer (eds.). Environmental Studies No. 72. Indian and Northern Affairs Canada, Ottawa. 459 pp.

Barrie, L.A., D. Gregor, B. Hargrave, R. Lake, D. Muir, R. Shearer, B. Tracey and T. Bidleman (1992) Arctic contaminants: sources, occurrence and pathways. Sci. Total Environ. 122:1-74.

Borgmann, U. and D.M. Whittle (1983) Particle-size-conversion efficiency and contaminant concentrations in Lake Ontario biota. Can. J. Fish. Aquat. Sci. 40:328-336.

Borgmann, U. and D.M. Whittle (1991) Contaminant concentration trends in Lake Ontario lake trout (*Salvelinus namaycush*): 1977 to 1988. J. Great Lakes Res. 17(3):368-381.

Bright, D.A., W.T. Dushenko, S.L. Grundy and K.J. Reimer (1995) Effects of local and distant contaminant sources: polychlorinated biphenyls and other organochlorines in bottom-dwelling animals from an Arctic estuary. Sci. Total Environ. 160/161:265-283.

Broman, D., C. Naf, C. Rolff, Y. Zebuhr, B. Fry and J. Hobbie (1992) Using ratios of stable nitrogen isotopes to estimate bioaccumulation and flux of polychlorinated dibenzo-p-dioxins (PCDDs and dibenzofurans (PCDFs) in two food chains from the northern Baltic. Environ. Toxicol. Chem. 11:331-345.

Cabana, G. and J.B. Rasmussen (1994) Modelling food chain structure and contaminant bioaccumulation using stable nitrogen isotopes. Nature 372(17):255-257.

Connolly, J.P. and C. Pederson (1988) A thermodynamic-based evaluation of organic chemical accumulation in aquatic organisms. Environ. Sci. Technol 22:99-103.

de Bruijn, F. Busser, W. Seinen and J. Hermens (1989) Determination of octanol/water partition coefficients for hydrophobic organic chemicals with the "slow-stirring" method. Environ. Toxicol. Chem. 8:499-512.

de Graff, N. and L. Mychasiw (1994) Lake trout recovery and contaminant management program in Lake Laberge, Yukon Territory. P.p. 301-304 in: Synopsis of Research Conducted Under the 1993/94 Northern Contaminants Program, J.L. Murray and R.G. Shearer (eds.). Environmental Studies No. 72. Indian and Northern Affairs Canada, Ottawa. 459 pp.

de Graff, N. (1992) Fish stock assessment of Bennett, Frances and Kluane lakes, 1990. Fish and Wildlife Branch, Yukon Department of Renewable Resources, Yukon Territorial Government, 61 pp.

de Vault, D.S., W.A. Willford, R.J. Hesselberg, D.A. Nortrupt, E.G.S. Rundberg, A.K.

Alwan and C. Bautista (1986) Contaminant trends in lake trout (*Salvelinus namaycush*) from the upper Great Lakes. Arch. Environ. Contam. Toxicol. 15:349-356.

Evans, M. (1994) Biomagnification of persistent organic contaminants in Great Slave lake. P.p. 295-300 in: Synopsis of Research Conducted Under the 1993/94 Northern Contaminants Program, J.L. Murray and R.G. Shearer (eds.). Environmental Studies No. 72. Indian and Northern Affairs Canada, Ottawa. 459 pp.

Hammar, J., P. Larsson and M. Klavins (1993) Accumulation of persistent pollutants in normal and dwarfed arctic char (*Salvelinus alpinus* sp. complex). Can. J. Fish. Aquat. Sci. 50:2574-2580.

Healey, M.C. (1975) Dynamics of exploited whitefish populations and their management with special reference to the Northwest Territories. J. Fish. Res. Board Can. 32:427-448.

Healey, M.C. (1978) The dynamics of exploited lake trout populations and implications for management. J. Wildl. Manage. 42(2):307-328.

Hebert, C.E. and G.D. Haffner (1991) Habitat partitioning and contaminant exposure in Cyprinids. Can. J. Fish. Aquat. Sci. 48:261-266.

Hewson, L.C. (1955) Age, maturity, spawning and food of burbot, *Lota lota*, in Lake Winnipeg. J. Fish. Res. Board Can. 12(6):930-940.

Howard, P.H. (1991) Handbook of environmental fate and exposure data for organic chemicals. Volume III - Pesticides, Lewis Publishers, Inc., Michigan, 684 pp.

Johnson, M.G., J.R.M. Kelso, and S.E. George (1988) Loadings of organochlorine contaminants and trace elements to two Ontario lake systems and their concentrations in fish. Can. J. Fish. Aquat. Sci. 45(Suppl. 1):170-178.

Kidd, K.A., J.E. Eamer and D.C.G. Muir (1993) Spatial variability of chlorinated bornanes (toxaphene) in fishes from Yukon lakes. Chemosphere 27(10):1975-1986.

Kidd, K.A., R.H. Hesslein, R.J.P. Fudge and K.A. Hallard (1995a) The influence of trophic level as measured by $\delta^{15}N$ on mercury concentrations in freshwater organisms. Water, Air Soil Pollut. 80:1011-1015.

Kidd, K.A. and D.W. Schindler (1995b) The biomagnification of organochlorines through the food web of Lake Laberge and other Yukon lakes. in: Synopsis of Research Conducted Under the 1994/95 Northern Contaminants Program, J.L. Murray and R.G. Shearer (eds.). Environmental Studies No. x. Indian and Northern Affairs Canada, Ottawa. in press.

Larsson, P., L. Collvin, L. Okla and G. Meyer (1992) Lake productivity and water chemistry as governors of the uptake of persistent pollutants in fish. Environ. Sci. Technol. 26(2):346-352.

Larsson, P., Olka, L. and L. Collvin (1993) Reproductive status and lipid content as factors in PCB, DDT and HCH contamination of a population of Pike (*Esox lucius* L.) Environ. Toxicol. Chem. 12:855-861.

Lockhart, W.L. (1993) Depositional trends - lake and marine sediments. P.p. 46-56 in: Synopsis of Research Conducted Under the 1992/93 Northern Contaminants Program, J.L. Murray and R.G. Shearer (eds.). Environmental Studies No. 70 Indian and Northern Affairs Canada, Ottawa. 285 pp.

McCarthy, J.F. and S.M. Bartell (1988) How the trophic status of a community can alter the bioavailability and toxic effects of contaminants. Functional Testing of Aquatic Biota for Estimating Hazards of Chemicals, ASTM STP 988, J. Cairns, Jr., and J.R. Pratt, Eds., American Society for Testing and Materials, Philadelphia, pp. 3-16.

Macdonald, C.R., C.D. Metcalfe, G.C. Balch and T.L. Metcalfe (1993) Distribution of PCB congeners in seven lake systems:Interactions between sediment and food-web transport. Environ. Toxicol. Chem. 12:1991-2003.

Mackay, D. (1982) Correlation of bioconcentration factors. Environ. Sci. Technol. 16:274-278.

Mackay, D., W. Ying Shiu and K. Ching Ma (1992) Illustrated handbook of physical-chemical properties and environmental fate for organic chemicals, Volume I, Lewis Publishers, Inc., Michigan, 697 pp.

Mackay, D.W. and F. Wania (1995) Transport of contaminants to the Arctic: Partitioning, processes and models. Sci. Total Environ. 160/161:25-38.

Madenjian, C.P., S.R. Carpenter and P.S. Rand (1994) Why are the PCB concentrations of Salmonine individuals from the same lake so highly variable? Can. J. Fish. Aquat. Sci. 51:800-807.

Miskimmin, B.M., D.C.G. Muir, D.W. Schindler, G.A. Stern and N.P. Grift (1995) Chlorobornanes in sediments and fish thirty years after toxaphene treatment of lakes. Environ. Sci. Technol. 29:2490-2495

Muir, D.C.G., C.A. Ford, N.P. Grift, D.A. Metner and W.L. Lockhart (1990) Geographical variation of chlorinated hydrocarbons in burbot (*Lota lota*) from remote lakes and rivers in Canada. Arch. Environ. Contam. Toxciol. 19:530-542.

Muir, D.C.G and W.L. Lockhart (1993) Contaminant trends in freshwater and marine fish. P.p. 167-173 in: Synopsis of Research Conducted Under the 1992/93 Northern Contaminants Program, J.L. Murray and R.G. Shearer (eds.). Environmental Studies No. 70 Indian and Northern Affairs Canada, Ottawa. 285 pp.

Muir, D.C.G and W.L. Lockhart (1994) Contaminant trends in freshwater and marine fish. P.p. 264-271 in: Synopsis of Research Conducted Under the 1993/94 Northern Contaminants Program, J.L. Murray and R.G. Shearer (eds.). Environmental Studies No. 72. Indian and Northern Affairs Canada, Ottawa. 459 pp.

Muir, D.C.G., N.P. Grift, W.L. Lockhart, P. Wilkinson, B.N. Billeck and G.J. Brunskill (1995) Spatial trends and historical profiles of organochlorine pesticides in arctic lake sediments. Sci. Total Environ. 160/161:447-457.

Muir, D.C.G and W.L. Lockhart (1995) Contaminant trends in freshwater and marine fish. in: Synopsis of Research Conducted Under the 1994/95 Northern Contaminants Program, J.L. Murray and R.G. Shearer (eds.). Environmental Studies No. x. Indian and Northern Affairs Canada, Ottawa. in press.

Oliver, B.G. and A.J. Niimi (1988) Trophodynamic analysis of polychlorinated biphenyl congeners and other chlorinated hydrocarbons in the Lake Ontario ecosystem. Environ. Sci. Technol. 22:388-397.

Palmer, M. (1992) Levels of contaminants in fish from Yukon lakes. P.p. 116-120 in: Synopsis of Research Conducted Under the 1991/92 Northern Contaminants Program, J.L. Murray and R.G. Shearer (eds.). Environmental Studies No. 68.

Indian and Northern Affairs Canada, Ottawa. 213 pp.

Peterson, B.J. and B. Fry (1987) Stable isotopes in ecosystem studies. Ann. Rev. Ecol. Syst. 18:293-320.

Rasmussen, J.B., D.J. Rowan, D.R.S. Lean and J.H. Carey (1990) Food chain structure in Ontario lakes determines PCB levels in lake trout (Salvelinus namaycush) and other pelagic fish. Can. J. Fish. Aquat. Sci. 47:2030-2038.

Rowan, D.J. and J.B. Rasmussen (1992) Why don't great lakes fish reflect environmental concentrations of organic contaminants? - An analysis of between-lake variability in the ecological partitioning of PCBs and DDT. J. Great Lakes Res. 18(4):724-741.

Saleh, M.A. (1991) Toxaphene: Chemistry, biochemistry, toxicity and environmental fate. Rev. Environ. Contam. Toxicol. 118:1-85

SAS Institute, Inc. 1985. User's guide: Statistics. SAS Institute, Inc., Cary, North Carolina.

Scott, W.B. and E.J. Crossman (1973) Freshwater Fishes of Canada. Bulletin 184. Fisheries Research Board of Canada, Ottawa, Ontario. pp.

Simonich, S.L. and R.A. Hites (1995) Global distribution of persistent organochlorine compounds. Science 269:1851-1854.

Sijm, D.T.H.M., W. Seinen and A. Opperhuizen (1992) Life-cycle biomagnification study in fish. Environ. Sci. Technol. 26(11):2162-2174

Sparling, P.D. and M.J. Connor (1996) Lake Laberge index fishery and toxicology study 1993 data report. Yukon Territorial Government, in press.

Spies, R. B., H. Kruger, R. Ireland and D. W. Rice (1989) Stable isotope ratios and contaminant concentrations in a sewage-distorted food web. Mar. Ecol. Prog. Ser. 54:157-170.

Stern, G.A., D.C.G. Muir, C.A. Ford, N. P. Grift, E. Dewailly, T.F. Bidleman and M.D. Walla (1992) Isolation and identification of two major recalcitrant toxaphene congeners in aquatic biota. Environ. Sci. Technol. 26:1838-1840.

Stow, C.A. (1995) Factors associated with PCB concentrations in Lake Michigan salmonids. Environ. Sci. Technol. 29:522-527.

Swackhamer, D. and R.A. Hites (1988) Occurrence and bioaccumulation of organochlorine compounds in fishes from Siskiwit Lake, Isle Royale, Lake Superior. Environ. Sci. Technol. 22:543-548.

Thomann, R.V. and J.P. Connolly (1984) Model of PCB in the Lake Michigan lake trout food chain. Environ. Sci. Technol. 18(2):65-71.

Thomann, R.V. (1989) Bioaccumulation model of organic chemical distribution in aquatic food chains. Environ. Sci. Technol. 23(6):699-707.

Thompson, S. (1996a) Fish stock assessment of Kusawa, Laberge and Teslin lakes, 1993, 1991, 1992. Fish and Wildlife Branch, Yukon Department of Renewable Resources, Whitehorse, Yukon, Y1A 4N6, in press.

Thompson, S. (1996b) Fish stock assessment of Marsh and Tagish lakes, 1993. Fish and Wildlife Branch, Yukon Department of Renewable Resources, Whitehorse, Yukon, Y1A 4N6, in press.

Trippel, E.A. and F.W.H. Beamish (1993) Multiple trophic level structuring in Salvelinus-Coregonus assemblages in boreal forest lakes. Can J. Fish. Aquat. Sci. 50:1442-1455.

Table V.1: Mean ± SD (range) of ΣCBZ, ΣHCH, ΣCHL, ΣPCB, ΣDDT and ΣCHB concentrations (ng.g^{-1} wet weight) in fish muscle and burbot liver collected from Fox, Kusawa and Laberge lakes, Yukon Territory. Within species, significant differences among variables are shown by different superscripts.

	n	ΣCBZ	ΣHCH	ΣCHL	ΣPCB	ΣDDT	ΣCHB
Fox Lake							
Burbot	14	6.95±2.59^{a} (12.9-4.12)	14.3±4.66^{a} (24.4-6.29)	19.0±7.67^{a} (38.9-11.4)	45.9±23.8^{a} (103-18.7)	67.7±30.5^{a} (125-32.7)	68.4±23.5^{a} (109-35.4)
Lake Trout	16	0.5±0.6^{a} (2.48-0.07)	0.8±1^{a} (4.3-0.05)	1.8±1.9^{a} (7.95-0.19)	5.34±3.57^{a} (14.3-1.35)	6.00±5.01^{a} (18.9-1.38)	7.7±7.5^{a} (27.3-0.65)
Lake Whitefish	13	0.40±0.36^{a} (1.36-0.12)	0.4±0.3^{a} (0.98-<0.01)	0.65±0.50^{a} (1.88-0.15)	3.75±4.10^{a} (16.3-1.10)	4.3±3.6^{a} (14.1-0.81)	5.2±5.2^{a} (18.5-0.33)
Northern Pike	8	0.2±0.1^{a} (0.31-0.06)	0.09±0.04^{a} (0.17-0.05)	0.1±0.07^{a} (0.28-0.05)	0.4±0.3^{a} (0.95-0.09)	0.54±0.31^{a} (1.05-0.16)	0.5±0.6^{a} (1.96-<0.01)
Round Whitefish	8	0.46±0.21^{a} (0.78-0.22)	0.69±0.35^{a} (1.50-0.36)	0.4±0.2^{a} (0.64-0.07)	1.1±0.23^{a} (1.51-0.85)	0.90±0.42^{a} (1.32-0.20)	1.8±0.87^{a} (3.44-0.74)
Kusawa Lake							
Lake Trout	10	1.2±0.87^{b} (2.96-0.11)	1.2±1.2^{a} (4.14-0.18)	17.3±8.81^{b} (35.7-7.02)	85.4±82.5^{b} (311-28.9)	44.2±68.0^{b} (228-9.20)	121±78.9^{b} (235-22.9)
Lake Whitefish	12	0.56±0.31^{a} (1.22-0.16)	0.47±0.36^{a} (1.12-0.12)	2.0±1.7^{b} (6.48-0.44)	19.6±20.9^{b} (69.1-2.17)	15.1±17.3^{b} (59.4-1.09)	17.0±14.4^{b} (54.9-2.72)
Longnose Sucker	6	0.29±0.10^{a} (0.42-0.13)	0.34±0.081^{a} (0.48-0.25)	1.6±0.53^{a} (2.27-0.91)	10.5±5.92^{a} (18.5-4.29)	10.3±3.59^{a} (13.8-5.54)	9.34±3.62^{a} (15.7-4.88)

Table V.1 (cont'd): Mean ± SD (range) of ΣCBZ, ΣHCH, ΣCHL, ΣPCB, ΣDDT and ΣCHB concentrations (ng.g^{-1} wet weight) in fish muscle and burbot liver collected from Fox, Kusawa and Laberge lakes, Yukon Territory. Within species, significant differences among variables are shown by different superscripts.

	n	ΣCBZ	ΣHCH	ΣCHL	ΣPCB	ΣDDT	ΣCHB
Kusawa							
Round Whitefish	6	0.62±0.12^{a} (0.79-0.46)	0.67±0.20^{a} (0.93-0.46)	1.7±0.88^{b} (3.11-0.58)	2.26±0.71^{b} (3.07-1.10)	1.3±0.52^{a} (2.09-0.56)	15.3±8.53^{b} (25.7-3.10)
Lake Laberge							
Burbot	16	19.8±8.23^{b} (40.4-10.0)	26.1±6.80^{b} (37.9-14.6)	261±201^{b} (681-87.7)	1210±926^{b} (3640-485)	2527±1990^{b} (7330-901)	2170±1130^{b} (4470-879)
Least Cisco	7	1.4±0.89 (2.29-0.17)	1.6±1.1 (2.94-0.15)	6.33±3.83 (11.5-1.09)	20.7±8.57 (35.1-8.53)	31.8±15.7 (58.2-9.87)	68.3±36.2 (97.2-10.8)
Lake Trout	12	3.01±1.33^{c} (5.47-1.44)	3.41±1.69^{b} (6.96-1.40)	44.34±48.00^{c} (166.48-13.31)	453.0±832.0^{c} (2528.24-53.61)	527.5±907.4^{c} (3014.76-44.59)	387.23±415.19^{c} (1443.15-112.21)
Lake Whitefish	30	1.1±0.59^{b} (3.30-0.13)	1.6±1.0^{b} (5.68-0.20)	8.91±5.65^{c} (28.7-1.78)	66.3±57.1^{c} (278-6.57)	82.5±63.6^{c} (284-10.4)	62.1±46.8^{c} (201-10.2)
Longnose Sucker	12	0.3±0.2^{a} (0.59-0.06)	0.37±0.18^{a} (0.71-0.14)	2.1±1.4^{a} (5.17-0.27)	13.4±7.34^{a} (23.86-1.09)	16.1±7.77^{a} (26.44-2.88)	17.5±12.1^{a} (44.60-2.17)
Northern Pike	8	0.2±0.06^{a} (0.26-0.08)	0.1±0.04^{a} (0.18-0.07)	0.94±0.31^{b} (1.42-0.50)	7.20±3.12^{b} (12.0-3.06)	8.35±2.74^{b} (12.3-5.46)	9.68±3.86^{b} (16.4-5.00)
Round Whitefish	7	0.77±0.48^{a} (1.67-0.22)	0.92±0.43^{a} (1.39-0.32)	3.2±2.0^{b} (5.67-0.84)	17.0±9.67^{c} (28.5-6.00)	22.6±11.0^{b} (33.8-7.01)	25.8±11.9^{b} (40.6-3.98)

Table V.2: Mean (± SD) $\delta^{15}N$ and % lipid of fish muscle (liver for lipid content in burbot), and weight, length and age of fishes from Laberge, Fox and Kusawa lakes, Yukon Territory. For each species, significant differences among lakes are shown with different superscripts.

Species	Lake	*n*	$\delta^{15}N$ (‰)	%Lipid ($g.g^{-1}$ ww)	Length (mm)	Weight (g)	Age (yr)
Burbot	Laberge	16	12.0 ± 0.48^{a}	38.55 ± 15.38^{a}	548 ± 132^{a}	$1.37E3\pm800^{a}$	$1E1\pm5^{a}$
	Fox	14	8.86 ± 0.71^{b}	28.49 ± 10.21^{b}	554 ± 87.7^{a}	$1.35E3\pm558^{a}$	$1E1\pm3^{a}$
Lake trout	Laberge	12	12.1 ± 0.87^{a}	6.77 ± 3.17^{a}	489 ± 60.4^{ab}	$1.43E3\pm586^{a}$	$2E1\pm5^{a}$
	Kusawa	10	9.90 ± 0.40^{b}	1.76 ± 1.56^{b}	525 ± 90.3^{a}	$1.70E3\pm1.06E3^{a}$	$2E1\pm7^{a}$
	Fox	16	8.84 ± 0.89^{c}	1.38 ± 1.34^{b}	434 ± 87.2^{a}	967 ± 626^{a}	$2E1\pm5^{a}$
Lake whitefish	Laberge	30	8.35 ± 1.1^{a}	2.84 ± 1.40^{a}	318 ± 81.4^{a}	432 ± 251^{a}	$1E1\pm4^{a}$
	Kusawa	12	7.23 ± 0.65^{b}	1.4 ± 0.77^{b}	379 ± 32.1^{b}	592 ± 156^{a}	$1E1\pm2^{a}$
	Fox	13	7.22 ± 0.98^{b}	0.99 ± 0.66^{b}	422 ± 46.0^{b}	846 ± 249^{b}	$1E1\pm6^{a}$
Least cisco	Laberge	7	8.1[illegible]±0.46	5.01 ± 2.89	172 ± 49.6	58 ± 41	4 ± 0.6
Longnose sucker	Laberge	12	7.[illegible]0.91^{a}	0.96 ± 0.51^{a}	433 ± 20.8^{a}	852 ± 112^{a}	-
	Kusawa	6	6.94 ± 0.22^{a}	1.2 ± 0.36^{a}	419 ± 20.4^{a}	767 ± 40.8^{a}	-
Northern pike	Laberge	8	9.88 ± 0.58^{a}	0.41 ± 0.09^{a}	634 ± 77.6^{a}	1825 ± 727.5^{a}	7 ± 2^{a}
	Fox	8	8.16 ± 2.03^{b}	0.28 ± 0.09^{b}	646 ± 105^{a}	$2.17E3\pm957^{a}$	8 ± 2^{a}
Round whitefish	Laberge	7	6.60 ± 0.80^{a}	2.1 ± 0.57^{a}	221 ± 115^{a}	$1.7E2\pm2.8E2^{a}$	-
	Kusawa	6	6.32 ± 0.36^{a}	2.3 ± 0.53^{a}	184 ± 44.8^{a}	58 ± 41^{a}	4 ± 1^{a}
	Fox	8	6.40 ± 1.66^{a}	1.8 ± 0.81^{a}	244 ± 88.1^{a}	$1.8E2\pm1.8E2^{a}$	5 ± 3^{a}

Table V.3a: Coefficients and intercepts (± SE, n = 37) of the multiple regression models predicting the log-transformed wet weight concentrations of ΣHCH, ΣCBZ, ΣCHL, ΣPCB, ΣDDT and ΣCHB in lake trout muscle from Laberge, Fox and Kusawa lakes, Yukon Territory. Intercepts with an asterisk were significantly different from 0 at $P < 0.05$.

	lipid	log weight	$\delta^{15}N$	Intercept	r^2	P	SE$_{est}$
ΣHCH	0.10±0.015	0.51±0.18		-1.9±0.53*	0.70	0.0001	0.19
ΣCBZ	0.11±0.017	0.52±0.19		-2.0±0.57*	0.69	0.0001	0.19
ΣCHL	0.051±0.028	1.1±0.27	0.20±0.055	-4.8±0.94*	0.71	0.0001	0.41
ΣCHB	0.060±0.035	1.2±0.33	0.26±0.068	-5.0±1.2*	0.70	0.0001	0.49
ΣDDT	0.12±0.025	0.82±0.24	0.22±0.048	-3.7±0.82*	0.83	0.0001	0.38
ΣPCB	-	1.2±0.29	0.31±0.051	-5.3±0.93*	0.66	0.0001	0.48

Table V.3b: Coefficients and intercepts (± SE, n = 29) of the multiple regression models predicting the log-transformed wet weight concentrations of ΣHCH, ΣCBZ, ΣCHL, ΣPCB, ΣDDT and ΣCHB in burbot liver from Laberge, Fox and Kusawa lakes, Yukon Territory. Intercepts with an asterisk were significantly different from 0 at $P < 0.05$

	lipid	weight	$\delta^{15}N$	log age	Intercept	r^2	P	SE_{est}
ΣHCH	5.0E-3±1.9E-3	1.0E-4±2.8E-5	0.057±0.013		0.37±0.12	0.73	0.0001	0.09
ΣCBZ			0.13±0.017	0.59±0.18	-0.95±0.27*	0.72	0.0001	0.15
ΣCHL			0.31±0.028	1.27±0.30	-2.74±0.44*	0.84	0.0001	0.25
ΣCHB			0.43±0.029	1.09±0.31	-3.07±0.45*	0.90	0.0001	0.26
ΣDDT		3.1E-4±7.6E-5	0.44±0.031		-2.45±0.35*	0.89	0.0001	0.27
ΣPCB		2.5E-5±7.5E-5	0.40±0.031		-2.24±0.35*	0.87	0.0001	0.28

Table VI.3c: Coefficients and intercepts (± SE, n = 16) of the multiple regression models predicting the log-transformed wet weight concentrations of ΣCHL, ΣPCB and ΣDDT in northern pike muscle from Laberge and Fox lakes, Yukon Territory. Intercepts with an asterisk were significantly different from 0 at $P < 0.05$.

	$\delta^{15}N$	lipid	Intercept	r^2	P	SE_{est}
ΣCHL	0.35±0.059	1.96±0.56	-4.33±0.56*	0.80	0.0001	0.24
ΣDDT	0.48±0.075	2.38±0.69	-4.89±0.69*	0.83	0.0001	0.29
ΣPCB	0.55±0.083	1.78±0.75	-5.40±0.75*	0.81	0.0001	0.33

Table V.3d: Coefficients and intercepts (± SE, n = 43) of the multiple regression models predicting the log-transformed wet weight concentrations of ΣCHL, ΣPCB, ΣDDT and ΣCHB in lake whitefish muscle from Laberge, Fox and Kusawa lakes, Yukon Territory. Intercepts with an asterisk were significantly different from 0 at $P < 0.05$

	lipid	weight	$\delta^{15}N$	log age	Intercept	r^2	P	SE_{est}
ΣCHL	0.20±0.27	-1.6E-3±3.3E-4		1.4±0.37	-0.46±0.27	0.66	0.0001	0.34
ΣCHB	0.18±0.043	-7.5E-4±2.1E-4	0.20±0.053		-0.21±0.41	0.65	0.0001	0.27
ΣDDT	0.13±0.25	-1.9E-3±4.7E-4	0.15±0.078	1.8±0.58	-0.83±0.55	0.64	0.0001	0.43
ΣPCB	0.14±0.052	-2.0E-3±4.2E-4		2.1±0.46	0.079±0.34	0.55	0.0001	0.45

Table V.3e: Coefficients and intercepts (± SE, *n* = 18) of the multiple regression models predicting the log-transformed wet weight concentrations of ΣCHL and ΣCHB in longnose sucker muscle from Laberge and Kusawa lakes, Yukon Territory. Intercepts with an asterisk were significantly different from 0 at $P < 0.05$

	lipid	length	$\delta^{15}N$	Intercept	r^2	P	SE_{est}
ΣCHL	0.24±0.11	6.9E-3±2.5E-3		-3.0±1.1*	0.49	0.007	0.22
ΣCHB	0.29±0.087	8.7E-3±2.0E-3	0.16±0.054	-4.1±0.96*	0.75	0.0001	0.18

Table V.4: Concentrations of major organochlorine groups [ng.g^{-1} wet weight ± SD (where available)] of burbot liver, and lake trout and whitefish muscle from arctic and subarctic lakes in Yukon and Northwest Territories.

	ΣCBZ	ΣHCH	ΣCHL	ΣPCB	ΣDDT	ΣCHB	%lipid
Burbot							
Alexie Lake, NWT[1]	-	4.89±1.62	14.7±5.88	26.9±18.0	13.6±7.88	40.5±26.6	26.3±12
Great Slave, NWT[1]	-	7.18±3.71	39.6±20.8	103.0±65.9	51.7±43.0	286.7±134	28.2±7.2
Great Slave, NWT[2]	23.1-13.2	15.2-7.3	152.4-76.9	227.5-92.5	95.7-27.8	1266-401	32.3-19.5
Trout Lake, NWT[4]	-	13.7±4.7	33.3±12.2	50.1±9.7	19.8±7.2	152±65.9	40.3±12
Atlin Lake, YT[5]	17.0	63.0	137.5	135	105	1533	33.1
Kluane Lake, YT[5]	7.8	2.1	9.9	50	43	54	35.1
Schwatka Lake, YT[5]	4.5	10.4	20.0	104	282	272	15.3
Teslin Lake, YT[5]	16.7	6.3	50.9	175	114	267	40.3
Lake Trout							
Lake Belot, NWT[1]	-	3.76±1.34	20.8±6.12	52.4±36.1	24.2±12.8	138.5±81.8	4.9±3.2
Colville Lake, NWT[1]	-	0.89±0.54	3.27±1.91	10.5±9.02	3.13±2.13	11.9±7.13	5.2±2.6
Travalliant Lake, NWT[1]	-	1.15±0.54	4.25±1.78	8.8±3.7	2.03±0.95	17.1±7.16	3.1±0.9
Great Slave Lake, NWT[2]	3.3-2.4	2.6-1.8	17.4-9.2	26.8-13.1	9.7-5.3	160-41.3	13.8-7.4
Peter Lake, NWT[3]	1.3±0.3	0.6±0.3	5.8±2.6	19.0±14.1	3.3±2.7	15.0±15.7	1.2±0.7
Raddi Lake, NWT[3]	1.7±0.9	1.6±0.60	12.0±4.4	33.5±9.9	17.1±7.0	42.8±18.2	4.0±2.9
Fish Lake, NWT[3]	2.4±0.85	1.6±0.4	13.5±6.3	31.9±15.5	14.3±3.9	50.6±27.8	4.2±1.9
Gordon Lake, NWT[4]		0.68±0.34	7.9±6.3	16.3±12.6	5.4±5.0	35.7±36.8	3.0±1.3
Trout Lake, NWT[4]		2.5±2.6	10.5±10.3	13.8±9.0	5.3±4.7	44.0±55.0	4.2±1.9
Atlin Lake, YT[5]	1.0	1.9	9.6	12.6	6.9	124	1.72
Bennett Lake, YT[5]	2.2	2.9	25.2	67.7	38.7	304	1.93
Kluane Lake, YT[5]	1.6	1.7	3.0	13.8	8.5	19	3.6
Marsh Lake, YT[5]	1.0	2.8	6.6	8.6	9.8	106	3.4
Tagish Lake, YT[5]	1.7	2.8	16.3	33.0	44.0	238	2.16
Teslin Lake, YT[5]	2.8	0.6	7.3	23.0	15.7	59	7.05
Lake Whitefish							
Colville Lake, NWT[1]	-	1.05±0.71	1.85±0.83	4.44±2.10	1.71±1.39	11.0±13.4	2.6±0.8
Great Slave, NWT[2]	2.4-1.2	1.8-0.8	6.2-3.1	5.9-1.7	2.1-1.0	38.7-14.7	2.5-6.7
Gordon Lake, NWT[4]		0.92±0.91	5.5±3.7	7.9±4.4	3.7±2.8	23.8±17.2	2.7±2.5
Atlin Lake, YT[5]	0.1	0.2	0.3	0.1	0.5	6.0	0.25
Bennett Lake, YT[5]	0.7	0.8	1.3	2.7	2.3	26.0	2.08
Kluane Lake, YT[5]	0.9	1.0	1.0	3.5	1.8	7.0	1.80
Marsh Lake, YT[5]	0.5	1.7	1.2	2.0	5.8	29.9	0.76
Tagish Lake, YT[5]	0.6	0.6	2.2	3.4	1.5	30.0	0.90

[1] Muir and Lockhart (1994).

[2] Data are from Evans (1994) and are shown here as a range of mean concentrations found in males and females from two sites on Great Slave Lake.

[3] Muir and Lockhart (1995).

[4] Muir and Lockhart (1993).

[5] Palmer (1992), samples are pooled tissues from several individuals.

Table V.5: Summary of the best variable or combination of variables for predicting the concentrations of ΣHCH, ΣCBZ, ΣCHL, ΣPCB, ΣDDT and ΣCHB in fish tissues from all Yukon lakes.

Species	ΣHCH	ΣCBZ	ΣCHL	ΣCHB	ΣDDT	ΣPCB
Lake trout	lipid log weight	lipid log weight	lipid log weight $\delta^{15}N$	lipid log weight $\delta^{15}N$	lipid log weight $\delta^{15}N$	log weight $\delta^{15}N$
Burbot	$\delta^{15}N$ weight lipid	$\delta^{15}N$ log age	$\delta^{15}N$ log age	$\delta^{15}N$ log age	$\delta^{15}N$ weight	$\delta^{15}N$ weight
Northern pike	$\delta^{15}N$	-	$\delta^{15}N$ lipid	$\delta^{15}N$	$\delta^{15}N$ lipid	$\delta^{15}N$ lipid
Lake whitefish	lipid	lipid	lipid weight log age	lipid weight $\delta^{15}N$	lipid weight $\delta^{15}N$ log age	lipid weight log age
Longnose sucker	lipid	lipid	lipid length	lipid length	-	-
Round whitefish	lipid	lipid	lipid	lipid	-	-

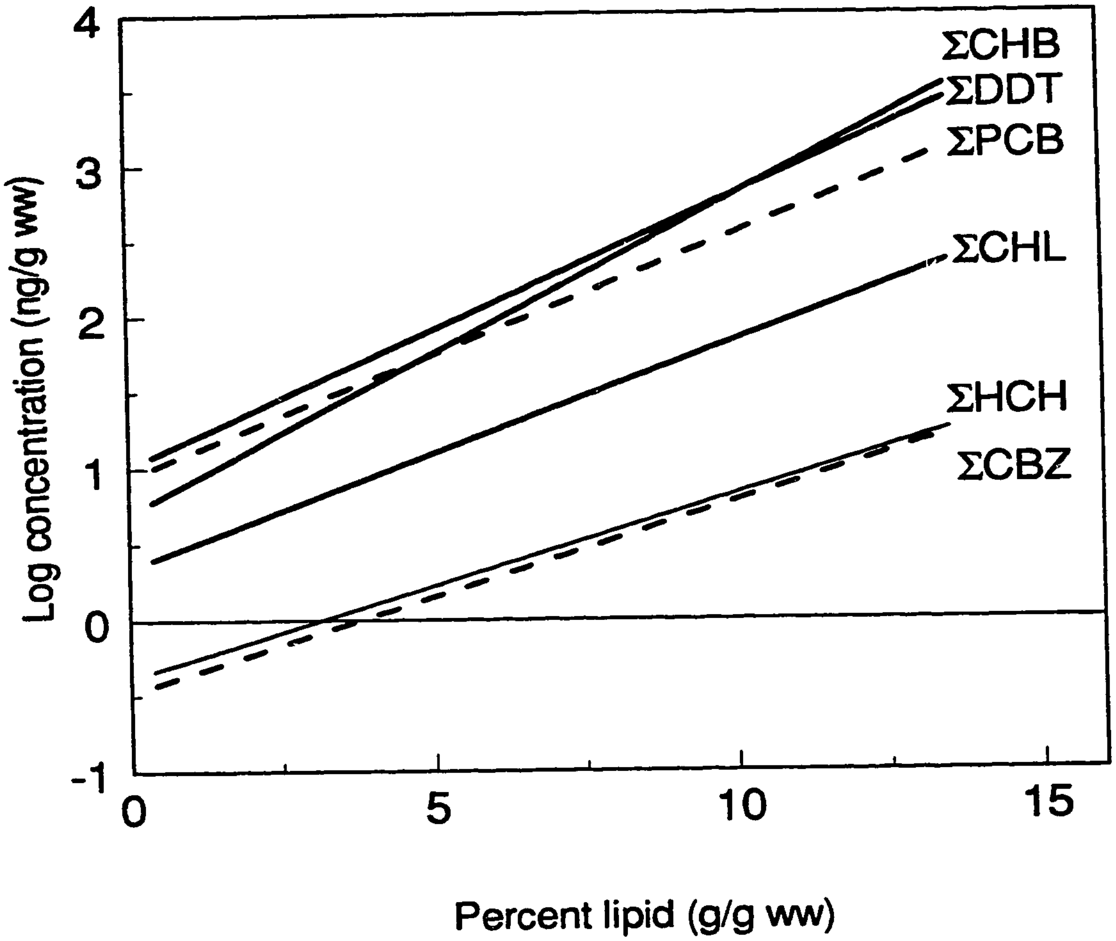

Figure V.1: Regressions of ΣHCH, ΣCBZ, ΣCHL, ΣPCB, ΣDDT, and ΣCHB (ng/g wet weight) versus lipid (g/g wet weight) in lake trout muscle from Laberge, Kusawa and Fox lakes, Yukon Territory. The dashed lines show the relationships for ΣPCB and ΣCBZ. No significant differences ($P > 0.05$) among slopes were found. Significant differences ($P < 0.05$) among intercepts are indicated by different letters after each equation.

logΣCBZ=0.13(0.016)lipid-0.48(0.076), r2=0.62 a
logΣHCH=0.12(0.015)lipid-0.38(0.071), r2=0.63 a
logΣCHL=0.15(0.028)lipid+0.34(0.13), r2=0.44 b
logΣPCB=0.16(0.032)lipid+0.94(0.14), r2=0.43 c
logΣDDT=0.21(0.025)lipid+0.70(0.11), r2=0.66 c
logΣCHB=0.18(0.034)lipid+1.0(0.16), r2=0.44 c

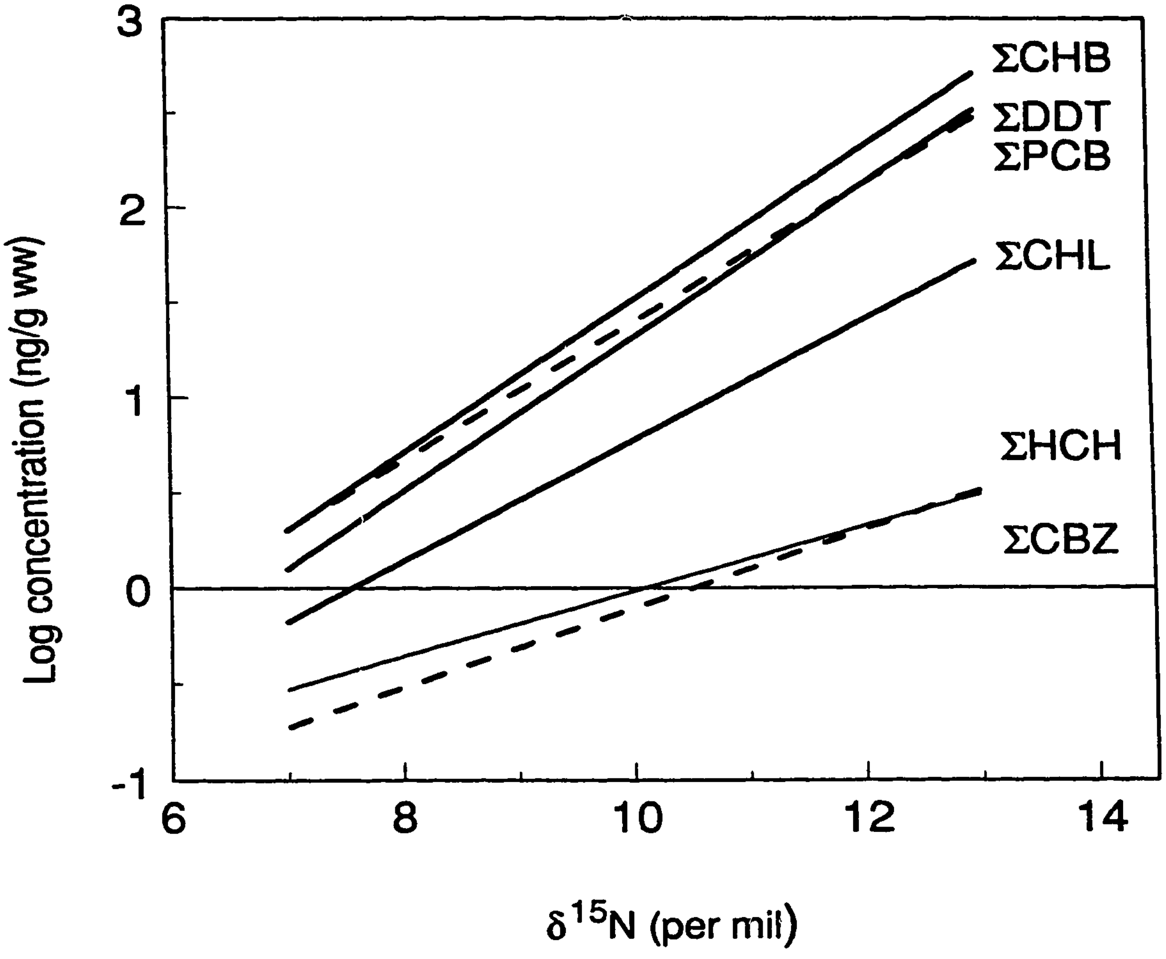

Figure V.2: Regressions of ΣHCH, ΣCBZ, ΣCHL, ΣPCB, ΣDDT, and ΣCHB (ng/g wet weight) versus δ^{15}N (per mil) in lake trout muscle from Laberge, Kusawa and Fox lakes, Yukon Territory. Among regressions, slopes that were not significantly different ($P > 0.05$) have the same letter preceeding the equations. The dashed lines show the relationships for ΣPCB and ΣCBZ.

a	logΣHCH=0.17(0.043)N-1.7(0.44), r2=0.30
a,b	logΣCBZ=0.21(0.042)N-2.2(0.43), r2=0.40
a,b	logΣCHL=0.32(0.056)N-2.4(0.58), r2=0.47
a,b	logΣPCB=0.36(0.060)N-2.2(0.61), r2=0.51
b	logΣDDT=0.40(0.057)N-2.7(0.59), r2=0.58
b	logΣCHB=0.40(0.067)N-2.5(0.68), r2=0.50

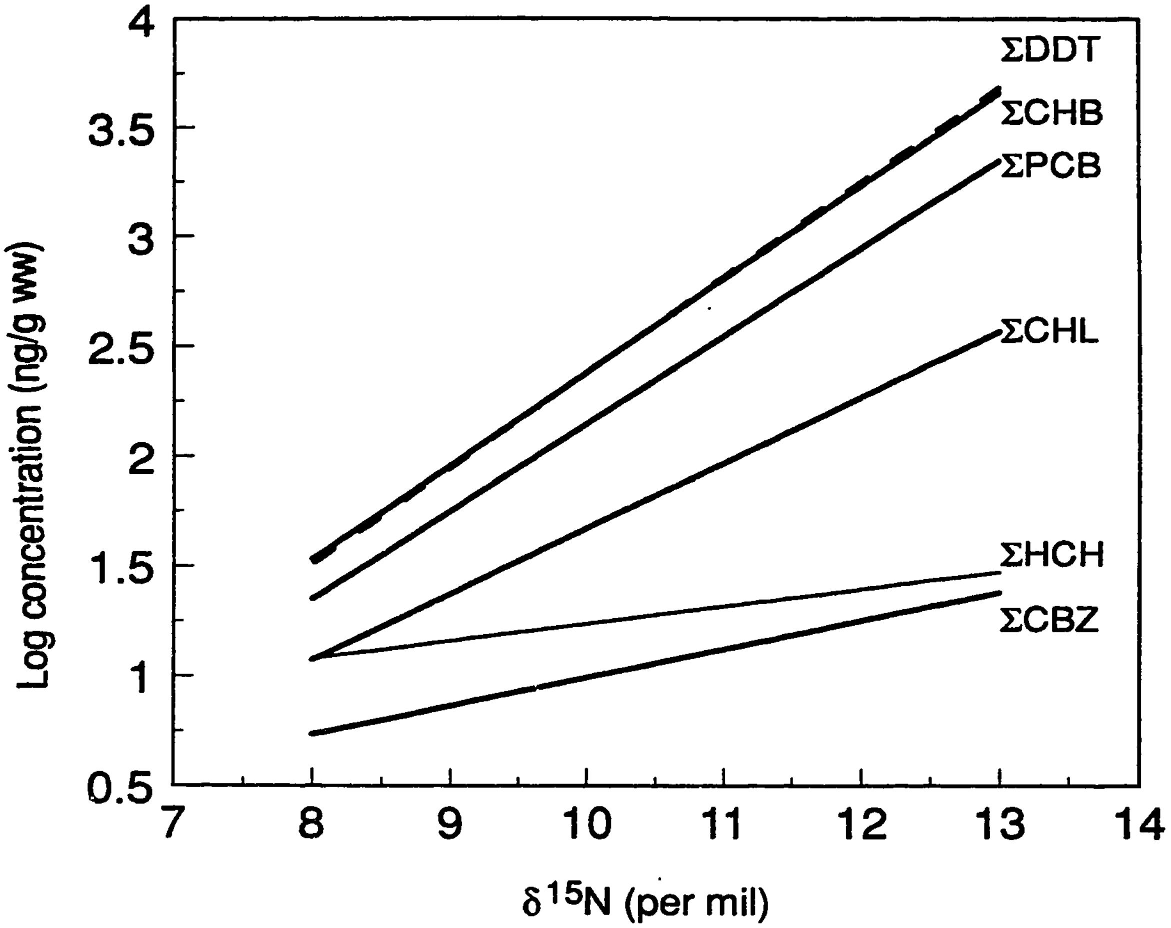

Figure V.3: Regressions of ΣHCH, ΣCBZ, ΣCHL, ΣPCB, ΣDDT, and ΣCHB (ng/g wet weight in liver) versus δ^{15}N (per mil) in burbot muscle from Laberge and Fox lakes, Yukon Territory. The dashed line shows the relationship for ΣDDT. Among regressions, slopes that were not significantly different (*P* > 0.05) have the same letter preceeding the equation.

a	log ΣHCH=0.078(0.015)N+0.45(0.16), r2=0.48
a	log ΣCBZ=0.13(0.019)N-0.29(0.21), r2=0.65
b	log ΣCHL=0.30(0.035)N-1.3(0.37), r2=0.73
b,c	log ΣPCB=0.40(0.036)N-1.8(0.39), r2=0.82
b,c	log ΣCHB=0.42(0.033)N-1.9(0.36), r2=0.85
c	log ΣDDT=0.43(0.039)N-2.0(0.41), r2=0.82

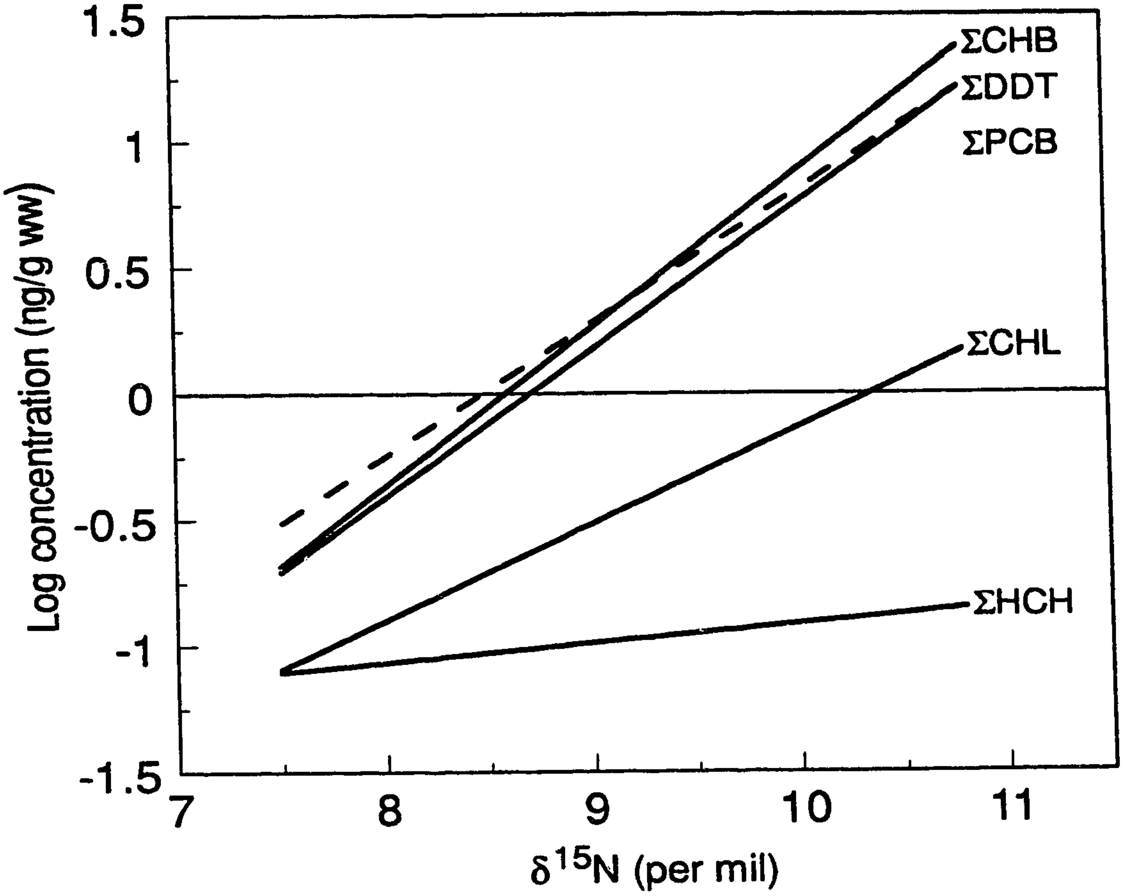

Figure V.4: Regressions of ΣHCH, ΣCHL, ΣPCB, ΣDDT, and ΣCHB (ng/g wet weight) versus $\delta^{15}N$ (per mil) in northern pike muscle from Laberge and Fox lakes, Yukon Territory. Among regressions, slopes that were not significantly different ($P > 0.05$) have the same letter preceeding the equation. The dashed line shows the relationship for ΣDDT.

a logΣHCH=0.077(0.034)N-1.7(0.31), r2=0.28
a,b logΣCHL=0.38(0.081)N-4.0(0.74), r2=0.62
b logΣDDT=0.52(0.099)N-4.5(0.90), r2=0.67
b logΣPCB=0.58(0.094)N-5.1(0.85), r2=0.73
b logΣCHB=0.75(0.16)N-6.7(1.4), r2=0.63

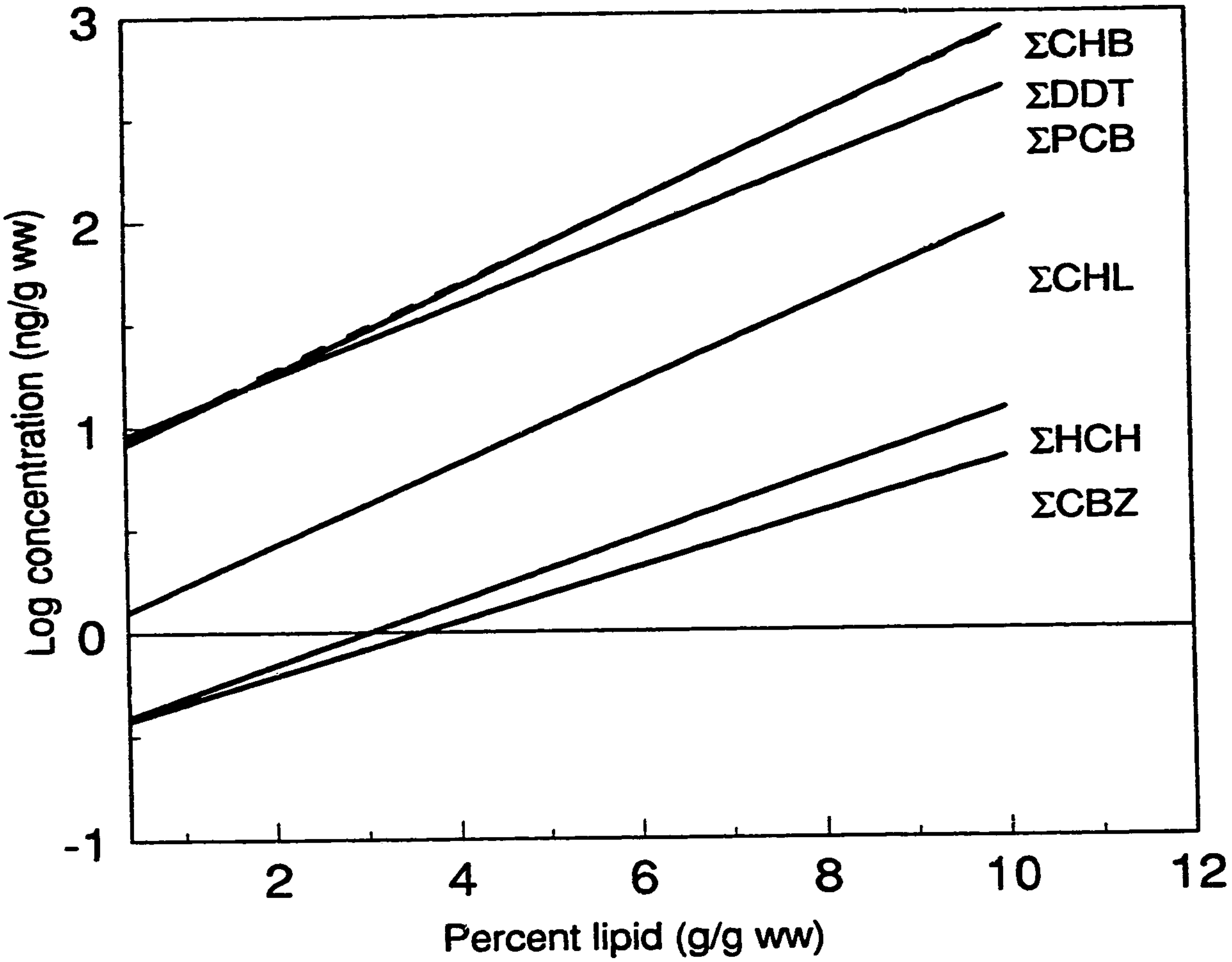

Figure V.5: Regressions of ΣHCH, ΣCBZ, ΣCHL, ΣPCB, ΣDDT, and ΣCHB (ng/g wet weight) versus lipid (ng/g wet weight) in lake whitefish muscle from Laberge, Kusawa and Fox lakes, Yukon Territory. The dashed line shows the relationship for ΣDDT. No significant differences ($P > 0.05$) between the slopes were found. Significant differences ($P < 0.05$) between intercepts are indicated by different letters after each regression equation.

logΣHCH=0.25(0.032)lipid-0.69(0.082), r2=0.53	a
logΣCBZ=0.19(0.021)lipid-0.60(0.052), r2=0.63	a
logΣCHL=0.27(0.042)lipid-0.12(0.11), r2=0.45	b
logΣPCB=0.22(0.053)lipid+0.81(0.14), r2=0.25	c
logΣDDT=0.26(0.056)lipid+0.76(0.14), r2=0.29	c
logΣCHB=0.29(0.043)lipid+0.68(0.11), r2=0.47	c

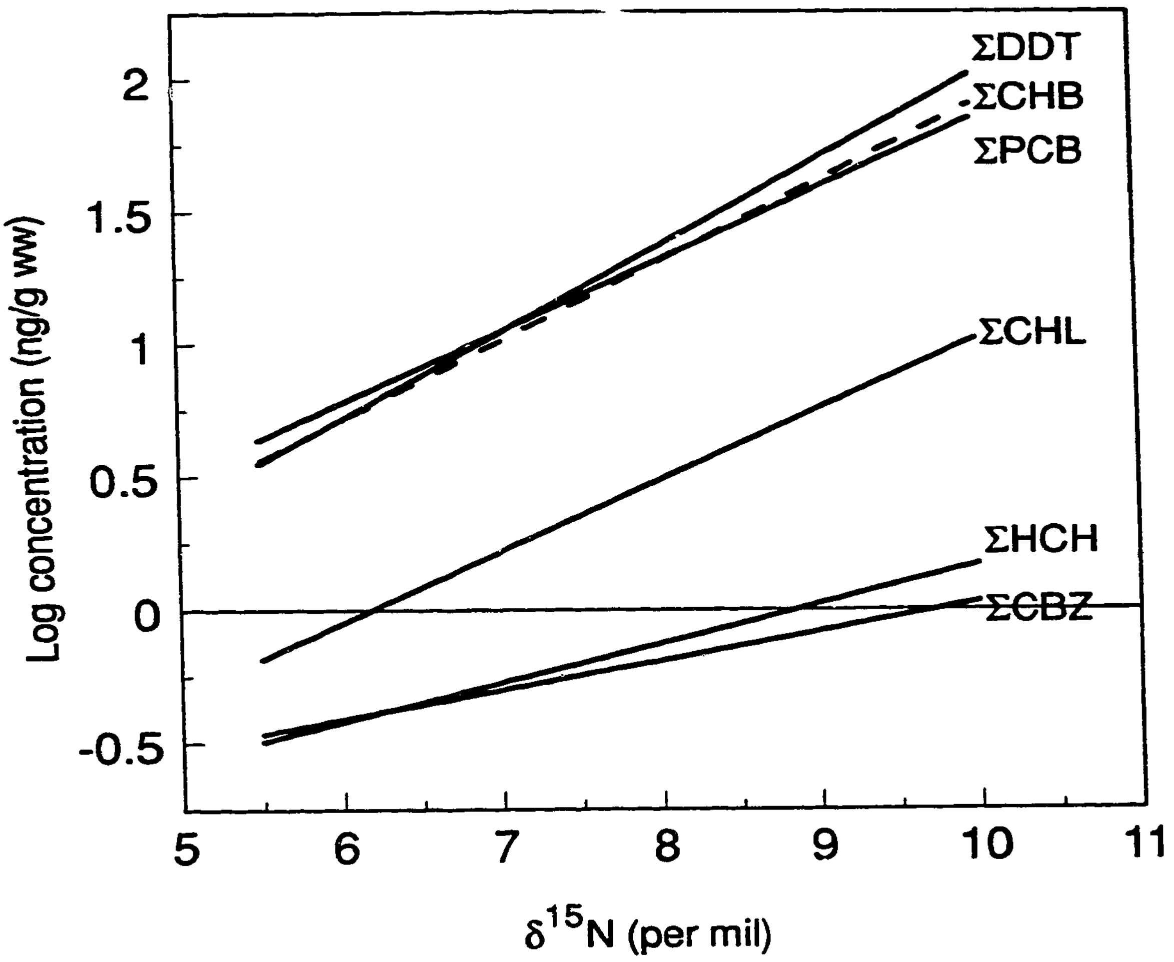

Figure V.6: Regressions of ΣHCH, ΣCBZ, ΣCHL, ΣPCB, ΣDDT, and ΣCHB (ng/g wet weight) versus δ^{15}N (per mil) in lake whitefish muscle from Laberge, Kusawa and Fox lakes, Yukon Territory. The dashed line shows the relationship for ΣCHB. No significant differences ($P > 0.05$) between slopes were found. Significant differences ($P < 0.05$) in intercepts are indicated by different letters following each regression equation.

logΣHCH=0.15 (0.048)N-1.3(0.39), r2=0.15	a
logΣCBZ=0.11(0.044)N-1.1(0.35), r2=0.12	a
logΣCHL=0.27(0.065)N-1.7(0.52), r2=0.26	b
logΣPCB=0.27(0.074)N-0.85(0.59), r2=0.22	c
logΣDDT=0.33(0.076)N-1.3(0.60), r2=0.28	c
logΣCHB =0.30(0.067)N-1.1(0.53), r2=0.30	c

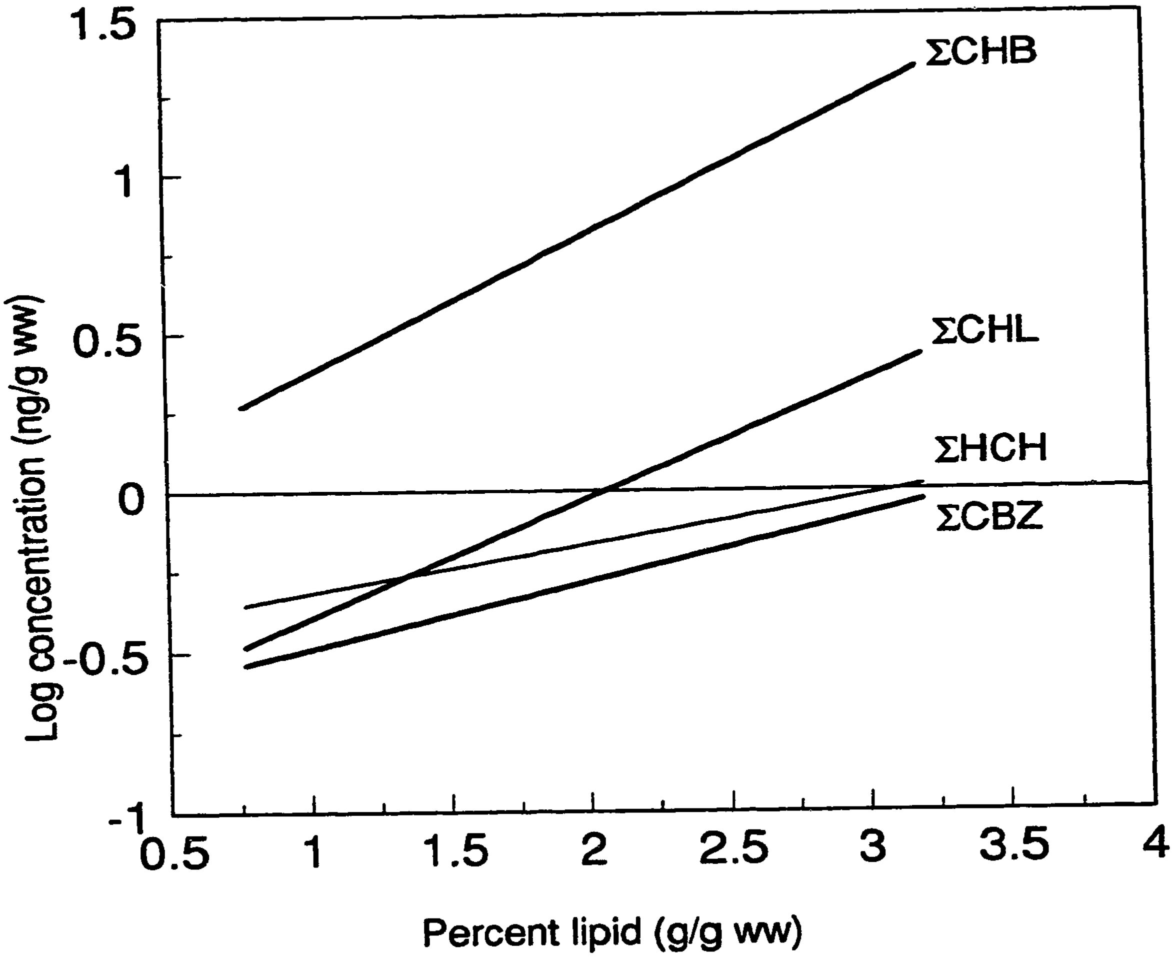

Figure V.7: Regressions of ΣHCH, ΣCBZ, ΣCHL and ΣCHB (ng/g wet weight) versus lipid (g/g wet weight) in round whitefish muscle from Laberge, Kusawa and Fox lakes, Yukon Territory. No significant differences were found among the slopes ($P > 0.05$). Significant differences between intercepts ($P < 0.05$) are indicated by different letters following each equation.

logΣHCH=0.15(0.051)lipid-0.47(0.11), r2=0.32	a
logΣCBZ=0.21(0.055)lipid-0.70(0.12), r2=0.42	a
logΣCHL=0.37(0.14)lipid-0.77(0.30), r2=0.28	a
logΣCHB =0.44(0.16)lipid-0.066(0.35), r2=0.28	b

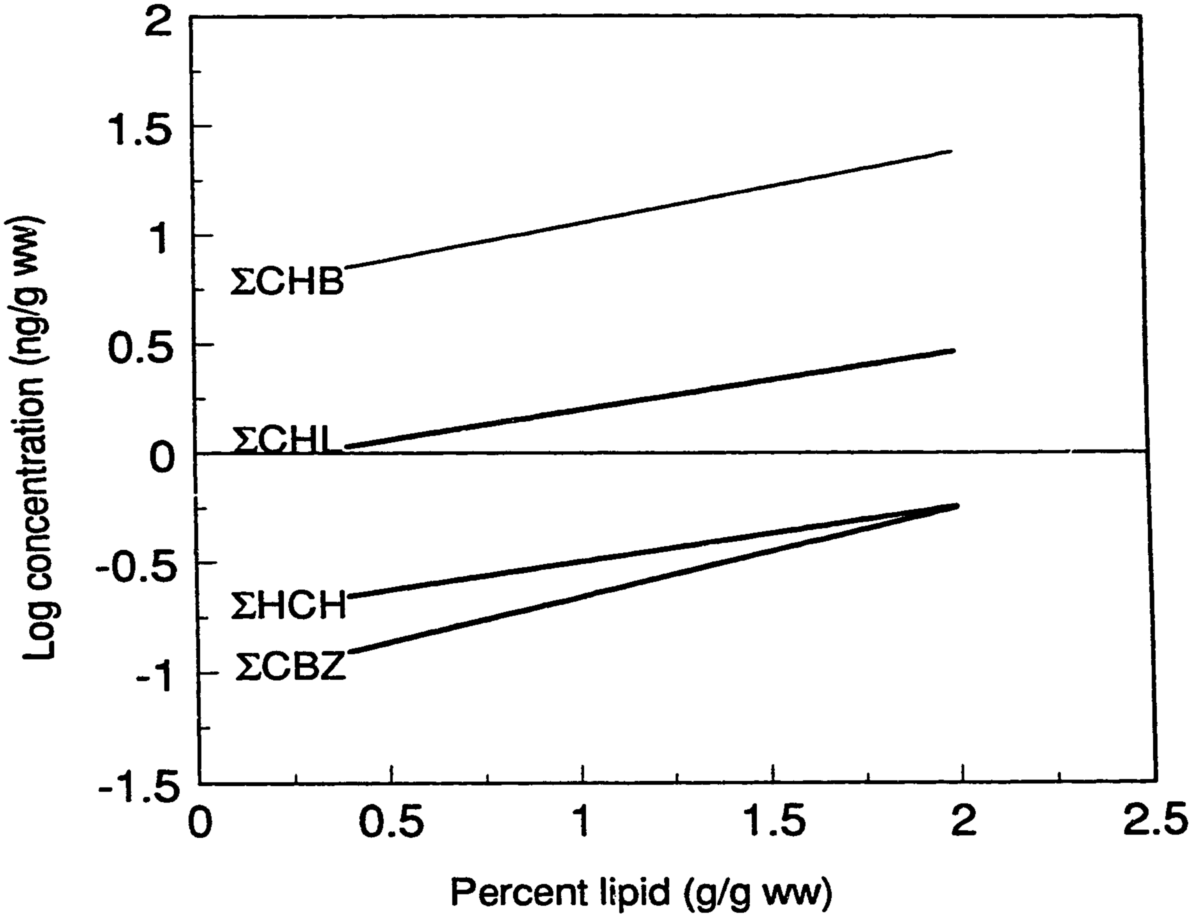

Figure V.8: Regressions of ΣHCH, ΣCBZ ΣCHL, and ΣCHB (ng/g wet weight) versus lipid (g/g wet weight) in longnose sucker muscle from Laberge and Kusawa lakes, Yukon Territory. No significant differences were found between slopes ($P > 0.05$). Significant differences between intercepts ($P < 0.05$) are indicated by a different letter following each equation.

logΣHCH=0.26(0.080)lipid-0.76(0.093), r2=0.39	a
logΣCBZ=0.41(0.083)lipid-1.1(0.096), r2=0.60	a
logΣCHL=0.27(0.13)lipid-0.076(0.15), r2=0.23	b
logΣCHB=0.33(0.14)lipid+0.72(0.16), r2=0.26	c

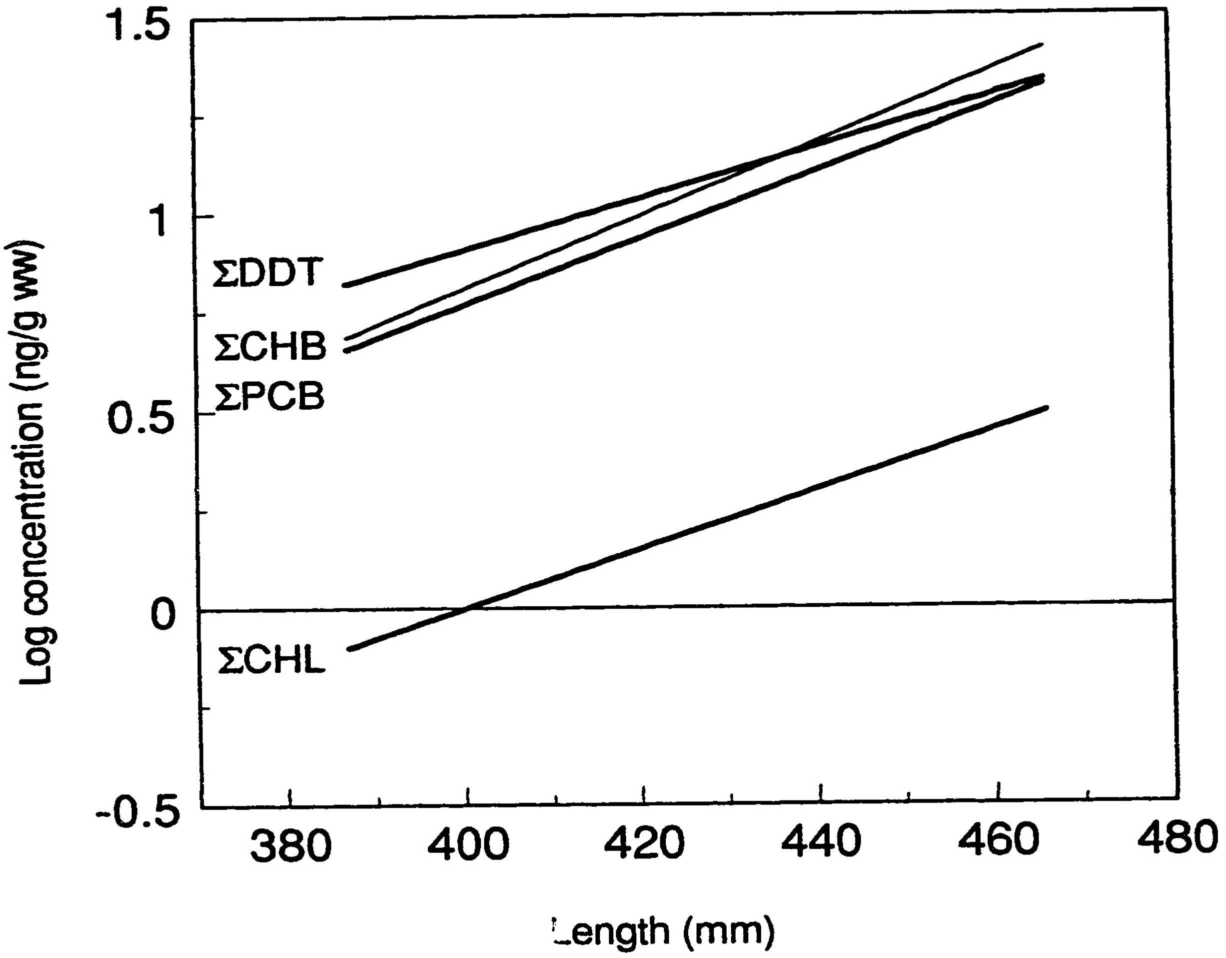

Figure V.9: Regressions of ΣCHL, ΣPCB, ΣDDT, and ΣCHB (ng/g wet weight) versus length (mm) in longnose sucker muscle from Laberge and Kusawa lakes, Yukon Territory. Slopes were not significantly different ($P > 0.05$). Significant differences among intercepts ($P < 0.05$) are indicated by different letters following each equation.

logΣCHL=0.0075(0.0027)length-3.0(1.2), r2=0.31 a

logΣDDT=0.0065(0.0025)length-1.7(1.1), r2=0.29 b

logΣPCB=0.0084(0.0033)length-2.6(1.4), r2=0.28 b

logΣCHB=0.0092(0.0025)length-2.9(1.3), r2=0.38 b

VI. GENERAL DISCUSSION

Although the use of most persistent organochlorines has been discontinued in North America since the 1970s and 1980s, these compounds continue to be detected in biota from the Arctic, and are occasionally found at concentrations that are considered hazardous to human health (Chapter I). Few long-term monitoring studies have been conducted, making it difficult to determine if concentrations of organochlorines in the arctic biosphere are declining. Although inputs of pollutants to the Arctic may be decreasing, such as is found in the Laurentian Great Lakes, this reduction is reflected much more slowly in biota, particularly in organisms from the upper trophic levels of food webs (Gobas et al., 1995). One would expect, given the long lifespans of many arctic species, that a contemporary decline in inputs would take many years to be exemplified in the top predators.

Some of the difficulties associated with assessing the effects of trophic position on organochlorine accumulation in biota are related to the uncertainties involved in determining an organism's trophic position. Traditionally, fishes and invertebrates have been categorized into discrete positions based on observed feeding habits, or stomach content analyses conducted either on organisms from the study lakes, or, more commonly, from systems far-removed from the ones of interest. Tissue $\delta^{15}N$ measurements are currently replacing and/or supplementing these traditional methods of determining trophic interactions because they provide a relatively long-term measure of dietary habits. In Chapter II, I compared the stomach contents of fishes, representing their short-term feeding habits, with their long-term trophic positioning, as determined by muscle $\delta^{15}N$. The results of this comparison indicated that although comparable information was consistently obtained for lower-trophic-level fishes, discrepancies between short-term and long-term feeding habits were observed for the top predators. Individuals that had fed upon fish had muscle $\delta^{15}N$ values consistent with a long-term diet of invertebrates; similarly, fishes containing strictly invertebrates had tissue $\delta^{15}N$ reflecting a piscivorous diet. Stomach contents occasionally represent rare meals and not the average feeding habits of individuals. Further, information from stable nitrogen isotope ratios is invaluable in that it provides a continuous arithmetic measure of the relative trophic positions of fish and invertebrates within systems, and among systems differing in species composition. Similarly, it quantifies the trophic positions for those individuals whose stomachs are empty, or whose stomach contents are unidentifiable, or do not actually represent what is digested and assimilated by the fish.

The relationship between $\delta^{15}N$ and organochlorine concentrations in biota was first examined in marine food webs. Broman et al. (1992) and Rolff et al. (1993) determined that while specific dioxins and furans accumulated through a littoral and pelagic food web in the northern Baltic, total concentrations of these chemicals decreased with increasing $\delta^{15}N$, perhaps due to increased metabolism of these compounds at higher trophic levels. A negative organochlorine-$\delta^{15}N$ relationship was also observed in a study done by Spies et al. (1989) on one species of marine fish collected near a sewage outfall. The authors believed that some individuals were feeding on an isotopically-lighter but more contaminated sewage-based food source than the other fish in the study, resulting in the observed negative relationship.

It is only recently that the relationship between biotic organochlorine concentrations and $\delta^{15}N$ have been examined in freshwater systems. My results indicated that $\delta^{15}N$ is a significant predictor of persistent organochorine concentrations through the food webs of Yukon lakes (Chapter III, IV), and is a better predictor of the more lipophilic organochlorines such as DDT and toxaphene than the less lipophilic compounds such as HCH (Chapter III). Concurrently, significant organochlorine-$\delta^{15}N$ and mercury-$\delta^{15}N$ have been observed for the food webs in Lake Ontario (Kiriluk et al., 1996), Great Slave Lake (Department of Indian Affairs and Northern Development, 1996), and lakes in central Ontario (Cabana and Rasmussen, 1994), thereby indicating that $\delta^{15}N$ has considerable potential for use in future studies of contaminant accumulation in freshwater systems.

The slopes of the organochlorine-$\delta^{15}N$ regressions found for the Yukon lakes studied herein were greater for the more lipophilic than less lipophilic organochlorines (Chapter III), indicating this relationship represents the biomagnification potential of a group of compounds or individual congener. However, among-region differences in the slopes of these relationships have been observed, indicating that the same organochlorine compounds accumulate differently through temperate and arctic food webs. Kiriluk et al. (1996) found a lower slope for log-transformed DDE concentrations (a highly lipophilic breakdown product of DDT and main component of total DDT) versus $\delta^{15}N$ ($0.15\ ug.g^{-1}.\ ‰^{-1}$) in the Lake Ontario food web than I found for log-transformed total DDT concentrations versus

$\delta^{15}N$ in biota from Lake Laberge (0.32 ng.g^{-1}. ‰$^{-1}$; Chapter III), suggesting that factors other than the lipophilicity of pollutants affect the magnitude of this relationship. Also, the log-transformed toxaphene-$\delta^{15}N$ slopes found in the Great Slave Lake food web (0.16 and 0.12 ng.g^{-1}. ‰$^{-1}$; Department of Indian Affairs and Northern Development, 1996) were lower than the results for the same species from Yukon lakes (0.19 to 0.25 ng.g^{-1}. ‰$^{-1}$; Chapter IV). Further characterization of the organochlorine-$\delta^{15}N$ relationships from other lakes is required to determine the factors underlying these regional differences in the accumulation of these pollutants between arctic lakes, and between arctic and temperate food webs.

The relative importance of trophic position and lipid on organochlorine accumulation in biota is difficult to determine because lipid content is significantly related to $\delta^{15}N$ (Chapter III and V; Kiriluk et al., 1996). However, analyses of the organochlorine-lipid and organochlorine-$\delta^{15}N$ relationships within each fish species have revealed some interesting differences. No significant differences in the slopes of the organochlorine-lipid relationships were observed for organochlorines ranging in lipophilicities. In contrast, the slopes of the organochlorine-$\delta^{15}N$ relationships for the top predators increased significantly with increasing lipophilicty of the organochlorines (Chapter V). This latter relationship was observed for lake trout, burbot and northern pike, but not for lake whitefish, which suggests that trophic position is a more significant factor for top predators and not forage fishes. These finding supports the models of Connolly and Pedersen (1988) and Thomann and Connolly (1984); trophic position is a more significant factor in organochlorine accumulation for the more lipophilic contaminants ($K_{ow}>10^4$) when compared to the less lipophilic contaminants, and for upper-trophic-level fishes when compared to forage fishes.

The concentrations of persistent organochlorines found in the top predators from Lake Laberge were anomalously high, and this has been attributed to a longer food chain in this lake when compared to other regional lakes (Chapter IV). Since 1991, all fishing on this lake has been stopped, including commercial, sport and subsistence fisheries. I have previously speculated that the unusually long food chain found in Lake Laberge may have been a result of heavy fishing pressure on the lake. The selective harvest of sensitive species such as lake trout and lake whitefish may have resulted in a shift in the species' dominance within this lake. The lack of intraspecific competition within the Laberge lake trout population may have enabled this fish to grow faster, and switch to higher-trophic-level feeding at a younger age than the populations in nearby lakes. Higher-trophic-level feeding, in turn, results in higher concentrations of organochlorines in the fishes (Rasmussen et al., 1990) because these fish feed upon more contaminated prey, and live longer (Martin, 1966), thereby increasing the length of their exposure to these compounds. No study has examined the relationship between fishing pressure and the biomagnification of organochlorines, most likely because the impact of fisheries on communities requires long-term studies and intensive techniques. Lake Laberge may provide a unique opportunity for such a study since the fisheries have been discontinued on the lake. The Yukon Territorial Government has plans to monitor the lake over the long-term to determine if species dominance in the fish community will change with the lack of fishing pressure (currently biomasses of burbot and longnose sucker are unusually high, Table I.1), and if this, in turn, affects the feeding habits of the top predators (N. de Graff, pers. comm., Fisheries and Wildlife Branch, Department of Renewable Resources, Yukon Territorial Government, Whitehorse). A recovery of the lake trout population in Laberge may, through increased competition among fish, result in more individuals feeding at a lower trophic level. In turn, this lower-trophic-level feeding may effectively reduce the concentrations of organochlorines found in their muscle.

The concentrations of organochlorines in fishes vary considerably among arctic and subarctic lakes that are believed to be contaminated solely by long-range transport and deposition (DIAND, 1996). Factors affecting the accumulation of these pollutants in arctic biota are not well understood. To date, most studies have been conducted on temperate lakes where warmer temperatures, higher productivity rates, and shorter maturation times and lifespans of the biota may effectively reduce an organism's exposure to and uptake of persistent organochlorines. Results from my research indicated that the length of the underlying food chain significantly affected the concentrations of persistent organochlorines in top predators from subarctic lakes, in agreement with the findings of Rasmussen et al. (1990) for temperate lakes. Although nitrogen isotope ratios appear to have significant potential in predicting the contaminant burdens in fishes, further studies on other arctic and subarctic freshwater food webs would strengthen our understanding of the variability observed in the organochlorine-δ^{15}N relationship.

References

Broman, D., C. Naf, C. Rolff, Y. Zebuhr, B. Fry and J. Hobbie (1992) Using ratios of stable nitrogen isotopes to estimate bioaccumulation and flux of polychlorinated dibenzo-p-dioxins (PCDDs and dibenzofurans (PCDFs) in two food chains from the northern Baltic. Environ. Toxicol. Chem. 11:331-345.

Cabana, G. and J.B. Rasmussen (1994) Modelling food chain structure and contaminant bioaccumulation using stable nitrogen isotopes. Nature 372(17):255-257.

Connolly, J.P. and C.J. Pedersen (1988) A thermodynamic-based evaluation of organic chemical accumulation in aquatic organisms. Environ. Sci. Technol. 22(1):99-103.

Department of Indian Affairs and Northern Development (1996) Canadian Arctic Contaminants Assessment Report. Chapter III: Ecosystem uptake and effects. (ed.) D.C.G. Muir, Department of Indian Affairs and Northern Development, in preparation.

Gobas, F.A.P.C., M.N. Z'Graggen and X. Zhang (1995) Time response of the Lake Ontario ecosystem to virtual elimination of PCBs. Environ. Sci. Technol. 29:2038-2046.

Kiriluk, R.M., M.R. Servos, D.M. Whittle, G. Cabana and J.B. Rasmussen (1996) Using ratios of stable nitrogen and carbon isotopes to characterize the biomagnification of DDE, mirex and PCB in a Lake Ontario pelagic food web. Can. J. Fish. Aquat. Sci., in press.

Martin, N.V. (1966) The significance of food habits in the biology, exploitation, and management of Algonquin Park, Ontario, lake trout. Trans. Am. Fish. Soc. 95:415-422.

Rasmussen, J.B., D.J. Rowan, D.R.S. Lean and J.H. Carey (1990) Food chain structure in Ontario lakes determines PCB levels in lake trout (Salvelinus namaycush) and other pelagic fish. Can. J. Fish. Aquat. Sci. 47:2030-2038.

Rolff, C., D. Broman, C. Naf and Y. Zebuhr (1993) Potential biomagnification of PCDD/Fs -New possibilities for quantitative assessment using stable isotope trophic position. Chemosphere 27(1-3):461-468.

Spies, R. B., H. Kruger, R. Ireland and D. W. Rice (1989) Stable isotope ratios and contaminant concentrations in a sewage-distorted food web. Mar. Ecol. Prog. Ser. 54:157-170.

Thomann, R.V. and J.P. Connolly (1984) Model of PCB in the Lake Michigan lake trout food chain. Environ. Sci. Technol. 18(2):65-71.

Appendix A: Length, weight, sex, age, date and 15N/14N for each fish collected from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993).

Lake	Species	Fish Number	Length (mm)	Weight (g)	Sex	Age	Date	15N/14N (per mil)
Fox	Burbot	173	689	2500	M	12	6/29/92	9.76
Fox	Burbot	196	604	1100	M	12	6/30/92	9.28
Fox	Burbot	208	730	2450	M	16	6/30/92	8.38
Fox	Burbot	210	650	1500	F	10	6/30/92	9.77
Fox	Burbot	905	498	1075	F	11	8/6/93	7.65
Fox	Burbot	906	505	950	M	10	8/6/93	7.99
Fox	Burbot	909	461	1100	M	7	8/6/93	8.22
Fox	Burbot	910	488	750	F	10	8/6/93	9.03
Fox	Burbot	1000	580	1650	M	16	8/21/93	8.73
Fox	Burbot	1001	435	800	M	9	8/21/93	9.41
Fox	Burbot	1002	542	1300	M	8	8/21/93	7.94
Fox	Burbot	1003	481	825	F	10	8/21/93	9.62
Fox	Burbot	1004	553	1275	F	11	8/21/93	9.16
Fox	Burbot	1005	540	1650	F	13	8/21/93	9.18
Fox	Lake trout	169	506	1500	F	22	6/29/92	
Fox	Lake trout	170	478	1000	M	16	6/29/92	
Fox	Lake trout	174	530	1500	F	11	6/29/92	
Fox	Lake trout	186	350	500	F	10	6/29/92	
Fox	Lake trout	187	450	1000	M	.	6/29/92	
Fox	Lake trout	191	128	20	I	.	6/29/92	
Fox	Lake trout	193	117	16	I	.	6/29/92	
Fox	Lake trout	194	109	14	I	.	6/29/92	
Fox	Lake trout	195	117	19	I	.	6/29/92	
Fox	Lake trout	197	437	900	F	24	6/30/92	
Fox	Lake trout	198	504	1300	F	20	6/30/92	8.12
Fox	Lake trout	203	390	800	F	28	6/30/92	
Fox	Lake trout	204	530	1600	F	35	6/30/92	9.01
Fox	Lake trout	206	419	850	M	26	6/30/92	8.73
Fox	Lake trout	209	674	5000	M	.	6/30/92	9.48
Fox	Lake trout	211	426	600	M	8	6/30/92	
Fox	Lake trout	212	525	1500	F	21	6/30/92	9.58
Fox	Lake trout	213	195	72	I	.	6/30/92	
Fox	Lake trout	563	408	700	M	15	6/7/93	
Fox	Lake trout	636	170	50	I	5	6/7/93	
Fox	Lake trout	637	181	60	I	7	6/7/93	
Fox	Lake trout	638	117	17	I	2	6/7/93	
Fox	Lake trout	639	510	1675	M	19	6/7/93	
Fox	Lake trout	640	521	1700	M	17	6/7/93	7.98
Fox	Lake trout	641	291	150	M	10	6/7/93	9.66
Fox	Lake trout	642	334	425	M	11	6/7/93	7.00
Fox	Lake trout	643	401	650	F	23	6/7/93	
Fox	Lake trout	658	447	1000	M	26	6/7/93	9.48
Fox	Lake trout	743	429	900	M	13	7/21/93	7.69
Fox	Lake trout	744	512	1450	M	15	7/21/93	8.01
Fox	Lake trout	745	487	1300	M	17	7/21/93	
Fox	Lake trout	760	447	1000	M	14	7/21/93	8.28
Fox	Lake trout	761	509	750	M	13	7/21/93	8.70

Appendix A: Length, weight, sex, age, date and 15N/14N for each fish collected from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993).

Lake	Species	Fish Number	Length (mm)	Weight (g)	Sex	Age	Date	15N/14N (per mil)
Fox	Lake trout	900	281	325	I	9	8/6/93	
Fox	Lake trout	901	578	2625	F	20	8/6/93	9.22
Fox	Lake trout	902	385	700	F	14	8/6/93	9.58
Fox	Lake trout	903	433	725	M	21	8/6/93	8.71
Fox	Lake trout	904	327	575	M	11	8/6/93	7.92
Fox	Lake trout	907	445	750	F	13	8/6/93	9.25
Fox	Lake trout	962	329	375	I	10	8/6/93	9.64
Fox	Lake trout	963	362	450	F	26	8/6/93	10.36
Fox	Lake trout	965	214	125	I	7	8/6/93	
Fox	Lake trout	966	159	50	I	4	8/6/93	
Fox	Lake whitefish	176	488	1250	M	19	6/29/92	
Fox	Lake whitefish	178	432	950	M	15	6/29/92	
Fox	Lake whitefish	179	345	400	F	.	6/29/92	
Fox	Lake whitefish	183	490	1000	F	.	6/29/92	
Fox	Lake whitefish	185	595	1200	F	29	6/29/92	
Fox	Lake whitefish	188	260	74	F	5	6/29/92	
Fox	Lake whitefish	189	176	51	I	3	6/29/92	
Fox	Lake whitefish	199	452	1000	F	24	6/30/92	8.79
Fox	Lake whitefish	200	455	1100	F	39	6/30/92	8.52
Fox	Lake whitefish	201	459	1000	F	29	6/30/92	
Fox	Lake whitefish	202	480	1200	M	25	6/30/92	
Fox	Lake whitefish	205	452	700	M	.	6/30/92	
Fox	Lake whitefish	207	440	700	F	.	6/30/92	
Fox	Lake whitefish	565	391	700	M	12	6/7/93	
Fox	Lake whitefish	566	447	950	M	14	6/7/93	
Fox	Lake whitefish	567	434	1000	M	20	6/7/93	
Fox	Lake whitefish	568	490	1200	M	16	6/7/93	
Fox	Lake whitefish	628	455	1050	F	14	6/17/93	7.92
Fox	Lake whitefish	629	448	1000	F	14	6/17/93	7.43
Fox	Lake whitefish	630	450	950	F	12	6/17/93	8.18
Fox	Lake whitefish	631	455	900	F	21	6/17/93	5.95
Fox	Lake whitefish	632	441	1000	M	16	6/17/93	8.45
Fox	Lake whitefish	633	448	1050	F	16	6/17/93	
Fox	Lake whitefish	634	440	575	F	13	6/17/93	8.03
Fox	Lake whitefish	635	468	1300	M	.	6/17/93	7.79
Fox	Lake whitefish	644	356	600	M	6	6/17/93	
Fox	Lake whitefish	645	364	550	M	6	6/17/93	
Fox	Lake whitefish	646	347	575	M	6	6/17/93	6.05
Fox	Lake whitefish	647	355	500	M	5	6/17/93	7.02
Fox	Lake whitefish	648	361	600	M	5	6/17/93	6.42
Fox	Lake whitefish	649	356	500	F	5	6/17/93	
Fox	Lake whitefish	650	365	625	F	6	6/17/93	5.44
Fox	Lake whitefish	651	364	525	M	6	6/17/93	
Fox	Lake whitefish	652	363	600	M	6	6/17/93	
Fox	Lake whitefish	653	355	500	M	5	6/17/93	
Fox	Lake whitefish	654	409	900	F	8	6/17/93	
Fox	Lake whitefish	655	423	925	F	10	6/17/93	

Appendix A: Length, weight, sex, age, date and 15N/14N for each fish collected from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993).

Lake	Species	Fish Number	Length (mm)	Weight (g)	Sex	Age	Date	15N/14N (per mil)
Fox	Lake whitefish	659	441	850	M	16	6/17/93	7.09
Fox	Lake whitefish	660	447	1000	M	23	6/17/93	7.10
Fox	Lake whitefish	661	434	875	M	14	6/17/93	8.13
Fox	Lake whitefish	662	456	900	M	15	6/17/93	7.65
Fox	Lake whitefish	663	443	900	M	15	6/17/93	
Fox	Lake whitefish	664	445	850	F	20	6/17/93	
Fox	Lake whitefish	666	433	650	M	13	6/17/93	
Fox	Lake whitefish	667	543	1000	F	16	6/17/93	
Fox	Lake whitefish	668	392	650	F	8	6/17/93	
Fox	Lake whitefish	767	460	950	F	10	7/21/93	
Fox	Lake whitefish	768	455	850	M	18	7/21/93	
Fox	Lake whitefish	769	418	700	M	7	7/21/93	
Fox	Lake whitefish	770	485	1050	M	13	7/21/93	
Fox	Lake whitefish	771	465	1050	F	12	7/21/93	
Fox	Lake whitefish	772	467	1150	F	.	7/21/93	
Fox	Lake whitefish	774	454	1050	F	14	7/21/93	
Fox	Lake whitefish	775	478	1150	F	18	7/21/93	
Fox	Lake whitefish	776	370	625	F	9	7/21/93	
Fox	Lake whitefish	777	362	450	M	6	7/21/93	
Fox	Lake whitefish	778	373	600	M	7	7/21/93	
Fox	Lake whitefish	779	436	925	F	7	7/21/93	
Fox	Lake whitefish	780	439	1000	M	8	7/21/93	
Fox	Lake whitefish	781	475	1100	M	12	7/21/93	
Fox	Lake whitefish	782	419	1050	F	16	7/21/93	
Fox	Lake whitefish	783	492	1150	M	20	7/21/93	
Fox	Lake whitefish	784	457	1125	M	17	7/21/93	
Fox	Lake whitefish	908	441	800	F	14	8/6/93	
Fox	Lake whitefish	911	407	750	F	8	8/6/93	
Fox	Lake whitefish	912	464	800	F	16	8/6/93	
Fox	Lake whitefish	913	468	800	M	15	8/6/93	
Fox	Lake whitefish	914	455	950	F	16	8/6/93	
Fox	Lake whitefish	915	[illegible]	1150	M	16	8/6/93	
Fox	Lake whitefish	916	[illegible]	2100	M	21	8/6/93	
Fox	Lake whitefish	917	[illegible]	1000	M	15	8/6/93	
Fox	Lake whitefish	918	450	1000	F	17	8/6/93	
Fox	Lake whitefish	920	447	750	M	15	8/6/93	
Fox	Lake whitefish	921	458	1250	M	16	8/6/93	
Fox	Lake whitefish	922	465	1175	M	14	8/6/93	
Fox	Lake whitefish	925	375	625	F	6	8/6/93	
Fox	Lake whitefish	926	472	1150	M	24	8/6/93	
Fox	Lake whitefish	927	465	1175	F	15	8/6/93	
Fox	Lake whitefish	928	430	875	F	19	8/6/93	
Fox	Lake whitefish	929	455	1050	M	17	8/6/93	
Fox	Lake whitefish	930	437	775	M	15	8/6/93	
Fox	Lake whitefish	931	458	1200	M	19	8/6/93	
Fox	Lake whitefish	932	465	1400	M	14	8/6/93	
Fox	Lake whitefish	933	475	1375	M	15	8/6/93	

Appendix A: Length, weight, sex, age, date and 15N/14N for each fish collected from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993).

Lake	Species	Fish Number	Length (mm)	Weight (g)	Sex	Age	Date	15N/14N (per mil)
Fox	Lake whitefish	934	370	575	I	6	8/6/93	
Fox	Lake whitefish	935	462	1075	M	16	8/6/93	
Fox	Lake whitefish	936	447	1050	F	11	8/6/93	
Fox	Lake whitefish	937	455	925	M	.	8/6/93	
Fox	Lake whitefish	938	477	1000	M	17	8/6/93	
Fox	Lake whitefish	939	454	925	F	14	8/6/93	
Fox	Lake whitefish	940	462	1225	M	11	8/6/93	
Fox	Lake whitefish	941	572	2500	M	13	8/6/93	
Fox	Lake whitefish	942	498	1450	M	17	8/6/93	
Fox	Lake whitefish	944	562	1300	F	19	8/6/93	
Fox	Lake whitefish	945	450	1250	M	18	8/6/93	
Fox	Lake whitefish	946	458	1100	F	18	8/6/93	
Fox	Lake whitefish	947	506	1500	F	23	8/6/93	
Fox	Lake whitefish	948	423	1000	M	8	8/6/93	
Fox	Lake whitefish	949	427	1025	F	8	8/6/93	
Fox	Lake whitefish	950	454	1050	F	15	8/6/93	
Fox	Lake whitefish	951	365	600	F	7	8/6/93	
Fox	Lake whitefish	952	438	1100	M	10	8/6/93	
Fox	Lake whitefish	953	444	1100	F	16	8/6/93	
Fox	Lake whitefish	954	450	850	F	14	8/6/93	
Fox	Lake whitefish	955	378	650	I	5	8/6/93	
Fox	Lake whitefish	956	374	650	I	6	8/6/93	
Fox	Lake whitefish	957	446	1100	M	.	8/6/93	
Fox	Lake whitefish	958	447	1150	M	12	8/6/93	
Fox	Lake whitefish	959	378	600	I	6	8/6/93	
Fox	Lake whitefish	960	356	500	I	7	8/6/93	
Fox	Lake whitefish	961	335	450	I	6	8/6/93	
Fox	Northern pike	750	618	1600	M	8	7/21/93	7.68
Fox	Northern pike	751	742	3100	M	4	7/21/93	8.43
Fox	Northern pike	753	657	2025	F	5	7/21/93	7.87
Fox	Northern pike	756	719	2875	F	6	7/21/93	9.06
Fox	Northern pike	757	657	2100	M	7	7/21/93	7.90
Fox	Northern pike	758	771	3625	F	8	7/21/93	8.90
Fox	Northern pike	759	750	3100	F	11	7/21/93	8.94
Fox	Northern pike	787	425	600	M	4	7/21/93	7.23
Fox	Northern pike	788	528	1250	F	4	7/21/93	
Fox	Northern pike	789	670	2710	M	10	7/21/93	8.32
Fox	Round whitefish	553	320	250	F	6	6/7/93	6.67
Fox	Round whitefish	554	269	175	M	5	6/7/93	5.89
Fox	Round whitefish	555	168	41	I	3	6/7/93	6.24
Fox	Round whitefish	556	168	39	I	3	6/7/93	6.55
Fox	Round whitefish	557	165	39	I	3	6/7/93	6.60
Fox	Round whitefish	558	167	39	I	3	6/7/93	6.30
Fox	Round whitefish	559	167	35	I	4	6/7/93	
Fox	Round whitefish	560	320	350	F	7	6/7/93	6.30
Fox	Round whitefish	561	168	40	I	2	6/7/93	
Fox	Round whitefish	564	380	500	F	11	6/7/93	6.65

Appendix A: Length, weight, sex, age, date and 15N/14N for each fish collected from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993).

Lake	Species	Fish Number	Length (mm)	Weight (g)	Sex	Age	Date	15N/14N (per mil)
Fox	Round whitefish	766	275	139	I	.	7/21/93	
Fox	Round whitefish	786	329	1050	M	7	7/21/93	
Kusawa	Lake trout	305	146	26	I	3	7/21/92	
Kusawa	Lake trout	308	136	27	I	4	7/21/92	6.98
Kusawa	Lake trout	920-0083	415	629	M	20	3/16/92	10.13
Kusawa	Lake trout	920-0086	471	963	F	22	3/16/92	9.75
Kusawa	Lake trout	920-0089	535	1588	M	13	3/16/92	9.49
Kusawa	Lake trout	920-0092	433	824	F	21	3/16/92	9.67
Kusawa	Lake trout	920-0093	513	1655	M	12	3/16/92	10.25
Kusawa	Lake trout	920-0094	698	3967	F	32	3/16/92	10.44
Kusawa	Lake trout	920-0096	646	3116	M	21	3/16/92	9.53
Kusawa	Lake trout	920-0097	460	1002	M	11	3/16/92	9.84
Kusawa	Lake trout	920-0098	555	1708	F	12	3/16/92	10.51
Kusawa	Lake trout	920-0102	524	1480	F	21	3/16/92	9.42
Kusawa	Lake trout	YTG104	248	150	F	5	7/2/93	
Kusawa	Lake trout	YTG105	213	100	F	4	7/2/93	
Kusawa	Lake trout	YTG106	186	50	F	3	7/2/93	
Kusawa	Lake trout	YTG108	381	550	M	.	7/2/93	
Kusawa	Lake trout	YTG109	780	5500	F	14	7/2/93	
Kusawa	Lake trout	YTG110	500	1150	M	.	7/2/93	
Kusawa	Lake trout	YTG111	395	600	M	21	7/2/93	
Kusawa	Lake trout	YTG112	380	500	M	13	7/2/93	
Kusawa	Lake trout	YTG117	380	500	F	11	7/2/93	
Kusawa	Lake trout	YTG119	650	2800	F	15	7/2/93	
Kusawa	Lake trout	YTG121	560	2100	F	17	7/2/93	
Kusawa	Lake trout	YTG123	415	650	M	16	7/2/93	
Kusawa	Lake trout	YTG124	440	650	M	.	7/2/93	
Kusawa	Lake trout	YTG129	415	700	M	9	7/2/93	
Kusawa	Lake trout	YTG131	663	3300	F	20	7/2/93	
Kusawa	Lake trout	YTG133	375	500	F	9	7/2/93	
Kusawa	Lake trout	YTG134	370	500	F	7	7/2/93	
Kusawa	Lake trout	YTG138	430	700	M	19	7/2/93	
Kusawa	Lake trout	YTG139	335	400	F	8	7/2/93	
Kusawa	Lake trout	YTG143	795	6250	F	15	7/2/93	
Kusawa	Lake trout	YTG16	505	1200	M	23	6/29/93	
Kusawa	Lake trout	YTG17	490	1100	F	17	6/29/93	
Kusawa	Lake trout	YTG18	470	1000	F	13	6/29/93	
Kusawa	Lake trout	YTG20	575	2200	M	17	6/29/93	
Kusawa	Lake trout	YTG21	545	2200	M	19	6/29/93	
Kusawa	Lake trout	YTG22	390	600	F	9	6/29/93	
Kusawa	Lake trout	YTG23	480	1000	F	18	6/29/93	
Kusawa	Lake trout	YTG24	455	700	M	22	6/29/93	
Kusawa	Lake trout	YTG25	440	700	M	18	6/29/93	
Kusawa	Lake trout	YTG26	405	600	F	8	6/29/93	
Kusawa	Lake trout	YTG27	205	100	F	3	6/29/93	
Kusawa	Lake trout	YTG29	340	400	M	.	6/29/93	
Kusawa	Lake trout	YTG31	440	800	F	10	6/29/93	

Appendix A: Length, weight, sex, age, date and 15N/14N for each fish collected from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993).

Lake	Species	Fish Number	Length (mm)	Weight (g)	Sex	Age	Date	15N/14N (per mil)
Kusawa	Lake trout	YTG32	430	800	F	9	6/29/93	
Kusawa	Lake trout	YTG34	525	1650	M	11	6/29/93	
Kusawa	Lake trout	YTG35	340	450	I	8	6/29/93	
Kusawa	Lake trout	YTG37	570	1900	F	14	6/29/93	
Kusawa	Lake trout	YTG38	410	650	F	10	6/29/93	
Kusawa	Lake trout	YTG39	440	950	M	9	6/29/93	
Kusawa	Lake trout	YTG48	482	1250	M	9	6/30/93	11.73
Kusawa	Lake trout	YTG49	414	650	F	12	6/30/93	10.69
Kusawa	Lake trout	YTG52	651	3300	F	.	6/30/93	10.95
Kusawa	Lake trout	YTG53	655	3500	F	19	6/30/93	10.84
Kusawa	Lake trout	YTG54	470	1000	F	22	6/30/93	
Kusawa	Lake trout	YTG55	630	2500	M	19	6/30/93	
Kusawa	Lake trout	YTG68	595	2800	F	17	6/30/93	
Kusawa	Lake trout	YTG71	420	600	M	9	6/30/93	
Kusawa	Lake trout	YTG73	630	2600	F	17	6/30/93	
Kusawa	Lake trout	YTG76	430	800	F	16	6/30/93	
Kusawa	Lake trout	YTG80	440	900	F	16	6/30/93	
Kusawa	Lake trout	YTG81	340	300	M	.	6/30/93	
Kusawa	Lake trout	YTG83	445	600	F	12	6/30/93	
Kusawa	Lake trout	YTG84	385	500	M	9	6/30/93	
Kusawa	Lake trout	YTG85	605	2150	F	28	6/30/93	
Kusawa	Lake trout	YTG87	430	700	M	.	6/30/93	
Kusawa	Lake trout	YTG89	520	1700	F	9	6/30/93	
Kusawa	Lake trout	YTG91	455	1100	F	17	6/30/93	
Kusawa	Lake trout	YTG92	540	1400	F	18	6/30/93	
Kusawa	Lake trout	YTG94	680	3600	M	20	6/30/93	
Kusawa	Lake trout	YTG95	562	1500	F	17	6/30/93	
Kusawa	Lake trout	YTG96	350	300	F	4	7/2/93	
Kusawa	Lake trout	YTG98	185	100	I	3	7/2/93	
Kusawa	Lake trout	YTG99	500	1200	M	13	7/2/93	
Kusawa	Lake whitefish	327	415	950	F	19	7/21/92	
Kusawa	Lake whitefish	328	343	600	M	7	7/21/92	5.48
Kusawa	Lake whitefish	329	410	750	F	21	7/21/92	6.43
Kusawa	Lake whitefish	330	395	700	M	24	7/21/92	
Kusawa	Lake whitefish	361	344	500	M	16	7/22/92	5.24
Kusawa	Lake whitefish	362	458	500	F	.	7/22/92	
Kusawa	Lake whitefish	364	350	600	M	17	7/22/92	
Kusawa	Lake whitefish	366	349	500	F	13	7/22/92	
Kusawa	Lake whitefish	373	354	600	M	13	7/23/92	6.40
Kusawa	Lake whitefish	374	354	500	M	9		6.53
Kusawa	Lake whitefish	375	368	550	F	9		7.80
Kusawa	Lake whitefish	376	378	600	F	16	7/23/92	5.56
Kusawa	Lake whitefish	377	392	900	F	17	7/23/92	5.13
Kusawa	Lake whitefish	378	370	600	M	.	7/23/92	
Kusawa	Lake whitefish	379	367	.	.	.	7/23/92	
Kusawa	Lake whitefish	380	404	.	.	.	7/23/92	
Kusawa	Lake whitefish	381	370	.	.	.	7/23/92	

Appendix A: Length, weight, sex, age, date and 15N/14N for each fish collected from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993).

Lake	Species	Fish Number	Length (mm)	Weight (g)	Sex	Age	Date	15N/14N (per mil)
Kusawa	Lake whitefish	382	375	.	.	.	7/23/92	
Kusawa	Lake whitefish	YTG1	365	500	M	9	6/29/93	7.77
Kusawa	Lake whitefish	YTG10	360	500	M	10	6/29/93	
Kusawa	Lake whitefish	YTG101	340	350	F	8	7/2/93	
Kusawa	Lake whitefish	YTG102	350	400	F	11	7/2/93	
Kusawa	Lake whitefish	YTG103	360	500	M	12	7/2/93	
Kusawa	Lake whitefish	YTG104	345	500	M	11	7/2/93	
Kusawa	Lake whitefish	YTG105	350	500	M	17	7/2/93	
Kusawa	Lake whitefish	YTG107	380	700	F	15	7/2/93	
Kusawa	Lake whitefish	YTG108	355	400	F	12	7/2/93	
Kusawa	Lake whitefish	YTG109	355	400	F	10	7/2/93	
Kusawa	Lake whitefish	YTG11	320	350	M	8	6/29/93	
Kusawa	Lake whitefish	YTG110	320	300	M	6	7/2/93	
Kusawa	Lake whitefish	YTG112	365	500	F	14	7/2/93	
Kusawa	Lake whitefish	YTG114	355	450	M	9	7/2/93	
Kusawa	Lake whitefish	YTG115	346	450	F	19	7/2/93	
Kusawa	Lake whitefish	YTG118	360	500	F	11	7/2/93	
Kusawa	Lake whitefish	YTG119	342	450	M	6	7/2/93	
Kusawa	Lake whitefish	YTG12	395	800	F	14	6/29/93	
Kusawa	Lake whitefish	YTG120	330	400	F	.	7/2/93	
Kusawa	Lake whitefish	YTG121	322	300	M	.	7/2/93	
Kusawa	Lake whitefish	YTG123	380	500	F	13	7/2/93	
Kusawa	Lake whitefish	YTG124	400	600	F	21	7/2/93	
Kusawa	Lake whitefish	YTG125	365	550	F	9	7/2/93	
Kusawa	Lake whitefish	YTG126	365	500	M	11	7/2/93	
Kusawa	Lake whitefish	YTG127	360	550	M	.	7/2/93	
Kusawa	Lake whitefish	YTG129	290	300	M	3	7/2/93	
Kusawa	Lake whitefish	YTG13	335	400	F	7	6/29/93	
Kusawa	Lake whitefish	YTG130	362	600	F	10	7/2/93	
Kusawa	Lake whitefish	YTG131	385	600	M	11	7/2/93	
Kusawa	Lake whitefish	YTG132	380	550	M	14	7/2/93	
Kusawa	Lake whitefish	YTG133	360	500	F	5	7/2/93	
Kusawa	Lake whitefish	YTG134	350	450	F	11	7/2/93	
Kusawa	Lake whitefish	YTG135	420	750	F	16	7/2/93	
Kusawa	Lake whitefish	YTG136	345	400	M	11	7/2/93	
Kusawa	Lake whitefish	YTG14	350	500	M	13	6/29/93	
Kusawa	Lake whitefish	YTG142	360	500	F	12	7/2/93	
Kusawa	Lake whitefish	YTG143	375	500	M	10	7/2/93	
Kusawa	Lake whitefish	YTG144	370	450	M	7	7/2/93	
Kusawa	Lake whitefish	YTG148	390	550	F	10	7/2/93	
Kusawa	Lake whitefish	YTG150	355	500	F	14	7/2/93	
Kusawa	Lake whitefish	YTG154	370	550	M	12	7/2/93	
Kusawa	Lake whitefish	YTG156	390	600	F	21	7/2/93	
Kusawa	Lake whitefish	YTG157	400	700	F	17	7/2/93	
Kusawa	Lake whitefish	YTG159	390	750	M	14	7/2/93	
Kusawa	Lake whitefish	YTG160	390	600	M	17	7/2/93	
Kusawa	Lake whitefish	YTG161	375	500	M	14	7/2/93	

Appendix A: Length, weight, sex, age, date and 15N/14N for each fish collected from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993).

Lake	Species	Fish Number	Length (mm)	Weight (g)	Sex	Age	Date	15N/14N (per mil)
Kusawa	Lake whitefish	YTG162	395	550	M	22	7/2/93	
Kusawa	Lake whitefish	YTG163	380	500	M	.	7/2/93	
Kusawa	Lake whitefish	YTG164	365	500	F	14	7/2/93	
Kusawa	Lake whitefish	YTG165	350	450	F	7	7/2/93	
Kusawa	Lake whitefish	YTG166	375	400	F	13	7/2/93	
Kusawa	Lake whitefish	YTG167	400	800	F	13	7/2/93	
Kusawa	Lake whitefish	YTG168	410	850	F	.	7/2/93	
Kusawa	Lake whitefish	YTG169	385	600	F	10	7/2/93	
Kusawa	Lake whitefish	YTG17	381	600	F	11	6/29/93	
Kusawa	Lake whitefish	YTG170	380	700	F	13	7/2/93	
Kusawa	Lake whitefish	YTG171	380	600	F	11	7/2/93	
Kusawa	Lake whitefish	YTG172	440	1100	M	.	7/2/93	
Kusawa	Lake whitefish	YTG173	330	400	M	5	7/2/93	
Kusawa	Lake whitefish	YTG175	380	500	M	16	7/2/93	
Kusawa	Lake whitefish	YTG176	370	500	M	9	7/2/93	
Kusawa	Lake whitefish	YTG177	360	500	F	13	7/2/93	
Kusawa	Lake whitefish	YTG178	385	550	F	12	7/2/93	
Kusawa	Lake whitefish	YTG179	320	400	M	.	7/2/93	
Kusawa	Lake whitefish	YTG18	427	750	M	14	7/2/93	
Kusawa	Lake whitefish	YTG180	390	700	M	15	7/2/93	
Kusawa	Lake whitefish	YTG181	415	900	F	21	7/2/93	
Kusawa	Lake whitefish	YTG182	392	650	F	12	7/2/93	
Kusawa	Lake whitefish	YTG183	375	500	M	.	7/2/93	
Kusawa	Lake whitefish	YTG184	310	400	F	9	7/2/93	
Kusawa	Lake whitefish	YTG185	325	400	M	10	7/2/93	
Kusawa	Lake whitefish	YTG19	377	600	F	14	6/29/93	
Kusawa	Lake whitefish	YTG2	360	500	M	10	6/29/93	7.29
Kusawa	Lake whitefish	YTG20	457	700	M	8	6/29/93	
Kusawa	Lake whitefish	YTG21	385	600	M	10	6/29/93	
Kusawa	Lake whitefish	YTG22	310	300	M	7	6/29/93	
Kusawa	Lake whitefish	YTG3	415	700	M	.	6/29/93	6.21
Kusawa	Lake whitefish	YTG38	340	400	I	10	6/29/93	
Kusawa	Lake whitefish	YTG4	455	900	M	20	6/29/93	7.91
Kusawa	Lake whitefish	YTG47	355	500	F	11	6/30/93	8.09
Kusawa	Lake whitefish	YTG48	354	400	F	.	6/30/93	7.49
Kusawa	Lake whitefish	YTG49	350	400	F	11	6/30/93	7.46
Kusawa	Lake whitefish	YTG5	375	600	M	11	6/29/93	7.23
Kusawa	Lake whitefish	YTG50	390	500	F	.	6/30/93	
Kusawa	Lake whitefish	YTG51	365	400	M	11	7/2/93	
Kusawa	Lake whitefish	YTG52	342	350	M	5	7/2/93	
Kusawa	Lake whitefish	YTG55	371	450	M	18	7/2/93	
Kusawa	Lake whitefish	YTG57	322	300	M	6	7/2/93	
Kusawa	Lake whitefish	YTG59	354	450	F	12	7/2/93	
Kusawa	Lake whitefish	YTG6	390	700	F	11	6/29/93	6.37
Kusawa	Lake whitefish	YTG60	330	350	I	10	7/2/93	
Kusawa	Lake whitefish	YTG68	340	350	F	9	7/2/93	
Kusawa	Lake whitefish	YTG69	365	500	M	13	7/2/93	

Appendix A: Length, weight, sex, age, date and 15N/14N for each fish collected from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993).

Lake	Species	Fish Number	Length (mm)	Weight (g)	Sex	Age	Date	15N/14N (per mil)
Kusawa	Lake whitefish	YTG7	390	800	M	12	6/29/93	6.52
Kusawa	Lake whitefish	YTG74	345	400	M	10	7/2/93	
Kusawa	Lake whitefish	YTG8	380	600	M	6	6/29/93	
Kusawa	Lake whitefish	YTG80	430	900	M	20	7/2/93	
Kusawa	Lake whitefish	YTG83	362	600	M	20	7/2/93	
Kusawa	Lake whitefish	YTG84	345	400	M	9	7/2/93	
Kusawa	Lake whitefish	YTG85	335	450	F	10	7/2/93	
Kusawa	Lake whitefish	YTG88	335	350	M	8	7/2/93	
Kusawa	Lake whitefish	YTG89	370	450	F	10	7/2/93	
Kusawa	Lake whitefish	YTG9	340	500	M	.		8.58
Kusawa	Lake whitefish	YTG90	340	400	M	10	7/2/93	
Kusawa	Lake whitefish	YTG91	370	500	F	14	7/2/93	
Kusawa	Lake whitefish	YTG92	360	400	F	11	7/2/93	
Kusawa	Lake whitefish	YTG94	355	450	M	10	7/2/93	
Kusawa	Lake whitefish	YTG95	365	500	M	13	7/2/93	
Kusawa	Lake whitefish	YTG96	315	300	F	.	7/2/93	
Kusawa	Lake whitefish	YTG97	370	550	F	14	7/2/93	
Kusawa	Lake whitefish	YTG98	335	350	M	.	7/2/93	
Kusawa	Lake whitefish	YTG99	355	500	F	15	7/2/93	
Kusawa	Longnose sucker	318	347	500	M	.	7/22/92	6.69
Kusawa	Longnose sucker	332	416	750	M	31	7/22/92	6.60
Kusawa	Longnose sucker	368	348	500	.	17	7/22/92	5.41
Kusawa	Longnose sucker	369	365	550	M	15	7/22/92	6.91
Kusawa	Longnose sucker	371	380	500	M	14	7/22/92	6.28
Kusawa	Longnose sucker	370	402	650	F	.	7/22/92	7.19
Kusawa	Longnose sucker	ytg40	420	750	M	.	6/30/93	7.01
Kusawa	Longnose sucker	ytg42	410	800	M	.	6/30/93	6.63
Kusawa	Longnose sucker	ytg43	405	750	F	.	6/30/93	6.96
Kusawa	Longnose sucker	ytg44	435	800	M	.	6/30/93	7.19
Kusawa	Longnose sucker	ytg45	395	700	F	.	6/30/93	6.75
Kusawa	Longnose sucker	ytg47	450	800	F	.	6/30/93	7.15
Kusawa	Round whitefish	333	128	16	I	.	7/21/92	
Kusawa	Round whitefish	334	125	17	I	2	7/21/92	
Kusawa	Round whitefish	336	207	71	I	7	7/21/92	4.99
Kusawa	Round whitefish	340	228	111	F	4	7/22/92	
Kusawa	Round whitefish	344	193	59	I	9	7/22/92	5.32
Kusawa	Round whitefish	673	100	7	I	2	6/29/93	
Kusawa	Round whitefish	674	107	5	I	2	6/29/93	
Kusawa	Round whitefish	675	142	24	I	3	6/29/93	6.27
Kusawa	Round whitefish	676	149	25	I	3	6/29/93	6.28
Kusawa	Round whitefish	677	152	28	I	3	6/29/93	6.17
Kusawa	Round whitefish	678	118	13	I	2	6/29/93	
Kusawa	Round whitefish	680	100	8	I	2	6/29/93	
Kusawa	Round whitefish	681	101	7	I	2	6/29/93	
Kusawa	Round whitefish	683	85	4	I	2	6/29/93	
Kusawa	Round whitefish	684	98	7.2	I	2	6/29/93	
Kusawa	Round whitefish	685	91	5.3	I	2	6/29/93	

Appendix A: Length, weight, sex, age, date and 15N/14N for each fish collected from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993).

Lake	Species	Fish Number	Length (mm)	Weight (g)	Sex	Age	Date	15N/14N (per mil)
Kusawa	Round whitefish	686	99	5.3	I	2	6/29/93	
Kusawa	Round whitefish	687	92	5.3	I	2	6/29/93	
Kusawa	Round whitefish	688	97	6.8	I	2	6/29/93	
Kusawa	Round whitefish	689	100	7.7	I	2	6/29/93	
Kusawa	Round whitefish	691	102	7.6	I	2	6/29/93	
Kusawa	Round whitefish	692	108	9.2	I	2	6/29/93	
Kusawa	Round whitefish	693	215	81.3	I	2	6/29/93	6.79
Kusawa	Round whitefish	694	254	125.5	M	4	6/29/93	5.79
Kusawa	Round whitefish	695	197	62	M	4	6/29/93	6.66
Kusawa	Round whitefish	696	149	25.7	I	3	6/29/93	
Laberge	Burbot	920-0026	360	340	M	6	3/11/92	12.79
Laberge	Burbot	920-0029	535	1187	M	8	3/11/92	12.48
Laberge	Burbot	920-0030	641	1940	F	.	3/11/92	11.20
Laberge	Burbot	920-0031	638	2354	F	.	3/11/92	11.72
Laberge	Burbot	920-0032	520	1025	F	11	3/11/92	11.50
Laberge	Burbot	920-0049	320	230	F	5	3/12/92	12.12
Laberge	Burbot	920-0050	455	738	M	.	3/12/92	13.04
Laberge	Burbot	920-0054	504	970	M	10	3/12/92	11.96
Laberge	Burbot	920-0055	509	1134	M	11	3/12/92	12.61
Laberge	Burbot	920-0056	500	931	F	12	3/12/92	11.23
Laberge	Burbot	920-0057	550	1090	F	.	3/12/92	12.02
Laberge	Burbot	920-0058	415	485	F	.	3/12/92	11.16
Laberge	Burbot	920-0059	706	2227	M	.	3/12/92	11.37
Laberge	Burbot	920-0067	326	255	I	.	3/12/92	12.62
Laberge	Burbot	920-0068	326	255	I	5	3/13/92	12.41
Laberge	Burbot	920-0069	592	1350	F	14	3/13/92	12.24
Laberge	Burbot	920-0070	787	2962	M	24	3/13/92	11.89
Laberge	Burbot	920-0071	628	1709	F	16	3/13/92	11.65
Laberge	Burbot	920-0072	665	2190	M	17	3/13/92	12.05
Laberge	Burbot	YTG1	505	725	M	12	7/31/93	
Laberge	Burbot	YTG11	470	900	M	7	8/1/93	
Laberge	Burbot	YTG17	675	2250	F	15	8/2/93	
Laberge	Burbot	YTG21	655	1700	M	13	8/2/93	
Laberge	Burbot	YTG22	590	1650	F	12	8/2/93	
Laberge	Burbot	YTG23	621	1700	.	13	8/2/93	
Laberge	Burbot	YTG25	505	950	M	8	8/3/95	
Laberge	Burbot	YTG26	515	950	M	11	8/3/95	
Laberge	Burbot	YTG28	346	275	M	5	8/3/95	
Laberge	Burbot	YTG29	380	300	F	6	8/3/95	
Laberge	Burbot	YTG30	450	800	F	7	8/3/95	
Laberge	Burbot	YTG3160	578	1350	M	11	7/30/93	12.16
Laberge	Burbot	YTG3161	420	500	M	5	8/3/93	11.97
Laberge	Burbot	YTG3162	685	2500	M	16	8/3/93	12.42
Laberge	Burbot	YTG3163	621	1700	F	13	8/2/93	11.96
Laberge	Burbot	YTG3164	431	600	M	.	8/5/93	10.27
Laberge	Burbot	YTG3165	390	450	M	5	8/5/93	12.52
Laberge	Burbot	YTG3166	635	2150	F	14	8/5/93	12.84

Appendix A: Length, weight, sex, age, date and 15N/14N for each fish collected from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993).

Lake	Species	Fish Number	Length (mm)	Weight (g)	Sex	Age	Date	15N/14N (per mil)
Laberge	Burbot	YTG3167	505	1050	F	12	7/30/93	11.83
Laberge	Burbot	YTG3168	660	1950	M	12	8/5/93	12.36
Laberge	Burbot	YTG3169	457	700	F	9	8/3/93	11.80
Laberge	Burbot	YTG3170	410	400	F	8	8/5/93	12.94
Laberge	Burbot	YTG3171	695	2250	F	14	8/4/93	12.40
Laberge	Burbot	YTG3172	625	1650	F	11	8/3/93	12.32
Laberge	Burbot	YTG33	604	1525	F	.	8/4/93	
Laberge	Burbot	YTG34	708	2350	M	14	8/4/93	
Laberge	Burbot	YTG35	570	1350	M	15	8/4/93	
Laberge	Burbot	YTG37	530	1050	F	9	8/4/93	
Laberge	Burbot	YTG4	384	425	M	7	7/31/93	
Laberge	Burbot	YTG40	420	500	M	5	8/4/93	
Laberge	Burbot	YTG41	457	700	F	9	8/4/93	
Laberge	Burbot	YTG42	360	275	M	5	8/5/93	
Laberge	Burbot	YTG43	445	700	F	7	8/5/93	
Laberge	Burbot	YTG44	435	600	F	8	8/5/93	
Laberge	Burbot	YTG45	410	400	F	8	8/5/93	
Laberge	Burbot	YTG47	685	2500	M	16	8/5/93	
Laberge	Burbot	YTG48	660	1950	M	12	8/5/93	
Laberge	Burbot	YTG49	635	2150	F	14	8/5/93	
Laberge	Burbot	YTG50	431	600	.	.	8/5/93	
Laberge	Burbot	YTG51	390	450	M	5	8/5/93	
Laberge	Burbot	YTG52	477	950	F	8	8/5/93	
Laberge	Burbot	YTG53	425	800	M	7	8/6/93	
Laberge	Burbot	YTG54	356	600	F	6	8/6/93	
Laberge	Burbot	YTG55	655	2400	M	24	8/6/93	
Laberge	Burbot	YTG56	446	850	F	12	8/6/93	
Laberge	Burbot	YTG57	633	1900	M	14	8/6/93	
Laberge	Burbot	YTG6	429	550	F	6	7/31/93	
Laberge	Burbot	YTG63	366	400	F	6	8/9/93	
Laberge	Burbot	YTG67	488	800	M	10	8/9/93	
Laberge	Burbot	YTG7	657	1900	M	13	7/31/93	
Laberge	Burbot	YTG70	230	100	F	3	8/10/93	
Laberge	Burbot	YTG71	455	600	F	6	8/10/93	
Laberge	Burbot	YTG76	457	600	M	5	8/10/93	
Laberge	Burbot	YTG77	453	600	F	7	8/10/93	
Laberge	Burbot	YTG8	505	1050	F	12	7/31/93	
Laberge	Burbot	YTG80	645	2200	.	16	8/11/93	
Laberge	Burbot	YTG81	422	600	M	9	8/11/93	
Laberge	Burbot	YTG82	374	400	M	8	8/11/93	
Laberge	Burbot	YTG85	564	1500	M	9	8/11/93	
Laberge	Burbot	YTG86	425	600	M	7	8/11/93	
Laberge	Burbot	YTG87	613	1700	F	13	8/11/93	
Laberge	Burbot	YTG89	443	550	M	12	8/11/93	
Laberge	Burbot	YTG90	510	800	M	8	8/11/93	
Laberge	Burbot	YTG94	446	600	F	7	8/11/93	
Laberge	Lake trout	920-0001					4/11/92	12.72

Appendix A: Length, weight, sex, age, date and 15N/14N for each fish collected from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993).

Lake	Species	Fish Number	Length (mm)	Weight (g)	Sex	Age	Date	15N/14N (per mil)
Laberge	Lake trout	920-0002					4/11/92	12.98
Laberge	Lake trout	920-0033	475	1241	M	.	4/11/92	11.16
Laberge	Lake trout	920-0040	485	1270	M	.	4/12/92	11.37
Laberge	Lake trout	920-0045	552	1640	M	25	4/12/92	12.69
Laberge	Lake trout	920-0051	539	2337	F	13	4/12/92	11.76
Laberge	Lake trout	920-0053	442	954	F	14	4/12/92	10.61
Laberge	Lake trout	920-0073	580	2349	M	16	4/13/92	11.95
Laberge	Lake trout	YTG1	462	1150	M	8	7/31/93	13.29
Laberge	Lake trout	YTG11	586	3100	F	14	8/2/93	
Laberge	Lake trout	YTG13	340	525	F	.	8/2/93	
Laberge	Lake trout	YTG14	460	1050	M	13	8/2/93	11.05
Laberge	Lake trout	YTG15	494	1675	M	18	8/2/93	12.77
Laberge	Lake trout	YTG16	403	700	F	.	8/2/93	
Laberge	Lake trout	YTG17	441	1025	M	15	8/2/93	
Laberge	Lake trout	YTG18	459	1200	M	10	8/2/93	
Laberge	Lake trout	YTG19	372	500	M	7	8/2/93	
Laberge	Lake trout	YTG2	453	1000	M	8	7/31/93	12.24
Laberge	Lake trout	YTG20	423	1000	M	9	8/3/93	12.9
Laberge	Lake trout	YTG21	387	600	F	.	8/3/93	
Laberge	Lake trout	YTG22	504	1450	M	12	8/4/93	
Laberge	Lake trout	YTG23	410	800	M	16	8/4/93	
Laberge	Lake trout	YTG24	392	800	F	8	8/4/93	
Laberge	Lake trout	YTG25	491	1550	F	9	8/4/93	
Laberge	Lake trout	YTG26	435	900	F	8	8/4/93	
Laberge	Lake trout	YTG27	447	1600	F	16	8/4/93	
Laberge	Lake trout	YTG28	441	1100	M	10	8/4/93	
Laberge	Lake trout	YTG3	423	950	F	10	7/31/93	
Laberge	Lake trout	YTG30	566	2100	M	13	8/5/93	
Laberge	Lake trout	YTG31	486	1200	F	10	8/5/93	
Laberge	Lake trout	YTG3173	441	1025	M	15	8/2/93	11.76
Laberge	Lake trout	YTG3175	441	1100	M	.	8/4/93	12.41
Laberge	Lake trout	YTG3176	716	5900	F	.	8/4/93	11.90
Laberge	Lake trout	YTG3177	402	1000	F	12	8/4/93	11.58
Laberge	Lake trout	YTG3178	435	900	F	8	8/4/93	13.11
Laberge	Lake trout	YTG3179	590	3150	M	.	7/30/93	12.06
Laberge	Lake trout	YTG3180	459	1200	M	10	8/2/93	10.35
Laberge	Lake trout	YTG3181	372	500	M	7	8/2/93	12.48
Laberge	Lake trout	YTG3182	392	800	F	8	8/4/93	13.18
Laberge	Lake trout	YTG3183	491	1550	F	9	8/4/93	13.41
Laberge	Lake trout	YTG3184	447	1250	M	.	8/4/93	12.82
Laberge	Lake trout	YTG3185	403	700	F	.	8/2/93	13.96
Laberge	Lake trout	YTG3186	410	800	M	16	8/4/93	12.36
Laberge	Lake trout	YTG3187	447	1600	F	.	8/4/93	12.86
Laberge	Lake trout	YTG3188	641	4000	F	9	8/2/93	12.35
Laberge	Lake trout	YTG3189	586	3100	F	14	7/31/93	12.17
Laberge	Lake trout	YTG32	535	2100	F	.	8/5/93	
Laberge	Lake trout	YTG33	342	475	F	7	8/5/93	

Appendix A: Length, weight, sex, age, date and 15N/14N for each fish collected from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993).

Lake	Species	Fish Number	Length (mm)	Weight (g)	Sex	Age	Date	15N/14N (per mil)
Laberge	Lake trout	YTG34	540	2000	M	18	8/5/93	
Laberge	Lake trout	YTG35	410	1000	M	8	8/5/93	12.77
Laberge	Lake trout	YTG36	409	800	M	.	8/5/93	
Laberge	Lake trout	YTG37	471	1200	M	15	8/5/93	
Laberge	Lake trout	YTG39	545	2100	F	8	8/5/93	
Laberge	Lake trout	YTG40	429	1150	F	10	8/6/93	
Laberge	Lake trout	YTG43	430	950	F	5	8/7/93	
Laberge	Lake trout	YTG45	522	2350	M	.	8/7/93	
Laberge	Lake trout	YTG46	537	2000	M	9	8/7/93	
Laberge	Lake trout	YTG47	433	1000	F	8	8/8/93	
Laberge	Lake trout	YTG48	543	2150	F	15	8/8/93	
Laberge	Lake trout	YTG49	387	700	M	7	8/8/93	
Laberge	Lake trout	YTG5	590	3150	M	24	7/31/93	
Laberge	Lake trout	YTG50	403	800	M	8	8/8/93	
Laberge	Lake trout	YTG53	440	1150	F	13	8/8/93	
Laberge	Lake trout	YTG54	497	1400	F	11	8/8/93	
Laberge	Lake trout	YTG55	488	1550	M	16	8/8/93	
Laberge	Lake trout	YTG56	507	1700	F	.	8/8/93	
Laberge	Lake trout	YTG57	410	900	M	6	8/8/93	
Laberge	Lake trout	YTG61	531	2500	F	16	8/8/93	
Laberge	Lake trout	YTG62	485	1400	F	.	8/8/93	
Laberge	Lake trout	YTG63	539	1900	F	30	8/8/93	
Laberge	Lake trout	YTG64	415	900	F	7	8/8/93	
Laberge	Lake trout	YTG65	443	1050	M	7	8/10/93	
Laberge	Lake trout	YTG68	450	1000	F	11	8/11/93	
Laberge	Lake trout	YTG69	389	700	M	10	8/11/93	
Laberge	Lake trout	YTG70	475	1200	M	11	8/11/93	
Laberge	Lake trout	YTG71	420	1000	M	.	8/11/93	
Laberge	Lake trout	YTG72	641	4000	F	9	8/11/93	
Laberge	Lake trout	YTG8	346	350	F	7	8/1/93	
Laberge	Lake whitefish	49	382	950	F	14	6/18/92	9.06
Laberge	Lake whitefish	50	396	800	F	.	6/18/92	
Laberge	Lake whitefish	114	206	79	I	.	6/23/92	7.16
Laberge	Lake whitefish	115	195	75	I	.	6/23/92	8.92
Laberge	Lake whitefish	117	195	76	I	5	6/23/92	7.57
Laberge	Lake whitefish	153	398	700	F	11	6/26/92	8.87
Laberge	Lake whitefish	159	195	70	I	.		8.22
Laberge	Lake whitefish	160	200	79	I	.		7.08
Laberge	Lake whitefish	161	190	58	I	5		7.31
Laberge	Lake whitefish	163	200	72	I	5		8.46
Laberge	Lake whitefish	165	209	82	I	4		7.89
Laberge	Lake whitefish	166	205	84	I	7		7.52
Laberge	Lake whitefish	222	164	37	I	.		6.80
Laberge	Lake whitefish	235	165	36	I	.		6.43
Laberge	Lake whitefish	248	118	14	I	2	7/8/92	5.22
Laberge	Lake whitefish	251	103	9	I	2	7/8/92	
Laberge	Lake whitefish	920-0017	313	355	M	12	4/11/92	9.52

Appendix A: Length, weight, sex, age, date and 15N/14N for each fish collected from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993).

Lake	Species	Fish Number	Length (mm)	Weight (g)	Sex	Age	Date	15N/14N (per mil)
Laberge	Lake whitefish	920-0018	332	442	F	11	4/11/92	7.83
Laberge	Lake whitefish	920-0019	335	402	F	14	4/11/92	10.08
Laberge	Lake whitefish	920-0020	331	438	M	11	4/11/92	9.28
Laberge	Lake whitefish	920-0021	377	617	F	12	4/11/92	7.05
Laberge	Lake whitefish	920-0023	337	433	M	9	4/11/92	8.54
Laberge	Lake whitefish	920-0024	350	477	M	12	4/11/92	9.39
Laberge	Lake whitefish	920-0025	385	595	F	10	4/11/92	8.01
Laberge	Lake whitefish	920-0028	390	638	F	12	4/11/92	7.05
Laberge	Lake whitefish	920-0039	320	367	F	9	4/12/92	7.85
Laberge	Lake whitefish	920-0048	368	596	F	9	4/12/92	9.27
Laberge	Lake whitefish	920-0052	428	844	M	22	4/12/92	6.65
Laberge	Lake whitefish	920-0060	351	486	F	16	4/13/92	9.87
Laberge	Lake whitefish	920-0061	327	399	F	8	4/13/92	8.06
Laberge	Lake whitefish	920-0062	320	341	F	8	4/13/92	7.87
Laberge	Lake whitefish	920-0063	315	347	M	8	4/13/92	9.19
Laberge	Lake whitefish	920-0064	298	297	F	8	4/13/92	10.21
Laberge	Lake whitefish	920-0065	335	412	M	11	4/13/92	8.09
Laberge	Lake whitefish	YTG100	301	350	M	8	8/3/93	
Laberge	Lake whitefish	YTG101	298	300	M	.	8/3/93	
Laberge	Lake whitefish	YTG105	317	500	F	8	8/3/93	
Laberge	Lake whitefish	YTG106	318	400	M	8	8/3/93	
Laberge	Lake whitefish	YTG107	320	400	F	.	8/3/93	
Laberge	Lake whitefish	YTG108	372	700	F	18	8/3/93	
Laberge	Lake whitefish	YTG109	299	350	M	.	8/3/93	
Laberge	Lake whitefish	YTG11	479	1300	F	21	7/29/93	
Laberge	Lake whitefish	YTG112	303	400	F	.	8/3/93	
Laberge	Lake whitefish	YTG114	306	300	M	7	8/3/93	
Laberge	Lake whitefish	YTG115	295	400	M	9	8/3/93	
Laberge	Lake whitefish	YTG117	290	400	M	6	8/3/93	
Laberge	Lake whitefish	YTG118	288	300	F	.	8/3/93	
Laberge	Lake whitefish	YTG119	320	400	M	9	8/3/93	
Laberge	Lake whitefish	YTG12	384	750	F	17	7/29/93	
Laberge	Lake whitefish	YTG121	276	300	M	7	8/3/93	
Laberge	Lake whitefish	YTG122	319	400	F	8	8/3/93	
Laberge	Lake whitefish	YTG124	302	350	M	.	8/3/93	
Laberge	Lake whitefish	YTG13	383	700	M	14	7/29/93	
Laberge	Lake whitefish	YTG131	431	1250	F	16	8/3/93	
Laberge	Lake whitefish	YTG137	330	400	F	13	8/4/93	
Laberge	Lake whitefish	YTG140	341	500	F	14	8/4/93	
Laberge	Lake whitefish	YTG142	319	350	M	9	8/4/93	
Laberge	Lake whitefish	YTG144	376	700	M	14	8/4/93	
Laberge	Lake whitefish	YTG145	372	700	F	14	8/4/93	
Laberge	Lake whitefish	YTG146	328	400	M	9	8/4/93	
Laberge	Lake whitefish	YTG147	327	350	F	10	8/4/93	
Laberge	Lake whitefish	YTG149	302	300	M	.	8/4/93	
Laberge	Lake whitefish	YTG154	365	600	F	.	8/4/93	
Laberge	Lake whitefish	YTG162	367	550	M	.	8/4/93	

Appendix A: Length, weight, sex, age, date and 15N/14N for each fish collected from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993).

Lake	Species	Fish Number	Length (mm)	Weight (g)	Sex	Age	Date	15N/14N (per mil)
Laberge	Lake whitefish	YTG163	385	700	M	20	8/4/93	
Laberge	Lake whitefish	YTG167	322	400	M	8	8/4/93	
Laberge	Lake whitefish	YTG17	373	600	F	15	7/31/93	
Laberge	Lake whitefish	YTG172	337	450	F	9	8/5/93	
Laberge	Lake whitefish	YTG176	344	550	F	15	8/5/93	
Laberge	Lake whitefish	YTG19	454	550	F	17	7/31/93	
Laberge	Lake whitefish	YTG20	347	500	F	12	7/31/93	
Laberge	Lake whitefish	YTG202	438	900	F	23	8/6/93	
Laberge	Lake whitefish	YTG203	425	1050	F	20	8/6/93	
Laberge	Lake whitefish	YTG204	376	750	M	11	8/6/93	
Laberge	Lake whitefish	YTG205	402	900	M	13	8/6/93	
Laberge	Lake whitefish	YTG206	398	900	M	16	8/6/93	
Laberge	Lake whitefish	YTG207	328	425	F	7	8/6/93	
Laberge	Lake whitefish	YTG208	393	800	F	14	8/6/93	
Laberge	Lake whitefish	YTG209	439	1050	F	19	8/6/93	
Laberge	Lake whitefish	YTG210	344	550	F	.	8/6/93	
Laberge	Lake whitefish	YTG211	415	1000	M	13	8/6/93	
Laberge	Lake whitefish	YTG212	379	700	F	13	8/6/93	
Laberge	Lake whitefish	YTG220	475	1300	F	27	8/6/93	
Laberge	Lake whitefish	YTG222	182	100	F	3	8/6/93	
Laberge	Lake whitefish	YTG223	446	1150	F	31	8/6/93	
Laberge	Lake whitefish	YTG224	432	1100	M	35	8/6/93	
Laberge	Lake whitefish	YTG233	370	650	F	20	8/6/93	
Laberge	Lake whitefish	YTG236	447	1300	F	21	8/6/93	
Laberge	Lake whitefish	YTG245	411	1000	F	18	8/6/93	
Laberge	Lake whitefish	YTG246	361	700	M	12	8/6/93	
Laberge	Lake whitefish	YTG247	396	850	M	14	8/6/93	
Laberge	Lake whitefish	YTG248	392	800	F	14	8/7/93	
Laberge	Lake whitefish	YTG249	375	650	F	17	8/7/93	
Laberge	Lake whitefish	YTG25	407	1000	F	19	7/31/93	
Laberge	Lake whitefish	YTG251	344	550	M	11	8/7/93	
Laberge	Lake whitefish	YTG252	299	350	M	5	8/7/93	
Laberge	Lake whitefish	YTG255	335	500	F	11	8/7/93	
Laberge	Lake whitefish	YTG256	351	500	M	10	8/7/93	
Laberge	Lake whitefish	YTG258	438	1300	F	20	8/7/93	
Laberge	Lake whitefish	YTG26	447	1250	F	26	7/31/93	
Laberge	Lake whitefish	YTG28	378	600	M	13	7/31/93	
Laberge	Lake whitefish	YTG283	380	700	F	13	8/8/93	
Laberge	Lake whitefish	YTG284	376	600	F	.	8/8/93	
Laberge	Lake whitefish	YTG286	322	400	M	10	8/8/93	
Laberge	Lake whitefish	YTG289	339	500	F	14	8/8/93	
Laberge	Lake whitefish	YTG29	322	400	F	5	7/31/93	
Laberge	Lake whitefish	YTG291	412	1100	F	21	8/8/93	
Laberge	Lake whitefish	YTG292	409	1000	F	18	8/8/93	
Laberge	Lake whitefish	YTG294	421	1150	F	.	8/8/93	
Laberge	Lake whitefish	YTG295	394	900	M	18	8/8/93	
Laberge	Lake whitefish	YTG296	384	800	F	17	8/8/93	

Appendix A: Length, weight, sex, age, date and 15N/14N for each fish collected from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993).

Lake	Species	Fish Number	Length (mm)	Weight (g)	Sex	Age	Date	15N/14N (per mil)
Laberge	Lake whitefish	YTG297	369	600	F	14	8/8/93	
Laberge	Lake whitefish	YTG298	365	650	F	11	8/8/93	
Laberge	Lake whitefish	YTG31	299	200	M	7	8/1/93	
Laberge	Lake whitefish	YTG32	436	1100	M	20	8/1/93	
Laberge	Lake whitefish	YTG321	426	1000	F	.	8/10/93	
Laberge	Lake whitefish	YTG33	335	500	F	9	8/1/93	
Laberge	Lake whitefish	YTG330	344	500	F	8	8/10/93	
Laberge	Lake whitefish	YTG331	340	450	F	14	8/10/93	
Laberge	Lake whitefish	YTG332	333	500	F	10	8/10/93	
Laberge	Lake whitefish	YTG338	315	400	F	.	8/10/93	
Laberge	Lake whitefish	YTG349	339	500	F	18	8/11/93	
Laberge	Lake whitefish	YTG351	312	400	M	13	8/11/93	
Laberge	Lake whitefish	YTG352	325	450	M	.	8/11/93	
Laberge	Lake whitefish	YTG353	304	350	F	.	8/11/93	
Laberge	Lake whitefish	YTG354	374	700	M	13	8/11/93	
Laberge	Lake whitefish	YTG355	200	100	M	3	8/11/93	
Laberge	Lake whitefish	YTG357	213	100	F	4	8/11/93	
Laberge	Lake whitefish	YTG36	345	500	M	12	8/1/93	
Laberge	Lake whitefish	YTG360	173	50	M	3	8/11/93	
Laberge	Lake whitefish	YTG37	369	600	F	14	8/1/93	
Laberge	Lake whitefish	YTG381	370	600	M	11	8/11/93	
Laberge	Lake whitefish	YTG382	374	650	M	14	8/11/93	
Laberge	Lake whitefish	YTG41	346	700	M	12	8/1/93	
Laberge	Lake whitefish	YTG42	428	1100	F	24	8/1/93	
Laberge	Lake whitefish	YTG43	335	500	F	.	8/2/93	
Laberge	Lake whitefish	YTG44	350	600	F	11	8/2/93	
Laberge	Lake whitefish	YTG45	310	500	F	.	8/2/93	
Laberge	Lake whitefish	YTG46	352	500	M	7	8/2/93	
Laberge	Lake whitefish	YTG47	409	850	F	20	8/2/93	
Laberge	Lake whitefish	YTG48	399	900	F	13	8/2/93	
Laberge	Lake whitefish	YTG49	361	700	M	12	8/2/93	
Laberge	Lake whitefish	YTG50	385	650	F	15	8/2/93	
Laberge	Lake whitefish	YTG51	370	550	F	21	8/2/93	
Laberge	Lake whitefish	YTG52	352	600	F	17	8/2/93	
Laberge	Lake whitefish	YTG53	376	600	M	13	8/2/93	
Laberge	Lake whitefish	YTG54	405	800	M	15	8/2/93	
Laberge	Lake whitefish	YTG55	353	600	F	12	8/2/93	
Laberge	Lake whitefish	YTG57	341	550	M	.	8/2/93	
Laberge	Lake whitefish	YTG58	365	600	F	18	8/2/93	
Laberge	Lake whitefish	YTG60	330	400	F	7	8/2/93	
Laberge	Lake whitefish	YTG61	333	500	F	9	8/2/93	
Laberge	Lake whitefish	YTG63	250	267		7	8/2/93	
Laberge	Lake whitefish	YTG64	354	500	F	12	8/2/93	
Laberge	Lake whitefish	YTG65	314	400	M	.	8/2/93	
Laberge	Lake whitefish	YTG66	315	400	M	11	8/2/93	
Laberge	Lake whitefish	YTG67	297	300	F	9	8/2/93	
Laberge	Lake whitefish	YTG68	290	300	F	6	8/2/93	

Appendix A: Length, weight, sex, age, date and 15N/14N for each fish collected from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993).

Lake	Species	Fish Number	Length (mm)	Weight (g)	Sex	Age	Date	15N/14N (per mil)
Laberge	Lake whitefish	YTG69	363	700	M	13	8/2/93	
Laberge	Lake whitefish	YTG71	306	350	F	11	8/2/93	
Laberge	Lake whitefish	YTG72	353	500	F	13	8/2/93	
Laberge	Lake whitefish	YTG73	345	500	F	.	8/2/93	
Laberge	Lake whitefish	YTG74	274	175	M	8	8/2/93	
Laberge	Lake whitefish	YTG75	253	150	M	.	8/2/93	
Laberge	Lake whitefish	YTG76	334	400	F	9	8/2/93	
Laberge	Lake whitefish	YTG77	336	400	F	10	8/2/93	
Laberge	Lake whitefish	YTG78	333	400	F	10	8/2/93	
Laberge	Lake whitefish	YTG82	224	100	F	4	8/3/93	
Laberge	Lake whitefish	YTG83	235	125	F	4	8/3/93	
Laberge	Lake whitefish	YTG86	291	300	F	.	8/3/93	
Laberge	Lake whitefish	YTG87	366	500	M	9	8/3/93	
Laberge	Lake whitefish	YTG89	430	875	M	.	8/3/93	9.89
Laberge	Lake whitefish	YTG90	308	300	F	10	8/3/93	
Laberge	Lake whitefish	YTG91	295	300	F	7	8/3/93	
Laberge	Lake whitefish	YTG92	331	400	M	12	8/3/93	8.97
Laberge	Lake whitefish	YTG93	276	225	M	5	8/3/93	7.92
Laberge	Lake whitefish	YTG94	374	550	F	.	8/3/93	
Laberge	Lake whitefish	YTG95	316	325	F	9	8/3/93	
Laberge	Lake whitefish	YTG98	298	275	M	6	8/3/93	8.95
Laberge	Lake whitefish	YTG99	344	500	M	12	8/3/93	
Laberge	Least cisco	31	210	100	I	4	6/9/92	8.26
Laberge	Least cisco	94	205	81	M	.		7.87
Laberge	Least cisco	95	200	66	F	.	6/23/92	8.34
Laberge	Least cisco	97	231	115	F	4	6/23/92	8.79
Laberge	Least cisco	99	215	91	M	3	6/23/92	7.54
Laberge	Least cisco	100	185	54	I	4	6/23/92	7.44
Laberge	Least cisco	101	210	85	M	.	6/23/92	7.50
Laberge	Least cisco	102	165	45	I	.	6/23/92	7.61
Laberge	Least cisco	103	187	61	F	5	6/23/92	7.46
Laberge	Least cisco	104	205	75	M	4	6/23/92	7.30
Laberge	Least cisco	105	215	86	M	4	6/23/92	7.71
Laberge	Least cisco	728	94	6.4	I	.	7/16/93	8.36
Laberge	Least cisco	730	120	12.6	I	.	7/16/93	8.34
Laberge	Least cisco	YTG59	190	25	F	2	8/2/93	
Laberge	Longnose sucker	16	424	750	F	.	6/9/92	
Laberge	Longnose sucker	69	415	750	M	.	6/18/92	7.18
Laberge	Longnose sucker	70	492	800	F	.	6/18/92	
Laberge	Longnose sucker	71	410	600	F	.	6/18/92	
Laberge	Longnose sucker	72	415	750	M	.	6/18/92	
Laberge	Longnose sucker	73	495	1000	F	.	6/18/92	
Laberge	Longnose sucker	74	455	900	F	.	6/18/92	5.80
Laberge	Longnose sucker	75	494	900	M	.	6/18/92	
Laberge	Longnose sucker	77	430	750	M	.	6/18/92	7.19
Laberge	Longnose sucker	370	402	650	F	18	7/22/92	7.87
Laberge	Longnose sucker	506	466	925	F	.	5/30/93	6.55

Appendix A: Length, weight, sex, age, date and 15N/14N for each fish collected from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993).

Lake	Species	Fish Number	Length (mm)	Weight (g)	Sex	Age	Date	15N/14N (per mil)
Laberge	Longnose sucker	YTG296	430	875	M	.	8/3/93	8.81
Laberge	Longnose sucker	YTG297	415	700	M	.	8/3/93	8.25
Laberge	Longnose sucker	YTG298	445	900	F	.	8/3/93	6.97
Laberge	Longnose sucker	YTG299	435	975	F	.	8/3/93	7.26
Laberge	Longnose sucker	YTG300	449	1000	M	.	8/3/93	8.82
Laberge	Longnose sucker	YTG301	433	900	F	.	8/3/93	7.74
Laberge	Longnose sucker	YTG302	413	825	F	.	8/3/93	
Laberge	Longnose sucker	YTG303	387	650	F	.	8/3/93	
Laberge	Longnose sucker	YTG304	300	275	I	.	8/3/93	
Laberge	Longnose sucker	YTG305	435	900	M	.	8/3/93	8.36
Laberge	Northern pike	398	524	1100	M	.	8/6/92	8.75
Laberge	Northern pike	399	574	1250	M	.	8/6/92	8.46
Laberge	Northern pike	YTG1	792	4000	F	8	7/28/93	10.04
Laberge	Northern pike	YTG11	702	2800	M	7	7/29/93	
Laberge	Northern pike	YTG14	635	2000	F	5	7/29/93	
Laberge	Northern pike	YTG17	748	4100	F	10	7/29/93	
Laberge	Northern pike	YTG18	615	1850	F	5	7/29/93	
Laberge	Northern pike	YTG2	666	2400	F	7	7/28/93	10.14
Laberge	Northern pike	YTG20	701	2250	F	5	7/29/93	
Laberge	Northern pike	YTG22	588	1250	M	5	7/29/93	
Laberge	Northern pike	YTG26	772	3300	F	9	7/29/93	
Laberge	Northern pike	YTG3	658	2300	M	8	7/28/93	8.79
Laberge	Northern pike	YTG30	650	2200	F	5	7/31/93	
Laberge	Northern pike	YTG33	655	2225	M	5	7/31/93	
Laberge	Northern pike	YTG34	660	2050	M	8	7/31/93	
Laberge	Northern pike	YTG35	730	2850	F	5	7/31/93	
Laberge	Northern pike	YTG36	740	3100	F	7	7/31/93	
Laberge	Northern pike	YTG37	685	2700	M	6	8/1/93	
Laberge	Northern pike	YTG38	648	2150	M	6	8/1/93	
Laberge	Northern pike	YTG4	635	1900	F	9	7/28/93	9.87
Laberge	Northern pike	YTG41	610	2250	M	4	8/1/93	
Laberge	Northern pike	YTG42	645	2300	M	5	8/1/93	
Laberge	Northern pike	YTG48	645	2050	M	4	8/1/93	
Laberge	Northern pike	YTG50	705	2900	F	7	8/1/93	
Laberge	Northern pike	YTG51	635	2200	F	7	8/1/93	
Laberge	Northern pike	YTG52	721	3000	F	6	8/1/93	
Laberge	Northern pike	YTG53	664	2300	F	5	8/1/93	
Laberge	Northern pike	YTG54	725	3600	M	8	8/1/93	
Laberge	Northern pike	YTG55	755	3250	F	8	8/1/93	
Laberge	Northern pike	YTG56	656	2300	F	8	8/1/93	
Laberge	Northern pike	YTG59	615	1900	F	5	8/2/93	
Laberge	Northern pike	YTG6	686	2650	M	6	7/28/93	10.20
Laberge	Northern pike	YTG63	632	1900	M	5	8/2/93	
Laberge	Northern pike	YTG64	640	2250	M	4	8/6/93	
Laberge	Northern pike	YTG66	709	700	F	4	8/6/93	
Laberge	Northern pike	YTG67	634	2200	M	5	8/6/93	
Laberge	Northern pike	YTG68	532	1300	M	3	8/6/93	

Appendix A: Length, weight, sex, age, date and 15N/14N for each fish collected from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993).

Lake	Species	Fish Number	Length (mm)	Weight (g)	Sex	Age	Date	15N/14N (per mil)
Laberge	Northern pike	YTG7	688	2700	F	6	7/28/93	10.78
Laberge	Northern pike	YTG70	1020	8500	F	.	8/7/93	
Laberge	Northern pike	YTG73	677	2650	M	7	8/7/93	
Laberge	Northern pike	YTG74	719	3600	M	8	8/7/93	
Laberge	Northern pike	YTG75	759	3700	F	7	8/7/93	
Laberge	Northern pike	YTG76	663	2400	M	6	8/7/93	
Laberge	Northern pike	YTG77	664	2750	F	5	8/8/93	
Laberge	Northern pike	YTG8	705	3100	F	10	7/29/93	9.68
Laberge	Northern pike	YTG9	647	2250	F	8	7/29/93	9.50
Laberge	Round whitefish	59	215	75	I	.	6/19/92	
Laberge	Round whitefish	60	205	62	I	.	6/19/92	
Laberge	Round whitefish	62	200	65	I	.	6/19/92	
Laberge	Round whitefish	64	250	150	F	.	6/19/92	7.24
Laberge	Round whitefish	65	210	71	I		6/19/92	
Laberge	Round whitefish	106	205	74	M		6/23/92	
Laberge	Round whitefish	108	193	64	M		6/23/92	
Laberge	Round whitefish	109	143	22	I		6/23/92	
Laberge	Round whitefish	110	202	71	M	3	6/23/92	
Laberge	Round whitefish	127	500	1250	M	23	6/24/92	
Laberge	Round whitefish	144	415	750	M	12	6/26/92	
Laberge	Round whitefish	146	458	1150	F	10	6/26/92	
Laberge	Round whitefish	149	465	1400	M	11	6/26/92	
Laberge	Round whitefish	150	398	800	F	11	6/26/92	
Laberge	Round whitefish	151	363	500	M	6	6/26/92	
Laberge	Round whitefish	152	459	800	F	15	6/26/92	5.70
Laberge	Round whitefish	155	444	1100	F	9	6/26/92	
Laberge	Round whitefish	220	185	53	I	.	7/2/92	6.87
Laberge	Round whitefish	224	126	14	I	.	7/2/92	
Laberge	Round whitefish	228	210	69	I	.	7/2/92	7.95
Laberge	Round whitefish	233	117	12	I	.	7/2/92	
Laberge	Round whitefish	235	165	36	I	.	7/2/92	
Laberge	Round whitefish	236	114	12	I	.	7/2/92	
Laberge	Round whitefish	238	255	168	I	.	7/2/92	
Laberge	Round whitefish	239	250	145	I	.	7/2/92	
Laberge	Round whitefish	253	265	146	M	.	7/8/92	
Laberge	Round whitefish	410	125	.	I	2	8/6/92	
Laberge	Round whitefish	411	120	.	I	3	8/6/92	
Laberge	Round whitefish	412	119	.	I	2	8/6/92	
Laberge	Round whitefish	413	130	.	I	.	8/6/92	
Laberge	Round whitefish	496	99	7	I	1	5/28/93	
Laberge	Round whitefish	510	158	33	I	3	6/1/93	
Laberge	Round whitefish	511	170	39	I	3	6/1/93	
Laberge	Round whitefish	512	192	55	I	3	6/1/93	
Laberge	Round whitefish	513	195	56	I	4	6/1/93	
Laberge	Round whitefish	514	205	42	I	4	6/1/93	
Laberge	Round whitefish	516	99	6	I	1	6/1/93	
Laberge	Round whitefish	517	99	6	I	1	6/1/93	

Appendix B: Taxa present in the stomachs of fishes from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993)

LAKE	FISH NO.	SPECIES	Chironomidae	Coleoptera	Diptera	Ephemeroptera	Formicidae	Gammarus	Hirudinea	*Hydracarina*	Lymnaeidae	Oligochaeta	Planorbidae/Valvatidae	Plecoptera	Sphaeriidae	Tipulidae	Tricoptera	Unidentified Invertebr	Zooplankton	Burbot	Broad Whitefish	Lake Trout	Lake Whitefish	Least Cisco	Longnose Sucker	Northern Pike	Round Whitefish	Slimy Sculpin	Unidentified Fishes
Fox	196	Burbot						X																					X
Fox	210	Burbot	X					X																					X
Fox	905	Burbot																										X	
Fox	909	Burbot																											X
Fox	169	Lake trout	X					X																					X
Fox	170	Lake trout	X																X										
Fox	174	Lake trout	X					X																					
Fox	186	Lake trout					X			X									X										
Fox	187	Lake trout															X												
Fox	191	Lake trout	X				X							X															
Fox	193	Lake trout																X											
Fox	194	Lake trout						X		X								X											
Fox	195	Lake trout								X																			
Fox	197	Lake trout	X					X																					
Fox	198	Lake trout	X														X												
Fox	203	Lake trout						X																				X	X
Fox	204	Lake trout						X																					X
Fox	206	Lake trout						X							X														
Fox	209	Lake trout						X																					
Fox	211	Lake trout	X	X			X										X											X	X
Fox	212	Lake trout	X					X																					
Fox	213	Lake trout						X																					
Fox	563	Lake trout	X					X																					
Fox	636	Lake trout	X																										
Fox	637	Lake trout	X																										
Fox	638	Lake trout	X																										
Fox	639	Lake trout																											X
Fox	640	Lake trout	X														X												
Fox	641	Lake trout	X																										
Fox	642	Lake trout	X																										
Fox	643	Lake trout	X												X														
Fox	743	Lake trout				X			X																				
Fox	744	Lake trout	X														X												
Fox	745	Lake trout	X														X												X
Fox	760	Lake trout																											X
Fox	761	Lake trout																									X		
Fox	900	Lake trout																											X
Fox	901	Lake trout																											X
Fox	902	Lake trout																											X
Fox	907	Lake trout	X																										
Fox	962	Lake trout																	X									X	
Fox	963	Lake trout	X																										
Fox	965	Lake trout	X							X																			
Fox	966	Lake trout																											
Fox	169	Lake whitefish	X					X																					X
Fox	176	Lake whitefish								X			X		X													X	
Fox	178	Lake whitefish											X																
Fox	179	Lake whitefish															X												
Fox	183	Lake whitefish	X																										
Fox	185	Lake whitefish									X																		
Fox	188	Lake whitefish	X							X							X												
Fox	189	Lake whitefish	X																										
Fox	199	Lake whitefish	X					X			X		X		X														
Fox	200	Lake whitefish						X					X		X														
Fox	201	Lake whitefish						X							X														
Fox	202	Lake whitefish						X							X														X
Fox	205	Lake whitefish						X					X																
Fox	207	Lake whitefish						X																					
Fox	565	Lake whitefish															X												
Fox	566	Lake whitefish						X	X																				
Fox	567	Lake whitefish	X										X																
Fox	568	Lake whitefish						X		X			X																
Fox	628	Lake whitefish	X							X		X			X														
Fox	629	Lake whitefish	X																										
Fox	630	Lake whitefish	X							X					X			X											
Fox	631	Lake whitefish													X			X											
Fox	632	Lake whitefish								X					X														
Fox	633	Lake whitefish								X					X			X											

Appendix B: Taxa present in the stomachs of fishes from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993)

LAKE	FISH NO.	SPECIES	Chironomidae	Coleoptera	Diptera	Ephemeroptera	Formicidae	Gammarus	Hirudinea	Hydracarina	Lymnaeidae	Oligochaeta	Planorbidae/Valvatidae	Plecoptera	Sphaeriidae	Tipulidae	Tricoptera	Unidentified Invertebr	Zooplankton	Burbot	Broad Whitefish	Lake Trout	Lake Whitefish	Least Cisco	Longnose Sucker	Northern Pike	Round Whitefish	Slimy Sculpin	Unidentified Fishes
Fox	634	Lake whitefish	X							X					X			X											
Fox	635	Lake whitefish	X					X		X		X			X			X											
Fox	644	Lake whitefish	X												X														
Fox	645	Lake whitefish	X								X				X														
Fox	646	Lake whitefish	X							X					X														
Fox	647	Lake whitefish	X															X											
Fox	649	Lake whitefish										X						X											
Fox	650	Lake whitefish								X					X			X											
Fox	651	Lake whitefish	X																										
Fox	652	Lake whitefish	X							X					X			X											
Fox	653	Lake whitefish	X					X		X					X														
Fox	654	Lake whitefish	X							X		X			X			X											
Fox	655	Lake whitefish	X												X														
Fox	659	Lake whitefish	X									X			X														
Fox	660	Lake whitefish	X							X					X														
Fox	661	Lake whitefish	X							X					X														
Fox	662	Lake whitefish																X											
Fox	663	Lake whitefish	X	X						X								X											
Fox	664	Lake whitefish									X		X																
Fox	666	Lake whitefish	X																										
Fox	667	Lake whitefish						X		X	X				X														
Fox	668	Lake whitefish	X							X					X			X											
Fox	767	Lake whitefish	X					X									X												
Fox	768	Lake whitefish	X								X						X												
Fox	769	Lake whitefish	X														X												
Fox	770	Lake whitefish															X												
Fox	771	Lake whitefish									X		X																
Fox	772	Lake whitefish						X					X				X												
Fox	774	Lake whitefish								X							X												
Fox	775	Lake whitefish							X		X						X											X	
Fox	776	Lake whitefish								X			X																
Fox	777	Lake whitefish							X								X												
Fox	778	Lake whitefish															X												
Fox	779	Lake whitefish	X										X		X														
Fox	780	Lake whitefish						X	X		X		X		X														
Fox	781	Lake whitefish															X												
Fox	782	Lake whitefish															X												
Fox	783	Lake whitefish									X																		
Fox	784	Lake whitefish	X					X	X	X	X		X				X												X
Fox	908	Lake whitefish													X														
Fox	911	Lake whitefish													X														
Fox	912	Lake whitefish													X														
Fox	913	Lake whitefish													X														
Fox	914	Lake whitefish										X			X														
Fox	915	Lake whitefish	X												X														
Fox	916	Lake whitefish	X																										
Fox	917	Lake whitefish													X														
Fox	918	Lake whitefish													X														
Fox	920	Lake whitefish													X														
Fox	921	Lake whitefish													X														
Fox	922	Lake whitefish													X														
Fox	925	Lake whitefish																	X										
Fox	926	Lake whitefish													X														
Fox	927	Lake whitefish	X																										
Fox	928	Lake whitefish	X												X														
Fox	929	Lake whitefish	X												X														
Fox	930	Lake whitefish	X												X														
Fox	931	Lake whitefish	X												X														
Fox	932	Lake whitefish	X												X														
Fox	933	Lake whitefish	X												X														
Fox	934	Lake whitefish	X												X														
Fox	935	Lake whitefish	X												X														
Fox	936	Lake whitefish	X												X														
Fox	937	Lake whitefish	X												X														
Fox	938	Lake whitefish	X												X														
Fox	939	Lake whitefish	X												X														
Fox	940	Lake whitefish	X												X														
Fox	941	Lake whitefish	X																										

Appendix B: Taxa present in the stomachs of fishes from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993)

LAKE	FISH NO.	SPECIES	Chironomidae	Coleoptera	Diptera	Ephemeroptera	Formicidae	Gammarus	Hirudinea	Hydracarina	Lymnaeidae	Oligochaeta	Planorbidae/Valvatidae	Plecoptera	Sphaeriidae	Tipulidae	Tricoptera	Unidentified Invertebr.	Zooplankton	Burbot	Broad Whitefish	Lake Trout	Lake Whitefish	Least Cisco	Longnose Sucker	Northern Pike	Round Whitefish	Slimy Sculpin	Unidentified Fishes
Fox	942	Lake whitefish											X																
Fox	944	Lake whitefish	X												X														
Fox	945	Lake whitefish	X												X														
Fox	946	Lake whitefish	X												X														
Fox	947	Lake whitefish																	X										
Fox	948	Lake whitefish	X												X														
Fox	949	Lake whitefish	X												X														
Fox	950	Lake whitefish	X												X														
Fox	951	Lake whitefish																	X										
Fox	952	Lake whitefish	X												X														
Fox	953	Lake whitefish	X												X														
Fox	954	Lake whitefish	X												X														
Fox	955	Lake whitefish	X																										
Fox	956	Lake whitefish																	X										
Fox	957	Lake whitefish	X																X										
Fox	958	Lake whitefish	X												X														
Fox	959	Lake whitefish	X												X														
Fox	960	Lake whitefish																	X										
Fox	961	Lake whitefish																	X										
Fox	750	Northern pike																											X
Fox	751	Northern pike																											X
Fox	756	Northern pike																											X
Fox	758	Northern pike																											X
Fox	787	Northern pike							X																			X	
Fox	788	Northern pike							X																			X	
Fox	553	Round whitefish	X																										
Fox	554	Round whitefish	X														X												
Fox	555	Round whitefish	X																										
Fox	556	Round whitefish	X																										
Fox	558	Round whitefish	X																										
Fox	559	Round whitefish	X																										
Fox	560	Round whitefish															X												
Fox	561	Round whitefish	X																										
Fox	564	Round whitefish				X											X												
Fox	766	Round whitefish	X																										
Fox	786	Round whitefish							X		X						X												
Kusawa	305	Lake trout											X																
Kusawa	308	Lake trout	X										X					X											
Kusawa	YTG104	Lake trout																	X										
Kusawa	YTG105	Lake trout																X											
Kusawa	YTG106	Lake trout																X											
Kusawa	YTG108	Lake trout																											X
Kusawa	YTG109	Lake trout																											X
Kusawa	YTG110	Lake trout															X												
Kusawa	YTG111	Lake trout																											X
Kusawa	YTG112	Lake trout													X			X											X
Kusawa	YTG117	Lake trout		X			X										X	X					X						
Kusawa	YTG119	Lake trout																											X
Kusawa	YTG121	Lake trout									X		X																
Kusawa	YTG123	Lake trout		X														X											
Kusawa	YTG124	Lake trout		X		X												X											
Kusawa	YTG129	Lake trout		X														X											
Kusawa	YTG131	Lake trout																											X
Kusawa	YTG133	Lake trout																											X
Kusawa	YTG134	Lake trout																											X
Kusawa	YTG138	Lake trout		X														X											
Kusawa	YTG139	Lake trout																											X
Kusawa	YTG143	Lake trout																											X
Kusawa	YTG16	Lake trout			X																								
Kusawa	YTG17	Lake trout			X									X															X
Kusawa	YTG18	Lake trout	X		X	X											X												
Kusawa	YTG20	Lake trout			X						X		X				X												
Kusawa	YTG21	Lake trout			X												X												
Kusawa	YTG22	Lake trout																											X
Kusawa	YTG23	Lake trout			X																								
Kusawa	YTG24	Lake trout	X																										
Kusawa	YTG25	Lake trout			X	X											X												X
Kusawa	YTG26	Lake trout			X								X				X												

Appendix B: Taxa present in the stomachs of fishes from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993)

LAKE	FISH NO.	SPECIES	Chironomidae	Coleoptera	Diptera	Ephemeroptera	Formicidae	Gammarus	Hirudinea	Hydracarina	Lymnaeidae	Oligochaeta	Planorbidae/Valvatidae	Plecoptera	Sphaeriidae	Tipulidae	Tricoptera	Unidentified Invertebr	Zooplankton	Burbot	Broad Whitefish	Lake Trout	Lake Whitefish	Least Cisco	Longnose Sucker	Northern Pike	Round Whitefish	Slimy Sculpin	Unidentified Fishes
Kusawa	YTG124	Lake whitefish	X						X	X			X		X														
Kusawa	YTG125	Lake whitefish	X						X	X			X		X														
Kusawa	YTG126	Lake whitefish	X							X			X		X														
Kusawa	YTG127	Lake whitefish	X							X			X		X														
Kusawa	YTG129	Lake whitefish	X										X		X														
Kusawa	YTG13	Lake whitefish	X							X																			
Kusawa	YTG130	Lake whitefish	X							X	X		X		X														
Kusawa	YTG131	Lake whitefish											X																
Kusawa	YTG132	Lake whitefish	X							X			X		X														
Kusawa	YTG133	Lake whitefish	X							X	X				X														
Kusawa	YTG134	Lake whitefish	X		X					X	X		X		X														
Kusawa	YTG135	Lake whitefish								X			X																
Kusawa	YTG136	Lake whitefish	X							X			X		X														
Kusawa	YTG14	Lake whitefish								X			X		X														
Kusawa	YTG142	Lake whitefish	X							X			X		X														
Kusawa	YTG143	Lake whitefish								X			X		X														
Kusawa	YTG144	Lake whitefish								X			X																
Kusawa	YTG148	Lake whitefish											X		X														
Kusawa	YTG150	Lake whitefish								X			X																
Kusawa	YTG154	Lake whitefish	X										X		X														
Kusawa	YTG156	Lake whitefish	X							X			X		X														
Kusawa	YTG157	Lake whitefish	X							X	X		X																
Kusawa	YTG159	Lake whitefish	X																										
Kusawa	YTG160	Lake whitefish	X							X			X		X														
Kusawa	YTG161	Lake whitefish	X							X			X		X														
Kusawa	YTG162	Lake whitefish	X												X														
Kusawa	YTG163	Lake whitefish	X							X					X														
Kusawa	YTG164	Lake whitefish	X							X			X		X														
Kusawa	YTG165	Lake whitefish	X							X			X		X														
Kusawa	[illegible]	Lake whitefish			X					X			X		X														
Kusawa	[illegible]	Lake whitefish											X		X														
Kusawa	[illegible]	Lake whitefish									X		X																
Kusawa	YTG169	Lake whitefish								X			X		X														
Kusawa	YTG17	Lake whitefish																X											
Kusawa	YTG170	Lake whitefish									X		X																
Kusawa	YTG171	Lake whitefish								X			X																
Kusawa	YTG172	Lake whitefish									X																		
Kusawa	YTG173	Lake whitefish								X			X																
Kusawa	YTG175	Lake whitefish	X										X		X														
Kusawa	YTG176	Lake whitefish	X							X			X		X														
Kusawa	YTG177	Lake whitefish	X										X		X		X												
Kusawa	YTG178	Lake whitefish								X			X		X														
Kusawa	YTG179	Lake whitefish	X							X			X		X														
Kusawa	YTG18	Lake whitefish								X			X		X														
Kusawa	YTG180	Lake whitefish	X								X		X		X														
Kusawa	YTG181	Lake whitefish									X		X																
Kusawa	YTG182	Lake whitefish	X							X			X		X														
Kusawa	YTG183	Lake whitefish	X							X			X																
Kusawa	YTG184	Lake whitefish	X							X			X		X		X												
Kusawa	YTG185	Lake whitefish			X					X			X				X												
Kusawa	YTG19	Lake whitefish	X										X		X			X											
Kusawa	YTG2	Lake whitefish	X												X														
Kusawa	YTG20	Lake whitefish											X		X														
Kusawa	YTG21	Lake whitefish	X							X			X		X														
Kusawa	YTG22	Lake whitefish													X														
Kusawa	YTG3	Lake whitefish											X		X														
Kusawa	YTG38	Lake whitefish	X							X					X														
Kusawa	YTG4	Lake whitefish			X								X																
Kusawa	YTG48	Lake whitefish	X												X														
Kusawa	YTG49	Lake whitefish	X							X					X														
Kusawa	YTG5	Lake whitefish								X			X		X														
Kusawa	YTG50	Lake whitefish	X							X					X														
Kusawa	YTG51	Lake whitefish	X		X										X														
Kusawa	YTG52	Lake whitefish	X												X														
Kusawa	YTG55	Lake whitefish	X							X			X		X														
Kusawa	YTG57	Lake whitefish	X							X			X		X		X												
Kusawa	YTG59	Lake whitefish	X							X			X		X														
Kusawa	YTG6	Lake whitefish	X								X		X		X														

Appendix B: Taxa present in the stomachs of fishes from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993)

LAKE	FISH NO.	SPECIES	Chironomidae	Coleoptera	Diptera	Ephemeroptera	Formicidae	*Gammarus*	Hirudinea	*Hydracarina*	Lymnaeidae	Oligochaeta	Planorbidae/Valvatidae	Plecoptera	Sphaeriidae	Tipulidae	Tricoptera	Unidentified Invertebr	Zooplankton	Burbot	Broad Whitefish	Lake Trout	Lake Whitefish	Least Cisco	Longnose Sucker	Northern Pike	Round Whitefish	Slimy Sculpin	Unidentified Fishes
Kusawa	YTG60	Lake whitefish	X										X		X														
Kusawa	YTG68	Lake whitefish	X		X								X		X		X	X											
Kusawa	YTG69	Lake whitefish													X														
Kusawa	YTG74	Lake whitefish	X							X	X		X		X														
Kusawa	YTG8	Lake whitefish	X							X			X																
Kusawa	YTG80	Lake whitefish									X																		
Kusawa	YTG83	Lake whitefish								X	X		X																
Kusawa	YTG84	Lake whitefish											X		X														
Kusawa	YTG85	Lake whitefish	X		X					X			X																
Kusawa	YTG88	Lake whitefish	X							X			X		X														
Kusawa	YTG89	Lake whitefish	X							X			X		X														
Kusawa	YTG90	Lake whitefish	X							X			X		X														
Kusawa	YTG91	Lake whitefish											X		X														
Kusawa	YTG92	Lake whitefish								X			X		X														
Kusawa	YTG94	Lake whitefish	X							X			X		X														
Kusawa	YTG95	Lake whitefish	X							X			X																
Kusawa	YTG96	Lake whitefish								X			X		X														
Kusawa	YTG97	Lake whitefish								X			X		X														
Kusawa	YTG98	Lake whitefish	X							X			X		X														
Kusawa	YTG99	Lake whitefish	X						X	X			X		X														
Kusawa	333	Round whitefish																	X										
Kusawa	334	Round whitefish																	X										
Kusawa	673	Round whitefish	X																										
Kusawa	674	Round whitefish	X															X											
Kusawa	675	Round whitefish	X														X												
Kusawa	676	Round whitefish									X							X	X										
Kusawa	678	Round whitefish	X																										
Kusawa	680	Round whitefish	X				X							X				X											
Kusawa	681	Round whitefish	X														X	X											
Kusawa	683	Round whitefish	X																										
Kusawa	684	Round whitefish	X														X												
Kusawa	685	Round whitefish	X															X											
Kusawa	686	Round whitefish	X																										
Kusawa	687	Round whitefish	X																										
Kusawa	688	Round whitefish	X											X															
Kusawa	689	Round whitefish	X																										
Kusawa	691	Round whitefish	X																										
Kusawa	692	Round whitefish	X															X											
Kusawa	693	Round whitefish															X												
Kusawa	694	Round whitefish	X																X										
Kusawa	695	Round whitefish																	X										
Kusawa	696	Round whitefish	X																										
Laberge	509	Burbot																											X
Laberge	532	Burbot																											X
Laberge	533	Burbot																						X					
Laberge	534	Burbot																							X				
Laberge	YTG1	Burbot																											X
Laberge	YTG11	Burbot																											X
Laberge	YTG17	Burbot																											X
Laberge	YTG21	Burbot																											X
Laberge	YTG22	Burbot																						X					
Laberge	YTG23	Burbot																						X					
Laberge	YTG25	Burbot																											X
Laberge	YTG26	Burbot																											X
Laberge	YTG28	Burbot																											X
Laberge	YTG29	Burbot																											X
Laberge	YTG30	Burbot																											X
Laberge	YTG33	Burbot																						X					X
Laberge	YTG34	Burbot																						X					X
Laberge	YTG35	Burbot																						X			X		
Laberge	YTG37	Burbot																											X
Laberge	YTG4	Burbot																											X
Laberge	YTG40	Burbot																											X
Laberge	YTG41	Burbot																						X					
Laberge	YTG42	Burbot																											X
Laberge	YTG43	Burbot																						X			X	X	
Laberge	YTG44	Burbot																						X				X	
Laberge	YTG45	Burbot																			X			X					

Appendix B: Taxa present in the stomachs of fishes from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993)

LAKE	FISH NO.	SPECIES	Chironomidae	Coleoptera	Diptera	Ephemeroptera	Formicidae	Gammarus	Hirudinea	Hydracarina	Lymnaeidae	Oligochaeta	Planorbidae/Valvatidae	Plecoptera	Sphaeriidae	Tipulidae	Tricoptera	Unidentified invertebr	Zooplankton	Burbot	Broad Whitefish	Lake Trout	Lake Whitefish	Least Cisco	Longnose Sucker	Northern Pike	Round Whitefish	Slimy Sculpin	Unidentified Fishes
Laberge	YTG298	Longnose sucker											X																
Laberge	YTG300	Longnose sucker	X																										
Laberge	YTG302	Longnose sucker	X																X										
Laberge	YTG303	Longnose sucker	X																X										
Laberge	YTG304	Longnose sucker	X																X										
Laberge	51	Lake trout																										X	X
Laberge	66	Lake trout																										X	X
Laberge	507	Lake trout																											X
Laberge	508	Lake trout	X																										X
Laberge	540	Lake trout																											X
Laberge	576	Lake trout	X															X											
Laberge	577	Lake trout	X							X								X											
Laberge	578	Lake trout	X							X								X											
Laberge	579	Lake trout	X																										
Laberge	580	Lake trout	X																										
Laberge	581	Lake trout	X															X											
Laberge	582	Lake trout	X															X											
Laberge	583	Lake trout	X															X											
Laberge	585	Lake trout	X															X											
Laberge	600	Lake trout																X											
Laberge	601	Lake trout	X															X											
Laberge	610	Lake trout	X			X												X											
Laberge	YTG1	Lake trout																						X				X	X
Laberge	YTG11	Lake trout																						X					
Laberge	YTG13	Lake trout																											X
Laberge	YTG14	Lake trout																						X					
Laberge	YTG15	Lake trout																											X
Laberge	YTG16	Lake trout																			X								
Laberge	YTG17	Lake trout																						X					
Laberge	YTG18	Lake trout																						X					
Laberge	YTG19	Lake trout																						X			X		
Laberge	YTG2	Lake trout																						X				X	X
Laberge	YTG20	Lake trout																											X
Laberge	YTG21	Lake trout																											X
Laberge	YTG22	Lake trout																										X	X
Laberge	YTG23	Lake trout																										X	X
Laberge	YTG24	Lake trout																						X					
Laberge	YTG25	Lake trout																											X
Laberge	YTG26	Lake trout																						X					
Laberge	YTG27	Lake trout																						X	X				
Laberge	YTG28	Lake trout																						X	X				X
Laberge	YTG3	Lake trout																						X					X
Laberge	YTG30	Lake trout																						X					
Laberge	YTG31	Lake trout																						X				X	
Laberge	YTG32	Lake trout																											X
Laberge	YTG33	Lake trout																										X	
Laberge	YTG34	Lake trout																										X	X
Laberge	YTG35	Lake trout																											X
Laberge	YTG36	Lake trout																						X					X
Laberge	YTG37	Lake trout																						X					X
Laberge	YTG39	Lake trout																							X				X
Laberge	YTG40	Lake trout																						X					
Laberge	YTG43	Lake trout																											X
Laberge	YTG45	Lake trout																						X					
Laberge	YTG46	Lake trout																						X					
Laberge	YTG47	Lake trout																						X	X				
Laberge	YTG48	Lake trout																							X				
Laberge	YTG49	Lake trout																											X
Laberge	YTG5	Lake trout																						X					
Laberge	YTG50	Lake trout																											X
Laberge	YTG53	Lake trout																						X				X	
Laberge	YTG54	Lake trout																											X
Laberge	YTG55	Lake trout																						X					
Laberge	YTG56	Lake trout																										X	
Laberge	YTG57	Lake trout																										X	
Laberge	YTG61	Lake trout																											X
Laberge	YTG62	Lake trout																											X
Laberge	YTG63	Lake trout																						X					

Appendix B: Taxa present in the stomachs of fishes from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993)

LAKE	FISH NO.	SPECIES	Chironomidae	Coleoptera	Diptera	Ephemeroptera	Formicidae	Gammarus	Hirudinea	Hydracarina	Lymnaeidae	Oligochaeta	Planorbidae/Valvatidae	Plecoptera	Sphaeridae	Tipulidae	Tricoptera	Unidentified Invertebr	Zooplankton	Burbot	Broad Whitefish	Lake Trout	Lake Whitefish	Least Cisco	Longnose Sucker	Northern Pike	Round Whitefish	Slimy Sculpin	Unidentified Fishes
Laberge	YTG64	Lake trout																					X	X					X
Laberge	YTG65	Lake trout																						X	X				
Laberge	YTG68	Lake trout																						X				X	
Laberge	YTG69	Lake trout																										X	X
Laberge	YTG70	Lake trout																											X
Laberge	YTG71	Lake trout																											X
Laberge	YTG72	Lake trout																						X					
Laberge	YTG8	Lake trout																				X			X				
Laberge	YTG3173	Lake trout																											X
Laberge	YTG3175	Lake trout																											X
Laberge	YTG3178	Lake trout																											X
Laberge	YTG3179	Lake trout																											X
Laberge	YTG3180	Lake trout																											X
Laberge	YTG3181	Lake trout																											X
Laberge	YTG3182	Lake trout																											X
Laberge	YTG3183	Lake trout																											X
Laberge	YTG3185	Lake trout																											X
Laberge	YTG3186	Lake trout																											X
Laberge	YTG3187	Lake trout																											X
Laberge	YTG3188	Lake trout																											X
Laberge	YTG3189	Lake trout																											X
Laberge	1	Lake whitefish	X							X		X							X										
Laberge	2	Lake whitefish	X							X			X	X	X														
Laberge	3	Lake whitefish	X							X			X		X														
Laberge	4	Lake whitefish	X							X			X		X			X											
Laberge	38	Lake whitefish	X										X				X												
Laberge	41	Lake whitefish	X										X	X			X												
Laberge	42	Lake whitefish	X										X		X														
Laberge	44	Lake whitefish	X							X			X																
Laberge	45	Lake whitefish	X							X			X																
Laberge	46	Lake whitefish	X							X	X		X		X														
Laberge	53	Lake whitefish								X			X																
Laberge	55	Lake whitefish	X										X																
Laberge	56	Lake whitefish											X																
Laberge	57	Lake whitefish	X							X			X		X														
Laberge	58	Lake whitefish	X												X														
Laberge	89	Lake whitefish											X				X	X											
Laberge	114	Lake whitefish	X							X					X														
Laberge	115	Lake whitefish	X							X																			
Laberge	115	Lake whitefish															X												
Laberge	118	Lake whitefish																X											
Laberge	129	Lake whitefish											X																
Laberge	138	Lake whitefish								X			X					X											
Laberge	139	Lake whitefish	X							X	X		X			X													
Laberge	141	Lake whitefish															X												
Laberge	142	Lake whitefish															X												
Laberge	153	Lake whitefish	X												X														
Laberge	156	Lake whitefish	X							X			X		X														
Laberge	158	Lake whitefish	X																										
Laberge	160	Lake whitefish	X					X		X									X										
Laberge	161	Lake whitefish																X											
Laberge	162	Lake whitefish																	X										
Laberge	163	Lake whitefish	X												X				X										
Laberge	165	Lake whitefish	X					X																					
Laberge	166	Lake whitefish	X							X					X				X										
Laberge	226	Lake whitefish																											X
Laberge	247	Lake whitefish								X									X										
Laberge	248	Lake whitefish	X					X		X									X										
Laberge	249	Lake whitefish																	X										
Laberge	250	Lake whitefish	X							X								X											
Laberge	251	Lake whitefish								X									X										
Laberge	400	Lake whitefish											X		X														
Laberge	401	Lake whitefish	X																										
Laberge	402	Lake whitefish								X	X		X																
Laberge	457	Lake whitefish	X																X										
Laberge	462	Lake whitefish								X	X																		
Laberge	497	Lake whitefish								X			X																
Laberge	498	Lake whitefish	X							X	X		X		X														

Appendix B: Taxa present in the stomachs of fishes from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993)

LAKE	FISH NO.	SPECIES	Chironomidae	Coleoptera	Diptera	Ephemeroptera	Formicidae	Gammarus	Hirudinea	Hydracarina	Lymnaeidae	Oligochaeta	Planorbidae/Valvatidae	Plecoptera	Sphaeriidae	Tipulidae	Tricoptera	Unidentified Invertebr	Zooplankton	Burbot	Broad Whitefish	Lake Trout	Lake Whitefish	Least Cisco	Longnose Sucker	Northern Pike	Round Whitefish	Slimy Sculpin	Unidentified Fishes
Laberge	499	Lake whitefish									X		X																
Laberge	500	Lake whitefish	X							X			X		X														
Laberge	501	Lake whitefish									X		X																X
Laberge	502	Lake whitefish								X			X																
Laberge	519	Lake whitefish	X													X													
Laberge	521	Lake whitefish	X							X					X														
Laberge	522	Lake whitefish	X							X			X		X														
Laberge	530	Lake whitefish	X							X																			
Laberge	531	Lake whitefish								X																			
Laberge	537	Lake whitefish	X										X																
Laberge	542	Lake whitefish	X							X			X					X											
Laberge	543	Lake whitefish	X	X																									
Laberge	544	Lake whitefish	X										X																
Laberge	545	Lake whitefish									X																		
Laberge	549	Lake whitefish	X							X																			
Laberge	550	Lake whitefish	X							X	X		X		X														
Laberge	597	Lake whitefish	X							X		X	X		X														
Laberge	618	Lake whitefish	X																										
Laberge	619	Lake whitefish	X							X																			
Laberge	626	Lake whitefish	X																										
Laberge	706	Lake whitefish	X																										
Laberge	725	Lake whitefish																	X										
Laberge	726	Lake whitefish																	X										
Laberge	727	Lake whitefish	X																										
Laberge	YL17	Lake whitefish								X									X										
Laberge	YL18	Lake whitefish								X									X										
Laberge	YL19	Lake whitefish								X	X		X						X										
Laberge	YL20	Lake whitefish								X									X										
Laberge	YL21	Lake whitefish	X							X									X										
Laberge	YL23	Lake whitefish	X							X									X										
Laberge	YL23	Lake whitefish								X									X										
Laberge	YL28	Lake whitefish	X							X									X										
Laberge	YL39	Lake whitefish	X							X																			
Laberge	YL41	Lake whitefish	X							X			X						X										
Laberge	YL43	Lake whitefish								X									X										
Laberge	YL44	Lake whitefish	X																										
Laberge	YL46	Lake whitefish								X					X				X										
Laberge	YL47	Lake whitefish	X																X										
Laberge	YTG100	Lake whitefish	X																										
Laberge	YTG101	Lake whitefish																X											
Laberge	YTG[illegible]	[illegible]h																X											
Laberge	YT[illegible]	[illegible]sh											X																
Laberge	YTG1[illegible]	[illegible]sh	X																										
Laberge	YTG10[illegible]	[illegible]efish											X																
Laberge	YTG109	Lake whitefish											X					X											
Laberge	YTG11	Lake whitefish											X		X														
Laberge	YTG112	Lake whitefish	X	X																									
Laberge	YTG114	Lake whitefish																X											
Laberge	YTG115	Lake whitefish		X																									
Laberge	YTG117	Lake whitefish																X											
Laberge	YTG118	Lake whitefish																X											
Laberge	YTG119	Lake whitefish																X											
Laberge	YTG12	Lake whitefish								X			X																
Laberge	YTG121	Lake whitefish																X											
Laberge	YTG122	Lake whitefish	X										X																
Laberge	YTG124	Lake whitefish																X											
Laberge	YTG13	Lake whitefish	X												X		X												
Laberge	YTG137	Lake whitefish					X																					X	
Laberge	YTG140	Lake whitefish																											X
Laberge	YTG145	Lake whitefish									X		X																X
Laberge	YTG146	Lake whitefish	X										X																
Laberge	YTG147	Lake whitefish											X																
Laberge	YTG149	Lake whitefish					X			X	X		X																
Laberge	YTG163	Lake whitefish									X		X																
Laberge	YTG167	Lake whitefish	X																										
Laberge	YTG17	Lake whitefish											X																
Laberge	YTG172	Lake whitefish	X								X		X															X	
Laberge	YTG176	Lake whitefish	X																										

Appendix B: Taxa present in the stomachs of fishes from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993)

LAKE	FISH NO.	SPECIES	Chironomidae	Coleoptera	Diptera	Ephemeroptera	Formicidae	Gammarus	Hirudinea	*Hydracarina*	Lymnaeidae	Oligochaeta	Planorbidae/Valvatidae	Plecoptera	Sphaeriidae	Tipulidae	Tricoptera	Unidentified Invertebr	Zooplankton	Burbot	Broad Whitefish	Lake Trout	Lake Whitefish	Least Cisco	Longnose Sucker	Northern Pike	Round Whitefish	Slimy Sculpin	Unidentified Fishes
Laberge	YTG19	Lake whitefish																										X	
Laberge	YTG20	Lake whitefish	X																										
Laberge	YTG203	Lake whitefish											X																
Laberge	YTG204	Lake whitefish											X																
Laberge	YTG205	Lake whitefish											X																
Laberge	YTG206	Lake whitefish											X																
Laberge	YTG207	Lake whitefish	X										X																
Laberge	YTG208	Lake whitefish									X		X																
Laberge	YTG209	Lake whitefish											X																
Laberge	YTG210	Lake whitefish											X																
Laberge	YTG211	Lake whitefish									X		X																
Laberge	YTG212	Lake whitefish									X																		
Laberge	YTG223	Lake whitefish									X		X																
Laberge	YTG224	Lake whitefish	X												X			X											
Laberge	YTG233	Lake whitefish																									X	X	
Laberge	YTG236	Lake whitefish											X																
Laberge	YTG245	Lake whitefish					X						X																
Laberge	YTG246	Lake whitefish											X																
Laborge	YTG247	Lake whitefish											X																
Laberge	YTG248	Lake whitefish									X		X																
Laberge	YTG249	Lake whitefish									X																		
Laberge	YTG25	Lake whitefish					X											X											
Laberge	YTG251	Lake whitefish									X		X																
Laberge	YTG252	Lake whitefish									X																		
Laberge	YTG255	Lake whitefish	X										X																
Laberge	YTG256	Lake whitefish											X																
Laberge	YTG26	Lake whitefish																						X					
Laberge	YTG28	Lake whitefish								X	X		X					X											
Laberge	YTG283	Lake whitefish																											X
Laberge	YTG284	Lake whitefish											X																
Laberge	YTG286	Lake whitefish	X																										
Laberge	YTG289	Lake whitefish																										X	
Laberge	YTG29	Lake whitefish											X																
Laberge	YTG292	Lake whitefish											X																
Laberge	YTG295	Lake whitefish											X																
Laberge	YTG296	Lake whitefish											X																
Laberge	YTG298	Lake whitefish											X																
Laberge	YTG3	Lake whitefish	X																										
Laberge	YTG31	Lake whitefish													X			X											
Laberge	YTG32	Lake whitefish																									X		
Laberge	YTG321	Lake whitefish									X		X																
Laberge	YTG33	Lake whitefish	X																										
Laberge	YTG330	Lake whitefish											X																
Laberge	YTG331	Lake whitefish											X																
Laberge	YTG332	Lake whitefish											X																
Laberge	YTG338	Lake whitefish	X																										
Laberge	YTG349	Lake whitefish																											X
Laberge	YTG351	Lake whitefish	X																										
Laberge	YTG352	Lake whitefish	X												X														
Laberge	YTG353	Lake whitefish													X														
Laberge	YTG354	Lake whitefish											X																
Laberge	YTG355	Lake whitefish	X																										
Laberge	YTG357	Lake whitefish	X																										
Laberge	YTG36	Lake whitefish											X																
Laberge	YTG360	Lake whitefish	X																										
Laberge	YTG37	Lake whitefish											X																
Laberge	YTG381	Lake whitefish											X																
Laberge	YTG382	Lake whitefish											X																
Laberge	YTG41	Lake whitefish											X																
Laberge	YTG42	Lake whitefish									X							X											
Laberge	YTG43	Lake whitefish											X		X														
Laberge	YTG44	Lake whitefish	X										X		X														
Laberge	YTG45	Lake whitefish											X																
Laberge	YTG46	Lake whitefish																											X
Laberge	YTG47	Lake whitefish	X																										
Laberge	YTG48	Lake whitefish	X										X				X												
Laberge	YTG49	Lake whitefish											X																
Laberge	YTG50	Lake whitefish	X										X																

Appendix B: Taxa present in the stomachs of fishes from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993)

LAKE	FISH NO.	SPECIES	Chironomidae	Coleoptera	Diptera	Ephemeroptera	Formicidae	*Gammarus*	Hirudinea	*Hydracarina*	Lymnaeidae	Oligochaeta	Planorbidae/Valvatidae	Plecoptera	Sphaeriidae	Tipulidae	Tricoptera	Unidentified Invertebr.	Zooplankton	Burbot	Broad Whitefish	Lake Trout	Lake Whitefish	Least Cisco	Longnose Sucker	Northern Pike	Round Whitefish	Slimy Sculpin	Unidentified Fishes
Laberge	YTG51	Lake whitefish		X						X			X																
Laberge	YTG52	Lake whitefish	X										X		X														
Laberge	YTG53	Lake whitefish											X																
Laberge	YTG54	Lake whitefish								X			X																
Laberge	YTG55	Lake whitefish											X																
Laberge	YTG57	Lake whitefish											X																
Laberge	YTG58	Lake whitefish	X										X																
Laberge	YTG60	Lake whitefish											X																
Laberge	YTG61	Lake whitefish											X																
Laberge	YTG63	Lake whitefish													X														
Laberge	YTG64	Lake whitefish											X																
Laberge	YTG65	Lake whitefish											X																
Laberge	YTG66	Lake whitefish											X																
Laberge	YTG67	Lake whitefish											X																
Laberge	YTG68	Lake whitefish	X										X																
Laberge	YTG69	Lake whitefish									X		X																
Laberge	YTG71	Lake whitefish													X		X												
Laberge	YTG72	Lake whitefish								X			X																
Laberge	YTG73	Lake whitefish											X																
Laberge	YTG74	Lake whitefish											X						X										
Laberge	YTG75	Lake whitefish								X			X		X														
Laberge	YTG76	Lake whitefish								X								X											
Laberge	YTG77	Lake whitefish											X																
Laberge	YTG78	Lake whitefish																										X	X
Laberge	YTG82	Lake whitefish	X																										
Laberge	YTG83	Lake whitefish								X			X																
Laberge	YTG86	Lake whitefish								X			X		X														
Laberge	YTG87	Lake whitefish	X							X			X																
Laberge	YTG89	Lake whitefish								X			X																
Laberge	YTG90	Lake whitefish											X																
Laberge	YTG91	Lake whitefish								X			X					X											
Laberge	YTG92	Lake whitefish								X			X																
Laberge	YTG93	Lake whitefish	X							X			X					X											
Laberge	YTG94	Lake whitefish											X																
Laberge	YTG95	Lake whitefish	X							X			X																
Laberge	YTG98	Lake whitefish											X					X											
Laberge	YTG99	Lake whitefish	X								X		X																
Laberge	YTG1	Northern pike																					X						
Laberge	YTG11	Northern pike																											X
Laberge	YTG14	Northern pike																						X					
Laberge	YTG17	Northern pike																							X				
Laberge	YTG18	Northern pike																											X
Laberge	YTG20	Northern pike																									X		
Laberge	YTG22	Northern pike																											X
Laberge	YTG26	Northern pike																						X					X
Laberge	YTG30	Northern pike																			X								
Laberge	YTG33	Northern pike																						X					
Laberge	YTG34	Northern pike																						X					
Laberge	YTG35	Northern pike																											X
Laberge	YTG36	Northern pike																						X					
Laberge	YTG37	Northern pike																						X					
Laberge	YTG38	Northern pike																						X					X
Laberge	YTG41	Northern pike																									X		
Laberge	YTG42	Northern pike																								X			
Laberge	YTG48	Northern pike																						X					
Laberge	YTG50	Northern pike																						X					
Laberge	YTG51	Northern pike																											X
Laberge	YTG52	Northern pike																						X					X
Laberge	YTG53	Northern pike																											X
Laberge	YTG54	Northern pike																						X					
Laberge	YTG55	Northern pike																						X					
Laberge	YTG56	Northern pike																		X								X	X
Laberge	YTG59	Northern pike																						X					
Laberge	YTG63	Northern pike																										X	
Laberge	YTG64	Northern pike																											X
Laberge	YTG66	Northern pike																											X
Laberge	YTG67	Northern pike																											X
Laberge	YTG68	Northern pike																											X

Appendix B: Taxa present in the stomachs of fishes from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993)

LAKE	FISH NO.	SPECIES	Chironomidae	Coleoptera	Diptera	Ephemeroptera	Formicidae	Gammarus	Hirudinea	Hydracarina	Lymnaeidae	Oligochaeta	Planorbidae/Valvatidae	Plecoptera	Sphaeriidae	Tipulidae	Tricoptera	Unidentified invertebrates	Zooplankton	Burbot	Broad Whitefish	Lake Trout	Lake Whitefish	Least Cisco	Longnose Sucker	Northern Pike	Round Whitefish	Slimy Sculpin	Unidentified Fishes
Laberge	YTG70	Northern pike																											X
Laberge	YTG73	Northern pike																						X					
Laberge	YTG74	Northern pike																						X					
Laberge	YTG75	Northern pike																									X		
Laberge	YTG76	Northern pike																											X
Laberge	YTG77	Northern pike																						X					
Laberge	YTG8	Northern pike																									X		
Laberge	59	Round whitefish	X																										
Laberge	60	Round whitefish															X												
Laberge	62	Round whitefish	X																										
Laberge	65	Round whitefish	X														X												
Laberge	106	Round whitefish	X									X																	
Laberge	108	Round whitefish	X														X												
Laberge	109	Round whitefish	X																										
Laberge	127	Round whitefish	X																										
Laberge	144	Round whitefish	X												X														
Laberge	146	Round whitefish	X																										
Laberge	149	Round whitefish	X										X		X														
Laberge	150	Round whitefish	X							X																			
Laberge	151	Round whitefish	X												X														
Laberge	152	Round whitefish	X										X																
Laberge	155	Round whitefish	X										X		X														
Laberge	220	Round whitefish	X																										
Laberge	228	Round whitefish									X																		
Laberge	233	Round whitefish	X																										
Laberge	235	Round whitefish	X																										
Laberge	236	Round whitefish	X																										
Laberge	238	Round whitefish	X														X												
Laberge	239	Round whitefish															X												
Laberge	253	Round whitefish	X								X																		
Laberge	496	Round whitefish	X																										
Laberge	510	Round whitefish	X																										
Laberge	511	Round whitefish	X																										
Laberge	512	Round whitefish	X							X																			
Laberge	513	Round whitefish	X																										
Laberge	514	Round whitefish	X																										
Laberge	516	Round whitefish	X																										
Laberge	517	Round whitefish	X																										
Laberge	520	Round whitefish	X								X							X											
Laberge	524	Round whitefish	X	X																									
Laberge	572	Round whitefish	X														X												
Laberge	574.1	Round whitefish	X																										
Laberge	574.2	Round whitefish	X																										
Laberge	574.3	Round whitefish	X																										
Laberge	574.4	Round whitefish	X																										
Laberge	574.5	Round whitefish	X																										
Laberge	574.6	Round whitefish	X																										
Laberge	574.7	Round whitefish	X																										
Laberge	574.8	Round whitefish	X																										
Laberge	574.9	Round whitefish	X																										
Laberge	587	Round whitefish	X																										
Laberge	588	Round whitefish	X																										
Laberge	590	Round whitefish	X																										
Laberge	596	Round whitefish	X																										
Laberge	598	Round whitefish	X																										
Laberge	599	Round whitefish																X											
Laberge	604	Round whitefish	X															X											
Laberge	605	Round whitefish	X							X																			
Laberge	606	Round whitefish	X							X																			
Laberge	607	Round whitefish	X																										
Laberge	608	Round whitefish	X																										
Laberge	612	Round whitefish	X																										
Laberge	715	Round whitefish	X																										
Laberge	716	Round whitefish	X																										
Laberge	717	Round whitefish									X																		
Laberge	YTG12	Round whitefish									X						X												
Laberge	YTG14	Round whitefish									X						X												
Laberge	YTG19	Round whitefish	X								X																		

Appendix B: Taxa present in the stomachs of fishes from Fox, Laberge and Kusawa lakes, Yukon Territory (1992-1993)

LAKE	FISH NO.	SPECIES	Chironomidae	Coleoptera	Diptera	Ephemeroptera	Formicidae	*Gammarus*	Hirudinea	*Hydracarina*	Lymnaeidae	Oligochaeta	Planorbidae/Valvatidae	Plecoptera	Sphaeriidae	Tipulidae	Tricoptera	Unidentified Invertebr	Zooplankton	Burbot	Broad Whitefish	Lake Trout	Lake Whitefish	Least Cisco	Longnose Sucker	Northern Pike	Round Whitefish	Slimy Sculpin	Unidentified Fishes
Laberge	YTG21	Round whitefish																X											
Laberge	YTG22	Round whitefish																X											
Laberge	YTG23	Round whitefish					X																						
Laberge	YTG24	Round whitefish	X																										
Laberge	YTG25	Round whitefish											X																
Laberge	YTG26	Round whitefish	X										X																
Laberge	YTG47	Round whitefish									X																		

Appendix C: Organochlorine data for fishes and invertebrates from Yukon lakes (1992-1994)

Lake	Species	Number	Tissue Extracted	Individual/ Composite	Method of Extraction	Length (mm)	Weight (g)	% Lipid (g/g ww)	15N/14N (per mil)	s-CBZ (ng/g ww)	s-HCH (ng/g ww)	s-CHL (ng/g ww)	s-DDT (ng/g ww)	s-PCB (ng/g ww)	s-CHB (ng/g ww)	Recoveries of Internal Standards
Fox	Burbot	1000	liver	individual	ball-mill	580	1650	31.30	8.73	4.60	9.01	12.61	32.73	18.74	44.33	67/66
Fox	Burbot	1001	liver	individual	ball-mill	435	800	32.60	9.41	5.03	13.87	13.22	45.06	26.78	40.53	68/86
Fox	Burbot	1002	liver	individual	ball-mill	542	1300	31.25	7.94	6.20	15.29	14.16	37.09	27.07	35.40	70/83
Fox	Burbot	1003	liver	individual	ball-mill	481	825	25.80	9.62	6.50	13.20	19.11	62.72	44.40	62.62	69/75
Fox	Burbot	1004	liver	individual	ball-mill	553	1275	28.60	9.16	6.60	10.62	22.01	89.71	53.27	88.45	62/80
Fox	Burbot	1005	liver	individual	ball-mill	540	1650	35.60	9.18	10.72	14.33	20.47	66.93	45.66	76.49	53/89
Fox	Burbot	173	liver	individual	ball-mill	689	2500	40.75	9.76	8.43	21.38	20.47	124.99	80.01	105.21	72/88
Fox	Burbot	196	liver	individual	ball-mill	604	1100	.	9.28	4.12	6.29	11.44	46.49	26.28	71.54	77/54
Fox	Burbot	208	liver	individual	ball-mill	730	2450	23.32	8.38	9.53	16.88	29.56	105.79	64.01	89.12	95/73
Fox	Burbot	210	liver	individual	ball-mill	650	1500	30.18	9.77	12.92	24.44	38.96	119.98	103.65	108.85	.
Fox	Burbot	905	liver	individual	ball-mill	498	1075	29.60	7.65	5.92	11.70	17.07	54.08	40.69	59.78	78/88
Fox	Burbot	906	liver	individual	ball-mill	505	950	44.76	7.99	5.28	15.52	14.17	51.75	31.07	53.95	81/89
Fox	Burbot	909	liver	individual	ball-mill	461	1100	18.01	8.22	4.41	11.88	11.75	43.51	28.18	46.26	75/84
Fox	Burbot	910	liver	individual	ball-mill	488	750	27.15	9.03	7.02	15.06	21.66	66.83	52.50	74.27	82/87
Laberge	Burbot	920-0026	liver	individual	ball-mill	360	340	45.80	12.79	10.03	19.97	87.69	919.96	583.82	878.52	66/72
Laberge	Burbot	920-0029	liver	individual	ball-mill	535	1187	63.70	12.48	19.38	32.20	172.08	1805.63	826.39	2148.42	70/83
Laberge	Burbot	920-0030	liver	individual	ball-mill	641	1940	21.01	11.20	18.03	27.91	238.99	2005.82	708.92	1681.82	94/88
Laberge	Burbot	920-0031	liver	individual	ball-mill	638	2354	47.70	11.72	19.70	30.45	197.37	1632.68	557.19	1800.12	85/90
Laberge	Burbot	920-0032	liver	individual	ball-mill	520	1025	42.76	11.50	20.51	23.09	204.11	1548.22	836.54	1718.39	75/81
Laberge	Burbot	920-0049	liver	individual	ball-mill	320	230	.	12.12	12.26	20.53	140.20	1527.42	970.76	1665.30	82/84
Laberge	Burbot	920-0054	liver	individual	ball-mill	504	970	52.26	11.96	28.42	28.00	267.09	2251.77	1057.94	2333.27	75/85
Laberge	Burbot	920-0055	liver	individual	ball-mill	509	1134	56.20	12.61	21.25	29.65	175.97	2308.28	1061.21	2329.73	72/71
Laberge	Burbot	920-0056	liver	individual	ball-mill	500	931	42.73	11.23	16.34	20.31	149.87	1105.65	626.98	1261.87	68/75
Laberge	Burbot	920-0057	liver	individual	ball-mill	550	1090	23.10	12.02	14.54	14.62	119.43	1465.64	894.70	1481.30	83/74
Laberge	Burbot	920-0059	liver	individual	ball-mill	706	2227	45.21	11.37	40.42	37.72	681.62	6973.09	3640.37	3966.49	97/99
Laberge	Burbot	920-0068	liver	individual	ball-mill	326	255	49.43	12.41	12.30	24.72	91.60	901.08	485.02	1122.83	69/86
Laberge	Burbot	920-0069	liver	individual	ball-mill	592	1350	33.37	12.24	15.85	17.19	156.81	1941.75	997.92	2083.43	70/72
Laberge	Burbot	920-0070	liver	individual	ball-mill	787	2962	33.15	11.89	20.23	29.45	642.77	7326.35	2942.71	4417.28	80/88
Laberge	Burbot	920-0071	liver	individual	ball-mill	628	1709	23.43	11.65	13.81	23.68	217.99	2085.83	811.41	1412.42	101/93
Laberge	Burbot	920-0072	liver	individual	ball-mill	665	2190	36.89	12.05	34.31	37.97	638.77	4631.87	2366.25	4466.68	100/95
Fox	Chironomid	D325	whole	composite	ball-mill	.	.	0.98	3.01	0.40	0.22	1.75	2.12	3.06	0.61	88/85
Fox	Chironomid	D334	whole	composite	ball-mill	.	.	1.23	3.60	0.50	0.45	2.27	3.02	7.20	1.87	79/89
Fox	Chironomid	E401	whole	composite	ball-mill	.	.	1.65	4.42	0.45	0.77	0.97	1.93	7.97	5.09	69/80
Fox	Chironomid	E402	whole	composite	ball-mill	.	.	1.37	5.25	0.34	0.65	1.13	2.65	17.57	5.69	71/66
Kusawa	Chironomid	D309	whole	composite	ball-mill	.	.	0.90	4.89	0.28	0.40	1.52	1.55	3.02	2.22	87/90
Kusawa	Chironomid	D427	whole	composite	ball-mill	.	.	1.62	4.61	0.39	0.61	0.48	0.41	8.33	2.12	61/75
Kusawa	Chironomid	D429	whole	composite	ball-mill	.	.	1.75	3.58	0.62	0.52	0.92	0.33	10.61	2.79	60/71
Kusawa	Chironomid	D431	whole	composite	ball-mill	.	.	1.72	3.69	0.50	0.79	0.65	0.43	7.88	3.68	63/77
Laberge	Chironomid	A48	whole	composite	ball-mill	.	.	4.50	.	1.38	1.07	1.71	29.04	7.03	6.31	120/95
Laberge	Chironomid	CH2	whole	composite	ball-mill	.	.	3.08	3.96	0.46	0.22	0.30	1.44	3.47	0.61	88/85
Laberge	Chironomid	D347	whole	composite	ball-mill	.	.	2.50	4.27	1.43	2.66	1.53	17.89	9.48	6.00	103/83
Laberge	Chironomid	D352	whole	composite	ball-mill	.	.	2.10	3.80	1.31	2.01	1.22	16.22	8.79	5.46	85/96
Laberge	Chironomid	D438	whole	composite	ball-mill	.	.	3.01	4.67	0.57	1.83	0.99	18.12	12.80	9.49	61/75
Laberge	Chironomid	D440	whole	composite	ball-mill	.	.	2.13	2.52	0.59	0.80	0.70	4.98	8.81	4.28	62/94
Laberge	Least cisco	102	whole	individual	soxhlet	165	45.1	7.69	7.61	2.11	2.82	9.33	37.23	22.18	87.08	72/65
Laberge	Least cisco	103	whole	individual	soxhlet	187	61.2	5.11	7.46	2.12	1.98	8.79	29.34	23.62	77.19	79/70
Laberge	Least cisco	31	whole	individual	soxhlet	210	100	4.14	8.26	1.27	1.36	5.62	39.30	23.58	97.15	59/95

Appendix C: Organochlorine data for fishes and invertebrates from Yukon lakes (1992-1994)

Lake	Species	Number	Tissue Extracted	Individual/ Composite	Method of Extraction	Length (mm)	Weight (g)	% Lipid (g/g ww)	15N/14N (per mil)	s-CBZ (ng/g ww)	s-HCH (ng/g ww)	s-CHL (ng/g ww)	s-DDT (ng/g ww)	s-PCB (ng/g ww)	s-CHB (ng/g ww)	Recoveries of Internal Standards
Laberge	Least cisco	728	whole	individual	soxhlet	94	6.4	1.71	8.36	0.21	0.15	1.09	9.87	8.53	10.80	57/73
Laberge	Least cisco	730	whole	individual	soxhlet	120	12.6	1.26	8.13	0.17	0.19	2.03	17.29	12.63	21.77	57/71
Laberge	Least cisco	95	whole	individual	soxhlet	200	65.8	6.10	8.34	1.50	1.78	6.02	31.15	19.37	89.98	58/70
Laberge	Least cisco	97	whole	individual	soxhlet	231	114.6	9.03	8.79	2.29	2.94	11.48	58.17	35.07	94.01	79/111
Fox	Lymnaeidae	E406	whole	composite	ball-mill	.	.	0.63	2.47	0.00	0.13	0.06	0.94	1.77	0.00	49/54
Fox	Lymnaeidae	E415	whole	composite	ball-mill	.	.	1.30	1.37	0.03	0.30	0.13	0.22	2.06	0.00	48/57
Kusawa	Lymnaeidae	C299	whole	composite	ball-mill	.	.	2.30	2.42	0.78	1.19	1.23	0.63	3.62	6.73	89/95
Kusawa	Lymnaeidae	D396	whole	composite	ball-mill	.	.	2.19	0.29	0.79	1.20	1.17	0.61	3.95	7.60	85/94
Kusawa	Lymnaeidae	D423	whole	composite	ball-mill	.	.	1.00	1.65	0.05	0.17	0.29	0.12	0.83	1.87	51/59
Kusawa	Lymnaeidae	D430	whole	composite	ball-mill	.	.	1.50	0.46	0.12	0.21	0.24	0.10	2.20	1.50	48/56
Kusawa	Lymnaeidae	SS2	whole	composite	ball-mill	.	.	2.70	.	0.62	0.95	1.07	0.61	3.22	7.93	90/89
Laberge	Lymnaeidae	A20	whole	composite	ball-mill	.	.	1.13	1.63	0.04	0.17	0.60	0.41	1.82	1.02	96/88
Laberge	Lymnaeidae	A4	whole	composite	ball-mill	.	.	0.60	2.59	0.19	0.40	0.35	0.53	0.82	1.26	80/85
Laberge	Lymnaeidae	B182	whole	composite	ball-mill	.	.	1.23	2.87	0.04	0.17	0.37	0.52	1.36	0.86	84/92
Laberge	Lymnaeidae	D433	whole	composite	ball-mill	.	.	1.74	1.78	0.05	0.43	0.12	1.05	0.75	1.24	48/66
Fox	*Gammarus*	A69	whole	composite	ball-mill	.	.	0.50	4.62	0.24	0.19	0.30	0.50	1.09	0.89	81/76
Fox	*Gammarus*	C266	whole	composite	ball-mill	.	.	0.87	1.62	0.36	0.33	0.77	0.68	1.26	0.87	84/90
Fox	*Gammarus*	E413	whole	composite	ball-mill	.	.	1.24	1.88	0.09	0.43	0.18	1.34	1.30	1.82	
Fox	*Gammarus*	E414	whole	composite	ball-mill	.	.	2.11	3.53	0.21	0.62	0.26	0.69	0.47	0.47	57/75
Fox	Valvatidae	C227	whole	composite	ball-mill	.	.	0.31	1.83	0.35	0.41	0.48	1.43	2.99	2.23	88/97
Fox	Valvatidae	C268	whole	composite	ball-mill	.	.	0.45	1.50	0.40	0.29	0.39	1.39	3.05	2.58	83/92
Fox	Valvatidae	D336	whole	composite	ball-mill	.	.	0.25	1.10	0.24	0.30	0.31	1.77	2.72	1.87	83/94
Fox	Valvatidae	E416.1	whole	composite	ball-mill	.	.	1.39	1.64	0.04	0.78	0.08	0.18	1.42	<0.01	59/66
Fox	Valvatidae	E416.2	whole	repeat	ball-mill			0.65		0.07	0.79	0.07	0.11	1.03	<0.01	66/72
Kusawa	Valvatidae	D372	whole	composite	ball-mill	.	.	1.50	2.05	0.15	1.01	0.61	0.70	3.13	2.16	99/82
Kusawa	Valvatidae	SN1	whole	composite	ball-mill	.	.	1.70	1.47	0.24	1.09	0.58	0.31	1.40	6.18	90/96
Laberge	Valvatidae	C279	whole	composite	ball-mill	.	.	0.18	1.00	0.12	0.13	0.30	1.43	2.50	1.99	80/90
Laberge	Valvatidae	D432	whole	composite	ball-mill	.	.	0.33	2.26	0.00	1.33	0.19	0.86	6.86	5.46	55/68
Laberge	Valvatidae	SS1	whole	composite	ball-mill	.	.	0.20	.	0.33	0.21	0.27	1.99	3.39	2.15	120/77
Fox	Lake trout	198	mus/skin	individual	soxhlet	504	1300	.	8.12	0.40	0.66	1.57	3.62	3.51	2.35	89/83
Fox	Lake trout	212	mus/skin	individual	soxhlet	525	1500	0.45	9.58	0.07	0.42	0.95	4.57	3.15	3.05	90/86
Fox	Lake trout	640	mus/skin	individual	soxhlet	521	1700	1.36	7.98	0.56	0.67	3.27	10.89	9.58	11.09	85/90
Fox	Lake trout	641	mus/skin	individual	soxhlet	291	150	2.16	9.66	0.36	0.72	0.88	6.76	5.38	3.54	86/76
Fox	Lake trout	642	mus/skin	individual	soxhlet	334	425	0.54	7.00	0.13	0.21	0.19	1.95	1.79	0.71	87/100
Fox	Lake trout	658	mus/skin	individual	soxhlet	447	1000	1.70	9.48	0.70	0.86	2.84	12.80	8.62	14.96	83/86
Fox	Lake trout	744	mus/skin	individual	soxhlet	512	1450	1.53	8.01	0.68	0.79	2.99	10.24	8.46	9.27	84/88
Fox	Lake trout	760	mus/skin	individual	soxhlet	447	1000	0.50	8.28	0.26	0.35	1.11	1.75	4.00	15.58	100/99
Fox	Lake trout	761	mus/skin	individual	soxhlet	509	750	0.94	8.70	0.30	0.65	0.84	1.92	1.95	9.67	82/91
Fox	Lake trout	901.1	mus/skin	individual	soxhlet			4.88		1.67	1.68	3.45	15.74	13.36	20.30	76/87
Fox	Lake trout	901.2	mus/skin	repeat	soxhlet			5.26		1.93	2.14	4.57	16.75	17.06	14.14	90/79
Fox	Lake trout	901.3	mus/skin	repeat	soxhlet	578	2625	5.87	9.22	2.48	4.30	7.95	18.87	14.33	27.29	82/102
Fox	Lake trout	902.1	mus/skin	individual	soxhlet	385	700	0.55	9.58	0.25	0.27	1.23	5.78	7.06	2.70	78/88
Fox	Lake trout	902.2	mus/skin	repeat	soxhlet			0.53		0.26	0.27	0.90	5.01	5.97	2.39	79/93
Fox	Lake trout	903	mus/skin	individual	soxhlet	433	725	2.58	8.71	0.93	0.96	2.35	7.92	6.63	14.69	77/95
Fox	Lake trout	904	mus/skin	individual	soxhlet	327	575	0.72	7.92	0.14	0.42	0.56	1.38	1.35	1.31	85/87
Fox	Lake trout	907	mus/skin	individual	soxhlet	445	750	1.51	9.25	0.65	0.73	1.21	3.74	4.81	3.55	80/84
Fox	Lake trout	962.1	mus/skin	individual	soxhlet	329	375	0.98	9.64	0.19	0.20	0.56	2.35	2.76	2.55	78/82

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Lake	Species	Number	Tissue Extracted	Individual/ Composite	Method of Extraction	Length (mm)	Weight (g)	% Lipid (g/g ww)	15N/14N (per mil)	s-CBZ (ng/g ww)	s-HCH (ng/g ww)	s-CHL (ng/g ww)	s-DDT (ng/g ww)	s-PCB (ng/g ww)	s-CHB (ng/g ww)	Recoveries of Internal Standards
Fox	Lake trout	962.2	muscle	individual	soxhlet			0.50		0.16	0.23	0.41	1.98	1.76	1.97	71/87
Fox	Lake trout	963.1	mus/skin	individual	soxhlet	362	450	0.68	10.36	0.15	0.05	0.27	1.57	2.06	0.65	79/81
Fox	Lake trout	963.2	muscle	individual	soxhlet			0.27		0.21	0.23	0.28	2.30	3.65	0.11	85/92
Kusawa	Lake trout	920-0102	mus/skin	individual	soxhlet	524	1480	0.86	9.42	0.77	0.59	7.34	9.20	28.94	30.25	114/114
Kusawa	Lake trout	920-0083	mus/skin	individual	soxhlet	415	629	0.27	10.13	0.11	0.18	8.55	15.78	56.97	23.86	102/106
Kusawa	Lake trout	920-0086	mus/skin	individual	soxhlet	471	963	0.88	9.75	1.25	0.68	24.88	27.63	67.09	160.11	117/117
Kusawa	Lake trout	920-0089	mus/skin	individual	soxhlet	535	1588	1.40	9.49	0.85	1.27	16.20	17.83	83.83	117.97	120/100
Kusawa	Lake trout	920-0092	mus/skin	individual	soxhlet	433	824	1.40	9.67	1.42	1.00	19.54	16.00	58.12	226.76	98/115
Kusawa	Lake trout	920-0093	mus/skin	individual	soxhlet	513	1655	1.41	10.25	0.56	1.04	17.46	19.86	61.71	146.40	110/104
Kusawa	Lake trout	920-0094	mus/skin	individual	soxhlet	698	3967	2.92	10.44	2.16	1.85	35.65	228.29	311.44	235.57	115/125
Kusawa	Lake trout	920-0096	mus/skin	individual	soxhlet	646	3116	5.94	9.53	2.96	4.14	20.99	81.06	105.67	155.10	117/110
Kusawa	Lake trout	920-0097	mus/skin	individual	soxhlet	460	1002	1.98	9.84	1.17	1.04	15.45	13.33	39.68	89.08	94/84
Kusawa	Lake trout	920-0098	mus/skin	individual	soxhlet	555	1708	0.57	10.51	0.25	0.19	7.02	12.55	40.98	22.88	94/74
Laberge	Lake trout	920-0001	mus/skin	individual	soxhlet	442	925	6.48	12.72	2.73	4.28	15.19	93.15	55.54	164.22	.
Laberge	Lake trout	920-0002	mus/skin	individual	soxhlet	376	606	4.60	12.92	1.84	2.27	17.69	54.23	71.76	157.65	79/74
Laberge	Lake trout	920-0033	mus/skin	individual	soxhlet	475	1241	8.62	11.16	2.91	4.02	23.83	156.67	60.44	208.77	108/78
Laberge	Lake trout	920-0040	mus/skin	individual	soxhlet	485	1270	13.12	11.37	5.47	3.59	166.48	3014.76	2528.24	1443.15	102/112
Laberge	Lake trout	920-0045	mus/skin	individual	soxhlet	552	1640	4.78	12.69	4.11	2.74	118.61	1711.19	1884.02	1025.94	111/128
Laberge	Lake trout	920-0051	mus/skin	individual	soxhlet	539	2337	12.37	11.76	3.95	6.11	48.50	353.72	130.06	314.73	88/88
Laberge	Lake trout	920-0053	mus/skin	individual	soxhlet	442	954	3.27	10.61	1.58	2.60	25.08	44.59	75.99	138.88	110/115
Laberge	Lake trout	920-0073	mus/skin	individual	soxhlet	580	2349	8.28	11.95	4.76	6.96	34.23	346.16	234.52	222.69	93/108
Laberge	Lake trout	YTG1	mus/skin	individual	soxhlet	453	1000	4.90	13.29	1.58	1.85	13.31	72.41	58.17	112.21	94/95
Laberge	Lake trout	YTG14	mus/skin	individual	soxhlet	460	1050	2.80	11.05	1.44	1.40	14.48	65.67	53.61	132.38	82/83
Laberge	Lake trout	YTG15	mus/skin	individual	soxhlet	494	1675	7.00	12.77	2.62	2.24	29.33	216.62	139.82	322.89	85/79
Laberge	Lake trout	YTG30	mus/skin	individual	soxhlet	566	2100	5.00	12.56	3.14	2.95	25.33	200.78	144.25	403.20	75/85
Kusawa	Longnose sucker	YTG40	muscle	individual	soxhlet	420	750	1.03	7.01	0.30	0.31	1.97	12.74	16.52	9.41	80/100
Kusawa	Longnose sucker	YTG42	muscle	individual	soxhlet	410	800	0.73	6.63	0.13	0.25	0.91	5.54	5.27	4.88	69/79
Kusawa	Longnose sucker	YTG43	muscle	individual	soxhlet	405	750	1.29	6.96	0.24	0.39	1.00	7.86	4.29	6.95	84/101
Kusawa	Longnose sucker	YTG44	muscle	individual	soxhlet	435	800	1.15	7.19	0.30	0.28	1.68	13.80	18.54	9.72	73/92
Kusawa	Longnose sucker	YTG45	muscle	individual	soxhlet	395	700	1.48	6.75	0.32	0.34	1.58	7.97	7.62	9.45	77/102
Kusawa	Longnose sucker	YTG47	muscle	individual	soxhlet	450	800	1.78	7.15	0.42	0.48	2.27	13.80	10.94	15.65	77/97
Laberge	Longnose sucker	69	muscle	individual	soxhlet	415	750	0.52	7.18	0.21	0.35	1.82	21.01	23.25	9.84	85/88
Laberge	Longnose sucker	74	muscle	individual	soxhlet	455	900	0.94	5.80	0.32	0.62	3.50	23.97	18.50	18.33	78/74
Laberge	Longnose sucker	77	muscle	individual	soxhlet	430	750	0.83	7.19	0.26	0.45	2.35	21.67	18.52	14.48	83/88
Laberge	Longnose sucker	296	muscle	individual	soxhlet	430	875	0.54	8.81	0.21	0.30	1.79	17.31	13.87	13.06	80/100
Laberge	Longnose sucker	297	muscle	individual	soxhlet	415	700	1.80	8.25	0.31	0.37	1.57	14.24	7.16	18.65	50/48
Laberge	Longnose sucker	298	muscle	individual	soxhlet	445	900	0.71	6.97	0.10	0.14	1.41	9.36	10.36	8.84	60/68
Laberge	Longnose sucker	299	muscle	individual	soxhlet	435	975	0.40	7.26	0.06	0.14	0.76	7.78	5.98	4.77	78/80
Laberge	Longnose sucker	300	muscle	individual	soxhlet	449	1000	0.88	8.82	0.27	0.51	3.57	26.44	19.36	44.60	81/50
Laberge	Longnose sucker	301	muscle	individual	soxhlet	433	900	2.14	7.74	0.59	0.71	5.17	25.62	23.86	34.35	88/111
Laberge	Longnose sucker	303	muscle	individual	soxhlet	387	650	0.52	7.29	0.08	0.15	0.27	2.88	1.09	2.17	72/86
Laberge	Longnose sucker	305	muscle	individual	soxhlet	435	900	0.98	8.36	0.24	0.29	1.76	14.04	11.97	23.19	93/91
Laberge	Longnose sucker	306	muscle	individual	soxhlet	466	925	1.26	6.55	0.43	0.39	1.36	9.02	6.92	17.12	80/99
Fox	Lake whitefish	300	mus/skin	individual	soxhlet	455	1100	.	8.52	0.12	0.35	0.55	2.43	1.85	2.51	
Fox	Lake whitefish	628	mus/skin	individual	soxhlet	455	1050	0.61	7.92	0.22	0.23	0.51	4.22	2.66	4.03	82/84
Fox	Lake whitefish	629	mus/skin	individual	soxhlet	448	1000	1.50	7.43	0.63	0.51	0.74	7.96	16.28	5.19	81/98
Fox	Lake whitefish	631	mus/skin	individual	soxhlet	455	900	0.48	5.95	0.18	0.21	0.34	1.62	2.99	0.96	80/86

Appendix C: Organochlorine data for fishes and invertebrates from Yukon lakes (1992-1994)

Lake	Species	Number	Tissue Extracted	Individual/ Composite	Method of Extraction	Length (mm)	Weight (g)	% Lipid (g/g ww)	15N/14N (per mil)	s-CBZ (ng/g ww)	s-HCH (ng/g ww)	s-CHL (ng/g ww)	s-DDT (ng/g ww)	s-PCB (ng/g ww)	s-CHB (ng/g ww)	Recoveries of Internal Standards
Fox	Lake whitefish	634	mus/skin	individual	soxhlet	440	575	0.63	8.03	0.31	0.67	1.30	6.82	3.41	18.46	80/100
Fox	Lake whitefish	635	mus/skin	individual	soxhlet	468	1300	2.44	7.79	0.88	0.68	1.88	14.12	7.54	12.46	
Fox	Lake whitefish	646	mus/skin	individual	soxhlet	347	575	1.93	6.05	0.45	0.98	0.64	3.52	1.10	3.86	80/77
Fox	Lake whitefish	647	mus/skin	individual	soxhlet	355	500	0.93	7.02	0.29	.	0.29	2.03	1.52	9.11	86/48
Fox	Lake whitefish	648	mus/skin	individual	soxhlet	361	600	0.58	6.42	0.17	0.29	0.32	0.81	1.65	1.80	106/100
Fox	Lake whitefish	650	mus/skin	individual	soxhlet	365	625	1.63	5.44	1.36	0.87	1.07	2.56	3.16	3.09	
Fox	Lake whitefish	660	mus/skin	individual	soxhlet	447	1000	0.57	7.10	0.16	0.19	0.15	2.71	1.70	0.33	90/100
Fox	Lake whitefish	661	mus/skin	individual	soxhlet	434	875	0.63	8.13	0.21	0.26	0.49	4.51	3.20	4.19	79/94
Fox	Lake whitefish	662	mus/skin	individual	soxhlet	456	900	0.93	8.13	0.17	0.14	0.17	2.24	1.79	2.09	80/96
Kusawa	Lake whitefish	328	mus/skin	individual	soxhlet	343	600	2.02	.	0.65	1.08	1.74	9.57	8.63	27.16	80/79
Kusawa	Lake whitefish	YTG1	mus/skin	individual	soxhlet	365	500	1.86	7.77	1.22	0.70	6.48	59.37	53.06	54.99	79/72
Kusawa	Lake whitefish	YTG2	mus/skin	individual	soxhlet	360	500	0.35	7.29	0.24	0.12	1.27	12.27	21.56	7.23	79/99
Kusawa	Lake whitefish	YTG3	mus/skin	individual	soxhlet	415	700	0.60	6.21	0.81	0.34	3.63	38.71	69.12	17.52	70/72
Kusawa	Lake whitefish	YTG4	mus/skin	individual	soxhlet	455	900	0.94	7.91	0.17	0.19	0.47	1.27	2.17	2.75	82/91
Kusawa	Lake whitefish	YTG47	mus/skin	individual	soxhlet	355	500	1.22	8.09	0.51	0.31	2.53	15.10	17.82	16.69	70/88
Kusawa	Lake whitefish	YTG48	mus/skin	individual	soxhlet	354	400	1.96	7.49	0.57	0.48	2.08	16.07	15.65	16.42	[illegible]/96
Kusawa	Lake whitefish	YTG49	mus/skin	individual	soxhlet	350	400	1.19	7.46	0.47	0.14	1.85	11.17	12.53	12.17	[illegible]9/63
Kusawa	Lake whitefish	YTG5	mus/skin	individual	soxhlet	375	600	0.73	7.23	0.40	0.29	1.03	12.81	22.54	6.87	75/71
Kusawa	Lake whitefish	YTG50	mus/skin	individual	soxhlet	390	500	2.44	.	0.64	0.72	1.56	2.04	5.52	12.89	84/81
Kusawa	Lake whitefish	YTG6	mus/skin	individual	soxhlet	390	700	0.38	6.37	0.16	0.12	0.44	1.92	3.54	2.72	80/90
Kusawa	Lake whitefish	YTG7	mus/skin	individual	soxhlet	390	800	2.68	6.52	0.83	1.12	1.35	1.09	2.66	26.56	80/81
Laberge	Lake whitefish	49	mus/skin	individual	soxhlet	382	950	3.38	9.06	1.22	2.33	9.48	52.17	43.30	49.53	
Laberge	Lake whitefish	50	mus/skin	individual	soxhlet	396	800	3.15	.	0.93	1.01	4.69	35.49	33.12	53.93	80/37
Laberge	Lake whitefish	114	whole	individual	soxhlet	206	79.3	2.03	7.16	1.33	1.05	5.76	47.75	26.47	24.23	
Laberge	Lake whitefish	115	whole	individual	soxhlet	195	75.4	2.83	.	1.18	1.21	4.72	25.61	18.82	48.46	
Laberge	Lake whitefish	117	whole	individual	soxhlet	195	76	5.15	7.57	1.50	1.84	5.32	20.32	22.25	42.02	
Laberge	Lake whitefish	153	mus/skin	individual	soxhlet	398	700	1.33	8.87	0.44	0.76	2.13	10.35	6.57	13.92	
Laberge	Lake whitefish	248	whole	individual	soxhlet	118	14.2	1.32	5.22	0.31	0.53	1.78	17.55	13.57	10.19	
Laberge	Lake whitefish	251	whole	individual	soxhlet	103	9.8	1.90	.	0.40	0.76	3.26	21.42	16.17	18.70	
Laberge	Lake whitefish	920-0017	mus/skin	individual	soxhlet	313	355	1.83	9.52	0.80	1.03	10.57	188.97	147.77	69.60	65/63
Laberge	Lake whitefish	920-0018	mus/skin	individual	soxhlet	332	442	7.47	7.83	3.30	5.68	28.70	169.15	92.06	200.86	100/100
Laberge	Lake whitefish	920-0019	mus/skin	individual	soxhlet	335	402	2.43	10.08	1.12	1.98	13.51	120.92	84.58	83.36	66/62
Laberge	Lake whitefish	920-0020	mus/skin	individual	soxhlet	331	438	4.69	9.28	1.77	2.43	14.62	190.16	121.22	100.15	78/75
Laberge	Lake whitefish	920-0021	mus/skin	individual	soxhlet	377	617	3.35	7.05	1.14	1.77	5.45	47.90	42.98	20.93	107/98
Laberge	Lake whitefish	920-0023	mus/skin	individual	soxhlet	337	433	2.97	8.54	1.44	2.56	11.89	100.55	64.04	200.86	74/100
Laberge	Lake whitefish	920-0024	mus/skin	individual	soxhlet	350	477	2.59	9.39	1.17	1.40	10.55	147.52	95.45	71.68	73/81
Laberge	Lake whitefish	920-0025	mus/skin	individual	soxhlet	385	595	1.62	8.01	0.86	1.15	6.27	57.03	52.61	24.49	116/106
Laberge	Lake whitefish	920-0028	mus/skin	individual	soxhlet	390	638	1.47	7.05	1.03	1.19	7.90	110.76	102.99	37.27	110/110
Laberge	Lake whitefish	920-0039	mus/skin	individual	soxhlet	320	367	1.62	7.85	0.77	0.73	8.96	62.97	45.33	45.63	79/78
Laberge	Lake whitefish	920-0048	mus/skin	individual	soxhlet	368	596	3.49	9.27	1.76	2.02	19.82	101.83	181.08	77.90	96/97
Laberge	Lake whitefish	920-0052	mus/skin	individual	soxhlet	428	844	1.57	6.65	1.05	1.11	16.47	283.84	277.78	50.04	
Laberge	Lake whitefish	920-0060	mus/skin	individual	soxhlet	351	486	3.48	9.87	1.72	2.66	10.05	78.97	66.28	50.71	110/115
Laberge	Lake whitefish	920-0061	mus/skin	individual	soxhlet	327	399	1.74	8.06	0.64	1.02	5.90	61.54	43.49	52.08	69/81
Laberge	Lake whitefish	920-0062	mus/skin	individual	soxhlet	320	341	2.43	7.87	1.64	2.39	10.94	89.56	63.54	138.12	100/100
Laberge	Lake whitefish	920-0063	mus/skin	individual	soxhlet	315	347	3.46	9.19	1.42	1.82	6.30	46.17	34.47	60.31	83/92
Laberge	Lake whitefish	920-0064	mus/skin	individual	soxhlet	298	297	3.53	.	1.25	1.81	8.85	54.59	46.38	81.71	73/84
Laberge	Lake whitefish	920-0065	mus/skin	individual	soxhlet	335	412	2.13	8.09	0.69	1.24	4.14	31.41	32.96	50.81	66/73

Appendix C: Organochlorine data for fishes and invertebrates from Yukon lakes (1992-1994)

Lake	Species	Number	Tissue Extracted	Individual/ Composite	Method of Extraction	Length (mm)	Weight (g)	% Lipid (g/g ww)	15N/14N (per mil)	s-CBZ (ng/g ww)	s-HCH (ng/g ww)	s-CHL (ng/g ww)	s-DDT (ng/g ww)	s-PCB (ng/g ww)	s-CHB (ng/g ww)	Recoveries of Internal Standards
Laberge	Lake whitefish	YTG89	mus/skin	individual	soxhlet	430	875	4.19	9.89	1.05	1.18	9.45	80.91	57.42	65.36	77/99
Laberge	Lake whitefish	YTG92	mus/skin	individual	soxhlet	331	400	2.23	8.97	0.84	0.65	9.70	137.53	92.59	59.95	78/97
Laberge	Lake whitefish	YTG93	whole	individual	soxhlet	276	225	0.90	7.92	0.13	0.20	2.98	25.62	22.61	10.84	77/108
Laberge	Lake whitefish	YTG98	whole	individual	soxhlet	298	275	5.02	8.95	1.52	1.49	7.07	57.44	39.60	50.31	83/86
Fox	Northern pike	750	muscle	individual	soxhlet	618	1600	0.39	7.68	0.06	0.07	0.13	0.54	0.25	0.18	83/82
Fox	Northern pike	751	muscle	individual	soxhlet	618	1600	0.20	8.43	0.28	0.07	0.05	0.23	0.45	0.19	80/93
Fox	Northern pike	753	muscle	individual	soxhlet	657	2025	0.27	7.87	0.31	0.09	0.10	0.71	0.68	0.22	62/83
Fox	Northern pike	757	muscle	individual	soxhlet	657	2100	0.31	7.90	0.09	0.05	0.07	0.48	0.17	0.00	76/108
Fox	Northern pike	758	muscle	individual	soxhlet	771	3625	0.19	8.90	0.13	0.17	0.15	0.83	0.61	0.71	55/62
Fox	Northern pike	759	muscle	individual	soxhlet	750	3100	0.20	8.94	0.06	0.10	0.09	0.32	0.28	0.49	82/78
Fox	Northern pike	787	muscle	individual	soxhlet	425	600	0.43	7.23	0.06	0.13	0.09	0.16	0.09	0.20	77/87
Fox	Northern pike	789	muscle	individual	soxhlet	670	2710	0.26	8.32	0.20	0.10	0.28	1.05	0.95	1.96	89/94
Laberge	Northern pike	YTG1	muscle	individual	soxhlet	701	2250	0.34	10.04	0.16	0.14	1.15	11.62	10.77	11.85	
Laberge	Northern pike	YTG2	muscle	individual	soxhlet	632	1850	0.50	10.14	0.22	0.15	1.08	8.94	8.56	11.42	67/86
Laberge	Northern pike	YTG3	muscle	individual	soxhlet	588	1250	0.46	8.79	0.14	0.09	1.12	9.68	6.10	8.60	65/89
Laberge	Northern pike	YTG4	muscle	individual	soxhlet	610	1500	0.46	9.87	0.10	0.09	0.50	5.60	3.06	5.05	77/96
Laberge	Northern pike	YTG6	muscle	individual	soxhlet	668	2050	0.31	10.20	0.17	0.13	0.75	5.46	5.28	7.64	66/82
Laberge	Northern pike	YTG7	muscle	individual	soxhlet	772	3300	0.25	10.78	0.26	0.18	0.96	7.69	7.58	11.56	64/80
Laberge	Northern pike	YTG8	muscle	individual	soxhlet	534	1000	0.51	9.68	0.08	0.07	0.59	5.53	4.26	5.00	60/62
Laberge	Northern pike	YTG9	muscle	individual	soxhlet	565	1400	0.49	9.50	0.21	0.11	1.42	12.28	11.98	16.36	68/84
Fox	Round whitefish	553	whole	individual	soxhlet	320	250	1.27	6.67	0.22	0.55	0.34	1.09	0.86	1.71	82/100
Fox	Round whitefish	554	whole	individual	soxhlet	269	175	1.15	5.89	0.37	0.43	0.41	1.06	1.35	1.09	85/90
Fox	Round whitefish	555	whole	individual	soxhlet	168	40.9	2.52	6.24	0.51	0.66	0.43	1.30	1.05	2.40	74/94
Fox	Round whitefish	556	whole	individual	soxhlet	168	39.2	2.40	6.55	0.58	0.62	0.36	0.92	1.21	1.48	70/72
Fox	Round whitefish	557	whole	individual	soxhlet	165	39	1.90	6.60	0.67	0.81	0.49	1.00	1.51	2.07	75/81
Fox	Round whitefish	558	whole	individual	soxhlet	167	39.4	3.30	6.30	0.78	1.50	0.64	1.32	1.06	3.44	66/71
Fox	Round whitefish	560	whole	individual	soxhlet	320	350	1.18	6.30	0.31	0.62	0.24	0.31	1.01	1.13	87/100
Fox	Round whitefish	564	whole	individual	soxhlet	380	500	0.77	6.65	0.23	0.36	0.07	0.20	0.85	0.74	88/91
Kusawa	Round whitefish	675	whole	individual	soxhlet	142	23.8	1.86	6.27	0.73	0.53	0.58	0.56	1.10	3.10	89/98
Kusawa	Round whitefish	676	whole	individual	soxhlet	149	24.7	1.73	6.28	0.59	0.46	1.11	0.97	1.94	9.52	106/129
Kusawa	Round whitefish	677	whole	individual	soxhlet	152	28.4	1.89	6.17	0.46	0.48	1.46	1.22	2.09	12.82	86/102
Kusawa	Round whitefish	693	whole	individual	soxhlet	215	81.3	2.46	6.79	0.60	0.76	2.17	1.57	2.69	17.63	83/92
Kusawa	Round whitefish	694	whole	individual	soxhlet	254	125.5	3.16	5.79	0.79	0.93	3.11	2.09	3.07	25.68	74/101
Kusawa	Round whitefish	695	whole	individual	soxhlet	197	62	2.81	6.66	0.52	0.84	1.80	1.26	2.69	23.20	59/76
Laberge	Round whitefish	60	whole	composite (6 fish)	soxhlet	211(17)	71(9.4)	2.01	.	1.67	1.33	5.67	33.82	26.78	29.00	91/85
Laberge	Round whitefish	64	whole	individual	soxhlet	250	149.5	1.70	7.24	0.68	0.74	5.34	33.19	24.34	33.78	66/70
Laberge	Round whitefish	110	whole	composite (6 fish)	soxhlet	210(9.3)	76(8.7)	3.21	.	1.07	1.39	4.18	24.67	16.93	40.55	94/86
Laberge	Round whitefish	152	whole	composite (6 fish)	soxhlet	459(8.9)	800(246)	1.48	5.70	0.33	0.74	1.73	12.28	6.00	3.98	106/104
Laberge	Round whitefish	220	whole	composite (5 fish)	soxhlet	179(22)	48(7.7)	2.68	6.87	0.75	0.59	3.83	31.68	28.49	19.10	103/86
Laberge	Round whitefish	224	whole	composite (6 fish)	soxhlet	120(4.8)	13(1.1)	2.13	.	0.71	0.32	1.06	15.38	9.92	22.90	120/92
Laberge	Round whitefish	410	whole	composite (4 fish)	soxhlet	123(5.1)	15(1.9)	1.75	.	0.22	1.36	0.84	7.01	6.61	31.04	83/85
Fox	Slimy sculpin	1993	whole	composite	soxhlet			2.81	5.08	4.26	1.00	0.85	1.83	2.27	2.77	50/80
Kusawa	Slimy sculpin	1993	whole	composite	soxhlet			4.04	7.44	0.54	0.89	2.02	0.84	2.93	26.31	56/70
Laberge	Slimy sculpin	1993	whole	composite	soxhlet			3.80		0.52	1.07	1.42	8.95	6.23	14.64	50/73
Fox	Tricopteran	A56	whole	composite	ball-mill			1.24	2.71	0.29	0.63	0.66	1.95	1.48	1.54	97/120
Fox	Tricopteran	C296	whole	composite	ball-mill			0.99	0.70	0.11	0.19	0.20	0.39	5.54	2.66	84/90
Fox	Tricopteran	E404	whole	composite	ball-mill			2.50	2.80	0.43	0.58	0.21	0.51	0.40	1.24	59/67

Appendix C: Organochlorine data for fishes and invertebrates from Yukon lakes (1992-1994)

Lake	Species	Number	Tissue Extracted	Individual/ Composite	Method of Extraction	Length (mm)	Weight (g)	% Lipid (g/g ww)	15N/14N (per mil)	s-CBZ (ng/g ww)	s-HCH (ng/g ww)	s-CHL (ng/g ww)	s-DDT (ng/g ww)	s-PCB (ng/g ww)	s-CHB (ng/g ww)	Recoveries of Internal Standards
Fox	Tricopteran	E409	whole	composite	ball-mill			0.82	4.52	0.05	0.13	0.00	0.08	0.00	0.00	
Fox	Tricopteran	E420	whole	composite	ball-mill			2.19	1.79	0.40	0.48	0.19	0.18	1.30	0.00	
Kusawa	Tricopteran	D322	whole	composite	ball-mill	.	.	1.10	2.54	0.13	0.44	0.39	0.47	4.47	4.20	80/87
Kusawa	Tricopteran	D426	whole	composite	ball-mill	.	.	0.58	0.69	0.13	0.34	0.29	0.18	2.96	1.93	79/68
Laberge	Tricopteran	A1	whole	composite	ball-mill	.	.	2.64	1.19	0.79	0.80	0.98	1.08	3.21	4.63	78/76
Laberge	Tricopteran	A21	whole	composite	ball-mill	.	.	2.02	2.85	0.30	0.46	0.59	2.02	2.21	2.04	67/68
Laberge	Tricopteran	B181	whole	composite	ball-mill	.	.	1.30	1.11	0.16	0.29	0.32	0.48	4.81	3.24	83/89
Laberge	Tricopteran	B189	whole	composite	ball-mill	.	.	1.40	2.51	0.13	0.26	0.48	0.60	6.11	4.13	85/88
Laberge	Tricopteran	D439	whole	composite	ball-mill	.	.	2.04	1.57	0.33	0.42	0.42	0.77	1.15	1.69	
Fox	Zooplankton	1993	whole	composite	ball-mill	.	.	2.70	2.91	0.25	0.40	0.52	1.06	2.10	2.60	83/96
Fox	Zooplankton	1994	whole	composite	ball-mill	.	.	3.45	3.72	0.71	1.71	2.25	1.73	2.21	28.74	55/72
Fox	Zooplankton	A66	whole	composite	ball-mill	.	.	2.60	3.43	0.25	0.47	0.55	0.55	0.86	2.77	81/92
Fox	Zooplankton	C213	whole	composite	ball-mill	.	.	3.25	3.99	2.08	2.86	4.49	5.47	12.06	12.12	82/95
Kusawa	Zooplankton	1993	whole	composite	ball-mill	.	.	0.11	3.24	0.13	0.30	0.44	0.23	1.11	2.59	79/89
Kusawa	Zooplankton	1994	whole	composite	ball-mill	.	.	4.74	1.95	0.54	0.88	0.72	0.89	1.57	4.55	60/67
Kusawa	Zooplankton	B108	whole	composite	ball-mill	.	.	0.40	1.19	0.18	0.19	0.46	0.16	0.88	2.15	66/88
Kusawa	Zooplankton	C225	whole	composite	ball-mill	.	.	0.12	3.49	0.10	0.41	0.85	0.18	1.19	2.24	86/95
Laberge	Zooplankton	1993	whole	composite	ball-mill	.	.	0.72	3.02	0.44	0.84	0.81	2.64	4.14	10.09	84/89
Laberge	Zooplankton	1994	whole	composite	ball-mill	.	.	3.00	4.60	0.37	0.66	0.80	4.50	4.84	11.47	
Laberge	Zooplankton	B150	whole	composite	ball-mill	.	.	0.95	4.56	0.73	0.94	0.97	3.13	5.45	12.01	83/74
Laberge	Zooplankton	B196	whole	composite	ball-mill	.	.	1.24	6.39	0.62	2.54	2.68	6.07	5.90	26.59	84/90
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Appendix D: Pearson Correlation Coefficients for Lake Trout Data from Laberge, Fox and Kusawa Lakes, YT

(n=33 to 38)	log HCH (ng/g ww)	log DDT (ng/g ww)	log CHB (ng/g ww)	log CHL (ng/g ww)	log CBZ (ng/g ww)	log PCB (ng/g ww)	lipid (g/g ww)	log age (yr)	length (mm)	log weight (g)	15N/14N (per mil)
log HCH	1	0.78971	0.78413	0.77013	0.90949	0.68088	0.90976	0.0473	0.51519	0.55837	0.55065
p		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.7905	0.0009	0.0003	0.0003
log DDT		1	0.89476	0.91515	0.86233	0.94406	0.81387	0.21751	0.50715	0.54258	0.75989
p			0.0001	0.0001	0.0001	0.0001	0.0001	0.2166	0.0012	0.0004	0.0001
log CHB			1	0.97335	0.86214	0.93608	0.71857	0.1557	0.53649	0.56647	0.70765
p				0.0001	0.0001	0.0001	0.0001	0.3792	0.0005	0.0002	0.0001
log CHL				1	0.85229	0.96361	0.69967	0.21555	0.57236	0.61282	0.68404
p					0.0001	0.0001	0.0001	0.2208	0.0002	0.0001	0.0001
log CBZ					1	0.79923	0.91768	0.1749	0.50891	0.54599	0.63173
p						0.0001	0.0001	0.3225	0.0011	0.0004	0.0001
log PCB						1	0.65736	0.23098	0.52873	0.54612	0.71148
p							0.0001	0.1887	0.0006	0.0004	0.0001
log lipid							1	0.02078	0.37049	0.419	0.64928
p								0.9086	0.024	0.0098	0.0001
log age								1	0.42362	0.37818	-0.02084
p									0.0125	0.0274	0.9069
length									1	0.94612	0.18842
p										0.0001	0.2573
log weight										1	0.2294
p											0.1659

Appendix D: Pearson Correlation Coefficients for Burbot Data from Laberge and Fox Lakes, YT

(n=28 to 30)										
	log HCH	log CHB	log CHL	log CBZ	log DDT	log PCB	15N/14N	lipid	weight	log age	length
	(ng/g ww)	(ng/g ww)	(ng/g ww)	(ng/g ww)	(ng/g ww)	(ng/g ww)	(per mil)	(g/g ww)	(g)	(yr)	(mm)
log HCH	1	0.7882	0.84188	0.88717	0.81503	0.81638	0.69331	0.52637	0.32261	0.1303	0.23565
p		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.004	0.0821	0.5005	0.21
log CHB		1	0.97609	0.90798	0.99408	0.98904	0.92363	0.43055	0.16447	0.17664	0.14024
p			0.0001	0.0001	0.0001	0.0001	0.0001	0.0222	0.3851	0.3593	0.4598
log CHL			1	0.94574	0.98711	0.98317	0.85181	0.36524	0.2863	0.29379	0.26371
p				0.0001	0.0001	0.0001	0.0001	0.056	0.1251	0.1219	0.1591
log CBZ				1	0.91781	0.9233	0.78112	0.45544	0.32575	0.29253	0.30748
p					0.0001	0.0001	0.0001	0.0149	0.079	0.1236	0.0984
log DDT					1	0.99535	0.90402	0.39392	0.22157	0.22029	0.19457
p						0.0001	0.0001	0.0381	0.2393	0.2508	0.3029
log PCB						1	0.90404	0.39837	0.18683	0.18624	0.16728
p							0.0001	0.0358	0.3229	0.3334	0.3769
15N/14N							1	0.49137	-0.04836	-0.04836	-0.07608
p								0.0079	0.7997	0.8033	0.6895
log lipid								1	-0.14002	-0.242	-0.19204
p									0.4773	0.2239	0.3276
weight									1	0.82094	0.94038
p										0.0001	0.0001
log age										1	0.87575
p											0.0001

Appendix D: Pearson Correlation Coefficients for Northern Pike Data from Laberge and Fox Lakes, YT

(n=16)											
	log HCH	log CHB	log CHL	log CBZ	log DDT	log PCB	15N/14N	lipid	weight	age	length
	(ng/g ww)	(ng/g ww)	(ng/g ww)	(ng/g ww)	(ng/g ww)	(ng/g ww)	(per mil)	(g/g ww)	(g)	(yr)	(mm)
log HCH	1	0.60455	0.46561	0.30766	0.35915	0.41627	0.51759	-0.10731	0.4285	0.08342	0.3248
p		0.0131	0.0691	0.2464	0.1719	0.1088	0.04	0.6924	0.0977	0.7587	0.2197
log CHB		1	0.90432	0.35064	0.84916	0.89725	0.79263	0.39716	-0.00028	0.00812	0.05474
p			0.0001	0.183	0.0001	0.0001	0.0003	0.1277	0.9992	0.9762	0.8404
log CHL			1	0.30199	0.97305	0.94797	0.78435	0.55534	-0.07258	-0.0656	0.01684
p				0.2556	0.0001	0.0001	0.0003	0.0255	0.7894	0.8093	0.9507
log CBZ				1	0.354	0.50219	0.35144	-0.22326	0.23619	0.04783	0.30182
p					0.1786	0.0474	0.1819	0.4059	0.3785	0.8604	0.2559
log DDT					1	0.97147	0.81686	0.52759	-0.04761	-0.10224	0.08867
p						0.0001	0.0001	0.0357	0.861	0.7063	0.744
log PCB						1	0.85638	0.41881	-0.00152	-0.03819	0.1348
p							0.0001	0.1064	0.9955	0.8883	0.6187
15N/14N							1	0.16408	0.27024	0.08491	0.38291
p								0.5437	0.3114	0.7546	0.1432
lipid								1	-0.76001	-0.55951	-0.70943
p									0.0006	0.0242	0.0021
weight									1	0.66964	0.9477
p										0.0045	0.0001
age										1	0.6578
p											0.0056

Appendix D: Pearson Correlation Coefficients for Lake Whitefish Data from Laberge, Kusawa and Fox Lakes, YT											
(n=44 to 55)											
	log HCH	log CHB	log CHL	log CBZ	log DDT	log PCB	15N/14N	lipid	weight	log age	length
	(ng/g ww)	(ng/g ww)	(ng/g ww)	(ng/g ww)	(ng/g ww)	(ng/g ww)	(per mil)	(g/g ww)	(g)	(yr)	(mm)
log HCH	1	0.71086	0.77865	0.79747	0.65513	0.62507	0.3932	0.78845	-0.25328	0.00932	-0.26756
p		0.0001	0.0001	0.0001	0.0001	0.0001	0.0052	0.0001	0.0621	0.9504	0.0483
log CHB		1	0.93501	0.83379	0.84858	0.82959	0.54754	0.7674	-0.47366	-0.14208	-0.38292
p			0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0003	0.3408	0.0039
log CHL			1	0.84529	0.93372	0.92739	0.51145	0.74102	-0.44849	-0.07379	-0.37902
p				0.0001	0.0001	0.0001	0.0002	0.0001	0.0006	0.6221	0.0043
log CBZ				1	0.73763	0.73423	0.34204	0.86204	-0.33287	-0.07597	-0.28507
p					0.0001	0.0001	0.0161	0.0001	0.013	0.6118	0.0349
log DDT					1	0.96002	0.53079	0.59932	-0.3944	-0.00122	-0.32686
p						0.0001	0.0001	0.0001	0.0029	0.9935	0.0149
log PCB						1	0.46637	0.55237	-0.37694	0.01184	-0.29018
p							0.0007	0.0001	0.0046	0.937	0.0336
15N/14N							1	0.48799	-0.0478	0.30479	0.0453
p								0.0004	0.7443	0.0443	0.7573
log lipid								1	-0.31458	-0.14403	-0.34823
p									0.0205	0.3396	0.0099
weight									1	0.73414	0.90641
p										0.0001	0.0001
log age										1	0.81285
p											0.0001

Pearson Correlation Coefficients for Round Whitefish Data from Laberge, Kusawa and Fox Lakes, YT											
(n=15 to 21)											
	log HCH	log CHB	log CHL	log CBZ	log DDT	log PCB	15N/14N	lipid	log weight	age	log length
	(ng/g ww)	(ng/g ww)	(ng/g ww)	(ng/g ww)	(ng/g ww)	(ng/g ww)	(per mil)	(g/g ww)	(g)	(yr)	(mm)
log HCH	1	0.42563	0.46234	0.37008	0.37449	0.3253	-0.0027	0.56364	-0.08422	-0.197	-0.07978
p		0.0544	0.0348	0.0987	0.0944	0.1502	0.9918	0.0078	0.7166	0.4816	0.731
log CHB		1	0.88294	0.51367	0.74009	0.79763	0.2459	0.52672	-0.39585	-0.27756	-0.37294
p			0.0001	0.0172	0.0001	0.0001	0.3414	0.0142	0.0757	0.3165	0.0959
log CHL			1	0.66449	0.80975	0.82983	0.12932	0.53362	-0.18326	-0.17862	-0.16033
p				0.001	0.0001	0.0001	0.6208	0.0127	0.4265	0.5242	0.4875
log CBZ				1	0.48519	0.50654	0.11639	0.65181	-0.38803	-0.66785	-0.37723
p					0.0258	0.0191	0.6564	0.0014	0.0822	0.0065	0.0918
log DDT					1	0.95673	0.23944	0.31148	-0.13099	0.2678	-0.1131
p						0.0001	0.3547	0.1693	0.5714	0.3346	0.6255
log PCB						1	0.35244	0.26[illegible]72	-0.11848	0.32346	-0.10597
p							0.1653	0.2462	0.609	0.2396	0.6475
15N/14N							1	0.00526	-0.1401	-0.24794	-0.16059
p								0.984	0.5918	0.3729	0.5381
lipid								1	-0.4349	-0.53898	-0.42127
p									0.0488	0.0382	0.0572
log weight									1	0.88568	0.99754
p										0.0001	0.0001
age										1	0.8897
p											0.0001

Pearson Correlation Coefficients for Longnose Sucker Data from Laberge and Kusawa Lakes, YT											
(n=18)											
	log HCH	log CHB	log CHL	log CBZ	log DDT	log PCB	15N/14N	lipid	weight	length	
	(ng/g ww)	(ng/g ww)	(ng/g ww)	(ng/g ww)	(ng/g ww)	(ng/g ww)	(per mil)	(g/g ww)	(g)	(mm)	
log HCH	1	0.76081	0.79945	0.8868	0.72119	0.57568	0.02175	0.65595	0.09468	0.31706	
p		0.0002	0.0001	0.0001	0.0007	0.0124	0.9317	0.0031	0.7086	0.1999	
log CHB		1	0.89268	0.74234	0.84835	0.73297	0.40075	0.54028	0.49602	0.61599	
p			0.0001	0.0004	0.0001	0.0005	0.0993	0.0206	0.0363	0.0065	
log CHL			1	0.74675	0.92641	0.9044	0.15702	0.49721	0.41113	0.55784	
p				0.0004	0.0001	0.0001	0.5338	0.0358	0.0901	0.0161	
log CBZ				1	0.61148	0.55778	0.02595	0.82809	-0.0058	0.32337	
p					0.007	0.0162	0.9186	0.0001	0.9818	0.1906	
log DDT					1	0.92415	0.30172	0.26855	0.39359	0.53784	
p						0.0001	0.2237	0.2813	0.1061	0.0213	
log PCB						1	0.15433	0.21451	0.39554	0.53333	
p							0.5409	0.3927	0.1042	0.0227	
15N/14N							1	-0.03953	0.20175	-0.01689	
p								0.8762	0.4221	0.947	
log lipid								1	-0.14645	0.1318	
p									0.562	0.6022	
weight									1	0.78714	
p										0.0001	

Appendix E: Mean and SD of organochlorine data for invertebrates from Yukon lakes (1992-1994)

(significant within-species differences among the three lakes are indicated by different letters following the average concentrations)

			n	% Lipid	s-CBZ		s-HCH		s-CHL		s-DDT		s-PCB		s-CHB	
Lake	Species			(g/g ww)	(ng/g ww)		(ng/g ww)		(ng/g ww)		(ng/g ww)		(ng/g ww)		(ng/g ww)	
Fox	Chironomid	average	4	1.31	0.42	a	0.52	a	1.53	a	2.43	a	8.95	a	3.32	a
		stdev		0.28	0.07		0.24		0.60		0.50		6.14		2.46	
Kusawa	Chironomid	average	4	1.50	0.45	a	0.58	a	0.89	a	0.68	a	7.46	a	2.70	a
		stdev		0.40	0.15		0.16		0.46		0.59		3.19		0.72	
Laberge	Chironomid	average	6	2.44	0.98	b	1.83	a	1.11	a	14.30	b	9.85	a	6.31	a
		stdev			0.46		0.89		0.53		10.00		3.06		2.90	
Fox	Lymnaeidae	average	2	0.97	0.02	a	0.22	a	0.10	a	0.58	a	1.92	a	<0.01	a
Kusawa	Lymnaeidae	average	5	1.94	0.47	b	0.74	a	0.80	b	0.41	a	2.76	a	5.13	b
		stdev		0.68	0.36		0.52		0.49		0.28		1.27		3.17	
Laberge	Lymnaeidae	average	4	1.18	0.08	a,b	0.29	a	0.36	a,b	0.63	a	1.19	a	1.10	c
		stdev		0.47	0.07		0.14		0.20		0.29		0.50		0.19	
Fox	*Gammarus*	average	4	1.18	0.23		0.39		0.38		0.80		1.03		1.01	
		stdev		0.69	0.11		0.18		0.27		0.37		0.38		0.57	
Fox	Valvatidae	average	5	0.61	0.22	a	0.51	a	0.27	a	0.98	a	2.24	a	1.34	a
		stdev		0.46	0.16		0.25		0.18		0.77		0.95		1.24	
Kusawa	Valvatidae	average	2	1.60	0.20	a	1.05	a	0.60	a	0.51	a	2.27	a	4.17	a
Laberge	Valvatidae	average	3	0.24	0.15	a	0.56	a	0.25	a	1.43	a	4.25	a	3.20	a
		stdev		0.08	0.17		0.67		0.06		0.57		2.30		1.96	
Fox	Tricopteran	average	5	1.55	0.26	a	0.40	a	0.25	a	0.62	a	1.74	a	1.09	a
		stdev		0.75	0.17		0.23		0.24		0.76		2.21		1.13	
Kusawa	Tricopteran	average	2	0.84	0.13	a	0.39	a	0.34	a	0.33	a	3.72	a	3.07	a
Laberge	Tricopteran	average	5	1.88	0.34	a	0.45	a	0.56	a	0.99	a	3.50	a	3.15	a
		stdev		0.55	0.26		0.22		0.26		0.62		1.99		1.28	
Fox	Zooplankton	average	4	3.00	0.82	a	1.36	a	1.95	a	2.20	a	4.31	a,b	11.56	a,b
		stdev		0.41	0.87		1.17		1.87		2.23		5.20		12.29	
Kusawa	Zooplankton	average	4	1.34	0.24	a	0.45	a	0.62	a	0.37	b	1.19	a	2.88	a
		stdev		2.27	0.20		0.30		0.20		0.35		0.29		1.13	
Laberge	Zooplankton	average	4	1.48	0.54	a	1.25	a	1.32	a	4.09	a	5.08	b	15.04	b
		stdev		1.04	0.16		0.87		0.91		1.54		0.76		7.74	