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Biotic interactions in temporal trends (1992–2010) of organochlorine contaminants in the aquatic food web of Lake Laberge, Yukon Territory

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HIGHLIGHTS

- ► Organochlorine contaminants in a sub-Arctic lake were monitored post-fishery closure.
- ► We observed significant temporal declines in OC from 1992 to 2010.
- ► Declines in OC were related to growth dilution for some species.
- ► Declines in OC were related to decreased lipids for some species.
- ► Zooplankton community changes may also have added to the declining trend in OC.

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ABSTRACT

Declines in 6 organochlorine (OC) contaminant groups; chlordane (CHL), DDT, HCH, toxaphene (CHB), PCB and chlorinated benzenes (CBz) were measured in biota of a sub-Arctic lake (Lake Laberge, YT) following the closure of a commercial fishery in 1991. This study examined morphological (length, weight, age), biochemical (lipid content, $\delta^{13}C$, $\delta^{15}N$), population and OC data for 9 fishes and zooplankton between 1993 and 2003 (2010 for lake trout) to investigate causes for the OC declines. Growth dilution was a major factor influencing the decrease of OCs in lake trout, round whitefish and possibly zooplankton most notably in the early 2000s. A decline in lipids of most fish species also contributed to OC declines, although no such change was evident for zooplankton. It is suspected that increases in fish populations or climate variations over the 1990s, may have contributed towards a shift in plankton community composition. From 1991 to 1999, CPUE increased for 7 of the fish species and declined for 2 others. Concurrently, the zooplankton community shifted from an abundance of *C. scutifer* in 1993 to dominance by *D. pribilofensis* in 2001. Nitrogen and carbon stable isotope data suggested that food web interactions for most fish species have not changed over time. Although concentrations of OCs have declined in many fishes, the "rate" of OC transfer (using slopes of log OC vs. nitrogen isotope ratios) through the food web was greater in 2001 than in 1993. Overall, the declines in OC concentrations in the fish from Lake Laberge occurred concurrently with changes in their growth, lipid, and abundance, suggesting that ecosystem responses to the closure of the fishery were in part responsible for the lower contaminants in these fishes. As a result of this study, the Yukon government rescinded the health advisory for limiting the consumption of fish from Lake Laberge.

1. Introduction

It is well established that a wide range of chlorinated pesticides (e.g. toxaphene (CHB), chlordanes (CHL), hexachlorocyclohexanes (HCH)) and industrial chemicals such as polychlorinated biphenyls (PCB) undergo long-range atmospheric transport and deposition in the sub- and high Arctic regions where they biomagnify up aquatic food chains (Barrie et al., 1992; Muir et al., 1992; Van Dijk and Guicherit, 1999; CACAR, 2003). Lake Laberge in the Yukon Territory was studied intensively in the early 1990s because of abnormally high levels of these organochlorine (OC) contaminants in fish, relative to surrounding lakes. Researchers showed the primary cause was not due to point source pollution (Nordin et al., 1993; Diamond et al., 2005), but rather Lake Laberge had a longer food chain (Kidd et al., 1998) and, as a result, its top predators had higher-than-average

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contaminant concentrations when compared to other regional lakes (Kidd et al., 1995b). It was hypothesized that the long food chain in this lake was an effect of the commercial fishery that existed on the lake for over 100 years.

Lake Laberge was commercially exploited since the summer of 1898 primarily for lake trout and whitefish, although incidental catches of other species such as Arctic grayling and burbot were also kept for sale or consumption (Seigel and McEwen, 1984; Thompson, 1996). After high OCs were measured in lake trout and burbot, Health Canada placed a health advisory on the consumption of fish from Lake Laberge causing a closure of the fishery in 1991–92. Since the first study of contaminants in Lake Laberge in 1991 (Connor and Sparling, 1996), concentrations of OCs have dropped dramatically in fish (Ryan et al., 2005). Several hypothesis have been put forth to explain the trends (Ryan et al., 2005), including biomass/growth dilution or shifts in trophic levels of predators and prey, or events unrelated to the cessation of the fishery, such as declines in atmospheric contaminant concentrations over the same period. We hypothesized that the closure of the 100-year commercial fishery contributed to the decline in OCs through biomass/growth dilution.

Several changes have occurred in the fish populations of Lake Laberge after the closure of the fishery. Fish abundances have increased from 1991 to 1999 for seven out of ten of the species (Foos, 2001). Lake trout also appear to have increased growth rates (Thompson, 1996) and were larger in body size (Ryan et al., 2005). An increased rate of growth, and recruitment, in fish following exploitation is an often-observed response (Hewson, 1955; Healey, 1975, 1978; Mills et al., 2000) but, to our knowledge, the effect of the closure of a fishery on contaminant levels in a sub-Arctic food web has not been studied.

Several key morphological and biochemical parameters can be used to examine the hypothesis that biomass/growth dilution contributed to the decreases in fish contaminant levels. Body size characteristics (length, weights) have been linked to contaminant concentrations in fish (Larsson et al., 1993; Kidd, 1996; Ryan et al., 2005) and it has been previously demonstrated that growth rates have a major influence on contaminant levels in biota (Thomann, 1989; Larsson et al., 1991; Sijm et al., 1992). OC concentration trends in Great Lakes lake trout were tied to fluctuations in the growth of alewives, and their varying diet, suggesting that food web interactions regarding food intake play a strong role in contaminant regulation (Borgmann and Whittle, 1991; Madenjian et al., 1999). Growth rates influence contaminant loads in organisms through biomass or growth dilution (Sijm et al., 1992). As fish increase their rate or size of prey consumption, they increase their growth rate (Matuszek et al., 1990; Pazzia et al., 2002) resulting in a larger biomass as well as potential changes in bioenergetics of assimilation, excretion or food conversion efficiencies (Persson and Greenberg, 1991; Pazzia et al., 2002). The body size/metabolism of the animal may increase in relation to contaminant intake or contaminant storage in lipids thus 'diluting' the contaminants within the body (Thomann, 1989; Clark and Mackay, 1991; Sijm et al., 1992; Hebert et al., 1997). Variability in tissue lipid content during growth may also cause changes in contaminant concentrations in aquatic organisms and there is significant evidence supporting the link between OC biomagnification and lipids (Thomann, 1989; Larsson et al., 1991, 1993).

An alternate hypothesis for the changes in OCs in Lake Laberge fishes relates to changes in food web structure. Although fishing exploitation may increase growth rates of targeted species, it also has the capacity to restructure a food web by eliminating predators (or by-catch species) thereby changing the balance of the ecosystem (Mills et al., 2000). Levels of contaminants are significantly related to the trophic position of aquatic animals (Kidd et al., 1995a, 1998; Fisk et al., 2001). Species at higher trophic levels have higher contaminant levels (of biomagnifying compounds) compared to those lower in the food web (Rasmussen et al., 1990; Kidd et al., 1995a; Zaranko et al., 1997). A change in prey or predator populations within an ecosystem may result in changes in dietary habits and subsequent OC accumulation. Since fish population abundances appear to have changed over time in Lake Laberge (Foos, 2001), it is possible that changes have also occurred within the food web structure. Such a hypothesis may be evaluated by comparing changes in carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ratios, because they are used to assess food sources and relative trophic level, respectively (Vander Zanden and Rasmussen, 1996; Das et al., 2000; Campbell et al., 2000).

Although studies of OC concentrations in biota often monitor a few key species, far fewer assess entire ecosystems for changes to abiotic inputs, productivity, dietary habits, fish abundance and OC concentrations across trophic levels. There are no other known studies of the effects of the closure of a commercial fishery on the contaminant loads in the food web of a sub-Arctic lake. This research focuses on temporal changes in six OC groups in a sub-Arctic lake food web and the relationship between biotic parameters and the concentrations of OCs over the span of more than 10 years (assessment of abiotic influences from atmospheric loading and primary productivity as determined through sediment core analysis (Ryan et al., in preparation) are reviewed in Ryan (2006). The main objective of Ryan et al. (2005) was to review differences in OC between two top fish predators (lake trout and burbot) among three lakes in the Yukon region, whereas the primary objective of this research was to determine the most probable biotic causes of the recent declines observed in OC concentrations specifically in fish from Lake Laberge using analyses of temporal trends of OC concentrations in seven species of fish and in bulk zooplankton, morphological (i.e., length, weight, age), biochemical (i.e., lipid content) and population data for fish, and food web structure using $\delta^{13}C$ and $\delta^{15}N$.

2. Materials and methods

2.1. Sample collections

Lake Laberge is approximately 40 km north of the city of Whitehorse in the Yukon Territory (61°11′N, 135° 12′W; Fig. 1). The lake is classified as oligotrophic and has had little change in this status over time as determined by limnological data collected and presented several times over the past two decades (Jack et al., 1983; Shortreed and Stockner, 1983; Kirkland and Gray, 1986; Kidd, 1996; Thompson, 1996; Foos, 1998; Ryan et al., 2005).

Nine fish species were collected from Lake Laberge including lake trout (*Salvelinus namaycush*), burbot (*Lota lota*), inconnu (*Stenodus leucichthys*), northern pike (*Esox lucius*), lake whitefish (*Coregonus clupeaformis*), least cisco (*Coregonus sardinella*), longnose sucker (*Catostomus catostomus*), round whitefish (*Prosopium cylindraceum*) and broad whitefish (*Coregonus nasus*) several times between 1992 and 2010 (Table 1). The primary collection years for all fish were 1992, 1993, 2000 and 2001 with a few species collected in 1996, 1998 and 1999. Burbot were collected in both spring and summer (March/April, July to September) while all other species were collected during the mid to late summer months (July to September) with the exception of 1992 lake trout which were collected in March and June. Additional lake trout were collected each summer from 2002 to 2010 (except for 2006). All 1992–1993 data were originally compiled as a single year and are subsequently referred to only as "1993" data in this study. Only seven of the nine species of fish captured from Lake Laberge were used for analysis. The inconnu, broad whitefish and Arctic grayling were not assessed as part of this study because of insufficient data for assessment of temporal trends.

Burbot were caught using long line angling while all other species were captured using small mesh index nets as described in Thompson (1996) and Foos (1998). These small mesh index nets included two gangs of nets each with three panels 23 m long, 2.4 m depth using mesh sizes of 3.8 cm, 6.4 cm and 7.6 cm. Net set times, mesh sizes and capture locations were kept as similar as possible over time. Small mesh nets were substituted with angling and tackle for