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Different mercury bioaccumulation rates between sympatric populations of dwarf and normal lake whitefish (*Coregonus clupeaformis*) in the La Grande complex watershed, James Bay, Québec

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Abstract. Fish mercury concentrations were monitored before and after the construction of the La Grande hydroelectric complex, located in the James Bay region, Québec, Canada. Monitoring results revealed that sympatric populations of dwarf and normal lake whitefish (*Coregonus clupeaformis*) occur in reservoirs and natural lakes of the area. Dwarf specimens bioaccumulate mercury more rapidly than normal individuals. In natural Sérigny Lake, 6–7 year old dwarf specimens show mean total mercury levels 1.5 times higher than normal individuals of the same age (0.33 vs 0.21 mg kg^{-1} wet weight). Eleven years after the impoundment of the Caniapiscau reservoir, 6–7 year old dwarf specimens show total mercury concentrations 3 times higher than normal specimens of similar ages (0.74 vs 0.27 mg kg^{-1}). Stomach content analysis showed that although large normal individuals feed on different prey than do dwarf individuals, similar methyl mercury levels were found in prey of both forms. We suggest that dwarf individuals bioaccumulate mercury more rapidly than normal specimens because they begin to mature at an earlier age (usually at age 2 to 3 compared to age 6 for normal specimens) and thus produce proportionally less flesh to dilute the mercury assimilated. Total mercury analysis indicating higher concentrations in flesh than in gonads support this hypothesis. Our results suggest that when monitoring mercury levels in fish in areas where populations of dwarf and normal lake whitefish coexist, dwarf and normal specimens must be distinguished because of their different bioaccumulation rates.

Introduction

Fish mercury concentrations were monitored before and after the construction of the La Grande hydroelectric complex. Mercury levels in reservoir fish increased by factors ranging from 3 to 7 depending on species and reservoir (Verdon et al. 1991; Schetagne et al. 1996). Non piscivorous fish reacted more rapidly than piscivores, as their mercury concentrations usually peaked after 5 years of flooding while peak concentrations were obtained after 10 to 12 years for piscivorous species. The shape of the total mercury-to-fish length relationship changed a few years after impoundment. For lake whitefish (*Coregonus clupeaformis*), the mercury-to-length relationship observed in natural lakes usually shows mercury concentrations increasing with fish length in a slightly curvilinear manner. The typical evolution of this relationship in reservoirs is as follows. Two to three years after impoundment, as mercury concentrations increase more rapidly in younger smaller fish than older larger fish, the relationship shifts and concentrations decrease with fish length (Schetagne et al. 1996). Seven to nine years after impoundment, as concentrations also increase in larger fish, the mercury-to-length relationship shifts back to its original shape, but at higher concentrations. Subsequently, as mercury concentrations decrease in both small and large fish, the whole curve shifts downward towards natural concentrations. Monitoring of mercury levels in reservoir fish in Canada and Finland indicates that the return to natural concentrations is completed 15 to 30 years after impoundment (Schetagne et al. 1996; Verdon et al. 1991; Bodaly et al. 1997; Verta et al. 1986).

Nine years after the impoundment of the Caniapiscau reservoir, mercury concentrations in lake whitefish still decreased with fish size. This led us to suspect the presence of dwarf populations of lake whitefish. If this was the case, small individuals (dwarf) could be older than large ones (normal) which would explain the inverse relation of mercury with fish length. The presence of sympatric populations of dwarf and normal lake whitefish would represent a good opportunity to look at the effects of growth rates on mercury bioaccumulation.

A study was initiated with the following objectives: to characterize dwarf and normal individuals among lake whitefish captured in the Caniapiscau area of the La Grande complex and to compare their mercury bioaccumulation rates.

Study area

The La Grande hydroelectric complex is located on the east side of James Bay, approximately at 54° N (Figure 1). The whole region is part of the Canadian Shield. At the onset of the project, the territory was free of any industrial activity and sparsely occupied by aboriginal people following a traditional lifestyle in a region of scattered coniferous forest with numerous peat bogs. The most common fish species in the region include longnose sucker (*Catostomus catostomus*), white sucker (*Catostomus commersoni*), lake whitefish (*Coregonus clupeaformis*), northern pike (*Esox lucius*) and lake trout (*Salvelinus namaycush*). Walleye (*Stizostedion vitreum*) and cisco (*Coregonus artedii*) are also common in the western part of the territory.

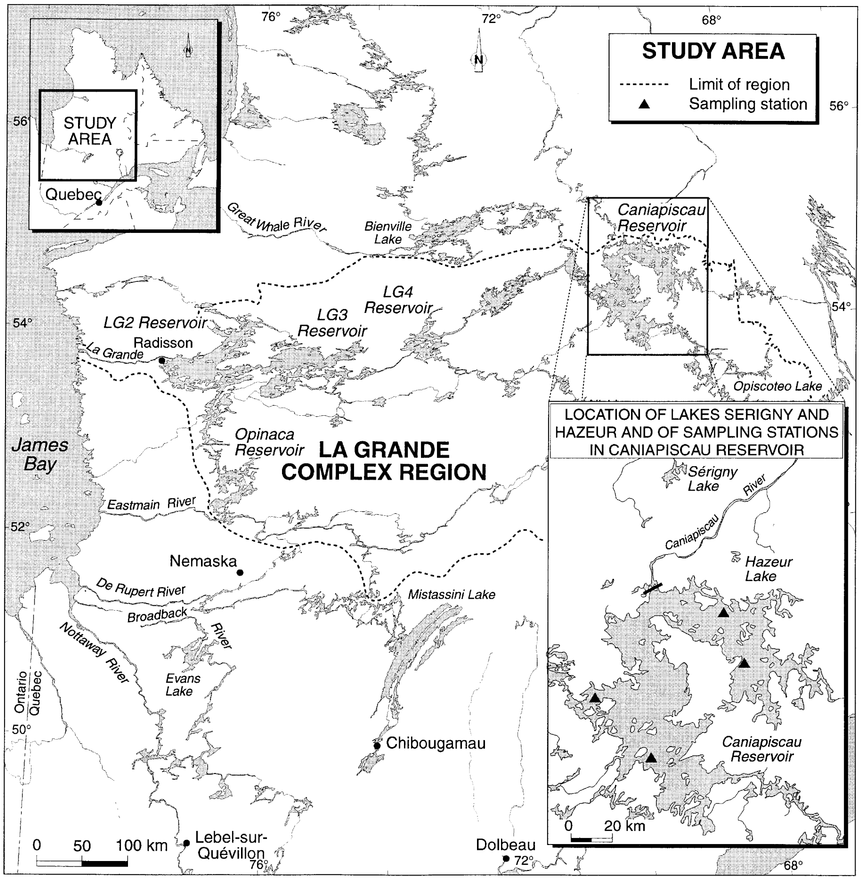


Figure 1. Map of the La Grande complex showing the Caniapiscau reservoir, Sérigny and Hazeur Lake.

Phase I of the La Grande complex resulted in the creation of 5 large reservoirs, ranging in terrestrial flooded areas from 700 (LG-4) to 3 400 km^2 (Caniapiscau).

Materials and methods

During summer 1993, sampling for dwarf and normal specimens of lake whitefish was part of the larger La Grande hydroelectric complex Environmental Monitoring Network. Lake whitefish were samples from 4 stations in the Caniapiscau reservoir and from 2 control lakes (Hazeur and Sérigny, Figure 1). Fish were collected 4 times between 30 June and 21 September, using gill nets with stretched mesh sizes ranging from 25 to 102 mm. All nets were 46 m long $\times$ 2.4 m high.

All fish captured were measured (total length, mm) and weighted ($\pm$10 g for specimens $>$200 mm and $\pm$0.1 g for smaller individuals). Sex and maturity were also determined (lake whitefish were considered mature when showing Nikolsky maturing stage III before 1 September or higher maturity stages whatever the month). Otoliths were collected for age determination, flesh samples, for mercury analysis and stomach contents were examined to determine feeding habits. We attempted to collect 30 specimens of each form of whitefish at every station for mercury analysis. These specimens were evenly distributed in 5 or 6 pre-selected length classes (50 mm for dwarf and 100 mm for normal).

Flesh samples were collected on the left side of the fish between the caudal and anal fins, in a relatively boneless area. They were frozen at -15 °C until analysis for total mercury (wet weight) by a certified laboratory, using cold vapour atomic absorption spectrophotometry. The procedure used involves the digestion of 300–500 mg of sample in sulfuric acid/nitric solution (NAQUADAT procedure, Environment Canada 1979) and had a detection limit of 0.05 $mg \cdot kg^{-1}$ wet weight (ww).

Stomachs were preserved in 70% alcohol until their contents could be identified, or frozen for mercury determination. Identification was carried out to the lowest possible level (usually genera). The inventory of the organisms was done by successive dilution in distilled water which allowed a clear distinction between organisms and inorganic debris, a manual separation and a grouping of organisms to obtain a minimum weight of material (0.2 mg dw) to perform mercury analysis. Organisms from several stomachs were pooled to obtain enough material for mercury analysis. The importance of a given prey in the feeding habit was assessed by volumetric displacement method (Hyslop 1980). Total mercury and methyl mercury concentrations of prey were measured by cold vapour atomic fluorescence spectrophotometry (Plourdes et al. 1996; Tremblay & Lucotte 1996). With this technique, 5–15 mg was digested in nitric acid-hydrochloride acid (Louchouarn et al. 1993). The method had a detection limit of 5 picograms of Hg, which corresponds to 5 ppb for a typical 1 mg sample. The detection limits represent three times the standard deviation of the procedural blanks. The accuracy of this method as well as the cold vapor atomic absorption spectrophotometry was tested by analyzing different standards which yielded mean concentrations comparable to the certified values.

Whitefish were classified as dwarf or normal individuals based on their length at maturity and their growth rate, dwarf whitefish having a smaller length at maturity and slower growth rates than normal individuals (Fortin &

Gendron 1990; Bodaly et al. 1991). For example, all whitefish larger than 300 mm were considered normal while mature fish smaller than 250 mm were classified as dwarfs. Other fish were classified normal or dwarf or unclassified depending on their growth rates. Immature fish younger than 3 years of age could not be classified due to the lack of difference in growth rates between the two forms.

The statistical approach used to compare bioaccumulation of mercury in flesh between dwarf and normal whitefish used polynomial regression analysis with indicator variables (Tremblay et al. 1996, 1997). Interpretation was based on mercury to length or age relationships and also on mean mercury levels estimated for standardized lengths specific to each form (dwarf: 200 mm, normal: 400 mm). T-tests were used to compare mean mercury concentration at a given age between dwarf and normal individuals. Non parametric Kruskal-Wallis tests were also employed when samples were of small size ($n < 10$) and assumptions of homoscedasticity could not be met.

Results

The length distribution of mature lake whitefish captured in the Caniapiscau reservoir clearly indicates 2 modes, a first one of small size fish at around 200 mm representing dwarf specimens and a second one of larger fish, at 480 mm, corresponding to normal individuals (Figure 2). Similar results were obtained in Sérigny Lake, where the first mode is located around 180 mm and the second one at 520 mm. However, in Hazeur Lake, only 1 mode was observed (500 mm), indicating the absence of the dwarf form.

Length distributions of mature whitefish from several water bodies located on the La Grande complex indicate that dwarf populations of lake whitefish are found only in lakes located in the eastern area (Figure 3). Similar results were observed in reservoirs as dwarf individuals only occurred in the La Grande 4 and Caniapiscau reservoirs located in the eastern area of the complex.

Figure 4 shows the distribution of length of mature lake whitefish as a function of their age, for Sérigny Lake and the Caniapiscau reservoir. They clearly show the coexistence of sympatric populations of dwarf and normal lake whitefish. Mature dwarf individuals are all $<$250 mm in length (TL), while mature normal individuals are exclusively larger than 300 mm.

Dwarf individuals begin to mature at age 2 or 3 and have a short life span, not exceeding 9 years. Normal individuals usually begin to mature at age 6 or 7 and have a much longer life span, reaching at least up to 34 years in Sérigny Lake. As shown in Figure 4, dwarf specimens also exhibit slower growth rates than normal individuals.

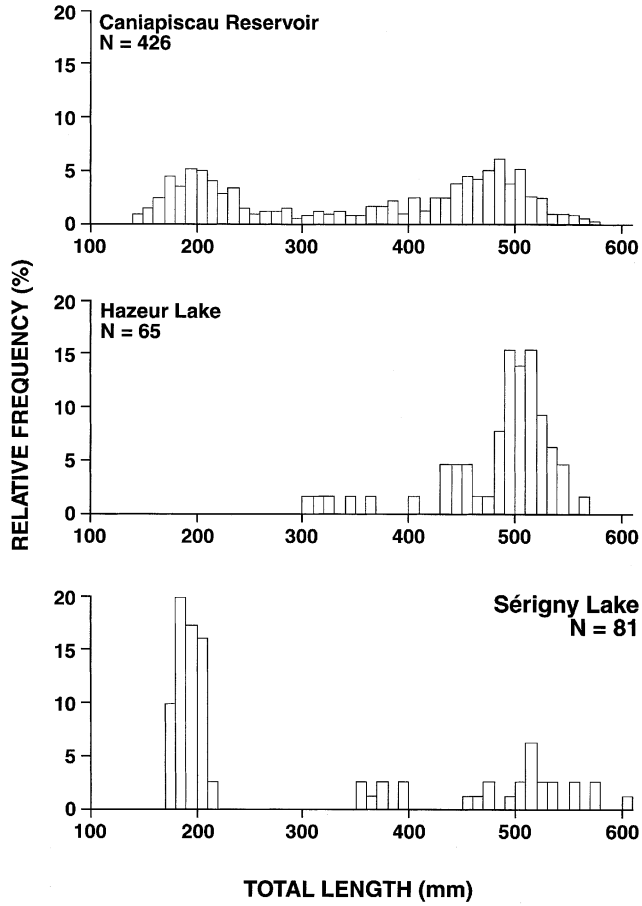


Figure 2. Length distribution of mature lake whitefish captured in the Caniapiscau area in 1993.

Dwarf individuals bioaccumulate mercury much more rapidly than normal individuals, either as a function of length or age (Figures 5 and 6). In Sérigny Lake, 6 or 7 year old dwarf specimens had significantly higher mercury concentrations (Kruskal-Wallis, $P > 0.05$) than normal individuals of the same age group (0.33 vs 0.21 mg kg^{-1}). In the Caniapiscau reservoir, the differences in bioaccumulation rates between the two forms are even more striking (Figure 6). In this water body, 6 or 7 year old dwarf specimens have mercury levels 3 times those measured for normal individuals of the same age group (0.74 vs 0.27 mg kg^{-1}).

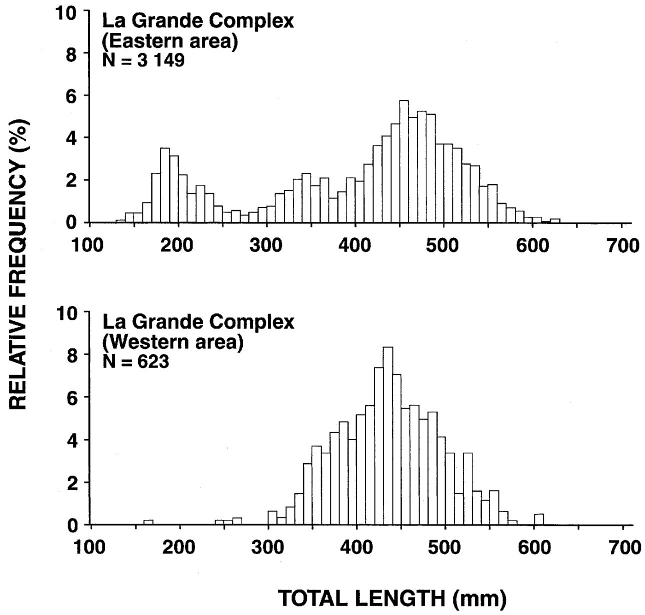
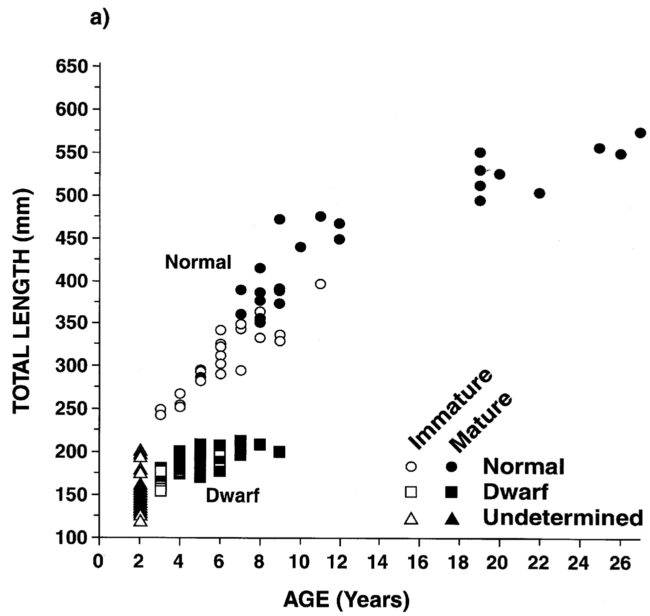


Figure 3. Length distribution of mature lake whitefish in the eastern and western areas of the La Grande complex.

Discussion

Our results clearly show the coexistence of sympatric populations of dwarf and normal lake whitefish in the Caniapiscau area. Other studies showed that dwarf and normal lake whitefish from this area were distinct morphologically and genetically. Bernatchez (1996) reported that allele frequency distributions were significantly different between the two forms, while Gendron (1994) found that gill raker counts were significantly lower for dwarf individuals. Similar differences in growth, length at maturity and morphological features were also reported for other sympatric populations of dwarf and normal whitefish found elsewhere in lakes (Bodaly 1979; Bodaly et al. 1991) or reservoirs (Fortin & Gendron 1990).

The absence of dwarf specimens in water bodies of the western area of the La Grande complex may be due to the presence of cisco (*C. artedii*). The scarcity of dwarf whitefish when populations of cisco occur was also reported by Bodaly (1979), Bodaly et al. (1991) and Doyon et al. (1997), for other regions of Canada. It is suggested that dwarf whitefish may not be able to support competition with ciscos (Bodaly 1979; Bodaly et al. 1991).



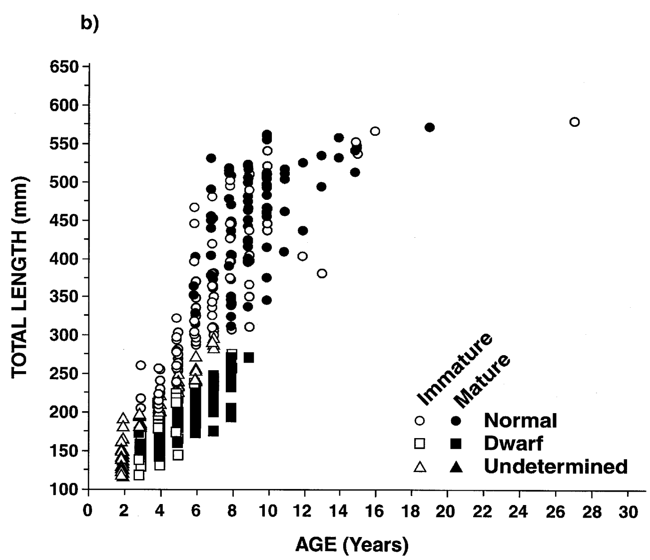


Figure 4. Total length to age distribution of lake whitefish from a) a natural lake (Sérigny Lake) and b) the Caniapiscau reservoir.

Results from this study clearly showed that dwarf lake whitefish bioaccumulate mercury more rapidly than normal individuals. A number of hypotheses were suggested to explain these differences.

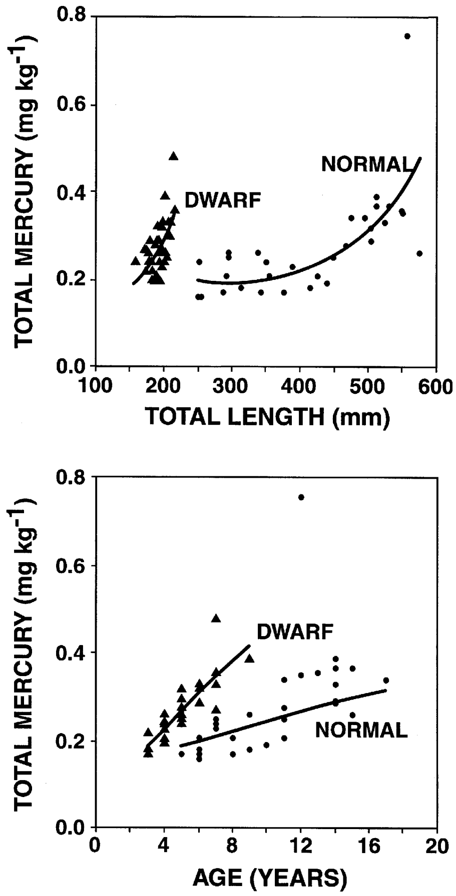


Figure 5. Mercury accumulation in dwarf and normal lake whitefish as a function of length or age (Sérigny Lake 1993).

First hypothesis: dwarf and normal lake whitefish may be feeding on different prey with different mercury concentrations. Stomach content analysis of dwarf and normal whitefish show that, although both forms feed mostly on zooplankton (chironomid pupae and cladocerans) during the 2–3 first years of life, at larger sizes, normal whitefish shift their diet towards benthic invertebrates (Doyon et al. 1997; Doyon et al. 1996). On the other hand, dwarf individuals continue to feed on zooplankton as they grow older. These results were obtained for sympatric populations of dwarf and normal whitefish coming from either the Caniapiscau reservoir or natural Sérigny Lake. However, methyl mercury concentrations in organisms collected in stomachs of both forms showed similar values (Table 1), invalidating this hypothesis.

Table 1. Percentage of volume and methylmercury concentration of major prey found in stomachs of dwarf and normal lake whitefish captured in 1993.

Whitefish	Sérigny Lake Prey	% of volume in stomach	Methylmercury (mg kg^{-1} wet weight)	Caniapiscau reservoir Prey	% of volume in stomach	Methylmercury (mg kg^{-1} wet weight)
Dwarf <250 mm	Zooplankton	100	0.032	Zooplankton	80	0.04
Normal <250 mm	Zooplankton	97	0.022	Zooplankton	88	0.06
Normal >350 mm	Benthic inv.	70	0.023	Benthic inv.	100	0.03
	Fish	25	0.05			
	Zooplankton	5	0.02			

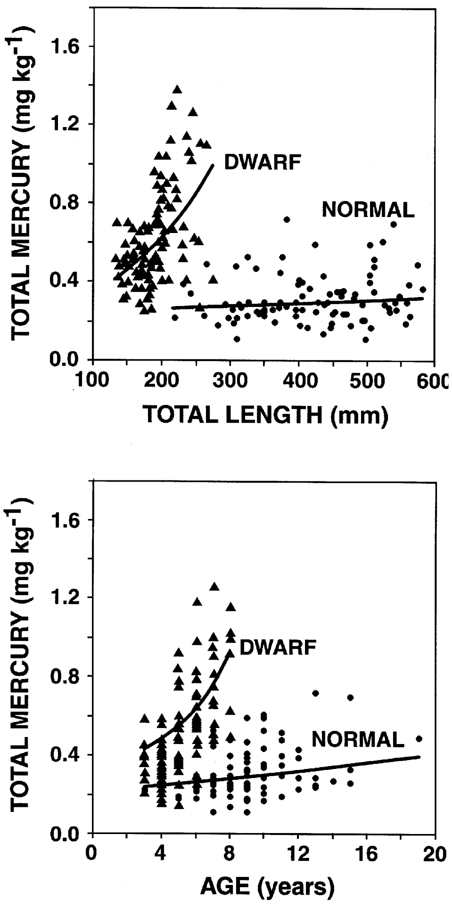


Figure 6. Mercury accumulation in dwarf and normal lake whitefish as a function of length or age (Caniapiscau reservoir 1993).

Second hypothesis: dwarf and normal lake whitefish bioaccumulate mercury at a different rate because of differences in growth rates, as smaller fish have higher metabolic rates (Beamish 1964; Reinert et al. 1974). Table 2 shows that growth rates of dwarf specimens, being much slower than normal individuals, support this hypothesis. For example, 7 year old dwarf specimens show a mean length of 208 mm (TL) in Sérigny Lake and 229 in the Caniapiscau reservoir, compared to 348 and 357 mm respectively for normal individuals. Dwarfs having a higher metabolic rate would allocate more energy towards maintenance and less to flesh production. This hypothesis of dilution with growth was also suggested by Hammer et al. (1993) to

Table 2. Mean length (TL, mm) of dwarf and normal lake whitefish captured in 1993 at ages 3 and 7 (sample size in given in parenthesis).

	Mean length (mm)			
Water body	Sérigny Lake		Caniapiscau reservoir	
Age of fish	3^+	7^+	3^+	7^+
Dwarf	172 (7)	208 (4)	155 (12)	229 (27)
Normal	247 (2)	348 (5)	229 (3)	357 (9)

Table 3. Mean length of fish (TL, mm) and total mercury concentrations (wet weight) measured in flesh and gonads of dwarf and normal lake whitefish in 1993.

		Dwarf				Normal			
Waterbody	Tissue	*n*	TL	Hg (mg kg^{-1})	*s*	*n*	TL	Hg (mg kg^{-1})	*s*
Sérigny Lake	Flesh	20	186	0.25	0.07	10	508	0.25	0.07
	Gonads	20	186	0.11	0.05	10	508	0.08	0.05
Caniapiscau	Flesh	21	205	0.42	0.09	24	471	0.42	0.08
	Gonads	21	205	0.17	0.09	24	471	0.11	0.08

explain differences in contaminant concentrations (DDT, PCB, etc.) between dwarf and normal arctic char.

Third hypothesis: dwarf specimens begin to mature at an earlier age than normal individuals, thus producing proportionally less flesh to dilute the mercury assimilated. Figures 4a and 4b show that dwarf specimens usually begin to mature at age 3 while normal individuals, at age 6. At age 8 dwarf specimens have usually spawned 6 times while normal individuals have usually spawned only 3 times. Furthermore, Table 3 shows that for both dwarf and normal lake whitefish, gonads are less concentrated in mercury than flesh. For example, mean total mercury levels of 0.28 and 0.42 mg kg^{-1} (wet weight) were found in flesh of dwarf and normal specimens from the Caniapiscau reservoir, compared to mean concentrations ranging from 0.11 to 0.17 mg kg^{-1} in the gonads. These data support the hypothesis that producing proportionally less flesh leads to higher mercury concentrations.

It is also interesting to note that as dwarfs mature at an earlier age than normal whitefish their growth rate rapidly decreases because they then allocate most of their energy to gonad production. At 3 years of age, dwarf specimens exhibited already significantly lower mean length than normal individuals of the same age but in older individuals, the difference in size is even more striking (Table 1), as is the difference in mercury concentrations (Figures 5 and 6).

In summary, the results from this study indicate that dwarf specimens of lake whitefish bioaccumulate mercury more rapidly than normal individuals. This discovery has brought a better understanding of the post impoundment evolution of mercury levels in lake whitefish of the Caniapiscau reservoir. When conducting monitoring of mercury levels in fish, in areas where populations of dwarfs and normal whitefish coexist, it is thus recommended that the 2 forms be distinguished because of their different bioaccumulation rates. They should be considered as different species for the statistical analysis and interpretation of mercury data.

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