SOME ENVIRONMENTAL IMPACTS OF HYDROELECTRIC PROJECTS ON FISH IN CANADA

Yiguang Zhong and Geoff Power[1]

INTRODUCTION

The vast territory and numerous rivers of Canada make it one of the richest countries in the world in terms of potential hydro energy. This substantial hydro energy has been exploited since the beginning of this century and development has expanded rapidly since then. In the 1980s, over 200 rivers and streams were blocked by hydroelectric projects (Rosenberg et al. 1987). In 1993, 399 hydropower stations were in operation the country with 62,047 MW of installed capacity and 320,411 GWH of electricity generation (Statistics Canada 1995). They accounted for 57.1 percent of the developable hydro energy and 62.1 percent of the country's annual electricity production (ICOLD 1992; Statistics Canada 1995). While new hydroelectric development has declined substantially in most developed countries since 1975 (Goldsmith and Hildyard 1984), Canada is one of few developed countries that continues to expand its already large hydroelectric capacity. Ten giant hydroelectric projects under construction will have 12,556 MW of generating capacity (Woods 1993). In fact, economic benefits have driven decision making on hydroelectric development in the country (Larocque 1993).

Hydroelectric developments normally involve blockage of river channels, impoundment of rivers, and regulation of discharge. These modifications inevitably cause major changes in the aquatic ecosystem in which fish live. In addition to ecological impacts, social and economic problems are causes for concern, such as high mercury levels in the hair of native peoples, or the collapse of local communities (Berkes 1988, 1990; Dickman 1991; Wagner 1984). Compared with other forms of pollution, less concern has been

[1] Yiguang Zhong and Dr. Geoff Power are **with** the Department of Biology, University of Waterloo, Waterloo ON Canada N2L 3GI

expressed about the environmental changes caused by hydroelectric development, although they may be just as serious, probably because effects on the ecosystem and humans are usually not displayed immediately. Some people have even argued that experience indicates minimal impacts from hydroelectric development (Abelson 1985; Kierans 1988), ignoring the evidence of severe environmental and social problems that have emerged around the world (Goldsmith and Hildyard 1984, 1986, 1992).

In Canada, many negative effects on aquatic ecosystems have been identified but data relating directly to fish are quite limited (Baxter 1977, 1985; Baxter and Glaude 1980; Efford 1975; Geen 1974). It is also unlikely that hydroelectric exploitation will cease in the near future. In consequence, we must understand the ecological effects and know the risks to fish resources in order to mitigate some of the worst consequences. Such information is needed for fisheries management and to assess proposals for new projects. The purpose of this paper is to provide an overview of the effects of hydroelectric development on Canadian fish. We identify three levels of impacts and their causal factors, focusing on information published in the last two decades. Mercury bioconcentration is a recognized problem that can have a serious impact on reservoir fish. It has been widely studied in Canada and is discussed separately. Several recommendations are made for research to improve the effectiveness of fisheries management and conservation.

LOCATIONS OF PROJECTS REVIEWED AND THE IMPACT MODEL

Major hydroelectric developments considered are located in the Saint John River in New Brunswick, the La Grande River in Quebec, and the Churchill River in Manitoba. In addition, fisheries studies associated with many other Canadian projects were reviewed (Figure 1).

Physical environmental changes in a river following hydroelectric development can affect fish directly or indirectly, and impacts may be classified by causal factors influencing the fish. Primary impacts are caused directly by the project. Secondary impacts result from modified physical-chemical conditions in the aquatic environment. Tertiary impacts are induced by changes in biotic factors in response to water regulation. Figure 2 summarizes the classification and lists the major impacts of hydroelectric projects on fish in Canada.

***figure* 7.** **Approximate locations of dams mentioned in the text used as examples of significant effects such structures can have on fish**

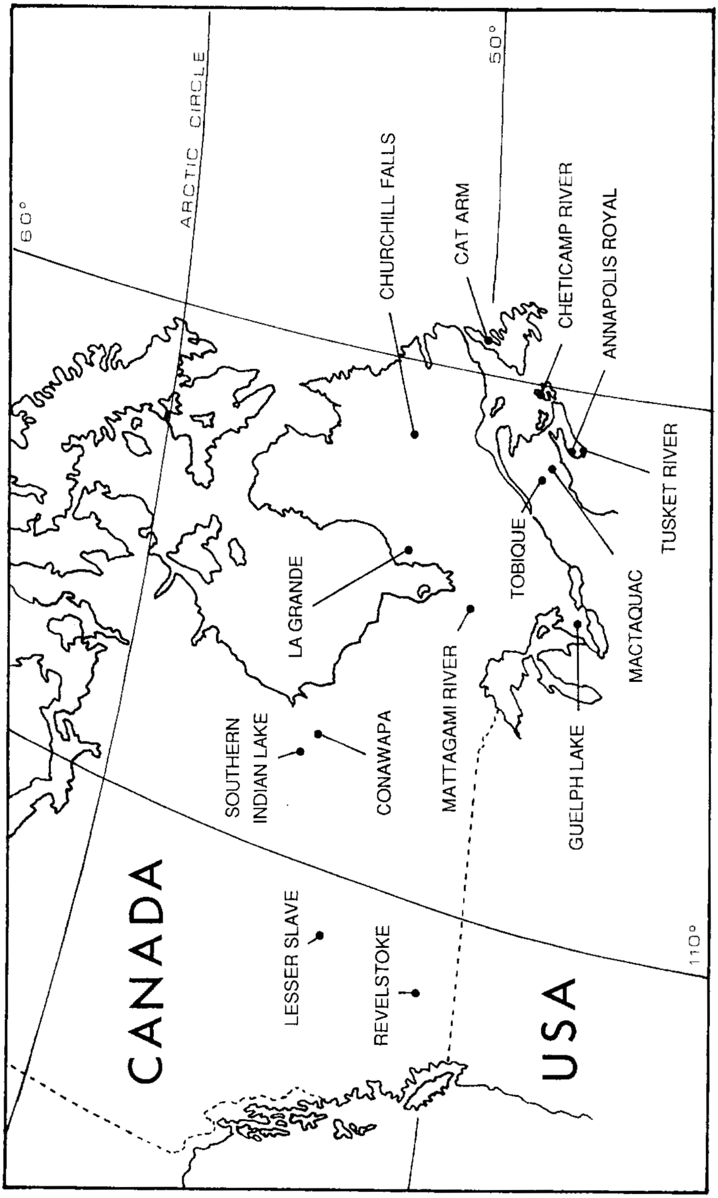
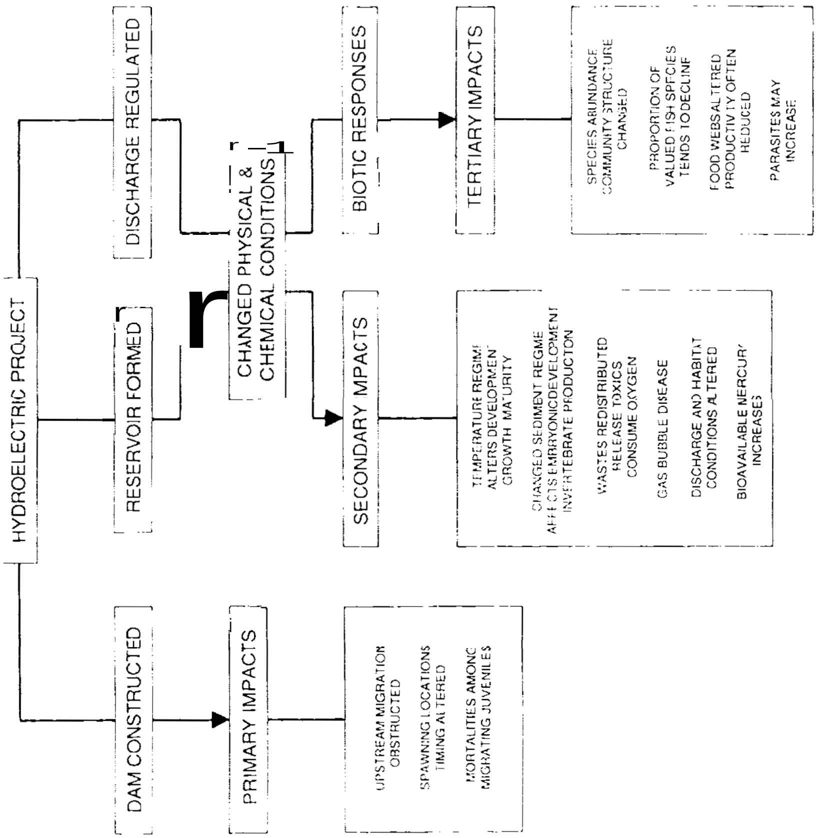


Figure 2. A classification of causes and three levels of environmental impacts of hydroelectric development on fish with a summary of main impacts identified in Canada



PRIMARY IMPACTS

One of the most serious primary impacts of hydroelectric dams is that they interrupt fish migration and damage fish. In many cases, fishways are employed to help fish, especially salmonids, bypass these barriers. Physical transportation by means of fish-lift systems and Hidrostal pumps has been successfully used for some species (Patrick and Sim 1985; Patrick and McKinley 1987; Jessop 1990a). However, fish passage facilities are not completely efficient at passing all species of fish since swimming abilities and preferred flow velocities are quite different among species. Observations at the Tobique Fishway, Saint John River, New Brunswick, indicated that American shad *(Alosa sapidissima)* did not readily use the fishway, while alewife *(A. pseudoharengus)* and blueback herring *(A. aestivalis)* ascended successfully (Ruggles and Watt 1975).

In an experiment to evaluate the effectiveness of different fishways for passing north-temperate, non-salmonid fish, Schwalme et al. (1985) found that preference for a vertical slot or a Denil fishway varied among species; northern pike *(Esox lucius)* strongly preferred the Denil fishways, two sucker species preferred the vertical slot fishway, and walleye *(Stizostedion vitreum)* and goldeye *(Hiodon alosoides)* would not use the fishways. Swanson (1990) indicated that the fish ladder at the Conawapa Generating Station, lower Nelson River, Manitoba, did not fully mitigate the loss of brook trout *(Salvelinus fontinalis)* passage. An ineffective fish ladder may expose fish to predation or cause severe overfishing due to disruption of the spawning migration as occurred for Acadian whitefish *(Coregonus canadensis)* (Edge 1984). Even the apparently successful fish passage facility at the Mactaquac Dam, Saint John River, causes delays in fish passage when alewife and blueback herring ascend in high numbers because of the limited capacity of the trucking operation (Jessop 1990b). At a tidal, low-head hydroelectric dam, Annapolis Royal in Nova Scotia, Stokesbury and Dadswell (1991) recorded 98 percent of the clupeids descending by way of the turbine, although two fishways adjacent to both sides of the turbine intake were accessible.

Downstream passage facilities for seaward migrating fish do not exist at most hydroelectric dams and substantial losses frequently occur when fish descend through the projects. Although coho salmon *(Oncorhynchus kisutch)* may spawn successfully above a dam, high mortalities of seaward-migrating smolts can occur when they descend through the turbines (Larkin 1984). Turbine-related mortality is different among species and turbine types.

Average juvenile mortalities were estimated to be 18 percent to 25 percent for trout, 14 percent for alewife, and 13.6 percent for yellow perch *(Perca flavescens)*, when they passed through a tube-type turbine (Ruggles 1990). Stokesbury and Dadswell (1991) reported that the Straflo turbine caused 46.3 percent mortality of juvenile clupeids. Major injuries were caused by changed pressure (64.5 percent) and mechanical contact (33.9 percent). Hydraulic shearing only accounted for 1.7 percent of the injuries. High turbine mortality affected both juvenile and adult fish. Hogans and Melvin (1985) estimated the mortality of American shad passing through a Straflo turbine to be 21.5–46.3 percent (in Stokesbury and Dadswell 1991). With a series of hydroelectric dams on a river, cumulative losses can be substantial among seaward migrants.

Fish below a dam may be damaged by the operational schedule of the project. Barnes et al. (1984) observed many lake whitefish *(Coregonus clupeaformis)* with mechanical injuries below a control structure leading to the forebay of the Churchill Falls hydroelectric facility, particularly after the control gates had been closed and reopened. In British Columbia, adult fish losses due to head injuries often occur in the powerhouse tailrace (Ennis 1990).

SECONDARY IMPACTS

Within Reservoirs

The most obvious effects of impoundment are increases in area, depth, and a shift from lotic to lentic conditions, which can influence species composition and abundance. In the Revelstoke Reservoir, British Columbia, populations of mountain whitefish *(Prosopium williamsoni)* and rainbow trout declined while bull trout and sucker species increased (Smith 1990). Raising the water depth over habitual spawning grounds may discourage reproduction in some species and benefit others. Filling of the Mactaquac Dam headpond, Saint John River, created new spawning and nursery habitats for alewife and blueback herring (Ruggles and Watt 1975). As a result, the numbers of these species passing through the fish-lift system increased from 22,000 to over 4.4 million annually between 1968 and 1987 (Jessop 1990a). On the other hand, drawdown may limit the reproductive success of some fish due to exposure of the littoral zone. Hirst (1991) indicated that drawdowns exceeding 10 m annually in reservoirs with limited tributary habitats kept densities of sport fish low.

It is generally expected that surface water temperatures in reservoirs will increase in summer after impoundment since the area exposed to sunlight is enlarged. However, in Southern Indian Lake, Manitoba, increased mean depth (3 m) caused **a** significant (1-2°C) cooling of the different basins of the lake, and winter temperature also decreased in South Bay because of increased inflow of cooler water (Hecky 1984).

Shoreline erosion can be severe in impoundments in Canada. Newbury and McCullough (1984) indicated that the proportion of the shoreline consisting of bedrock in Southern Indian Lake was reduced from 76 percent to 14 percent after impoundment in 1976, and the total volume of shoreline materials removed ranged from less than 1 to over 23 $m^3 \cdot m^{-1} \cdot year^{-1}$. They estimated that it would take at least *35* years for restabilization of three-quarters of the shoreline. **A** calculation indicated that extensive shoreline erosion added 4x10" t of mineral sediment annually to Southern Indian Lake during the first three years of the impoundment (Hecky and McCullough 1984). The sediment released into the reservoir increases turbidity and can settle out on the eggs and be detrimental to embryonic development. Fudge and Bodaly (1984) estimated that winter sedimentation on spawning grounds of lake whitefish ranged from 1–4 mm in depth and contributed to high mortalities of lake whitefish eggs in Southern Indian Lake. High turbidity can also cause primary productivity in reservoirs to shift from nutrient-limited to light-limited because of poor light penetration (Hecky and Guildford 1984).

Hydroelectric developments constructed on the main stem of rivers can cause water quality to deteriorate when organic wastes settle in reservoirs and decompose anaerobically. This can reduce the biological assimilative capacity of the rivers and is especially true for reservoirs with long retention times. The assimilative capacity of the Saint John River has been reduced in this way (Dominy 1973). Organic wastes, which settled on the bottom of reservoirs in the river, had a high oxygen demand, and reduced water flow in the reservoirs gave more time for the biological oxygen demand (BOD) to consume the available oxygen. Fish kills occurred in the headponds due to shortages of oxygen (Ruggles and Watt 1975). Pollution and dam construction were considered to be responsible for approximately 40 percent reduction in the Atlantic salmon *(Salmo salar)* stock in the Saint John River, due to elimination of some freshwater spawning and rearing habitats (Dominy 1973). Severe oxygen depletion was also observed in summer and winter in the Notigi Reservoir, Manitoba, after the Churchill River diversion (Bodaly and Rosenberg 1990).

Following impoundment, the catch of lake whitefish, which accounted for 85 percent of the fish yield from Southern Indian Lake, declined quickly despite a 21 percent increase in surface area. Catch per unit effort fell to about half of its pre-impoundment value within a four-year period. Total catch fell to a fifth of earlier landings six years after impoundment, and had not recovered four years later (Bodaly et al. 1984a, 1989). Fudge and Bodaly (1984) concluded that the substantial decrease in catch was the result of low survival of lake whitefish eggs due to serious sedimentation. However, Barnes and Bodaly (1990) later suggested that the Missi Falls control dam contributed to the decline of the lake whitefish in Southern Indian Lake by preventing fish that migrated downstream returning to the lake.

Downstream Impacts

Gas supersaturation resulting in gas bubble disease may be a cause of fish mortality below dams. This has usually been considered to be the result of heavy spillway discharge (Brooker 1981). However, MacDonald and Hyatt (1973) showed that the concentrations of dissolved oxygen and nitrogen gases were substantially increased when water passed through turbines operating at low load levels. Concentrations of dissolved nitrogen gas were increased as much as 20 percent above atmospheric equilibrium.

Temperature changes downstream of a reservoir may influence distribution and movement of fish. Spence and Hynes (1971) found that four southern species disappeared downstream from a small flood control dam while they occurred in the impoundment and upstream and attributed this to low temperatures below the impoundment. The variation of water temperature is important for stimulating the migration of some species. In the Annapolis River, Nova Scotia, Stokesbury and Dadswell (1989) observed that peak downstream migration of three herring species coincided with a sharp decline in water temperature to below 12°C, while higher water levels appeared to play little role in the emigration. Barnes and Bodaly (1994) observed that a large number of lake whitefish congregating below the Missi Falls control dam at Southern Indian lake originated from lakes downstream of Missi Falls on the lower Churchill River; they suggested that low temperature discharge from the dam in summer attracted the fish to the control dam.

River discharge is closely related to velocity, depth, and the wetted area of a river. Hughes and Peden (1989) indicated that Umatilla dace, *Rhinichthys umatilla* (= *osculus*), which is a rare species in Canada, is threatened by unsuitable water flows when water levels are manipulated for power or flood control. Therefore, changes in discharge from a hydroelectric project may have significant effects on downstream fish habitat. Jessop (1990b) observed that increasing discharge (May–June) from the Mactaquac Dam reduced the year-class abundance of blueback herring, but not of alewives, which may be related to the fact that blueback herring spawn later than alewife, Similarly, the proportion of chinook salmon *(Oncorhynchus tshawytscha)* of the Nechako River, British Columbia, appeared to be negatively correlated with flow release from the Kenney Dam in August (Bradford 1994).

Fish usually tend to exhibit some physiological changes when they are in stressful situations. Increased discharge, high velocity, and discharge of water with a low oxygen content may stress fish. Barnes et al. (1984) reported that lake whitefish below the Lobstick control structure at the Churchill Falls hydroelectric facility exhibited many stress-related symptoms. Their liver somatic index, gonad somatic index, stomach content volume, condition factor, and muscle and gonad protein levels were significantly lower than those in the reservoir and a control lake. They also had a low rate of circuli formation on the scales.

In Canada, hydroelectric developments often involve river diversion. Reduced flow will influence fish populations in the residual river after diversion. However, Ruggles (1988) indicated juvenile Atlantic salmon abundance in the Cheticamp River did not decline but increased from about 15 fish to 30 fish per 100 m^2 when approximately 18 percent of the drainage area had been diverted for power generation in the Wreck Cove Hydro-electric Project, Nova Scotia. He attributed it to the new flow regime in the river after diversion; that is, peak flows in the spring and autumn are moderated and summer low flows are augmented by release from the reservoir. However, his conclusions may have been influenced by a general increase in Atlantic salmon abundance coinciding with the study. In the Nechako River, British Columbia, discharge is reduced to 12 percent of the volume before diversion. Bradford (1994) reported that, when the majority of chinook salmon spawn in the upper reaches, survival of offspring is poorer than when spawning is concentrated downstream, where flows are augmented by tributaries to 51 percent of the original.

In contrast, in the lower La Grande River and its estuary, fishing activity largely ceased from 1979 to 1981 because of flow modifications in traditional fishing areas and other social and economic effects related to the hydro project (Berkes 1982). Commercial fishing may also be impaired by changes in the physical condition of the fishing grounds, such as increased debris and poor shoreline access (Bodaly and Rosenberg 1990).

MERCURY CONTAMINATION IN RESERVOIR FISH

Mercury concentration in fish has been identified as a serious impact in a number of newly impounded hydroelectric reservoirs in Canada since the late 1970s (Bodaly and Hecky 1979). The increase in fish mercury levels was generally believed to be a consequence of bacterial methylation stimulated by decomposition of flooded organic materials (Bodaly et al. 1984b; Hecky et al. 1987; Jackson 1988; Brouard et al. 1990; Johnston et al. 1991; LeDrew 1992; Ramlal et al. 1993). Recently, Louchouarn et al. (1993) suggested that long distance atmospheric transport of mercury and suspension of the humic horizon from flooded soils are important in mercury cycling. Methyl mercury, which can be absorbed directly from water across the gills, or be obtained from food, is the form in which most of the mercury is concentrated in fish and its toxicity is 10 times that of inorganic mercury (Hecky et al. 1991).

Mercury Bioaccumulation

Mercury levels in fish generally increase with age, size, and weight of fish (Scott 1974; Brouard et al. 1990; Strange et al. 1991; LeDrew 1992). Fish mercury accumulation varies significantly among species and is assumed to be related to diet: the higher the fish are in the food chain, the more mercury they accumulate (Bodaly et al. 1984b; Strange et al. 1991). Mercury concentrations tend to rise more quickly in nonpiscivorous than in piscivorous fish, which generally maintain high mercury levels much longer (Bodaly et al. 1984b; Brouard et al. 1990). Piscivores exhibit greater intraspecific variability in mercury levels than omnivores living in the same habitat (Johnston et al. 1991).

Even at the same trophic level, fish species may differ markedly in their mercury content. In Cat Arm reservoir, Arctic char *(Salvelinus alpinus)* accumulated almost twice as much mercury as brook trout, although in summer they consumed similar food organisms (Jacques Whitford 1993). In

Southern Indian Lake and La Grande 2 reservoirs, the mercury levels in northern pike were usually higher than those in walleye (Bodaly et al. 1984b; Brouard et al. 1990). Both species are piscivorous and have similar diets; different mercury concentrations were attributed to the habitat occupied and behavior (Brouard et al. 1990; Jackson 1991; Strange et al. 1991). The northern pike generally inhabits shallow inshore regions, where the methylation/demethylation (M/D) ratios were higher than in offshore regions (Ramlal et al. 1993), but the more active walleye ranged over a wider area and were apt to venture into offshore regions (Jackson 1991; Strange et al. 1991).

Differences in mercury concentrations among species may be also connected with their internal mechanisms for absorption and excretion of mercury. In Southern Indian Lake, higher mercury levels were recorded in the flesh than in the liver of northern pike and walleye, but the reverse was found in lake whitefish (Jackson 1991). Since lake whitefish had an anomalously weak tendency to accumulate methyl mercury, a rapid temporal decrease of mercury content after the initial increase, and a much higher ratio of liver MeHg to muscle MeHg, Jackson (1991) suggested that lake whitefish might have a special mechanism of excretion or different metabolic pathways for methyl mercury.

Environmental Factors Associated with Mercury Concentration

Mercury concentrations in fish are associated with the area of land tlooded to form the reservoir. In Southern Indian Lake and the Churchill River diversion area, mercury levels in several species of fish, especially piscivorous fish, are correlated with the area of land flooded and increase in water level (Bodaly et al. 1984b; Jackson 1991). Residence time of water in a reservoir is related to biological production and the mercury export rate and is correlated with mercury levels. The duration of reservoir filling is also correlated with fish tnercury levels. There was a significant delay in the rise in mercury concentration in fish in La Grande 3 reservoir, which took three years and four months to fill, compared to other reservoirs in the development (Brouard et al. 1990). In both the La Grande and Nelson rivers, fish in the lower reservoirs tended to accumulate more mercury than those in upper reservoirs (Bodaly et al. 1984b; Brouard et al. 1990). Mercury accumulation through a reservoir chain might be responsible for this phenomenon and it may be considered a cumulative impact.

Mercury contamination in fish not only happens in the impoundments but also extends downstream from the reservoirs. It may reflect changes in the amount of discharge rather than increased concentrations of Hg in the water itself. In the La Grande River basin, Quebec, Brouard et al. (1990) observed that mercury levels were markedly higher in five species of fish in downstream rivers, where the discharge had greatly increased following impoundment. The same situation was observed in the Southern Indian Lake region. Three fish species in Issett Lake, which received water diverted from South Bay, Southern Indian Lake, showed significantly higher mercury concentrations than they did in South Bay (Strange et al. 1991). But mercury levels of fish in reduced-flow sections of the La Grande complex tended to remain much the same as in natural environments, and lake whitefish and lake trout *(Salvelinus namaycush)* in the estuary of the La Grande River showed significantly lower mercury concentrations than those from freshwater downstream of the reservoir (Brouard et al. 1990). Mercury accumulation might be restrained in sea water. Migratory populations of cisco *(Coregonus artedi)* and lake whitefish exhibited much lower mercury levels than resident populations of the same species in the La Grande River, although both resident and anadromous populations of lake whitefish showed significantly higher mercury levels after construction of the hydroelectric complex (Roy 1989), compared with the pre-impoundment levels (Smith and Berkes 1975).

High temperature was an important factor that stimulated methylation but retarded demethylation in laboratory experiments (Wright and Hamilton 1982) and in lakes (Hecky et al. 1991; Ramlal et al. 1993). Rates of methyl mercury demethylation in lakes and reservoirs were inversely related to temperature (Bodaly et al. 1993; Ramlal et al. 1993). Mercury concentrations in four species of planktivorous, omnivorous, and piscivorous fishes were significantly and positively correlated with mean epilimnetic water temperature (Bodaly et al. 1993). Lake whitefish mercury concentrations were significantly and negatively related to sulphide (S^{2-}) concentrations in surface water (Jackson 1991) .

Duration of Mercury Bioaccumulation

Fish generally concentrate mercury most rapidly in the early period of impoundment and reach maximum levels three to nine years after impoundment depending on the species and location (Table 1). Once the peak level has been reached, mercury concentrations in fish tend to decrease with increased age of the reservoirs. Recent monitoring data showed mercury levels in fish had fallen steadily in Southern Indian Lake and Cat Arm reservoirs (Strange 1993; Jacques Whitford 1993).

Table 7. **Evolution of mercury concentrations in fish (mg·kg^{-1}) after impoundments in three Canadian reservoirs. (Numbers in parentheses are years after reservoir impoundment.)**

Data sources: Southern Indian Lake, from Bodaly et al. 1984, Strange et al. 1991, Strange 1993; La Grande 2, from Brouard et al. 1990; Cat Arm, from Jacques Whitford 1993.

Reservoir	Species	Length class (mm)	Baseline value	Early impoundment		Peak level sampling		Latest sampling	
				Level	BCF*	Level	BCF*	Level	BCF*
La Grande 2	Longnose sucker	400	0.160	0.410	2.56 (3)	0.670	4.19 (5)	**0.610**	3.81 (9)
	Lake whitefish	400	0.160	0.520	3.25 (3)	0.570	3.56 (5)	0.480	3.00 (9)
	Northern pike	700	1.610	1.310	2.15 (3)	2.990	4.90 (9)	2.990	4.90 (9)
	Walleye	400	0.680	1.920	2.82 (3)	2.800	4.12 (9)	2.800	4.12 (9)
Cat Arm	Brook trout	161-180	0.108	0.288	2.67 (2)	0.409	3.79 (6)	0.28	2.11 (9)
	Arctic char	161-180	0.220	0.444	2.00 (2)	0.847	3.85 (6)	0.548	2.49 (9)
Southern Indian Lake	Lake whitefish	301-400	0.068	0.278	4.09 (3)	0.278	4.09 (3)	0.064	0.94 (16)
	Northern pike	501-600	0.300	0.810	2.70 (2)	1.155	3.85 (8)	0.548	1.83 (16)
	Walleye	331-430	0.280	0.677	2.42 (2)	0.658	2.35 (6)	0.461	1.64 **(16)**

*BCF: Biocentration factor

In Southern Indian Lake, mercury levels in lake whitefish fell to background levels 12 to 16 years after impoundment, and northern pike also showed a significant decline in mercury concentration over the same period (Strange 1993). Likewise brook trout and Arctic char in Cat Arm reservoir displayed 55.7 percent and 64.7 percent reductions in mercury, respectively, nine years after impoundment. In the La Grande River basin mercury in lake whitefish and longnose sucker *(Catostomus catostomus)* showed only slight decreases four years after they reached the peak levels, while northern pike and walleye had their the highest concentrations in 1988, nine years after impoundment.

Inputs of external organic materials may have a strong influence on this evolution. Heavy bank erosion, contributing new organic materials, may lengthen the duration of higher concentration (Verdon et al. 1991). Brouard et al. (1990) expected the mercury levels in predatory and nonpredatory fish species in the La Grande reservoirs would return to natural levels 20–30 years after flooding. Strange et al. (1991) expected that northern pike and walleye mercury concentrations in Southern Indian Lake would remain high for many years. However, heavy fishing pressure in new reservoirs in the early years might be an effective way of reducing fish mercury concentrations and maintaining them at a safe level for human consumption. Removal of a large proportion of the fishery resource with high mercury loads from Finnish reservoirs greatly reduced mercury levels in the remaining fish (Göthberg 1983; Verta 1990).

TERTIARY IMPACTS

Hydroelectric development will cause impacts on all kinds of aquatic organisms due to alternations in the physical and chemical environment both upstream and downstream of the projects. These biological changes may lead to tertiary impacts on fish through trophic, host-parasite, habitat competition, or in other ways. Some of them may be positive, others negative, depending on the species. The population increases of white sucker *(Catostomus commersoni)* and longnose sucker in Beechwood and Mactaquac reservoirs, Saint John River, were related to the immense expansion of macrobenthos after impoundment (Ruggles and Watt 1975). The year-class size of blueback herring exhibited a decrease with increasing May–June discharge in the Saint John River (Jessop 1990b), apparently the result of reduced abundance of those plankton utilized at first feeding when high discharge from the dam resulted in low phyto- and zooplankton biomass in the headpond. Bodaly and Lesack (1984) found that the abundance of young-of-the-year of northern pike in Wupaw Bay, Southern Indian Lake, in the first year of impoundment was 4–10 times larger than in the following three years. Flooded terrestrial vegetation contributed to the successful first reproduction.

Physiological changes in biota frequently observed below dams may be induced by fluctuations in water level, sediment loading and transparency, or variations in the temperature regime (Baxter and Claude 1980). McKinley et al. (1993) found that total plasma nonesterified acids in lake sturgeon *(Acipenser fulvescens)* upstream of hydroelectric facilities were significantly higher than those downstream during the spring. They suggested that low plasma nonesterified acid concentrations in downstream sturgeon may be attributed to varying flow regimes altering the downstream nutritional status of the fish.

The population of fish parasites may increase after impoundment but the reason is not clearly understood. Mackie et al. (1983) reported that after impoundment of Guelph Lake, the prevalence and intensity of dominant fish parasites was significantly higher in the reservoir than downstream. Bodaly et al. (1984a) reported that there was a marked increase in *(Triaenophorus)* infestation of lake whitefish after impoundment of Southern Indian Lake and a dramatic increase (from 12 to 72 percent) of fish judged as second-class quality because of darker color and high rates of parasite infestation. **As** a result, the mean gross revenue of the fishery in Southern Indian Lake decreased 66 percent and it could not meet its capital costs (Wagner 1984).

Fish populations often increase rapidly in a new reservoir partly because of expansion of water volume and partly because food organisms increase in the impoundment. Bruce (1984) estimated that the long-term potential yield from the Stnallwood Reservoir, 7269 km^2, would be 2071 $t \cdot year^{-1}$. However, lack of information on reservoir fisheries indicated that, in Canada, there is not much interest in developing commercial fisheries in reservoirs, which, as Baxter and Glaude (1980) suggested, could be a beneficial effect of hydro-electric development.

MANAGEMENT DEMANDS AND RECOMMENDATIONS

Our knowledge about impacts of hydroelectric development on fish has increased in the last 20 years and an environmental impact assessment is an essential component of the feasibility study for any new development. Discoveries from previous impact studies, such as mercury bioaccumulation in fish, are now important elements to be predicted, evaluated and mitigated, if possible, in planning new hydroelectric developments in Canada (Ontario Hydro 1990; Power 1993; Yu and McCormick 1990). The problem is, we still do not know enough for confident prediction. For example, population declines of some rare species—Acadian whitefish, Umatilla dace, green sturgeon *(Acipenser medirostris)*, and white sturgeon *(A. transmontanus)*, for example—have been connected with hydroelectric development (Edge 1984; Houston 1988; Hughes and Peden 1989). These losses have not been attributed to any specific changed environmental factor. To improve the effectiveness of fisheries management and precision of impact assessment, more research emphasizing some of the following topics is recommended.

Secondary Impacts Caused by Changes of Hydrological Conditions

Compared with China, where research has demonstrated that the distribution, growth, reproduction, abundance, and species composition of fish in rivers can be greatly influenced by changes in water temperature, water level, discharge, and velocity following hydroelectric development (Zhong and Power 1996), similar hydrological changes in regulated Canadian rivers have not yet been connected with effects on fish (Berkes 1981, 1990; Hecky 1984). On the other hand, there is evidence that the environmental consequences of impoundment and flow regulation may extend hundreds of kilometers downstream from a dam. Although Geen (1974) indicated 20 years ago that information on downstream impacts was seriously lacking, no great progress has been made. An exception is the study by Auer (1996), which showed that a change from peaking to run of the river operation greatly stimulated the spawning of lake sturgeon.

Tertiary Impacts

The tertiary impact is probably the most difficult to reveal because these impacts are more complicated and more subtle than primary and secondary impacts. This is reflected in the lack of literature on tertiary impacts. In the publications reviewed for this paper, most tertiary impacts were suggested without direct data to support them, for example, a concern that a proposed water diversion in British Columbia for hydroelectric purposes might result in parasite fauna exchanges across the Continental Divide (Arai and Mudry 1983). As a result, few tertiary impacts have been predicted or assessed.

Physiological and Biochemical Consequences of Mercury Concentration in Fish

In Canada, published research on mercury sources, environmental factors, accumulation mechanisms, and the duration of elevated mercury levels is available but we have little information about physiological, biochemical, and ecological consequences for fish. We assume the effects are negligible, but are they?

Fish Adaptation to a Changed Aquatic Environment

Fish can obviously tolerate some changes to the environment in which they live, but it is difficult to predict the responses of fish communities to change. When simulating distributions of fish populations in the La Grande 2 Reservoir, Morrison et al. (1985) suggested that adaptation of fish populations to new spawning areas was responsible for inconsistencies between observations and model predictions between the first and second years of impoundment. Information on fishes' adaptability to environmental changes would be useful for resource management and for impact assessment because it is relevant for planning mitigation measures for proposed new developments.

Predevelopment Survey

Changes caused by development can only be measured if adequate predevelopment data are available. Unfortunately, baseline information is generally insufficient for execution of initial studies (Larkin 1984), and this leads to reduced precision in the impact assessment. Since the direction of hydroelectric exploitation is moving north in Canada, where environmental conditions are less studied, detailed surveys on habitats and fish populations should be conducted in those remote areas in advance of any development to provide more usable and precise background data.

CONCLUSIONS

Many environmental impacts of hydroelectric development on fish have been identified in Canada in the last two decades. The primary impacts appear immediately when the natural migration pathways of fish are blocked and arc the most obvious. Upon completion of the project, modified physical-chemical conditions both in reservoirs and downstream create secondary impacts. Compared with the primary impacts, secondary impacts tend to be more subtle and more harmful to fish because they may exist for extended periods and few effective measures are available to mitigate these impacts. The responses of other biotic groups to changes in the aquatic environment induce tertiary impacts through the food chain, fish population dynamics, and host-parasite relationships. This is the process of readjusting fish communities to the new environments. To increase our knowledge about the impacts of hydroelectric development on fish and to improve the effectiveness of fisheries management and bioconservation, more effort should be focused on the secondary and tertiary impacts. Intensive predevelopment surveys and long-term postdevelopment monitoring are critically important in this respect.

REFERENCES

Abelson, P.H. 1985. "Electric power from the North." *Science*. 228: 1487.

Arai, H.P. and D.R. Mudry. 1983. "Protozoan and metazoan parasites of fishes from the headwaters of the Parsnip and McGregor rivers, British Columbia: a study of possible parasite transfaunations." *Canadian Journal of Fisheries and Aquatic Science* 40: 1676–1684.

Auer, N.A. 1996. "Response of spawning lake sturgeons to change in hydroelectric facility operation." *Transactions of the American Fisheries Society* 125: 66–77.

Barnes, M., G. Power, and R. Downer. 1984. "Stress-related changes in lake whitefish (*Coregonus clupeaformis*) associated with a hydroelectric control structure." *Canadian Journal of Fisheries and Aquatic Science* 41: 1528–1533.

Barnes, N. and R.A. Bodaly. 1990. "Aggregations of lake whitefish (*Coregonus clupeaformis*) below the Missi Falls control dam: investigations into the collapse of the Southern Indian Lake fishery." In *Joules in the Water–Managing the Effects of Hydroelectric Development*, edited by C.E. Delisle and M.A. Bouchard, 175–195. Canadian Society of Environmental Biologists.

Barnes, N.E. and R.A. Bodaly. 1994. "Origin and abundance of lake whitefish (*Coregonus clupeaformis*) congregating below a hydroelectric control dam in northern Canada." *Regulated Rivers: Research & Management* 9: 295–302.

Baxter, R.M. 1977. "Environmental effects of dams and impoundments." *Annual Reviews of Ecology and Systematics* 8: 255–283.

Baxter, R.M. 1985. "Environmental effects of reservoirs." In *Microbial Processes in Reservoirs. Development of Hydrobiology 27*, edited by D. Gunnison, 1–26. Dr. W. Junk Publishers. Dordrecht. Boston. Lancaster.

Baxter, R.M. and P. Glaude. 1980. "Environmental effects of dams and impoundments in Canada: experience and prospects." *Canadian Bulletin of Fisheries and Aquatic Sciences* 205.

Berkes, F. 1981. "Some environmental and social impacts of the James Bay hydroelectric project, Canada." *Journal of Environmental Management* 12: 157–172.

Berkes, F. 1982. "Preliminary impacts of the James Bay hydroelectric project, Quebec, on estuarine fish and fisheries." *Arctic* 35: 524–530.

Berkes, F. 1988. "The intrinsic difficulty of predicting impacts: lessons from the James Bay hydro project." *Environmental Impact AssessmentReview* 8:201–220.

Berkes, F. 1990. "Impacts of James Bay development." In *Joules in the Water-Managing the Effects of Hydroelectric Development,* edited by C.E. Delisle and M.A. Bouchard, 623-636. Canadian Society of Environmental Biologists.

Bodaly, R.A. and R.E. Hecky. 1979. "Post-impoundment increases in fish mercury levels in the Southern Indian Lake reservoir, Manitoba." *Canadian Fisheries and Marine Service Manuscript Report* 1531: iv + 15p.

Bodaly, R.A. and Lesack, F.W. 1984. "Response of a boreal northern pike *(Esox lucius)* population to lake impoundment: Wupaw Bay, Southern Indian Lake, Manitoba." *Canadian Journal of Fisheries and Aquatic Sciences* 41: 706–714.

Bodaly, R.A., T.W.D. Johnson, R.J.P. Fudge, and J.W. Clayton. 1984a. "Collapse of the lake whitefish *(Coregonus clupeaformis)* fishery in Southern Indian Lake, Manitoba, following lake impoundment and river diversion." *Canadian Journal of Fisheries and Aquatic Sciences* 50: 692–700.

Bodaly, R.A., R.E. Hecky, and R.J.P. Fudge. 1984b. "Increases in fish mercury levels in lakes flooded by the Churchill river diversion, northern Manitoba." *Canadian Journal of Fisheries and Aquatic Sciences* 41: 682–691.

Bodaly, R.A., J.D. Reist, D.M. Rosenberg, P.J. McCart, and R.E. Hecky. 1989. "Fish and fisheries of the Mackenzie and Churchill river basins, northern Canada." In *Proceedings of the International Large River Symposium,* edited by D.P. Dodge, 128–144. Canadian Special Publication of Fisheries and Aquatic Science 106.

Bodaly, R.A. and D.M. Rosenberg. 1990. "Retrospective analysis of predictions and actual impacts for the Churchill-Nelson hydroelectric development, northern Manitoba." In *Joules in the Water-Managing the Effects of Hydroelectric Development,* edited by C.E. Delisle and M.A. Bouchard, 221–242. Canadian Society of Environmental Biologists.

Bodaly, R.A., J.W.M. Rudd, and R.J.P. Fudge. 1993. "Mercury concentrations in fish related to size of remote Canadian Shield lakes." *Canadian Journal of Fisheries and Aquatic Sciences* 50: 980–987.

Bradford, M.J. 1994. "Trends in the abundance of chinook salmon *(Oncorhynchus tshawytscha)* of the Nechako river, British Columbia." *Canadian Journal of Fisheries and Aquatic Sciences* 51: 965–973.

Brooker, M.P. 1981. "The impact of impoundments on the downstream fisheries and general ecology of rivers." *Advances in Applied Biology* 6: 91–152.

Brouard, D., C. Demers, R. Lalumiere, R. Schetagne, and R. Verdon. 1990. "Summary report. Evolution of mercury levels in fish of the La Grande hydroelectric complex, Quebec (1978–1989)." Joint report. Vice-présidence Environment, Hydro-Québec and Groupe Environment Shooner Inc., p. 97.

Bruce, W. 1984. "Potential fisheries yield from Smallwood reservoir, western Labrador, with special emphasis on lake whitefish." *North American Journal of Fisheries Management* 4: 48–66.

Dickman, M. 1991. "Failure of an environmental impact assessment to predict the impact of mine tailings on Canada's most northerly hypersaline lake." *Environmental Impact Assessment Review* 11: 171–180.

Dominy, C.L. 1973. "Recent changes in Atlantic salmon *(Salmo salar)* runs in the light of environmental changes in the Saint John river, New Brunswick, Canada." *Biological Conservation* 5: 105–113.

Edge, T.A. 1984. "Preliminary status of the Acadian whitefish, *Coregonus canadensis*, in southern Nova Scotia." *Canadian Field-Naturalist* 98: 86–90.

Efford, I.E. 1975. "Assessment of the impact of hydro-dams." *Journal of Fisheries Research Board of Canada* 32: 196–209.

Ennis, G.L. 1990. "Towards cooperative management of the impacts of hydro regulation on the salmon resources of British Columbia." In *Joules in the Water-Managing the Effects of Hydroelectric Development*, edited by C.E. Delisle and M.A. Bouchard, 555–578. Canadian Society of Environmental Biologists.

Fudge, R.J.P. and R.A. Bodaly. 1984. "Postimpoundment winter sedimentation and survival of lake whitefish *(Coregonus clupeaformis)* eggs in Southern Indian lake, Manitoba." *Canadian Journal of Fisheries and Aquatic Sciences* 41: 701–705.

Geen, G.H. 1974. "Effects of hydroelectric development in western Canada on aquatic ecosystems." *Journal of the Fisheries Research Board of Canada* 31: 913–927.

Goldsmith, E. and N. Hildyard, (eds.). 1984. *The Social and Environmental Effects of Large Dams*. Vol. 1. Cornwall UK: Wadebridge Ecological Centre, p. 331.

Goldsmith, E. and N. Hildyard. 1986. *The Social and Environmental Effects of Large Dams*. Vol. 2. Cornwall UK: Wadebridge Ecological Centre, p.346.

Goldsmith, E. and N. Hildyard, (eds.). 1992. *The Social and Environmental Effects of Large Dams*. Vol. 1. Cornwall UK: Wadebridge Ecological Centre, p. 243.

Göthberg, A. 1983. "Intensive fishing--a way to reduce the mercury level in fish." *Ambio* 12: 259–261.

Hecky, R.E. 1984. "Thermal and optimal characteristics of Southern Indian lake before, during, and after impoundment and Churchill river diversion." *Canadian Journal of Fisheries and Aquatic Sciences* 41: 579–590.

Hecky, R.E. and S.J. Guildford. 1984. "Primary productivity of Southern Indian lake before, during, and after impoundment and Churchill river diversion." *Canadian Journal of Fisheries and Aquatic Sciences* 41: 591–604.

Hecky, R.E. and G.K. McCullough. 1984. "Effect of impoundment and diversion on the sediment budget and nearshore sedimentation of Southern Indian lake." *Canadian Journal of Fisheries and Aquatic Sciences* 41: 567–578.

Hecky, R.E., R.A. Bodaly, N.E. Strange, D.J. Ramsey, C. Anema, and R.J.P. Fudge. 1987. "Mercury bioaccumulation in yellow perch in limnocorrals simulating the effects of reservoir formation." *Canadian Data Report Fisheries and Aquatic Sciences* 628: v+158 p.

Hecky, R.E., D.J. Ramsey, R.A. Bodaly, and N.E. Strange. 1991. "Increased methylmercury contamination in fish in newly formed freshwater reservoir." In *Advances in Mercury Toxicology,* edited by T. Suzuki, N. Imura, and T. Clarkson, 33–52. New York: Plenum Press.

Hirst, S.M. 1991. "Impacts of the operation of existing hydroelectric developments on fishery resources in British Columbia." Volume II. Inland Fisheries. *Canadian Manuscript Report of Fisheries and Aquatic Sciences* 2093.

Hogans, W.E. and G.D. Melvin. 1985. "Mortality of adult American shad *(Alosa sapidissima)* passed through a Straflo turbine at the low-head tidal power generating station at Annapolis Royal, Nova Scotia." T.P.H. Applied Fisheries Research, Wolfville, Nova Scotia. (cited from Stokesbury and Dadswell 1991).

Houston, J.J. 1988. "Status of the green sturgeon, *Acipenser medirostris*, in Canada." *Canadian Field-Naturalist.* 102: 286–290.

Hughes, G.W. and A.E. Peden. 1989. "Status of the Umatilla dace, *Rhinichthys umatilla*, in Canada." *Canadian Field-Naturalist.* 103: 193–200.

ICOLD (International Committee of Large Dam). 1992. "The world's hydro resources." *International Water Power and Dam Construction* 44(8): 45–52.

Jackson, T.A. 1988. "The mercury problem in recently formed reservoirs of northern Manitoba (Canada): effects of impoundment and other factors on the production of methyl mercury by micro-organisms in sediments." *Canadian Journal of Fisheries and Aquatic Sciences* 45: 97–121.

Jackson, T.A. 1991. "Biological and environmental control of mercury accumulation by fish in lakes and reservoirs of northern Manitoba, Canada." *Canadian Journal of Fisheries and Aquatic Sciences* 48: 2449–2470.

Jacques Whitford. 1993. *Cat Arm environmental effects monitoring study*. Jacques Whitford Environment, St. John's, Newfoundland. p. 36.

Jessop, B.M. 1990a. "Passage and harvest of river herring at the Mactaquac dam, Saint John river: an attempt at active fishery management." *North American Journal of Fisheries Management* 10: 33–38.

Jessop, B.M. 1990b. "Stock-recruitment relationships of alewives and blueback herring returning to the Mactaquac dam, Saint John river, New Brunswick." *North American Journal of Fisheries Management* 10: 19–32.

Johnston, T.A., R.A. Bodaly, and J.A. Mathias. 1991. "Predicting fish mercury levels from physical characteristics of boreal reservoirs." *Canadian Journal of Fisheries and Aquatic Sciences* 48: 1468–1475.

Kierans, T. 1988. "Recycled run-off from the North." *Journal of Great Lakes Research* 14: 255–256.

Larkin, P.A. 1984. "A commentary on environmental impact assessment for large projects affecting lakes and streams." *Canadian Journal of Fisheries and Aquatic Sciences* 41: 1121-1127.

LeDrew, Fudge Associates Ltd. 1992. *Cat Arm reservoir monitoring study (1990).* LeDrew, Fudge Associates Limited, St. John's, Newfoundland. 60 pages.

Larocque, G.S. 1993. "Dam design and construction activities in Canada (1986-1992)." *International Water Power and Dam Construction* 445(8): 15-16.

Louchouarn, P., M. Lucotte, A. Mucci, and P. Pichet. 1993. "Geochemistry of mercury in two hydroelectric reservoirs in Quebec, Canada." *Canadian Journal of Fisheries and Aquatic Sciences* 50: 269-281.

MacDonald, J.R., and R.A. Hyatt. 1973. "Supersaturation of nitrogen in water during passage through hydroelectric turbines at Mactaquac dam." *Journal of the Fisheries Research Board of Canada* 30: 1392-1394.

Mackie, G.L., W.B. Morton, and M.S. Ferguson. 1983. "Fish parasitism in a new impoundment and differences upstream and downstream." *Hydrobiologia* 99: 197-205.

McKinley, R.S., T.D. Singer, J.S. Ballantyne, and G. Power. 1993. "Seasonal variation in plasma nonesterified fatty acids of lake sturgeon *(Acipenser fulvescens)* in the vicinity of hydroelectric facilities." *Canadian Journal of Fisheries and Aquatic Sciences* 50: 2440-2447.

Morrison, K.A., N. Therien, and B. Coupal. 1985. "Simulating fish redistribution in the LG-2 reservoir after flooding." *Ecological Modelling* 28: 97-111.

Newbury, R.W., and G.K. McCullough. 1984. "Shoreline erosion and restabilization in the Southern Indian lake reservoir." *Canadian Journal of Fisheries and Aquatic Sciences* 41: 558-565.

Ontario Hydro. 1990. *Hydroelectric Generating Station Extensions Mattagami River Environmental Assessment.* Ontario Hydro.

Patrick, P.H. and B. Sim. 1985. "Effectiveness of a Hidrostal pump in the live transfer of American eels." *Hydrobiologia* 128: 57-60.

Patrick, P.H. and R.S. McKinley. 1987. "Field evaluation of a Hidrostal pump for live transfer of American eels at a hydroelectric facility." *North American Journal of Fisheries Management* 7: 303-305.

Power, G. 1993. "A synthesis of environmental studies, to 1990, at the Cat Arm hydroelectric development with suggestions and a set of hypotheses for future monitoring." In *Proceedings of Cat Arm Reservoir Environmental Effects Monitoring Workshop.* Newfoundland and Labrador Hydro.

Ramlal, P.S., C.A. Kelly, J.W.M. Rudd, and A. Furutani. 1993. "Sites of methyl mercury production in remote Canadian Shield lakes." *Canadian Journal of Fisheries and Aquatic Sciences* 50: 972-979.

Rosenberg, D.M., Bodaly, R.A., Hecky, R.E., and Newbury, R.W. 1987. "The environmental assessment of hydroelectric impoundments and diversions in Canada." In *Canadian Aquatic Resources*, edited by M.C. Healey and R.R. Wallace, 71-104. Canadian Bulletin of Fisheries and Aquatic Sciences 215.

Roy, D. 1989. "Migration et concentration en mercure des salmonidés de la région de l'embouchure de La Grande Rivière." *Société d'énergie de la Baie James*, 24 p. (cited from Brouard et al. 1990).

Ruggles, C.P. 1988. "Juvenile Atlantic salmon *(Salmo salar)* abundance and angling success before and after river diversion." *Biological Conservation*. 43: 279–294.

Ruggles, C.P. 1990. "Fish passage through a tube turbine." In *Joules in the Water-Managing the Effects of Hydroelectric Development*, edited by C.E. Delisle and M.A. Bouchard, 485–538. Canadian Society of Environmental Biologists.

Ruggles, C.P. and W.D. Watt. 1975. "Ecological changes due to hydroelectric development on the Saint John river." *Journal of the Fisheries Research Board of Canada* 32: 161–170.

Schwalme, K., W.C., Mackay, and D. Lindner. 1985. "Suitability of vertical slot and Denil fishways for passing north-temperate, nonsalmonid fish." *Canadian Journal of Fisheries and Aquatic Sciences* 42: 1815–1822.

Scott, D.P. 1974. "Mercury concentration of white muscle in relation to age, growth, and condition in four species of fishes from Clay lake, Ontario." *Journal of the Fisheries Research Board of Canada* 31: 1723–1729.

Smith, E.C., and F.Berkes. 1975. "Mercury levels in fish in the La Grande river area, northern Quebec." *Bulletin of Environmental Contamination and Toxicology* 13 (6): 673–677.

Smith, H.A. 1990. "Revelstoke reservoir (Columbia river system): biophysical status to 1987." In *Joules in the Water-Managing the Effects of Hydroelectric Development*, edited by C.E. Delisle and M.A. Bouchard, 297–325. Canadian Society of Environmental Biologists.

Spence, J.A. and H.B.N. Hynes. 1971. "Differences in benthos upstream and downstream of an impoundment." *Journal of the Fisheries Research Board of Canada* 28: 45–46.

Statistics Canada. 1995. *Annual Statistics 1993*. Catalogue 57–206. Statistics Canada.

Stokesbury, K.D.E. and M.J. Dadswell. 1989. "Seaward migration of juveniles of three herring species, *Alosa*, from an estuary in the Annapolis river, Nova Scotia." *Canadian Field-Naturalist* 103(3): 388–393.

Stokesbury, K.D.E. and M.J. Dadswell. 1991. "Mortality of juvenile clupeids during passage through a tidal, low tidal hydroelectric turbine at Annapolis Royal, Nova Scotia." *North American Journal of Fisheries Management* 11: 149–154.

Strange, N.E., R.A. Bodaly, and R.J.P. Fudge. 1991. "Mercury concentrations of fish in Southern Indian lake and Issett lake, Manitoba, 1975-88: The effects of lake impoundment and Churchill river diversion." *Canadian Technical Report of Fisheries and Aquatic Sciences* 1824: iv + 30 p.

Strange, N.E. 1993. *Mercury in Fish in Northern Manitoba Reservoirs and Associated Waterbodies: Results from 1992 Sampling*. Winnipeg Manitoba: North/South Consultants Inc.

Swanson, G.M. 1990. "The impacts of hydroelectric development on the fisheries of the lower Nelson river." In *Joules in the Water-Managing the Effects of*

Hydroelectric Development, edited by C.E. Delisle and M.A. Bouchard. 199-220. Canadian Society of Environmental Biologists.

Verdon, R., D. Brouard, C. Demers, R. Lalumiere, M. Laperle, and R. Schetagne. 1991. "Mercury evolution (1978-1988) in fish of the La Grande hydroelectric complex, Quebec, Canada." *Water, Air, and Soil Pollution* 56: 405–417.

Verta, M. 1990. "Changes in fish mercury concentrations in an intensively fished lake." *Canadian Journal of Fisheries and Aquatic Sciences* 47: 1888–1897.

Wagner, M.W. 1984. "Postimpoundment change in financial performance of the Southern Indian lake commercial fishery." *Canadian Journal of Fisheries and Aquatic Sciences* 41: 715–719.

Woods, J.L. 1993. "Changes and challenges for North American hydropower." *International Water Power and Dam Construction.* 45(8): 41–45.

Wright, D.R. and R.D. Hamilton. 1982. "Release of methyl mercury from sediments: effects of mercury concentration, low temperature, and nutrient addition." *Canadian Journal of Fisheries and Aquatic Sciences* 39: 1459—1466.

Yu, M.S. and B.J. McCormick. 1990. "Environmental issues and effects for the proposed Little Jackfish river hydroelectric development." In *Joules in the Water-Managing the Effects of Hydroelectric Development,* edited by C.E. Delisle and M.A. Bouchard, 327–354. Canadian Society of Environmental Biologists.

Zhong, Y. 1995. Environmental impacts of hydroelectric projects on fish—Case studies based on experiences in Canada and China. M.Sc. thesis. University of Waterloo, Waterloo, Ontario. p. 137.

Zhong, Y. and G. Power. 1996. "The environmental impacts of hydroelectric projects on fish resources in China." *Regulated Rivers: Research and Management* 12: 81–98.