POTENTIAL TEMPERATURE EFFECTS ON BROAD WHITEFISH (*Coregonus nasus*) FROM WARM WATER DISCHARGE EFFLUENT

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August 2015

1. BROAD WHITEFISH IN THE MACKENZIE RIVER

Broad whitefish are an anadromous species (spend most of their lives in the ocean but ascend rivers to spawn). Broad Whitefish migrate back and forth across all three of the settled land claims in the lower Mackenzie (Inuvialuit, Gwich'in, Sahtu settlement areas). They spawn on gravel reefs and shoals after spending the summer feeding along the coast and in the delta channels and lakes. They spawn when water temperatures reach 0 °C. Low water levels at the Ramparts Rapids south of Fort Good Hope likely stop them from moving further up the river at this time (Treble and Reist, 1997).

> "A long time ago about 1945, one never heard of high catches of whitefish or coney. Now they catch whitefish and coney at Norman Wells. Lots now. Maybe they pass the rapids now today. It might depend on the water levels in the river. About 1945 whitefish don't stay at FGH Ramparts area because the Mackenzie ice is rough. The whole fish takes off. Today if you set nets in the Mackenzie River you gonna catch coney and whitefish because there is no more rough ice. We have seen that the whitefish abundance is going down very slowly. At Norman Wells, where they are drilling that oil field the smoke ends up in the spring run-off to the river. We saw that was no good, but we also saw there was nothing wrong with the water" (Jim Perrault FGH).

Broad whitefish have been harvested as long as there have been people living in and near the Mackenzie River (Treble and Reist, 1997). Many fishers found the catch to be extremely low in 2003, possibly because of the unusual warm weather and low water levels. Fishermen interviewed all stated that there are fewer people fishing today, and they are catching fewer fish than were caught in the 1950's and 1960's when everyone had dog teams (Treble and Reist, 1997). There has been no noticeable change in the size of broad whitefish caught. They suggested that maybe the fish have moved to other areas of the Delta, or their migration routes have changed. There was some local concern with fish quality and the cumulative effects of pollution from developments along the Mackenzie River as well as its tributaries (Treble and Reist, 1997).

"There are two kinds of whitefish. The whitefish from the lakes are a darker colour and they are firmer. Whitefish from the rivers are more white or silvery in colour and the flesh when you cook it, is more soggy with water in the meat" (Freeman, 1997). It is generally agreed that when the summer water temperature is higher the quality of the fish is lower:

> "If you got a hot summer there would be no fish; the bottom gets warm and the fish don't move. If you take a fish out of the net your finger would go right through the fish… when it's warm in the summer there's not much fish." (Freeman 1997).

The best places for setting nets in the river include the eddies and stretches of clear water and near where creeks flow into the river channels. Following northerly or westerly winds the water becomes cloudy or water levels may rise and fewer fish are caught at that time. After an east wind the water becomes clearer again and fish become more plentiful. In hot summers fewer fish are caught, for it is believed that the fish move around less in warmer water (Freeman, 1997).

2. TEMPRATURE EFFECTS

Temperature is the most all-pervasive environmental factor that influences aquatic organisms, including fish. No study of fish in relation to their environment (fish ecology) would be meaningful without consideration of thermal relationships (Coutant, 1976). For example, temperature regimes influence migration, egg maturation, spawning, incubation success, growth, inter- and intraspecific competitive ability, and resistance to parasites, diseases, and pollutants (Armour, 1991). The functional properties of temperature acting on individual fish or on the population of any one fish species can be summarized:

Temperature can act:

- as a lethal agent that kills the fish directly;
- as a stressing agent that destroys the fish indirectly;
- as a controlling factor that sets the pace of metabolism and development;
- as a limiting factor that restricts activity and distribution;
- as a masking factor that interacts with other environmental factors by blocking or altering their potential expression;
- as a directing agent in gradients that stimulate sensory perception and orient activity (Coutant, 1976).

A major problem hindering precise understanding of temperature effects is that many environmental factors may influence fish simultaneously. Furthermore, some factors function synergistically, which consequently masks the influence of individual relations (Armour, 1991). Depending upon the magnitude and rates of the thermal changes, there may be minor readjustments of the rates of metabolism and growth, or major changes in the distribution of species and of the functioning of the affected aquatic ecosystems (Coutant, 1976).

Genetic adaptation (geographic variation); pH; Oxygen; stress; photoperiod; diel cycles; seasonal changes; sex; age and size; life-cycle stage; parasites and diseases; diet; salinity; competition; predators; chemicals.

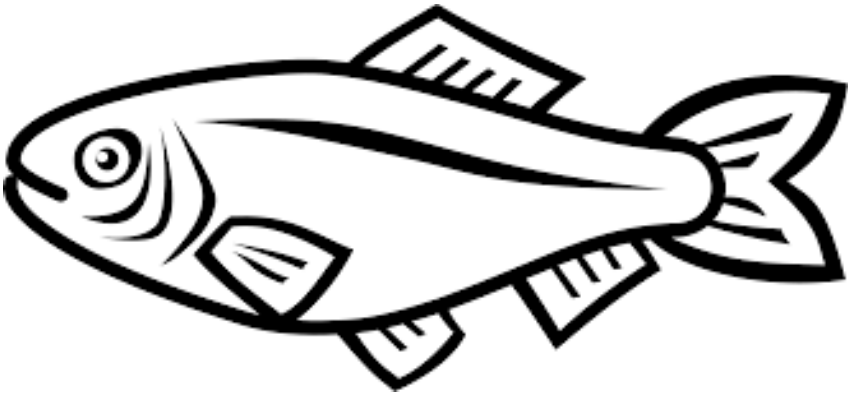

Figure 1: Some examples of factors that can influence the response of fish to temperature regimes.

The direct effects of thermal discharges on marine organisms fall into four categories, the mean temperature in relation to “normal”, the absolute temperature (as it may approach lethal levels), short-term fluctuations in temperature and potential barriers to fish migration. These conditions tend to favour eurythermal species, notably those from the littoral or warmer zoogeography, while inhibiting stenotherms or cooler-water species (Bamber, 1995). A potential increase in background temperature would exacerbate the effects of mean and absolute temperature, although operating on a “previously selected” local community. While a natural temperature rise of 1°C above normal can have a marked impact on even littoral species, any effluent temperature effects will be localized within a small area (Bamber, 1995).

Because the migrations of fish are triggered by specific environmental cues such as change in water temperature, water clarity or daylength, they are concentrated over a short period of time. Similarly, especially in rivers the migrating fish are concentrated into a small spatial area. This increases their vulnerability to human activities. Contaminants entering an ecosystem may affect fish populations. For less toxic contaminants, individual fish must either swim elsewhere to avoid it or neutralize the effects by some mechanism. Both of these activities consume energy, thus the fish will grow slower and reproduce less, or it may become more susceptible to disease, predators or parasites. Also, if the contaminant affects a habitat critical to the fish for a particular life history function, the fish may avoid that area until the contaminant dissipates. Thus, activities such as feeding, migration or reproduction may be disrupted with negative effects at both the individual and the population level. Effects of habitat change at the level of individual fish may be disruption of migratory patterns and decline in growth and reproduction. Effects at the level of the fish population may include reduction in numbers of fish either directly or through disruption of life history events (Reist, 1997b).

Despite the wealth of biological information on temperature effects, a biologist faced with the pressing pragmatic problem of predicting or assessing the biological costs or benefits to a fishery resource of super-imposing some heat increment of a few degrees on a specific river system encounters an extremely complex and difficult task. Thus, the biologist is likely to use the direct observational approach of investigating the effects of elevated temperatures on salmon or other desired species on site, using local fish and on-site water (Nakatani, 1968).

If the temperature of a reach of a stream is raised by 5-10 C, it is probable that cold water fish will avoid this reach and will be replaced by warm water fish. Thus, without any direct visible mortality, the character of the fish and supporting aquatic life will change. It will also change because the temperature impacts successful spawning and hatching of eggs (www.watercenter.org).

For salmonids, increases in surface water temperature beyond diurnal or seasonal averages, have the potential to accelerate embryo development, alter the timing of emergence, growth and downstream migration of juveniles, reduce metabolic efficiencies of food conversion into growth (i.e. due to thermal stress and oxygen deficiency), alter adult spawning migration and spawning timing, increase susceptibility to disease and shift the competitive advantage of salmonids over non-salmonid species (env.gov.bc.ca).

For lake whitefish, continuous addition of waste heat sufficient to raise the temperature 1, 2, or 3 °C above ambient on the spawning grounds during December – April would advance the time of hatching 8, 16 or 21 days, respectively (Berlin et al. 1977). Temperature plays the predominant role in controlling both seasonal and daily growth of early larvae (Perrier et al. 2012). The optimum temperature range for incubation of lake whitefish eggs was 3.2 to 8.1 °C (Brooke, 1975).

Downstream communities responded to warming below dams with shifts in the macroinvertebrate community, increased fish species richness, and reductions in cold water fish species population densities (Leassard and Hayes, 2003).

Insects are often the dominant macroinvertebrates in stream and river communities.

Water temperature is one important parameter that can differentiate tributaries both within and among drainage systems. Temperature affects growth, metabolism, reproduction, emergence, and the distribution of aquatic insects. In addition, the species composition of insect communities has been shown to change with temperature both seasonally (within a stream reach), microgeographically (along the length of a given river), and macrogeographically (among drainage systems). Thus the magnitude and pattern of historical, annual, seasonal, and diel temperature fluctuations may be important in selecting and maintaining the array of insect species in a given reach of a stream (Vannote and Sweeney, 1980).

Why no study of macroinvertebrates in the sediments?

To date the impact of thermal emissions has not been addressed in life cycle assessment despite the narrow thermal tolerance of most aquatic species (Veroness et al. 2010).

3. IMPERIAL OIL NORMAN WELLS OPERATION 2002-2006 AQUATIC EFFECTS MONITORING PROGRAM RESULTS

The most modern Central Processing Facility (CPF) has been operating at Norman Wells since 1980. Thirty-five years of warm water effluent discharging into the Mackenzie River. IORL has been operating since 1921. Under terms and conditions of the Water Licence, IORL is required to conduct scheduled sampling and analysis of water discharged from the site to the surrounding environment. The prime objective of the monitoring is to measure the concentration of chemicals-of-concern to ensure that fish, fish habitat and water of the Mackenzie River will not be adversely affected by releases from the Norman Wells facility. IORL must also measure temperature of water at the intake and outlet of the facility. Outlet water is consistently 10-15 °C higher than inlet water and reaches temperatures of 27 °C in late August.

At Imperial Oil Resources Norman Wells Operation, the effluent from the Central Processing Facility (CPF) discharge channel undergoes very slow dispersion in the Mackenzie River and travels over a long distance downstream. The dilution of the effluent to 0.1% of the initial concentration is predicted to be beyond the area investigated during the dye tracer studies (i.e. over 8060 m downstream), past Rader Island (Golder, 2007).

Distance below the outflow that the increased temperature is maintained?

There was a slight effluent effect on growth of fish exposed to 100% concentration of Refinery Waterflood Basin and CPF Impounding Area effluents versus control fish in laboratory dilution water (smaller body weights).

Mackenzie River dilution water also had an effect on the growth of fish during 2004 and the effect was stronger during the fall period (smaller body weights).

The effluent did not result in death to any fish. The results suggested that, during the fall, water from the Mackenzie River could potentially be more stressful to fish than the effluents. These findings were supported by the minimal amount of hydrocarbons in the effluent, the dispersion of the effluent, and higher hydrocarbon levels in river water and sediments. However, this conclusion did not take into account temperature effects.

Biological and chemical factors are known to affect fish quality. Of particular importance are 1) the species; 2) factors within species such as age, season, sexual maturity, access to feed, feed composition; and 3) the physical and chemical conditions experienced by the individual fish, such as salinity, temperature, pressure and oxygen concentration (Golder Associates 2007).

Temperature increases can alter adult spawning migration. People of Fort Good Hope have noticed decreases of fish caught in nets during the annual fall spawning migration period for whitefish. For the previous AEMP study, Fort Good Hope and Tsiigehtchic reported delayed migration of fall spawning species in 1983 and changes in the quality of flesh of whitefish (i.e. more watery). Concerns about watery whitefish flesh were not addressed, but was probably due to natural processes during the lifecycle. This conclusion does not account for potential impact of warmer discharge water on fish growth and reproduction. The complaint regarding 'watery' flesh of whitefish was also borne out by the analyses of Mackenzie River fish. The northern whitefish had higher water content and lower fat content than most other samples of whitefish for which data have been found, but investigation of this matter remained incomplete (Golder Associates, 2007).

There was no indication that the condition of fish downstream of Norman Wells was different from that of fish upstream of Norman Wells. But fish travel, so how can one be certain that the fish sampled upstream hadn't already spent a long time downstream before moving upstream? It is possible that the fish captured in Tulita are not discrete stocks from those downstream, and that they mix freely with fish downstream of Norman Wells. In addition, the fish moving seasonally (e.g. the broad whitefish migrating from the delta region to spawn upstream of Fort Good Hope at the Ramparts Rapids area from late August to October) could continue their journey further upstream past Norman Wells (Golder Associates, 2007).

The lower Mackenzie River is defined as that area north of the Ramparts Rapids area on the mainstem (i.e., immediately south of Fort Good Hope). From the perspective of coregonids such as broad whitefish this definition is biologically meaningful. A prominent feature of the Mackenzie River at the Ramparts area is the presence of a discontinuity in the bedrock forming the river bed. This discontinuity consists of a vertical displacement of bedrock extending almost completely across the river bed. The upstream bed is a few meters higher than the downstream bed. Thus, during the low water levels present at the time of the fall upstream migration of broad whitefish, most of the flow of the Mackenzie River occurs through a narrow chute near the east bank of the river. The high flow associated with this feature likely prevents any upstream movement of migratory fish at this time of year. Effectively, from the perspective of the fish and for fishery management this barrier delimits the broad whitefish in the lower portion of the Mackenzie River (Reist and Chang-Kue, 1997). Therefore, broad whitefish in the lower Mackenzie River likely comprise a group of fish separate from any found upstream of this area (Reist, 1997).

4. CUMULATIVE EFFECTS AND CLIMATE CHANGE

Generally, warmer temperatures and increased precipitation (from climate change) are predicted with the amount being greater in the winter than the summer. Such changes if realized to the degree predicted will have profound effects on the fish populations in the Mackenzie River. These changes include: 1) alteration of the species of fish present in the lower Mackenzie River, with the loss of some and the northward colonization by others, 2) change in the production characteristics (growth, reproduction, etc.) of the fish species now present in the area, and 3) habitat changes and perhaps alteration of the structure of the aquatic ecosystems (e.g., change in food web pattern) (Reist 1997b).

Five general types of impacts may affect broad whitefish – exploitation, physical injury, contaminants, local habitat alteration, and global environmental change. These impacts result in effects at three levels: 1) the individual fish, 2) the biological population, and 3) the aquatic ecosystem. Several different types of impacts may also affect the same population – for example, contaminants and local environmental change may both cause the fish to expend energy to overcome their effects thus decreasing growth and reproductive rates. It is possible that multiple impacts on broad whitefish generate both additive (the net result of more than one impact is the addition of all the individual effects) and multiplicative (the net result of more than one impact is greater than the sum of the effects of all individual impacts) cumulative effects (Reist, 1997b). Conservative approaches to fisheries management, research into the effects of human activities on the fish population, and the establishment of effective monitoring programs are suggested as the appropriate strategies to assess cumulative impacts and help ensure the continued health of broad whitefish populations in the lower Mackenzie River (Reist, 1997b). Cumulative effects can also be defined as occurring when either a material, force or effect from a single source persistently occurs at a rate greater than can be dissipated by the recipient, or when two or more materials, forces or effects come together and produce a compounded result (Peterson et al. 1987).

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