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MEMORANDUM

TO: **Nechako Water Engagement Initiative Technical Working Group**

FROM: **Jennifer Carter, M.R.M., R.P.Bio., Susan Johnson, Ph.D., Rachel Chudnow, Ph.D., and Jayson Kurtz, R.P.Bio., Ecofish Research Ltd.**

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FILE: **1316-09**

RE: **Water Temperature Effects on Nechako River Resident Fish**

1. INTRODUCTION

During Main Table and Technical Working Group (TWG) meetings of the Nechako Water Engagement Initiative (WEI), concerns were raised about potential effects of water temperature on resident fish in the Nechako River. The TWG asked Ecofish Research Ltd (Ecofish) to review scientific studies and other information and summarize key factors with recommendations for WEI consideration on how Rio Tinto Alcan (RTA) operations affect resident fish through temperature effects in the Nechako River. This memo provides an overview of water temperature and resident species in the Nechako River, describes how water temperature affects resident fish, reviews scientific literature on temperature tolerances of species and life history stages of concern, and discusses how this information can inform water management decisions to minimize the negative effects of temperature on resident species in the Nechako River.

1. BACKGROUND

1.1. Nechako River Water Temperature

The Nechako River originates in the Coastal Mountains and has a hydrograph dominated by snowmelt with a spring freshet (Hernández-Henríquez *et al.* 2017). Water temperature in the river is well studied with respect to the effects of Rio Tinto water impoundment and controlled release (see Section 1.3). However, natural water temperature variation in the Nechako River is less understood and like other water bodies in the region is subject to a variety of influences including resource development, land use, and climate change (Carter and Kurtz 2022). A recent study on climate change impacts in the Fraser River Basin showed that the frequency of temperature extremes in the Nechako River watershed has increased in recent decades and Nechako River natural water temperatures often exceed 18°C and sometimes 20°C (Islam *et al.* 2019). Additionally, reduction in riparian shading resulting from land clearing for agricultural and residential development and forestry has been linked to increased water temperatures in the Nechako River (Beschta 1997). Extreme water temperatures have a variety of impacts on fish physiology and behaviour and can vary by fish species and life stage.

1.2. Fish Temperature Tolerance

The body temperature of fish is a direct function of water temperature because they cannot produce significant metabolic heat (Beitinger *et al.* 2000). Therefore, water temperature regulates biochemical and physiological processes and behavioural activities of fish. Temperature tolerances in fish have been widely studied through laboratory and field studies for nearly a century (e.g., Fry *et al.* 1942; Brett 1971; Coutant 1977; Sullivan *et al.* 2000; Beitinger and Lutterschmidt 2011). Temperature tolerances are quantified in a variety of ways and are often described as an organism's lower and upper thermal limits that may vary by exposure time, species, and life stage (e.g., Beitinger and Lutterschmidt 2011; Sullivan *et al.* 2000). Lethal effects are the most dramatic of temperature effects to fish and are defined as mortality that arises from acute temperature exposure (<96 hours), while sublethal effects not resulting in mortality are associated with chronic temperature exposure (weeks to months) and include changes in growth, competitive interactions, behaviour and/or disease prevalence that can lead to reduced survival (Sullivan *et al.* 2000; Beitinger and Lutterschmidt 2011). Optimal temperatures are generally described as preferred temperature ranges where fish exhibit normal physiological functions and behavioural patterns and lie between the lower and upper thermal limit range. Sub-optimal water temperatures are outside of this range and require physiological adjustment or behaviour change for fish to tolerate these temperatures (Sullivan *et al.* 2000). Thermal limits and optimal temperatures can be inferred based on fish distribution (i.e., the rarity or abundance of fish observed in habitats at given temperature) or measured directly from physiological studies (Ford *et al.* 1995; Coker *et al.* 2001; Roberge *et al.* 2002). Thus, thermal protection criteria for fish are usually based on a combination of criteria derived from laboratory experiments (optimum growth temperatures and upper thermal tolerance for survival) and field distributional data (McCullough *et al.* 2001).

1.3. Summer Temperature Management Program

Management for warm water temperature through thermal protection criteria in the Nechako River has been a consideration for migrating salmon. In the 1980s, the Department of Fisheries and Oceans and others expressed concern about negative effects on Sockeye Salmon from warm river temperatures due to low flows, and starting in 1987, Rio Tinto was obliged to reduce temperature-related risks to returning Sockeye Salmon by releasing cooling water flows during the spawning migration period in July and August (NFCP 2016). At that time, a threshold of 20°C was considered the highest daily mean temperature tolerated for risk of pre-spawn mortality for migrating adult Sockeye Salmon (Macdonald *et al.* 2012); thus, this water temperature has been designated as a target for management through the summer beginning in July. However, temperature tolerances for resident fish that may utilize the Nechako River throughout the year have not been considered in this management decision. An overview of the effects of temperature on resident fish and summary of temperature tolerances for resident species and life histories is presented in this report for consideration in water temperature management in the Nechako River.

1.4. Resident Fish

For this and other work under the WEI, all fish species within the Nechako watershed excluding White Sturgeon and anadromous salmon[1] are considered resident fish (Chudnow and Kurtz 2022). The timing and duration of resident fish habitat use within the Nechako watershed varies between species. For example, some species complete all life cycle stages within the Nechako watershed by necessity (e.g., Lake Trout in the Cheslatta Lake, isolated by fish barriers), while others migrate between the Nechako watershed and other systems to complete specific life history stages (e.g., Bull Trout, Pacific Lamprey).

The Nechako River provides habitats for a diverse assemblage of 18 resident fish species including burbot (Lotidae; 1 species), lamprey (Petromyzontidae; 1 species), minnows (Cyprinidae; 7 species), salmonids (Salmonidae; 3 species), sculpins (Cottidae; 2 species), and suckers (Catostomidae; 4 species) (Table 1). Chudnow *et al.* (2022a) provides a summary of the native distribution, conservation status, population trends, life histories, and socio-economic and social context for each of these resident fish species assemblages.

Table 1. Nechako River resident fish species.

Family	Common Name	Scientific Name
Burbots	Burbot	*Lota lota*
Lampreys	Pacific Lamprey	*Entosphenus tridentatus*
Minnows	Brassy Minnow	*Hybognathus hankinsoni*
	Lake Chub	*Couesius plumbeus*
	Leopard Dace	*Rhinichthys falcatus*
	Longnose Dace	*Rhinichthys cataractae*
	Northern Pikeminnow	*Ptychocheilus oregonensis*
	Peamouth Chub	*Mylocheilus caurinus*
	Redside Shiner	*Richardsonius balteatus*
Salmonids	Bull Trout	*Salvelinus confluentus*
	Mountain Whitefish	*Prosopium williamsoni*
	Rainbow Trout	*Oncorhynchus mykiss*
Sculpins	Prickly Sculpin	*Cottus asper*
	Slimy Sculpin	*Cottus cognatus*
Suckers	Bridgelip Sucker	*Catostomus columbianus*
	Largescale Sucker	*Catostomus macrocheilus*
	Longnose Sucker	*Catostomus catostomus*
	White Sucker	*Catostomus commersonii*

[1] White Sturgeon and anadromous salmon are present in the watershed. These species are discussed in Chudnow *et al.* (2022a; White Sturgeon), Carter and Kurtz (2022; Pacific Salmon), and Chudnow *et al.* (2022b; Chinook Salmon).

1.5. Potential Effects of Water Temperature on Nechako River Resident Fish

Warm water temperatures have the potential to cause a variety of effects to the various life stages of the resident fish species in the Nechako River. For instance, fish use water temperature as a physiological cue to initiate maturation, ovulation in females, and sperm development in males and extreme water temperatures can delay or halt this process (e.g., Davies and Bromage 2002; Boryshpolets *et al.* 2009). Water temperature is also integral in initiating spawning behaviors and can potentially affect timing of spawning migrations and initiation of nest digging (Dodge and Maccrimmon 1971; Warren *et al.* 2012). Likewise, embryos are particularly sensitive to water temperature with thermal tolerances up to 8 °C lower than other life stages (Dahlke *et al.* 2020). Increasing water temperatures increases oxygen demand and can reduce egg viability (Martin *et al.* 2020) and survival for eggs and larvae (Weber *et al.* 2016). Additionally, water temperature plays a role in growth rate, rates of feeding, and other physiological processes for both juvenile and adult fish (e.g., Elliot 1975; Lobon-Cervia and Rincon 1998; Myrick and Cech 2000).

2. METHODS

2.1. Temperature Tolerance Literature Review

A literature review was completed to identify temperature tolerances for species and life histories in the Nechako River to evaluate potential temperature targets for water management decisions. This study is interested in effects of warm water on resident fish, thus, the review of literature focused on the tolerance range from the optimal temperature to the upper thermal limit. Because temperature targets for management should be below temperatures that result in lethal effects and resident fish are susceptible to chronic temperature exposure, temperature targets for management decisions are evaluated based on suboptimal temperatures, which we have considered being the lowest known temperature in the upper thermal limit range associated with sublethal effects or, where data are limited, the upper thermal limit reported based on observed habitat use (as described in Section 1.2).

2.2. Species/Life History Selected for Temperature Management

Completing a detailed review of fish temperature tolerance for all 17 resident species in the Nechako River is complex; therefore, criteria was developed to focus on species and life history stages that are high priority for management. Three questions related to management on a provincial and federal level, locally within the Nechako area, as well as specifically to the WEI process were developed to characterize whether a species is considered high priority for management.

1. Is the species listed provincially or federally as a species of concern?
2. Is the species considered highly important socially, culturally, or economically?
3. Has the Main Table identified the species as a concern?

If the answer to any of these questions is yes, the species is considered a high priority for management and temperature targets are evaluated and discussed in detail. If the answer to all questions is no, the species is considered a low priority for management and although temperature tolerances are presented, they are not discussed in detail (Figure 2).

For species considered high priority for management, temperature targets were evaluated for life stages that are most likely to be affected by suboptimal temperatures in the Nechako River. Water temperatures are warmest in the Nechako River between the months of June and September (Figure 1), which is defined hereafter as the summer period. The periodicity of each life stage for Nechako River resident fish species was evaluated during the summer period. Those life stages that overlap are considered at risk of temperature effects and temperature targets are evaluated for water management decisions. Life stages are defined as adults (non-spawning adults), spawning (spawning adults), incubation (eggs), and juveniles (fry emergence and rearing).

Below we consider which life history stages are likely to be present in the Nechako River for each high priority species during the summer period. A brief review of temperature tolerances reported in the literature for those life history stages is provided, and the lowest suboptimal temperature reported for the species is determined for water temperature management.

Figure 1. Observed (black) and simulated (pink) daily mean water temperatures in the Nechako River watershed (1950-2015). Shading represents daily water temperatures in individual years for 5-95% ranges. From (Islam *et al.* 2019; supplementary figure S2).

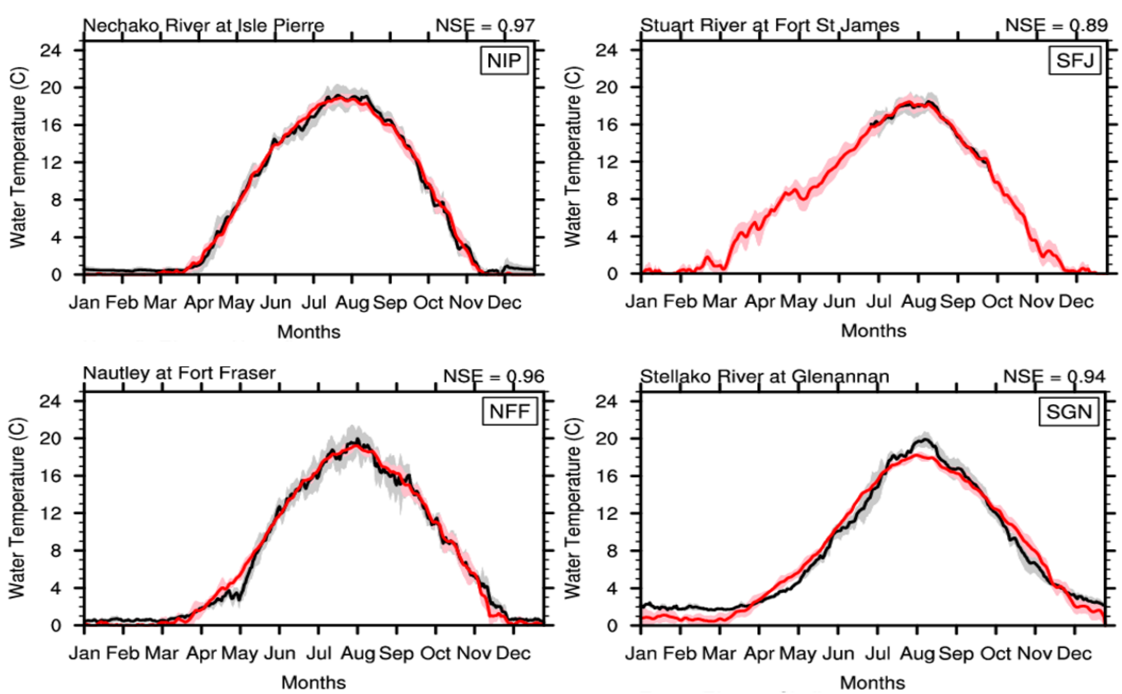
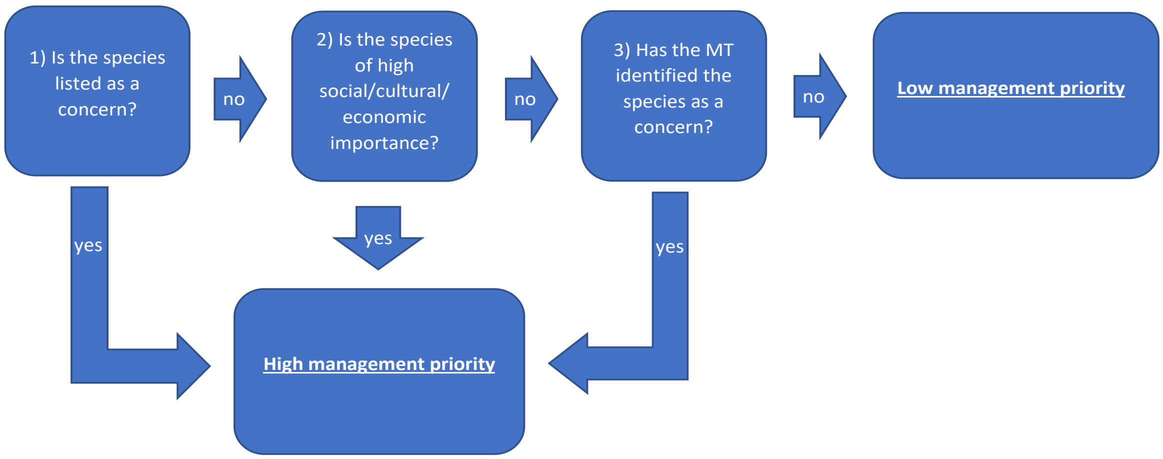


Figure 2. Flow diagram to show how species were grouped into management priority classifications.



3. RESULTS

Water temperature tolerances for resident fish species are summarized in Table 2 and are described for the species of management priority in the subsections below.

Table 2. Water temperature tolerance for the resident fish species in the Nechako River.

Family	Species	Scientific Name	Temperature Preference / Tolerance[1]				References
			Spawning	Incubation	Rearing	Adult	
Burbots (Lotidae)	Burbot	*Lota lota*	**Opt**: 0.6 - 1.7 °C **SOpt**: > 4 °C	**Opt**: 2 - 5 °C **SOpt**: > 6 °C	Unknown	**Opt**: 15.6 - 18.3 °C **SOpt**: > 23.3 °C	Scott and Crossman 1973; Roberge 2002; McPhail 2007
Lampreys (Petromyzontidae)	Pacific Lamprey	*Entosphenus tridentatus*	**SOpt**: > 20 °C	**Opt**: 10 - 18 °C **SOpt**: > 22 °C	**Lethal**: 27.7 - 28.5 °C	**SOpt**: > 20 °C	Meeuwig *et al.* 2005; Uh and Whitesel 2016
Minnows (Cyprinidae)	Brassy Minnow	*Hybognathus hankinsoni*	**Opt**: 16 - 17 °C	**Opt**: 18 ° C	**Opt**: 15.7 - 23.5 °C	**SOpt**: > 35.5 °C	Coker *et al.* 2001; Roberge *et al.* 2002; Scheurer *et al.* 2003; McPhail 2007; Radford and Sullivan 2014
Minnows (Cyprinidae)	Lake Chub	*Couesius plumbeus*	**Opt**: 10 - 19 °C	**Opt**: 8 - 19 °C	Unknown	**SOpt**: 25 - 30 °C	Brown *et al.* 1970; Coker *et al.* 2001; Roberge *et al.* 2002; McPhail 2007; Darveau *et al.* 2012
Minnows (Cyprinidae)	Leopard Dace	*Rhinichthys falcatus*	Unknown	Unknown	**Opt**: 21.2 °C	**Opt**: 15 - 19 °C **SOpt**: 23 - 28 °C	Coker *et al.* 2001; Roberge *et al.* 2002; McPhail 2007; Zimmerman 2009
Minnows (Cyprinidae)	Longnose Dace	*Rhinichthys cataractae*	**Opt**: 11.7 °C	**Opt**: 15.6 °C	Unknown	**Opt**: 15 - 20.5 °C **SOpt**: 28 - 31.4 °C	Black 1953; Coker *et al.* 2001; Roberge *et al.* 2002; Hasnain *et al.* 2010
Minnows (Cyprinidae)	Northern Pikeminnow	*Ptychocheilus oregonensis*	**Opt**: 12 - 18 °C	**Opt**: > 18 °C	**Opt**: 20 - 23 °C	**Opt**: 21.4 - 29°C	Black 1953; Roberge *et al.* 2002; FERC 2011
Minnows (Cyprinidae)	Peamouth Chub	*Mylocheilus caurinus*	**Opt**: 10 - 15 °C	**Opt**: < 12 °C	**Opt**: < 21.3 °C	**SOpt**: < 27 °C	Schultz 1935; Black 1953; Porter and Rosenfeld 1999; Coker *et al.* 2001; Roberge *et al.* 2002; FERC 2011
Minnows (Cyprinidae)	Redside Shiner	*Richardsonius balteatus*	**Opt**: 14.5 - 18 °C	**Opt**: 21 - 23 °C	**Opt**: 12.5 - 20 °C **SOpt**: 24 °C	**SOpt**: > 25 °C	Black 1953; Porter and Rosenfeld 1999; Coker *et al.* 2001; Roberge *et al.* 2002; FERC 2011
Salmonids (Salmonidae)	Bull Trout	*Salvelinus confluentus*	**Opt**: 2 - 9 °C **SOpt**: > 9 °C	**Opt**: 2 - 4 °C **SOpt**: < 8 °C	**Opt**: 12 - 14 °C **SOpt**: 16 - 22 °C **Lethal**: 20.9 °C	**Opt**: < 15 °C **SOpt**: > 18 °C	McPhail and Murray 1979; Ford *et al.* 1995; Hillman and Essig 1998; Selong *et al.* 2001; FERC 2011
Salmonids (Salmonidae)	Mountain Whitefish	*Prosopium williamsoni*	**Opt**: 4.5 - 7 °C	**Opt**: 6 - 8.8 °C **SOpt**: > 9 °C	**Opt**: 8.8 - 12 °C **SOpt**: 17.1 - 21.6 °C	**Opt**: 9.6 - 17.7 °C **SOpt**: > 22 °C	Rajagopal 1979; Ford *et al.* 1995; McPhail and Troffe 1998; Coker *et al.* 2001; Quinn *et al. 2009;* Brinkman *et al.* 2013; FERC 2011; Schmidt *et al.* 2019
Salmonids (Salmonidae)	Rainbow Trout	*Oncorhynchus mykiss*	**Opt**: 10 - 15.5 °C	**Opt**: 10 - 12 °C **SOpt**: > 18 °C	**Opt**: 10 - 18 °C **SOpt**: > 22 °C	**Opt**: 12 - 18 °C **SOpt**: > 18 °C	Scott and Crossman 1973; Humpesch 1985; Ford *et al.* 1995; Coker *et al.* 2001; Bear *et al.* 2007; FERC 2011
Sculpins (Cottidae)	Prickly Sculpin	*Cottus asper*	**Opt**: 8 - 13 °C	Unknown	**Opt**: 13 - 18 °C **SOpt**: > 21 °C	**SOpt**: > 24 °C	Black 1953; EBA 2006; Porter and Rosenfeld 1999; Coker *et al.* 2001; Roberge *et al.* 2002; McPhail 2007; Tabor *et al.* 2007; FERC 2011
Sculpins (Cottidae)	Slimy Sculpin	*Cottus cognatus*	**Opt**: 8 - 10°C	**Opt**: 7.7 °C	**Opt**: 13 - 18 °C **SOpt**: < 21 °C	**Opt**: 13 - 15 °C **SOpt**: 23 - 25 °C	Symons *et al.* 1975; Coker *et al.* 2001; Roberge *et al.* 2002; McPhail 2007; FERC 2011; Gray *et al.* 2018
Suckers (Catostomidae)	Bridgelip Sucker	*Catostomus columbianus*	**Opt**: 10 - 15 °C	Unknown	Unknown	**Opt**: 21.4 - 29 °C	Roberge *et al.* 2002
Suckers (Catostomidae)	Largescale Sucker	*Catostomus macrocheilus*	**Opt**: 7.5 - 15 °C	Unknown	**SOpt**: > 29 °C	**Opt**: 21.4 - 29 °C	Black 1953; Coker *et al.* 2001; Roberge *et al.* 2002; FERC 2011
Suckers (Catostomidae)	Longnose Sucker	*Catostomus catostomus*	**Opt**: 5 - 10 °C	**Opt**: 8 - 17 °C	**SOpt**: > 27 °C	**SOpt**: > 27 °C	Black 1953; Coker *et al.* 2001; Roberge *et al.* 2002; FERC 2011; Hasnain *et al.* 2010
Suckers (Catostomidae)	White Sucker	*Catostomus commersonii*	**Opt**: 10 - 12 °C	**Opt**: 10 - 16 °C	**Opt**: 19 - 26 °C	**Opt**: 23.4 - 25.5 °C **SOpt**: 27.8 - 31.6 °C	Koenst and Smith 1982; Corbett and Powles 1983; Coker *et al.* 2001; Roberge *et al.* 2002; Hasnain *et al.* 2010

[1] Opt = Optimum, SOpt = Sub - optimal. Temperature thresholds that are unknown are excluded.

3.1. Bull Trout

Bull Trout are considered a high priority for management because they have COSEWIC status of "Special Concern", are blue-listed provincially, and have high social importance (COSEWIC 2012; MOE 2021). Bull Trout in the upper Fraser and Nechako System are well studied relative to populations elsewhere. Not all life stages are believed to occur within the Nechako system nor are specific individuals typically present in the Nechako System year-round. Spawning activity and juvenile rearing is thought to be confined to tributaries of the upper Fraser River (Pillipow and Williamson 2004; Chudnow 2021). In fluvial populations, juveniles rear in natal tributaries for one to four years at which point they undergo a piscivorous shift and migrate downstream into larger river systems (Fraley and Shepard 1989; Rieman and McIntyre 1993). These sub-adults remain in riverine habitats until reaching sexual maturity between three to eight years of age (Fraley and Shepard 1989; Rieman and McIntyre 1993). Though data demonstrating use of the Nechako watershed by sub-adult Bull Trout is limited, it is probable that some individuals move into the Nechako watershed and may remain throughout summer to exploit foraging opportunities.

In addition, a subset of adult migrants appear to remain in the Nechako watershed throughout summer, reflective of skip-spawning behaviour (i.e., when individuals forgo spawning in a particular year; Rideout and Tomkiewicz 2011), a strategy that has been observed in Bull Trout populations throughout the species range (Bahr and Shrimpton 2004; Fraley and Shepard 1989; Hogen and Scarnecchia 2006; Johnston and Post 2009; Chudnow 2021). Due to similarities in foraging and overwintering behaviour expected between sub-adult and adult Bull Trout, and lack of quantitative information regarding the temperature optimum or critical thresholds for the sub-adult life stage, both sub-adult and adult Bull Trout life stages are considered together. Therefore, temperature targets were evaluated and are presented for the adult life stage only.

Bull Trout are a highly temperature sensitive species and have one of the lowest thermal tolerances of any North American salmonid (COSEWIC 2012; Haas 2001; Selong *et al.* 2001). The species requires cold water to fulfil all life stages. There are no temperature-related studies specific to Bull Trout using the Nechako River; however, there are several temperature-related studies for the species in general. Adult Bull Trout are observed over a relatively broad temperature range and are usually found at temperatures <18°C with a temperature optimum <15°C (Dunham *et al.* 2003; Fraley and Shepard 1989; Hillman and Essig 1998; Haas 2001; Gutowsky *et al.* 2017). As only sub-adult and adult life stages are known to be present in the Nechako System, based on the available literature, we consider >18°C as the suboptimal temperature for Bull Trout.

3.2. Rainbow Trout

Various discussions at WEI Main Table and TWG meetings suggest Rainbow Trout have high social and economic importance in the Nechako River watershed and are therefore considered a high priority for management. Rainbow Trout in the Nechako River are not well studied but it is known that adults migrate from the Nechako River to tributaries to spawn in the spring (Abelson and Slaney 1990). Although spawning, incubation, and fry emergence occurs in tributaries, juvenile fish could move into the Nechako River during the summer period to rear. Thus, temperature targets for juvenile and adult life stages were evaluated for water management decisions.

Thermal tolerances for Rainbow Trout are generally well studied; however, there are no temperature-related studies specific to the Nechako River. The optimal temperature for rearing Rainbow Trout is generally reported to be between 10°C and 18°C (Ford *et al.* 1995; Oliver and Fidler 2001), and chronic exposure of suboptimal temperatures >22°C have been shown to decrease juvenile survival (Bear *et al.* 2007). Thermal tolerance data are limited for non-spawning adults. Optimal temperatures for Rainbow Trout adults are reported to be between 12°C and 18°C, with suboptimal temperatures >18°C based on observed habitat use (Raleigh *et al.* 1984). For both juvenile and adult life stages >18°C is the lowest suboptimal temperature for Rainbow Trout.

3.3. Mountain Whitefish

Various discussions at WEI Main Table and TWG meetings suggest Mountain Whitefish have high social importance in the Nechako River watershed and are therefore considered a high priority for management. Mountain Whitefish in the Nechako River are not well studied but it is generally known that spawning occurs in the fall, fry emergence occurs up to early June and rearing occurs year-round. Therefore, temperature targets were evaluated for juveniles and adults.

Data on thermal tolerances for Mountain Whitefish are limited, and there are no temperature-related studies specific to the Nechako River. One laboratory study recommends a chronic temperature criterion of 17.1°C, which was reported as the upper 95% confidence limit of the temperature for maximum growth (Brinkman *et al.* 2013). Although other literature suggests suboptimal temperatures as high as 21.6 °C, a conservative suboptimal temperature of >17°C is considered herein for juveniles. One laboratory study investigating temperature preferences for Mountain Whitefish between fall and spring found 17.7°C was the highest preferred temperature, which occurred prior to spawning in the fall (Ihnet and Bulckley 1985). However, summer temperature preferences were not measured in this study. Although Mountain Whitefish are observed in water above 17.7°C during the summer (Ford *et al.* 1995; Quinn *et al.* 2009), it is unclear what temperature threshold initiates negative effects. Therefore, a suboptimal temperature of 17°C is considered the lowest suboptimal temperature for both juvenile and adult life stages.

4. DISCUSSION

4.1. Scientific Certainty

The wide variety of studies on temperature tolerances for fish published in the historical and contemporary literature introduce some uncertainty when establishing a temperature threshold that applies to specific life history stages, species, and habitats. For instance, studies completed in a laboratory have very controlled conditions that are not representative of natural environmental conditions whereas field studies are influenced by a variety of factors not related to temperature that may influence observational results. Furthermore, differences in laboratory methods and metrics may influence temperature tolerance results. For example, water temperature tolerances are reported for a variety of biological and behavioural metrics (e.g., swim speed, growth rate, feeding rate, habitat preferences) and each variable may respond differently to temperature (Suochon and Tissot 2012). Additionally, the rate of temperature change applied in a laboratory experiment can influence results because some degree of acclimation to suboptimal temperatures can occur that can increase temperature tolerances for some fish (Beitinger and Lutterschmidt 2011).

The literature review conducted here found temperature-related research specific to the Nechako River to be highly limited for most resident fish species, and limited data available for adult life stages more broadly. As a result, adaptations to the temperature regime of the Nechako River may not be represented within the thermal tolerances identified, and there is uncertainty in the suboptimal temperatures for adult life stages for Bull Trout, Rainbow Trout, and Mountain Whitefish reported herein. However, more data were available for juvenile life stages, and in most cases the literature identified juveniles as more temperature sensitive than adults. As a result, the presence of more certain data for this life stage for all species for which this life stage is present in the river (i.e., Rainbow Trout and Mountain Whitefish) is valuable for providing conservative temperature target recommendations for species where information for other life stages is limiting.

4.2. Potential PMs

Performance measures are metrics for evaluating how changes in flow affect a particular interest or issue. The following text describes favorable flow scenarios, performance measures, and/or objectives for the key issues discussed earlier in this document. This information is provided for consideration by the WEI Technical Working Group and Main Table to support the structured decision-making process. It is important to recognize that the draft performance measures etc. presented here might be revised, replaced, or ignored depending on the specific needs and interest of the WEI.

Temperature tolerance data available for resident fish species considered a high priority for management and their respective life stages of concern is sufficient to recommend a temperature target for management decisions. The lowest suboptimal temperature reported across fish species and life stages of concern was >17.1°C. Therefore, a conservative limit of 17°C to 18°C would be protective of all species and life stages, with 18°C potentially having slightly less protection for Mountain Whitefish juveniles. Because we are concerned with negative effects of chronic temperature exposure, it is recommended that the performance measure established to measure how well a temperature target is being achieved be calculated based on mean weekly maximum temperatures (MWMT). MWMT is recommended over mean weekly average temperatures (MWAT) because MWAT averages out peak temperatures that may exceed lethal limits, which could put sensitive species at risk (Oliver and Fidler 2001). Furthermore, MWMT is consistent with many provincial and federal guidelines for water temperature (Oliver and Fidler 2001; ODEQ 1996; USFS 1995).

4.3. Thermal Regime and Operational Influence

It is important to consider that optimal temperatures for fish are often exceeded in nature. As discussed in Section 1.1 rivers in the BC Interior are frequently at or near 20°C and the frequency of temperature extremes has increased in recent decades in the Nechako River and more broadly in the Nechako watershed (Islam *et al.* 2019). Although we may seek to reduce the consecutive weeks fish experience thermal extremes, it may not be natural to eliminate them completely. Furthermore, this highlights the complexity of managing a river's temperature in a warming climate.

A target thermal regime for the Nechako River that may be beneficial for fish will greatly influence operations. The large amount of water release necessary to cool water temperatures downstream is a trade-off for other management objectives, and more water is required to cool downstream temperatures as temperature targets decrease (Triton 2008). Therefore, the temperature threshold must be justified and feasible from an operational perspective (i.e., to still have water left over for other uses). Nonetheless, changes to the current STMP that consider resident fish species may be feasible and may provide benefits during warm years.

5. CONCLUSION/CLOSURE

Ecofish was asked to support the WEI by reviewing the current scientific knowledge about effects of warm water on resident fish in the Nechako River. The following key points summarize our current understanding of water temperature effects and tolerances for resident species and life histories of concern:

- Thermal tolerances in the literature may vary based on the type of study, methods, and response variables measured.
- Temperature-related research specific to the Nechako River is highly limited for most resident fish species.
- Temperature-related research is more definitive for juvenile life stages, which are generally more sensitive to temperature than non-spawning adults.
- The lowest sub-optimal temperature across all resident species and life histories of concern was 18°C with the exception of Mountain Whitefish juveniles, which was 17.1°C.

Yours truly,

Ecofish Research Ltd.

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