Ecofish Research Ltd.
600 Comox Rd.
Courtenay, B.C. V9N 3P6

Phone: 250-334-3042
Fax: 250-897-1742
info@ecofishresearch.com
www.ecofishresearch.com

MEMORANDUM

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

FROM: **Rachel Chudnow, Ph.D., William Twardek, Ph.D., and Adam Lewis, M.Sc., R.P.Bio., Ecofish Research Ltd.**

DATE: **March 9, 2023**

FILE: **1316-09**

RE: **Nechako River Resident Fish Habitat – V2**

1. INTRODUCTION

During Nechako Water Engagement initiative (WEI) Main Table and Technical Working Group meetings, concerns were raised about potential effects of Rio Tinto (Alcan; RTA) operations on fish populations in the Nechako system[1]. One priority is to better understand how changes in flow affect resident fish habitats in the Nechako River. The Technical Working Group (TWG) asked Ecofish Research Ltd. (Ecofish) to review literature and summarize the status of current knowledge regarding Nechako River resident fish species, with focus on informing how changes in flow may affect rearing and overwintering habitats (i.e., issues #25 and #26) and develop recommendations for WEI consideration. This memo provides an overview of flow related impacts on resident fish and offers practicable recommendations to inform water management decisions and minimize the negative effects of operational flows on these species in the Nechako River.

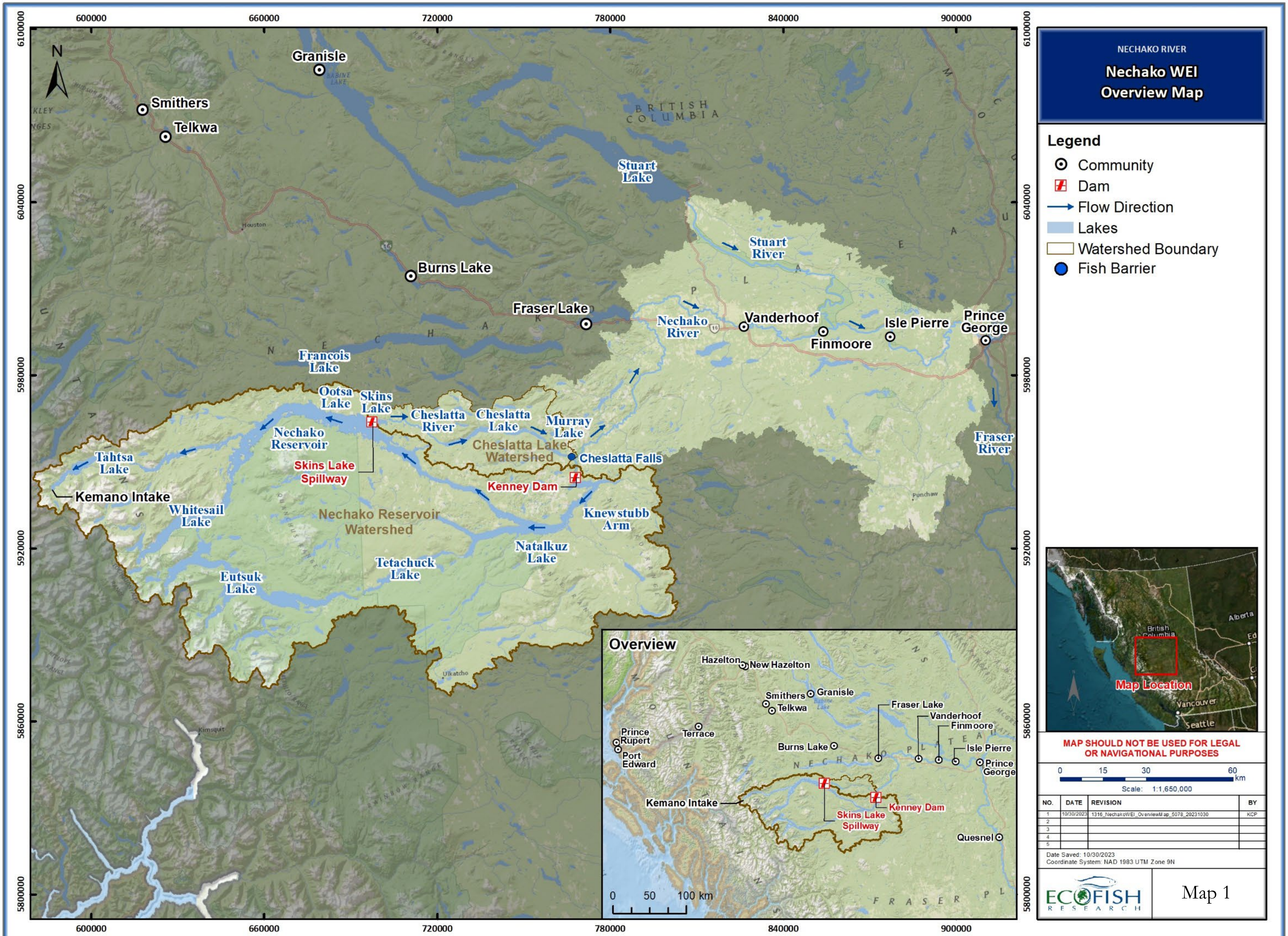
2. BACKGROUND

2.1. Geographic Scope

The Nechako Reservoir is located approximately 200 km west of Prince George, British Columbia and was created to provide water for Rio Tinto Alcan's Kemano Hydroelectric Project, constructed in the 1950s to provide energy to operate an aluminium smelter in Kitimat, BC. A hydrological overview of the Nechako River Basin is provided by Beel *et al.* (2022), summarized here. The reservoir was formed by the construction of the Kenney Dam on the Nechako River (at the east end of the reservoir), which inundated a chain of six major lake and river systems (Ootsa, Whitesail, Knewstubb, Tetachuck, Natalkuz, and Tahtsa, ~420 km total length). The Nechako Reservoir is ~910 km^2 with a normal annual drawdown of ~3 m (10 ft); low water is in late spring, and high water occurs in late summer.

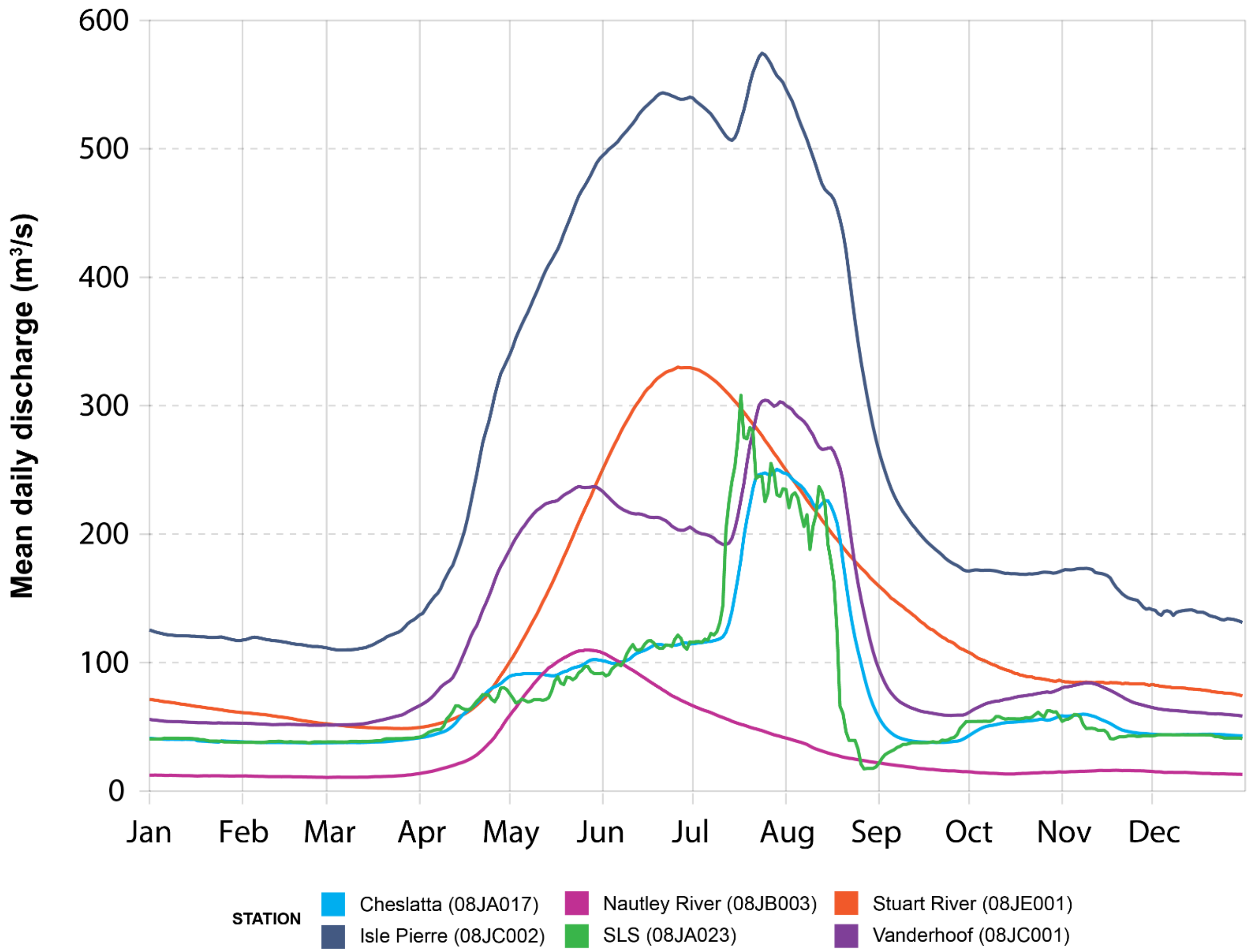
[1] For the purpose of this memo the Nechako system is defined as the area including the Nechako Reservoir, Cheslatta River watershed, and Nechako River watershed.

All flow from the Nechako Reservoir to the Nechako River is currently via Skins Lake Spillway, which directs flow into the Cheslatta watershed, from where water flows into the Nechako River, downstream of Cheslatta Falls, located 9 km downstream of Kenney Dam (Map 1). The Nechako Reservoir provides the majority of flow in the upper Nechako River (there is minimal local inflow); here, flow is reduced to ~30% of pre-dam conditions and mean flow ranges from ~40 to 240 m^3/s (Figure 1). The Nautley River (~95 km downstream of the dam) and local inflows together make moderate contributions and mean flow in the Nechako River at Vanderhoof (~150 km downstream of the dam) ranges from ~65 m^3/s to 270 m^3/s. The Stuart River contributes significant inflow and by Isle Pierre (~215 km downstream of the dam), mean flows range from ~120 m^3/s to 560 m^3/s. The Nechako River flows into the Fraser River at Prince George ~275 km downstream of the dam. The Nechako River has a hydrograph dominated by snowmelt with a summer freshet.



Path: M:\Projects-Active\1316\MXD\1316_NechakoWEI_OverviewMap_5078_20231030.mxd

Figure 1. **Time series of Nechako River discharge at various sites throughout the river.**



2.2. Resident Fish Definition

For this and other work under the WEI, all fish species within the Nechako watershed excluding White Sturgeon and anadromous salmon[2] are considered resident fish. 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*

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

2.3. Current Level of Knowledge

Resident fish serve important ecological roles. However, river specific information is highly limited or absent for all species excluding some socio-economically and culturally important salmonids (i.e., Bull Trout and Rainbow Trout; Ableson 1985, 1990; Tredger *et al.* 1985; Slaney 1986; Ableson and Slaney 1990; Chudnow *et al.* 2022a). Literature review identified only one study that occurred prior to Nechako Reservoir impoundment and provided reference to resident species (Lyons and Larkin 1952). Post-construction research including resident fish species has generally been limited to fish presence or habitat quantity and quality reconnaissance surveys, with a subset of reporting including additional demographic information (e.g., lengths, weights, ages). No directed studies investigating population structure, abundance trends, local distribution, movements, or life histories were identified in documents reviewed for most species. As a result of data limitations, descriptions of the life history strategies, habitat use, and periodicity for all species excluding Bull Trout and Rainbow Trout is approximated using available literature for other systems.

2.4. Life Histories

The majority of Nechako River resident fish species are broadly distributed across both the province of British Columbia and within the Nechako system (i.e., most species found in four or more of the province's seven zoogeographic zones; McPhail and Carveth 1993; Chudnow *et al.* 2022a.). Only three species, Bull Trout (*Salvelinus confluentus*), Burbot (*Lota lota*), and Pacific Lamprey (*Entosphenus tridentatus*), have distributions within the Nechako system that are restricted solely to the Nechako River, though these species are found extensively across the province of British Columbia (Chudnow *et al.* 2022a).

Resident species vary significantly in their life history strategies, habitat requirements, and movement patterns. The majority of species are spring spawning (e.g., minnows, Pacific Lamprey, Rainbow Trout, and suckers), while Bull Trout and Mountain Whitefish spawn in fall, and Burbot spawn in winter (Scott and Crossman 1973; Roberge *et al.* 2002; McPhail 2007). Most species are resident in the Nechako River year-round (e.g., most minnows, sculpins, and suckers). However, some species are known to leave river mainstems and migrate to adjacent tributary habitats to spawn (e.g., Lake and Peamouth chubs, Mountain Whitefish, Rainbow Trout and a subset of Largescale, Longnose, and White sucker populations; Scott and Crossman 1973; McPhail 2007). Others are only present in the Nechako River seasonally. Bull Trout make long distance spawning migrations to upper Fraser River tributaries (i.e., > 300 km; Chudnow 2021; Taylor *et al.* 2021). While Nechako River Pacific Lamprey are believed to be anadromous, spawning and rearing within the Nechako River before out-migrating to the ocean, returning to the Nechako River at approximately age 5+ to spawn (Scott and Crossman 1973; Hart and Clemens 1988; McPhail 2007). Pacific Lamprey are also the only resident species considered here that are known to have semelparous populations (i.e., die following spawning; McPhail 2007). Though in some coastal Pacific Lamprey populations substantial numbers of adults survive, and some may out migrate to marine habitats and may spawn a second time (McPhail 2007), it is not known if any proportion of the Nechako River Pacific Lamprey population repeat spawn.

2.5. Nechako River Distribution and Habitat Use

As stated in Section 2.3 above, Nechako River specific distribution and habitat use data is highly limited or absent for most resident fish species. Here, discussion is limited to those species for which this information is available (i.e., Bull Trout and Rainbow Trout). For all other species, life stage specific habitat use is described in Appendix A using available information from across the species range. Generally, non-salmonid resident fish juveniles rear in shallow, low velocity areas with abundant vegetative cover and adult rearing occurs primarily in low velocity areas (excluding longnose dace and slimy sculpin; Scott and Crossman 1973; Roberge *et al.* 2002; McPhail 2007; Chudnow *et al.* 2022a.). In contrast, resident salmonid species generally rear in tributaries within shallow, low velocity stream margins, with adult rearing in higher velocity riffles, runs, and pools with adjacent cover (Scott and Crossman 1973; Roberge *et al.* 2002; McPhail 2007; Chudnow *et al.* 2022a.). Most salmonid and non-salmonid species overwinter in deep water with available cover (e.g., pools; Scott and Crossman 1973; Roberge *et al.* 2002; McPhail 2007; Chudnow *et al.* 2022a.).

2.5.1. Bull Trout

Past research has not identified the presence of suitable spawning habitat to support resident populations of Bull Trout in the Nechako River (ARC Environmental Ltd. 1998; Chudnow 2021). Instead, best available information suggests that Bull Trout present within the Nechako River are sub-adult and adult fluvial migrants (Chudnow 2021; Taylor *et al.* 2021). The river has been identified as important overwintering and foraging habitat for a population complex of Bull Trout that spawn and rear in tributaries of the upper Fraser River (Chudnow 2021; Taylor *et al.* 2021). In fall, Bull Trout distribute broadly throughout both the Stuart and Nechako rivers and, in the Nechako, individuals have been observed from the river's confluence with the Fraser River at Prince George to upstream of its confluence with the Nautley River. Individuals are believed to be relatively sedentary overwinter, using deep pools and areas of groundwater input to avoid ice and for protection from both terrestrial and avian predators (Bahr and Shrimpton 2004; Schoby and Keeley 2011).

In spring and early summer (i.e., in the period surrounding freshet and Pacific salmon juvenile dispersal events), Bull Trout redistribute throughout the Nechako and Stuart rivers and are known to prey on out-migrating juvenile Chinook and Sockeye Salmon (Brown 1995; Chudnow 2021). Most Bull Trout out-migrate from the Nechako River in late summer and early fall to habitats in the mainstem Fraser River and associated spawning tributaries, before returning to the Nechako River in late fall to overwinter (Pillipow and Williamson 2004; Chudnow 2021; Taylor *et al.* 2021). It also appears that a proportion of the overwintering population remain in the Nechako River throughout summer (composed of skip-spawners[3] and sub-adults that have not yet reached sexual maturity). However, evidence of this is limited to a small number of telemetry detections throughout the summer months.

2.5.2. Rainbow Trout

Rainbow Trout are common throughout the Nechako River and their distribution and habitat use is dependent on life stage. In spring, adults out-migrate from the Nechako River to adjacent tributaries to spawn (Ableson and Slaney 1990). Most Nechako River tributaries are only seasonally wetted and/or have been identified as incapable of supporting spawning resident fish, including Rainbow Trout (Ableson and Slaney 1990). Important tributaries identified for Rainbow Trout production include Clear, Greer, Swanson, and Targe creeks (Tredger *et al.* 1985). Historically, the old Nechako Canyon was also important to Rainbow Trout production (Tredger *et al.* 1985). Following egg deposition, eggs incubate for several weeks, and fry rear almost exclusively in tributary streams (Envirocon Ltd. 1984). Parr appear to use habitat in both tributaries and the mainstem Nechako River, and it appears most juveniles reside in the upper reaches of the river in similar habitats to those used by juvenile Chinook salmon (Envirocon Ltd. 1984; see Chudnow *et al.* 2022c for juvenile Chinook habitat description). Both juveniles and adults are thought to use the Nechako River overwinter (Slaney *et al.* 1984).

2.6. Population Trends and Conservation Status

All resident fish species present within the Nechako River excluding Bull Trout have been assessed by the British Columbia provincial government as "Secure" / "Least Risk" and do not have federal conservation listing (BC MOE 2021a, 2021b). Bull Trout are listed in the province of British Columbia as a "Species of Special Concern" (BC MOE 2021a, 2021b). Literature review did not identify any quantitative monitoring or qualitative descriptions of population trends for any resident fish species in the Nechako River, excluding limited, short term quantitative monitoring for Bull Trout and Rainbow Trout.

Enumeration data suggest that Bull Trout and Rainbow Trout populations were severely depressed in the early 1980s. Low abundances were attributed to recreational fishing pressure in combination with reservoir impoundment and subsequent flow manipulation induced impacts on downstream habitats (Ableson 1985; Slaney 1986). Available data suggests Bull Trout abundance in the upper Fraser watershed is stable (Hagen and Decker 2011). The most recent abundance data for Bull Trout in the region exists for a single spawning population (Goat River[4]) assessed in the early 2000s (Pillipow and Williamson 2004). Rainbow Trout abundance increased following a recreational fishery

[3] Sexually mature individuals that forgo spawning in a particular year (Rideout and Tomkiewicz 2011).

[4] Goat River Bull Trout are known to use the Nechako River for wintering and foraging, and potentially sub-adult rearing (Pillipow and Williamson 2004; Chudnow 2021).

closure in 1983 and the standing stock increased three fold by 1986 (Slaney 1986). However, no contemporary abundance information is available for the species.

3. METHODS

A literature review and data search were conducted to locate all known information on the influence of flow on Nechako River resident fish since the commencement of Kemano hydroelectric operations and flow releases through the Skins Lake Spillway. Specific efforts were undertaken to review British Columbia Utilities Commission (BCUC), Fisheries and Oceans Canada (DFO), Kemano Completion Project (KCP), Nechako Environmental Fund (NEEF), and Nechako Fisheries Conservation Program (NFCP) reports. Information was collected via online searches including Google, Google Scholar, federal government databases (e.g., CSAS, DFO 2021; Federal Science Libraries Network, DFO 2022), and organizational databases (e.g., NEEF 2022; NFCP 2022; UNBC 2022), and review of scanned archival copies of government and organizational reports.

Few of these studies provided information directly pertaining to resident fish within the Nechako River, and information regarding the relationship between resident fish and flow was limited to a few sources (i.e., Slaney *et al.* 1984; Slaney 1987; Bruce 1991). For this reason, the following analysis incorporates available information collected across Nechako River fish species (i.e., including anadromous salmonids and White Sturgeon) with emphasis on resident salmonids, the resident species with the most available information to inform the analysis. For all species excluding those for which Nechako River specific data were available (i.e., Bull Trout and Rainbow Trout), we infer possible impacts of flow regulation based on known attributes of life histories and habitat use in other systems and by using salmonid species as a proxy.

4. RESULTS

4.1. Overview of Potential Pathways of Effect

All Nechako River resident fish species are greatly influenced by river flow (i.e., discharge), which has been called the 'master variable' for fish communities (Poff *et al.* 1997; Bergendorf 2002). Flow directly affects physical habitat through multiple mechanisms which govern the amount of physical space available for fish and their food and the quality of available habitats (i.e., by determining channel width, water depth, and velocity; Raleigh *et al.* 1986). The combination of water velocity and depth affect the 'fundamental ecological determinants' of temperature, dissolved oxygen, turbidity, and nutrient concentrations (Ryder and Kerr 1989). While in combination with meteorological conditions, flow also plays an important role in determining a river's winter hydrologic regime, contributing to ice formation processes and spring ice-break-up (Blachut 1988; Brown *et al.* 2011).

Temporal variation in flow is also a critical aspect shaping fish communities in riverine systems. Fish have evolved to natural variations in flow in ways that maximize their survival (Lytle and Poff 2004).

Seasonal flow variation is also a defining factor in determining fish life history event timing, physiology, behaviour, and adaptations to local conditions. For example, seasonal flow patterns directly impact reproductive strategies, feeding, and growth, and ultimately play a role in individual survival (Bergendorf 2002).

Hydropower operations can alter the natural flow regime both in terms of the magnitude of water released and the timing of releases (Trussart *et al.* 2002). Although some hydroelectric facilities release constant flow year-round, variation is common. Further, even when hydroelectric flow release is constant, meteorological conditions and unregulated downstream inflows can impose flow variability (Blachut 1988; Davie and Mitrovic 2014). The time scale over which flow fluctuates also has important consequences for fish. Peaking plant operations may negatively impact fish habitat by stranding individuals or their food or by displacing them from preferred habitats, thereby reducing growth and/or survival. While the same change in flow magnitude occurring over a longer time period may have no negative effects on fish or fish habitat.

4.2. Identified Pathways of Effect

As discussed above, information available to identify the effects of flow regulation on most resident fish species (i.e., excluding salmonids) is highly limited. Even when considering salmonid species, the majority of information regarding flow mediated impacts on Nechako River fish productivity was developed for anadromous species (i.e., Chinook and Sockeye Salmon) and White Sturgeon and to a significantly lesser extent for resident species (i.e., limited information exists only for Bull Trout and Rainbow Trout).

Here, we identify key pathways through which RTA operations could potentially effect Nechako River resident fish species as the result of flow alteration. Using available evidence gathered across all fish species present in the Nechako River (i.e., leveraging existing information including that available for Chinook Salmon and White Sturgeon), these can be summarized as flow-mediated changes to:

1. Hydraulically suitable habitat quality and availability;
2. River geomorphology and sediment processes (i.e., input and flushing);
3. Temperature effects (i.e., altered thermal regime);
4. Dissolved oxygen effects;
5. Community structure;
6. Food availability;
7. Winter hydraulic regime (i.e., icing processes); and
8. Tributaries and off-channel habitat access and habitat quality.

All of these factors could ultimately affect overall species production and impact the relative species abundances and fish community composition in the river. In Sections 4.2.1 to 4.2.8 below, we discuss available evidence regarding the impacts of these threats / potential limiting factors.

4.2.1. Hydraulically Suitable Habitat

Resident fish are dependent on appropriate juvenile and adult habitats to facilitate their growth and survival (Nunn *et al.* 2012). The interaction between flow and stream morphology determines the quantity and quality of habitat available for rearing (Raleigh *et al.* 1986). Low flows can reduce habitat availability and decrease overall carrying capacity. This can occur through multiple mechanisms including reduced mainstem stream width and/or depth, connectivity loss between mainstem and adjacent tributary or off-channel habitats, or reduced off-channel habitat quantity or quality (see Section 4.2.8; Bergendorf 2002; Bradford and Taylor 2021). While high flows can displace individuals from rearing habitats and result in physical scour of periphyton (attached algae), benthic invertebrates, or the substrate, reducing aquatic productivity (see Section 4.2.6; Johnson *et al.* 2022a) or modifying substrate habitats.

The availability of adequate overwintering habitats are critically important for winter survival. These habitats must minimize energy expenditure, allow fish to avoid adverse environmental conditions, and decrease the likelihood of predation (Raleigh *et al.* 1984; Brown *et al.* 2011). Overwintering habitats vary by species and/or life stage[5] and may include areas such as pools, off-channel habitats, or areas near sources of groundwater input (described in Faulkner *et al.* 2011). Access to suitable habitats may require small-scale microhabitat shifts, movements to different mesohabitats and macrohabitats, or even greater migrations (Cunjak 1996; Huusko *et al.* 2007).

In fall and early winter, salmonids tend to move to habitats with increased water depth, reduced water velocities, and suitable cover (Cunjak 1996; Hiscock *et al.* 2002; Huusko *et al.* 2007; Brown *et al.* 2011). Generally, fish movements in winter are minimal and decline throughout the winter (Cunjak 1996; Jakober *et al.* 1998; Hiscock *et al.* 2002; Huusko *et al.* 2007). However, movement patterns can be complex and may be related to the stability of winter conditions (see Section 4.2.7; Huusko *et al.* 2007). Low base flows from late summer to winter can have an important influence on the quantity and quality of fish habitat (Raleigh *et al.* 1984). For example, Mitro *et al.* (2003) found that low over winter flows decreased the amount of preferred bank habitat for Rainbow Trout, which appeared to result in increased mortality. Fish that inhabit pool habitat may be buffered to the impacts of low flows (Dare *et al.* 2002), though access to these habitats may be restricted if connecting riffle areas become too shallow (Bradford and Heinonen 2008; Brown *et al.* 2011).

[5] For example, small fish seek cover in interstitial spaces in the stream substrate, whereas large-bodied individuals may have to move into slow velocity areas to find suitable shelters from ice and predators (McMahon and Hartman 1989; Lindstrom and Hubert 2004).

Flow mediated impacts on habitat quality and quantity can also modify fish behaviour and individual habitat choice (e.g., see Bjornn 1971). Density dependent factors in combination with agonistic behaviour may lead to displacement of subordinate fish from high quality rearing habitats, negatively impacting their survival through increased predation risk and occupancy of unsuitable habitats (Lister and Walker 1966; Reimers 1968). Flow is also an important cue for the onset of many resident fish migration patterns, and therefore loss of peak flow events could impact migration timing (Roberge *et al.* 2002; McPhail 2007).

In general, flows approximating the natural flow regime will provide and maintain the most suitable rearing habitats. Riffles and other shallow areas such as stream margins are more sensitive to low flows than deeper habitats like pools (Bradford and Heinonen 2008). As such, species that rely on shallow habitats may be more vulnerable to reductions in flow (see Chudnow *et al.* 2022a.).

4.2.2. River Geomorphology and Sediment Processes

Geomorphic changes, particularly to the sediment regime are some of the most significant effects of flow regulation in the Nechako system (Neill 1987; Rood 1987). Flow diversion has led to significant levels of bank erosion in the Cheslatta River watershed and to a lesser extent within the Nechako River, including two known avulsion events (i.e., major sediment erosion events; Hay and Company Consultants Inc. 2000; McAdam 2012). While flow regulation and decreased flow variation has limited the Nechako River's capacity to transport sediment (Neill 1987; Rood 1987). Together, these changes have resulted in significant increases in fine sediment throughout the river (Neill 1987; Rood 1987; McAdam *et al.* 2005; NHC 2015, 2016; Gateuille *et al.* 2019).

Increased sediment deposition in combination with resulting vegetative encroachment have narrowed the main river channel and led to losses of off-channel habitat connectivity (Neill 1987; Rood 1987; Johnson *et al.* 2022b). Increases in fine sediment deposition and reduced sediment flushing can also decrease the survival of eggs or alevin for species that incubate in the substrate through entrapment or smothering (i.e., reductions or loss of intra-gravel flow decreasing metabolic waste flushing and dissolved oxygen levels, discussed in Section 4.2.4; Bergendorf 2002; NFCP 2005).

There are no Nechako River specific data regarding the effect of changes in geomorphology and sediment processes on resident fish species, however information is available for both Chinook Salmon and White Sturgeon. Available evidence suggests these processes are not a significant concern as a factor limiting Chinook Salmon productivity (i.e., increased sediment deposition; Reiser *et al.* 1985; NFCP 2005) but they have been implicated as an important factor in ongoing Nechako River White Sturgeon recruitment failure (McAdam *et al.* 2005; McAdam 2011, 2015; DFO 2014). Therefore, the impact of flow-mediated changes in river geomorphology and sediment processes on resident fish remain an important unknown.

4.2.3. Altered Thermal Regime

One priority identified during the WEI process is to better understand how RTA operations affect resident fish through temperature effects in the Nechako River (i.e., issue 24). As a result, this topic is given specific consideration in Carter *et al.* (2022), which should be referred to for a detailed discussion. In summary, flow is closely associated with temperature, a "master" variable influencing fish physiology (Brett and Groves 1979). Air temperature is a primary driver of water temperature. At low flows, river volume and subsequent thermal buffering of air temperature is reduced. This results in increased water temperature variation towards observed air temperatures as flow moves from a release point (such as Skins Lake spillway; Caissie 2006). Typically, , lower flow results in higher water temperature in spring and summer, whereas in fall and winter, lower flow may lead to quicker cooling and may increase ice formation (discussed in Section 4.2.7; Faulkner *et al.* 2011). Temperature governs the rate of metabolic processes, influencing egg and juvenile development (Carter *et al.* 2022). Across all species and life stages, when water approaches a upper temperature limit, individuals can succumb to thermal stress and elevated mortality (Carter *et al.* 2022).

Many Nechako River resident fish species have high temperature tolerances, while salmonids generally prefer relatively cool temperatures, with temperature optima varying across life stages and populations (see Carter *et al.* 2022; Chudnow *et al.* 2022a). Therefore, water temperatures that are protective of salmonids are likely protective of all resident fish species. In the Nechako River, the Summer Temperature Monitoring Program (STMP) moderates elevated water temperatures during Sockeye Salmon migration by manipulating the timing and volume of reservoir water input, through Skins Lake flow releases (NFCP 2005). As Sockeye have similar temperature optima as Bull Trout and Rainbow Trout, Skins Lake flow releases are likely to provide appropriate thermal conditions for these species and be protective of all Nechako River resident fish species (Carter and Kurtz 2022; Carter *et al.* 2022). As other non-salmonid resident fish species tend to have higher thermal tolerances, warmer water may favour these species (Carter *et al.* 2022; Chudnow *et al.* 2022a).

4.2.4. Dissolved Oxygen

Appropriate water column and intra-gravel dissolved oxygen levels are required for successful fish spawning, egg incubation, and rearing. Reduced flow (and increased temperature) can decrease water's dissolved oxygen content. This can increase egg mortality and modify fish behaviour. Generally, fish avoid areas when dissolved oxygen is reduced to a level where it induces physiological stress (Whitmore *et al.* 1960). Though no information is available regarding Nechako River specific dissolved oxygen conditions in resident fish habitats, information is available for Chinook Salmon and White Sturgeon.

Chinook Salmon eggs have a small surface-to-volume ratio and are the largest of all Pacific salmon eggs (Healey 1991). They therefore require high intra-gravel flow and dissolved oxygen concentrations for survival (≥ 8 mg/L for high egg survival; Reiser *et al.* 1985; Raleigh *et al.* 1986; Healey 1991). In addition, both spawning and juvenile Chinook may modify their behaviour in response to low dissolved oxygen levels (i.e., < 3.4 mg/L spawners cease migration, Alabaster 1969; < 4.5 mg/L juvenile habitat avoidance, Whitmore *et al.* 1960). Available evidence also suggests White Sturgeon require dissolved oxygen concentrations greater than 6.0 mg/l across life stages (Sullivan *et al.* 2003). Since available evidence suggests dissolved oxygen concentrations are not likely limiting spawning, egg survival, or rearing Chinook Salmon or White Sturgeon within the mainstem Nechako River given previously recorded concentrations (French 2005; NFCP 2005), it is likely that is also not a limiting factor for Nechako River resident fish within mainstem habitats.

4.2.5. Community Structure

Flow regulation can cause complex changes within ecological communities (Bruce 1991; NFCP 2005; Dewson *et al.* 2007; Bilotta *et al.* 2017). Bruce (1991) identified multiple flow-mediated mechanisms that could change competitive interactions or predation encountered by Nechako River Chinook Salmon, which are relevant to all Nechako River fish species. These include but are not limited to:

1. Changes in a species' social behavior;
2. Overcrowding as a result of changes to habitat quantity and quality;
3. Shifts in species' spatial and temporal distribution (including prey, discussed in Section 4.2.6);
4. Shifts in species' absolute and relative abundance; and
5. Temperature mediated impacts on fish physiology or flow mediated impacts on fish habitat use and swimming ability resulting in shifts in competitive, predatory, or predator avoidance ability.

No directed research has been conducted in the Nechako River to date that has explored if, or how, known interactions between Nechako River fish species have been modified by flow regulation. However, expert opinion by Slaney (1987) suggested that lower discharge would decrease velocity and increase water temperature to the benefit of many non-salmonid resident species (e.g., minnows, sculpins, and suckers). It is possible that flow regulation could result in an increase in the abundance of these species, increasing the potential for competition or predation. However, the likelihood and extent of such a shift in community structure is unknown and remains a data gap.

4.2.6. Food Availability

Resident fish species are reliant on a variety of prey, ranging from periphyton, other algaes, and vascular plants, to invertebrates and fish (McPhail 2007). Flow regulation has the potential to modify food availability for all species through multiple mechanisms. Johnson *et al.* (2022a) and Abell and Lewis (2022) consider productivity in the Nechako River and adjacent Cheslatta River watershed, respectively, and should be consulted for a detailed discussion of this topic.

The effects of flow regulation on algal, vascular plant, and invertebrate communities has been well studied (Envirocon Ltd. 1984; Biggs and Close 1989; Dewson *et al.* 2007; Bilotta *et al.* 2017); and many of the flow related mechanisms impacting these organisms mirror those impacting the fish community (i.e., presence of hydraulically suitable habitat, sedimentation, icing processes; Envirocon Ltd. 1984). Habitat alteration as a result of these factors can modify the overall abundance of algae, invertebrates, and prey fish (Johnson *et al.* 2022a). It can also affect individual size and the species composition, distribution, and relative abundance of plants, invertebrates, and prey fish (Minshall and Winger 1968; Envirocon Ltd. 1984; Ward and Stanford 1987; Caldwell *et al.* 2018; Johnson *et al.* 2022a). This directly effects overall food availability and the abundance of preferred prey for resident species and has the potential to result in decreased individual growth, increased intra- and inter-species competition, displacement, and increase predation risk due to prolonged prey search periods (Hilborn and Walters 1992).

Flow regulation can alter the availability of hydraulically suitable habitat for aquatic plants and invertebrates by changing the velocity, depth, and wetted area of a river (Jowett and Duncan 1990; Morgan *et al.* 1991; Moog 1993; Cortes *et al.* 2002). While flow mediated changes to other mechanisms (e.g., sedimentation) can alter benthic invertebrate and periphyton habitat availability and habitat quality. For example, reduced sediment flushing and increased sediment deposition have reduced streambed interstitial space within the river (McAdam *et al.* 2005; NHC 2015, 2016; Gateuille *et al.* 2019), which tends to decrease benthic invertebrate prey production (Duan *et al.* 2008).

High flows can cause physical scour of periphyton (attached algae) and benthic invertebrates, reducing aquatic productivity (e.g., Biggs and Close 1989). As is typical for interior British Columbian rivers, high flows occur during part of the growing season and scour presumably occurs to some extent during freshet, although applicable flow thresholds are unknown. In relative terms, scour is expected to limit aquatic productivity in the Nechako River to a lesser extent than in the Cheslatta River watershed where flows have greatly increased following reservoir construction; However, the overall magnitude of effect is unknown (Abell and Lewis 2022; Johnson *et al.* 2022a).

In addition, flow mediated mechanisms can also affect migration cues for multiple fish species, including those that are important prey for resident fish. For example Chinook salmon juvenile out-migration timing and duration is linked to flow (Raymond 1968; Berggren and Filardo 1993; Sykes *et al.* 2009; Sturrock *et al.* 2020). As Chinook Salmon juveniles are a known prey to a number of resident species including Bull Trout and Northern Pikeminnow (Chudnow *et al.* 2022a), flow mediated mechanisms impacting the abundance of and timing of Chinook Salmon out-migrations, or life history patterns of other fish species could impact food availability for predators.

Despite all potential impacts highlighted above and presented in Abell and Lewis (2022) and Johnson *et al.* (2022a), available information does not provide a clear quantifiable understanding of the relationship between flow and food availability for Nechako River resident fish. As a result, flow mediated impacts to food availability remain an unknown.

4.2.7. Icing processes

Both meteorological and flow regimes can be important factors contributing to resident fish overwinter survival due to their impact on ice formation processes within the river. For fall spawning species, eggs require suitable physical habitat conditions for successful incubation while all overwintering individuals are reliant on adequate habitats to minimize energy expenditure, avoid adverse environmental conditions, and decrease the likelihood of predation (Raleigh *et al.* 1984; Brown *et al.* 2011). Decreased early winter flows can lead to quicker cooling and more severe ice formation (e.g., earlier and thicker formations of surface, frazil, and anchor ice which extend further distances upstream) (Blachut 1988; Faulkner *et al.* 2011; Brown *et al.* 2011). Together, these ice formation processes can negatively impact egg development and individual rearing through various mechanisms including; modified water velocity, reduced or absent intra-substrate flow, streamflow diversion, habitat fragmentation, and substrate freezing (topics that are detailed in Blachut (1988); Faulkner *et al.* (2011); and Brown *et al.* (2011), and summarized below).

The physical presence of ice, or resultant impacts on water velocity can result in fish avoidance or displacement (Brown *et al.* 2000; Lindstrom and Hubert 2004). Depending on location and formation type, ice can increase or reduce adjacent sub-surface or near-bed water velocities, and can even result in loss of flow (Blachut 1988). Salmonids have been found to be more mobile in areas with unstable ice conditions compared to areas with stable ice conditions (Jakober *et al.* 1998; Simpkins *et al.* 2000; Brown *et al.* 2000). Increases in ice formation have also been found to impact salmonid habitat choice and substantially increase their movements overwinter (i.e., frequency and/or duration; Jakober *et al.* 1998; Brown 1999; Simpkins *et al.* 2000; Brown *et al.* 2000; Annear *et al.* 2002; Dare *et al.* 2002; Lindstrom and Hubert 2004; Bradford and Heinonen 2008). For example, Cutthroat Trout have been observed to leave preferred woody-debris cover in the presence of icing (Brown *et al.* 1994; Brown and Mackay 1995), while multiple salmonid species have been observed moving to the bottom of deep pools or to shallow nearshore areas under shelf ice during frazil ice episodes (Jakober *et al.* 1998; Simpkins *et al.* 2000; Huusko *et al.* 2007). Such movements to alternative habitats negatively impact individual energy reserves and decrease winter survival rates (Brown *et al.* 2011).

Several icing processes[6] can also result in habitat fragmentation or habitat loss due to the physical presence of ice structures within the water column, if it results in ice penetration into the substrate, or if ice formations upstream divert flow away from specific habitats (e.g., shore zones, and off-channel habitats; Maciolek and Needham 1952; Blachut 1988; Brown *et al.* 2011). This can result in loss of fish access to suitable overwintering habitats or fish stranding (Maciolek and Needham 1952; Brown *et al.* 2011). Fish can also become isolated in pockets of open water (Brown *et al.* 2011) and

[6] Examples of icing process that can lead to such impacts include surface ice contact with substrate, anchor ice formation extending from the streambed to underside of surface ice cover, hanging dams, and ice jams.

subject to increased mortality due to freezing or high predation rates in spring, prior to complete ice break-up (Brown *et al.* 2000; Faulkner *et al.* 2011). Ice emergence above the water's surface can also permit frost penetration to the streambed and subsequent substrate freezing, impacting species and life stages that use substrate interstitial space for cover (Reiser and Wesche 1979; Walsh and Calkins 1986; McMahon and Hartman 1989; Lindstrom and Hubert 2004). While, spring ice break up can result in substantial levels of substrate ice scour which can displace fish from these habitats (Healey 1987).

Winter temperatures[7] and ice formation and distribution[8] have been recorded in the Nechako River over multiple decades (Blachut 1986a, 1986b, 1987, 1988; Blachut and Bams 1987; Faulkner 1994, 1999; Faulkner and Ennevor 1999; Wilkins and Faulkner 1999a, 1999b, 1999c; NFCP 2005). However, this literature review was only able to identify Nechako River specific winter icing conditions data for the period of 1980 – 1996, and no contemporary information on surface or anchor ice formation was located. Further, this data primarily relates to winter habitat conditions in areas known to be important to Chinook Salmon and are not reflective of the river as a whole.

Generally, the river has solid ice cover over a five month period (as recorded at Vanderhoof; Blachut 1988). The date of freeze-up is highly variable, but generally occurs between October and January (Blachut 1988). Flow regulation generally prevents spring freshet driven ice-break up (NFCP 2005). Instead, ice break-up is slow with patchy melting along the river's length as ice "rots" in place with rising air and water temperatures (NFCP 2005). Shore ice is the last type of formation to melt in spring (NFCP 2005). Ice conditions in the upper river are highly variable and dependent on both reservoir discharge and meteorological conditions (Blachut 1988). Solid surface ice formation has been estimated to extend upstream to approximately 29 rkm below Cheslatta Falls (Blachut 1988; NFCP 2005). Modelling of the winter regime under combinations of alternative flows and air temperature by Blachut (1988) suggested surface ice would extend further upstream at flows of 10.6 m^3/s vs. 31.1 m^3/s.

Extensive anchor ice formation has been documented throughout the upper and middle Nechako River, extending at least from 25 rkm upstream to 70 rkm (i.e., Diamond Island downstream; Blachut 1986a). Anchor ice within the river was described by Blachut (1988) as:

> *"blanketing the streambed for several kilometres… emergent at the water surface, and attached to the underside of surface ice cover"* (at discharges of 30-35 m^3/s).

---

[7] Water and air temperatures sourced from Water Survey of Canada stations at Bert Irvine's Lodge and Vanderhoof (Blachut 1988; NFCP 2005).

[8] A combination of aerial (1975 – 1996) and satellite photography (various dates between 1972 – 1985) and land based observations (1975 – 1996) (Blachut 1986a, 1986b, 1987, 1988; Blachut and Bams 1987; Faulkner 1994, 1999; Faulkner and Ennevor 1999; Wilkins and Faulkner 1999a, 1999b, 1999c; NFCP 2005).

In the upper river, anchor ice was found to exceed 30 cm thickness, filling most of the free water space and limiting available shallow, nearshore habitats (Blachut 1986b). Significant reductions in subsurface water velocity have also been observed in shallow nearshore areas at Diamond Island (Blachut 1988). While shore ice (≤ 25 cm thickness) has been observed extending to the substrate with no evidence of subsurface flow and evidence of nearshore scour (Blachut 1988). Given climatic and geomorphic changes that have occurred since data collection and lack of information regarding winter conditions and icing effects on Nechako River resident fish species, the impact of icing processes on resident fish remains a data gap.

4.2.8. Loss of Fish Access to Tributary and Off-channel Habitat

A priority identified during the WEI process is to better understand how RTA operations affect fish access to tributary and off-channel habitats (i.e., issues 18 and 19). As a result, this topic is given specific consideration in Johnson *et al.* (2022b), which should be referred to for a detailed discussion. In summary, alteration of Nechako River flows has likely influenced river connectivity with tributary and off-channel habitats as well as modified habitat availability within off-channel habitats. This could occur as the result of multiple mechanisms:

1. Loss of lateral connectivity as the result of reduced flows, sedimentation, debris deposition, or vegetative encroachment;
2. Fish passage blockages as the result of debris deposition; or
3. Reduced off-channel habitat quantity as the result of reduced flows.

Information on fish access to Nechako River tributaries is highly limited (i.e., few streams investigated over a relatively short temporal window within the mid-1980s and late 1990s; Tredger *et al.* 1985; ARC Environmental Ltd. 1998). Flow mediated impacts to off-channel habitat availability has also been the subject of preliminary investigations (Hamilton 1987; Reid Crowther and Partners Ltd. 1987). This work found available off-channel habitat declined with decreased discharge. Specifically, off-channel wetted area decreased 22.5 – 72.8% with discharge reduction from 56.6 to 30.0 m^3/s, while higher flows inundated and provided fish access to off-channel habitats, until flow levels reached a point at which they 'flooded out' (Hamilton 1987; Reid Crowther and Partners Ltd. 1987). Literature review was unable to identify any work examining fish access to off-channel habitats. As a result, the impact of flow regulation on fish access to tributary and off-channel habitats remains a major data gap.

4.2.9. Existing Habitat-Flow Relationships for Nechako River Salmonids

Assessments presented in Slaney *et al.* (1984) provide the only habitat-flow relationships for resident fish species within the Nechako River. This work was limited to Bull Trout and Rainbow Trout. A description of habitat-flow relationships and key considerations surrounding their use is provided in Appendix B. No habitat-flow relationship information is available for Nechako River Mountain

Whitefish. However, Mountain Whitefish habitat preferences' are similar to those of Rainbow Trout (DosSantos 1985), with use of both the mid-channel and river's margins during different times of day (Envirocon Ltd. 1984; McPhail 2007; Schmidt *et al.* 2019). Therefore, existing habitat-flow relationships for Rainbow Trout are likely valuable in inferring relationships for Mountain Whitefish.

Slaney *et al.* (1984) presented three methodologies for estimating the relationship between salmonid habitat and flow including an instream flow incremental method (IFIM) model, a habitat quality index (HQI), and a fixed percentage approach (i.e., Montana method; Tennant 1976). The IFIM was conducted for juvenile and adult Rainbow Trout, while both the HQI and fixed percentage approaches were applied to both Bull Trout and Rainbow Trout. The IFIM and HQI were assessed over four alternative flow regimes[9] ranging from 0 – 70 m^3/s, measured at Cheslatta Falls across five reaches in the upper Nechako River from spring to fall (Figure 2). The fixed percentage approach was used in combination with estimates derived by Anon (1979) to estimate minimum winter flow requirements.

4.2.9.1. IFIM Results

Usable habitat area for adult Rainbow Trout across the entirety of the upper Nechako River was maximized by flows > 70 m^3/s (i.e., composite of reaches 1 – 5; Figure 3). Two of the four alternative flow scenarios led to substantial decreases in useable habitat (regime B, > 40%; regime C, > 43% decrease). Further modelling indicated that an optimum flow regime, defined as the lowest amount of flow that would maximize Rainbow Trout habitat, varied by reach at flows ranging from 74-100 m^3/s. For the most productive reaches, this constituted 90 m^3/s (Reach 1) and 74 m^3/s (Reach 5).

[9] Flow regime A: summer 70 m^3/s, winter 38 m^3/s, peak 170 m^3/s; Flow regime B: summer 28 m^3/s, winter 14 m^3/s, peak 170 m^3/s; Flow regime C: summer 24-20 m^3/s, winter 11 m^3/s, peak 170 m^3/s; Flow Regime D: summer 57 m^3/s, winter 28 m^3/s, peak 280-340 m^3/s.

Figure 2. Nechako River survey reaches. Sourced from Slaney *et al.* (1984).

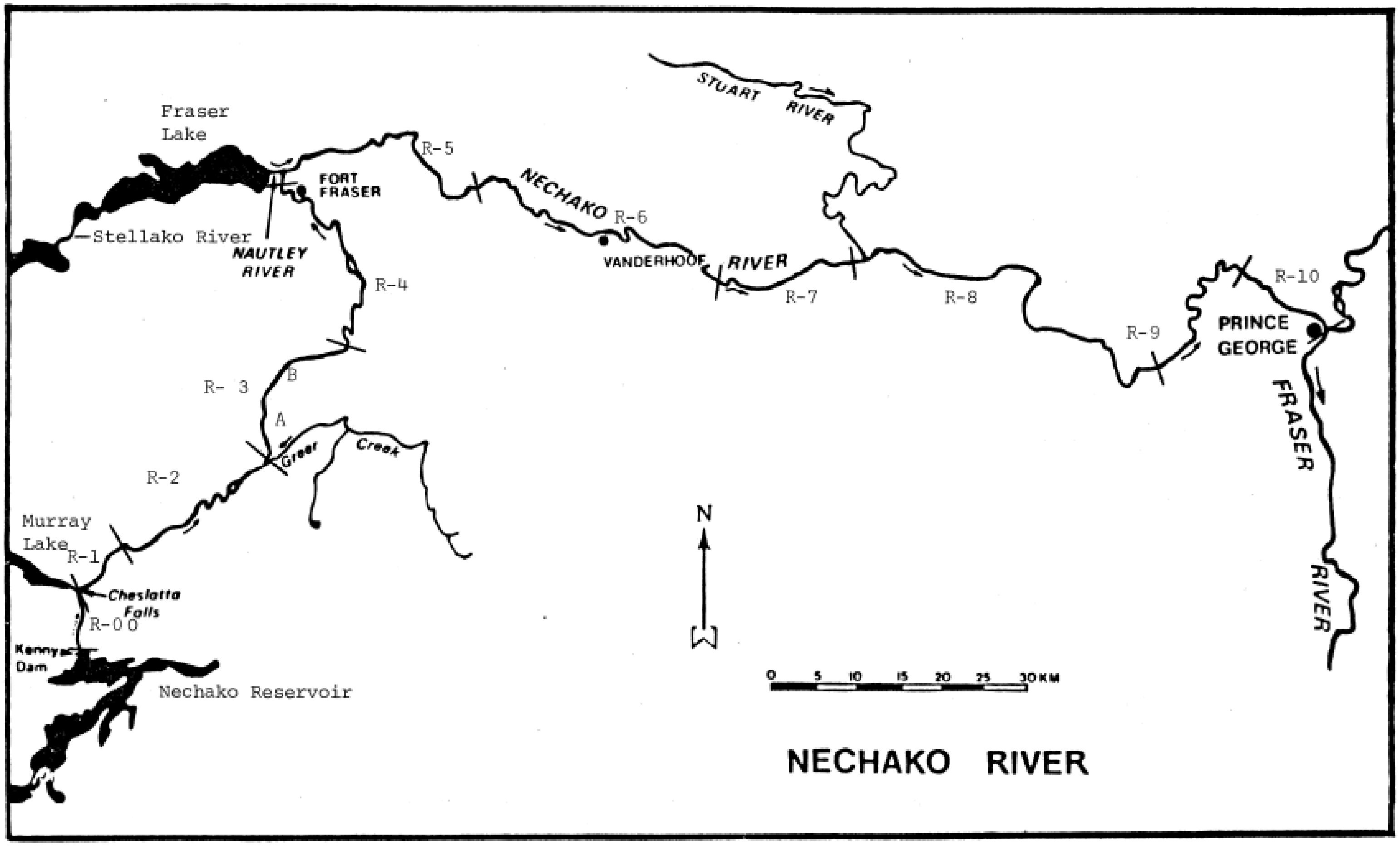
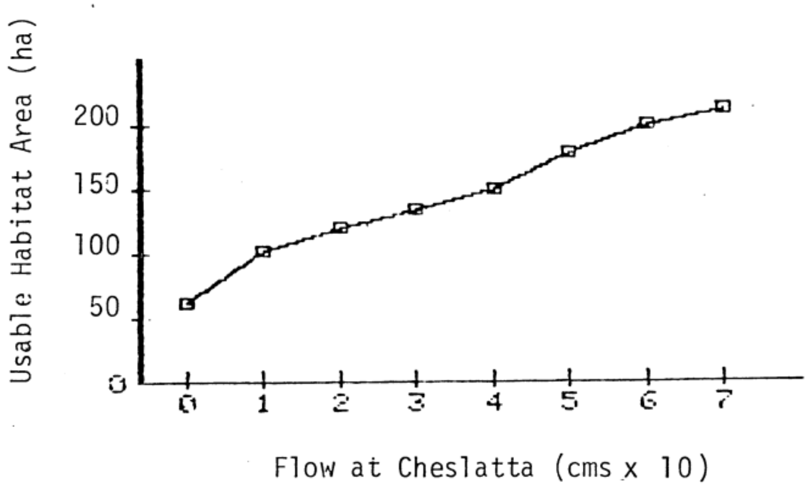
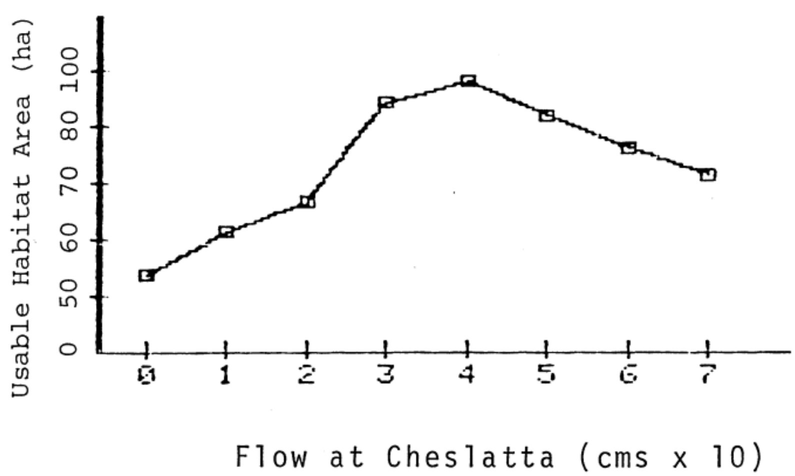


Figure 3. **Instream flow incremental method (IFIM) results showing modelled usable habitat area for adult Rainbow Trout for the composite of Reach 1 to 5 as a function of flow (cm/s) at Cheslatta Falls (September tributary inflow of 26.3 cm/s incorporated). Sourced from Slaney *et al.* (1984).**



Predicted optima for juvenile Rainbow Trout occurred at lower flows, and like results for adults, useable habitat area peaked at different flows in different reaches. Across the entirety of the upper Nechako River (i.e., composite of reaches 1 – 5), usable habitat area peaked at ~40 m^3/s for rearing fish and declined thereafter (Figure 4).

Figure 4. **Instream flow incremental method (IFIM) results showing modelled usable habitat area for juvenile Rainbow Trout for the composite of Reach 1 to 5 as a function of flow (cm/s) at Cheslatta Falls (September tributary inflow of 26.3 cm/s incorporated).**



4.2.9.2. HQI Results

The HQI model estimated combined Bull Trout and Rainbow Trout biomasses to be highest under flow regimes A (14,200 kg) and only moderately lower under flow regime D (13,500 kg). In contrast, both regimes B and C were estimated to substantially decrease biomass (-44% and -65% respectively).

4.2.9.3. Fixed Percentage (Montana or Tennent Method) Results

Analysis suggested that flow of 77 m^3/s was needed for "good trout production" with flows of 38 m^3/s at Cheslatta Falls during fall and winter providing sufficient depth in riffles to minimize risk of significant overwinter mortality resulting from ice formations. Later critique by Slaney (1987) suggested flows of 39.4 m^3/s should be provided over winter to protect all life stages.

4.2.10. Establishing Habitat-Flow Relationships for non-Salmonid Resident Fish

Many non-salmonid resident fish families (e.g., minnows, sculpins, and suckers) may be more resilient to reduced discharge than salmonids. These species tend to prefer slower, warmer, more vegetated habitats and have wider ranges of environmental tolerances than salmonids (Twomey *et al.* 1984; Reeves *et al.* 1987; McPhail 2007; Chudnow *et al.* 2022a). However, species' specific responses to decreased flow vary. There is limited information to inform our understanding of the specific flow effects on Nechako River non-salmonid resident fish. Expert opinion by Slaney (1987) is the sole source of river specific information identified by this literature review, and suggested that lower discharge would decrease velocity and increase water temperature, to the benefit of non-salmonid resident species.

In research conducted in other North American systems, many non-salmonid species (e.g., Burbot, minnows, White Sucker) have been found to be resilient to flow reductions in cold, small rivers (Twomey *et al.* 1984; Zorn *et al.* 2012). While others (e.g., Brassy Minnow, Lamprey, Redside Shiner, and Spiny Sculpin) have been found to be relatively more sensitive (Rodnick 1983; Reeves *et al.* 1987; Falke *et al.* 2010; Zorn *et al.* 2012). Interpretation and application of findings from this research to Nechako River resident fish populations must be done with caution, as a river's spatial scale is an important determinant of its sensitivity to flow withdrawal. Further, the relationship between species and flow is often life-stage specific, and therefore flows that are protective of specific life stages may not be for others. For example, adult Nechako River White Suckers are likely more resilient to changes in flow than salmonids (Twomey *et al.* 1984). However, juvenile suckers appear to have similar microhabitat preferences as juvenile salmonids (Bruce 1991). Despite significant data limitations discussed further in Section 5.1 below, available information suggests flows that are protective of Nechako River resident salmonid species are also likely protective of the fish community as a whole.

5. DISCUSSION

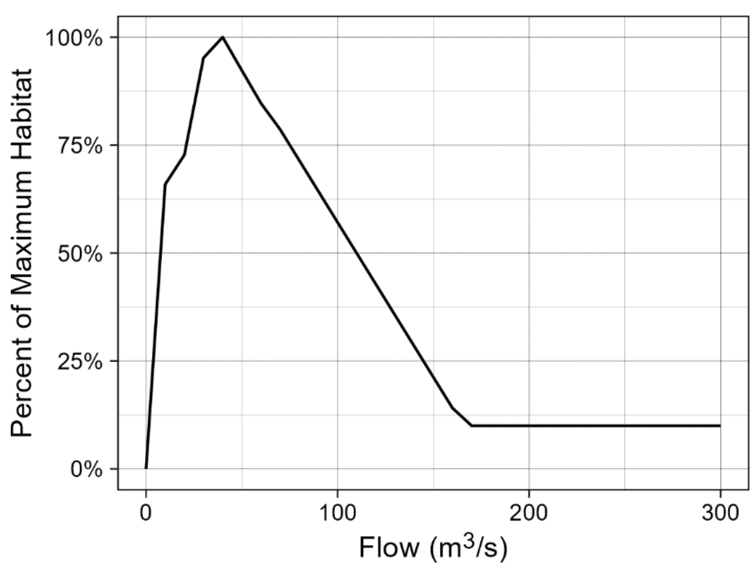
5.1. Potential Performance Measures

We have identified preliminary performance measures for WEI consideration for the purpose of evaluating how flow scenarios potentially affect Nechako River resident fish. Additionally, suggestions are provided regarding how performance measures could be further developed if the WEI wishes to consider issues in greater detail. Potential performance measures are described below in relation to the periods of interest, rearing (issue #25) and overwintering (issue #26).

Juvenile Rearing Habitat – Nechako River specific habitat-flow information for juvenile resident fish is limited to the IFIM model outputs presented by Slaney *et al.* (1984) for juvenile Rainbow Trout. Given the lack of available information for other species and the higher sensitivity of salmonids to changes in flow than other resident fish, this information provides the basis for the most appropriate PM. Accordingly, we propose PM1 below.

- PM1: *Relationship between flow and juvenile Nechako River Rainbow Trout habitat (as weighted usable area; WUA) for a composite of Reach 1 to Reach 5 (Figure 2, Figure 5). Adapted from Envirocon Ltd. (1984) and Slaney et al. (1984).*

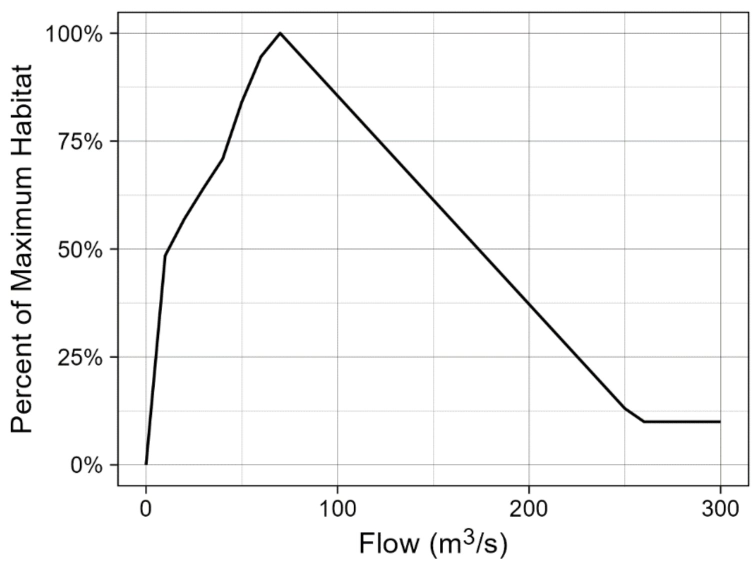
Figure 5. Estimated weighted useable habitat area for juvenile Rainbow Trout in the Nechako River as a function of flow (m^3/s) at Cheslatta Falls. Adapted from Envirocon Ltd. (1984) and Slaney *et al.* (1984).



Adult Rearing Habitat – Nechako River specific habitat-flow information for adult resident fish rearing is limited to the outputs of IFIM, HQI and fixed percentage models presented by Slaney *et al.* (1984) for Bull Trout and Rainbow Trout. Given the lack of available information for other species and the higher sensitivity of salmonids to changes in flow than other resident fish, this information provides the basis for the most appropriate PM. Accordingly, we propose PM2 below.

- PM2: *Relationship between flow and adult Nechako River Bull Trout and Rainbow Trout habitat (as weighted usable area; WUA) for a composite of Reach 1 to Reach 5 (Figure 2, Figure 6). Adapted from Envirocon Ltd. (1984) and Slaney et al. (1984).*

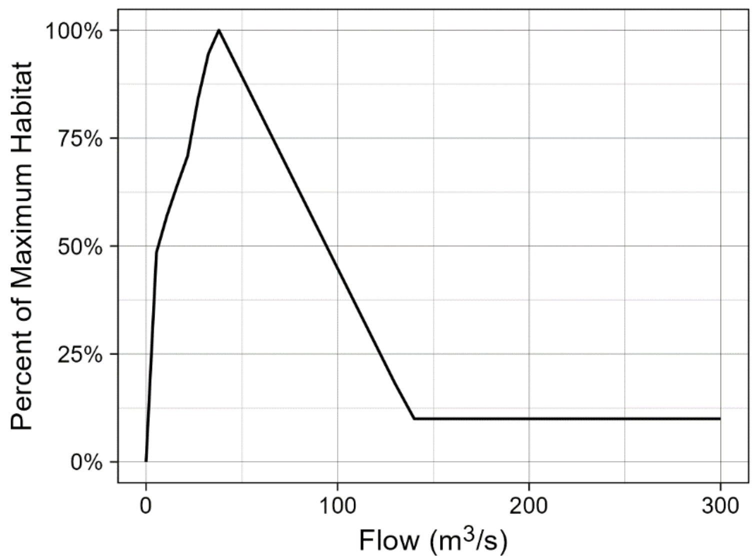
Figure 6. Estimated weighted useable habitat area for adult Bull Trout and Rainbow Trout in the Nechako River as a function of flow (m^3/s) at Cheslatta Falls. Adapted from Envirocon Ltd. (1984) and Slaney *et al.* (1984).



Overwintering Habitat – Nechako River specific habitat-flow information for resident fish overwintering is limited to the outputs of the fixed percentage model presented by Slaney *et al.* (1984) for Bull Trout and Rainbow Trout. Given the lack of available information for other species and the expected similarities in habitat conditions required for successful overwintering between species, this information provides the basis for the most appropriate PM. Accordingly, we propose PM3 below.

- PM3: *Relationship between flow and Nechako River Bull Trout and Rainbow Trout overwintering habitat (as weighted usable area; WUA) for a composite of Reach 1 to Reach 5 (Figure 2, Figure 7). Adapted from Envirocon Ltd. (1984) and Slaney et al. (1984).*

Figure 7. Estimated weighted useable habitat area for Bull Trout and Rainbow Trout overwintering in the Nechako River as a function of flow (m^3/s) at Cheslatta Falls. Adapted from Envirocon Ltd. (1984) and Slaney *et al.* (1984).



5.1. Uncertainties and Data Gaps

Quantifying the relationship between flow and resident fish habitat requires a clear understanding of Nechako River resident fish habitat quantity and quality. Numerous studies since pre-dam construction have investigated fish distribution and habitat use in the Nechako River. However, few studies have considered species other than Chinook Salmon and White Sturgeon. Specific data on resident fish rearing and overwintering habitats in the Nechako River are limited, and only a few studies of Bull Trout and Rainbow Trout were identified through this literature review. These species comprise only two of the 18 resident fish species known to inhabit the Nechako River, and while these species are of high management priority, information on the flow-habitat relationships for the full resident fish community are relevant to the management of this watershed.

Beyond these considerations, the performance measures presented in Section 5.1 above were developed based on relationships established through datasets collected through environmental studies associated with KCP development. Though this work (i.e., that of Slaney *et al.* 1984 and Slaney 1987) provides useful information on the relationship between Bull Trout and Rainbow Trout and flow for the upper Nechako River, no contemporary analysis has occurred. Given the physical changes that have occurred in the Nechako River and associated tributaries as the result of flow regulation and other factors (discussed in NFCP 2005) and more broadly across freshwater ecosystems in recent decades (Carpenter *et al.* 2011; Reid *et al.* 2019), collecting contemporary information on

Nechako River resident fish abundances and distributions across various life stages is of high importance if further performance measure refinement is identified as a WEI priority. With a more complete understanding of the types of habitats resident fish use within the Nechako River, flow alternatives could then be considered in the context of species and/or life-stage specific flow relationships.

6. CONCLUSION/CLOSURE

Ecofish was asked to support the WEI by reviewing the current scientific knowledge about effects of operational flow on resident fish rearing and overwintering habitats in the Nechako River. The following key points summarize our current understanding of flow effects for resident species and life histories of concern.

- Flow is a master variable (Poff *et al.* 1997), and has significant impacts on the quantity and quality physical habitat and fish behavior through changes to water depth, velocity, temperature, food transport, etc. Accordingly, the Nechako River flow regime is expected to influence the habitat productivity for resident fish.

- Available information regarding the distribution and habitat use of the Nechako River by resident fish species is limited for all but two of 18 resident fish species (Bull Trout and Rainbow Trout). While these salmonid species are a higher management priority than many other resident species, information on the flow-habitat relationships for the full resident fish community are important to the management of this watershed.

- Best available information to inform the development of PMs for Nechako River resident fish are analyses of char and Rainbow Trout habitat within the upper river (Raleigh *et al.* 1984; Slaney *et al.* 1984; Slaney 1987). These analyses were heavily relied on to develop PMs in this analysis.

- Lack of contemporary information on the habitat use and distribution of all resident fish species is a data gap for the development of flow alternatives.

Yours truly,

Ecofish Research Ltd.

Prepared by:

Signed

Rachel Chudnow, Ph.D., R.P.Bio.

Fisheries Scientist

Reviewed by:

Signed

Adam Lewis, M.Sc., R.P.Bio.

Senior Fisheries Scientist

Signed

William Twardek, B.Sc., Ph.D., M.Sc., R.P.Bio.

Fisheries Scientist

REFERENCES

Abell, J. and F.J.A. Lewis. 2022. Issue #15,16 – Cheslatta Watershed Productivity. Consultant's memorandum prepared for the Nechako Water Engagement Initiative Technical Working Group by Ecofish Research Ltd., December 5, 2022.

Ableson, D.H.G. 1985. Fisheries management plan upper Nechako River watershed including Murray and Cheslatta Lakes. British Columbia Ministry of Environment, Prince George, British Columbia, Canada.

Ableson, D.H.G. 1990. Fisheries management plan upper Nechako River watershed including Murray and Cheslatta lakes. British Columbia Ministry of Environment.

Ableson, D.H.G. and P.A. Slaney. 1990. Revised sport fisheries management plan for the Nechako River and the Murray/Cheslatta system. B.C. Fish and Wildlife Branch, B.C. Fish and Wildlife Branch Report.

Alabaster, J.S. 1969. The dissolved oxygen and temperature requirements of king salmon, *Oncorhynchus tshawytscha*, in the San Joaquin Delta, California. Journal of Fish Biology 34:331-332.

Annear, T.C., W. Hubert, D. Simpkins, and L. Hebdon. 2002. Behavioural and physiological response of trout to winter habitat in tailwaters in Wyoming, USA. Hydrological Processes 16(4):915-925.

Anon. 1979. Chinook salmon studies on the Nechako River. Fisheries and Marine Service, Volume 3.

ARC Environmental Ltd. 1998. Selected Nechako River tributaries: Fish habitat assessment and inventory. ARC Environmental Ltd., Report prepared for the Ministry of Environment, Lands, Parks, Omenica Region by ARC Environmental Ltd., Kamloops, British Columbia, Canada.

Bahr, M.A. and J.M. Shrimpton. 2004. Spatial and quantitative patterns of movement in large bull trout (*Salvelinus confluentus*) from a watershed in north-western British Columbia, Canada, are due to habitat selection and not differences in life history. Ecology of Freshwater Fish 13(4):294–304.

BC MOE (British Columbia Ministry of Environment). 2021a. Fish Inventories Data Queries. Government. Available online at: https://a100.gov.bc.ca/pub/fidq/welcome.do. Accessed on August 20, 2022.

BC MOE (British Columbia Ministry of Environment). 2021b. BC Species and Ecosystems Explorer. Government. Available online at: https://a100.gov.bc.ca/pub/eswp/. Accessed on August 20, 2022.

Beel, C., J. Kurtz, and F.J.A. Lewis. 2022. Hydrological overview of the Nechako River Basin. Consultant's memorandum prepared for the Nechako Water Engagement Initiative Technical Working Group by Ecofish Research Ltd. *In progress.*

Bergendorf, D. 2002. The influence of in-stream habitat characteristics on Chinook Salmon (*Oncorhynchus tshawytscha*). Report prepared for the Northwest Fisheries Science Center of the National Oceanic and Atmospheric Association, Seattle, Washington.

Berggren, T.J. and M.J. Filardo. 1993. An Analysis of Variables Influencing the Migration of Juvenile Salmonids in the Columbia River Basin. North American Journal of Fisheries Management 13(1):48–63.

Biggs, B.J.F. and M.E. Close. 1989. Periphyton biomass dynamics in gravel bed rivers: the relative effects of flows and nutrients. Freshwater Biology 22(2):209–231.

Bilotta, G S., N.G. Burnside, M.D. Turley, J.C. Gray, and H.G. Orr. 2017. The effects of run-of-river hydroelectric power schemes on invertebrate community composition in temperate streams and rivers. PLOS ONE 12(2):e0171634.

Bjornn, T.C. 1971. Trout and Salmon Movements in Two Idaho Streams as Related to Temperature, Food, Stream Flow, Cover, and Population Density. Transactions of the American Fisheries Society 100(3):423–438.

Blachut, S.P. 1986a. Nechako River (winter) trip report, November 1985. Fisheries and Oceans Canada (DFO), Internal Department of Fisheries and Oceans Memo, Blachut to G. Ennis 1986.

Blachut, S.P. 1986b. Nechako River (winter) trip report, January 1986. Fisheries and Oceans Canada (DFO), Internal Department of Fisheries and Oceans Memo, Blachut to G. Ennis 1986.

Blachut, S.P. 1987. Winter studies 1986/1987 - Interim report. Fisheries and Oceans Canada (DFO), Internal Department of Fisheries and Oceans Memo, Blachut to R. Bell-Irving 1987.

Blachut, S.P. 1988. The winter hydrologic regime of the Nechako River, British Columbia. Fisheries and Oceans Canada (DFO), Canadian Manuscript Report of Fisheries and Aquatic Sciences 1964, Vancouver, BC, Canada.

Blachut, S.P. and R.A. Bams. 1987. Over-winter flows. Nechako River Court Action. DFO Expert Reports Volume 4 of 8.

Bradford, M.J. and J.S. Heinonen. 2008. Low Flows, Instream Flow Needs and Fish Ecology in Small Streams. Canadian Water Resources Journal 33(2):165–180.

Bradford, M.J. and G.C. Taylor. 2021. Diversity in freshwater life history in stream-type Chinook salmon from the Fraser River, Canada.

Brett, J.R. and T.D.D. Groves. 1979. Physiological Energetics. Pages 279–352 Fish Physiology. Elsevier.

Brown, T.G. 1995. Stomach contents, distribution, and potential of fish predators to consume juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in the Nechako and Stuart rivers, B.C. Fisheries and Oceans Canada (DFO), 2077, Nanaimo, British Columbia, Canada.

Brown, R.S. 1999. Fall and Early Winter Movements of Cutthroat Trout, *Oncorhynchus clarki*, in Relation to Water Temperature and Ice Conditions in Dutch Creek, Alberta. Environmental Biology of Fishes 55(4):359–368.

Brown, R.S. and W.C. Mackay. 1995. Fall and winter movements of and habitat use by cutthroat trout in the Ram River, Alberta. Transactions of the American Fisheries Society 124(6):873-885.

Brown, T.G., E. Wite, D. Kelly, L. Rzen, and J. Rutten. 1994. Availability of juvenile Chinook Salmon to predators along the margins of the Nechako and Stuart rivers, B.C. Fisheries and Oceans Canada, Canadian Manuscript Report of Fisheries and Aquatic Sciences 2245.

Brown, R.S., G. Power, S. Beltaos, and T.A. Beddow. 2000. Effects of hanging ice dams on winter movements and swimming activity of fish. Journal of Fish Biology 57(5):1150–1159.

Brown, R.S., W.A. Hubert, and S.F. Daly. 2011. A Primer on Winter, Ice, and Fish: What Fisheries Biologists Should Know about Winter Ice Processes and Stream-Dwelling Fish. Fisheries 36(1):8–26.

Bruce, J.A. 1991. Review of literature on competitive and predator-prey interactions with juvenile salmonids in the context of reduced stream flows. Aquatic Resources Limited, Report prepared for the Department of Fisheries and Oceans (DFO) by Aquatic Resources Limited, Vancouver, BC, Canada.

Caissie, D. 2006. The thermal regime of rivers: a review. Freshwater Biology 51(8):1389–1406.

Caldwell, T.J., G.J. Rossi, R.E. Henery, and S. Chandra. 2018. Decreased streamflow impacts fish movement and energetics through reductions to invertebrate drift body size and abundance: Reduced streamflow changes drift, fish behavior and fish energetics. River Research and Applications 34(8):965–976.

Carpenter, S.R., E.H. Stanley, and M.J. Vander Zanden. 2011. State of the World's Freshwater Ecosystems: Physical, Chemical, and Biological Changes. Annual Review of Environment and Resources 36(1):75–99.

Carter, J. and J. Kurtz. 2022. Review of Water Temperature Effects on Salmon. Draft V2. Consultant's memorandum prepared for the Nechako Water Engagement Initiative Technical Working Group by Ecofish Research Ltd., May 4, 2022.

Carter, J., R. Chudnow, S. Johnson, and J. Kurtz. 2022. Review of Temperature Effects on Resident Fish. Consultant's report prepared for the Nechako Water Engagement Initiative Technical Working Group by Ecofish Research Ltd. *In Progress*.

Chudnow, R. 2021. Confronting uncertainties in a freshwater recreational fishery: a case study of fluvial bull trout (*Salvelinus confluentus*) in central British Columbia. PhD Dissertation, University of British Columbia, Vancouver, BC, Canada.

Chudnow, R., J. Carter, S. Johnson, and J. Kurtz. 2022a. Resident Fish Backgrounder. Consultant's report prepared for the Nechako Water Engagement Initiative Technical Working Group by Ecofish Research Ltd. *In Progress*.

Chudnow, R., W.M. Twardek, J. Abell, T. Hatfield, and F.J.A. Lewis. 2022b. Review of Flow Effects on White Sturgeon. Draft V1. Consultant's report prepared for the Nechako Water Engagement Initiative Technical Working Group by Ecofish Research Ltd. *In Progress*.

Chudnow, R., W.M. Twardek, W. Rublee, and F.J.A. Lewis. 2022c. Nechako River Salmon – Review of Flow Effects on Chinook Salmon. Draft V1. Consultant's report prepared for the Nechako Water Engagement Initiative Technical Working Group by Ecofish Research Ltd. *In Progress*.

Chudnow, R., J. Braga, and F.J.A. Lewis. 2022d. Nechako River Salmon – Supplemental Nechako Chinook Salmon Escapement Analysis. Draft V1. Consultant's report prepared for the Nechako Water Engagement Initiative Technical Working Group by Ecofish Research Ltd. *In Progress*.

Cortes, R.M.V., M.T. Ferreira, S.V. Oliveira, and D. Oliveira. 2002. Macroinvertebrate community structure in a regulated river segment with different flow conditions. River Research and Applications 18(4):367–382.

Cunjak, R.A. 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. Canadian Journal of Fisheries and Aquatic Sciences 53(S1):267–282.

Dare, M.R., W.A. Hubert, and K.G. Gerow. 2002. Changes in Habitat Availability and Habitat Use and Movements by Two Trout Species in Response to Declining Discharge in a Regulated River during Winter. North American Journal of Fisheries Management 22(3):917–928.

Davie, A.W. and S.M. Mitrovic. 2014. Benthic algal biomass and assemblage changes following environmental flow releases and unregulated tributary flows downstream of a major storage. Marine and Freshwater Research 65(12):1059.

Dewson, Z.S., A.B.W. James, and R.G. Death. 2007. A review of the consequences of decreased flow for instream habitat and macroinvertebrates. Journal of the North American Benthological Society 26(3):401–415.

DFO (Fisheries and Oceans Canada). 2014. Recovery strategy for White Sturgeon (*Acipenser transmontanus*) in Canada. Fisheries and Oceans Canada, Ottawa, Canada.

DFO (Fisheries and Oceans Canada). 2021. Canadian Science Advisory Secretariat (CSAS). Available online at: https://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm. Accessed on August 18, 2022.

DFO (Fisheries and Oceans Canada). 2022. Fisheries and Oceans Canada Library. Available online at: https://science-libraries.canada.ca/eng/fisheries-oceans/. Accessed on August 18, 2022.

DosSantos, J.M. 1985. Comparative food habits and habitat selection of mountain whitefish and rainbow trout in the Kootenai River, Montana. Master of Science, Montana State University, Bozeman, Montana, USA.

Duan, X., Z. Wang, and S. Tian. 2008. Effect of streambed substrate on macroinvertebrate biodiversity. Frontiers of Environmental Science & Engineering in China 2(1):122–128.

Envirocon Ltd. 1984. Fisheries Resources of the Nechako River system baseline information. Kemano Completion Hydroelectric Development. Vancouver, BC, Canada.

Envirocon Ltd. 1989. Kemano completion Project environmental studies: Potential for entrainment of fishes through the proposed power plant intake in West Tahtsa Lake and water release facilities at Kenney Dam: A preliminary environmental impact assessment. Prepared for Aluminium Company of Canada, Ltd. Vancouver, B.C.

Falke, J.A., K.R. Bestgen, and K.D. Fausch. 2010. Streamflow Reductions and Habitat Drying Affect Growth, Survival, and Recruitment of Brassy Minnow across a Great Plains Riverscape. Transactions of the American Fisheries Society 139(5):1566–1583.

Faulkner, G. and B. Ennevor. 1999. Winter conditions on the Nechako River, 1992 - 1993. Nechako Fisheries Conservation Program, Nechako Fisheries Conservation Program data report M92-4, Vancouver, BC, Canada.

Faulkner, G. 1994. Winter conditions on the Nechako River, 1991 - 1992. Nechako Fisheries Conservation Program, Nechako Fisheries Conservation Program data report M91-4, Vancouver, BC, Canada.

Faulkner, G. 1999. Winter conditions on the Nechako River, 1990 - 1991. Nechako Fisheries Conservation Program, Nechako Fisheries Conservation Program data report M90-4, Vancouver, BC, Canada.

Faulkner, S., T. Hatfield, S. Buchanan, D. Bustard, and A. Lewis. 2011. Salmonid winter ecology in interior BC streams subject to severe icing. Draft 1. Consultant's report prepared by Ecofish Research Ltd and Solander Ecological Research, February 2012.

French, T. 2005. Water and Sediment Quality in the Nechako River (British Columbia, Canada): The Synergistic Effects of Point-Source Effluents, Historic Flow Reductions and Submerged Macrophytes. Prepared for the Nechako White Sturgeon Recovery Initiative, c/o BC Ministry of Water, Land and Air Protection, Environmental Stewardship Division, Prince George, British Columbia, Canada.

Gateuille, D., P.N. Owens, E.L. Petticrew, B.P. Booth, T.D. French, and S.J. Déry. 2019. Determining contemporary and historical sediment sources in a large drainage basin impacted by cumulative effects: the regulated Nechako River, British Columbia, Canada. Journal of Soils and Sediments 19(9):3357–3373.

Hagen, J. and S. Decker. 2011. The status of bull trout in British Columbia: A synthesis of available distribution, abundance, trend, and threat information. Ministry of Environment Ecosystems Protection & Sustainability Branch, Aquatic Conservation Science Section, (FTC 110; Fisheries Technical Report.

Hamilton, R. 1987. Relationship of flow to rearing habitat. Expert report prepared for Nechako court case. Dept. of Fisheries and Oceans, Habitat Management Division, Vancouver, B.C.

Hart, J.L. and W.A. Clemens. 1988. Pacific fishes of Canada. Fisheries Research Board of Canada, Ottawa, Ont.

Hay and Company Consultants Inc. 2000. Options for passing flows through the Cheslatta Fan. Report prepared for the Nechako Environmental Enhancement Fund Management Committee MENV-22, Vancouver, BC, Canada.

Healey, M.C. 1987. The Ecology of Chinook Salmon that spawn in headwater tributaries and river flows necessary to conserve such populations. Nechako River Court Action. DFO Expert Reports Volume 1 of 8.

Healey, M.C. 1991. Life history of Chinook Salmon (*Oncorhynchus tshawytscha*). Pages 311–394 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. UBC Press, Vancouver.

Hilborn, R. and C.J. Walters. 1992. Quantitative fisheries stock assessment and management: Choice, dynamics and uncertainty. Chapman and Hall.

Hiscock, M.J., D.A. Scruton, J.A. Brown, and K.D. Clarke. 2002. Winter Movement of Radio-Tagged Juvenile Atlantic Salmon in Northeast Brook, Newfoundland. Transactions of the American Fisheries Society 131(3):577–581.

Huusko, A., L. Greenberg, M. Stickler, T. Linnansaari, M. Nykänen, T. Vehanen, S. Koljonen, P. Louhi, and K. Alfredsen. 2007. Life in the ice lane: the winter ecology of stream salmonids. River Research and Applications 23(5):469–491.

Jakober, M.J., T.E. McMahon, R.F. Thurow, and C.G. Clancy. 1998. Role of stream ice on fall and winter movements and habitat use by bull trout and cutthroat trout in Montana headwater streams. Transactions of the American Fisheries Society: 223–235.

Johnson, S., J. Abell, and J. Kurtz. 2022a. Nechako River Productivity. Draft V1. Consultant's report prepared for the Nechako Water Engagement Initiative Technical Working Group by Ecofish Research Ltd. *In Progress.*

Johnson, S., I. Girard, and J. Kurtz. 2022b. Issue #2 – Nechako River Fish Access to Tribs and Side-Channels. Draft V1. Consultant's memorandum prepared for the Nechako Water Engagement Initiative Technical Working Group by Ecofish Research Ltd. *In Progress*.

Jowett, I.G. and M.J. Duncan. 1990. Flow variability in New Zealand rivers and its relationship to in-stream habitat and biota. New Zealand Journal of Marine and Freshwater Research 24(3):305–317.

Lindstrom, J.W. and W.A. Hubert. 2004. Ice Processes Affect Habitat Use and Movements of Adult Cutthroat Trout and Brook Trout in a Wyoming Foothills Stream. North American Journal of Fisheries Management 24(4):1341–1352.

Lyons, L.C. and P.A. Larkin. 1952. The effects on sport fisheries of the Aluminum Company of Canada development in the Nechako Drainage. B.C. Game Department, Game Commission Office, Fisheries Management Report 10.

Lister, D.B. and C.E. Walker. 1966. The effect of flow control on freshwater survival of chum, coho, and chinook salmon in the Big Qualicum River. Canadian Fish Culturist 37:3–25.

Lytle, D.A. and N.L. Poff. 2004. Adaptation to natural flow regimes. Trends in Ecology & Evolution 19(2):94–100.

Maciolek, J.A. and P.R. Needham. 1952. Ecological Effects of Winter Conditions on Trout and Trout Foods in Convict Creek, California, 1951. Transactions of the American Fisheries Society 81(1):202–217.

McAdam, S.O. 2011. Effects of substrate condition on habitat use and survival by white sturgeon (*Acipenser transmontanus*) larvae and potential implications for recruitment. Canadian Journal of Fisheries and Aquatic Sciences 68(5):812–822.

McAdam, S.O. 2012. Diagnosing white sturgeon (*Acipenser transmontanus*) recruitment failure and the importance of substrate condition to yolksac larvae survival. PhD Dissertation, University of British Columbia, Vancouver, BC, Canada.

McAdam, D.S.O. 2015. Retrospective weight-of-evidence analysis identifies substrate change as the apparent cause of recruitment failure in the upper Columbia River white sturgeon (*Acipenser transmontanus*). Canadian Journal of Fisheries and Aquatic Sciences 72(8):1208–1220.

McAdam, S.O., C.J. Walters, and C. Nistor. 2005. Linkages between White Sturgeon Recruitment and Altered Bed Substrates in the Nechako River, Canada. Transactions of the American Fisheries Society 134(6):1448–1456.

McMahon, T.E. and G.F. Hartman. 1989. Influence of Cover Complexity and Current Velocity on Winter Habitat Use by Juvenile Coho Salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 46(9):1551–1557.

McPhail, J.D. 2007. The freshwater fishes of British Columbia. The University of Alberta Press, Edmonton, Alberta, Canada.

McPhail, J.D. and R. Carveth. 1993. Field key to the freshwater fishes of British Columbia. Province of British Columbia Resources Inventory Committee, Victoria, British Columbia.

Minshall, G.W. and P.V. Winger. 1968. The Effect of Reduction in Stream Flow on Invertebrate Drift. Ecology 49(3):580–582.

Mitro, M.G., A.V. Zale, and B.A. Rich. 2003. The relation between age-0 rainbow trout (*Oncorhynchus mykiss*) abundance and winter discharge in a regulated river. Canadian Journal of Fisheries and Aquatic Sciences 60(2):135–139.

Moog, O. 1993. Quantification of daily peak hydropower effects on aquatic fauna and management to minimize environmental impacts. Regulated Rivers: Research & Management 8(1–2):5–14.

Morgan, R.P., R.E. Jacobsen, S.B. Weisberg, L.A. McDowell, and H.T. Wilson. 1991. Effects of Flow Alteration on Benthic Macroinvertebrate Communities below the Brighton Hydroelectric Dam. Journal of Freshwater Ecology 6(4):419–429.

NEEF (Nechako Environmental Enhancement Fund). 2022. Nechako Environmental Enhancement Fund Resource Library. Available online at: https://www.neef.ca/resources/resource-library. Accessed on August 20, 2022.

Neill, C.R. 1987. Effects of flow regulation on channel morphology, sediment transport and deposition, and flushing flows. Nechako River Court Action. DFO Expert Reports Volume 7 of 8.

NFCP (Nechako Fisheries Conservation Program). 2005. Nechako Fisheries Conservation Program technical data review 1988-2002. Nechako Fisheries Conservation Program, Vanderhoof, B.C.

NFCP (Nechako Fisheries Conservation Program). 2022. Library. https://www.nfcp.org/library.

NHC (Northwest Hydraulic Consultants). 2015. Nechako Sturgeon Spawning Gravel September 2012 Substrate Assessment. Report prepared for British Columbia Ministry of Forests, Lands and Natural Resource Operations.

NHC (Northwest Hydraulic Consultants). 2016. Sediment Transport Investigation on the Vanderhoof Reach of the Nechako River. Page 69. Report prepared for British Columbia Ministry of Forests, Lands and Natural Resource Operations.

Nunn, A.D., L.H. Tewson, and I.G. Cowx. 2012. The foraging ecology of larval and juvenile fishes. Reviews in Fish Biology and Fisheries 22(2):377–408.

Pillipow, R. and C. Williamson. 2004. Goat River bull trout (*Salvelinus confluentus)* biotelemetry and spawning assessments 2002–03. British Columbia Journal of Ecosystems and Management 4(2).

Poff, N., J.D. Allan, M. Bain, J. Karr, K. Prestegaard, B. Richter, R. Sparks, and J. Stromberg. 1997. The Natural Flow Regime: A Paradigm for River Conservation and Restoration. Bioscience 47.

Raleigh, R.F., T. Hickman, R.C. Solomon, and P.C. Nelson. 1984. Habitat suitability information: rainbow trout. United States Fish and Wildlife Service, FWS/OBS-82/10.60.

Raleigh, R.F., W.J. Miller, and P.C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: Chinook Salmon. 82 (10.122).

Raymond, H.L. 1968. Migration Rates of Yearling Chinook Salmon in Relation to Flows and Impoundments in the Columbia and Snake Rivers. Transactions of the American Fisheries Society 97(4):356–359.

Reeves, G.H., F.H. Everest, and J.D. Hall. 1987. Interactions Between the Redside Shiner (*Richardsonius balteatus*) and the Steelhead Trout (*Salmo gairdneri*) in Western Oregon: The Influence of Water Temperature. Canadian Journal of Fisheries and Aquatic Sciences 44(9):1603–1613.

Reid Crowther and Partners Ltd. 1987. A study of some aspects of the geomorphology of the Nechako River. Report prepared for Dept. of Fisheries and Oceans, Habitat Protection Branch, Vancouver, BC.

Reid, A.J., A.K. Carlson, I.F. Creed, E.J. Eliason, P.A. Gell, P.T.J. Johnson, K.A. Kidd, T.J. MacCormack, J.D. Olden, S.J. Ormerod, J.P. Smol, W.W. Taylor, K.Tockner, J.C. Vermaire, D. Dudgeon, and S.J. Cooke. 2019. Emerging threats and persistent conservation challenges for freshwater biodiversity. Biological Reviews 94(3):849–873.

Reimers, P.E. 1968. Social behaviour among juvenile fall chinook salmon. Journal of the Fisheries Research Board of Canada 25:2005–2008.

Reiser, D.W. and T.A. Wesche. 1979. In Situ Freezing as a Cause of Mortality in Brown Trout Eggs. The Progressive Fish-Culturist 41(2):58–60.

Reiser, D.W., M.P. Ramsy, and T.R. Lambert. 1985. Review of flushing flow requirements in regulated streams.

Rideout, R.M. and J. Tomkiewicz. 2011. Skipped Spawning in Fishes: More Common than You Might Think. Marine and Coastal Fisheries 3(1):176–189.Roberge, M.J., M.B. Hume, C.K. Minns, and T. Slaney. 2002. Life history characteristics of freshwater fishes occurring in British Columbia and the Yukon, with major emphasis on stream habitat characteristics. Fisheries and Oceans Canada, Canadian Manuscript Report of Fisheries and Aquatic Sciences 2611, Cultus Lake, British Columbia, Canada.

Rodnick, K.J. 1983. Seasonal distribution and habitat selection by the redside shiner, *Richardsonius balteatus*, in a small Oregon Stream. Master of Science, Oregon State University, Corvallis, OR.

Rood, I.M. 1987. A study of some aspects of the geomorphology of the Nechako River. Report prepared by Reid Crowther and Partners Ltd., North Vancouver, British Columbia.

Ryder, R.A. and S.R. Kerr. 1989. Environmental priorities: placing habitat in perspective. Proceedings of the National Workshop on effects of habitat alteration on salmonid stocks 105:2–12.

Schmidt, B., K. Fitzsimmons, and A. Paul. 2019. Mountain whitefish overwintering habitat use in the McLeod River. Alberta Conservation Association, Sherwood Park, Alberta, Canada.

Schoby, G. and E. Keeley. 2011. Home range size and foraging ecology of bull trout and westslope cutthroat trout in the Upper Salmon River Basin, Idaho. Transactions of the American Fisheries Society 140:636–645.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada, Ottawa, Canada.

Simpkins, D.G., W.A. Hubert, and T.A. Wesche. 2000. Effects of Fall-to-Winter Changes in Habitat and Frazil Ice on the Movements and Habitat Use of Juvenile Rainbow Trout in a Wyoming Tailwater. Transactions of the American Fisheries Society 129(1):101–118.

Slaney, P.A. 1986. An assessment of the rainbow trout (Salmo gairdneri) population in the upper Nechako River and the effects of a sportfishery closure. British Columbia Ministry of Environment, Lands, and Parks, Fisheries Branch, Fisheries Management Report 89, Victoria, British Columbia.

Slaney, P.A. 1987. Assessment of the influence of flows on rainbow trout and char populations of the Nechako River. Nechako River Court Action. DFO Expert Reports Volume 2 of 8.

Slaney, P.A., D.H.G. Ableson, and R.L. Morley. 1984. Habitat capability of the Nechako River for rainbow trout and char and the effects of various flow regimes. Page 35. British Columbia Fisheries Branch, 63.

Sturrock, A.M., S.M. Carlson, J.D. Wikert, T. Heyne, S. Nusslé, J.E. Merz, H.J.W. Sturrock, and R.C. Johnson. 2020. Unnatural selection of salmon life histories in a modified riverscape. Global Change Biology 26(3):1235–1247.

Sullivan, A.B., H.I. Jager, and R. Myers. 2003. Modelling white sturgeon movement in a reservoir: the effect of water quality and sturgeon density. Ecological Modelling 167(1–2):97–114.

Sykes, G.E., C.J. Johnson, and J.M. Shrimpton. 2009. Temperature and Flow Effects on Migration Timing of Chinook Salmon Smolts. Transactions of the American Fisheries Society 138(6):1252–1265.

Taylor, E., R. Chudnow, R. Pillipow, I. Spendlow, and B. Poorten. 2021. Microsatellite DNA analysis of overwintering bull trout (*Salvelinus confluentus*) and its implications for harvest regulation and habitat management. Fisheries Management and Ecology 0:1–11.

Tennant, D.L. 1976. Instream Flow Regimens for Fish, Wildlife, Recreation and Related Environmental Resources. Fisheries 1(4):6–10.

Tredger, D., B. Yaworski, and J. Ptolemy. 1985. Reconnaissance report: Nechako River. Columbia Ministry of Environment Fish and Wildlife Branch.

Trussart, S., D. Messier, V. Roquet, and S. Aki. 2002. Hydropower projects: a review of most effective mitigation measures. Energy Policy 30(14):1251–1259.

Twomey, K.A., K.L. Williamson, and P.C. Nelson. 1984. Habitat suitability index models and instream flow suitability curves: White sucker. United States Fish and Wildlife Service, FWS/OBS-82/10.64.

UNBC (University of Northern British Columbia). 2022. Northern BC Archives and Special Collections - Northern BC Archives. Available online at: https://search.nbca.unbc.ca/index.php/northern-bc-archives-special-collections-1. Accessed on May 15, 2022.

Walsh, M. and D. Calkins. 1986. River ice and salmonids. Fourth workshop on hydraulics of river ice. Ecole Polytechnique, Montreal, Quebec, Canada.

Ward, J.V. and J.A. Stanford. 1987. The Ecology of Regulated Streams: Past Accomplishments and Directions for Future Research. Pages 391–409 *in* J. F. Craig and J. B. Kemper, editors. Regulated Streams: Advances in Ecology. Springer US, Boston, MA.

Whitmore, C.M., C.E. Warren, and P. Doudoroff. 1960. Avoidance Reactions of Salmonid and Centrarchid Fishes to Low Oxygen Concentrations. Transactions of the American Fisheries Society 89(1):17–26.

Wilkins, S.P. and G. Faulkner. 1999a. Winter conditions on the Nechako River, 1987 - 1988. Nechako Fisheries Conservation Program, Nechako Fisheries Conservation Program data report M88-6, Vancouver, BC, Canada.

Wilkins, S.P., and G. Faulkner. 1999b. Winter conditions on the Nechako River, 1988 - 1989. Nechako Fisheries Conservation Program, Nechako Fisheries Conservation Program data report M88-8, Vancouver, BC, Canada.

Wilkins, S.P. and G. Faulkner. 1999c. Winter conditions on the Nechako River, 1989 - 1990. Nechako Fisheries Conservation Program, Nechako Fisheries Conservation Program data report M89-4, Vancouver, BC, Canada.

Zorn, T.G., P.W. Seelbach, and E.S. Rutherford. 2012. A Regional-Scale Habitat Suitability Model to Assess the Effects of Flow Reduction on Fish Assemblages in Michigan Streams [1]: A Regional-Scale Habitat Suitability Model to Assess the Effects of Flow Reduction on Fish Assemblages in Michigan Streams. JAWRA Journal of the American Water Resources Association 48(5):871–895.

APPENDICES

Appendix A. Resident Fish Periodicity, Distribution, and Habitat Summary

LIST OF TABLES

Table 1. Resident fish periodicity, distribution, and habitat summary.

Family	Species	Scientific Name	Life History Periods[1]			Preferred Habitat Characteristics[2]					Spatial Behaviour	References
			Spawning	Fry Emergence	Overwintering	Spawning	Incubation	Rearing	Adult	Overwintering		
Burbots (Lotidae)	Burbot	*Lota lota*	Dec - Mar	Dec - Apr	None	Low velocity, silt to fine gravel substrate, e.g., behind deposition bars.	Non-adhesive, demersal on substrate.	**YOY:** Unknown, may concentrate behind deposition bars until shifting to benthic habitat. **JUV:** Cover (e.g., boulders).	Deep main channels, turbid water.	Deep water (i.e., pools, lakes).	Multiple kilometer spawning movements.	Scott and Crossman 1973; Roberge *et al.* 2002; McPhail 2007; Ashton *et al.* 2019
Lampreys (Petromyzontidae)	Pacific Lamprey	*Entosphenus tridentatus*	Apr - Jul	Aug - Nov	Unknown	0.3 - 4.0 m deep, 0.37 - 0.46 m/s velocities, e.g., pool tailouts, gravel shoals.	Demersal in substrate nest.	**YOY:** Shallow, low velocity water, buried in fine substrate, near river margins. **JUV:** 0.6 - 0.8 m deep, 0.0 - 0.1 m/s velocity, buried in fine substrate.	Under rocky substrate.	Dependent on migration timing. Can occur in freshwater or ocean.	Anadromous species. **Adult:** Upstream freshwater migrations (Jul - Jun). **JUV:** Outmigration (Sep - Jun/Jul).	Scott and Crossman 1973; Hart and Clemens 1988; McPhail 2007
Minnows (Cyprinidae)	Brassy Minnow	*Hybognathus hankinsoni*	Jun - Aug	Jun - Aug	Nov - Mar[3]	Shallow, vegetative cover, fine substrate.	Adhesive, demersal on substrate of vegetation.	**YOY** & **JUV**: < 1.5 m deep, fine substrate, vegetative cover.	< 0.5 m/s velocity, fine substrate, vegetative cover.	Deep water (i.e., pools, lakes).	Schooling behaviour, seasonal habitat shifts to fluvial habitats.	Roberge *et al.* 2002; Scheurer *et al.* 2003; McPhail 2007; Radford and Sullivan 2014
Minnows (Cyprinidae)	Lake Chub	*Couesius plumbeus*	May - Aug	May - Aug	Nov - Mar[3]	Shallow, substrate unimportant.	Non-adhesive, demersal eggs.	**YOY**: < 1 m deep margins, vegetative cover, fine substrates. **JUV**: Pools or littoral habitat, vegetative cover, fine substrates.	Benthic specialists. In shallow water, form aggregations around woody debris.	Deep water (i.e., pools, lakes).[4]	Schooling behavior when appropriate cover unavailable. Evidence of spawning and post-spawning dispersal (tributary habitat).	Brown *et al.* 1970; Lane *et al.* 1996; Roberge *et al.* 2002; McPhail 2007; Davis 2016
Minnows (Cyprinidae)	Leopard Dace	*Rhinichthys falcatus*	Jul	Jul - Aug	Nov - Mar[3]	Flowing water, rock substrate.	Adhesive, demersal in substrate (i.e., in intersitial space).	**YOY** & **JUV**: < 0.10 m deep, < 0.50 m/s velocity, fine substrate (e.g., shallow pools, backwaters).	< 1 m deep, < 0.40 m/s, fine to cobble substrates (e.g., gravel deposition areas, braided channels).	Deep water (i.e., pools).[4]	Juveniles move into higher velocity margin habitats during freshet.	Roberge *et al*. 2002; McPhail 2007; Zimmerman 2009
Minnows (Cyprinidae)	Longnose Dace	*Rhinichthys cataractae*	May - Jul	May - Aug	Nov - Mar[3]	0.4 - 1.0 m/s surface velocities, coarse gravel substrate, riffles.	Adhesive, demersal in substrate nest.	**YOY** & **JUV**: Shallow pools, riffles, and other low velocity areas, fine substrate.	0.4 - 0.5 m/s velocity, coarse gravel to boulder substrates, vegetative cover.	Deep water, riffles.	Evidence of major seasonal movements.	McPhail and Lindsay 1970; Peden 1991; Roberge *et al.* 2002; McPhail 2007

[1] All resident fish species rear year-round.

[2] Quantified estimates of habitat features are based on available literature. Where no quantitative estimate is available qualitative estimates (i.e., shallow, deep, low, medium, high / shallow, deep / fine, medium, large) are used.

[3] Species (or closely-related species) are known to overwinter, but specific months are unknown. November-March assigned based on minimum winter season in the study area.

[4] Assigned based on information available for similar species.

Table 1. Continued (2 of 4).

Family	Species	Scientific Name	Life History Periods[1]			Preferred Habitat Characteristics[2]					Spatial Behaviour	References
			Spawning	Fry Emergence	Overwintering	Spawning	Incubation	Rearing	Adult	Overwintering		
Minnows (Cyprinidae)	Northern Pikeminnow	*Ptychocheilus oregonensis*	May - Jun	May - Aug	Nov - Mar[3]	< 0.4 m/s velocity, gravel or cobble substrate.	Adhesive, demersal on substrate.	**YOY** & **JUV**: < 0.25 m deep, vegetative cover, fine substrate.	> 1 m deep, < 1 m/s velocity.	Deep water.	Upstream spawning migration.	Jeppson and Platts 1959; Beamesderfer 1992; Roberge *et al.* 2002; McPhail 2007
Minnows (Cyprinidae)	Peamouth Chub	*Mylocheilus caurinus*	May - Jun	May - Jun	Nov - Mar[3]	Flowing water, gravel substrate.	Adhesive, demersal on substrate.	**YOY**: Tributary mouths, shallow, low velocity water. **JUV**: < 0.5 m deep, < 0.1 m/s velocity, vegetative cover, gravel substrate.	Low velocity, vegetative cover, gravel or rubble substrate.	Deep water (i.e., pools).[4]	Schooling behavior and seasonal migrations. Juveniles move into low-gradient tributaries (summer) and return to main river (overwinter).	Scott and Crossman 1973; Porter and Rosenfeld 1999; Roberge *et al.* 2002; McPhail 2007; Davis 2016
Minnows (Cyprinidae)	Redside Shiner	*Richardsonius balteatus*	Apr - Jul	May - Aug	Nov - Mar[3]	0.1 m deep, gravel substrate, vegetative cover, riffles.	Adhesive, demersal on substrate or vegetation.	**YOY** & **JUV**: < 0.5 m deep, < 0.1 m/s velocity, fine to gravel substrate.	1 - 2 m deep, < 20 m/s velocity, fine substrate, vegetative or woody cover.	Deep water.	Unknown.	Porter and Rosenfeld 1999; Roberge *et al.* 2002; McPhail 2007
Salmonids (Salmonidae)	Bull Trout	*Salvelinus confluentus*	Aug - Sep	Apr - May	Oct - Apr	Low gradient, 0.03 - 0.80 m/s velocity, gravel, cover, e.g., (undercut banks, pools).	Demersal in redd.	**YOY**: Low velocity margins, unembedded gravel. **JUV**: Pools, large woody debris.	Pools, overhead cover, groundwater input.	Low velocity, instream or overhead cover, groundwater input.	Long distance spawning migrations and post-spawning dispersal. Fidelity to spawning and wintering sites.	Post and Johnston 2002; McPhail 2007; Starcevich *et al.* 2012
Salmonids (Salmonidae)	Mountain Whitefish	*Prosopium williamsoni*	Oct - Nov	Mar - Jun	Nov - Mar	Upwelling inflow, pool heads, riffles.	Adhesive, demersal on substrate.	**YOY** & **JUV**: < 0.5 m deep, low velocity, sand to fine gravel substrate.	0.6 - 1.1 m deep, 30 - 80 m/s velocity, coarse gravel or cobble substrate (e.g., pools, riffles, runs).	Shallow (< 1 m), large cobble substrate.	Spawning, foraging movements and schooling behavior.	Ford *et al.* 1995; McPhail and Troffe 1998; McPhail 2007; Schmidt *et al.* 2019

[1] All resident fish species rear year-round.
[2] Quantified estimates of habitat features are based on available literature. Where no quantitative estimate is available qualitative estimates (i.e., shallow, deep, low, medium, high / shallow, deep / fine, medium, large) are used.
[3] Species (or closely-related species) are known to overwinter, but specific months are unknown. November-March assigned based on minimum winter season in the study area.
[4] Assigned based on information available for similar species.

Table 1. Continued (3 of 4).

Family	Species	Scientific Name	Life History Periods[1]			Preferred Habitat Characteristics[2]					Spatial Behaviour	References
			Spawning	Fry Emergence	Overwintering	Spawning	Incubation	Rearing	Adult	Overwintering		
Salmonids (Salmonidae)	Rainbow Trout	*Oncorhynchus mykiss*	Apr - Jun	Jun - Aug	Oct - May	0.3 - 0.9 m/s velocity, fine substrate, vegetated banks, riffle, pools, pool tailouts.	Demersal in redd.	**YOY**: Shallow, low velocity margins, gravel substrate. **JUV**: < 0.25 m deep, 0.2 -0.4 m/s velocity margins, cobble to boulder substrate.	Riffles, runs, glides, pools, cover (e.g., riparian vegetation, large woody debris, cobble to boulder substrates).	Daytime concealment (e.g., cobble-boulder substrate or woody debris).	Spawning migrations to tributary habitat and post-spawning dispersal.	Scott and Crossman 1973; Humpesch 1985; Raleigh *et al.* 1984; Bjornn and Reiser 1991; Flebbe and Dolloff 1995; Meyer and Gregory 2000; Roberge *et al.* 2002; McPhail 2007
Sculpins (Cottidae)	Prickly Sculpin	*Cottus asper*	Feb - Jul	Feb - Aug	None	Low velocity, cobble, boulder, flat rock substrates, woody debris.	Adhesive, under nest rock (i.e., in substrate).	**YOY** & **JUV**: Low velocity margins, cover (e.g., woody debris).	Low velocity, boulder substrate, large woody debris.	Deeper water, cover.	Unknown.	Porter and Rosenfeld 1999; Roberge *et al.* 2002; EBA 2006; McPhail 2007; Tabor *et al.* 2007
Sculpins (Cottidae)	Slimy Sculpin	*Cottus cognatus*	Apr - May	Apr - Jun	None	Shallow, rocky substrate.	Adhesive, under nest rock (i.e., in substrate).	**YOY**: Low velocity margins, seasonally flooded vegetation. **JUV**: Shallow, low velocity, gravel to cobble substrate.	Moderate velocity riffles or runs, coarse gravel or cobble substrates.	Unknown	Relatively stationary (i.e., movements generally < 100 m).	Roberge *et al.* 2002; McPhail 2007; Gray *et al.* 2018
Suckers (Catostomidae)	Bridgelip Sucker	*Catostomus columbianus*	Apr - Jun	Jul	Nov - Mar[3]	Riffles adjacent to lower velocity areas.	Adhesive, demersal on or in substrate (i.e., interstitial spaces).	**YOY**: Shallow, margins, fine substrate. **JUV:** 0.1 -0.2 m/s velocity backwaters.	0.4-0.9 m/s velocity, rocky substrate.	Pools, riffles.[4]	Unknown.	Scott and Crossman 1973; Roberge *et al.* 2002; McPhail 2007
Suckers (Catostomidae)	Largescale Sucker	*Catostomus macrocheilus*	Apr - Jul	May - Aug	Nov - Mar[3]	Deep water near areas of slower water (e.g., pool tailouts).	Adhesive, demersal on or in substrate (i.e., interstitial spaces).	**YOY**: Shallow or open areas, low velocity, seasonally flooded vegetation. **JUV**: 0.25 - 0.50 m deep, low velocity, fine to cobble substrates.	Low to moderate gradient, slow water, deep pools.	Pools, riffles.[4]	Evidence of spawning migrations, otherwise relatively sedentary.	McEvoy 1998; Roberge *et al.* 2002; McPhail 2007

[1] All resident fish species rear year-round.

[2] Quantified estimates of habitat features are based on available literature. Where no quantitative estimate is available qualitative estimates (i.e., shallow, deep, low, medium, high / shallow, deep / fine, medium, large) are used.

[3] Species (or closely-related species) are known to overwinter, but specific months are unknown. November-March assigned based on minimum winter season in the study area.

[4] Assigned based on information available for similar species.

Table 1. Continued (4 of 4).

Family	Species	Scientific Name	Life History Periods[1]			Preferred Habitat Characteristics[2]					Spatial Behaviour	References
			Spawning	Fry Emergence	Overwintering	Spawning	Incubation	Rearing	Adult	Overwintering		
Suckers (Catostomidae)	Longnose Sucker	*Catostomus catostomus*	Apr - Jun	Apr - Jul	Nov - Mar[3]	0.30 - 0.45 m/s velocity riffles, gravel (0.5 - 10.0 cm) substrate.	Adhesive, demersal on or in substrate (i.e., interstitial spaces).	**YOY**: < 0.1 m deep water, low velocity, soft substrate, submerged vegetative cover. **JUV**: Shallow, low velocity areas, soft cover, (e.g., side-channels, beaver ponds).	Low to moderate gradient, low velocity, deep pools.	Pools, riffles.[4]	Evidence of complex spawning, foraging, and overwintering migrations, otherwise relatively sedentary.	Geen *et al.* 1966; McPhail 2007; McPhail and Lindsay 1970; Scott and Crossman 1973
Suckers (Catostomidae)	White Sucker	*Catostomus commersonii*	May - Jun	May - Jul	Nov - Mar[3]	< 1 m deep riffles adjacent to deeper pools, coarse gravel substrate.	Adhesive, demersal on or in substrate (i.e., interstitial spaces).	**YOY**: Shallow, weedy areas, soft substrate. **JUV**: Low velocity, silt-sand substrate, vegetative cover.	1 - 2 m deep, low gradient, low velocity, fine substrate.	Backwater channels, pools, runs.	Movement into tributary streams to spawn.	Geen *et al.* 1966; Nelson 1968; Corbett and Powles 1983; Quinn and Ross 1985; Brown *et al.* 2001; Roberge *et al.* 2002; McPhail 2007

[1] All resident fish species rear year-round.

[2] Quantified estimates of habitat features are based on available literature. Where no quantitative estimate is available qualitative estimates (i.e., shallow, deep, low, medium, high / shallow, deep / fine, medium, large) are used.

[3] Species (or closely-related species) are known to overwinter, but specific months are unknown. November-March assigned based on minimum winter season in the study area.

[4] Assigned based on information available for similar species.

Table 2. Resident fish thermal preferences summary.

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 *et al.* 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 & 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

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

Table 2. Continued (2 of 2).

Family	Species	Scientific Name	Temperature Preference / Tolerance[1]				References
			Spawning	Incubation	Rearing	Adult	
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**: 18.8 - 21.6 °C	**Opt**: 9.6 - 17.4 °C **SOpt**: > 22 °C	Rajagopal 1979; Ford *et al.* 1995; McPhail and Troffe 1998; Coker *et al.* 2001; 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.* 1976; 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.

REFERENCES

Ashton, N.K., N.R. Jensen, T.J. Ross, S.P. Young, R.S. Hardy, and K.D. Cain. 2019. Temperature and Maternal Age Effects on Burbot Reproduction. North American Journal of Fisheries Management 39(6):1192–1206.

Beamesderfer, R.C. 1992. Reproduction and early life history of northern squawfish, *Ptychocheilus oregonensis*, in Idaho's St. Joe River. Environmental Biology of Fishes 35(3):231–241.

Bear, E.A., T.E. McMahon, and A.V. Zale. 2007. Comparative Thermal Requirements of Westslope Cutthroat Trout and Rainbow Trout: Implications for Species Interactions and Development of Thermal Protection Standards. Transactions of the American Fisheries Society 136(4):1113–1121.

Bjornn, T.C. and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. Pages 83–138 *in* W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society, Maryland, United States of America.

Black, E.C. 1953. Upper Lethal Temperatures of Some British Columbia Freshwater Fishes. Journal of the Fisheries Research Board of Canada 10(4):196–210.

Brinkman, S.F., H.J. Crockett, and K.B. Rogers. 2013. Upper Thermal Tolerance of Mountain Whitefish Eggs and Fry. Transactions of the American Fisheries Society 142(3):824–831.

Brown, J.H., U.T. Hammer, and G.D. Koshinsky. 1970. Breeding Biology of the Lake Chub, *Couesius plumbeus*, at Lac la Ronge, Saskatchewan. Journal of the Fisheries Research Board of Canada 27(6):1005–1015.

Brown, R.S., G. Power, and S. Beltaos. 2001. Winter movements and habitat use of riverine brown trout, white sucker and common carp in relation to flooding andice break-up. Journal of Fish Biology 59:1126–1141.

Coker, G.A., C.B. Portt, and C.K. Minns. 2001. Morphological and ecological characteristics of Canadian freshwater fishes. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2554.

Corbett, B. and P.M. Powles. 1983. Spawning and Early-Life Ecological Phases of the White Sucker in Jack Lake, Ontario. Transactions of the American Fisheries Society 112(2B):308–313.

Darveau, C.A., E.B. Taylor, and P.M. Schulte. 2012. Thermal Physiology of Warm-Spring Colonists: Variation among Lake Chub (Cyprinidae: *Couesius plumbeus*) Populations. Physiological and Biochemical Zoology 85(6):607–617.

Davis, L. 2016. Overwinter habitat of minnows in small, southern Ontario streams. Master of Science, University of Guelph, Guelph, Ontario.

EBA (EBA Engineering Consultants Ltd.). 2006. The Kelowna Shore Zone Fisheries and Wildlife Habitat Assessment: Appendix A: Sculpin. EBA Engineering Consultants Ltd., Kelowna, British Columbia, Canada.

FERC (Federal Energy Regulatory Commission). 2011. Application for Hydropower License for the Boundary Hydroelectric Project and Application for Surrender of Hydropower License for the Sullivan Creek Project: Environmental Impact Statement. Federal Energy Regulatory Commission, Draft environmental impact assessment, Washington, DC.

Flebbe, P.A. and C.A. Dolloff. 1995. Trout Use of Woody Debris and Habitat in Appalachian Wilderness Streams of North Carolina. North American Journal of Fisheries Management 15(3):579–590.

Ford, B.S., P.S. Higgins, A.F. Lewis, K.L. Cooper, T.A. Watson, C.M. Gee, G.L. Ennis, and R.L. Sweeting. 1995. Literature review of the life history, habitat requirements, and mitigation/compensation strategies for thirteen sport fish species in the Peace, Liard, and Columbia River drainages in British Columbia. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2321.

Geen, G.H., T.G. Northcote, G.F. Hartman, and C.C. Lindsey. 1966. Life histories of two species ofcatostomid fishes in Sixteen mile Lake, British Columbia, with particular reference to inlet stream spawning. Journal of the Fisheries Research Board of Canada 23:1761–1788.

Gray, M.A., R.A. Curry, T.J. Arciszewski, K.R. Munkittrick, and S.M. Brasfield. 2018. The biology and ecology of slimy sculpin: A recipe for effective environmental monitoring. FACETS 3(1):103-127.

Hart, J.L. and W.A. Clemens. 1988. Pacific fishes of Canada. Fisheries Research Board of Canada, Ottawa, Ont.

Hasnain, S.S., C.K. Minns, and B.J. Shuter. 2010. Key Ecological Temperature Metrics for Canadian Freshwater Fishes. Ontario Ministery of Natural Resources, Sault, St. Marie, Ontario, Canada.

Hillman, T.W. and D. Essig. 1998. Review of bull trout temperature requirements: a response to the EPA bull trout temperature rule. Unpublished report prepared for Idaho Department of Environmental Quality. Bioanalysts, Inc., Boise, ID.

Humpesch, U. 1985. Inter- and intra-specific variation in hatching success and embryonic development of five species of salmonids and Thymallus thymallus. Archiv Fur Hydrobiologie 104(1):189–144.

Jeppson, P.W. and W. S. Platts. 1959. Ecology and Control of the Columbia Squawfish in Northern Idaho Lakes. Transactions of the American Fisheries Society 88(3):197–202.

Koenst, W.M. and L.L. Smith. 1982. Factors influencing growth and survival of white sucker, *Catostomus commersoni*. Enivronmental Protection Agency (EPA).

Lane, J.A., C.B. Portt, and C.K. Minns. 1996. Nursery habitat characteristics of Great Lakes fishes. Fisheries and Oceans Canada (DFO), 2338, Ottawa, Canada.

McEvoy, D.H. 1998. Movement and habitat use of the largescale sucker (*Catostomus macrocheilus*) in the Clark Fork River Montana. Master of Science, The University of Montana, Missoula, Montana, USA.

McPhail, J.D. 2007. The freshwater fishes of British Columbia. The University of Alberta Press, Edmonton, Alberta, Canada.

McPhail, J.D. and C.C. Lindsey. 1970. Freshwater Fishes of Northwestern Canada and Alaska.

McPhail, J.D. and C.B. Murray. 1979. Early life history and ecology of Dolly Varden (*Salvelimus Malma*) in the Upper Arrow lakes. Report prepared for B.C. Hydro and Power Authority and Kootenay Region Fish and Wildlife Branch.

McPhail, J.D. and P.M. Troffe. 1998. The mountain whitefish (*Prosopium williamsoni*): a potential indicator species for the Fraser System. University of British Columbia, Report prepared for Environment Canada Environmental Conservation Branch, Vancouver, BC, Vancouver, BC, Canada.

Meeuwig, M.H., J.M. Bayer, and J.G. Seelye. 2005. Effects of Temperature on Survival and Development of Early Life Stage Pacific and Western Brook Lampreys. Transactions of the American Fisheries Society 134(1):19–27.

Meyer, K.A. and J.S. Gregory. 2000. Evidence of concealment behavior by adult rainbow trout and brook trout in winter. Ecology of Freshwater Fish 9(3):138–144.

Nelson, J.S. 1968. Hybridization and Isolating Mechanisms Between *Catostomus commersonii* and *C. macrocheilus* (Pisces: Catostomidae). Journal of the Fisheries Research Board of Canada 25(1):101–150.

Peden, A.E. 1991. Status of the leopard dace, *Rhinichthys falcatus*, in Canada. Canadian Field Naturalist 105:179–188.

Porter, M. and J. Rosenfeld. 1999. Microhabitat selection and partitioning by an assemblage of fish in the Nazko River. British Columbia Ministry of Fisheries, Fisheries Project Report RD 77, Vancouver, BC, Canada.

Post, J. and F. Johnston. 2002. Status of bull trout *Salvelinus confluentus* in Alberta. Wildlife Status Report No. 39; Wildlife Status Report.

Quinn, S.P. and M.R. Ross. 1985. Non-Annual Spawning in the White Sucker, *Catostomus commersoni*. Copeia 1985(3):613.

Radford, D.S. and M. Sullivan. 2014. Status of the Brassy Minnow (*Hybognathus hankinsoni*) in Alberta. Alberta Conservation Association, Alberta Wildlife Status Report 68.

Rajagopal, P.K. 1979. The embryonic development and the thermal effects on the development of the mountain whitefish, *Prosopium williamsoni* (Girard). Journal of Fish Biology 15(2):153–158.

Raleigh, R.F., T. Hickman, R.C. Solomon, and P.C. Nelson. 1984. Habitat suitability information: rainbow trout. United States Fish and Wildlife Service, FWS/OBS-82/10.60.

Roberge, M.J., M.B. Hume, C.K. Minns, and T. Slaney. 2002. Life history characteristics of freshwater fishes occurring in British Columbia and the Yukon, with major emphasis on stream habitat characteristics. Fisheries and Oceans Canada, Canadian Manuscript Report of Fisheries and Aquatic Sciences 2611, Cultus Lake, British Columbia, Canada.

Scheurer, J.A., K.D. Fausch, and K.R. Bestgen. 2003. Multiscale Processes Regulate Brassy Minnow Persistence in a Great Plains River. Transactions of the American Fisheries Society 132(5):840–855.

Schmidt, B., K. Fitzsimmons, and A. Paul. 2019. Mountain whitefish overwintering habitat use in the McLeod River. Page 19. Alberta Conservation Association, Sherwood Park, Alberta, Canada.

Schultz, L.P. 1935. The Spawning Habits of the Chub, *Mylocheilus Caurinus*–A Forage Fish of Some Value. Transactions of the American Fisheries Society 65(1):143–147.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Reseach Board of Canada, Ottawa, Canada.

Selong, J.H., T.E. McMahon, A.V. Zale, and F.T. Barrows. 2001. Effect of Temperature on Growth and Survival of Bull Trout, with Application of an Improved Method for Determining Thermal Tolerance in Fishes. Transactions of the American Fisheries Society 130(6):1026-1037.

Starcevich, S., P. Howell, S. Jacobs, and P. Sankovich. 2012. Seasonal movement and distribution of fluvial adult bull trout in selected watersheds in the Mid-Columbia River and Snake River Basins. PLoS ONE 7(5).

Symons, P.E.K., J.L. Metcalfe, and G.D. Harding. 1976. Upper Lethal and Preferred Temperatures of the Slimy Sculpin, *Cottus cognatus*. Journal of the Fisheries Research Board of Canada 33(1):180-183.

Tabor, R.A., E.J. Warner, K.L. Fresh, B.A. Footen, and J.R. Chan. 2007. Ontogenetic Diet Shifts of Prickly Sculpin in the Lake Washington Basin, Washington. Transactions of the American Fisheries Society 136(6):1801–1813.

Uh, C.T. and T.A. Whitesel. 2016. The potential threat of a warming climate to Pacific Lamprey: thermal tolerance of larvae. Poster session, Seaside, OR.

Zimmerman, B.J. 2009. Microhabitat Use by the Redside Dace (*Clinostomus Elongatus*) in Ohio. Master of Science, Bowling Green State University, Bowling Green, Ohio, United States of America.

Appendix B. Habitat-Flow Relationship Primer

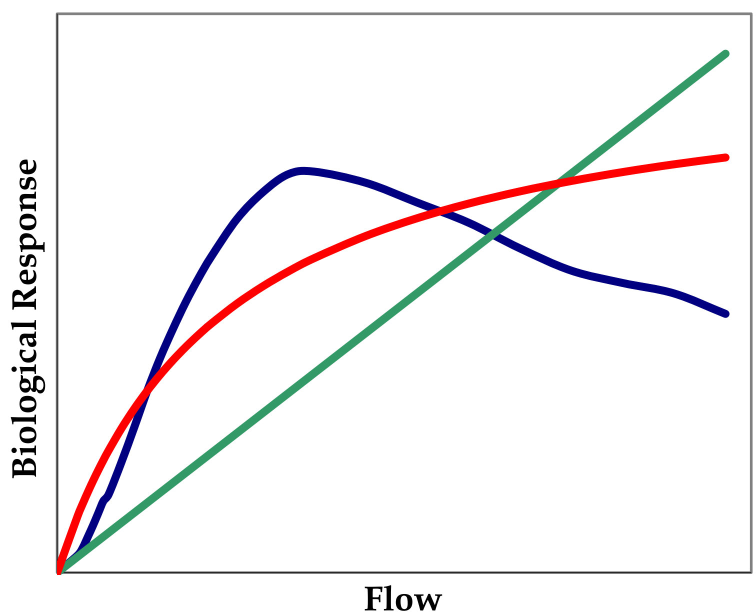
TABLE OF CONTENTS

LIST OF FIGURES

1. QUANTIFYING THE RELATIONSHIP BETWEEN FISH AND FLOW

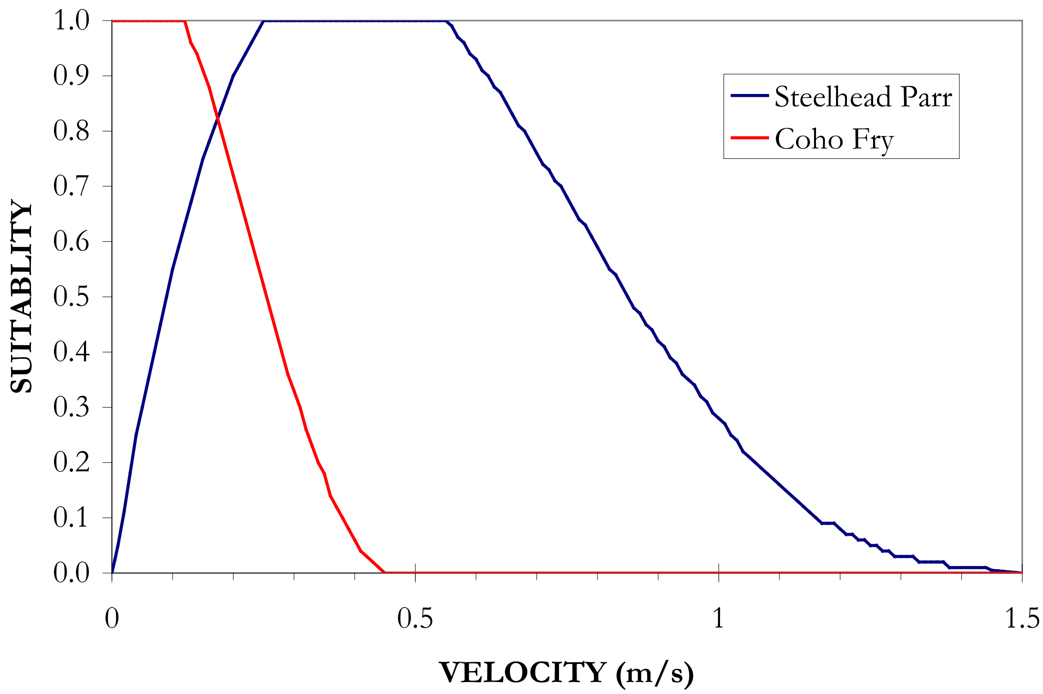
A key aspect of the relationship between fish and flow can be characterized using a response curve. The shape of this curve is a critical determinant of recommendations regarding water use and the protection of aquatic resources (Figure 1). The selection of the curve that is most appropriate for a particular system will be a balance of available scientific information and the practicalities imposed by existing legislation and policy. Numerous methods have been devised to predict the effect of changes in flow on fish (see EA Engineering, Science and Technology Inc. 1986; Jowett 1997), but the underlying premise of almost all methods is a correlation between habitat and fish abundance or biomass. Although abundance or biomass are the parameters that managers are ultimately concerned with, developing relationships of flow vs. abundance is difficult. For assessment purposes, resource managers have therefore often turned to simpler surrogate measures, the most common of which is the relationship between fish habitat and flow. This metric is relatively easy to quantify in relation to flow and for this reason, key components of environmental legislation are generally habitat-based.

Figure 1. Example of typical response curves characterizing the relationship between fish communities and flow.



Habitat suitability index (HSI) curves use directed observations and experimental studies to quantitatively describe the relationship between fish behaviour, measured as relative habitat use, and habitat characteristics (e.g., hydrologic variables such as depth, velocity, substrate, and cover). Reliable curves can be constructed when fish presence is measured consistently and accurately over the full range of conditions available over many streams. Typically, fish habitat observations are presented as a histogram or a probability-of-use curve that is scaled to one. These indices demonstrate that fish are more commonly found at specific parameter values. It also implies that fish can discriminate between these values either directly or indirectly by sensing covarying parameters and that these habitat choices have adaptive significance, conferring higher fitness. There are distinct differences in habitat use between species and life histories. These differences in microhabitat use can drive differences in species abundance between, and within rivers (e.g., steelhead parr use consistently higher water velocities than coho salmon fry; Figure 2). Despite species-specific differences, observed habitat use patterns are typically characterised by higher observations of individuals at intermediate depths and velocities and less observations at extremes.

Figure 2. Habitat suitability curve for velocity for steelhead parr and Coho Salmon fry, based on British Columbia provincial government data.



The survival benefit of occupying a specific depth or velocity is difficult to measure. The premise of many instream flow methods is that habitat use reflects fish preference and results in higher growth and survival. The approach presented in Fausch (1984) of measuring the energetic benefits of specific stream positions has been well accepted in the literature. There is strong evidence of adaptive value to habitat choices. For example, depth and velocity influence access to food (e.g., high velocities deliver more food), energy expenditure (e.g., velocity refuges reduce the cost of holding), and risk of predation (e.g., deep habitats offer protection from avian predators). However, the simplicity of HSIs introduce errors that can underestimate flow requirements of fish because frequency of habitat use is not the only key factor affecting survival and production (Rosenfeld and Naman 2021).

2. CONSIDERATIONS ESTABLISHING PROTECTIVE FLOWS

Because the *Fisheries Act* and associated policies focus on habitat, rather than fish production, there is a very real concern that provision of fish habitat as we presently understand it may not maximize productive capacity. Conversely, reliance on fish production as an indicator of productive capacity is riddled with pitfalls. Fish abundance is notoriously variable (Hall and Knight 1981; Hilborn and Walters 1992) and impact assessments are confounded by trends induced by factors other than those being tested by an impact assessment (Smith *et al.* 1993). For example, anadromous salmonid production may increase following a water release, suggesting improved productive capacity. However, the change may be due to a long-term change in ocean productivity or to a decrease in the abundance of a predator that is sensitive to changes in marine temperature. As a result, reliance on productivity as an indicator of productive capacity may not give reliable results.

REFERENCES

EA Engineering, Science and Technology Inc. 1986. Instream Flovs Methadologies. Report prepared for the Electric Power Research Institute Research Project 2194-2, Palo Alto, California, USA.

Fausch, K.D. 1984. Profitable stream positions for salmonids: relating specific growth rate to net energy gain. Canadian Journal of Zoology 62(3):441–451.

Hall, J.D. and N.J. Knight. 1981. Natural Variation in Abundance of Salmonid Populations in Streams and its Implications for Design of Impact Studies. EPA–600/S3-81-021. U.S. Environmental Protection Agency, Corvallis, OR.

Hilborn, R. and C.J. Walters. 1992. Quantitative fisheries stock assessment and management: Choice, dynamics and uncertainty. Chapman and Hall.

Jowett, I.G. 1997. Instream flow methods: a comparison of approaches. Regulated Rivers: Research & Management 13(2):115–127.

Rosenfeld, J.S. and S.M. Naman. 2021. Identifying and mitigating systematic biases in fish habitat simulation modeling: Implications for estimating minimum instream flows. River Research and Applications 37(6):869–879.

Smith, E.P., D.R. Orvos, and J. Cairns Jr. 1993. Impact Assessment Using the Before-After-Control-Impact (BACI) Model: Concerns and Comments. Canadian Journal of Fisheries and Aquatic Sciences 50(3):627–637.