Ecofish Research Ltd.
Suite 101 - 2918 Eby Street
Terrace, B.C. V8G 2X5

Phone: 250-635-7364
info@ecofishresearch.com
www.ecofishresearch.com

MEMORANDUM

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

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

DATE: **March 27, 2023**

FILE: **1316-09**

RE: **Review of Flow Effects on Nechako River White Sturgeon – 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 watershed. One priority is to better understand how changes in flow affect White Sturgeon and their habitats within 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 White Sturgeon, with focus on informing how changes in flow may affect spawning and rearing habitats (i.e., issues #28 – 29) and White Sturgeon productivity (i.e., issue #30) to develop recommendations for WEI consideration. This memo provides an overview of flow related impacts on White Sturgeon throughout their life history and offers practicable recommendations to inform water management decisions and minimize the negative effects of operational flows on Nechako River White Sturgeon.

2. BACKGROUND

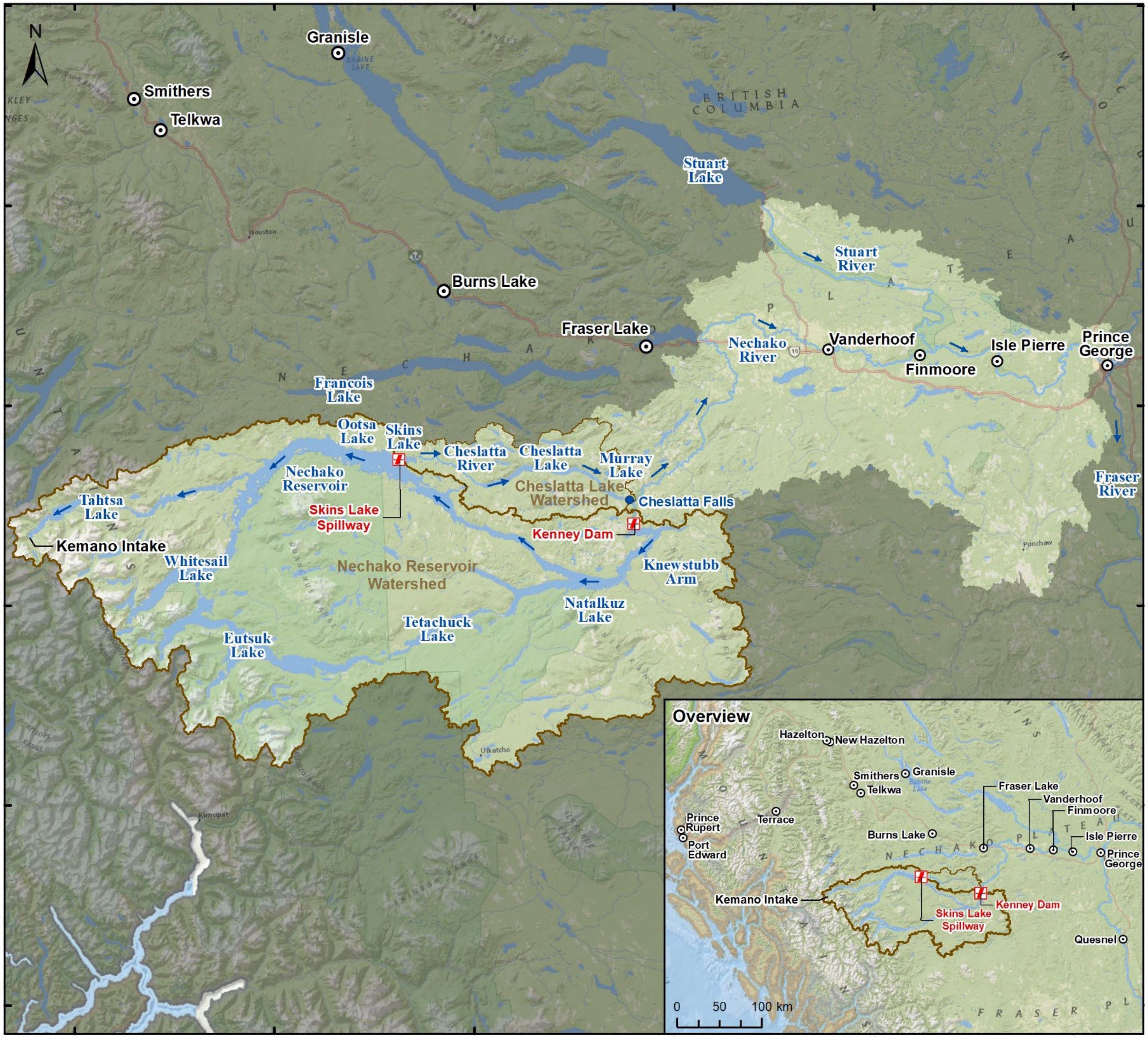
2.1. Geographic Scope

A hydrological overview of the Nechako watershed is provided by Beel and Kurtz (2022), summarized here. The Nechako Reservoir is located approximately 200 km west of Prince George, British Columbia (BC) (Map 1) and was created to provide water for Rio Tinto Alcan's Kemano Hydroelectric Project, which was constructed in the 1950s to provide energy to operate an aluminium smelter in Kitimat, BC. 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.

All flow from Nechako Reservoir to the Nechako River is currently via Skins Lake Spillway, which directs flow into the Cheslatta River watershed, from where water flows into the Nechako River, downstream of Cheslatta Falls, located 9 km downstream of Kenney Dam. The Nechako Reservoir provides most of the 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.

2.1. Nechako River Watershed Distribution

White Sturgeon distribution within the Nechako River watershed has been well documented since the 1980s (Dixon 1986; RL&L 2000a; NWSRI 2022a). Multiple decades of regional research and monitoring has identified the species throughout the Nechako River and Stuart River watersheds (i.e., in Fraser, Stuart, Talka, and Trembleur lakes and Nechako, Nautley, and Stuart river mainstems; Cadden 2000; DFO 2014). The Nechako population is most prevalent in the Nechako River mainstem from Isle Pierre (rkm 67) to the Nautley River confluence (rkm 192), and three high use areas, including a single confirmed spawning site, have been identified in the river (Table 1; Figure 2, Appendix A; Envirocon Ltd. 1984; Sulak and Clugston 1998; RL&L 1999, 2000a; DFO 2014). High use areas include between Isle Pierre and the Stuart River (rkm 67 to 79), at the Sinkut River confluence (rkm 115 to 117), and downstream of Vanderhoof (confirmed spawning site, rkm 122 to 127; DFO 2014). In addition, the Nechako River confluence with the Fraser River has been identified as critical feeding habitat and as a potential spawning location for the Upper Fraser population (DFO 2014).



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Map 1

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Figure 1. 31-year mean daily discharge (1990 – 2020) at sites in the Nechako River watershed.

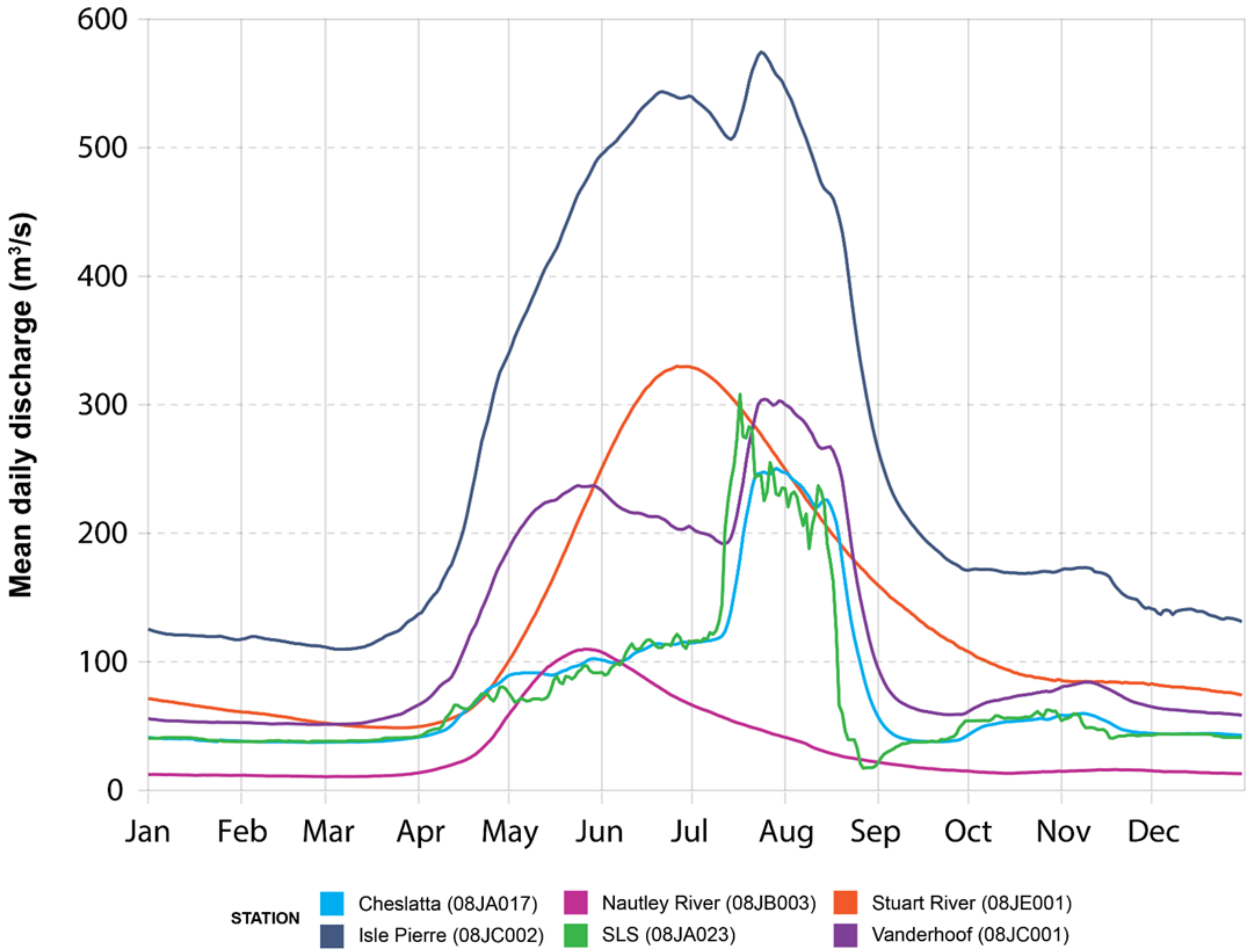


Table 1. Summary of Nechako watershed critical White Sturgeon habitats. Adapted from DFO (2014).

Location	Spawning	Yolk Sac Larvae	Feeding Larvae	Early Juvenile	Late Juvenile and Adult
Nechako - Fraser River Confluence[1]	o	o	o		X
Vanderhoof Braided Section	X	X	X		X
Sinkut River Confluence				X	X
Leduc Creek Confluence				X	X
Finmoore				X	X
Keilor's Point				X	X
Culvert Hole				o	X
Powerline				o	X
Sturgeon Point					X
Pinchi Bay (Stuart Lake)					X
Tachie River Confluence					X
Stuart Lake (Lower Half)					X
Trembleur Lake Confluence					X
Fraser Lake					X

[1] Habitat use by Upper Fraser group not Nechako group

[X] Confirmed critical habitat

[o] Suspected critical habitat

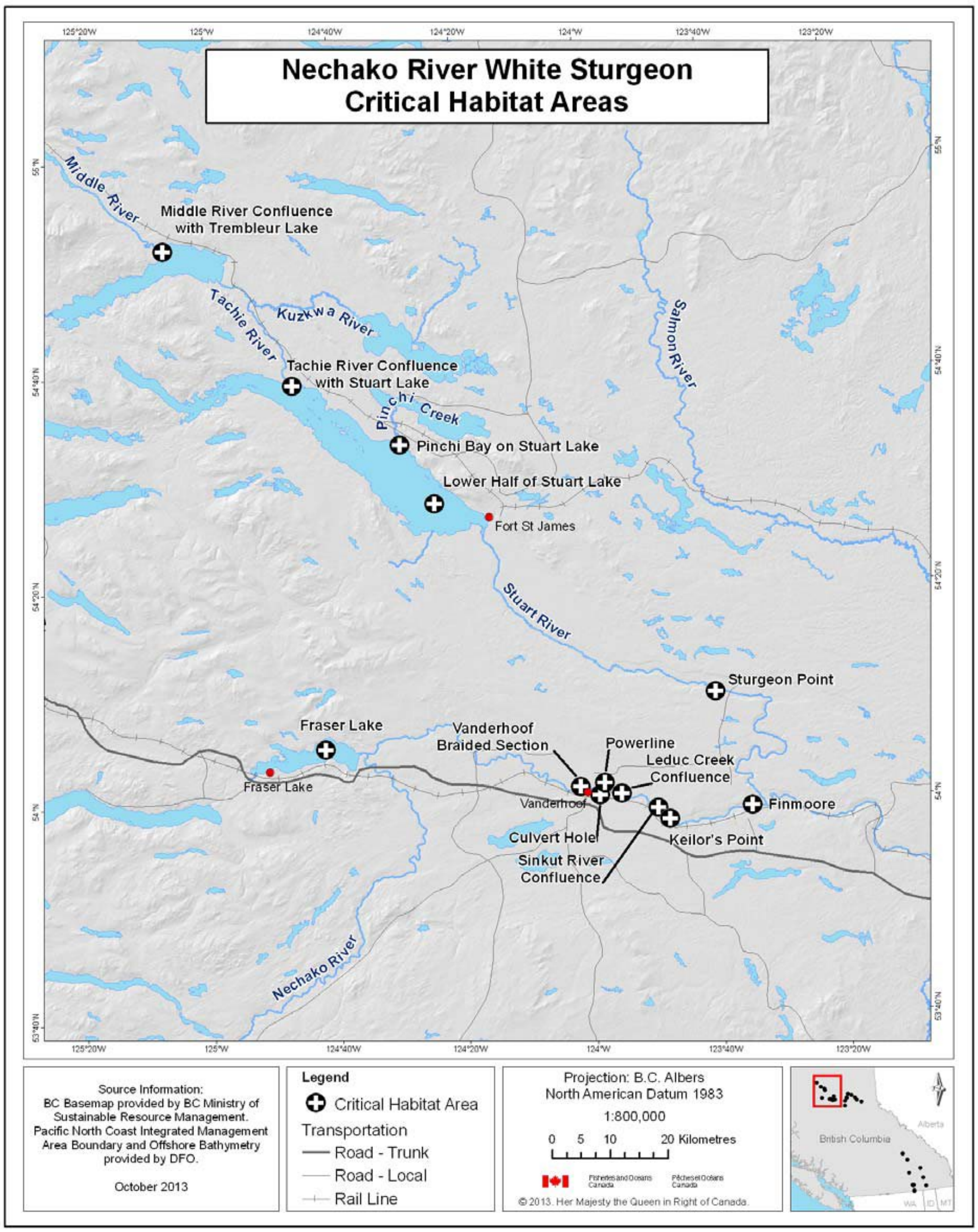
[p] Possible habitat use

White Sturgeon distribution and habitat use within the Stuart River watershed is not well understood. First Nations knowledge, historical information from Hudson's Bay Company records, and anecdotal information from long-time residents provide evidence that both juvenile and adult White Sturgeon were historically abundant in portions of the Stuart River and Stuart Lake (Cadden 2000; Toth and Yarmish 2003). Contemporary information is limited to Fraser River watershed-wide monitoring in the late 1990s (RL&L 1996, 1997, 1998, 1999, 2000a, 2000b) and a preliminary Stuart River watershed-specific White Sturgeon survey by Toth and Yarmish (2003). Available evidence[1] suggests that at the time of assessment in 2002, the Stuart River did not provide suitable habitat to support a self-sustaining population of White Sturgeon (Toth and Yarmish 2003). However, Toth and Yarmish (2003) did identify the presence of suitable juvenile rearing habitat within the Stuart River. It is unclear if observed low catch rates and absence of juvenile fish are a result of the sampling approach used or if instead, they reflect recruitment failure (Toth and Yarmish 2003).

[1] Evidence includes habitat assessment results, low adult catch rates, and no captures of juveniles (Toth and Yarmish 2003).

Despite these findings, additional evidence from mark-recapture and movement studies, First Nations knowledge, and local community members suggests that White Sturgeon may use this system at greater rates than survey efforts have identified (RL&L 2000a). At a minimum, the Stuart River serves as a migratory corridor for White Sturgeon moving between habitats in the Nechako River and Stuart Lake (RL&L 1996, 1997, 1998, 2000a, 2000b; Toth and Yarmish 2003). There is also some evidence that the lower river may also be used for spawning (RL&L 2000b).

Figure 2. Nechako River White Sturgeon critical habitats. Sourced from DFO (2014).



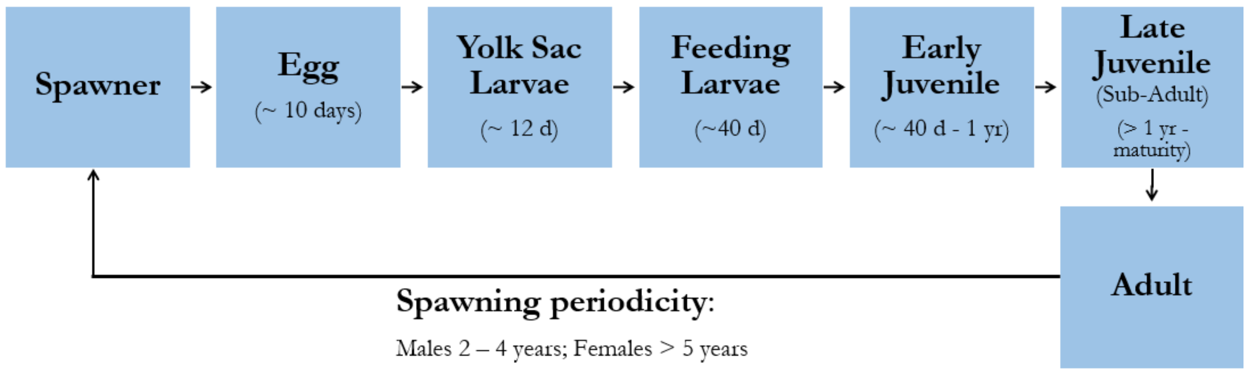
2.2. Life History, Movement behaviour, and Habitat Use

White Sturgeon are the largest of nine endemic North American sturgeon (Family: Acipenseridae) species / sub-species (Scott and Crossman 1973; Lebreton *et al.* 2004). All North American sturgeon are highly vulnerable to anthropogenic impacts and are conservation listed as "Threatened" or "Endangered" in at least portions of their range (Lebreton *et al.* 2004; BC MOE 2021; USWS 2022). These species' vulnerability results from shared life history characteristics as migratory, slow-growing, late-maturing, and long-lived fish (e.g., maximum age > 100 years; Bemis and Kynard 1997; Lebreton *et al.* 2004). British Columbian White Sturgeon populations have been identified in four regions and corresponding Designatable Units (DUs; Upper Columbia; Lower Fraser, Upper Fraser, and Upper Kootenay; McPhail 2007; COSEWIC 2012). Although some populations across the species range demonstrate facultative anadromy with rare movements between coastal drainages, all White Sturgeon occurring in British Columbia, excluding those within the lower Fraser River, are inland, freshwater populations (PSMFC 1992; COSEWIC 2012).

All White Sturgeon make seasonally specific movements for feeding and overwintering, and for spawning in the case of mature adults, which can result in large aggregations in preferred habitats (Hildebrand *et al.* 2016). Movement patterns (e.g., for spawning, foraging, or overwintering; duration, upstream verse downstream direction; and distance travelled are highly variable between populations and individuals (summarized in Hildebrand *et al.* 2016). They can range from minimal localized movements to long-distance dispersals (e.g., long-term residency in preferred high use areas or short-distance movements < 10 km, Golder 2006; to travel distances >1,000 km; Hildebrand *et al.* 2016). For example, adult sturgeon tagged in the Columbia River have been detected within the Fraser River (Welch *et al.* 2006), while juveniles believed to have originated from the Fraser, Columbia, Sacramento, and San Joaquin rivers have been observed off the coasts of the Aleutian Islands (PSMFC 1992), Baja California (Ruiz-Campos *et al.* 2011), and Vancouver Island (Hildebrand *et al.* 2016). Despite evidence of long-distance movements, generally White Sturgeon remain in specific areas for extended periods of time and make relatively localized seasonal movements to different habitats for spawning, foraging, and overwintering (e.g., < 100 km; Golder 2010; Nelson *et al.* 2004, 2013a, 2013b; Nelson and McAdam 2012; BC Hydro 2016; Beardsall and McAdam 2016). It is important to note that across the species range the presence of anthropogenic barriers to fish passage constrain White Sturgeon movements (e.g., Columbia impoundments; Hildebrand *et al.* 2016).

Generally, populations inhabit river mainstems, large tributaries, reservoirs, and large lakes in systems dominated by a snowmelt-driven hydrograph and which contain deep, swift, and turbulent mainstem channels with associated off-channel habitat (e.g., floodplains, side-channels; Parsley *et al.* 1993; Paragamian *et al.* 2001; Perrin *et al.* 2003; Coutant 2004; McPhail 2007). However, our understanding of White Sturgeon habitat use across life stages in unregulated systems is limited, as most work has focused in regulated rivers and on the spawner life stage (Smyth *et al.* 2016). There is also substantial heterogeneity in the literature regarding the division of White Sturgeon life history stages (DFO 2014; Hildebrand *et al.* 2016). Here, we use life history terminology consistent with the six life stages presented in DFO (2014) and Smyth *et al.* (2016) (Figure 3).

Figure 3. White Sturgeon Life Cycle. Modified from McAdam (2020).



2.2.1. Spawning and Incubation

The life history characteristics defining the White Sturgeon spawning life stage vary between populations (e.g., spawning timing, presence of migrations, movement patterns, spawning periodicity, age-at-sexual-maturity, and individual fecundity; McPhail 2007; Hildebrand *et al.* 2016). In the Nechako River, spawning has been identified from May to mid-June (Parsley *et al.* 1993; RL&L 1994; Perrin *et al.* 2003; McPhail 2007), whereas across other populations, spawning has been observed to range in timing from early spring to early summer (Parsley *et al.* 1993; RL&L 1994; Perrin *et al.* 2003; McPhail 2007). Generally, populations stage on spawning grounds prior to spawning (Bemis and Kynard 1997) on the descending limb of the spring freshet, shortly after peak spring discharge, as water temperature increases (McPhail 2007).

Most research to inform our understanding of White Sturgeon spawning habitat characteristics comes from regulated systems (Parsley 1991; Parsley *et al.* 1993; McCabe and Tracy 1994; Parsley and Beckman 1994; Paragamian *et al.* 2001). In many of these systems White Sturgeon are undergoing recruitment failure, and spawning habitat conditions have been identified as potential contributors (e.g., Columbia, Kootenay (Kootenai), Nechako; DFO 2014; Hildebrand *et al.* 2016). The physical habitat conditions determining specific spawning site selection are not known, but are thought to be related to water depth, velocity, turbulence, and substrate composition (DFO 2014; Hildebrand *et al.* 2016).

Hildebrand *et al.* (2016) summarizes common spawning habitats as:

> Areas with hydraulic complexity such as deep turbulent areas of the mainstem or major tributary confluences (Hildebrand et al. 1999; Parsley and Kappenman 2000; Howell and McLellan 2007; Golder 2009; Mcdonald et al. 2010), high velocity runs near rapids (Lepla and Chandler 2001), and immediately downstream from dam outlets (Parsley and Kappenman 2000; Golder 2003a, 2003b, 2005a, 2005b).

These habitats provide substrate coarse enough to provide an attachment site for eggs with water velocities and turbulence levels high enough to remove settling fines, provide appropriate dissolved oxygen levels, and reduce egg predation (Parsley *et al.* 1993, 2002; McCabe and Tracy 1994). Spawning areas also tend to be located at, or immediately upstream of suitable, low velocity depositional zones that typically have high gravel density that supports larval hiding and feeding (NWSRI 2008).

Spawning in regulated watersheds has been observed over a narrower range of conditions than in unregulated systems, most commonly in deep, turbulent, > 1 m/s^{-1} velocity water over coarse substrate (Parsley *et al.* 1993; Parsley and Beckman 1994; RL&L 2000b; Paragamian *et al.* 2001; Perrin *et al.* 2003; Golder 2005a, 2005b). White Sturgeon spawning in the unregulated lower Fraser River, where successful recruitment is known to occur, has been observed over a broader range of habitat conditions than have been reported in regulated systems. Available evidence indicates that spawning occurs both in turbulent mainstem areas with cobble to boulder substrates (Perrin *et al.* 2003) as well as in large channels (depth 1.5 – 4.0 m, with laminar flow and mean near-bed velocity 0.8 – 2.1 m/s^{-1}, and sand to cobble substrate; RL&L 2000b). Once initiated, spawning continues for several weeks (DFO 2014). Inter-system differences in spawning initiation temperatures highlight White Sturgeon's ability to spawn over a wide range of temperatures, although additional evidence suggests thermal tolerances are influenced by the local environment (Rodgers *et al.* 2018).

Many of the reaches currently used by White Sturgeon for spawning were also used historically (Kohlhorst 1976; McAdam *et al.* 2005; Paragamian *et al.* 2009). Populations have been observed to continue spawning in these habitats even when conditions are sub-optimal and additional spawning habitat is available elsewhere in the river (summarized in Hildebrand *et al.* 2016). In some cases, continued spawning in these sub-optimal locations is suspected to be contributing to ongoing recruitment failure by reducing larval and juvenile survival (McAdam *et al.* 2005; McAdam 2011, 2012). For example, in the Nechako River, spawning currently occurs over gravel substrate with high levels of fines (McAdam *et al.* 2005), whereas in the Kootenay (Kootenai) River, Ross *et al.* (2015) recently observed spawning over clay and sand. Such substrate conditions likely reduce egg and larval survival (see Section 4.2.1; McAdam *et al.* 2005; McAdam 2011, 2012, 2015).

DFO (2014) was the first to identify critical White Sturgeon habitats in the Nechako River, including spawning sites (Table 1, Appendix A). The first is a suspected spawning site for the Upper Fraser Group, located at the confluence of the Nechako and Fraser Rivers. The second is a single known spawning site for the Nechako group (see Table 1, Figure 2, and Appendix A) reported on by Smyth *et al.* (2016):

> The site is located at the braided section at Vanderhoof and is used by the Nechako group. Physical habitat data for the site at Vanderhoof are broadly consistent with those for the lower Fraser River, and they indicate that spawning occurs in side channel habitats, in addition to the main channel thalweg (Sykes 2010). At the 59 sites sampled, median depth was 1.65 m (range: 0.60–3.80 m) and median near-bed water velocity was 0.85 m/s (range: 0.13–1.15 m/s). The dominant substrates were gravel (40–65%) and fines (10–60%), with cobble (20–65%) present in upstream areas (Sykes 2010).

Although iteroparous (i.e., capable of spawning multiple times throughout their life), sturgeon generally do not spawn annually (Bemis and Kynard 1997). Reproductive periodicity varies by sex and generally, increases with age (Smyth *et al.* 2016). Limited Nechako population specific data suggest an average spawning interval of 3 to 5 years (Hildebrand *et al.* 2016). However, the full range of spawning interval length is unknown. Previous estimates of longer spawning gaps (i.e., 9 – 11 years; Scott and Crossman 1973; Semakula and Larkin 1986) are not supported by more recent research (Hildebrand *et al.* 2016).

Female fecundity is proportional to body size, ranging from 0.7 to 4.0 million eggs per female (Scott and Crossman 1973; McPhail 2007). Although no population specific fecundity estimates exist for the Nechako population, in the lower Columbia, female fecundity was found to range between 39,400 to 713,000 eggs (Wydoski and Whitney 2003). White Sturgeon are communal, broadcast spawners (Wang *et al.* 1985; Conte *et al.* 1988; Paragamian *et al.* 2001). Gametes are released and fertilized in the water column before the negatively buoyant, adhesive eggs settle on the substrate as demersal embryos (Wang *et al.* 1985; Conte *et al.* 1988; Paragamian *et al.* 2001; Deng *et al.* 2002).

In the presence of high water velocity, some level of downstream egg dispersal can occur, however dispersal rates and distances have not been well quantified (Hildebrand *et al.* 2016). Coarse substrate is believed to be an important incubation habitat feature, providing both interstitial refuge during egg development and for larvae following hatching (Johnson *et al.* 2006; Crossman and Hildebrand 2014; Hildebrand *et al.* 2016). High, consistent discharge levels are also thought to be important to incubation success by removing fine sediments (i.e., reducing the likelihood of egg smothering) and reducing predation (e.g., predator exclusion or reduced predation efficiency; Gadomski and Parsley 2005; Hildebrand and Parsley 2013; DFO 2014). The duration of the egg incubation period is temperature dependent, ranging from four to 21 days prior to larval hatching (average 5 to 10 days; Wang *et al.* 1985; Conte *et al.* 1988; DFO 2014; Hildebrand *et al.* 2016). In general, eggs develop faster at warmer temperatures, and it has been suggested that 120 accumulated thermal units are needed to complete incubation (Boucher *et al.* 2014; Jay *et al.* 2014, 2020).

2.2.2. Yolk Sac, Feeding Larvae, and Early Juveniles

Upon hatching, yolk sac larvae enter a 'swim-up phase' and are suspended in the water column before settling to the bottom and hiding in substrate interstitial spaces (Brannon *et al.* 1985;

Hildebrand *et al.* 2016). Substrate condition and water velocity are thought to significantly impact yolk sac larval settlement and the frequency and magnitude of downstream dispersal (DFO 2014; Crossman and Hildebrand 2014). Passive drift dispersal has been observed in both laboratory studies (lasting ≤ 6 days post hatch, dph; Brannon *et al.* 1984, 1985; Deng *et al.* 2002; Kynard and Parker 2005; McAdam 2011) and in regulated river systems (e.g., long range dispersal in the lower Columbia River > 180 km downstream of spawning site; McCabe and Tracy 1994). Observed drift behaviour has been hypothesized to occur in response to suboptimal larval settlement conditions (i.e., lack of unembedded substrate with available interstitial hiding spaces; McAdam 2011), and generally, immediate yolk sac larvae hiding is prevalent across several sturgeon species, including White Sturgeon, when appropriate substrates are present (e.g., Richmond and Kynard 1995; Gessner *et al.* 2009; McAdam 2011).

We have limited understanding regarding larvae and early juvenile physical habitat requirements. This is due to a combination of reduced larval and juvenile abundance due to ongoing recruitment failure in multiple populations and significant challenges associated with field investigations of early life stages (DFO 2014). Larvae are known to begin leaving the substrate for exogenous feeding approximately 8-16 dph (Doroshov *et al.* 1983; Buddington and Christofferson 1985; Gawlicka *et al.* 1995), after approximately 200 accumulated thermal units (Boucher 2012). They spend progressively more time away from available cover travelling via nocturnal drift (McAdam 2012; DFO 2014), which is thought to provide individuals with access to preferred feeding locations (e.g., low velocity side channels; McAdam 2012) and can also result in long distance larval dispersal (McCabe and Tracy 1994). Literature is conflicting regarding the age at which metamorphosis occurs (suggested range of 20 – 50 dph; McPhail 2007; Hildebrand *et al.* 2016). For the purpose of discussion here, we have adopted an age of 40 dph for this life stage shift, as presented in DFO (2014) and Smyth *et al.* (2016).

Across early juvenile life stages, low velocity habitats appear important (e.g., side channels, sloughs, deep mainstem sections; Bennett *et al.* 2005; Glova *et al.* 2008). In the Nechako River, small numbers of juvenile White Sturgeon (< 100 TL) have been encountered in low velocity areas with fine substrate either associated with tributary confluences, deep pools, or nearshore areas with vegetative cover (Envirocon Ltd. 1984; RL&L 1999, 2000b). Following metamorphosis, early juvenile fish can initially grow rapidly under optimal temperatures and with abundant food resources before growth rates slow (Brannon *et al.* 1985; Hildebrand *et al.* 2016). Survival during early life stages is extremely low (i.e., estimated 0.0004%, from emergence until age 1 +; Gross *et al.* 2002).

2.2.3. Late Juveniles and Adults

The age cutoff for the end of the early juvenile stage varies in the literature (Hildebrand *et al.* 2016; Smyth *et al.* 2016). Here, we have adopted an age of 1+ for the transition between the early juvenile and late juvenile (sub-adult) stages. Upon reaching age 1+, survival rates increase (i.e., survival for late juvenile and adult life stages ranges from 91 – 97%; Whitlock 2007; Irvine *et al.* 2007), and habitat use becomes similar to that of later life stages (i.e., adults and spawners; Hildebrand *et al.* 2016; DFO 2014; Smyth *et al.* 2016).

Late juvenile White Sturgeon grow rapidly and have been observed to reach ~ 30 cm by age 2+ and greater than 1 m by age 12+ (Beamesderfer *et al.* 1989). Inter-population growth rates are variable, but generally fish grow faster in areas with longer growing seasons, abundant food resources, and warmer water (Smyth *et al.* 2016). The transition between the late juvenile and adult life stage occurs when individuals reach sexual maturity (Hildebrand *et al.* 2016; Smyth *et al.* 2016). The age at which sexual maturity occurs is sex and population specific, but generally males mature at smaller sizes and younger ages than females (Males: ~ age 12+; Females: ~ age 15 - 32; Galbreath 1985; Semakula and Larkin 1986; PSMFC 1992). Available evidence suggests Nechako White Sturgeon may reach sexual maturity at substantially older ages (> 40 yrs; Table 2; RL&L 2000a, 2000b). However, it is not known if the advanced age of spawners within the Nechako River reflects sampling bias (i.e., sampling geared toward capture of large adult fish), limited sample size, or poor recruitment (i.e., upward age skew due to failure to catch, or lack of young cohorts; RL&L 2000a).

Table 2. Length-at-age estimates for sexually mature Nechako River White Sturgeon. Sourced from RL&L (2000a).

Stock Group	Maturity Code (*State*)[1]	Mean FL (cm)	Age Data			Percent Composition
			n	Mean Age (yrs)	Range	
SG-5	**MALES**					
	01 (*Non-reproductive*)	112.5	*2*	22.0	13-31	2.5
	02 (*Maturing*)	145.6	*42*	37.0	18-67	52.5
	03 (*Early Reproductive*)	155.8	*28*	40.2	32-67	35.0
	04 (*Late Reproductive*)	205.4	*7*	64.4	40-88	8.8
	05 (*Ripe*)	193.0	*1*	62.0	62	1.2
	06 (*Spent*)					
	FEMALES					
	11 (*Non-reproductive*)	132.0	*1*	26.0	26	2.5
	12 (*Pre-vitellogenic*)	157.4	*29*	40.4	24-62	72.5
	13 (*Early vitellogenic*)	193.4	*6*	56.5	35-83	15.0
	14 (*Late vitellogenic*)	200.3	*3*	67.0	65-71	7.5
	15 (*Ripe*)					
	16 (*Spent*)					
	17 (*Pre-vitellogenic with attritic oocytes*)	230.5	*1*	71.0	71	2.5

Note: Blank cells represent no data.

[1] Description of maturity state classifications adapted from Conte et al. (1988). For a more detailed description of maturity codes, refer to RL&L (1996a).

Late juveniles and adults share similar habitats and demonstrate similar behaviors (e.g., movement patterns and aggregations; Hildebrand *et al.* 1999; Parsley *et al.* 2007, 2008; DFO 2014). Information regarding physical habitat requirements for late juvenile and non-spawning adult White Sturgeon are highly limited across the species range, however, the periodicity and movements of these fish have been well studied (summarized in Hildebrand *et al.* 2016). In the Nechako River, preferred late juvenile and adult habitats (i.e., depths, velocity, cover) have not been specifically investigated, however high use areas / critical habitats have been identified (see Section 2.2 and Appendix A; DFO 2014) and multi-year adult movement monitoring as part of ongoing research has characterized seasonal movement timing and sampled specific habitat parameters at fish capture locations (e.g., depths, velocities, see RL&L 2000a; Toth and Yarmish 2003; NWSRI 2022a).

Nechako White Sturgeon movement distances exceed those seen elsewhere in the Fraser River watershed (RL&L 2000a). The largest seasonal movements occur in spring as fish redistribute to preferred feeding and spawning locations in the Nechako River (e.g., the area between Vanderhoof and Whitemud Rapids) or move into the Stuart River watershed (RL&L 2000a). Fish also make spring movements for feeding opportunities, which generally occur prior to Sockeye Salmon spawning run timing (RL&L 2000a). Movements tend to be relatively more localized during summer (RL&L 2000a, 2000b; Hildebrand *et al.* 2016). However, the Nechako population moves more during the summer relative to other Fraser River Watershed populations (RL&L 2000a). These movements may coincide with salmon predation when migrating Sockeye Salmon are present in the river (RL&L 2000a; Smyth *et al.* 2016).

Fall is the second most active season of movement as individuals redistribute to overwintering habitats (RL&L 2000a; Hildebrand *et al.* 2016). Fall movements to preferred overwintering habitats are more prevalent in the Nechako population than other Fraser River watershed populations (RL&L 2000a, 2000b) and generally occur as water temperatures, flow, and food resources decrease (RL&L 2000a). Following fall movements, individuals become dormant (i.e., movements and feeding are highly limited) and aggregate in deep, low velocity habitats (RL&L 2000a; COSEWIC 2012). The timing and duration of overwintering dependent on population (generally ranging from October to March; RL&L 2000a, 2000b; Nelson *et al.* 2004).

2.3. Conservation Status, Population Structure, and Population Trends

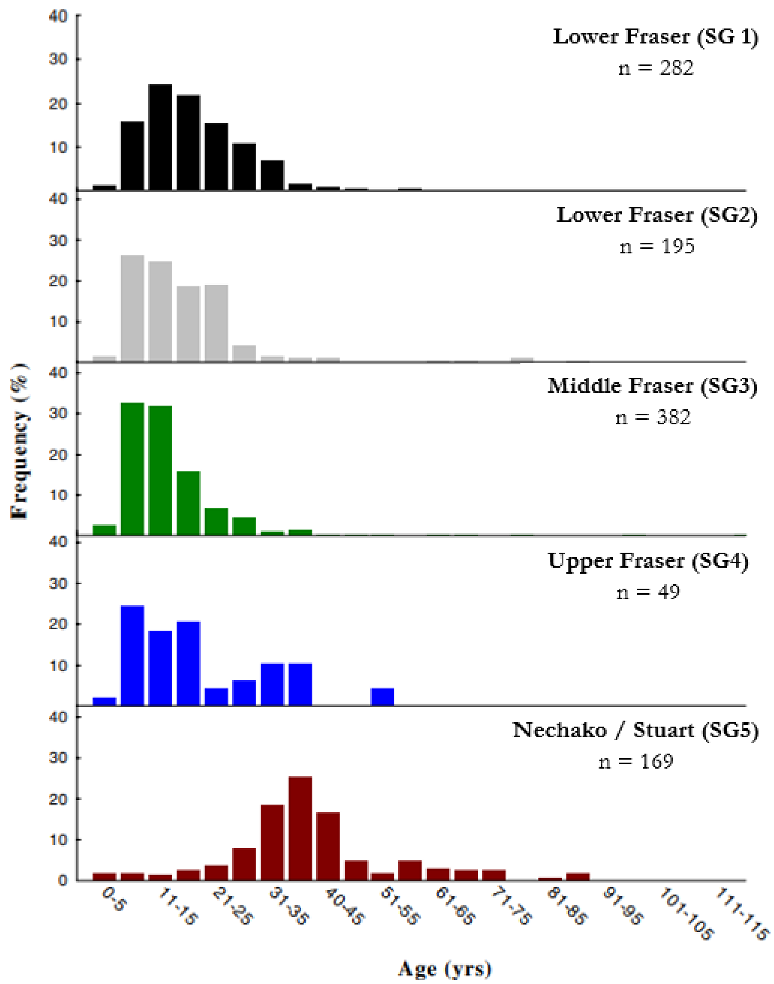
Canadian White Sturgeon populations are divided into four Designatable Units (DUs: Lower Fraser River, Upper Fraser River, Upper Columbia, and Upper Kootenay; COSEWIC 2012). All have federal and provincial conservation designation (COSEWIC 2012; BC MOE 2021). The Upper Fraser River DU is composed of three genetically distinct populations, the Middle Fraser, Upper Fraser, and Nechako (RL&L 2000a; Smith *et al.* 2002; Schreier *et al.* 2012; DFO 2014). These populations are not separated by the presence of physical barriers and although individuals have been observed moving between the regions (i.e., middle and upper Fraser and Nechako rivers; Lheidli T'enneh First Nation 2007, 2008; Nelson *et al.* 2021), such movements are believed to be limited (Lheidli T'enneh Band 2001; Golder 2003c; Lheidli T'enneh First Nation 2008; Sykes 2008; FRSCS 2012). Available evidence from tagging and genetic research strongly suggests the three population groups are reproductively isolated and that all White Sturgeon within the Nechako River basin belong to a single population (Schreier *et al.* 2012).

Long-term, fishery independent, historic population abundance and trend data are not available for Canadian White Sturgeon populations (COSEWIC 2012). Abundance monitoring for the Upper Fraser DU began with the initiation of the Fraser River White Sturgeon Monitoring Program in the mid-1990s (RL&L 2000a). Prior to this period, Nechako River population trends were only informed by catch records (Dixon 1986; Walters *et al.* 2005; Whitlock and McAllister 2012). Despite data limitations, stock assessments have demonstrated that White Sturgeon population abundance has declined across the species Canadian range (COSEWIC 2012). Drivers of declines vary among population groupings, however, habitat alteration (e.g., river regulation, diking, dredging, gravel mining), fishing pressure (i.e., directed harvest, incidental capture), and changes in water quality have been identified as critical threats (DFO 2014). Multiple populations in regulated systems (i.e., Columbia, Kootenay (Kootenai), and Nechako) are undergoing recruitment failure, evidenced by skewed population age structure[2] (Figure 4) and absence of juveniles (RL&L 2000b; Korman and Walters 2001; French *et al.* 2004; McAdam *et al.* 2005; DFO 2014).

Nechako population abundance was first estimated in 1999 as 571 (421 – 890; CI 95%) individuals (RL&L 2000a). Subsequent estimates by Korman and Walters (2001), COSEWIC (2012), and DFO (2014) suggest abundance has continued to decrease over time. In addition, analysis by Carruthers *et al.* (unpublished) also demonstrated population decline, however the initial population estimate from this analysis was substantially higher than previous estimates (Smyth *et al.* 2016).

[2] Note upper age skew in Nechako population age frequency distribution may reflect ongoing recruitment failure.

Figure 4. Age frequency distribution of Fraser River Drainage White Sturgeon stock groups (SG). Modified from NWSRI (2004).



2.4. Current Level of Knowledge

No quantitative data on Nechako White Sturgeon population trends, life history, or habitat use are available prior to flow regulation in the 1950s. Preliminary work in the 1970s and 1980s was primarily in support of sport fishery management and work related to the Kemano hydroelectric project (Envirocon Ltd. 1984). Research focused on biophysical descriptions of the watershed, individual movement patterns, and population demographics (e.g., age, growth, and maturity rates; Aitken 1981; Envirocon Ltd. 1984; Dixon 1986; Cadden 2000). The first intensive White Sturgeon monitoring program in the Fraser River watershed began in 1995 (i.e., the Fraser River White Sturgeon Monitoring Program; FRWSMP). The impetus for this program was the federal conservation listing of the species in 1991 and several documented adult sturgeon mortalities in the early 1990s

(COSEWIC, 'Threatened'; Lane 1991; RL&L 2000a). The FRWSMP conducted detailed research on population dynamics, life history, genetics, and movements throughout the watershed (RL&L 2000a). It was also the first research to identify the Nechako population as a unique stock and document evidence of recruitment failure (NWSRI 2004). These findings led to the closure of the Nechako and Stuart River catch-and-release fisheries, initiation of population recovery planning, and creation of the Nechako White Sturgeon Recovery Initiative (NWSRI) in 2000.

The NWSRI mandate is to identify causes of Nechako White Sturgeon population decline and recruitment failure and to design and implement habitat protection, restoration, and management, based on scientific research and local and traditional knowledge (NWSRI 2022b). Work is science focused and conducted by two committees: a Technical Working Group which is responsible for research and recovery strategy implementation, and a Community Working Group that shares information and builds public and financial support for recovery efforts (NWSRI 2020). One of the first initiatives undertaken by the NWSRI was development of a Nechako White Sturgeon Recovery Plan (NWSRI 2004), which documented evidence of recruitment failure and established specific population recovery goals and objectives.

Since recovery plan publication, regional level research by the NWSRI, provincial government, First Nations, and consulting organizations have shared the joint objective to improve Nechako White Sturgeon recruitment and increase population abundance and have often engaged in collaborative work. All initiative activities are documented in annual program reports and other documents, available from the NWSRI website (NWSRI 2022c). Research has included a stock assessment, population monitoring across life stages, telemetry program, and body of work on habitat conditions and their impacts on population abundance and recruitment success (Table 3; reports available from Government of British Columbia 2022 and NWSRI 2022c).

The Nechako population was included in impact analysis reporting conducted for Fraser River White Sturgeon populations (Hatfield *et al.* 2004). In addition, the federal government has engaged in mandated reporting for the population as part of *Species at Risk Act* (SARA) listing, which has included threat assessment and critical habitat identification (DFO 2014; Smyth *et al.* 2016). Despite extensive monitoring and other directed research conducted over the past five decades, there are still several significant data gaps and critical uncertainties impacting efforts to improve recruitment success and support long-term population sustainability (see Section 5).

In other portions of the species Canadian Range, White Sturgeon are also the subject of recovery efforts. On the Fraser River, the Fraser River Sturgeon Conservation Society (FRSCS) conducts research and outreach similar to the NWSRI, primarily in the lower river (FRSCS 2022). Recently, a recovery potential assessment was completed for the population which may provide more contemporary information than is available for the Nechako River (English *et al.* 2021). Work in the Columbia River is driven by a BC Hydro Water Use Plan (BC Hydro 2022). There is a significant body of ongoing work within the watershed. For example, in the upper Columbia River, recovery work is guided by the Upper Columbia White Sturgeon Recovery Plan (UCWSRP), created in 2002 and updated in 2012 (Hildebrand and Parsley 2013). A population model has also been developed to support stock assessment (Challenger *et al.* 2021).

Table 3. Selected regional scale Nechako River White Sturgeon specific research initiatives.

Subject	Research Topic	Example Citations
Population dynamics	Stock assessment	Korman and Walters 2001
	Juvenile monitoring	Reports available from NWSRI 2022a
	Spawning monitoring	Golder 2001, 2003c; CSTC 2016
	Recruitment biochronology	EDI 2013
	Movement dynamics and habitat use	Toth and Yarmish 2003; Liebe *et al.* 2004, 2005, 2007; Lheidli T'enneh First Nation 2008
	Population structure / genetics	Smith *et al.* 2002; Schreier *et al.* 2012
Habitat conditions	Predation	Babey *et al.* 2020
	Turbidity, sediment transport, and pollution	NHC 2013, 2015a, 2016; Owens *et al.* 2019
	Thermal tolerance	Penman 2021
	Fluvial dynamics impacts	Gauthier-Fauteux 2017
	Substrate impacts	(McAdam *et al.* 2005; McAdam 2011, 2012, 2015; NHC 2015a, 2015b)
	Habitat remediation and management	NWSRI 2008; McAdam *et al.* 2018
Fish culture		NWSRI 2005; NWSRI 2022d
Fisheries	Selective harvest	CSTC 2006, 2007

3. METHODS

A literature review and data search were conducted to locate all known information on the influence of flow on Nechako River White Sturgeon since the commencement of Kemano hydroelectric operations and flow releases through 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 White Sturgeon Recovery Initiative (NWSRI) 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 provincial and organizational databases (e.g., NEEF 2022; NWSRI 2022d; UNBC 2022), and through review of scanned archival copies of government and organizational reports.

This assessment is based primarily on the work of Smyth *et al.* (2016)[3], limiting our consideration to identified threats that directly result from, or that can be influenced or ameliorated by flow regulation. We provide further discussion and additional lines of evidence of potential flow mediated effects on Nechako White Sturgeon specifically, drawing on regional research and where relevant, information from other flow regulated systems (e.g., Kootenay (Kootenai) and Columbia).

4. RESULTS

4.1. Overview of Potential Pathways of Effect

White Sturgeon spawning, incubation, emergence, and rearing are strongly influenced by river flow (i.e., discharge), which has been called the 'master variable' for fish communities (Poff *et al.* 1997). 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.

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).

[3] Smyth *et al.* (2016) provides the most recent comprehensive assessment of threats and limiting factors to Canadian White Sturgeon survival and recovery as part of the federal Recovery Potential Assessment process. The document collated existing information from a variety of sources including stock assessment (Korman and Walters 2001), impact hypotheses (Hatfield *et al.* 2004), the federal recovery strategy (DFO 2014), and conservation listing assessment (COSEWIC 2012).

Smyth *et al.* (2016) states:

> The life history of White Sturgeon is closely linked to river hydrology. The precise mechanisms responsible for population decline and recruitment failure are still unproven, but river regulation is heavily implicated… Both habitat quality and quantity have declined throughout the species' range…[and] …changes to White Sturgeon habitat or to the habitats of prey species are believed to be directly related to impacts on recruitment and overall carrying capacity.

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. However, 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 Potential Pathways of Effect

Here, we identify key pathways through which RTA operations could potentially effect Nechako River White Sturgeon. These can be summarized as flow-mediated changes to:

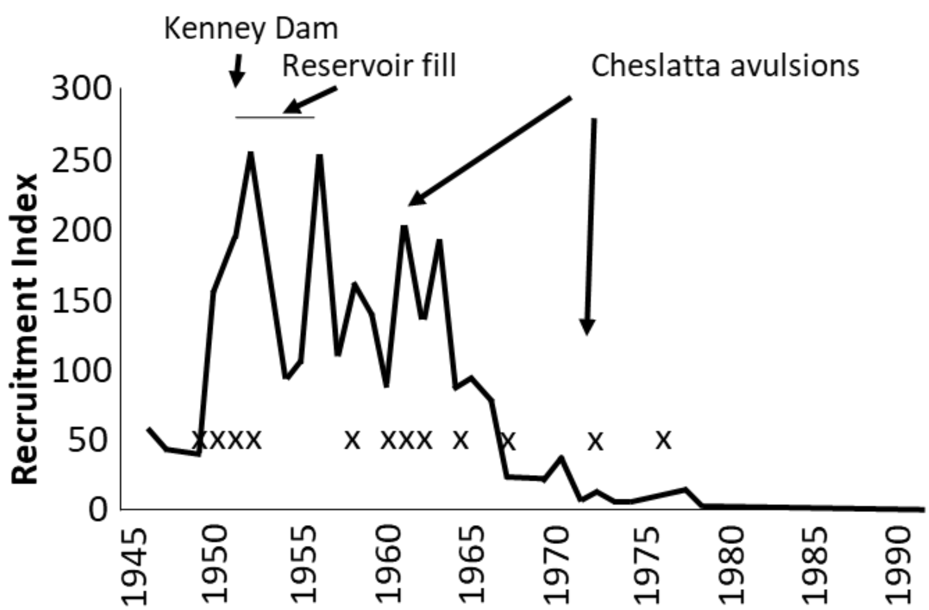
1. River geomorphology and sediment processes;
2. Micro-habitat water velocity;
3. Temperature;
4. Turbidity;
5. Dissolved oxygen;
6. Food availability;
7. Community structure;
8. Winter hydraulic regime; and
9. Habitat access.

In Sections 4.2.1 to 4.2.9 below, we discuss available evidence regarding the impacts of these potential limiting factors.

4.2.1. 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 watershed (Neill 1987; Rood 1987). Flow diversion has led to significant bank erosion in the Cheslatta River watershed and Nechako River, including two known avulsion events that are an identified pathway impacting recruitment (i.e., major sediment erosion events; Figure 5; Hay and Company Consultants Inc. 2000; McAdam 2012). In addition, flow regulation and decreased flow variation have 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 2015a, 2015b, 2016; Gateuille *et al.* 2019). Increased sediment deposition has degraded substrate condition and supported vegetative encroachment throughout the river, narrowing the main river channel and effecting off-channel habitat connectivity (Figure 6; Neill 1987; Rood 1987; Johnson *et al.* 2022a).

Figure 5. Historic pattern of projected recruitment. Years when flow at Vanderhoof exceeded 500 m^3/s are indicated by x's. Sourced from McAdam *et al.* (2005).



High sediment deposition rates compounded by reduced substrate flushing have increased substrate embeddedness throughout the river (i.e., interstitial infilling by fine sediments; McAdam *et al.* 2005; NHC 2015a, 2015b, 2016; Gateuille *et al.* 2019). This occurs across a range of flows, however when flows are approximately 300 cm/s, backwatering of the only confirmed Nechako River White Sturgeon spawning site at Vanderhoof (rkm 122 to 127; DFO 2014) promotes deposition of sand and fines in spawning sites (McAdam, pers. comm. 2022). Increased presence of fine sediments can lead to egg suffocation or can prevent egg adhesion to the substrate and cause egg displacement (McCabe and Tracy 1994; Parsley and Kappenman 2000; Deng *et al.* 2002). Substrate infilling also prevents yolk sac larvae from hiding and lengthens larval drift duration as individuals seek appropriate rearing habitats (McAdam *et al.* 2005; McAdam 2011, 2015; DFO 2014). These habitat impacts are hypothesized to decrease larval survival (McAdam *et al.* 2005; McAdam 2011, 2015; DFO 2014) and have been implicated as an important secondary effect of flow regulation contributing to Nechako and Columbia population recruitment failures, though the specific mechanism of effect is uncertain

(Figure 5; Korman and Walters 2001; McAdam *et al.* 2005; McAdam 2011, 2012, 2015; McAdam, pers. comm. 2022).

Figure 6. Pre- and post-regulation aerial photos of the Nechako River at Vanderhoof (upstream from Burrard Avenue Bridge) showing increased extent of vegetated islands due to sedimentation. Sourced from NHC (2008).

a) Pre-regulation Q = 614 m^3/s (1951)

b) Post-regulation Q = 780 m^3/s (2007)

Research efforts are ongoing to clarify the role of sediment transport processes and substrate degradation on White Sturgeon spawning success and early juvenile survival (McAdam *et al.* 2005; McAdam 2011, 2012, 2015; McAdam, pers. comm. 2022). Although the NWSRI has undertaken efforts to improve substrate quality at the confirmed Nechako River White Sturgeon spawning site at Vanderhoof (rkm 122 to 127; DFO 2014) through substrate cleaning efforts (e.g., see NHC 2016), to date this work has not provided long-term habitat improvement with cleaned gravel observed to quickly infill with sediment (NHC 2016; McAdam, pers. comm. 2022). Physical works to clean gravel and prevent subsequent interstitial infilling are planned for 2023 (McAdam, pers. comm. 2022).

4.2.2. Micro-habitat Water Velocity

Available evidence suggests White Sturgeon choose spawning sites in high velocity, deep, turbulent areas (see Section 2.2.1; Parsley *et al.* 1993; Hildebrand *et al.* 1999; Parsley and Kappenman 2000; Golder 2003c; Perrin *et al.* 2003). Increased flow velocity in a flow regulated system has been shown to stimulate White Sturgeon spawning movements and initiate spawning activity, however the habitat characteristics important for successful spawning are not clear (Schaffter 1997; Jackson *et al.* 2016). It has been hypothesized that high water velocity and turbulence improves egg viability and early juvenile survival by: 1) dispersing eggs and yolk sac larvae, and in turn decreasing depensatory effects (i.e., disease, predation, competition; Parsley *et al.* 1993, 2002; McCabe and Tracy 1994; Muir *et al.* 2000; Israel *et al.* 2009; Hildebrand *et al.* 2016); 2) reducing fine substrate settlement, promoting egg adhesion and decreasing displacement (Deng *et al.* 2002); promoting egg settlement in well oxygenated areas (i.e., prevents smothering; Sulak and Clugston 1998, 1999); and 3) maintaining interstitial refugia for eggs and yolk sac larvae (McAdam *et al.* 2005; Johnson *et al.* 2006). Water velocity may also play an important role in feeding larvae dispersal via drift to appropriate feeding habitats when food is locally limited (Parsley *et al.* 1993; McAdam 2012; Howell and McLellan 2014).

A hydrodynamic modelling and empirical study explored the Nechako River in the Vanderhoof area to clarify how discharge influences White Sturgeon habitats. Modelling by NHC (2008) predicted spring discharge would need to exceed 450-500 m^3/s to promote a suitable distribution of spawning and juvenile habitats. At typical spring discharge rates (1981-2008 mean of 170 m^3/s), available spawning habitat was not predicted to be well associated with appropriate egg and larval habitat (NHC 2008). Empirical analysis of the relationship between historic spring flows and recruitment has not identified a relationship between recruitment events[4] and discharge level (McAdam, pers. comm. 2022). At present, the relative contribution of this potential pathway of effect on ongoing recruitment failure remains uncertain.

4.2.3. Altered Thermal Regime

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

[4] Three to four limited recruitment pulses have been observed over an approximately 20-year period (McAdam, pers. comm. 2022).

Skins Lake Spillway; Caissie 2006). Typically, in spring and summer, lower flow results in higher water temperature. While in fall and winter, low flows may lead to quicker cooling and may increase ice formation (discussed in Section 4.2.8; Faulkner *et al.* 2011).

Water temperature is an important habitat attribute significantly impacting all White Sturgeon life stages. When water approaches White Sturgeon's upper temperature limits, individuals can succumb to thermal stress and elevated mortality (Wang *et al.* 1985, 1987; Penman 2021). Temperature also governs the rate of metabolic processes, influencing egg and juvenile development (Carter *et al.* 2022) and is thought to be an important environmental driver of spawning timing (DFO 2014; Hildebrand *et al.* 2016). Across the species range, temperature thresholds have been investigated for White Sturgeon life stages (Hildebrand *et al.* 2016). Nechako population specific research has identified temperature criteria for incubation, larval, and early juvenile life stages, which appear to be most sensitive to environmental temperatures (e.g., see Boucher *et al.* 2014; Bates *et al.* 2014; Cheung 2019; Penman 2021).

Although the specific physiological and environmental drivers that initiate White Sturgeon spawning are poorly understood, available evidence points to temperature as a key factor (DFO 2014; Hildebrand *et al.* 2016). Previous work has highlighted the importance of a natural thermal regime rather than stable temperatures for oocyte development and ovulation, as well as potential negative impacts of elevated temperatures on these processes (i.e., > 18°C; Webb *et al.* 2001). Spawning effort and egg survival may be reduced at thermal extremes (Webb *et al.* 2001; Ross *et al.* 2015). Spawning begins once temperatures reach an appropriate threshold, which varies from 8 – 20°C across populations (DFO 2014; Hildebrand *et al.* 2016). In the Nechako River, previous field observations suggest that spawning is initiated in spring once temperatures reach 10 – 16°C (DFO 2014).

Across the species range, incubation temperature for successful egg development generally ranges between 8° – 20°C (Hildebrand *et al.* 2016). Optimal incubation temperatures have been estimated to range from 13 – 17°C, with decreased survival at temperatures below and above this range, and no survival over 24°C (Wang *et al.* 1985; Webb *et al.* 2001). Nechako White Sturgeon specific research by Cheung (2019) identified that larval development and growth rates are greatest following incubation at 12°C. Given that temperatures in the Nechako River at Vanderhoof tend to remain between 10 – 15°C during the spawning and incubation period, they appear appropriate for White Sturgeon. Further, data collected as part of the NWSRI show that spawning appears to be occurring regularly and gametes are viable, indicating that temperature is not negatively affecting spawning and incubation (NWSRI 2014).

Optimal temperatures for the yolk sac larvae life stage range from 12 – 16°C, with highest survival occurring at ~14°C (Wang *et al.* 1985, 1987). Research using Nechako population brood investigating White Sturgeon yolk sac and feeding larvae growth and stress levels, measured as whole-body cortisol, found both metrics were higher at warmer temperatures (Boucher *et al.* 2014; Bates *et al.* 2014).

Further, Boucher *et al.* (2014) found survival of both life stages were reduced at higher temperatures. Taken together, findings of increased stress and mortality with increased temperature from 13.5 – 17°C suggest relatively cooler temperatures may be optimal for these life stages. Given the known Nechako population spawning period, larval life stages are likely present in the river between mid-June and mid-July (Sykes 2010). Temperatures during this period are typically between 13 – 17°C, suggesting that larvae could be exposed to sub-optimal temperatures for a portion of these life history stages.

Work by Penman (2021) provides the primary source of data regarding early juvenile Nechako White Sturgeon temperature criteria. This analysis evaluated temperature tolerance over four ecologically relevant temperature conditions and found that acclimation to temperatures above 18°C reduced condition and increased metabolic stress (temperatures tested include 15°C, 18°C, 21°C, and 24°C; Penman 2021). The analysis also found temperature thresholds were dependent on acclimation temperatures (i.e., temperatures experienced earlier in life influence tolerance during subsequent development; Penman 2021). Although the Summer Temperature Monitoring Program (STMP)[5] mitigates the occurrence of water temperatures in exceedance of 20°C during a portion of the warmest months, water temperatures at the White Sturgeon spawning site at Vanderhoof commonly surpass 18°C and occasionally surpass 22°C while early juvenile fish are present in the river, indicating sub-optimal temperatures during portions of this life stage (i.e., in July and August; Environment Canada 2022).

Generally, late juvenile and adult White Sturgeon tolerate warmer and more variable temperatures than earlier life stages (tolerance range of ~ 4°C – > 20°C across species distribution; DFO 2014). Optimal water temperature estimates for late juvenile and adult White Sturgeon are more uncertain than for earlier life stages. Available evidence suggests temperatures less than 18°C are optimal for late juveniles (McConnell 1989; Lepla and Chandler 2001). Adult White Sturgeon activity levels have been observed to decline at temperatures below 15°C, suggesting optimal summer water temperature is above this threshold (Haynes *et al.* 1978; Howell and McLellan 2014). Specific thermal preferences are unknown for late juvenile and adult White Sturgeon in the Nechako River, and therefore the potential for impacts of this pathway of effect are uncertain. However, STMP flows during the warmest months (July and August) will reduce negative temperature effects on late juvenile and adult White Sturgeon.

4.2.4. Reduced Turbidity

Turbidity is a measure of the relative clarity of water, influenced by the presence of suspended solids (USGS 2022), that impacts fish navigation, foraging, and predation (Ortega *et al.* 2020). For example,

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[5] The STMP program mediates elevated water temperatures during summer Stuart River Sockeye Salmon migration although the Nechako River via Skins Lake Spillway releases. The goal of program is to minimize the frequency of temperatures > 20°C during the period of July 20 – August 20, annually (NFCP 2022).

increased turbidity decreases predator capture rates (Ortega *et al.* 2020) and as a result turbid areas can provide refuge for prey species such as juvenile White Sturgeon (Gadomski and Parsley 2005).

Smyth *et al.* (2016) stated:

> Drift by White Sturgeon larvae may expose them to predation, which may decrease when water is turbid (e.g., during freshet). Regulated systems tend to have reduced turbidity due to…the diminished erosive potential of lower peak flows. Since predators of sturgeon larvae are primarily visual hunters, increased water clarity in regulated systems may allow for a higher predation rate on early juveniles (i.e., less than 1 year old)…
>
> Reduced turbidity due to lower flows was assessed to be a moderately plausible explanation for recruitment failure in the Nechako River (Korman and Walters 2001). Such an effect could reduce spawning success or increase predation on juvenile fish by visual predators…[However], DFO (2014) assessed risks associated with this threat to be low for the Nechako group.

More recent work on juvenile sturgeon predation found that otters can eat White Sturgeon up to 70 cm in length (Babey *et al.* 2020), although the contribution of otter predation to sturgeon mortality rates is unknown. Given that otters are visual predators, it is plausible that flow regulation and corresponding reduced turbidity in the Nechako River has increased otter predation on juvenile sturgeon (Ortega *et al.* 2020).

4.2.5. Dissolved Oxygen

Reduced flow and increased temperature can decrease sub-surface and interstitial dissolved oxygen concentrations and generally, fish avoid areas where dissolved oxygen concentrations are reduced to levels that induce stress (Whitmore *et al.* 1960). Resultant movement away from such habitats has associated energetic consequences for White Sturgeon across life stages, particularly during juvenile and adult winter dormancy (Speers-Roesch *et al.* 2018).

Juvenile White Sturgeon prefer higher dissolved oxygen concentrations than adults. Juvenile growth rates increase as dissolved oxygen concentration increases (Cech *et al.* 1984), and dissolved oxygen concentrations below 3 mg/L have been observed to result in substantial juvenile mortality (Sullivan *et al.* 2003). Available evidence for this and other sturgeon species suggests dissolved oxygen concentrations should be greater than 6 mg/L across life stages (Sullivan *et al.* 2003). Based on observed Nechako White Sturgeon habitat dissolved oxygen concentrations (> 10 mg/L), dissolved oxygen does not appear to be limiting for the population across life stages (French 2005).

4.2.6. Food Availability

Multiple White Sturgeon life history stages (i.e., emergent yolk sac larvae through early juveniles) are reliant on aquatic invertebrate prey, which is critical to first year growth and survival (Coulter 2021). The effects of flow regulation on invertebrate communities has been well studied (e.g., Envirocon Ltd. 1984; Dewson *et al.* 2007; Bilotta *et al.* 2017; Rosero-López *et al.* 2020), and many of the mechanisms impacting aquatic invertebrates mirror those impacting the fish community (i.e., presence of hydraulically suitable habitat, sedimentation, thermal regime, dissolved oxygen levels, food availability, and icing processes; Envirocon Ltd. 1984). Habitat alteration as a result of these factors can modify invertebrate species composition, distribution, relative abundance, and individual size (Minshall and Winger 1968; Envirocon Ltd. 1984; Ward and Stanford 1987; Caldwell *et al.* 2018). This directly effects overall food availability and the abundance of preferred prey for aquatics species (i.e., including White Sturgeon and a major adult White Sturgeon prey source, Sockeye Salmon; DFO 2014). Reduced prey availability 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). All these factors could ultimately reduce White Sturgeon growth and survival, affecting overall production.

Johnson *et al.* (2022b) investigated the relationship between flow and productivity in the Nechako River but was unable to quantify how flow affects benthic invertebrates and their habitat. Given the aforementioned uncertainty, it is not possible to assess the potential magnitude of this pathway of effect at this time (i.e., invertebrate prey availability for juvenile sturgeon). Adult White Sturgeon are reliant of piscivorous prey, including Pacific Lamprey and Sockeye Salmon (Smyth *et al.* 2016). Both species are in decline in the Nechako River (e.g., two of the four Designatable Units of Sockeye Salmon using the Nechako River have declined in abundance and are conservation listed as "Endangered"; COSEWIC 2017). Given known population declines, reduced prey availability is likely impacting adult fish, however the magnitude of impact is uncertain.

4.2.7. Community Structure

Altered stream flow as the result of flow regulation can cause complex changes within ecological communities (Bruce 1991; NFCP 2005). This can have important implications for native species such as White Sturgeon and the interactions they have with other organisms in the community through processes including:

1. Shifts in prey (see Section 4.2.6), predator, and competitor composition and abundance;
2. Overcrowding as a result of changes to habitat quantity and quality;
3. Impacts on fish physiology resulting in shifts in competitive, predatory, or predator avoidance ability; and
4. Shifts in species' spatial and temporal distribution.

No directed research has been conducted in the Nechako River to date that has explored if, or how, interactions between White Sturgeon and the rest of the fish community 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 increase these species' abundance, increasing the potential for competition or predation with early White Sturgeon life stages.

Work by Korman and Walters (2001) proposed that increased early life stage predation by minnows was a highly plausible effect, but more recent research has not corroborated this theory (Smyth *et al.* 2016). Given uncertainties, the likelihood and extent of such a shift in community structure is unknown.

Altered stream flow has also affected the Nechako River plant community. Decreased flow velocity and increased sediment deposition has increased emergent vegetation and macrophyte growth in portions of the river, including in off-channel habitats and the primary White Sturgeon spawning area at Vanderhoof (Neill 1987; Rood 1987; French 2005; Johnson *et al.* 2022a). This has reduced overall off-channel habitat availability for rearing (Johnson *et al.* 2022a). Increased plant growth has further reduced current velocities in the river mainstem, which could negatively impact spawning given sturgeon's preference for high velocity spawning habitats (Parsley *et al.* 1993; Perrin *et al.* 2003; Hildebrand *et al.* 2016). Increased vegetation may also impact incubation success due to increased fine sediment deposition which can cover spawning habitat and eggs, reduce benthic dissolved oxygen, and increase contaminant storage (French 2005).

The Water Engagement Initiative (WEI) process has also identified concerns regarding the potential effects of invasive reed canary grass (*Phalaris arundinacea*) on the Nechako River fish community and the potential effect of Rio Tinto (Alcan) operations and the growth and distribution of reed canary grass. This topic is given specific consideration in Wright (2022), summarized here. Reed canary grass has been confirmed within the Nechako River and although the species has not been studied in the Nechako watershed, the literature concludes that this prolific species spreads rapidly and overtakes native riparian vegetation, decreasing habitat availability and suitability for a variety of fish and wildlife species. Field studies specifically evaluating the distribution and effects of reed canary grass in the Nechako watershed, and trial studies on physical (e.g., tillering) and flow control (e.g., flooding) measures would improve our understanding and management of this invasive species and its impacts on the fish community, including White Sturgeon.

4.2.8. Icing Processes

Juvenile and adult fish rely on adequate overwintering habitats to minimize energy expenditure, avoid adverse environmental conditions, and for juveniles, to decrease the likelihood of predation (Raleigh *et al.* 1984; Brown *et al.* 2011). Both meteorological and flow regimes can be important factors contributing to White Sturgeon overwinter survival due to their impacts on ice formation processes within the river. In flow regulated systems, 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 White Sturgeon overwintering habitat quality and connectivity through various mechanisms, summarized below.

Ice penetration into the water column can increase water velocities in adjacent open water areas or increase near-bed velocities, resulting in fish avoidance or displacement (e.g., due to formation of anchor ice, hanging dams, ice jams; Brown *et al.* 2000; Lindstrom and Hubert 2004). Directed movements from such areas are energetically costly to juveniles and adult White Sturgeon during winter dormancy (Speers-Roesch *et al.* 2018). 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 or if ice formations upstream divert flow away from specific habitats (e.g., nearshore areas or off-channel habitats; Maciolek and Needham 1952; Blachut 1988; Brown *et al.* 2011). This can result in loss of access to suitable overwintering habitats or at the extreme, fish stranding (Maciolek and Needham 1952; Brown *et al.* 2011). Fish can also become isolated in pockets of open water (Brown *et al.* 2011). For some life stages this can result in increased mortality due to freezing or high predation rates in spring, prior to complete ice break-up (Faulkner *et al.* 2011; Brown *et al.* 2011).

Winter temperatures[7] and ice formation and distribution[8] have been recorded in the Nechako River over multiple decades by studies focussed on the Nechako Chinook Salmon population. We identified Nechako River specific winter icing conditions data for the period of 1980 – 1996, however we were unable to identify contemporary information on surface or anchor ice formation. At Vanderhoof, the river has solid ice cover over a five-month period, generally between October and January although the date of freeze-up is highly variable (Blachut 1988). Flow regulation generally prevents spring freshet driven ice-break up, promoting a prolonged break-up 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). Extensive anchor ice formation has been documented throughout the upper and middle Nechako River, extending at least from 25 rkm upstream to 70 rkm downstream (i.e., Diamond Island; 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).

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).

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[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.

[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).

There is limited information regarding White Sturgeon overwintering habitat characteristics, dormant fish behaviour, or life stage specific overwinter survival in the Nechako River. However, it is possible that the species' relatively sedentary behaviour and general preference for deep, low velocity water (McPhail 2007; Robichaud *et al.* 2017) may make them more resilient to changes in flow and icing conditions overwinter (i.e., less likely to be affected by shore ice or ice mediated increases in water velocity) than species that occupy shallow-water habitats and are more sensitive to flow changes (Bradford and Heinonen 2008).

4.2.9. Habitat Access

Habitat fragmentation as the result of dam construction has significantly impacted multiple White Sturgeon populations across the species range (Smyth *et al.* 2016). In the Nechako River, available literature indicates that Kenney Dam does not fragment White Sturgeon habitat because of historical, naturally occurring barriers to fish passage in the Nechako Canyon (DFO 2014; Robertson, pers. comm. 2023)[9]. RTA operations have the potential to affect fish access to tributary and off-channel habitats downstream of Cheslatta Falls (i.e., WEI issues 18 and 19; Johnson *et al.* 2022a). Alteration of Nechako River flows has likely influenced river connectivity to, and habitat availability and quality in off-channel habitats, which have been identified as important to early White Sturgeon life stages (Bennett *et al.* 2005; McAdam *et al.* 2005; Glova *et al.* 2008). Potential mechanisms include:

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; and
3. Reduced off-channel habitat quantity or quality as the result of reduced flows.

Information on fish access to Nechako River off-channel habitats and changes to habitat quantity and quality as the result of flow regulation is limited (Hamilton 1987; Reid Crowther and Partners 1987). Preliminary work investigating the effects of discharge on off-channel habitat availability 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 1987). Literature review did not identify Nechako specific studies examining fish access to off-channel habitats or effects of flow on off-channel habitat quality. As a result, the impact of flow regulation on fish access to, and quality of off-channel habitats remains uncertain.

[9] However, traditional ecological knowledge suggests that White Sturgeon were historically, or may currently be present within the Nechako Reservoir (Robertson, pers. comm. 2023).

4.3. Experience from other jurisdictions

Pallid Sturgeon is a conservation listed species native to the Mississippi and Missouri River watersheds (United States Endangered Species Act listing as "Endangered"; USDA 2015; USFWS 2022). River regulation has been identified as a significant threat to the long-term persistence of the species across its range (USACE 2018). There are two distinct Pallid Sturgeon populations in the Missouri River ("upper" and "lower" populations; Jacobson *et al.* 2016). Similar to Nechako White Sturgeon, Pallid Sturgeon in both the upper and lower Missouri River are experiencing recruitment failure (USACE 2018). Primary causes of recruitment failure in the lower river are unknown, and although habitat fragmentation has been identified as the primary factor limiting recruitment in the upper river, secondary drivers are unclear (USACE 2018).

To identify causes of Pallid Sturgeon recruitment failure, a large-scale science and adaptive management plan for the Missouri River system was initiated in 2016 (USACE 2018). The plan includes recovery initiatives for four species, including Pallid Sturgeon (USACE 2018). Project success is measured through a hierarchy of specific goals, objectives, and performance metrics and targets, outlined in USACE (2018). Despite challenges associated with the spatial scale and jurisdictional complexity of the Missouri River watershed, efforts are now underway to mediate habitat fragmentation and evaluate Pallid Sturgeon response to flow alteration through adaptive management. In support of the WEI process we spoke with Joe Bonneau, Manager of the Missouri River Recovery Program to discuss U.S. Army Corps of Engineers' Pallid Sturgeon adaptive management and recovery efforts, detailed below (Bonneau, pers. comm. 2022).

Pallid Sturgeon in the upper river historically spawned within the mainstem Missouri River and a major tributary, the Yellowstone River. Both systems are now dammed, fragmenting historic sturgeon spawning habitat. Loss of upstream habitats is believed to be the primary driver of recruitment failure, as larvae can no longer drift and settle in high quality rearing habitats. Instead, larvae appear to settle in a downstream reservoir (Lake Sakakawa) which has anoxic substrate, leading to 100% mortality.

Adaptive management work is ongoing in both the Yellowstone and upper Missouri rivers to address limiting factors. To address the blockage of adult migration by the dam, a fish bypass in the Yellowstone River was completed in spring 2022 and has been observed to be successfully passing adult fish (i.e., potential spawners). However, it is uncertain whether fish spawning further upstream in the Yellowstone River will lead to recruitment. Targeted monitoring of drifting embryos[10] and juveniles is expected to provide preliminary results of project success within the next few years.

In the upper Missouri River mainstem, flow trials out of Fort Peck dam are being used to attempt to influence the location of Pallid Sturgeon spawning using flow and temperature criteria. Specifically, this work is aimed at increasing water temperature and mimicking a lower degree spring pulse flow in hopes of stimulating sturgeon spawning just downstream of the dam. Note that cold temperatures are an issue on the Missouri River because flow releases from the dam are taken from the hypoliminion (deep water), in contrast to the Nechako where flow releases are taken from the epilimnion (surface waters). It is hypothesized that this flow trial will improve recruitment by increasing drift distance and thus opportunities for larval settlement prior to individuals encountering conditions in the reservoir. Flow trials have not yet occurred due to climate conditions (i.e., current drought prevents warm water discharge over the gate and releases are limited to deep water releases through the powerhouse). Like work within the Yellowstone River, targeted monitoring of drifting embryos and juveniles is expected to provide preliminary results of project success within the first few years following flow trials.

In the lower river, the primary limiting factor resulting in recruitment failure is not known. Over the past 20 years, significant efforts were directed at addressing suspected limiting factors through restoration, however none have proven successful thus far. Project Manager Joe Bonneau reflected that increased focus on identifying limiting factors, specifically the primary limiting factor which remains unknown, would have saved substantial time and budget. As a result, the organization has shifted focus from restoration actions to scientific studies aimed to identify limiting factors in the system, which are currently in development.

[10] Age 0+ Pallid Sturgeon had not been identified in the river through 20 years of monitoring, and in the lower river specifically, it was thought that no 0+ fish were present (i.e., in the upper river larvae have been identified in the reservoir, indicating downstream drift through the upper river). After significant investment, including the development of larval drift modelling using one million embryos and substantial sampling methodology changes (e.g., shift from random to targeted sampling in suspected areas where larvae are modelled to drift), monitoring is now regularly encountering > 10,000 individuals.

5. DISCUSSION

Nine potential pathways of effect of flow on Nechako River White Sturgeon have been identified (see Section 4.2). Each pathway is summarized separately, although interactions and trade-offs should be considered when evaluating flow scenarios. Decreased early life stage survival appears to be the primary limitation for Nechako River White Sturgeon recruitment (McAdam, pers. comm. 2022), and is hypothesized to be most strongly related to flow-mediated changes in river geomorphology and sediment processes (e.g., substrate quality; McAdam, pers. comm. 2022). Other pathways of effect for both juvenile and adult sturgeon, such as flow-mediated effects on micro-habitat velocity, temperature, food availability, and community structure have also been identified as potentially important factors, but are thought to have lower magnitude of effect than the primary pathway (see Sections 4.2.2, 4.2.3, 4.2.6, and 4.2.7). At present, the specific mechanisms (and their interactions) that result in recruitment failure remain uncertain (McAdam, pers. comm. 2022; Smyth *et al.* 2016).

Although Nechako White Sturgeon have been studied extensively relative to other non-salmonid fish species in the river, many critical data gaps remain pertaining to their population status, ecology, and life stage specific relationships to flow. Our understanding of White Sturgeon habitat use primarily comes from highly impacted systems and we have less understanding of unregulated, less-impacted systems (Hildebrand *et al.* 2016). The primary knowledge gaps across the species range include: drivers of recruitment failure in dam-affected systems, lack of clarity surrounding specific population threats (e.g., how flow specifically affects populations), and uncertainties surrounding basic biological information (e.g., population demographics and life history ecology) (DFO 2014). Environmental and physiological cues for spawning are poorly understood (Hildebrand *et al.* 2016). Behavioral plasticity such as immediate larval hiding versus drift dispersal (Braaten *et al.* 2008; McAdam 2011) strongly influences habitat selection, but the environmental triggers and survival implications are not well understood (Hildebrand *et al.* 2016) because early life stages are difficult to study (McAdam, pers. comm. 2022). In the Nechako River, index monitoring of juveniles (< 1 m in length) since 2004 (NWSRI 2022a) has not successfully captured larval sturgeon (McAdam, pers. comm. 2022). Further, survey methodologies have changed over time, complicating interpretation of temporal data. These data gaps and research challenges are common in populations of White Sturgeon and other sturgeon species.

Recent (i.e., since 2010) and planned adaptive research by the NWSRI is well suited to reduce uncertainties regarding the role of streambed substrate as a primary limiting factor of early life stage survival (McAdam, pers. comm. 2022). Studies have included the addition of clean gravel-cobble at two known spawning sites in 2011 with subsequent monitoring of spawners and juveniles (McAdam *et al.* 2018) as well as a sediment sampling program aimed at assessing the historical and contemporary sediment dynamics at the identified critical spawning habitat area at Vanderhoof (NHC 2016). Success of initial substrate restoration work was limited as clean gravels were found to quickly infill with finer sediments due to sediment dynamics in the area (see Section 4.2.1;

McAdam, pers. comm. 2022). As a result, further research with a modified methodology to prevent fine substrate deposition on clean gravel has been developed but has not yet been implemented due to challenges relating to operations (McAdam, pers. comm. 2022). In the short-term, continued index monitoring using standardized methods developed by the NWSRI (see NWSRI 2022a) will provide insight into Nechako River population dynamics. Further, collection and analysis of age structures from all captured sturgeon will allow researchers to characterize the flow conditions experienced by individual sturgeon and relate flow conditions during sensitive periods to recruitment.

Current uncertainties in the behavior of White Sturgeon behaviour and the factors affecting growth, reproduction, and survival create substantial uncertainty regarding the efficacy of a specific flow regime to recover Nechako White Sturgeon populations. After literature review and expert consultation, fundamental data gaps were determined to preclude development of meaningful flow-related performance measures for White Sturgeon in structured decision making under the WEI at this time.

6. CLOSURE

This memo has reviewed the potential for changes in flow to affect Nechako White Sturgeon across life history stages. Outcomes of the review will be used to determine if recommendation of preliminary performance measures for the WEI are appropriate and to identify data gaps that could be addressed with further study.

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..

President, Senior Fisheries Scientist

Signed

William Twardek, Ph.D., R.P.Bio.

Fisheries Scientist

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Bonneau, J. 2022. Manager, Missouri River Recovery Program, U.S. Army Corps of Engineers Gavins Point Project. Conversation with Rachel Chudnow and William Twardek on December 7, 2022.

McAdam, S. 2022. British Columbia Ministry of Land, Water and Resource Stewardship Hydroelectric Impacts Biologist and Nechako White Sturgeon Recovery Initiative Technical Working Group member. Conversation with Rachel Chudnow on September 30, 2022.

Robertson, M. 2023. Senior Advisor, Cheslatta Carrier Nation and Nechako Water Engagement Initiative Technical Working Group member. Email to Jayson Kurtz on February 2, 2023.

APPENDICES

Appendix A. Nechako River Critical White Sturgeon Habitats

Appendix A. Nechako River Critical White Sturgeon Habitats

LIST OF FIGURES

Figure 1. Map of critical habitat for Upper Fraser River white sturgeon: Nechako River confluence with the Fraser River (DFO 2014).

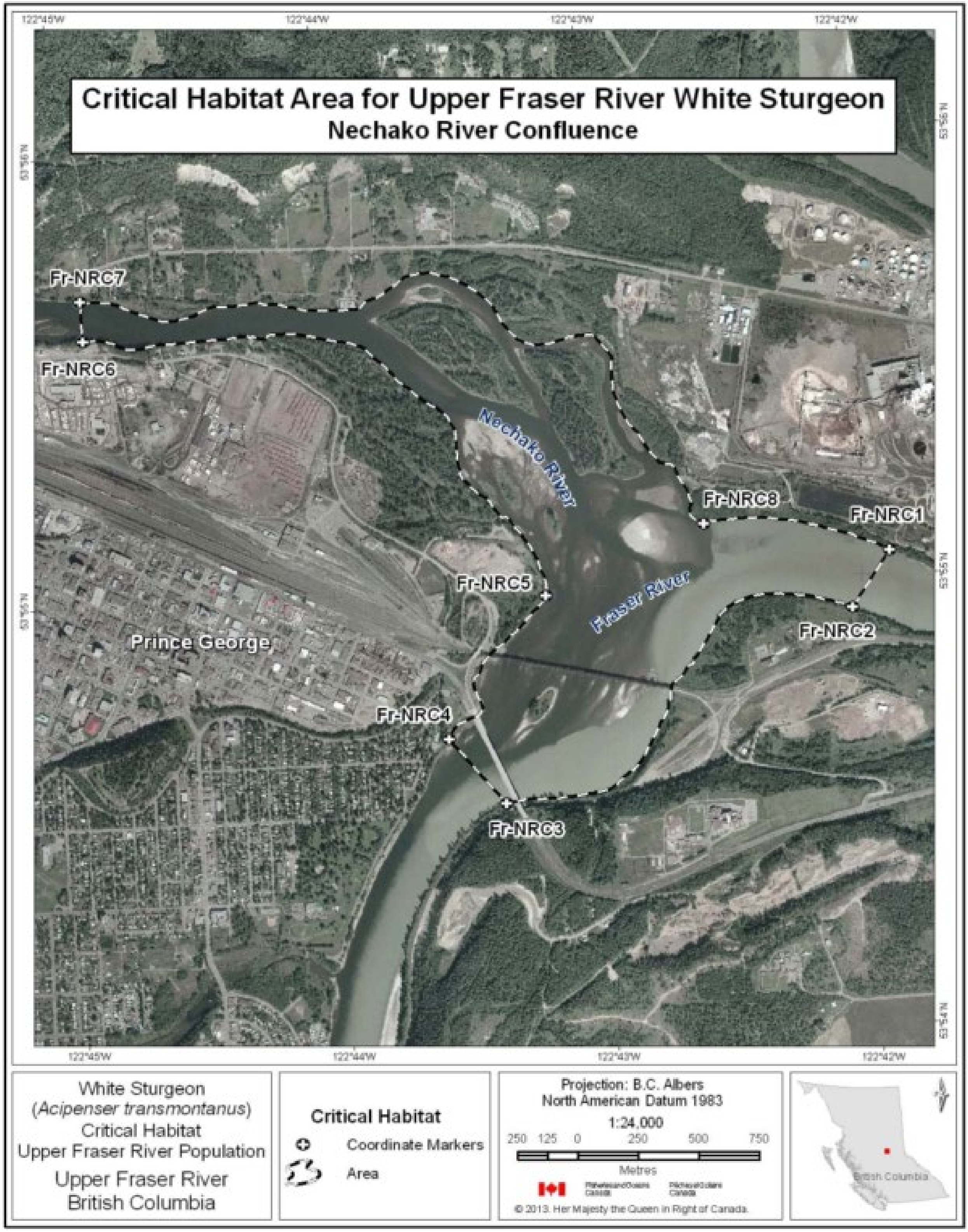


Figure 2. Map of critical habitat for Nechako River white sturgeon: Vanderhoof braided section of the Nechako River (DFO 2014).

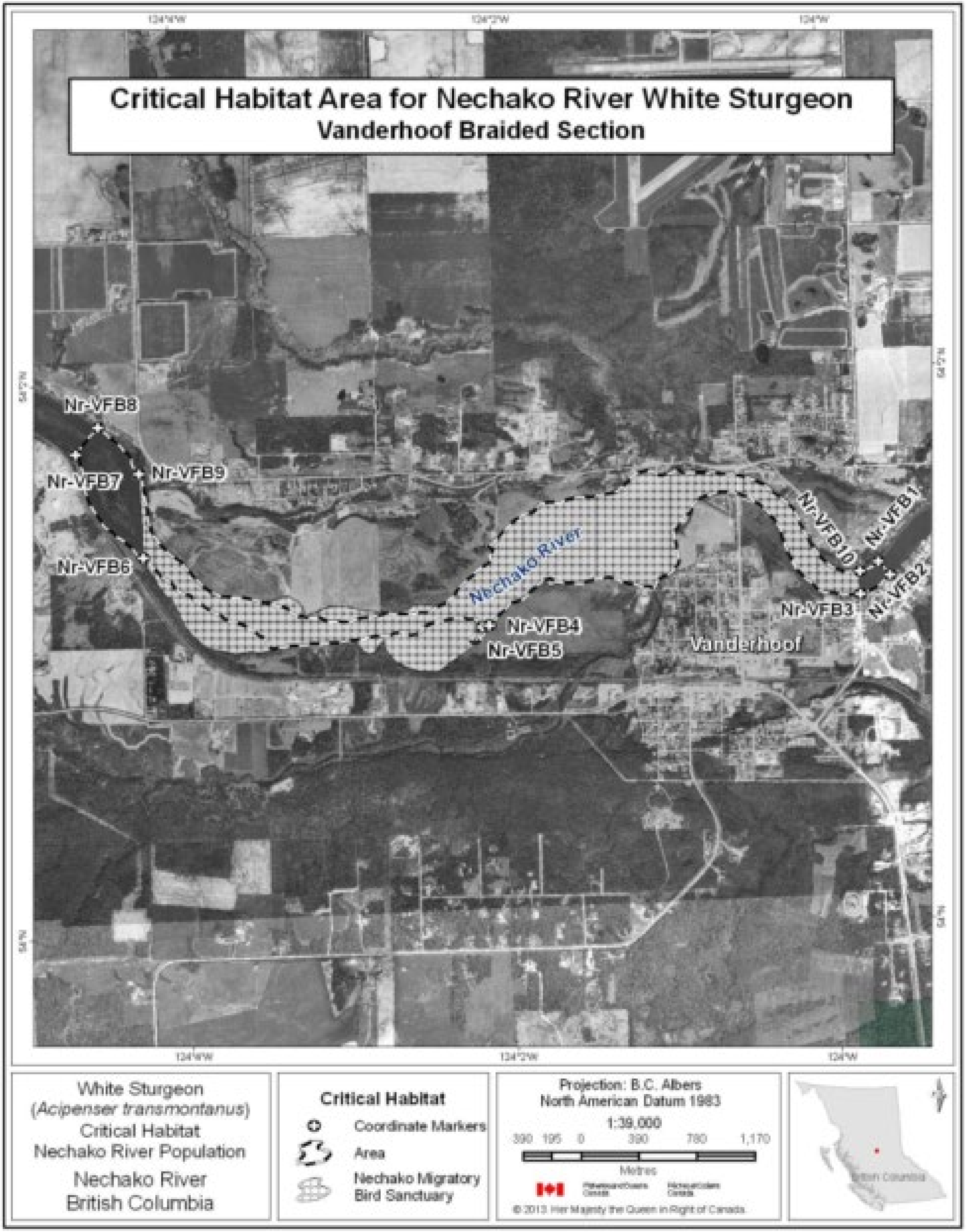


Figure 3. Map of critical habitat for Nechako River white sturgeon: Sinkut River confluence with the Nechako River (DFO 2014).

Figure 4. Map of critical habitat for Nechako River white sturgeon: Leduc Creek confluence with the Nechako River (DFO 2014).

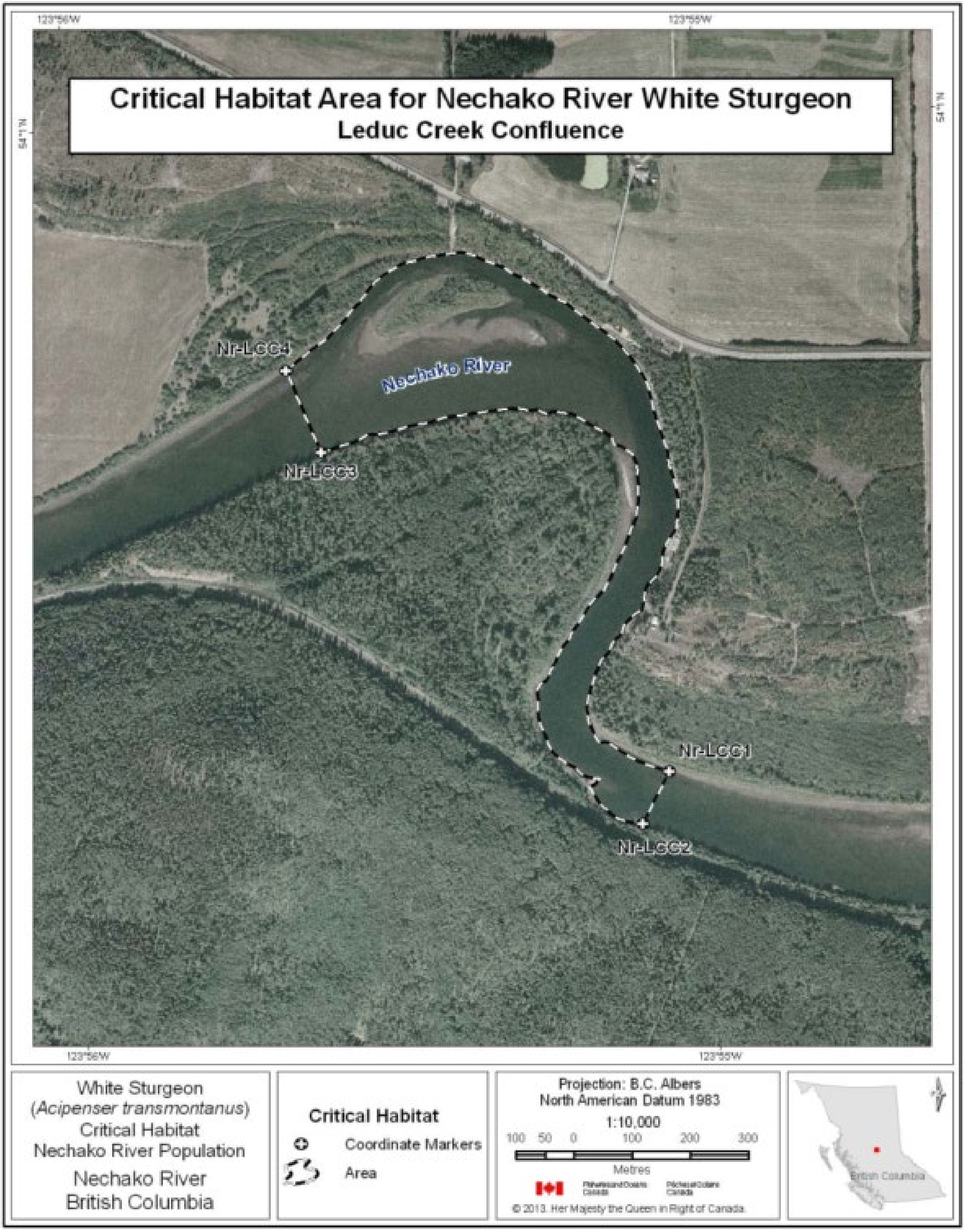


Figure 5. Map of critical habitat for Nechako River white sturgeon: Finmoore (DFO 2014).

Figure 6. Map of critical habitat for Nechako River white sturgeon: Keilor's Point (DFO 2014).

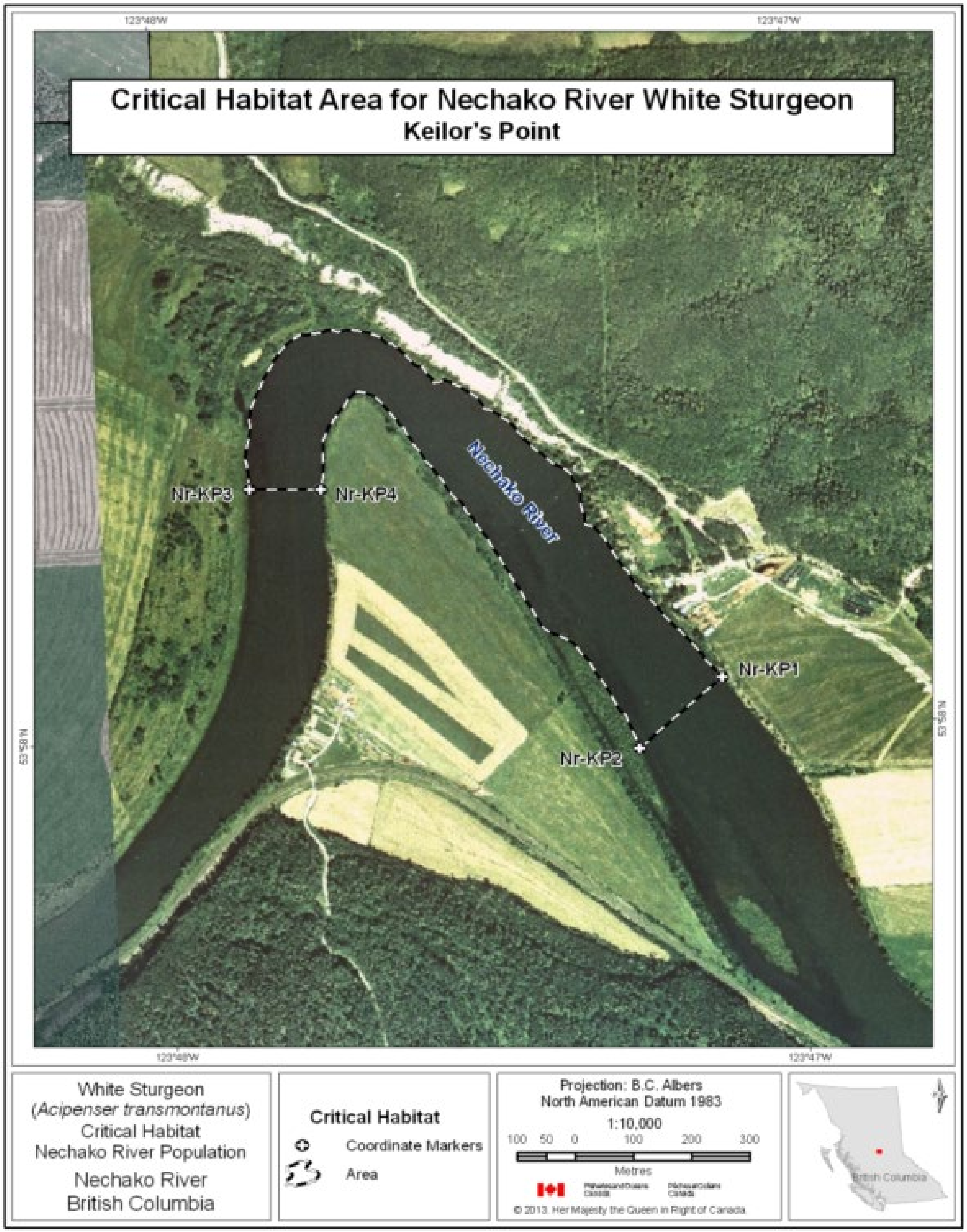


Figure 7. Map of critical habitat for Nechako River white sturgeon: Culvert Hole (DFO 2014).

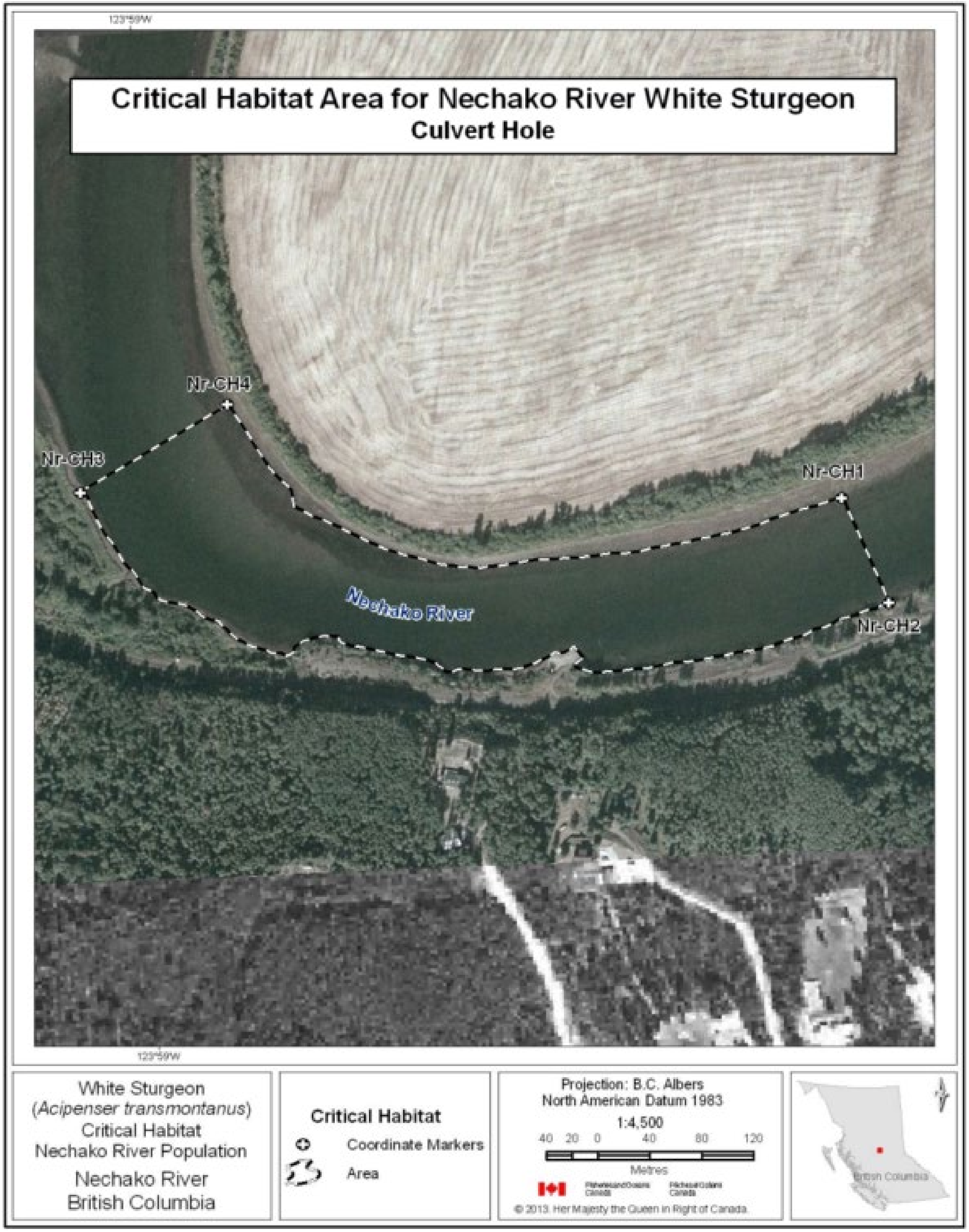


Figure 8. Map of critical habitat for Nechako River white sturgeon: Powerline (DFO 2014).

Figure 9. Map of critical habitat for Nechako River white sturgeon: Sturgeon Point (DFO 2014).

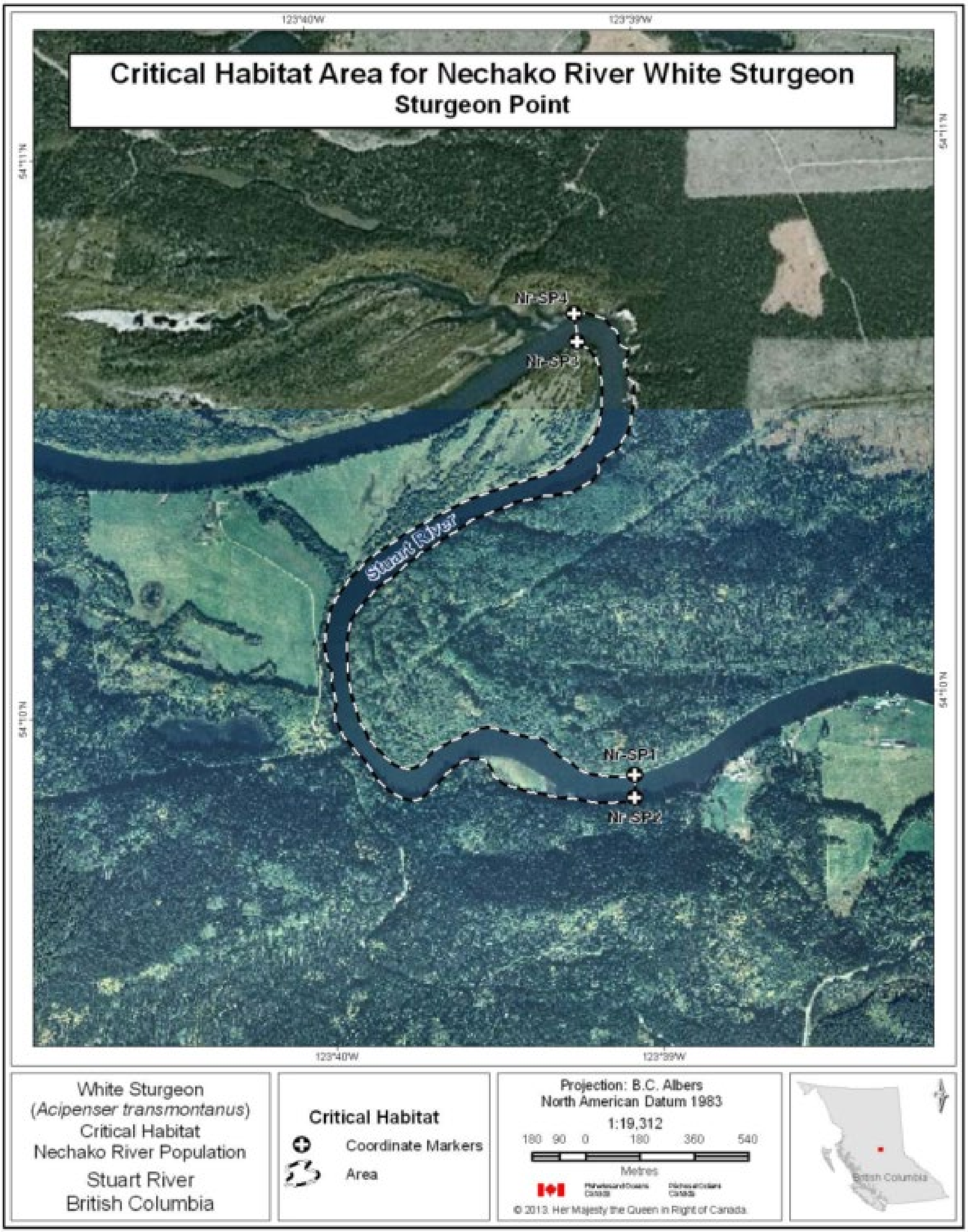


Figure 10. Map of critical habitat for Nechako River white sturgeon: Pinchi Bay on Stuart Lake (DFO 2014).

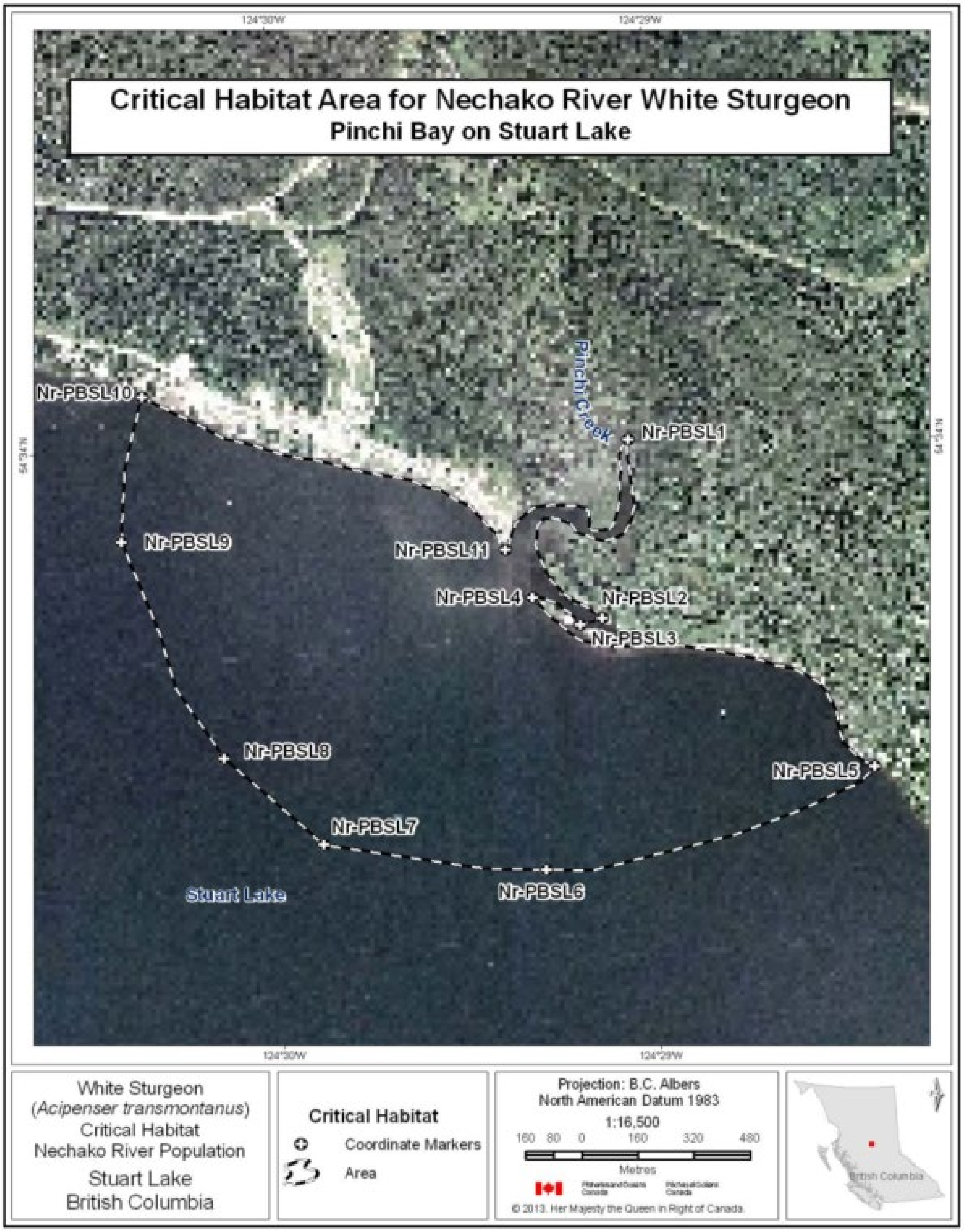


Figure 11. Map of critical habitat for Nechako River white sturgeon: Tachie River confluence with Stuart Lake (DFO 2014).

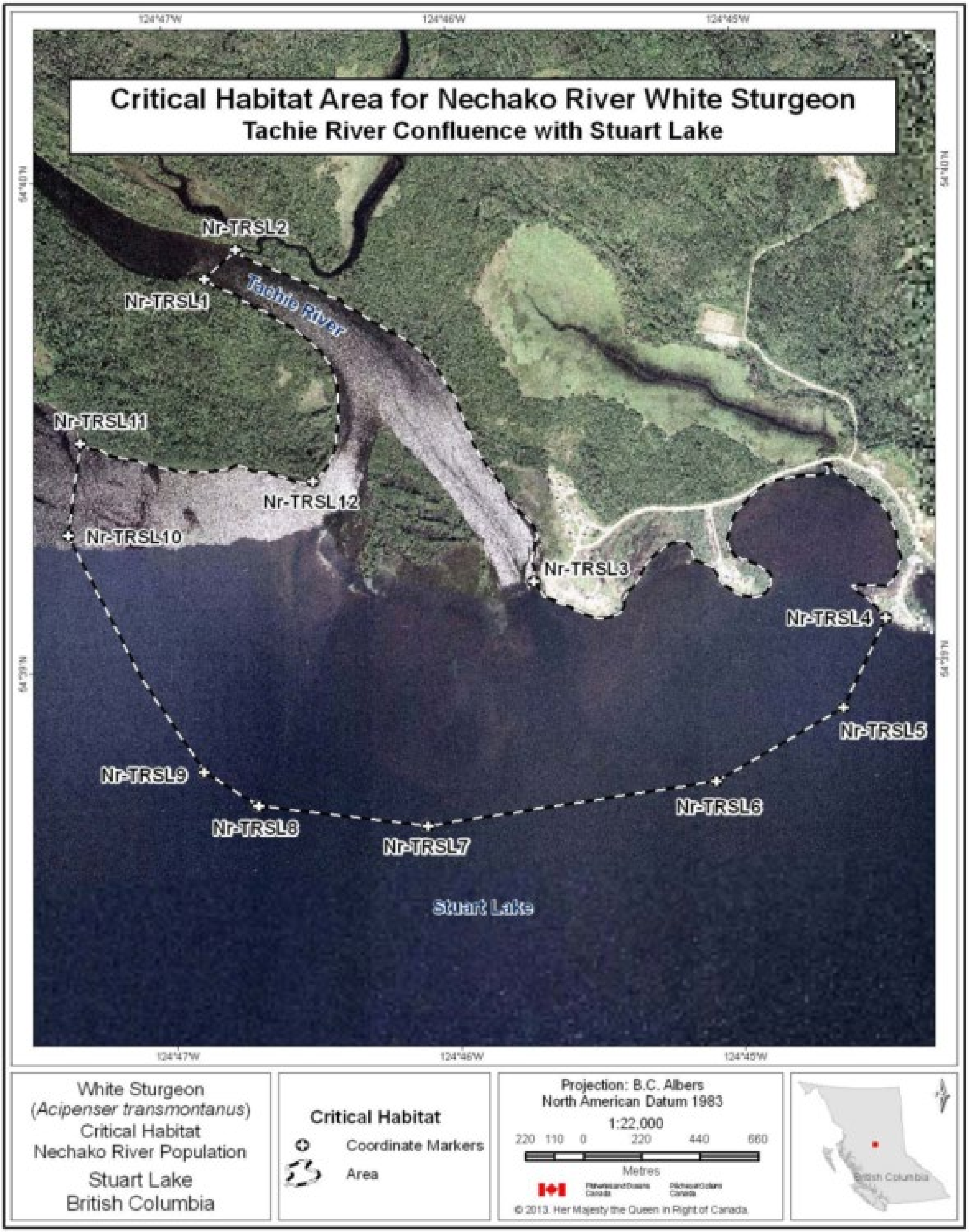
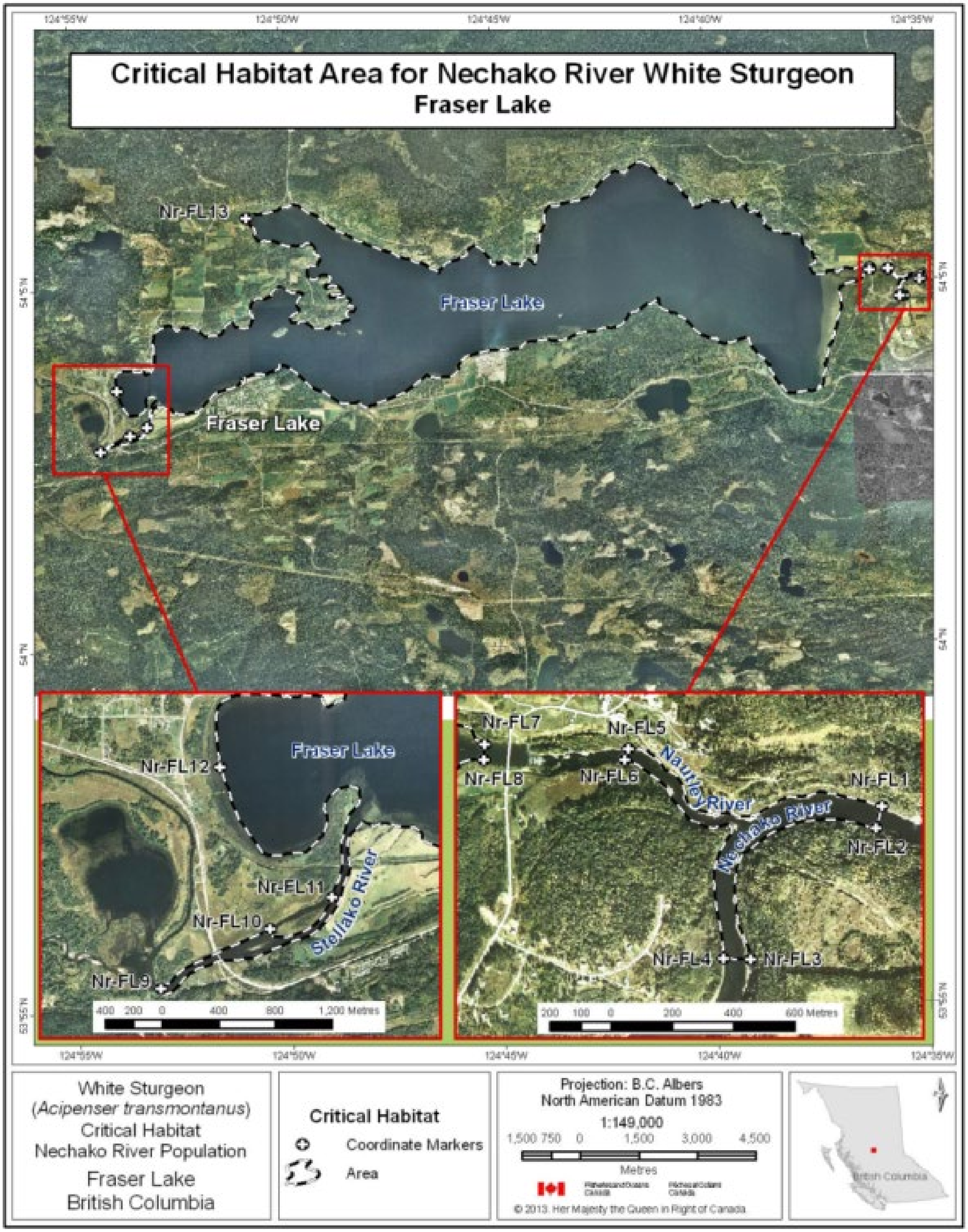


Figure 12. Map of critical habitat for Nechako River white sturgeon: Lower Half of Stuart Lake (DFO 2014).

Figure 13. Map of critical habitat or Nechako River white sturgeon: Middle River confluence with Trembleur Lake (DFO 2014).

Figure 14. Map of critical habitat for Nechako River white sturgeon: Fraser Lake and Nautley River confluence with the Nechako River (DFO 2014).



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