

Linkages between White Sturgeon Recruitment and Altered Bed Substrates in the Nechako River, Canada

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Abstract.—Reconstructed recruitment was compared with the relatively limited set of anthropogenic alterations to the Nechako watercourse to identify and investigate potential causes of recruitment failure of Nechako River white sturgeon *Acipenser transmontanus*. Back-calculation of historic recruitment shows that recruitment was present but variable from 1946 until 1964. Subsequent to 1964 there was a rapid decline, principally in 1967, and recruitment failure has continued since that time. Flow regulation, which began in 1952 with the completion of Kenney Dam, preceded recruitment failure by 15 years and therefore flow regulation does not supply a simple uncausal explanation for recruitment failure.

We propose that sediment input from an upstream channel avulsion in 1961, in combination with elevated flows in 1964 and 1967, led to alterations to riverbed substrates in critical white sturgeon habitat. Using air photos and specific gauge analysis, we identified a “sediment wave” in the upper Nechako River. The timing and location of avulsion sediments indicates that recruitment failure is most likely due to alteration of main channel substrates rather than the loss of off-channel habitat. Findings are discussed with reference to general hypotheses for recruitment failure in other white sturgeon populations.

Flow regulation and floodplain abstraction are common anthropogenic impacts affecting white sturgeon *Acipenser transmontanus* (Coutant 2004), as well as other sturgeon species (Birstien 1993). For some populations the impacts have led to essentially complete recruitment failure, which has been the principal cause of endangerment (Coutant 2004). Chronic recruitment failure in the Kootenay, Columbia, and Nechako Rivers was one of the primary reasons for the recent endangered classification of this species in Canada (COSEWIC 2003). The fact that recruitment failure began at least 30 years ago underscores the urgent need to identify causes and mitigation measures.

White sturgeon life history shares many attributes with other flood-spawning species, making them particularly prone to the effects of river regulation. They are highly fecund nonannual spawn-

ers, which typically spawn after the spring–summer freshet peak. Spawning sites are most often found in turbulent or turbid river sections areas upstream of floodplains (Parsley and Beckman 1993; Perrin et al. 2003; Coutant 2004); however, many floodplains are now unavailable or severely diminished. Given that spawning and fertilized eggs are regularly observed in populations exhibiting recruitment failure, this problem is apparently not due to lack of egg production. Relatively high survival after age 1 (Ireland et al. 2002) suggests recruitment failure occurs because of poor survival before that age. Gross et al. (2002) reached a similar conclusion using a more theoretical elasticity analysis.

The historic nature of recruitment failures complicates analysis because of uncertainty about historic stock abundance and the variety of factors affecting the large rivers that white sturgeon inhabit. Coutant's (2004) recent review, which examined white sturgeon over their entire range, suggested that the lack of newly wetted vegetation, and particularly its provision of egg adhesion sites

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and physical cover for larvae, provided a broadly applicable hypothesis for recruitment failure. Analysis of Nechako River white sturgeon provides an independent test because this population was not included in Coutant's (2004) analysis.

Despite the unique features of the Nechako River population, analysis of its recruitment failure has not been widely reported. The genetic basis for identifying this population as distinct was presented in Smith et al. (2002). The presence of a population of 571 fish was identified during a basin wide study between 1995 and 1999 (RL&L Environmental Services, Ltd. 2000), and recruitment failure was suggested due to extremely low juvenile abundance. Further evaluation of the population status as well as early development of recruitment failure hypotheses were presented by Korman and Walters (2001). Recruitment failure hypotheses were further developed within the recovery plan (NRWSRP 2004) including the hypothesized effect of altered riverbed substrates on recruitment addressed in this analysis.

Early investigations of the substrate needs of larval and juvenile white sturgeon (Brannon et al. 1984, 1985) suggest that substrate alterations may affect their survival through mechanisms such as the infilling of substrate interstices. Further support for such links is provided by ongoing investigations of the relationship between geomorphic change and its links to recruitment failure in the Kootenai River (Paragamian et al. 2001; USACE 2004; USGS 2004), where it has been difficult to argue that the recruitment failure was due to loss of floodplain characteristics because most floodplain development occurred well before the recruitment failure.

This study examines hindcasted recruitment time series in conjunction with the timing and location of sediment deposition in the Nechako River and evaluates whether sediment-mediated effects are the likely cause of recruitment failure. Flow manipulation and associated effects are the only major developments in the Nechako River likely to affect white sturgeon spawning and recruitment, and thus present the simplest case study for analysis of white sturgeon recruitment failure. In addition to the limited set of anthropogenic factors affecting the population, we consider that a lag between dam completion and recruitment failure, and the rapidity of this failure, are useful attributes for recruitment failure diagnosis.

Methods

A recruitment time series was estimated based on age composition data collected during a 1995–

1999 study of white sturgeon in the Nechako watershed (see RL&L Environmental Services, Ltd. 2000). Fish from the Nechako River were primarily (93%) captured with set lines. Age estimates from annuli counts on fin ray cross-sections were made by at least two experienced readers.

Given the importance of age validation, we compared the age distributions from Dixon (1986) and RL&L Environmental Services, Ltd. (2000) as a means of examining aging bias, after correction for gear type and capture year.

Apparent relative recruitments R_t for years t prior to the age sampling were back-calculated by assuming that

$$R_{t-a} = P_a \times e^{aM},$$

where P_a is the proportion of the sample fish that were age a at $t = 1995$. A natural mortality rate of $M = 0.08$ was assumed, based on analysis of catch curves and tagging studies reviewed in Korman and Walters (2001). The key assumption in this method, besides the sample proportions of fish at age being representative of the age composition of the remaining extant population, is that M has been stable over time. Because the scarce young (age-10–20) fish included in the calculation (and leading to low recruitment estimates) had been common when sampled with the same gear in 1982 (Dixon 1986), there is no reason to suspect that younger fish are underrepresented in the sample as a result of gear bias. Also, including higher M for younger ages (as seen in tagging data, e.g., Ireland 2002) would not change the index pattern at all except to scale it upward in absolute magnitude, because no such younger fish were included directly in the estimation via nonzero P_a values.

For analysis of geomorphic change, we examined time series air photos. Four habitat clusters were identified in air photos taken May–June 1978 (Figure 1). Each cluster contained at least one putative spawning site, identified as a chute or rapid, where water velocities were likely to be elevated under flood conditions (e.g., S1a = spawning site a in cluster 1), which was located upstream of a putative rearing site (e.g., R3b = rearing site b in cluster 3), identified as an area with increased riparian habitat such as a flanking floodplain. Within each habitat cluster, analysis focused on changes at the putative spawning and rearing habitat units based on air photos covering both the pre- and postregulation period (i.e., pre- and post-1952). We also observed substrate characteristics during an October 2002 field reconnaissance.

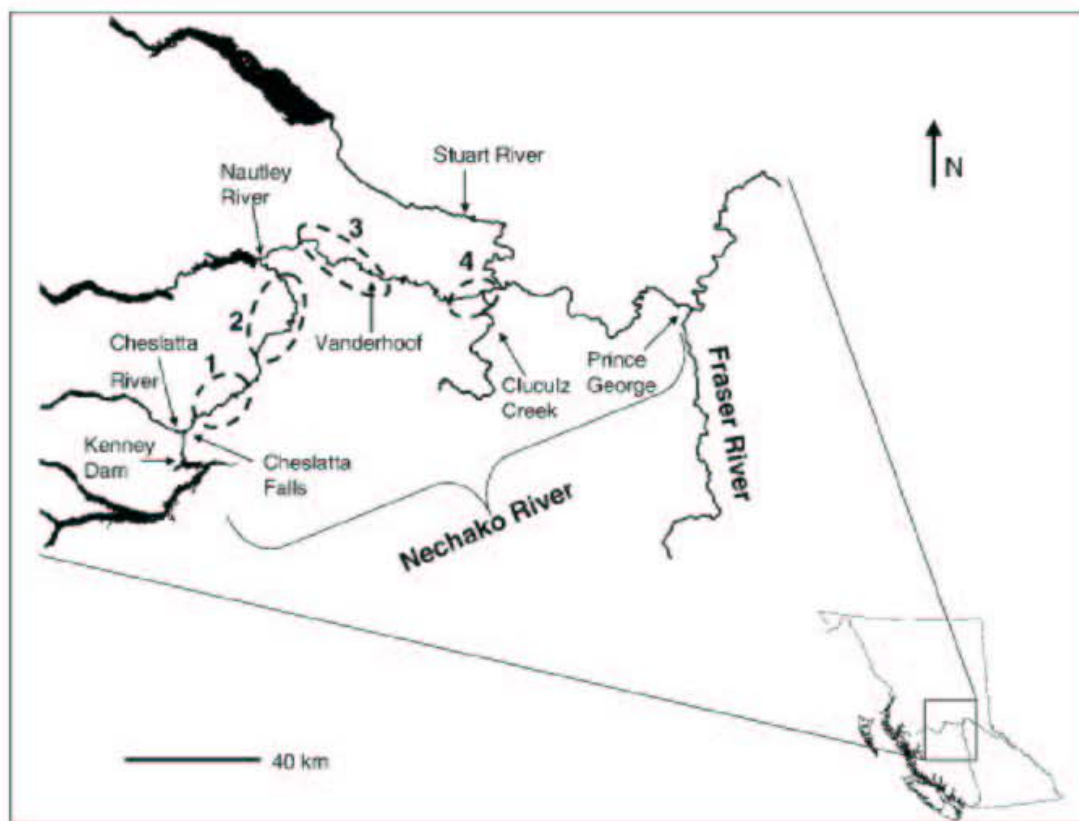


FIGURE 1.—Map of the study area. Numbers indicate the habitat clusters within which putative spawning and rearing habitat units are located. The spawning site is located in habitat cluster 3.

Site-specific evaluation of riverbed elevation changes was achieved by specific gauge analysis of data from the rating tables for the Water Survey of Canada (WSC) gauge site at Vanderhoof (08JC001) for the period 1949–2002. The specific flows analyzed were 113, 227, and 340 m³/s. Temporal changes in water-level gauge height at specific flows indicate changes in the channel bed elevation.

Flow data were extracted from the HYDAT da-

tabase of the WSC. Because of the limited flow data for the Upper Nechako River, flows upstream of the Nautley confluence were estimated by subtracting Nautley River flow (gauge 08JA001) from Nechako River flow at Vanderhoof (gauge 08JC001). Any errors caused by this method are considered to be minor relative to the effects of river regulation.

Results

Hydrograph Alterations

Since the completion of Kenney Dam in 1952, there have been marked declines in both total annual flow volume (because of out-of-basin diversion) and freshet discharge (Figure 2). The reservoir-filling period is notable for its extremely low flows between 1953 and 1956. Subsequent to this period, until 1978, releases to the Nechako River were more variable during the freshet period, the average annual peak discharge being reduced to approximately half of the preregulation value. A more uniform release strategy was adopted in 1981, comprising low flows through the former spring freshet period and moderate flows in the summer (Figure 2). After 1981, the only year with a high spring freshet flow event was 1997.

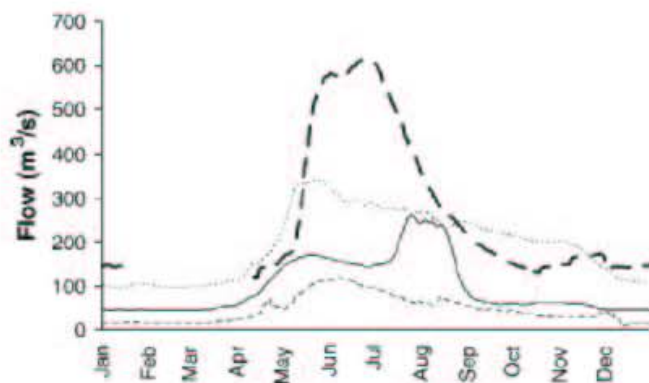


FIGURE 2.—Annual hydrograph of the Nechako River above the Nautley River confluence (bold dashes = pre-1952, dashes = 1953–1956, fine dashes = 1957–1977, and solid = 1978–1999). Flow data are unavailable from January 19 to April 11 for 1950–1952.

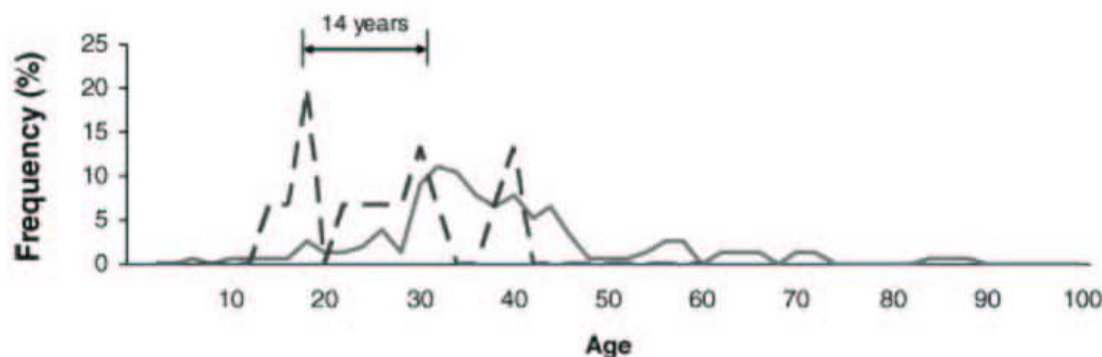


FIGURE 3.—Comparison of corrected age distributions from previous studies by Dixon (1982; dashed line) and RL&L Environmental Services, Ltd. (2000; solid line).

Recruitment Reconstruction

Comparison of aging results from Dixon (1986) and RL&L Environmental Services, Ltd. (2000) used standardized capture years of 1980 and 1995, respectively, and considered only fish caught with set lines. After these standardizations, the modal age shows a difference of 14 years between studies (Figure 3).

Poor representation of fish less than 15 years old, possibly resulting from gear selectivity, and limited abundance of fish older than 50 years makes recruitment reconstruction most accurate for the period 15–50 years before the mean capture year (1996). Therefore, we began analysis of the recruitment time series starting with 1946. The general pattern of projected recruitment indicates variable recruitment from 1946 to 1964 (Figure 4). The rapid decline in recruitment may have begun in 1964, although recruitment until 1966 is still within the pre-1964 range, but most definitely declined in 1967. Since 1967, recruitment has remained very low with only minor variation.

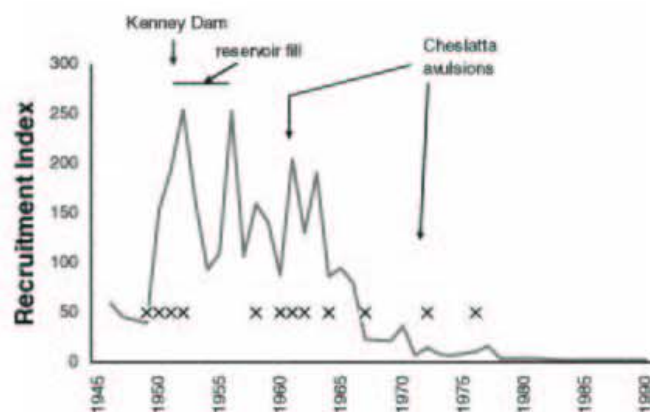


FIGURE 4.—Historic pattern of projected recruitment ($M = 0.08$). Years when flow at Vanderhoof exceeded $500 \text{ m}^3/\text{s}$ are indicated by Xs.

Geomorphic Analysis

Variation in photo quality and discharge limited the comparisons to the years indicated in Table 1. Identification of sediment accumulation at putative spawning and rearing sites indicates such accumulation throughout the upper river. Because of the comparability of multiple photos, 1966–1973 can be clearly identified as a period of sediment accumulation for site R2b. For other sites the timing of accumulation cannot be defined more precisely than 1953–1985, because of the availability of air photos. Accumulations noted for site R4 in 1966 had a notably different composition, appearing to be an effect of localized down-cutting at the mouth of the Cluculz Creek rather than an accumulation of Cheslatta avulsion material.

Specific gauge analysis for the Vanderhoof water survey site indicates relatively stable conditions from the period of dam completion until 1970, when a period of aggradation began (Figure 5). The most significant aggradation occurred between 1975 and 1995, and a period of degradation began in 1996. In addition, the technical notes recorded for this site indicate large accumulations of sand and gravel in 1972 and 1976.

Discussion

Unbiased age estimation is critical for recruitment reconstruction, and errors may be incurred as a result of capture methods or inaccurate age estimation. Fish used for age estimation were primarily (93%) captured with set lines. Although set lines are biased toward larger fish, they apparently have little bias for fish above the size at about age 15 (Elliott and Beamesderfer 1990). The sampling method should therefore have little effect on the present analysis, which focuses on events more than 15 years before the mean capture year; very

TABLE 1.—Relative sediment changes from air photo analysis. Symbols indicate changes between years with comparable photos as follows: no change (=), increase (+), large increase (++). A more defined period of sediment accumulation is noted by the underlining for site R2b.

Habitat cluster	Habitat unit	1928	1946	1947	1951	1953	1960	1961	1966	1973	1974	1985	1990	1995
1	S1a	No detectable change												
	S1b	No detectable change												
	R1	No detectable change												
2	S2a									=	-----			=
	S2b									+	-----		+	
	S2b						=	-----					=	
	R2a						=	-----						=
	R2b						=	-----	=+	-----	+			
	R2b		+	-----						+	=	-----		=
	R2b		+	-----									+	
3	S3									++	-----		++	
	R3a					+	-----			+				
	R3b		No detectable change											
4	S4					+	-----		+					
	R4					+	-----		+					

few fish (6 of 170) younger than age 15 were included in the analysis.

Although full age validation has not been achieved for white sturgeon, a comparison of the aging results from Dixon (1986) and RL&L Environmental Services, Ltd. (2001) provides a preliminary means of validation. The similarity between shifts in modal age of 14 years and the interstudy interval of 15 years are a strong indication of annual annuli formation in older fish. This alone does not provide full age validation (Campana 2001), but it does indicate that the aging bias suggested by Paragamian and Beamesderfer (2003) does not apply to the Nechako population. Similar inference is provided by Veinot and Evans (1999) for fish from the lower Columbia River. Further analysis of a population from the upper Columbia River indicated that aging bias identified by Paragamian and Beamesderfer (2004) may be due to methodology rather than aging error (Golder As-

sociates 2005). As a result of these findings, we pursued the present analysis assuming that age estimates were accurate. Although aging imprecision has been demonstrated (Rien and Beamesderfer 1994), its effect on this analysis should be minimal because imprecision would generally dampen variation but would not alter the timing of the marked changes, such as in 1967.

Regulation of Nechako River flows began in 1952 with the completion of Kenney Dam, and the following 3 years had very low flows because of reservoir filling requirements (Figure 2). Subsequently total annual river flow was still markedly lower than preregulation as a result of significant out-of-basin water diversions. However, flows during 1957–1977 remained quite variable, and both high-discharge freshets and low winter flows occurred occasionally throughout this period. A further marked and consistent decline in freshet volume began in 1978 (Figure 2) and continued with the 1981 adoption of a new flow regime, in which even-greater flow diversions were balanced with moderate summer flow releases for the protection of anadromous salmonids.

The rapid recruitment decline in 1967 occurred 15 years after the initiation of flow manipulation. The absence of a more immediate recruitment response to flow alterations, or in conjunction with the second major reduction in freshet volume in 1978, indicates the absence of a direct effect of flow alteration. Although the degree of hydrograph alterations has been variable since impoundment, the greatest effect on the flows was during the 3 initial years of reservoir filling. Yet recruitment persisted during this period. In addition, there is

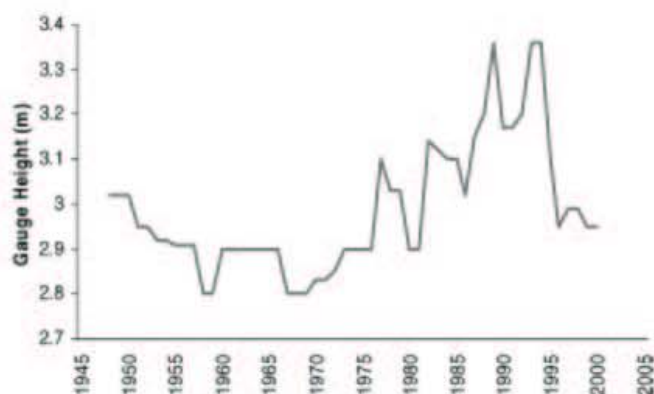


FIGURE 5.—Specific gauge analysis for the Water Survey of Canada gauge at Vanderhoof at a flow of 227 m³/s.



FIGURE 6.—Air photo of the Nechako River at braided river section at site R3a on July 9, 1985 (flow = 175 m^3/s), indicating the known spawning site (Sp) and the Water Survey of Canada gauge site (WSC). The community of Vanderhoof is located in the lower right.

no apparent recruitment signal due to freshet flows of historic magnitude in 1976. Taken together, these findings indicate that hydrograph alterations, by themselves, do not provide a simple uncausal explanation for the observed recruitment failure of the Nechako population.

The only other major perturbation to this watershed between 1952 and 1967 was an avulsion into the upper Nechako River near Cheslatta Falls in August 1961 (Hay and Company 2000). This was one of two avulsions (the second was in July 1972), which collectively added 1,000,000 m^3 of silt, sand, and fine gravel into the river channel; about half of this material was subsequently moved downstream (Rood and Neill 1987). Tracking the downstream sediment movements by using air photos is challenging, given the uneven availability of suitable quality photos at the required flows. However, the availability of multiple photos at site R2b provides a more precise identification of sediment accumulation between 1966 and 1973, indicating that Cheslatta avulsion sediments arrived upstream of the Vanderhoof spawning site between 1966 and 1973. Substrate accumulations at site R3a, immediately downstream of the recently confirmed spawning site (Figure 6), occurred between 1953 and 1973. However, the lack

of accumulation at site R2b between 1960 and 1966 suggests that sediment accumulation at site R3b most probably occurred after 1966. These two observations indicate that recruitment failure was coincident with changes in substrate conditions in the vicinity of the Vanderhoof spawning site.

Channel aggradation at the Vanderhoof WSC gauge, which began in 1970 (Figure 5), is a further indication of the presence and timing of a sediment wave. The presence of high flow in 1964, 1967, and 1972 make these the mostly likely years for major downstream sediment movement, and the first two of these years coincide with years when recruitment declined. Cheslatta avulsion sediment is considerably finer than the original gravel and cobble bed material of the Nechako River, which has been essentially immobile since the onset of regulation. The period of greatest aggradation at the WSC gauge occurred between 1975 and 1995, indicating a considerable lag time for the sediment wave moving down the channel. However, accumulation had already occurred downstream at site S4, suggesting that the avulsion material traveled in at least two waves: a more rapid, finer textured wave that passed Vanderhoof without causing identifiable aggradation but deposited further downstream, and a slower, coarser wave that first

appeared at the Vanderhoof WSC gauge in 1970. The lag between the initiation of recruitment failure and the aggradation at the Vanderhoof gauge site is probably caused by a delay in sediments moving through the large depositional area located in the 2 km between the known spawning site and the WSC gauge site. The occurrence of such a lag is consistent with the passage of a sediment wave that would reach upstream sites first and move more slowly through lower gradient river sections. Alternatively, the earlier indications of recruitment failure in 1964 might be attributable to the introduction of finer sediments first noted at site S4 between 1953 and 1966. These findings, which suggest a causal linkages between flow regulation, sediments, and recruitment failure are consistent with similar findings for the Kootenay white sturgeon (Paragamian et al. 2001; USFWS 1999).

The downstream passage of sediment load may support two competing hypotheses about causes of recruitment failure, given that changes have been noted for both in- and off-channel habitats (Rood and Neill 1987; NHC 2003; NHC and McAdam 2003). Rood and Neill (1987) identified a 34% loss of type I side channels (those separated by a treed island) between 1953 and 1973–74, and a 64% loss by 1986. Side-channel habitats apparently provide important juvenile-rearing habitat (Lane and Rosenau 1995), and large losses of habitats such as these would support the riparian habitat hypothesis presented by Coutant (2004). However, several lines of evidence suggest that in-channel changes are more likely to be the primary cause of recruitment failure.

Although floodplains are critical components of fluvial systems and therefore may affect recruitment via ecosystem productivity, floodplain abstraction does not appear to have caused outright recruitment failure in the Nechako watershed. Before the institution of flow regulation, Nechako River freshets led to annual overbank flooding of river margins, but full floodplain inundation was rare (NHC and McAdam 2003). Postregulation declines in flood magnitude limited the availability of off-channel habitat starting in the early 1950s. Thus, the delayed recruitment failure of Nechako white sturgeon indicates that significant losses of floodplain habitat preceded the dramatic recruitment decline in 1967. Continued recruitment in the lower Fraser River in light of the loss of 85% of historic wetland habitat (Boyle et al. 1997) is another indication that recruitment can persist in the face of significant floodplain losses. A similar pattern is also present on the Kootenay River,

where dyking was largely complete by 1940 (Constable 1957; USACE 2004); however, recruitment occurred until flow regulation was begun in 1974 (Paragamian et al. 2001). Examination of these cases clearly indicates that although loss of off-channel habitat may affect stock productivity, it does not appear to provide an explanation for rapid and persistent recruitment failure.

The recent identification of the only known spawning site in the Nechako River just upstream of the significant floodplain area at Vanderhoof (Figure 6; Liebe et al. 2004) provides further evidence that recruitment failure is more likely to be caused by alterations to channel substrates. Losses of side-channel habitats, identified by Rood and Neill (1987), are spread over the 150 km of the river from Vanderhoof upstream to Cheslatta Falls; only very limited changes have been identified downstream of Vanderhoof (NHC 2003). Therefore the majority of side-channel losses occurred upstream of the present spawning location. Although Rood and Neill (1987) could not precisely identify the timing of side-channel losses, the identification of a sediment wave suggests these habitats were probably lost sequentially rather than synchronously. Therefore the rapidity of the recruitment failure versus the likely progressive nature of side-channel losses, in combination with the present spawning location being downstream of most of the lost side channels, indicates that the recruitment failure is probably not the result of loss of side-channel habitats. The exclusion of this hypothesis suggests that the hypothesis presented by Coutant (2004) does not appear to be the predominant mechanism of recruitment failure in the Nechako River. In this case, alterations in the bed substrate of main channel habitats are the more likely factors causing recruitment failure.

Various mechanisms have been proposed by which finer-grained sediment may limit recruitment, including effects such as increased predation because of the loss of interstitial refuges along with egg suffocation by sand cover (Paragamian et al. 2001; Koch 2004; NRWSRI 2004). Sand movements have been observed to cover eggs in the Kootenay River (Paragamian 2001). Although sand movement is apparent in the Nechako River (NHC and McAdam 2003), it does not appear to be rapid enough to cause egg burial. Geomorphological effects of bed load movement on interstitial habitats and bed armoring are therefore more likely mechanism for this effect in the Nechako River. Further experimentation is definitely justified to examine these mechanisms. Experimental miti-

gation to diminish the sand fraction and increase interstitial spaces, using flow or others means, should also be examined.

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