4. Achieve population characteristics of these species within 100 years that, while fluctuating due to natural variability, represent on average full mitigation for losses of resident fish.

2.0 BIOLOGY AND STATUS

2.1 Species Description

The white sturgeon (*Acipenser transmontanus*) is one of seven North American and 23 total sturgeon species that inhabit temperate large river systems throughout the Northern Hemisphere (Robins et al. 1980). The white sturgeon was initially described by Richardson in 1863 from a specimen collected in the Columbia River near Fort Vancouver, Washington (Scott and Crossman 1973). Green sturgeon (*Acipenser medirostris*) are also found in the Columbia River but are restricted to coastal areas (Scott and Crossman 1973, Brown 1989).

All sturgeon are characterized by a cartilaginous skeleton and persistent notochord (Scott and Crossman 1973). They possess a tube-like mouth and four barbels located on the ventral surface of a hard protruding snout. All sturgeon have five rows of bony plates (scutes): one dorsal, two ventral, and two lateral (Scott and Crossman 1973). Denticles make the skin feel rough between the rows of scutes. The arrangement and number of scutes are diagnostic for white sturgeon: 11 to 14 dorsal, 36 to 48 lateral, and 9 to 12 ventral scutes (Scott and Crossman 1973). Bajkov (1955) also described white sturgeon with seven rows of scutes. About 3% of the specimens examined displayed this characteristic and were collected downstream from Bonneville Dam, the lowermost dam on the Columbia River. White sturgeon with seven rows of scutes also have been recorded in the Columbia River.

Several authors have noted snout dimorphism in white sturgeon (Crass and Gray 1982; Brannon et al. 1986). Landlocked forms appear to have more pointed snouts than those with access to the ocean (Brannon et al. 1986). Different snout shapes may reflect different temperatures or other factors that individuals experience during development (Ruban and Sokolov 1986, Brannon et al. 1987) or perhaps an adaptation to fast moving water.

2.2 Distribution & Movements

White sturgeon are a facultative anadromous species that inhabits large rivers, estuaries, and the near-shore ocean from Ensenada, Mexico to the Aleutian Islands (Figure 4). Significant white sturgeon populations spawn in the Columbia, Fraser, and Sacramento river systems (Scott and Crossman 1973, Lee et al. 1980, Lane 1991). These populations likely mix in the ocean but only occasional movement of tagged fish has been observed among the three main river systems (DeVore et al. 1999). Many white sturgeon populations and individuals are currently restricted to fresh water by impassable dams or historic natural barriers. Prior to extensive development, populations with access to the ocean probably included a mixture of anadromous and resident life histories with the incidence of anadromy decreasing in the upper river reaches.

White sturgeon historically had access from the ocean all the way to Windermere Lake in the upper Columbia and Shoshone Falls in the upper Snake River (Figure 4). Populations in the upper reaches of the basin were most likely resident but benefited from the availability of anadromous salmon. A Kootenay River population was isolated upstream of Bonnington Falls since the last glaciation approximately 10,000 years ago (Northcote 1973). White sturgeon inhabited the upper Columbia mainstem, lower Spokane River, lower Pend d'Oreille River, and

Kootenay River to Bonnington Falls, and probably also used portions of smaller tributaries including the Sanpoil, Kettle, Slocan, and Salmo rivers (Hildebrand and Birch 1996, Prince 2001). Distribution was probably patchy with fish concentrated in areas of favourable habitat. Significant concentrations of white sturgeon were reported during the early 1900s in the mainstem downstream from Castlegar, the lower Kootenay River, Arrow Lakes, Big Eddy near Revelstoke, and the present site of Mica Dam (Prince 2001).

At least two significant subpopulations remain in the upper Columbia River and other remnant populations consisting of a few individuals occur, or are suspected, throughout other portions of the historic range (Figure 4). The largest subpopulation resides in the free-flowing transboundary reach between Hugh L. Keenleyside Dam (HLK) and Lake Roosevelt (FDR). White sturgeon in the 56 km section of the Columbia River between HLK and the international boundary have been intensively studied since 1990 (Hildebrand and English 1991; RL&L 1993, 1994a, 1994b, 1995, 1996a). Sturgeon in this section are concentrated throughout the year in four deep, low velocity areas: the area downstream from HLK, Kootenay eddy at the Kootenay River confluence, Fort Shepherd Eddy, and Waneta Eddy at the Pend d'Oreille River confluence. Considerably less is known about sturgeon distribution and density in the approximately 40 km section of river between the border and Lake Roosevelt. This area was surveyed for sturgeon in 1998 with limited effort (DeVore et al. 1998, Kappenman et al. 2000). Significant catches of adult sturgeon occurred in the transition zone of the upper reservoir and smaller numbers were caught in other areas upstream to the border. Sturgeon have only occasionally been caught in Lake Roosevelt during years of intensive sampling for other fish species.

The extent of movements and mixing of sturgeon throughout the transboundary reach is unclear. Telemetry studies in the Canadian portion of the reach have identified localized movements between adjacent high use areas and into staging areas for spawning. Long distance seasonal migrations have not been observed although some fish tagged in Canada have moved into U.S. portions of the river and upper Lake Roosevelt. Similar patterns were observed in a small telemetry study conducted from 1988-1991 where sturgeon tagged near Marcus Flats in upper Lake Roosevelt were generally observed to remain in that area (Brannon and Setter 1992).

A second significant subpopulation of white sturgeon currently inhabits Arrow Lake Reservoir (ALR). This subpopulation appears to be substantially smaller than the group in the transboundary reach between HLK and FDR. Sturgeon sampling and telemetry studies have been conducted in ALR from 1995-2000 (RL&L 1998c, 1999b, 2000b). A significant sturgeon concentration was identified in the Beaton Flats area at the confluence of Beaton Arm and the main body of ALR. Radiotagged fish were observed to remain in this area throughout the winter but several fish moved during spring and summer upstream to Revelstoke or into Beaton Arm near the confluence with the Incommappleux River. Despite observations of sturgeon entrained through HLK and anecdotal reports, only one sturgeon has been caught in assessment fisheries in lower Arrow reservoir.

Other small remnant white sturgeon populations occur throughout the historic upper Columbia River range. Adult sturgeon have been collected during systematic investigations in Slocan Lake and Duncan Reservoir of the Kootenay system but not in Kinbasket Reservoir, Revelstoke Reservoir, or Trout Lake (RL&L 1996b, 1996c, 2000a). However, given the large size of these reservoirs and limited sampling effort, the failure to catch a white sturgeon does not necessarily preclude their existence, but may suggest that population densities are very low (RL & L 2000a).

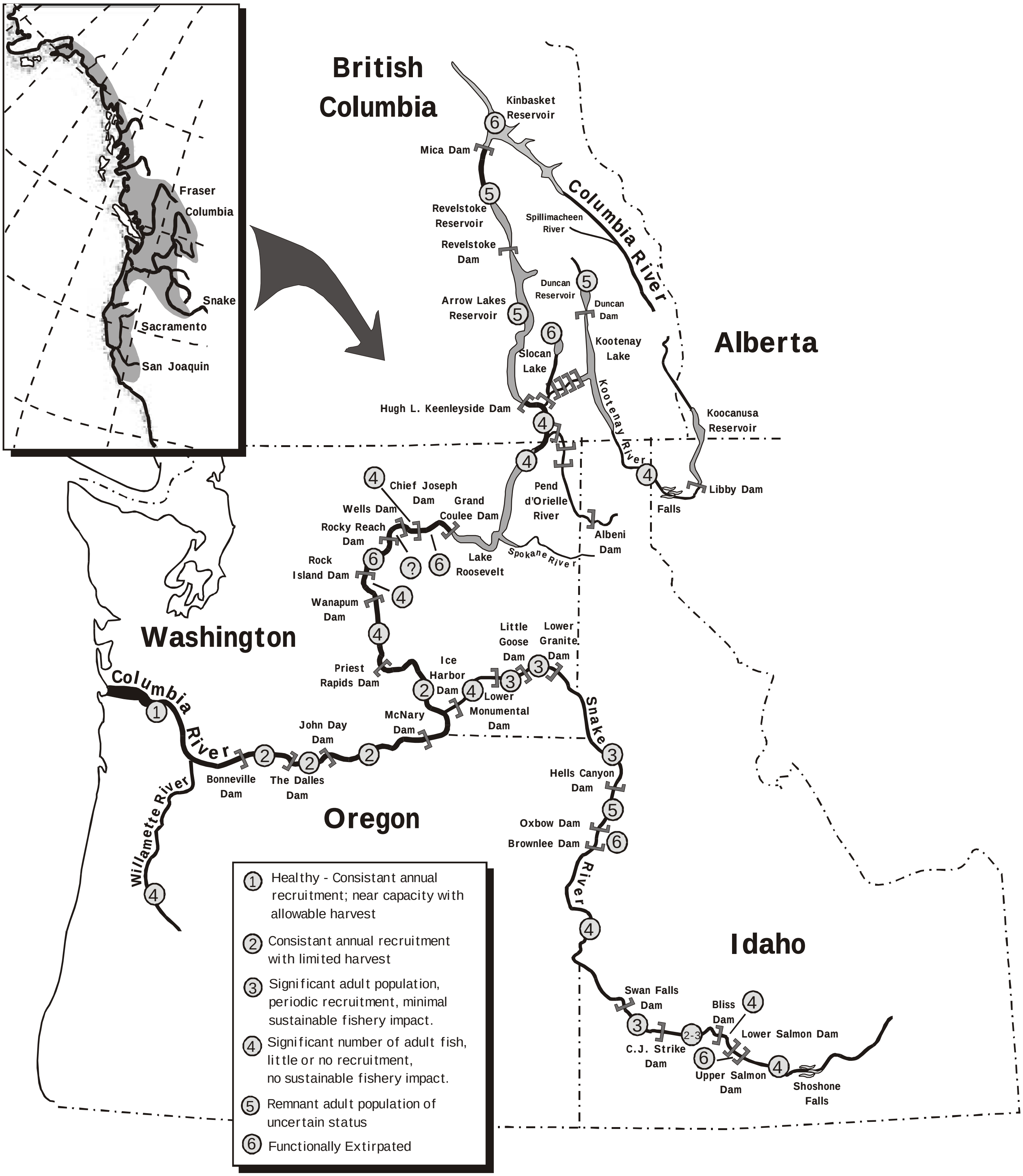

Figure 4. **Freshwater and saltwater range of white sturgeon (Scott and Crossman 1973, Moyle 1976, Lane 1991) and the distribution and status of Columbia River subpopulations.**

2.3 Genetics & Stock Structure

White sturgeon populations along the Pacific coast of North America are closely related. Anders and Powell (2002) observed 26 unique mitochondrial DNA (mtDNA) sequences (haplotypes) in samples from 13 locations in the Columbia, Snake, Kootenay, Fraser, Nechako, and Sacramento rivers. The two most common haplotypes were represented by 64% of the 260 fish sequenced and were observed at 100% and 85% of the sample sites (Anders and Powell 2002). Similar overlap among populations was reported by Bartley et al. (1985) based on electrophoretic analysis of allele frequencies, Brown et al. (1990) based on mtDNA, and McKay et al. (2002) based on mtDNA. Expansive haplotype distribution indicates little genetic divergence and significant gene flow throughout a major portion of the species' range (Anders and Powell 2002). However, there is little evidence to support high levels of contemporary gene flow, especially in post-impoundment systems (McKay et al. 2002, Anders, personal communication). This conclusion is consistent with observed recaptures of small numbers of tagged Columbia River in the Sacramento and Fraser rivers (DeVore et al. 1999).

Small but significant differences in genetic frequencies and diversity are apparent among populations in the Sacramento, Columbia, and Fraser systems based on electrophoretic and mtDNA analysis (Bartley et al. 1985, Brown et al. 1990, Nelson et al. 1999, Mckay et al. 2002, Anders and Powell 2002). Bartley et al. (1985) observed the greatest heterozygosity in the Sacramento population that also contained several variant alleles not observed in other populations. However, more extensive sampling by Anders and Powell (2002) found that all haplotypes represented in the Sacramento River were also present in the more diverse Columbia River population although frequencies were different. Four of eight Sacramento haplotypes were not represented in the Fraser River.

Some differences were apparent between the Fraser and Columbia rivers (Brown et al. 1990, Nelson et al. 1999, Mckay et al. 2002, Anders and Powell 2002). Brown et al. (1990) observed 4 unique types in the Fraser and 2 in the Columbia. Mckay et al. (2002) observed 5 unique types in the Fraser, 2 in the Nechako, and 7 in the Columbia. Anders and Powell (2002) observed 5 unique haplotypes in the lower Fraser River, 2 in the Nechako River, and another 8 types in the Columbia but not the Fraser. Haplotype and nucleotide diversity was slightly greater in the Fraser than the Columbia (Brown et al. 1990, Anders and Powell 2002). Brown et al. (1990) suggested that following the last ice age, the Columbia River population probably provided the founders for the Fraser River population, based on zoogeographical evidence. They speculated that recent overexploitation and habitat destruction explain the reduced diversity of Columbia River populations relative the more recently colonized Fraser River population. However, Anders and Powell (2002) suggested that this pattern may be due to historical panmixia and that latitudal-based clinal variation appears to occur less distinctly in white sturgeon than in other North American sturgeons.

White sturgeon genetic studies have consistently documented decreasing diversity with distance upstream (Bartley et al. 1985, Brannon et al. 1987, Brown et al. 1990, McKay et al. 2002, Anders and Powell 2002). Total number of haplotypes were negatively correlated with inland distance from the Pacific Ocean in all river systems studied (Anders and Powell 2002). Genetic differences were most pronounced in the Kootenay River white sturgeon population where heterozygosity was the lowest observed in the Kootenay River (Bartley et al. 1985, Brannon et al. 1987, Setter and Brannon 1990, Anders and Powell 2002). There is also a clear genetic distinction between populations in the upper and lower Fraser River (Brown et al. 1992, Nelson et al. 1999, Mckay et al. 2002, Anders and Powell 2002). This pattern is consistent with a suggestion that anadromous behavioural patterns may be less prevalent among fish in the upper portions of basins.

These results suggest that the genetically composition and other adaptations of the upper Columbia white sturgeon population in Canada and the U.S. upstream from Lake Roosevelt may be unique. Diversity of sturgeon sampled from Lake Roosevelt was the lowest observed among any population except the Kootenay (Anders and Powell 2002).

Significant genetic differences also reflect population differences in other characteristics. For instance, the genetic unique Kootenai River white sturgeon have been observed to spawn at consistently lower temperatures and water velocities than other white sturgeon populations. This behaviour may represent an adaptation to local conditions.

2.4 Abundance & Population Trends

White sturgeon abundance in the Columbia River between HLK and the Canada-U.S. border has been estimated at about 1,400 adults based on mark-recapture sampling from 1990-2001 (RL&L 2002). Estimates are based on steadily increasing recapture percentages of marked fish in each year of sampling. Approximately one out of every two white sturgeon captured since 1995 was a recapture of a fish previously marked by researchers. Population size is similar to that of the ESA-listed Kootenay River white sturgeon (1,470 adults in 1995: V. Paragamian, Idaho Department of Fish and Game, personal communication).

The population status in the U.S. portion of the Columbia River above Lake Roosevelt is unknown. The Canadian estimate mainly reflects the number of white sturgeon that reside in the four high-use areas north of the border and is likely an underestimate of the total population in the transboundary reach between HLK and Lake Roosevelt. One year of catch and catch per unit effort data is available for the U.S. portion of the transboundary reach but data is not adequate to estimate abundance. Differences in size composition, growth, and condition of sturgeon sampled in U.S. and Canada portions of the transboundary reach (RL&L 1996b; DeVore et al. 2000) may suggest that fish near Lake Roosevelt are a localized population that does not frequently intermix with stocks in the Canadian portion of the Columbia River.

An aging, decreasing cohort of large sturgeon are now present in the transboundary reach and Lake Roosevelt. As the current population has aged, size distribution in Canadian samples has steadily shifted over the last 20 years from a population dominated by juvenile and subadult fish less than 100 cm in length to one dominated by subadult and adult fish greater than 100 cm in length (Figure 5). The reported size distribution of white sturgeon in Roosevelt Lake is similarly dominated by adult fish (Figure 5).

Current abundance in Arrow Lakes Reservoir is unknown but is apparently much less than the transboundary population. A total of 25 white sturgeon have been captured from 1995-1999 (RL&L 2000a). All were 38 years of age or older (i.e., 1957 year-class). These fish either were trapped in the reservoir following construction of HLK in 1968, or have since moved into the reservoir via the boat lock. Like the transboundary population, the ALR fish are all large subadults or adults. One spawning event was documented near Revelstoke in 1999 but the absence of younger fish in the ALR population indicates a failure of natural recruitment (RL&L 2000b).

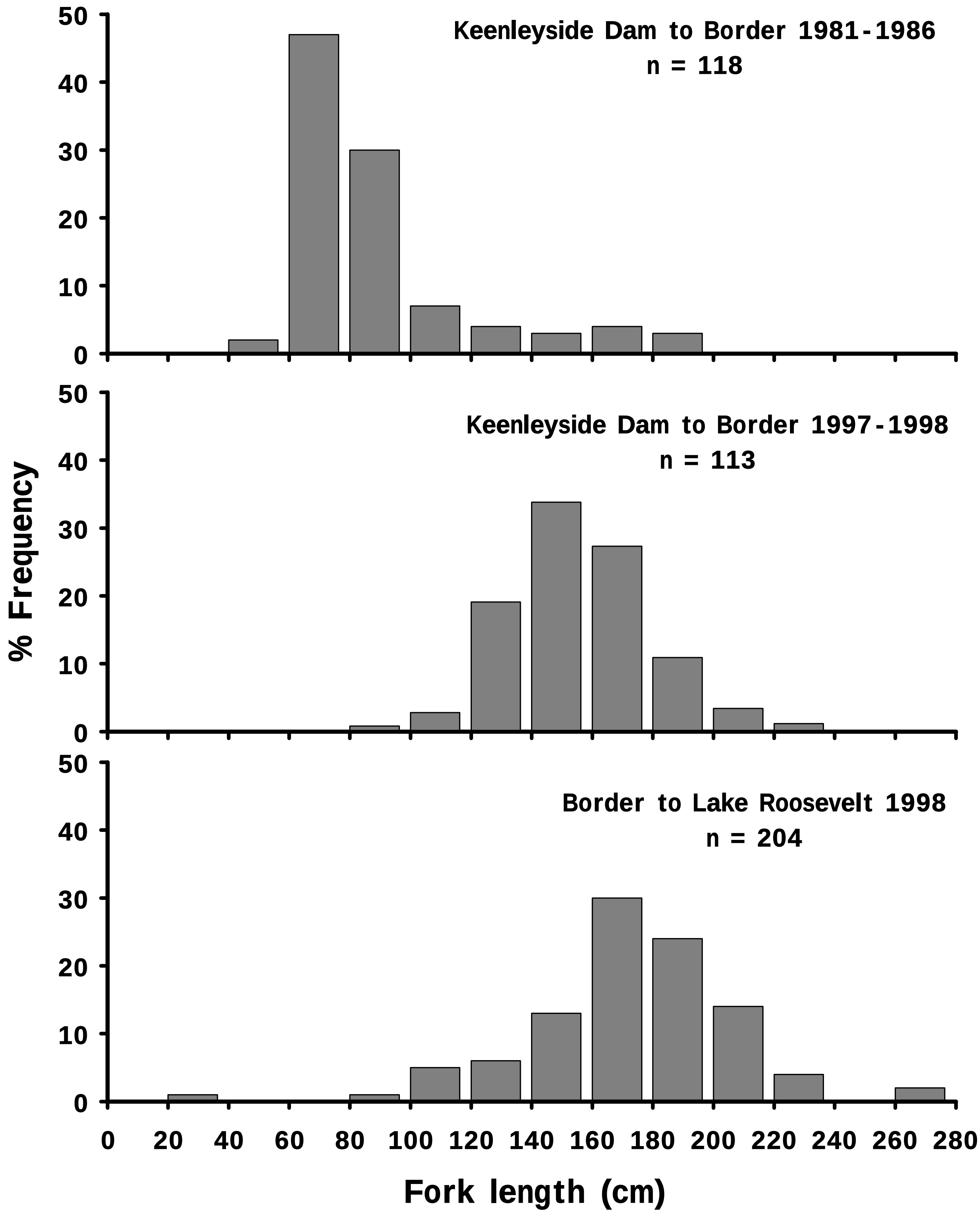

Figure 5. Length-frequency distributions of white sturgeon captured in the upper Columbia River (RL&L 2002; DeVore et al. 2000).

2.5 Growth, Condition, Maturation, & Survival

Individual growth, condition, maturation, and survival are sensitive indicators of sturgeon population productivity and key drivers of population size composition, biomass, reproductive potential, and future trends. In general, faster growth, better condition, increased survival, and earlier maturation all contribute to healthier, more robust populations. Weak, threatened, or endangered populations are generally associated with low values in one or more of these population parameters.

Individuals from inland sturgeon populations tend to grow slower and reach smaller sizes than fish in populations with access to the ocean. Reduced growth of inland sturgeon typically results from cooler temperatures, low system productivity, and lack of access to abundant food resources. Problems have been compounded by the loss of anadromous sources of food and nutrients. Maximum sizes collected during survey sampling in the upper Columbia River were approximately 270 cm fork length (RL&L 1996b; DeVore et al. 2000). On average, white sturgeon in the upper Columbia River population have been estimated to grow at 3-5 cm per year through age 30 and 2-3 cm per year for ages 30-50 based on ages assigned from circulus counts in fin ray sections. Growth rates reported by RL&L (1996b) for Canadian portion of the transboundary reach (k = 0.027) were less than those reported by DeVore et al. (1999a) for the U.S. portion (k = 0.035). Individual growth rates are highly variable. Many tagged fish appeared to grow at two-three times the average rate while others did not grow at all even after several years at large (RL&L 1996b). However, recent growth data for tagged Kootenay and lower Columbia river white sturgeon indicates that annual increments are less than projected from fin rays and that sturgeon may be substantially older than previously thought (Paragamian and Beamesderfer,In review).

Condition factor is also typically lower for inland than for anadromous white sturgeon populations (Beamesderfer 1993). Condition factor is an index of skinniness or plumpness based on weight for a given length. Condition factor reported for upper Columbia River sturgeon by RL&L (1996b) is near average for white sturgeon but considerably less than reported in downstream populations. Condition factor in the U.S. portion of the transboundary reach was less than average for white sturgeon.

Sexual maturity of white sturgeon does not occur until relatively large sizes and advanced ages (Semakula and Larkin 1968; Chapman 1989; Welch and Beamesderfer 1993). Maturation occurs over a wide range of sizes and ages and substantial differences occur among populations depending on growth. Males typically mature at smaller sizes and ages than females, and may spawn in all or most years following maturation. Females typically mature at larger sizes and older ages and do not spawn every year. In the upper Columbia River, mature male white sturgeon were observed at sizes of 106 - 207 cm Fl and ages of 16 - 46 (RL&L 1996b). Most males greater than 150 cm and age 25 were mature. Mature females were observed at sizes of 137 - 271 cm Fl and ages of 27 - 65. Most females greater than 170 cm and age 30 were mature. Frequencies of ripe, developing, and resting stages suggest that the spawning interval at full female maturity in the upper Columbia River may be significantly greater than the 3 years reported for in lower Columbia River (Welch and Beamesderfer 1993). Sizes of maturation in the upper Columbia River was similar to those reported by Welch and Beamesderfer (1993) for lower Columbia River populations.

Annual survival rates for long-lived fish like white sturgeon are typically quite high in the absence of fishing and often exceed 90% (Semakula 1963, Cochnauer 1983, Kohlhorst et al. 1991, Beamesderfer et al. 1995, DeVore et al. 19935). Because sturgeon are so long-lived, population trends are extremely sensitive to very small changes in survival of only a few percent. Most methods of estimating survival are not accurate enough to discern differences this small. Survival rates have not been estimated for the upper Columbia River white sturgeon population in part because of confounding effects of declining recruitment. However, annual survival rates of 90% or greater are consistent with maximum ages observed in the population. Maximum ages of 65 and 96 years were reported for the transboundary sturgeon population by RL&L (1996b) and DeVore et al. (1999a), respectively.

2.6 Food & Feeding

White sturgeon are primarily benthic feeders on invertebrates and fish but are often surprising selective in their choice of food. Food items are probably detected with chemo- and electro-receptors located on four sensory barbels and the snout rather than by sight (Brannon et al. 1985; Buddington and Christofferson 1985). However, white sturgeon have been observed actively pursuing prey throughout the water column (S. King, Oregon Department of Fish and Wildlife, personal communication). No information is available on food habitats in the upper Columbia River but other white sturgeon juveniles are reported to eat amphipods, isopods, mysids, clams, snails, small fish (such as sculpins and assorted fry), and fish eggs (Muir et al. 2000; McCabe et al. 1993). Larger sturgeon feed increasingly on fish including euchalon, northern anchovy, American shad, lamprey, Pacific herring and various salmonids (McCabe et al. 1993; Sprague et al. 1993). Large adult sturgeon are capable of consuming large prey including adult salmon.

Diet can vary substantially with time of year as white sturgeon take advantage of seasonally abundant prey items, especially anadromous and estuarine fishes in areas where they are accessible. The lower Columbia River white sturgeon population feeds heavily on the eulachon run during late winter, adult shad and lamprey in late spring and early summer, anchovies that enter the estuary in summer and early fall, and salmon that are present primarily from spring through fall. Blockages of anadromous fish runs into the upper Columbia have eliminated a food source that was likely important to the pre-development white sturgeon population. This food source was most abundant in the fall and may have provided an important energy source for overwintering with significant implications for spawning frequency and fecundity (Hildebrand and Birch 1996).

Many movement and migration patterns appear related to feeding. Where habitat is relatively homogenous such as in marine waters, estuaries, low gradient mainstem areas of the lower basin, and reservoirs, white sturgeon move frequently and range widely in search of scattered or mobile food resources. Fish are more sedentary in the upper basin where the river consists of interspersed rapids and pools where fish can hold and feed on prey delivered by the river. High-use areas by white sturgeon in the Canadian portion of the upper Columbia River and the river-Lake Roosevelt transition zone are all depositional environments where food items settle out and become available to benthic-oriented feeders such as white sturgeon. These low velocity areas adjacent to fast water allow sturgeon to optimize energetic benefits. In the case of holding areas below dams, entrained fish likely represent an important food source for white sturgeon.

2.7 Spawning Behavior & Habitat

White sturgeon spawn during spring and early summer by broadcasting eggs over clean rocky substrate in turbulent river habitats. Fish gather in aggregations to spawn and several males spawn with each female. Spawning is accompanied by darting, rolling, and breaching activity. Many lower basin white sturgeon populations undertake upstream spawning migrations beginning in fall or winter while populations in close proximity to spawning sites display more localized movements.

White sturgeon generally spawn at temperatures of 14 to 18°C (Figure 6). These temperatures correspond with optimums identified during incubation experiments. Based on laboratory experiments with white sturgeon collected from San Francisco Bay, Wang et al. (1985, 1987) reported that (i) the optimum temperature range for incubation was between 14 and 16°C; (ii) successful incubation was observed from 10 to 18°C; (iii) temperatures in excess of 18°C caused substantial abnormalities; and (iv) temperatures below 14°C extended incubation and hatching times, but did not result in developmental abnormalities. RL&L (1997a) incubated wild-caught eggs *in situ* in capsules and showed generally lower hatch success at temperatures exceeding 18°C.

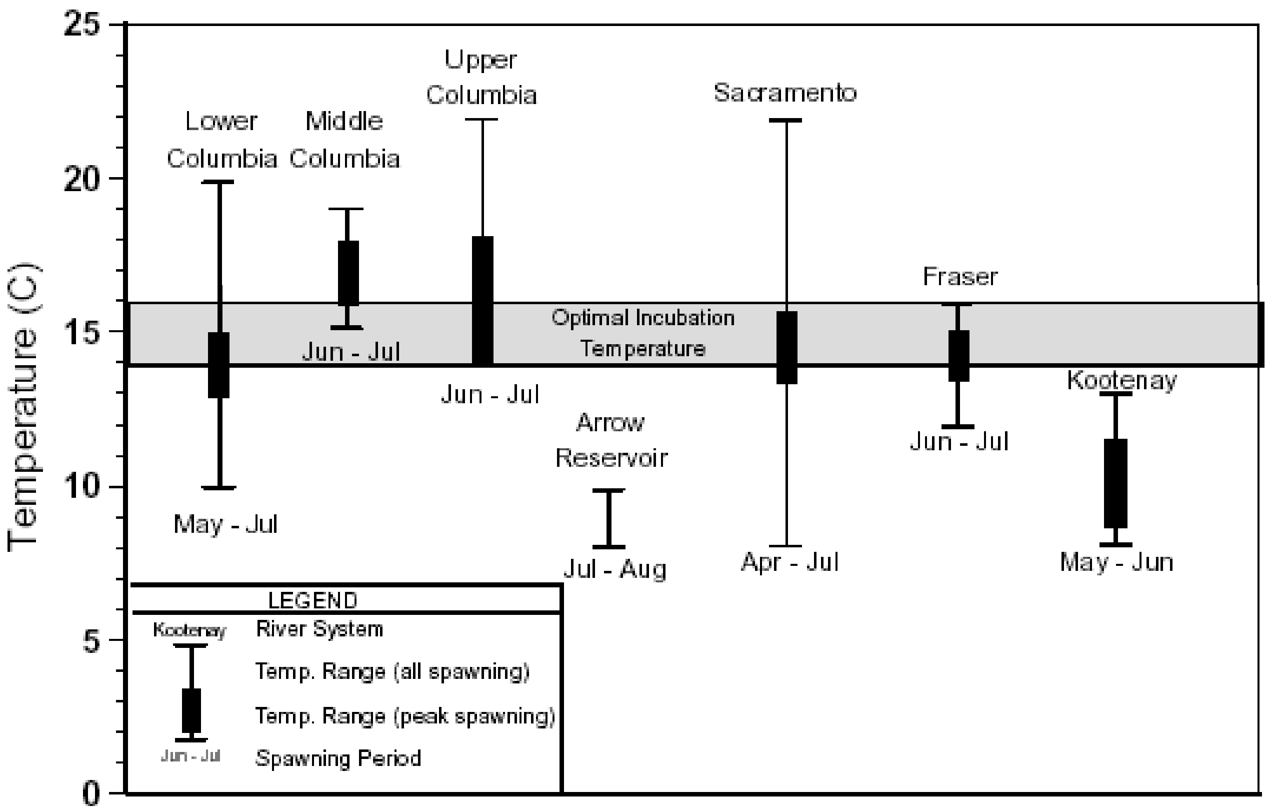

Figure 6. Water temperatures associated with spawning by white sturgeon (Anders and Beckman 1993; Parsley et al. 1993; Hildebrand and Mckenzie 1994; RL&L 1995, 1996a, 1996b, 1996c, 1997a, 1998a, 1998b, 1998c, 1998d, 1999a, 1999b, 1999c, 1999d; Perrin et al. 1999, 2000).

Water temperature prior to spawning may also affect sturgeon spawning success. Exposure of gravid cultured white sturgeon females to ambient water temperatures (10-19°C) from October to March has been found to result in a high incidence of ovarian regression during late oogenesis (Webb et al. 1999; Webb et al. 2001). Similar problems were not apparent at colder temperatures. Cold water requirements for successful completion of ovarian development have also been documented in other sturgeon species (Kazanskii 1963; Kazanskii and Molodtsov 1973; Williot et al. 1991; Chebanov and Savelyeva 1999).

Spawning often occurs later in the year and over more contracted periods in upper basin and northern populations, in part due to colder spring temperatures. However, Arrow Lakes Reservoir and Kootenay River populations spawn at temperatures well below presumed optimums that no longer occur (or never occurred) in those systems during the typical spawning timeframe. Optimum spawning temperatures for these populations may be less than those identified for Sacramento River white sturgeon.

Spawning sites are selected based on substrate, water velocity, depth, and other factors that are poorly understood. Preferred spawning substrates are large cobble and rock where fine material has been cleared from interstices by the current (Figure 7). Smaller substrate appears to be used by populations in the Sacramento, Fraser, and Kootenay systems but data on those systems is either limited (Sacramento and Fraser) or suggests use of fine substrate is not successful (Kootenay). Evidence to support the active selection of clean coarse substrates is available for other sturgeon species. For instance, following the introduction of coarse, clean rock in a known lake sturgeon spawning area, most spawning activity occurred over the new rock substrate.

High water velocity is a key attribute of spawning site selection. Mean water column velocities typically range from 0.5 to 2.5 m/s (Figure 7). Parsley et al. (1993) also observed consistently greater spawning success in reaches and high-discharge years that provided higher velocities. Lower than average spawning velocities (0.2 – 1.0) have been reported for Kootenay white sturgeon but spawning in that system is not successful (Paragamian et al. 2001). High velocities scour fine material that can smother eggs, exclude potential predators, and may help disperse larvae. Habitat suitability criteria developed for U.S. populations of white sturgeon identify 0.8 m/s as a minimum and 1.7 m/s or greater as optimum (Parsley et al. 1993; Parsley and Beckman 1994). RL&L (1996a, 1996b, 1996c), in reviewing available information on sturgeon spawning requirements, recommended water velocities of greater than 1.5 m/s to provide for sturgeon spawning in the Upper Columbia River.

Spawning site selection also appears related to turbulence (M. Parsley, U.S. Geological Survey, personal communication), although this effect is difficult to quantify. Sturgeon spawning commonly occurs in only a portion of the available area that meets general substrate, velocity, and depth criteria.

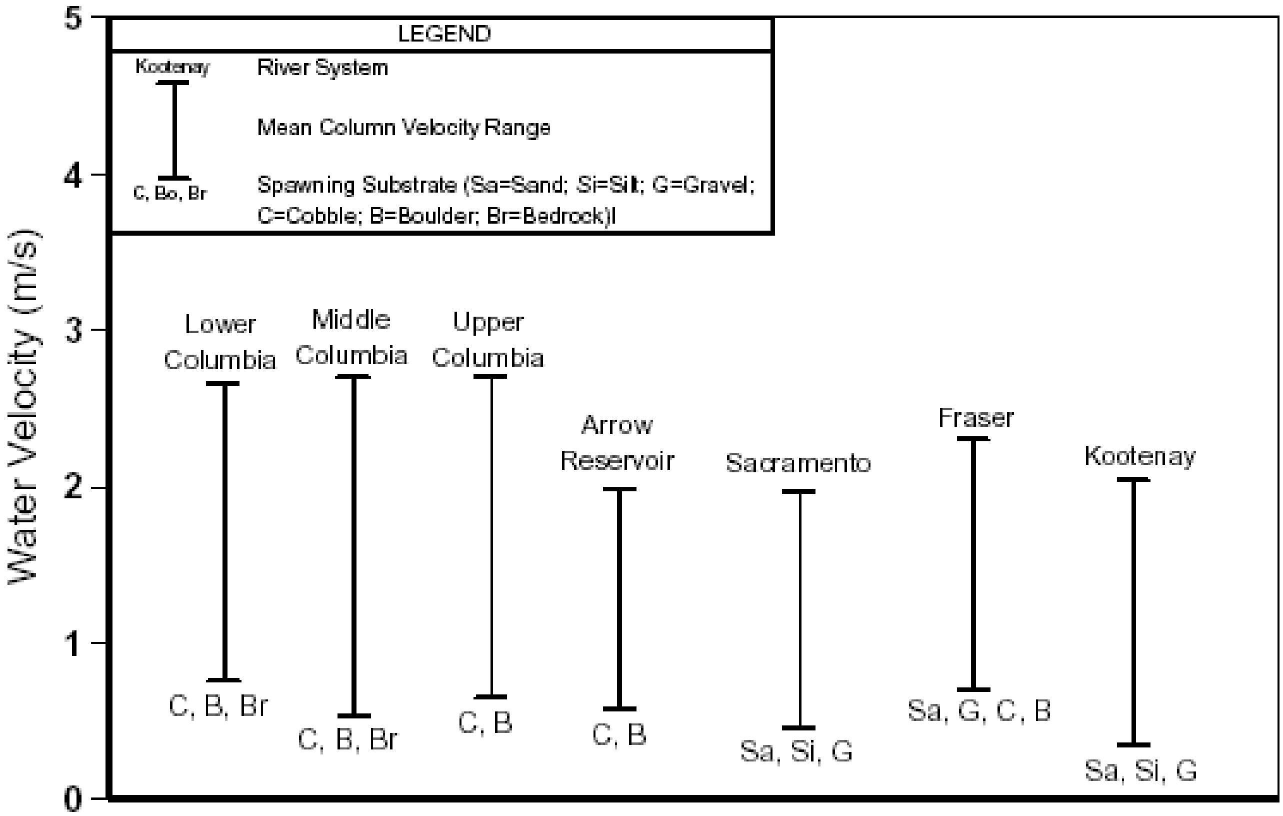

Figure 7. Substrates and water velocities associated with sturgeon spawning site selection (Parsley et al. 1993; RL&L 1996a, 1996b, 1996c; Perrin et al. 2000).

White sturgeon spawn at a wide range of water depths (0.5 to 50 m) and depth does not appear to be a highly critical factor influencing spawning site selection. Spawning depth observations include: 3 – 5 m at the Pend d'Oreille – Columbia River confluence (RL&L 1996a, 1996b), 4.5 – 25 m in the lower Columbia (Parsley and Beckman 1994), 2 – 24 m in the lower Fraser River in 1998 (Perrin et al. 1999), and 0.5 – 6.5 m in the lower Fraser River in 1999 (Perrin et al. 2000). Parsley and Beckman (1994) proposed a relationship between suitability for spawning and depth that was 0 at depths of 2 m or less, increased linearly from 0 to 1 between 2 m and 4 m, and remained at 1 for all depths from 4 to at least 25 m.

Spawning of white sturgeon has been documented in the Columbia River near Waneta (Figure 8) every year since surveys began in 1993 (RL&L 1995, 1996a, 1996b, 1996c, 1997a, 1997b, 1999a, 1999b, 1999c, 1999d). The number of distinct spawning events has ranged from 4 in 1994 to 9 in each of 1995 and 1996 (RL&L 2002). Both the Waneta and Fort Shepherd eddies are used for staging by pre-spawning white sturgeon. Spawning occurs at the confluence of the Pend d'Oreille River which is several degrees warmer than the Columbia River during spring and largely retains a natural hydrograph. The confined channel morphology downstream from Waneta results in turbulent outflow and high water velocities over a wide range of discharges. Spawning in the Waneta area often occurs at water temperatures greater than the 18°C identified as a maximum for successful spawning.

Figure 8. White sturgeon spawning area at the confluence of the Pend d'Oreille and Columbia river. Spawning occurs in the bridge area within the influence of the Waneta Dam tailrace (RL&L 1994a).

Numbers of spawning events and eggs collected at Waneta were considerably greater in 1995 and 1996 than in other years. The main difference between years was the timing and volume of peak discharges from the Pend d'Oreille River. Discharges were higher and declined more steadily in 1995 and 1996. These patterns suggest a positive relationship between spawning activity and discharge. It is important to note in this respect that this observation pertains to discharge as opposed to water velocity, and that the relationship between discharge and mean velocity is generally not linear.

Discharge spikes frequently in of the lower Pend d'Oreille River during the spawning period due to load shaping operations at Waneta Dam and other facilities upstream. The occurrence of spawning during load shaping periods suggested that daily or weekly fluctuations in flow may not preclude spawning, if the proper cues are present prior to the spawning act to stimulate vitellogenesis and ovulation and if sufficient discharge is provided to maintain velocities in spawning habitats above a critical level. There is some concern, however, that fluctuating discharge during the spawning period may influence both the intensity of spawning and egg survival. Based on the limited data collected, spawning intensity was greatest when discharges were high and steady, as was the case in 1995 and 1996. Sustained high discharges may increase egg survival by providing high velocities that exclude predators in egg deposition areas and high turbidity that inhibits visual predation.

Use of other spawning sites in the upper Columbia River is unclear. No spawning has been documented in the U.S. portion of the transboundary reach although little work has been conducted there (Kappenman et al. 2000). No spawning has been documented in the HLK tailrace despite apparently-suitable velocities and substrates and widespread observations of tailrace spawning in lower Columbia River impoundments (RL&L 1998a). Spawning was documented upstream of ALR near Revelstoke in 1999 (RL&L 2000b). Many historic spawning sites may no longer be available. Based on the presence of suitable habitat and anecdotal observations of local residents, spawning may have occurred at numerous locations along the mainstem Columbia River or in larger tributaries, including Kettle Falls, Tin Cup Rapids at the outlet of Lower Arrow Lake, the Narrows between Lower and Upper Arrow Lakes, the canyon section above Revelstoke, and the canyon section in the lower Pend d'Oreille River (Hildebrand and Birch 1996).

2.8 Early Life History & Recruitment

Despite annual spawning of transboundary sturgeon at Waneta, recruitment of juvenile sturgeon into the population has been very low since at least 1980 (Figure 9). The first year of life is a critical period and appears to be the bottleneck that has led to the dire status of sturgeon in the transboundary reach. Spawning occurs every year and removal of eggs to a hatchery setting has demonstrated their viability. However, few naturally-spawned individuals are surviving from egg to age 1.

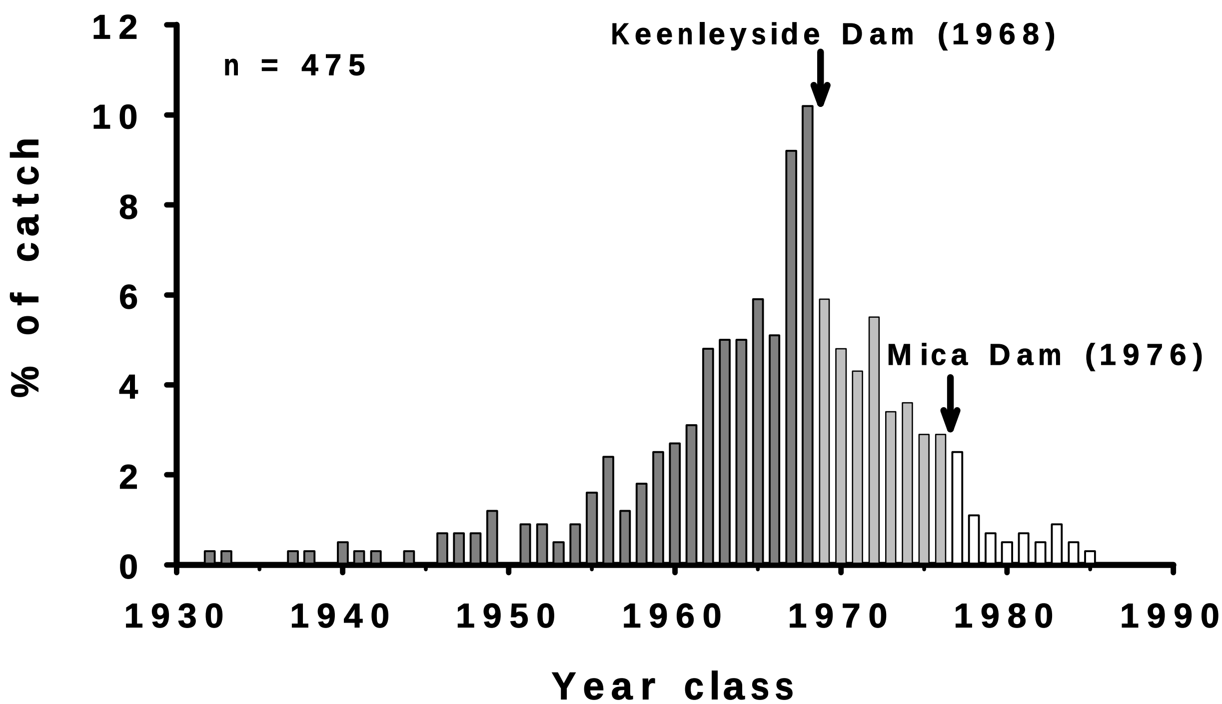

Figure 9. Reflection of historic recruitment and mortality rates of upper Columbia River white sturgeon based on current age composition expressed in terms of year class (RL&L 1994; Hildebrand and Birch 1996).

Figure 10. Juvenile white sturgeon at approximately 2-3 months of age.

Early life history includes incubation, hatching, dispersal, and hiding phases (Parsley et al. 2002). Hatching typically occurs 5-10 days after spawning depending on temperature (Wang et al. 1985). Upon hatching, larval white sturgeon enter a swim-up phase in which they leave the substrate and are suspended in the water column (Brannon et al. 1985). This behaviour disperses larval sturgeon into available rearing habitats. The swim-up phase may last up to 5 or 6 days with time spent in the water column inversely related to water velocity (Brannon et al. 1985; Conte et al. 1988). In the Columbia River below Bonneville Dam, white sturgeon larvae are transported over 175 km downstream from spawning areas (McCabe and Tracy 1993). Following dispersal, white sturgeon enter a hiding phase in which they avoid light and seek refuge in the substrate. The hiding stage for white sturgeon generally lasts 20-25 days until the yolk is absorbed, whereupon the fish move out of the substrate to begin feeding (Parsley et al. 2002). Young white sturgeon appear to remain closely associated with rough substrates throughout their first summer as evidenced by their very low susceptibility to sampling by any method.

White sturgeon eggs, larvae, and young-of-the-year are vulnerable to a variety of mortality factors and first year survival rates are very low even under optimum conditions. Eggs are vulnerable to extreme temperatures, abrupt temperature changes, suffocation by sediments, mechanical damage, infection, contaminants, and fluctuating flows that allow predator access into egg deposition areas (Parsley et al. 2002). Larvae are particularly vulnerable to predation at the swim-up stage and factors that increase time spent in the drift (i.e., slower current velocity due to reduced discharge from upstream dams) or visibility (i.e., increased water clarity due to upstream impoundments) will undoubtedly reduce survival. The dispersal phase might also transport larvae into downstream reservoirs where food may be scarce or introduced predators may be abundant. Larvae may starve during the transition from endogenous to exogenous feeding, particularly if environmental factors have reduced food availability at this critical time. Effects of any one of these mortality factors may be small but the compounded effects of many incremental increases in mortality may be enough to explain current recruitment failures.

Following the first year or two, mortality of juvenile white sturgeon appears to be relatively low. Juveniles use a wide variety of habitats. Juvenile white sturgeon in the lower Columbia River occur in many of the same low to moderate velocity habitats as adults and subadults. In the lower Fraser River, slough and large backwater habitats adjacent to the mainstem provide important rearing habitats (Lane and Rosenau 1995); these types of habitats are unavailable in the Columbia River between HLK and Lake Roosevelt.

While factors controlling year class strength are poorly understood, recruitment has been widely correlated with flow volume in many sturgeon species including white sturgeon (Votinov and Kasyanov 1978; Kohlhorst et al. 1991; Anders and Beckman 1993). Kohlhorst et al. (1991) positively correlated white sturgeon year-class strength with the volume of freshwater flow through the Sacramento-San Joaquin River Estuary. In the lower Columbia River high springs flows were correlated with the availability of high velocity spawning habitat, spawning success, and subsequent recruitment (Anders and Beckman 1993). Further, differences in recruitment among several subpopulations were related to channel morphology effects on velocity at different flows. Flow effects may be related to: 1) increased availability of suitable spawning sites, 2) reduced predation on eggs, 3) decreased predation on larvae and juveniles, 4) increased flooding of side channel and slough areas that provide higher quality rearing habitats than mainstem areas, or 5) effects of related conditions such as temperature.

Table 1. Critical areas and periods for white sturgeon life history stages in the transboundary reach of the upper Columbia River (Hildebrand and Birch 1996).

Life Requisite	Critical Period	Critical Areas	Comments
Spawning	Late May to late July	Pend d'Oreille-Columbia confluence	represents the only confirmed spawning area for white sturgeon in the Columbia River between HLK and Grand Coulee dams; spawning has occurred annually at this location since 1993 with an estimated 3 to 8 spawning events per year; limited data suggest spawning intensity is related to discharge and temperature although recruitment appears minimal in all years
Incubation	Late May to lat July	Pend d'Orelle-Columbia confluence	Eggs incubate for 5-10 days depending on water temperature . Survival to hatch may depend on water quality and substrate characteristics that protect embryos from physical damage and predation
Rearing			
Larval	Early June to late August	Unknown; suspected to occur in upper portions of Lake Roosevelt	represents the period following hatch when endogenous feeding larvae undertake passive movements to suitable downstream rearing habitats; this may be the most critical period in the recruitment cycle; predation and high levels of total dissolved gases may influence survival rates
Young-of-the-year	August to December	Unknown; suspected to occur in upper portions of Lake Roosevelt	follows shift to exogenous feeding; may represent next most critical stage in early survival (i.e., suitability and availability of food items in rearing habitats is unknown); pollutant contamination may affect food abundance; predation rates associated with increases in predator abundance and increased water clarity may also reduce survival
Younger juveniles	All year	Unknown; suspected to occur mainly in Lake Roosevelt	represents age-1 to age-7 fish; very low use of transboundary reach for this life-stage; reduced survival at the larval and YOY stages may account for low abundance of younger juveniles
Older juveniles	All year	Within localized areas Columbia R. and within Lake Roosevelt	Ages 8 to 15; low use of Columbia R. by this life-stage; most fish > age-15; found in same habitats as adults; main factors limiting use by this life-stage are habitat availability and suitability. Changes in biotic productivity of the river may influence food availability and thus production.
Adult Feeding	All year; greater use from May to October	Mainly in four localized areas of the lower Columbia River (HLK area, Kootenay, Fort Shepherd, and Waneta eddies); in U.S., also exhibit greatest use of localized areas (e.g., Kettle Falls, China Bend, Dead Mans Eddy)	represents immature sub-adults (15 to 30 years old) and mature adults (generally older than age-30; population in transboundary reach composed mainly of fish older than age-30; limited sampling in U.S. indicates similar size-class (and presumably age-class) composition; population in lower Columbia is about 1400 fish; fish use shallow mainstem areas in the summer; highest use in all seasons is for areas with depths over 15 m; food abundance/composition has likely changed in response to dam operations and exotic species introductions
Overwintering	November to March	Restricted to 4 areas of the Columbia in B.C. (HLK area, Kootenay, Ft Shepherd, Waneta); U.S. sites unknown	in winter, fish tend to be found only in deeper portions (>20 m depth); since the availability of deep-water habitats is limited, the importance of these areas during the winter period is increased; since regulation of the river, winter flows and water temperatures have increased, possibly reducing the suitability of overwintering habitats
Staging (Pre-spawners)	November to late May	Known staging areas are Ft. Shepherd eddy, Waneta eddy, and the HLK area; use of the Kootenay Eddy for staging not documented	represents locations selected by pre-spawning females (and possibly pre-spawning males) that provide suitable low velocity holding areas near spawning areas; higher use of Ft. Shepherd Eddy may reflects depths >50 m at this location; flow fluctuations that increase velocities in staging areas and temperatures increases during the winter period may affect spawning intensity

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