3.0 REASONS FOR DECLINE

3.1 Exploitation & incidental catch

White sturgeon are extremely vulnerable to overfishing because of their delayed age of maturation (15 years or greater) and longevity (up to 100 years) (Beamesderfer and Farr 1997, Boreman 1997). If significant numbers of subadults are harvested, too few fish survive to adulthood to spawn and replentish the population. Only very low exploitation rates of 5%-10% can be supported by productive sturgeon populations and unproductive populations can sustain no harvest at all (Rieman and Beamesderfer 1990).

The decline of the sturgeon is the cumulative effect of many factors and harvest is likely one of them. Significant harvesting started at the same time as the recruitment problem and has likely accelerated the population decline. White sturgeon were used by native peoples although catches were probably small. Anecdotal information suggests that harvest of sturgeon in the upper Columbia River basin remained low through the 1950s (Prince 2001). Catches of sturgeon during this period were noteworthy events, with accounts periodically published in local newspapers. Angling for sturgeon became popular in the mid-1970s and this popularity increased steadily to the 1990s. Beginning in the late 1980s, several guiding outfits commenced operations on the Columbia River; sturgeon was one of the species targeted by the guides. Harvest data are generally unavailable for upper Columbia River sturgeon. Reported harvests between Lake Roosevelt and the international boundary averaged 60 sturgeon per year from 1988-1995 (Brad James, Washington Department of Fish and Wildlife, unpublished data). Catch and harvest data are available for the Canadian portion of the river (HLK to the border) only from 1992 when an estimated 204 white sturgeon were caught, of which 43 were killed (ARA Consulting Group 1992). Fisheries were largely curtailed by 1996 with protective regulations in Canadian and U.S. sport fisheries and by voluntary reductions in subsistence harvest by First Nations people.

Historic overfishing in the lower Columbia River may have affected numbers of lower basin fish available to migrate into the upper basin although migration rates are unknown. Over fishing collapsed sturgeon populations in the lower Columbia, Fraser, and Sacramento-San Joaquin rivers around the turn of the century. Populations in each of these areas were severely overfished within 10-20 years by unregulated, targeted, commercial exploitation (Semakula and Larkin 1968; Galbreath 1985). These populations have since recovered to varying degrees following enactment of protective fishing regulations but significant improvements required 50 years or more.

3.2 Dams & Reservoirs

Dam and reservoir construction and operation affect white sturgeon by 1) blocking movements between widely-distributed spawning, rearing, and feeding habitats needed to complete the life cycle, 2) flooding productive riverine habitats, 3) eliminating anadromous fish runs that provided food and marine-derived nutrients, 4) reducing habitat suitability by changing temperature patterns, flow, water chemistry, nutrient transport, and water clarity, 5) increasing mortality either directly as a result of dam construction and entrainment, or indirectly as a result of gas supersaturation, and 6) changing species composition and abundance of prey, competitor, and predator species.

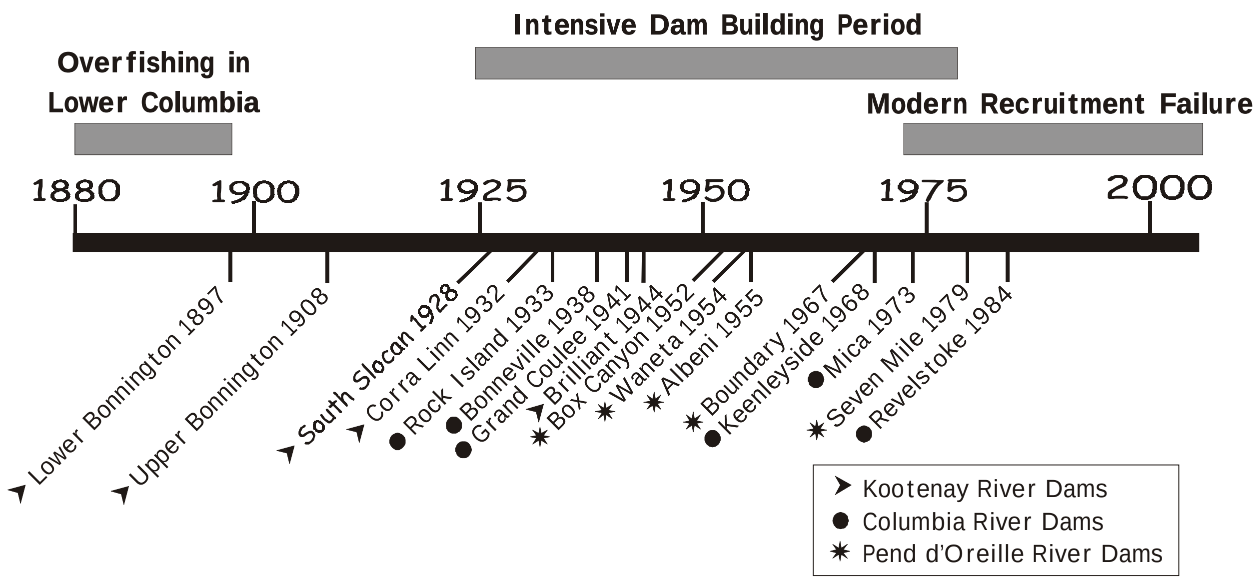

Figure 11. Time line of dam construction and white sturgeon impacts in the Columbia River basin. (Modern recruitment failure may have begun earlier than indicated if sturgeon ages are underestimated as recent data suggests.)

Upper Columbia River sturgeon were cut off from the lower basin population and anadromous food resources by construction of Rock Island (1933), Bonneville (1939), and Grand Coulee dams (1941). These dams were among the first large mainstem dams in an intensive building phase that continued into the 1970s (Figure 11). Mainstem dams fragmented sturgeon habitat into short riverine sections connected by long impoundments. White sturgeon in the Columbia and Snake rivers have been isolated into at least 30 separate reaches, functionally extirpated from 8 reaches, and are likely to become extirpated in another 8 reaches without intervention (Figure 4). Remaining subpopulations are primarily restricted to reaches with significant riverine habitat and subpopulations in marginal habitat areas have been lost or consist solely of a few remnant individuals.

In the Kootenay River, South Slocan Dam (1928) eliminated access to the base of Lower Bonnington Falls. Brilliant Dam (1944) restricted access to the lower 2.8 km of the river and cut off the Slocan River system. Upper Bonnington Dam (1907) and Corra Linn Dam (1932) further fragmented the lower Kootenay River habitat. Access into the Pend d'Oreille River was blocked by Waneta Dam (1954). Other Pend d'Oreille River dams including Box Canyon (1952), Albeni (1955), and Boundary (1967), also had significant effects on water clarity, seasonal temperature ranges, gas saturation levels, and the aquatic community composition experienced by downriver populations of white sturgeon.

The modern recruitment failure in the upper Columbia River white sturgeon population coincides with the construction since 1968 of three large Columbia River mainstem dams. HLK, Mica, and Revelstoke dams were built to provide hydropower generation and flood control following ratification of the Columbia River Treaty between the U. S. and Canada. The construction of the HLK Dam in 1968 isolated sturgeon populations in the former Arrow Lakes, cut off access by fish in the transboundary reach to spawning, rearing and feeding areas in the upper basin, and replaced a highly diverse and productive river-lake ecosystem with a homogenous, oligotrophic reservoir. Mica Dam, constructed in 1973, further fragmented the river ecosystem above Arrow Lakes Reservoir, flooded over 250 km of the Columbia River mainstem that may have provided spawning and feeding habitats, reduced productivity by trapping nutrients, and increased water clarity by trapping sediments. Revelstoke Dam (1984) effectively eliminated the 130 km section of flowing river between Mica Dam and Arrow Lakes Reservoir and sealed the fate of sturgeon in this segment of the river by eliminating and cutting off access to the upper riverine habitat that may have served as a spawning area.

3.3 Flow Regulation

Increased storage in the upper basin and hydro system operation have generally eliminated floods, reduced spring flows, and increased late summer through winter discharges. Mica, HLK, and Duncan dams provide 15.5 million acre feet (MAF) of usable storage (7.0, 7.1, and 1.4 respectively). These storage reservoirs capture a large portion of the spring runoff for release to meet high power demands in fall and winter (Figure 12). Reservoirs are also drawn down and regulated for flood control from September through April. Unregulated spring runoff peaked during June and July in the upper Columbia River, and about one month earlier in the Kootenay and Pend d'Oreille basin. Spring peak flows at the international boundary often exceeded 4,500 cubic meters per second or cms (160,000 cubic feet per second or cfs) but currently average about 1,700 cms (60,000 cfs). Flood flows occurred in winter following rain on snow events or in spring as a result of snowmelt. The largest recorded flood occurred in June 1894 as the result of rapid melting of an above-normal snow pack and produced an estimated 19,250 cubic meters per second (680,000 cfs) at the international boundary. The lowest recorded historic flow at the boundary was 365 cms (12,900 cfs).

Flow regulation has likely contributed to poor spawning and early-rearing success of white sturgeon in the upper Columbia River. Recruitment of juvenile sturgeon has been widely correlated with spring flow volume (Beamesderfer and Farr 1997). White sturgeon depend on riverine habitats and seasonal floods to provide suitable spawning conditions. Seasonal flow patterns likely cue maturation, migration, and spawning. Adhesive eggs are broadcast over rocky substrates in turbulent high-velocity habitat that accompanies high flow. High flows help disperse eggs and juveniles, and exclude predators. In addition, high flows in unimpounded floodplain systems increase access to food resources in newly inundated areas, and decrease predator densities. Periodic floods also flush fine sediment from river bed cobble and prevent armoring that reduce suitability for egg incubation, larval and juvenile fish rearing, and invertebrate diversity. Flow effects can be complex because of interactions with temperature and turbidity.

Hydro system operation also results in daily flow fluctuations for power load but the effects of these peaking patterns on white sturgeon are unclear. Discharge is generally increased during weekdays and daytime to meet increased power demands. Spawning occurs downstream from Waneta dam despite extensive peaking operations although spawning is not producing significant numbers of juvenile sturgeon. Studies downstream of a lower Columbia River dam showed that these peaking operations can result in scouring of eggs and embryos from the riverbed (Counihan and Parsley 2001). However, successful spawning and recruitment of white sturgeon has been observed downstream of lower Columbia River dams operated for peaking. Studies on Russian sturgeon have identified adverse changes in behaviour and maturation following highly fluctuating discharges during winter that required sturgeon to maintain an increased level of activity. Similar effects have not been documented for white sturgeon, but recent studies downstream from John Day Dam on the lower Columbia documented that white sturgeon position within the tailrace of the dam during the spawning period was not influenced by operations at the dam (M. Parsley, U.S. Geological Survey, personal communication).

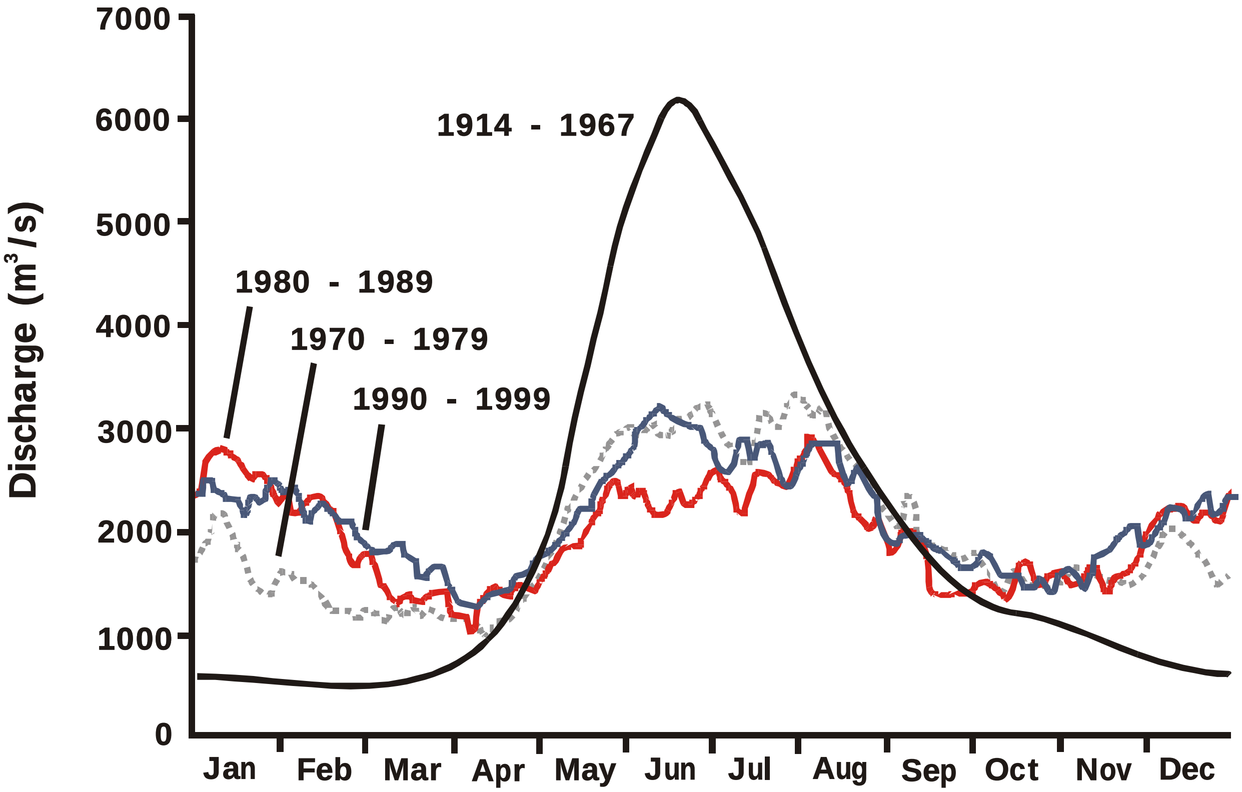

Figure 12. **Mean daily discharge in the Columbia River at Birchbank during the pre-Keenleyside Dam period (1914-1967) and for three post-regulation periods, including 1970-1979, 1980-1989 and 1990-1998 (Water Survey of Canada data for stream gauging stations 08NE003 [Trail; for 1914-1937] and 08NE049 [Birchbank; for 1937-1998]).**

3.4 Water Quality

Temperature: Significant temperature changes have accompanied construction and operation of dams and reservoirs. Upstream of Revelstoke, water temperatures are similar in summer but warmer in fall and winter as compared to the pre-impoundment period (Figure 13). Downstream of HLK, average fall and winter temperatures are similar but temperatures from May through September are 2-3ºC warmer than occurred historically (Figure 13). Recent observations suggest that winter temperatures are warmer and cold winter periods are briefer (Ric Olmsted, personal communication) Pend d'Oreille River temperatures currently rise faster than in the Columbia River during the spawning season and get much warmer (e.g. 24ºC in 1998). It is unclear if Pend d'Oreille temperature patterns are similar to historic conditions because pre-impoundment data are lacking. Lake Roosevelt provides a much wider range of temperatures and more complex thermal environment than historically occurred in the river it replaced.

Effects of changing temperature patterns on white sturgeon are poorly understood but are likely to be complex. Water temperature and seasonal patterns in water temperature affect sturgeon maturation, spawning, incubation, development, energy requirements, food production, growth rate, and survival rate. Changes in the timing of temperature-controlled processes could disrupt the synchrony between these and other processes affected by other environmental factors (McAdam 2001). Several sturgeon trapped in portions of the upper basin upstream of HLK Dam may no longer have access to temperatures suitable for spawning.

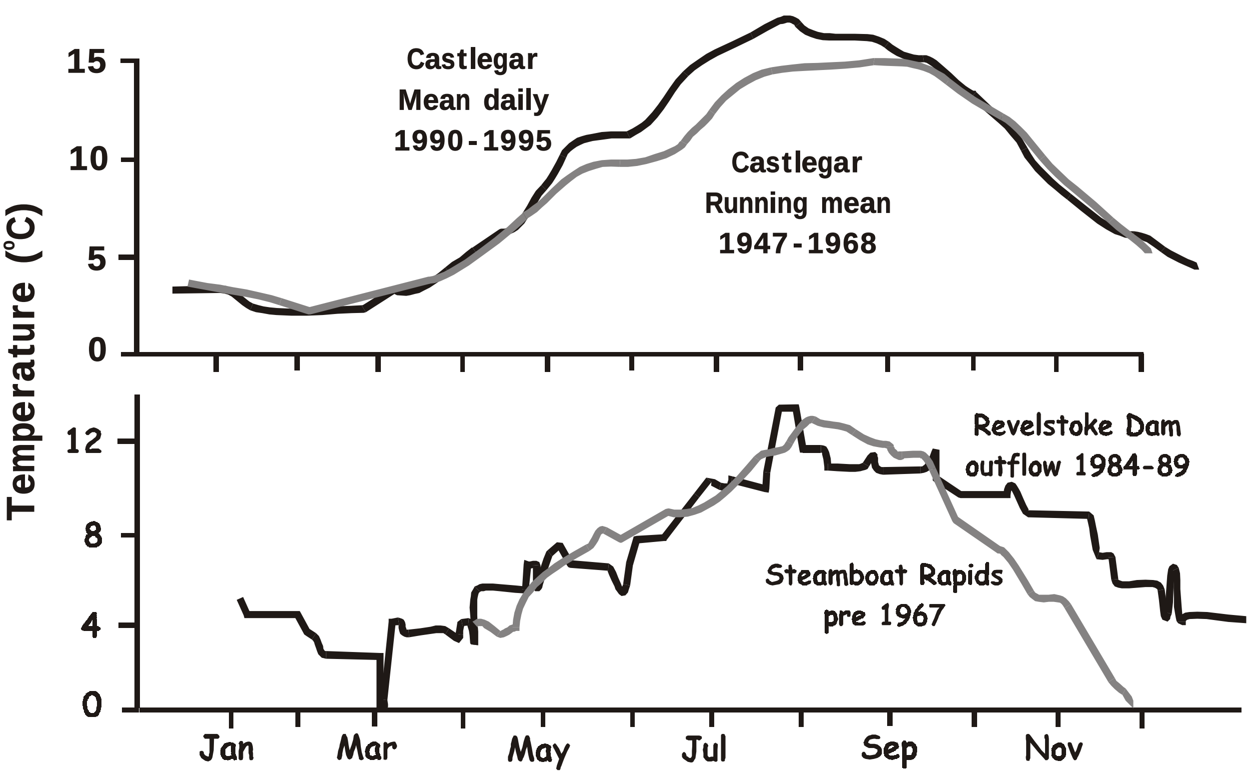

Figure 13. Changes in average Columbia River water temperature at Castlegar and Revelstoke (McAdam 2001).

Turbidity: The construction of upstream reservoirs has drastically reduced river turbidity. Turbidity was historically high because of runoff from glacial systems. However, upstream reservoirs act as settling basins and have reduced sediment transport downstream.

Changes in turbidity may have significant implications for sturgeon. For instance, predation on juvenile sturgeon has likely increased with water clarity, especially during the larval dispersal phase. Laboratory studies by Gadomski and Parsley (2001) documented higher predation rates by prickly sculpins (*Cottus asper)* on white sturgeon yolk-sac larvae (1-2 wk. old) at low turbidities (30 and 23 larvae per trial at 0 and 20 NTU) than at high turbidities (18 larvae per trial at 60 and 180 NTU). Lower turbidities combined with reduced flows decrease the effective search volume for predators hunting for larval sturgeon.

Turbidities associated with successful sturgeon spawning and recruitment were 6 to 92 NTU in the lower Fraser River (Perrin et al. 2000) and 2.2 to 11.5 NTU in the lower Columbia River (McCabe and Tracy, 1993.) Ktunaxa elders report (Bill Green, personal communication*)* that they historically observed sturgeon spawning in high turbidity (as opposed to high velocity) environments, including the Columbia River in the Spillimacheen area and in the Kootenay River near Bonners Ferry. Current turbidities generally are below 1 NTU year round near Birchbank, B.C. which is downstream from the Kootenay River confluence.

Total Dissolved Gases: Dam construction and operation has increased dissolved gas to supersaturation levels downstream from several facilities including Mica, Revelstoke, HLK, Waneta, and Brilliant. Supersaturation occurs when plunging water entrains air which is dissolved into the water at depth. Dissolved gas levels are referred to as total dissolved gas (TDG) in the U.S. and total gas pressure (TGP) in Canada.

During spring spills, TGP levels in the Columbia, Kootenay, and Pend d'Oreille rivers often exceed the B. C. guideline of 110%. Since 1977, the Columbia River below HLK was identified as having the highest TGP concentrations of the 35 major rivers or lakes examined in B.C. (Clark 1977). TGP in the mainstem below the dam can increase to levels that occasionally exceed 135% and often exceed 120%. TGP levels up to 144% saturation were measured below HLK on 17 August 1976. TGP levels in excess of 135% have been observed below Waneta Dam primarily during spill periods from May through June (RL&L unpubl. data). Levels exceeding 125% can occur downstream of Brilliant Dam on the Kootenay River.

Current dam operations include an extensive TGP monitoring program and measures to reduce excessive levels. For instance, operational modifications at HLK Dam since 1994 have substantially reduced TGP levels during certain periods of the year by increasing discharge through low level ports rather than the spillway. Planned expansions of power plants at HLK and Brilliant are projected to reduce TGP although elevated levels will still occur between June and September in some years (Holms and Pommen 1999; Aspen 2000).

The deleterious effects of high TGP levels on fish have been well documented (Weitkamp and Katz 1980; Fickiesen and Montgomery 1978; Ebel at al. 1975; Ash et al. 1981; Fidler 1988). High TGP levels cause gas bubble trauma (GBT) that involves the growth of gas bubbles internal or external to the animal. GBT occurs when fish exposed to high dissolved gas levels at depth move into shallower water where hydrostatic pressure is low and will not compensate for excess TGP.

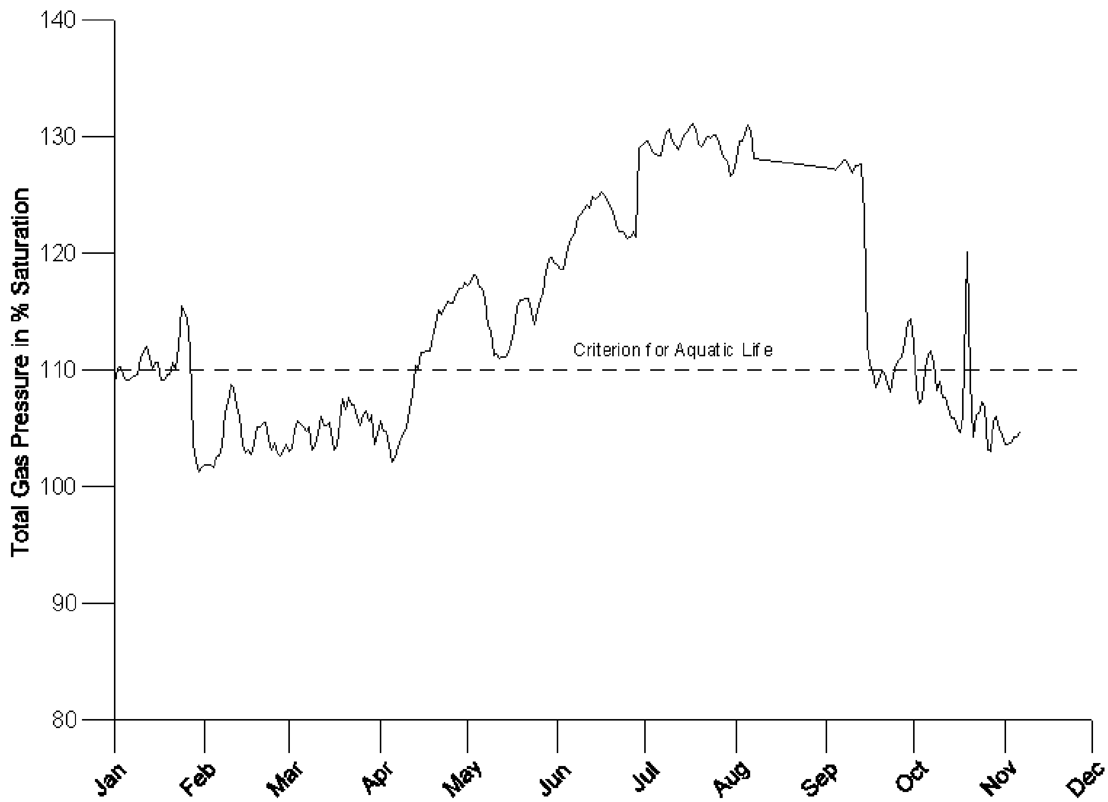

Figure 14. Example of recent TGP patterns in the upper Columbia River at Birchbank, B.C. for 1996 (Holms and Pommen 1999).

High TGP levels have been shown to produce mortalities and affect the behaviour of larval white sturgeon in the laboratory but the significance in the wild and implications for recruitment are unclear. The maximum recommended gas pressure for cultured (and presumably wild) white sturgeon is 110% (Conte et al. 1988). Counihan et al. (1998) documented GBT in larval sturgeon consisting of a gas bubble in the bucchal cavity and/or nares. Larvae exposed to 118% TDG for 10 days did not exhibit mortalities but 50% mortality occurred at 131% TGP after 13 days of exposure. Even at apparently sublethal levels, GBT increased buoyancy and reduced the ability of larvae to control their depth which could reduce survival. Counihan et al (1998) reported that 1 to 2 day old white sturgeon displayed signs of GBT following a 15 min. exposure to 118% TGP.

Sturgeon are most likely to be affected by gas bubble trauma during the planktonic, post-hatch dispersal stage when larvae are suspended in the water column and drift at variable depths (Shrimpton et al. 1993). Effects may include direct mortality, altered dispersal patterns, and increased susceptibility to predation. TGP levels exceed thresholds for gas bubble trauma for significant periods of time through the sturgeon spawning, incubation, and dispersion period. Both Brilliant and Waneta dams typically spill during the June to July period when dispersal occurs and spill can also occur at HLK. White sturgeon larvae can be exposed to high TGP levels (up to 138%) in the Pend d'Oreille plume where it enters the Columbia River.

3.5 Contaminants

The Upper Columbia River has several known sources of contaminants including: Cominco Ltd.'s lead-zinc smelter at Trail, Celgar Pulp Co.'s pulp mill at Castlegar, municipal sewage treatment plants (primary and secondary treatment only), Stoney Creek landfill, abandoned mines, and storm water runoff (MacDonald Environmental Sciences Ltd. 1997). Historic and current industrial activity and residential development along the river have contributed metals and a myriad of organic compounds to water and/or sediments (Table 2). These compounds are potentially bioavailable to fish and other aquatic fauna.

When coupled with other habitat alterations, the introduction of contaminants into aquatic systems may increase stress and negatively impact physiologic functions. Contaminant effects can vary from acute (lethal; immediate) to chronic (sublethal; life-long effects). Although acute effects will have an immediate population effect, chronic effects may manifest themselves over time and throughout several generations, potentially altering an organism's behaviour, genetics, reproduction and general ability to function in a "normal" manner (Rand and Petrocelli 1985). Uptake of and effects from contaminants will vary depending on life stage and the type, duration, and nature of exposure (Heath 1995). Exposure can occur through contaminants in water, sediment, suspended sediments, and food (i.e. plankton, periphyton and other fish species) and through parental burden.

Longevity, late maturation, benthic habitats, and position at the top of the food chain could make white sturgeon highly susceptible to exposure and bioaccumulation of contaminants. However, there is little information on bioaccumulation and the physiological effects of environmental contaminants on white sturgeon.

Table 2. List of contaminants thought to be an issue in the Upper Columbia River

Metals
Lead, Zinc, Arsenic, Cadmium, Copper, Chromium, Mercury, Iron, Nickel, Cobalt, Selenium, Strontium, Silver
Also others for which little is known (Antimony, Indium, Germanium, Bismuth, Vanadium, Thallium)
Organic compounds
PCBs (Aroclors, mono and di- ortho substituted, co-planar)
Organochlorine pesticides
Dioxins/Furans
Chlorophenols
Resin & Fatty Acids
Pharmaceuticals
Hormones
PAHs (polyaromatic hydrocarbons)
Other Hydrocarbons associated with storm water runoff and industrial spills
Inorganic compounds
Detergents, Chlorine, Ammonia
Potential Persistent Metabolites of the following (chemical spills at Cominco):
Sulphuric acid
Ammonium sulphate
Sodium carbonate
Slag (metals mixtures)
Acid solutions, dusts and other unidentified solutions
PBDE's (polybrominated diphenyl ether; fire retardant)

3.6 Nutrients

Nutrient inputs into the upper Columbia River system have been reduced by the combined effects of elimination of anadromous fish runs, reservoir construction upstream, and reduced effluent discharges. Prior to the construction of Grand Coulee Dam, anadromous fish runs were likely a significant source of marine derived nitrogen, phosphorus, and trace elements in addition to a food source. Upstream reservoirs act as nutrient sinks and reduce downstream transport from the upper basin. Historic effluent discharges from the Cominco fertilizer plant artificially increased nutrient levels in the upper Columbia River and Lake Roosevelt. Municipal and industrial sources have been substantially reduced by widespread construction of sewage treatment plants that provide primary and secondary treatment.

Reduced nutrient levels have substantially reduced the biological productivity of the upper Columbia River ecosystem. Lower productivity has likely reduced food availability for sturgeon and resulted in lower rates of growth, survival, condition, and maturation. These changes have likely reduced the carrying capacity of the system for sturgeon and reproductive potential of the population. Reduced productivity may also have contributed to poor juvenile survival and the lack of recruitment.

3.7 Habitat Diversity & Geomorpholgy

The riverine habitat structure has been substantially altered by impoundment, channel modification, flood control, and flow regulation. Substantial diversity was lost as a result of impoundment. Changes in river geomorphology as a result of flood control and flow regulation are more subtle but no less significant. Floods help maintain channel diversity by periodically scouring and rearranging materials to create pool and backwater habitats. Regulated flows result in a more uniform river channel and an armoured substrate.

These changes reduce aquatic habitat diversity, alter flow conditions at potential spawning and nursery areas, and alter substrates in incubation and rearing habitats necessary for survival (Partridge 1983; Apperson and Anders 1991). Complex habitats may provide important seasonal forage areas and refuges from high discharges. Side channels and low-lying marshlands provide extremely productive habitats which may be used directly by sturgeon or by important food sources.

3.8 Changes in Fish Species Composition

Substantial changes in the relative composition of fish species have accompanied introduction of exotic species and development in the upper Columbia River. The pre-development fish community included large numbers of anadromous fishes including spring and summer chinook salmon (*Oncorhynchus tshawytscha)*, sockeye salmon (*Oncorhynchus nerka*), coho salmon (*Oncorhynchus kisutch),* steelhead (*Oncorhynchus mykiss)*, and Pacific lamprey (*Lampetra tridentata*). The resident fish community included bull trout (*Salvelinus confluentus*) and burbot (*Lota lota*). The primary changes have been the elimination of anadromous species and an increase in introduced species.

The current fish community of the mainstem Columbia River between HLK and Lake Roosevelt is dominated by mountain whitefish (*Prosopium williamsoni*), rainbow trout (*Oncorhynchus mykiss),* northern pikeminnow (*Ptychocheilus oregonensis*), and suckers

(Catostomidae). Whitefish are currently very abundant. Kokanee (*Oncorhynchus nerka*) are also common with most likely entrained from Arrow but a few also originating in Lake Roosevelt. Bull trout numbers are currently low in Columbia River between HLK Dam and Lake Roosevelt.

The current fish assemblage in Lake Roosevelt is a result of anthropogenic actions that have created an unbalanced, ever-shifting, perturbed hybrid lotic/lentic reservoir ecosystem. The community is dominated by introduced species including walleye (S*tizostedion vitreum*) and smallmouth bass (*Micropterus dolomieui*) as well as kokanee salmon. The majority of the salmonid assemblage consists of coastal rainbow trout, brook trout, and brown trout. Native salmonids including bull trout, westslope cutthroat trout, and redband trout are rarely encountered. In addition, mountain whitefish populations have been replaced by lake whitefish.

The Arrow Lakes fish community is currently dominated by kokanee and mountain whitefish. An Arrow Lakes stock of large adfluvial rainbow trout has drastically declined since the completion of Mica and Revelstoke dams. Revelstoke Reservoir fish species include kokanee, rainbow trout, bull trout, mountain whitefish, burbot, longnose sucker, largescale sucker, redside shiner, peamouth, northern pikeminnow, and prickly sculpin. Since impoundment there has been a trend towards increased abundance of kokanee and bull trout, with a corresponding decline in the abundance of mountain whitefish and rainbow trout. Longnose sucker and peamouth numbers increased dramatically from 1985 to 1995. Significant fish species in Kinbasket Reservoir include kokanee, rainbow trout, bull trout, and mountain whitefish. Kokanee were not present prior to impoundment but were stocked to take advantage of the extensive pelagic habitats in the reservoir.

Impacts on sturgeon of changes in the resident fish community are poorly understood but predator and prey species are likely affected. Adult sturgeon are not known to have any predators in fresh water except man. However, other species such as rainbow trout, northern pikeminnow, suckers, and walleye may prey on white sturgeon eggs, larvae, and small juveniles. Abundance of large rainbow trout is very high in the transboundary reach. Northern pikeminnow are a piscivorous cyprinid that consumes fish eggs and a variety of larval and juvenile fish species. Sucker spp. are bottom feeders and are known to consume sturgeon eggs where not excluded by high velocities. Walleye are a highly effective predator on fish and have become very abundant in Lake Roosevelt following illegal introduction. Large numbers of walleye migrate into upper Lake Roosevelt and river upstream from June to August when larval white sturgeon are dispersing downstream and also leaving the substrate to begin feeding.