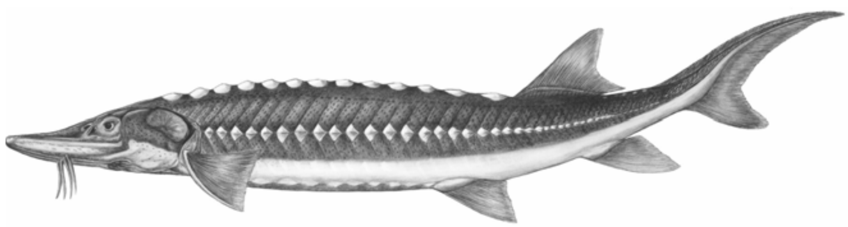
COSEWIC
Assessment and Update Status Report

on the

White Sturgeon
Acipenser transmontanus

in Canada



ENDANGERED
2003

COSEWIC
COMMITTEE ON THE STATUS OF
ENDANGERED WILDLIFE
IN CANADA

COSEPAC
COMITÉ SUR LA SITUATION DES
ESPÈCES EN PÉRIL
AU CANADA

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COSEWIC
Assessment Summary

Assessment Summary – November 2003

Common name
White sturgeon

Scientific name
Acipenser transmontanus

Status
Endangered

Reason for designation
A long-lived species with a 30-40 year generation time and late maturity, that has suffered over a 50% decline in the last three generations. Three of six populations are in imminent threat of extirpation. Extant populations are subject to threats of habitat degradation and loss through dams, impoundments, channelization, diking and pollution. Illegal fishing (poaching) and incidental catches are also limiting. In addition, a developing commercial aquaculture industry may also impose additional genetic, health and ecological risks to wild populations.

Occurrence
British Columbia

Status history
Designated Special Concern in April 1990. Status re-examined and uplisted to Endangered in November 2003. Last assessment based on an update status report.

COSEWIC
Executive Summary

White Sturgeon
Acipenser transmontanus

Species Information

The white sturgeon, *Acipenser transmontanus*, is the largest freshwater fish in Canada, sometimes exceeding 6 m in length. Sturgeon have rows of large bony plates, called scutes, along the back and sides. The scutes are quite sharp when the fish are young but gradually wear down as they age. Sturgeon skeletons are mostly cartilage instead of bone. They have no teeth but can extend their mouth to reach out and engulf food. The eggs hatch into larvae with an attached yolk sac, then metamorphose to look like miniature adults within 30 days.

Green sturgeon, *Acipenser medirostris*, are sometimes found in the same rivers. These two species look similar and can be confused. White sturgeon have two rows of 4 - 8 scutes on the ventral surface between the pelvic and anal fins; green sturgeon have only one row of 1- 4 scutes. Green sturgeon are rarely seen in freshwater and are most often caught in salt-water commercial fisheries. Occasionally they are seen in the lower portions of larger coastal rivers in the late summer or early fall.

Distribution

Spawning populations of white sturgeon are known to occur in three large river systems on the Pacific coast of North America (in the Fraser, Columbia and Sacramento drainages). In Canada, white sturgeon are found only in British Columbia: in the Fraser River system from the estuary upstream past the Morkill River, northwest of McBride; in the upper Columbia system in Arrow and Slocan lakes and in the mainstem downstream of Hugh L. Keenleyside Dam; and in the Kootenay River from Kootenay Lake upstream to the U.S. border. Reports of sturgeon from the Skeena, Nass and Yukon rivers, when checked, have been found to be green sturgeon.

Habitat

Over the past century, white sturgeon habitat in British Columbia has declined in both quality and quantity. The diversion and regulation of water flows have likely had the most severe influence on sturgeon populations. Dams have heavily altered the flow regimes in the Columbia, Kootenay and Nechako systems. The possible effects of dams are wide ranging, including changes to water quality, streamflows, water temperature and habitat, as well as changes in species composition. The Fraser River mainstem is free running and has not been as heavily altered, but the amount of available sturgeon habitat on the lower river has declined since human settlement. Dredging, gravel extraction, dyking and channelization have been common practices. Contamination may also play a role in degrading habitat within and downstream from areas of high human use.

Biology

The white sturgeon is a long-lived species. Some individuals in the Fraser River have been aged at over 100 years. Age of maturity varies with location and sex and can be anywhere from 14 years of age, for males in the lower Fraser River, to over 30 years for males in more northern areas. Although they typically survive spawning, it can be many years before they spawn again.

Although often sedentary or localized in their movements, in some areas it is necessary for white sturgeon to move long distances between the various types of habitat necessary to complete their life history. They eat a variety of organisms from benthic invertebrates like crayfish, shrimp and clams to fish such as lamprey, salmon, and smelt.

Population Sizes and Trends

Population declines have occurred throughout their Canadian range, particularly in the lower Fraser, Nechako, Columbia and Kootenay rivers. The abundance of sturgeon in the Fraser River mainstem upstream of Hell’s Gate may be naturally low but stable.

Limiting Factors and Threats

White sturgeon are particularly vulnerable to overfishing due to their slow growth, late maturity and long life. The sturgeon commercial fishery that occurred prior to 1920 devastated sturgeon abundance in the lower mainland of British Columbia. Human activities also affect sturgeon populations through habitat change, particularly dam construction and flow regulation.

Special Significance of the Species

The white sturgeon was once a valuable commercial species and is still highly valued for societal and cultural reasons, both recreationally and traditionally. Some First Nation’s peoples have harvested white sturgeon since long before Europeans arrived. The value of this large, ancient species as part of our natural heritage is tremendous, but cannot be estimated.

Existing Protection or Other Status Designations

Throughout B.C., commercial and sport harvest has been prohibited since 1994 and some First Nations have voluntarily curtailed their fisheries. On the U.S. side, harvest is prohibited in the Kootenai River system (the same population is found in the Kootenay River and Kootenay Lake in B.C.) and upper Columbia rivers. The Kootenai River population was listed as endangered under the U.S. Endangered Species Act on September 6, 1994.

The Kootenai White Sturgeon Recovery Plan, developed by U.S. Fish and Wildlife Service with input from Canadian agencies, is in the implementation phase. Recovery planning processes are under way for white sturgeon populations in the Nechako, upper Columbia and Fraser rivers. Recovery efforts for the transboundary white sturgeon populations in the upper Columbia and Kootenay rivers are closely coordinated with U.S. agencies. The recovery plan for the upper Columbia River white sturgeon is complete. Completion of the Nechako River white sturgeon recovery plan is targeted for 2004. Work on the Fraser River recovery planning process is in the preliminary stages. Recovery efforts have brought together: provincial and local governments; First Nations; experts in sturgeon biology, fish culture, recovery of endangered species, effects of hydroelectric dams, and habitat restoration; public and industrial stakeholders; and U.S. regulatory and tribal agencies for transboundary groups. In an attempt to compensate for failing recruitment, an experimental conservation culture facility has been established for the Kootenay (Kootenai) and Columbia sturgeon at Fort Steele, B.C.

COSEWIC HISTORY

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It arose from the need for a single, official, scientifically sound, national listing of wildlife species at risk. In 1978, COSEWIC designated its first species and produced its first list of Canadian species at risk. On June 5, 2003, the *Species at Risk Act* (SARA) was proclaimed. SARA establishes COSEWIC as an advisory body ensuring that species will continue to be assessed under a rigorous and independent scientific process.

COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses the national status of wild species, subspecies, varieties, or other designatable units that are considered to be at risk in Canada. Designations are made on native species and include the following taxonomic groups: mammals, birds, reptiles, amphibians, fishes, arthropods, molluscs, vascular plants, mosses, and lichens.

COSEWIC MEMBERSHIP

COSEWIC comprises members from each provincial and territorial government wildlife agency, four federal organizations (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biosystematic Partnership, chaired by the Canadian Museum of Nature), three nonjurisdictional members and the co-chairs of the species specialist and the Aboriginal Traditional Knowledge subcommittees. The committee meets to consider status reports on candidate species.

DEFINITIONS
(After May 2003)

Species	Any indigenous species, subspecies, variety, or geographically or genetically distinct population of wild fauna and flora.
Extinct (X)	A species that no longer exists.
Extirpated (XT)	A species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A species facing imminent extirpation or extinction.
Threatened (T)	A species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A species of special concern because of characteristics that make it particularly sensitive to human activities or natural events.
Not at Risk (NAR)**	A species that has been evaluated and found to be not at risk.
Data Deficient (DD)***	A species for which there is insufficient scientific information to support status designation.

* Formerly described as “Vulnerable” from 1990 to 1999, or “Rare” prior to 1990.
** Formerly described as “Not In Any Category”, or “No Designation Required.”
*** Formerly described as “Indeterminate” from 1994 to 1999 or “ISIBD” (insufficient scientific information on which to base a designation) prior to 1994.

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Canada

The Canadian Wildlife Service, Environment Canada, provides full administrative and financial support to the COSEWIC Secretariat.

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Acipenser transmontanus

in Canada

2003

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SPECIES INFORMATION

Name and classification

The white sturgeon, *Acipenser transmontanus* Richardson, is in the order Acipenseriformes, which includes the sturgeons and paddlefishes. The French common name is esturgeon blanc. Additional English common names include Pacific sturgeon, Columbia sturgeon, Oregon sturgeon and Sacramento sturgeon.

Description

The white sturgeon (Fig. 1) is the largest fish found in the fresh waters of Canada; some individuals exceed 6 m in length (Scott and Crossman 1973). Upper river populations tend to be smaller in size. Sturgeon have five rows of scutes, along their back and sides. The scutes are quite sharp when the fish are young but gradually wear down as they age. Sturgeon skeletons are cartilaginous except for small amounts of bone in the pelvic area, skull and jaw. They have no teeth but can extend their mouth to reach out and engulf food.

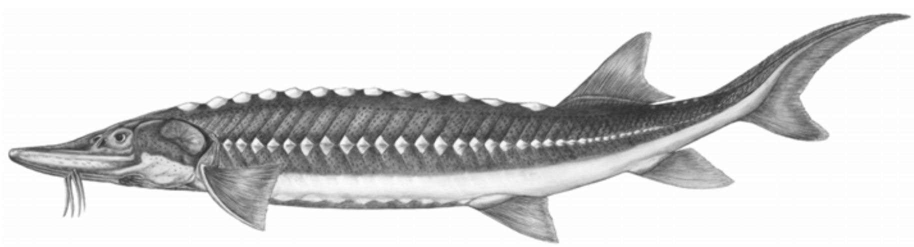

Figure 1. Adult Nechako River white sturgeon, *Acipenser transmontanus* Richardson (drawing by Loucas Raptis).

Fertilized eggs are brown and adhesive. Eggs hatch as larvae with an attached yolk sac. Larvae lack the long snout and scutes, and are not ventrally flattened like the fry to adult stages. The larvae metamorphose to look like miniature adults less than a month after hatching.

There are two species of *Acipenser* on the Pacific coast; the other is the green sturgeon, *Acipenser medirostris*. These two species look similar and can be confused. The back of the white sturgeon is grey to black in colour with perhaps some hints of olive green. The body of the green sturgeon is definitely green to olive green in colour, but the colour may fade, after a period in freshwater (Slack and Stace-Smith 1996). There are several methods for distinguishing the two species (McPhail and Carveth 1993, Lane 1991, Scott and Crossman 1973). One that is recommended (Foley 1995) uses the number of scutes posterior to the vent; green sturgeon have one row of 1 - 4 scutes between the pelvic and anal fins, while white sturgeon have two rows of 4 - 8. In British Columbia the green sturgeon is rarely observed in freshwater and is most often seen as bycatch in salt-water commercial fisheries. Occasionally, they are present in the lower portions of B.C.'s larger coastal rivers in the late summer or early fall.

Nationally significant populations

<u>Proposed Population Breakdown</u>

SP1: Lower Fraser River - downstream of Hell's Gate (km 0 to km 211),
SP2: Middle Fraser River - Hell's Gate to Prince George (km 211 to km 790),
SP3: Upper Fraser River - upstream of Prince George (km 790 to ~1100),
SP4: Nechako River (tributary of Fraser River, enters mainstem at Prince George),
SP5: Upper Columbia River, and
SP6: Kootenay River.

Fraser River

Four populations of white sturgeon are proposed for the Fraser River system (SP1-4). Geographic, behavioural, life history data, phenotypic differences (RL&L 2000) and spawning studies (Perrin *et al.* 1999, 2000 and 2003), as well as the analyses of mitochondrial DNA (mtDNA) (Nelson *et al.* 1999; Pollard 2000, Smith 2002) give support to the identification of four distinct population units in this drainage.

The lower Fraser River population (SP1) is likely the only facultative anadromous group in Canadian waters; the others are inland groups. There is some supportive evidence for marine migrations, or juvenile rearing in the estuary, by some individuals in this population, based on concentrations of strontium in pectoral fin rays (Vienott, *et al.* 1999). Other Fraser River populations (RL&L 2000 and Smith 2002) are found in the mainstem between Hell's Gate and the Nechako River confluence, at Prince George (SP2); the mainstem Fraser River upstream of Prince George (SP3); and in the Nechako River system (SP4).

Differences in fish assemblages between the Fraser River above and below the Fraser Canyon can be related to the location of glacial refugia and subsequent postglacial invasion routes (McPhail and Carveth 1992). These different assemblages have been maintained over time indicating that the canyon can act as both a downstream and upstream barrier to fish movement. The Fraser River fauna above the canyon appear to have originated from the upper Columbia River and other inland refugia, while the lower Columbia River was a major source to the lower Fraser River.

While Fraser River white sturgeon populations do not have complete geographic isolation, significant migration impediments, such as the rapids at Hell's Gate and other fast water sites, are present in the river and may limit movement between populations (RL&L 2000). One contributing factor may be that the Hell's Gate fishways were designed to accommodate the size and swimming abilities of Pacific salmon (Saxvik 2001), not sturgeon. There may also be behavioural barriers as mark/recapture and radio telemetry studies have indicated that movements between populations are rare (RL&L 2000). Long stretches of poor habitat (such as hydraulic glides lacking deep pools and channel structure) may impede movement between populations. A distance of more than 70 km of broad shallow river separates the middle Fraser group from the upper Fraser group (Yarmish and Toth 2002). A similar stretch of habitat is found in the lower 60 km of the Nechako River. Only occasionally have sturgeon been found in this section. Demographic data have indicated that sturgeon populations in the Fraser River have distinct growth rates, implying that these fish reared in different habitats (RL&L 2000; Lane 1991). There is no doubt that conditions in the upper Fraser River are dissimilar from those in the lower river and that different adaptations are likely selected. Phenotypic variation in snout length has been detected between lower- and upper-river groups (RL&L 2000). Specifically, white sturgeon below Hell's Gate had a significantly shorter snout length at a given fork length than those in the middle Fraser and Nechako rivers (ANCOVA: $p<0.01$).

Perrin *et al.* (1999, 2000 and 2003) indicate that embryos and larvae do not become entrained in surface water but remain close to the refuge provided by the water-substrate interface in the lower Fraser River. Larvae 1 – 8 days posthatch were found 3 – 5 km downstream of the inflow to the sidechannels where spawning occurred; none were found in sampling either upstream or downstream of those same sidechannels. At the mainstem study site, near the confluence of the Coquihalla River, no eggs or larvae were collected more than 2 km downstream of the confluence, most within 0.5 km. There were no eggs or larvae collected in the 23 km sampled in the mainstem upstream of the Coquihalla River. Their study suggests, that in natural flow situations, where velocities provide suitable settling sites, fertilized eggs and larvae may not drift far enough downstream to mix with other populations.

Genetic studies have shown that the white sturgeon in the lower Fraser River, downstream of Hell's Gate, are distinct from the rest of the Fraser system, although there is also evidence that the lower Fraser group is composed of an unresolved mixture of populations (Nelson *et al.* 1999; Pollard 2000; RL&L 2000, Smith *et al.* 2002). Smith *et al.* (2002) studied mtDNA (Fig. 2) to test for gene-flow barriers in the Fraser River, between the groups indicated by information on movement of tagged fish, potential migratory impediments and clusters in distribution (RL&L 2000). Division of the Fraser River into four groups best explained mtDNA variation, partitioning 19.9% ($P<0.001$) among groups and 1.8% ($P=0.161$) among sites within groups (Smith *et al.* 2002). Some aspects of the data show that lower Fraser River white sturgeon are similar to those in the Columbia; however, it has not been determined whether this is due to migration or a relatively short coalescence time.

Upper Columbia River

The upper Columbia River is defined as the mainstream river and reservoirs upstream from the Grand Coulee Dam in Washington State, as well as the Kootenay River below Bonnington Falls and the lower Pend d'Oreille River below Waneta Dam (Fig. 3). The transboundary group inhabiting this area is proposed as population SP5.

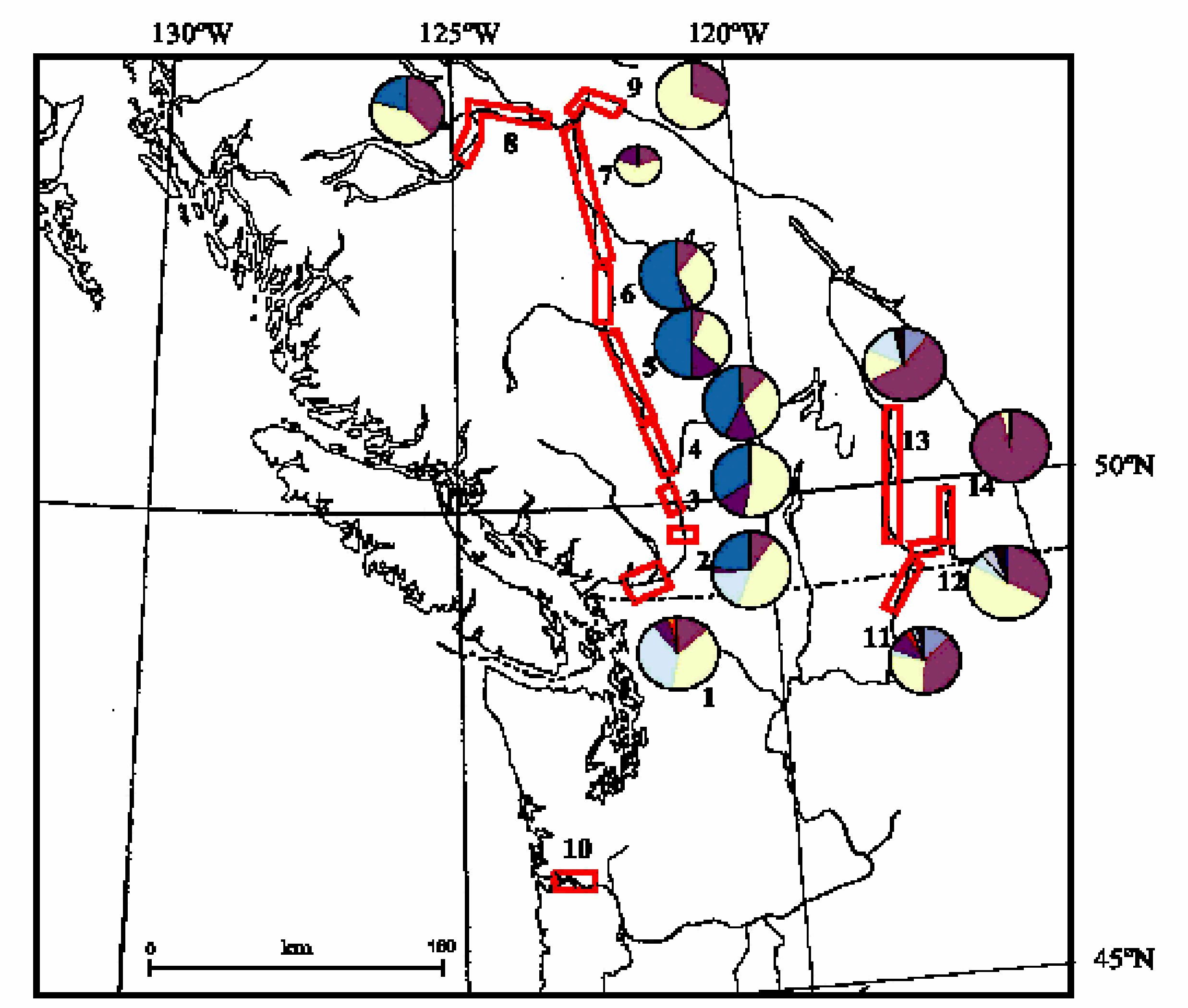

Figure 2. The 14 white sturgeon population clusters sampled and mtDNA haplotype distributions for Canadian clusters (Nelson et al. 1999). Each cluster, shown by boxes, was separated by a large zone of low sturgeon densities. Pies indicate number of different haplotypes. Relative size of pie indicates sample size (n= 5 - 30). Lower Fraser River = 1 & 2; Middle Fraser River = 3, 4, 5 & 6; Upper Fraser River = 9; Nechako River = 8; Upper Columbia River = 11, 12 & 13; Kootenay River = 14. Cluster 7 was low density and not included in the analysis of population structure due to low sample size. (Diagram provided by C. Smith.)

The upper Columbia River population is geographically separated and isolated from Fraser River populations by a series of dams in the mainstem Columbia River (Fig. 3). In B.C., radio telemetry and tagging studies have shown that white sturgeon downstream from Hugh L. Keenleyside (HLK) Dam are generally either sedentary or localized in their patterns of movement (RL&L 1995), although limited movement of white sturgeon has been detected in the transboundary reach (from HLK Dam in Canada to Lake Roosevelt in the U.S.). Upper Columbia white sturgeon have been totally isolated from lower Columbia River populations in the United States since 1941 following the construction of Grand Coulee Dam and the formation of Lake Roosevelt. Kettle Falls (upstream of Grand Coulee Dam in Washington State) is thought to have formed a seasonal barrier to white sturgeon migration prior to its inundation by Lake Roosevelt. Construction of HLK, Mica, and Revelstoke dams on the mainstem Columbia River, Brilliant Dam on the lower Kootenay River, and Waneta Dam on the lower Pend d'Oreille River (all in B.C.) further fragmented the population and altered the natural flow regime. There are no recent records of sturgeon upstream of Revelstoke Dam and only remnant populations remain in the Arrow Lakes (upstream of HLK Dam) and Slocan Lake (which drains into the lower Kootenay River below the site of Bonnington Falls). The largest documented group in this population resides in the area between HLK Dam and the Canada-U.S. border. Remnant groups or isolated individuals occur, or are suspected, throughout the remainder of the drainage.

Genetic evidence supports the distinction of a white sturgeon population in this area. Analyses by Nelson *et al.* (1999) indicated the fish in this portion of the Columbia River represented a biologically significant unit distinct from the Kootenay River population. Pairwise F_{ST} analysis, from composite haplotype data, resulted in a value of 0.3176 between upper Columbia River and Kootenay Lake, indicating a significant difference in haplotype frequency between the two groups (Nelson *et al* 1999).

Mitochondrial DNA studies by Nelson *et al.* (1999) and Smith (2002) indicate possible sub-structuring within the upper Columbia River. Samples from Arrow Reservoir, Kootenay River downstream of Brilliant Dam, and the Columbia River below HLK Dam indicate these groups may have formed distinct breeding groups prior to impoundment. Chi-squared analysis of RFLP (restriction fragment length polymorphism) data indicated differences were not significant at $\alpha = 0.05$, but sample sizes were small. Results of analyses of microsatellite data were closer to Hardy-Weinberg equilibrium when the three sites were analyzed separately, rather than together, suggesting the possibility of some sub-structuring. These analyses are preliminary and the authors indicated that larger sample sizes would be required to clarify the situation.

No status review for this population, or for Columbia River white sturgeon in general, has been completed under the Endangered Species Act (U.S.A). A petition for listing Columbia white sturgeon was received by the National Marine Fisheries Service in 1992. No status review was initiated at that time, because the petition did not contain sufficient information to indicate that a review was warranted.

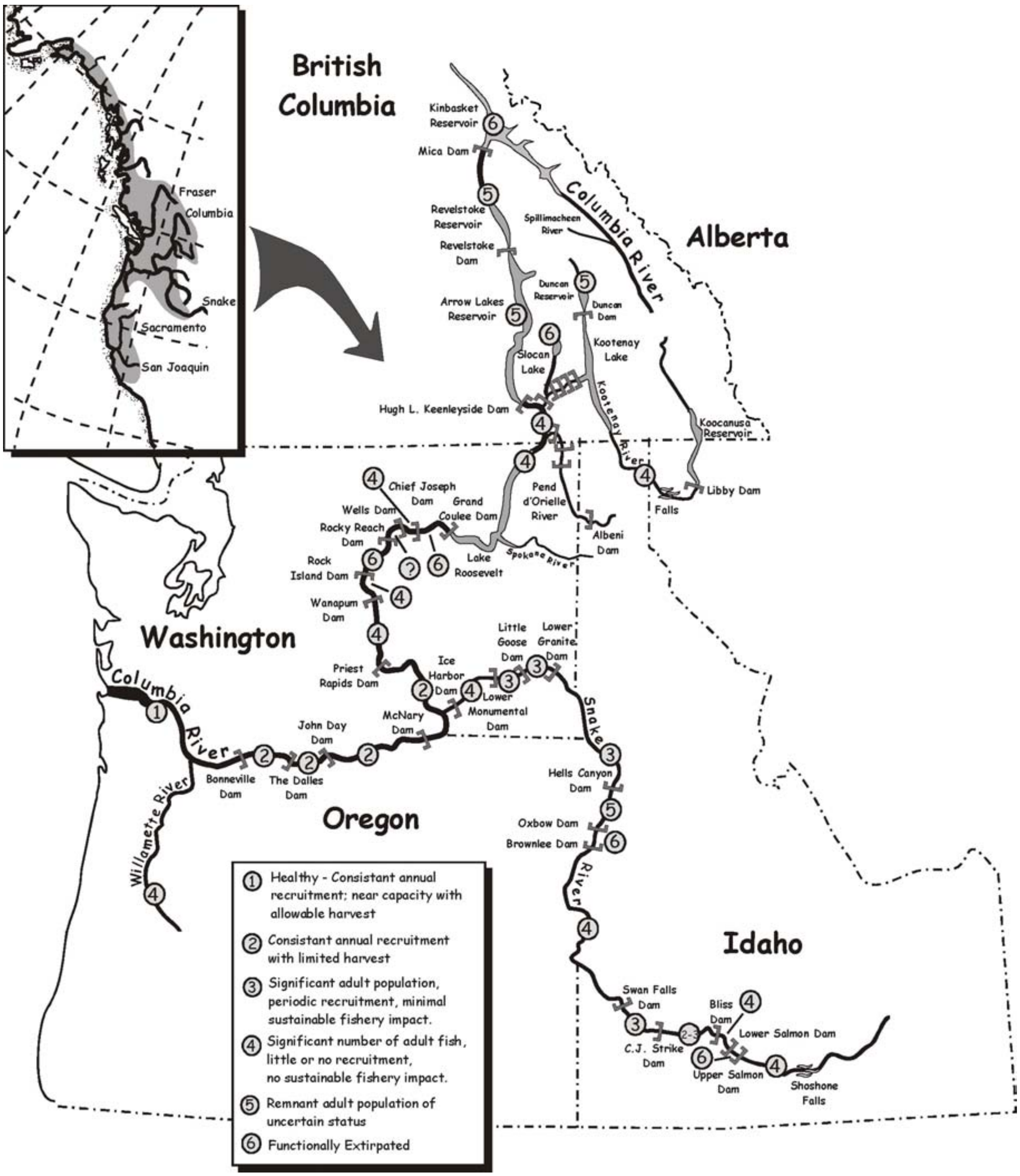

Figure 3. Columbia River system showing dams and status of populations (UCRRP 2002).

Kootenay River (called the Kootenai River in the U.S.)

The Kootenay River population (SP6) is another transboundary group that moves freely between Kootenai Falls, Montana, downstream as far as the West Arm of Kootenay Lake, B.C. Genetic analyses conducted by Nelson *et al*. (1999) concluded that there were statistically significant differences between the Kootenay population and those in the Columbia and Fraser rivers (F_{ST} values ranged from 0.50 to 0.75 for pairwise analysis of mtDNA haplotype data). The Kootenay River population is isolated, and has likely been separated from the rest of the Columbia River drainage since the last ice age by a natural barrier at Bonnington Falls, downstream of Kootenay Lake (Northcote 1973). This population is considered a “distinct population segment” under the U.S. Endangered Species Act.

DISTRIBUTION

Global range

Spawning populations of white sturgeon are known to occur in three large river systems on the Pacific coast of North America (in the Fraser, Columbia and Sacramento rivers; Fig. 4). White sturgeon are known to be anadromous and have been recorded in other coastal locations; however, these individuals are believed to be transient not resident (E.D. Lane, Malaspina College, pers. comm.).

Canadian range

White sturgeon are found in the Fraser River system from the estuary upstream past the Morkill River, northwest of McBride (Yarmish and Toth 2002, Fig. 5). They occur in large tributaries (including the Harrison, Nechako and Stuart rivers, and the lower reaches of the Bowron, McGregor and Torpy rivers), and in large lakes (such as Fraser, Takla, Trembleur, Stuart, Williams and Harrison lakes). In the Columbia system they are found in the Columbia River mainstem, Kootenay River and lower Pend d’Oreille River, and also in larger reservoirs (including Kootenay, Arrow, and Duncan reservoirs). Although there have been anecdotal reports of white sturgeon in Okanagan Lake, the presence of sturgeon in this drainage has never been confirmed (S. Matthews, B.C. Ministry of Water, Land and Air Protection, pers. comm.). White sturgeon have been identified from several rivers on Vancouver Island, but are not resident. Records of sturgeon from the Skeena, Nass and Yukon rivers, when checked, have been found to be green sturgeon (Lane 1991).

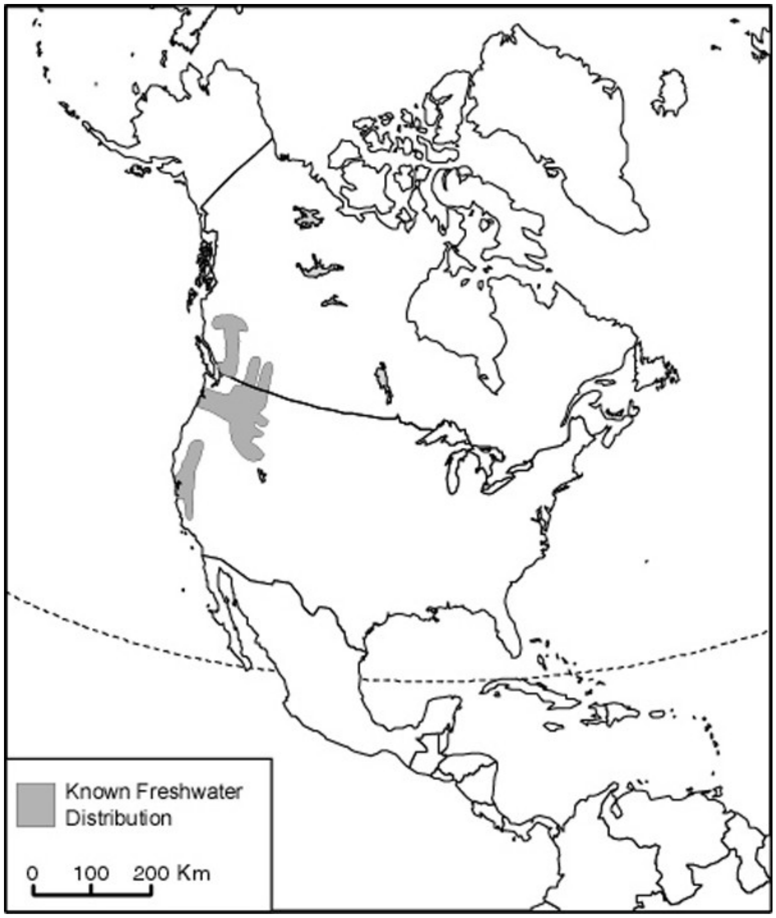

Figure 4. North American, and global, freshwater distribution of white sturgeon (*Acipenser transmontanus*).

In the Fraser River system, their range covers about 1100 km of mainstem river habitat, 400 km in the Nechako and Stuart rivers, plus the confluence areas of major tributaries (RL&L 2000). In this system, the extent of occurrence of the populations is likely very similar to their historical distribution (Table 1). A study was undertaken, through the Carrier-Sekani Tribal Council, that attempted to ascertain the historical upper limit of white sturgeon distribution in the Nechako River; however, inconsistencies in the information made it impossible to come to any conclusions (D. Cadden, B.C. Ministry of Water, Land and Air Protection, pers. comm.).

Populations in the Columbia and Kootenay rivers are isolated and fragmented above or between dams (Cannings and Ptolemy 1998; Fig. 3). In the Columbia, they are known to range from the upper end of the Arrow Reservoir to Grand Coulee Dam in the U.S. This is a distance of about 500 km, fragmented about mid-way by HLK Dam. Revelstoke Dam, completed in 1984, eliminated 130 km of free-flowing river upstream between Arrow Lakes Reservoir and the Mica Dam. A canyon in this section may have contained spawning habitat prior to flooding (Hildebrand *et al*. 1999). Mica Dam may

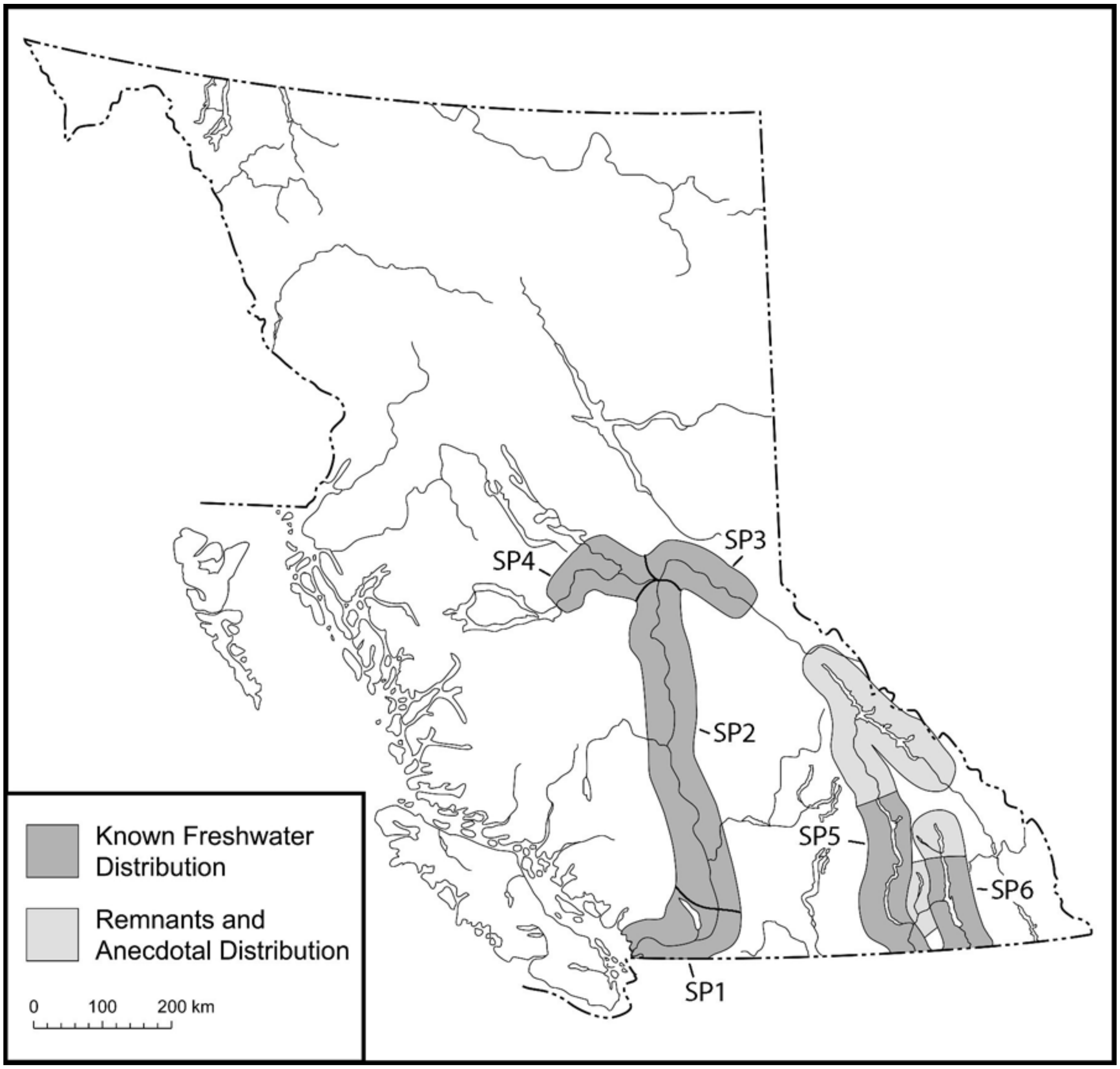

Figure 5. Canadian freshwater distribution of white sturgeon (*Acipenser transmontanus*).

have alienated over 250 km of river habitat, as anecdotal reports indicate isolated individual sturgeon may still occur in Kinbasket Reservoir and the mainstem Columbia River upstream as far as Spillimacheen. Information from First Nations elders indicates that historically sturgeon may have occasionally followed salmon upstream on feeding forays, but were probably not resident in this section of the river (Failing and Gregory 2003). Construction of Waneta Dam also blocked sturgeon access to the Pend d'Oreille River (UCRRP 2002).

Table 1. Area of occupancy and extent of occurrence for white sturgeon in Canada.					
Sturgeon Population	Region	Estimated Current Range		Estimated Historical Range	
		Area of occupancy (km^2)	Extent of occurrence (km^2)	Area of occupancy (km^2)	Extent of occurrence (km^2)
SP1	Lower Fraser River	500	2,360	>500	2,360
SP2	Middle Fraser River	980	9,700	980	9,700
SP3[1]	Upper Fraser River	70	2,970	70	2,970
SP4[2]	Nechako River	470	10,720	>470	10,720
SP5[3]	Upper Columbia River	440	12,190	<950	17,380
SP6[3,4]	Kootenay River	480	6,780	<550	7,930
Total	British Columbia	2,870	44,720	<3,450	51,060

Area estimates provided by S. Cheesman (B.C. Ministry of Sustainable Resource Management, Aquatic Information Branch, Victoria, B.C.) using the BC Watershed Atlas (a digital product based on existing NTS 1:50,000 mapping) and ArcView.
[1]SP3 estimates are preliminary only as distribution and habitat investigations are still underway.
[2]SP4 estimates do not account for possible downstream contraction of habitat use due to altered conditions.
[3]SP5 & SP6 estimates of historical occupancy are high as they are based on current impoundment conditions.
[4]SP6 estimates of historical range do not include the area in B.C. between Canal Flats and the international border (the section above Kootenai Falls, Montana), as historical anecdotal information has not been verified. Including this area brings historical area of occupancy to 640 km² and extent of occurrence to 18,358 km².

The Kootenay River (Kootenai River in the U.S.) population migrates freely between Kootenay Lake, B.C., and Kootenai Falls, in Montana. Historic anecdotal evidence suggests the presence of white sturgeon above Kootenai Falls in both Montana and B.C. (Duke *et al*. 1999). This has not been confirmed, but if true, white sturgeon may have ranged as far upstream as Canal Flats in B.C., roughly 120 km upstream of their current upper distribution limit. This is not included in current estimates of historical range (Table 1) as it has not been verified. Isolated individuals have been found in Slocan Lake and Duncan Reservoir indicating these areas and Slocan River were utilized, at least seasonally, prior to construction of Brilliant and Duncan dams; this represents about 130 km of lost habitat.

HABITAT

Habitat requirements

White sturgeon are not evenly distributed throughout their range; they tend to cluster in suitable habitat. Habitat use varies with life-history stage and season, and may involve migrations to spawning and feeding areas, making critical habitat difficult to define. In regulated rivers, all the remaining deep low velocity areas adjacent to faster water (including the confluence areas of large tributaries) are likely extremely important. In these systems spawning and rearing habitat may require restoration to allow natural recruitment to occur.

Spawning habitat

White sturgeon spawning habitat is difficult to study due the time of year and location (during flood events in large rivers). A recent study by Perrin et al. (2003) indicates that spawning habitat may vary between natural systems and those that are impounded. In the meandering reach of the lower Fraser River, Perrin et al. (2003) found evidence that spawning occurred only in sidechannels with substrates comprised of gravel, cobble and sand. Boulder and cobble predominated in the mainstem study site, which was located in a confined area of the mainstem. Flows at apparent spawning sites were mainly laminar with near-bed velocities averaging 1.7 m/s. The lower Fraser River is highly turbid. In 1999 average turbidity during the spawning period was 42.2 ± 2.9 nephelometric turbidity units (NTU), with a peak of 92 NTU; suspended solids averaged 102.2 ± 7.4 mg/L (peaking at 222 mg/L). Most eggs and larvae were collected at water depths between 3.0 and 4.5 m and at near-bed velocities of > 1.5 m/s for eggs, and 0.5 to 1.5 m/s for larvae. These data indicate that sturgeon use a greater variety of habitat for spawning than seen in impounded systems (Perrin et al. 2003). In regulated systems sturgeon utilize fast, turbulent water over clean, large rocky substrate (Hildebrand et al. 1999, Anders et al. 2001, UCRRP 2002). In the Columbia River below McNary Dam, spawning habitat was characterized as having a mean water column velocity of 0.8 to 2.8 m/s with cobble, boulder and bedrock substrates (Parsley et al. 1993). Spawning has occurred in the Kootenai River in an area characterized by large mobile sand dunes; the eggs collected at this site were covered in sand (Duke et al. 1999). The recovery team considers selection of this spawning site to be detrimental to egg survival and believes the behaviour may be due to changes in water velocity as a result of flow regulation. Mean water column velocities typically range between 0.5 to 2.5 m/s at most sites studied; however, lower than average velocities (0.2 to 1.0 m/s) have been reported in the Kootenay River, where spawning has been unsuccessful (UCRRP 2002). The recommended spawning velocity for the upper Columbia River is 1.7 m/s or greater with water depths of 4 m or greater (UCRRP 2002). Based on limited data, spawning intensity is greatest when discharges are high and steady (UCRRP 2002). Survival to hatch is also expected to be greatest under these conditions, as high velocities in egg deposition areas may exclude some predators and provide high turbidity. Higher turbidity can decrease vulnerability to visual predators, improving juvenile survival (Gadomski et al. 2001).

Juvenile habitat

Lane and Rosenau (1995) described juvenile (<1 m in length) habitat in the lower Fraser River. The lower reaches of tributaries, large backwaters, sidechannels and sloughs were utilized. The authors indicate a depth > 5 m, low velocities and variable current direction, high turbidity and relatively warm water were important factors in determining high suitability rearing habitat. They also noted that there was a distinct movement from sloughs and backwaters to mainstem areas as summer progressed. Data from the middle Fraser River (between Boston Bar and French Bar Canyon) indicate larger juveniles (≤ 100 cm) occupy the same areas as those used by adult fish (RL&L 2000). In the Fraser River mainstem above Prince George (SP3), younger sturgeon were most often encountered in the lowest reaches of large tributaries and near tributary confluences (RL&L 2000), and in the area between the confluence of the Willow and the Bowron rivers

(Yarmish and Toth 2002). No data are available on the upper Columbia River, but in the lower Columbia River (downstream of McNary Dam) older juveniles were documented at depths of 2 - 58 m at mean column and near-substrate velocities of 0.1-1.2 and 0.1-0.8 m/s; young-of-the-year were collected at depths of 9-57 m with mean water column and near-substrate velocities of 0.2-0.6 and 0.1-0.6 m/s (Parsley *et al.* 1993). Substrates at collection sites varied from finer particles through to boulder and hard clay, but were predominated by sand (the most common substrate in the lowest reach). Ktunaxa Nation elders have historically observed juveniles, to about 30 cm in size, in seasonally flooded wetland areas and in slack water in Indian Creek near its confluence with the Goat and Kootenay rivers (Failing and Gregory 2003).

Adult habitat

Although they will briefly move into shallower areas to feed during spring and summer, in the Fraser River adults are typically found in deep near-shore areas, adjacent to heavy flows, defined by deposits of sand and fine gravels with backwater and eddy flow characteristics (RL&L1994 and 2000). The high-use areas in the upper Columbia River are all depositional areas where food items settle out; these areas also support high densities of fish species that likely provide an additional food source (UCRRP 2002). White sturgeon in the Columbia system tend to hold in deep (> 20 m), calm areas during the winter period (Apperson and Anders 1991; RL&L 1994 and 2000; Hildebrand *et al.* 1999; UCRRP 2002). This may be an energy conservation measure particularly important to prespawning females (Hildebrand et al. 1999). Required habitat in less productive northern areas with less water flow (like the upper Fraser River) may be widely dispersed, include tributaries, and require longer migrations than in larger, more southern systems (Yarmish and Toth 2002).

Trends in habitat

Over the past century, most white sturgeon habitat in British Columbia has declined in quality and quantity, but quantitative measures are not available. River regulation and diversion has likely had the most severe influence on sturgeon habitat. Changes to the natural hydrograph of the Columbia, Kootenay and Nechako rivers have been profound (Duke *et al*. 1999, Hildebrand *et al*. 1999, RL&L 2000, Anders *et al*. 2001, Korman and Walters 2001, UCRRP 2002). Although it is clear that flow changes have had an important influence, there has been little agreement on the exact mechanisms limiting sturgeon populations (Hildebrand *et al*. 1999, Anders *et al*. 2001, Korman and Walters 2001).

The hypothesized effects of dams and river regulation are wide ranging (Duke *et al*. 1999, Hildebrand *et al*. 1999, RL&L 2000, Anders *et al*. 2001, Korman and Walters 2001, UCRRP 2002). They include both habitat and biological effects such as changes in channel morphology and substrate composition, water quality and quantity, predator-prey relationships, and creation of migration barriers.

The loss and degradation of habitat from human activities other than dams has occurred in all drainages (Lane and Rosenau 1995, Duke *et al*. 1999, Hildebrand *et al*.

1999, RL&L 2000, Rosenau and Angelo 2000, Anders *et al*. 2001, UCRRP 2002). The mainstem Fraser River has not been as heavily altered and remains free running; nevertheless, the amount of available sturgeon habitat has declined since European settlement. Dredging, gravel mining, channelization and dyking in the lower Fraser River have been common practices (Lane and Rosenau 1995, RL&L 2000, Rosenau and Angelo 2000). The conversion of wetlands began to accelerate after the turn of the century, e.g. Sumas Lake had been drained to create Sumas Prairie (3,600 ha) by 1924 (Campbell *et al*. 2002). Overall, the area of wetland complexes in the lower Fraser valley has been reduced by about 70% (Environment Canada 1996, Campbell *et al*. 2002). These wetlands would likely have included valuable juvenile rearing habitat and food production areas. In other parts of the province, slough and large backwater areas adjacent to the mainstem have been altered on the Nechako River (Rood and Neill 1987), the Columbia River between HLK and Grand Coulee Dams (Hildebrand *et al*. 1999) and in the Kootenay River drainage (Anders *et al*. 2001). In the Nechako River, Rood and Neill (1987) measured the loss of sidechannel length due to flow reduction at 50-80%, depending on the section of river. To protect agricultural use in the floodplain of the Kootenay River, extensive dyking has occurred between Bonner's Ferry, Idaho, and Kootenay Lake. This has effectively alienated most backwater, side channel and slough habitat (Apperson and Anders 1991). The loss of juvenile rearing habitat in these areas may be contributing to population declines, as some spawning does occur on some years but recruitment is insignificant.

In the Nechako River, the flow regime was significantly altered by the construction of Kenney Dam and the Skins Lake Spillway, and the diversion of flows westward in an underground tunnel, through a powerhouse at Kemano, B.C., and then to the coast. Diverted water released from the spillway and directed through the Cheslatta system now enters the Nechako River at Cheslatta Falls, about 9 km downstream of Kenney Dam. Large sediment inputs occurred following two avulsions of the Cheslatta River, in 1961 and 1972. As a result several hundred thousand tonnes (about 0.45M m^3) of sand and gravel has been transported down river (Rood and Neill 1987). Lower flows and reduced sediment transport capacity have increased accumulation in the channel. Studies are in progress to determine if sediment deposition has resulted in altered channel morphology and the cutting off of important side-channel habitat (S. McAdam, B.C. Ministry of Water, Land and Air Protection, pers. comm.). Reductions in peak flows and land use changes have also resulted in large increases in macrophyte growth. Decay of this plant material was identified as a potential threat, as it can decrease the amount of oxygen available near the river bed and contribute to reduced juvenile survival (Korman and Walters 2001). Other possible effects of dense macrophyte beds include dramatic changes to temperature profiles, a decrease in water velocities and an associated increase in sedimentation, and an increased capacity to retain contaminants in accumulated muds (French 2001).

Contamination is a concern within, and downstream from, areas of high human use (RL&L 2000, Anders *et al*. 2001, UCRRP 2002). The Lower Mainland area of the Fraser River is home to more than two million people, diverse industrial activities and many farms, suggesting potential pollution problems (Lane and Rosenau 1995, RL&L 1996b).

Although these effects have not been well studied in the lower Fraser River (RL&L 2000), the pollution of sturgeon foraging-habitat by human activities has been reported in Europe (Rochard *et al*. 1990). Sturgeon with access to marine derived nutrients (i.e. salmon and eulachon runs) may not be exposed to the same contaminant loads as those that rely solely on resident in-stream food sources.

White sturgeon captured in the middle Fraser River (downstream of pulp mills) have contained contaminants including mercury, dioxins, furans and coplanar PCBs (MacDonald *et al*. 1997). Sampled levels ranged from 0.16 – 1.44 $mg.kg^{-1}$ WW in liver and 0.18 to 1.42 $mg.kg^{-1}$ in white muscle in six fish collected near Prince George and Williams Lake. The concentration of mercury in white muscle and liver tissue of two fish exceeded the provincial tissue residue criteria for people who consume low quantities of fish, 0.5 $mg.kg^{-1}$ WW (Pommen 1989). In all six fish the levels exceeded the maximum recommended for people with high weekly consumption rates (0.1 $mg.kg^{-1}$). Much lower background values were measured in other fish species from uncontaminated lakes (0.08 – 0.26 $mg.kg^{-1}$ WW). In the white sturgeon the concentrations of polychlorinated dibenzo-*p*-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and coplanar PCBs (expressed as 2,3,7,8-tetrachorodibenzo-p-dioxin toxic equivalents, TCDD TEQs) ranged from 22.75-61.8 in liver, 0.54-3.87 in white muscle, and 17.6-114 in red muscle. Many of the red muscle and liver samples exceeded the Health Canada working guidelines of 15-30 ppt 2,3,7,8-TCDD TEQs for the protection of human health (1990). Although this study was related to human health issues, the authors noted that the observed levels of contaminants may have constituted a threat to the health and vitality of sturgeon populations in the Fraser River downstream of Prince George (SP2), based on the mortality observed in the developing embryos of other species (Walker *et al*. 1991 and 1992, Spitsbergen *et al.* 1991).

Contamination is also a potential concern in the upper Columbia and Kootenay rivers (Duke *et al*. 1999, Anders *et al*. 2001, UCRRP 2002). Giorgi (1993, as cited by UCRRP 2002) sampled the lower Columbia River and noted that contaminated sediments or bioaccumulation of contaminants in prey could impact reproductive success or survival of juveniles. Contaminant sources in the Columbia River drainage include pulp mills, smelting and refining operations, abandoned mines, tailing dumps, farms and sewage discharges (UCRRP 2002). Although many operations have made efforts to decrease inputs over the years, the effects of current discharges and the legacy of contaminants is unknown.

Protection/ownership

White sturgeon are subject to protection from harmful alteration, disruption or destruction of fish habitat provided by Section 35 of the federal Fisheries Act. At the provincial level, the mainstems of the Fraser, Stuart and Thompson rivers are listed as protected rivers under Section 4 of the Fish Protection Act, which prevents the construction of bank to bank dams. The waters inhabited by white sturgeon in Canada are owned by the crown; however the use of water is licensed, including use for hydro power.

BIOLOGY

General

The white sturgeon is a long-lived species. Growth, age of maturity, and spawning intervals vary with location and sex. Sexually mature adults gather in aggregations to broadcast spawn during spring and early summer. Fertilized eggs fall to the bottom and adhere quickly to the substrate. Embryonic development under controlled conditions has been studied for culture purposes (Wang (1985) and Beer (1981), cited in Conte *et al*. 1988). At 15^{o} C eggs hatch in 6.5 days into larvae. Yolk-sac larvae go through a dispersal period where they move vertically and swim or drift with the current for about five or six days in the lab (Brannon *et al.* 1986 and Conte *et al*. 1988). The dispersal period may be considerably shorter under natural conditions as larvae may actively select particular velocities (Perrin *et al.* 1999). Larvae are most vulnerable to predation during dispersal (Hildebrand *et al*. 1999). After the dispersal phase larvae become negatively phototaxic and hide in the substrate during daylight. At 15^{o} C the yolk sac is absorbed around 12 to 14 days of age and the larvae begin to actively feed during daylight (Conte *et al*. 1988). About 20 to 30 days post-hatch, larvae metamorphose into fry (young-of-the-year). Around 55 days they orient to the current and swim freely exhibiting diurnal movement toward the surface at sunset and descending to the bottom at sunrise.

In the following sections, reported data on age characteristics are from age analyses using a small cross-section of the leading right pectoral fin ray. This is the most practical and reliable ageing method studied (Brennan and Cailliet 1989). Age estimates are less accurate for slow growing fish in colder systems or in regulated rivers with a less defined growing period. In these cases, true age can be underestimated because the growth rings form close together. This is a known problem for white sturgeon in the Kootenay and Columbia rivers (UCRRP 2002, Paragamian and Beamesderfer 2003). Under-aging may be a problem in all white sturgeon populations as the bias increases with age (Paragamian and Beamesderfer. 2003). Under estimating age in demographics such as age of sexual maturity and generation time would increase the risk of extirpation.

Reproduction

Length-frequency distributions for populations and age analyses indicate regular recruitment is occurring in the mainstem Fraser River, SP1-3 (RL&L 2000 and Yarmish and Toth 2002). Populations in all regulated systems (Nechako, Columbia and Kootenay rivers, SP4-6) are undergoing an extended recruitment failure (RL&L 2000, Hildebrand *et al*. 1999, Duke *et al*. 1999). The Nechako River population is aging with few fish younger than 30 years of age (Fig. 6). Recruitment reconstruction (Korman and Walters 2001) indicates recruitment declined slowly as the Nechako Reservoir filled; it then dropped suddenly in 1964 and has failed since 1967 as flow regulation impacts took effect (S. McAdam pers. comm.). Regular spawning events continue to be documented in the Canadian portion of the Columbia River; however, age structure analysis shows that recruitment began to decline in 1969 and has failed completely since 1985 (RL&L 1994). Maximum operating level for HLK was achieved in 1969 and Revelstoke Dam was completed in 1984. Studies on the Kootenay River indicate recruitment has been severely constrained since 1972, the year Libby Dam became partially operational (Duke *et al*. 1999).

In the Fraser River, age of sexual maturity increases from the lower river to the upper river (RL&L 2000). Below Hell's Gate some females may spawn as young as 18 and males at 14 years of age (Semakula and Larkin 1968). The preliminary age estimate for first spawning in females in the mid-river population is late 20s; males could be younger than 20 years of age. As yet data are limited on the upper Fraser population but J. Yarmish (Lheidli T'enneh First Nation, pers. comm.) believes they are late maturing and may not reach maturity until about 30 years of age. In the Nechako River system, females may not reach maturity until their late 40s, or older, and males may not spawn until their early 30s (although this is a slow growing subpopulation, this estimate may be skewed by the lack of younger fish in the population). In the Columbia River, females may mature as early as 27 years of age and males may start to mature at 16 (RL&L 1995). In Kootenay River females, the earliest spawning may occur is at age 22 and for males at 16 (Duke *et al*. 1999).

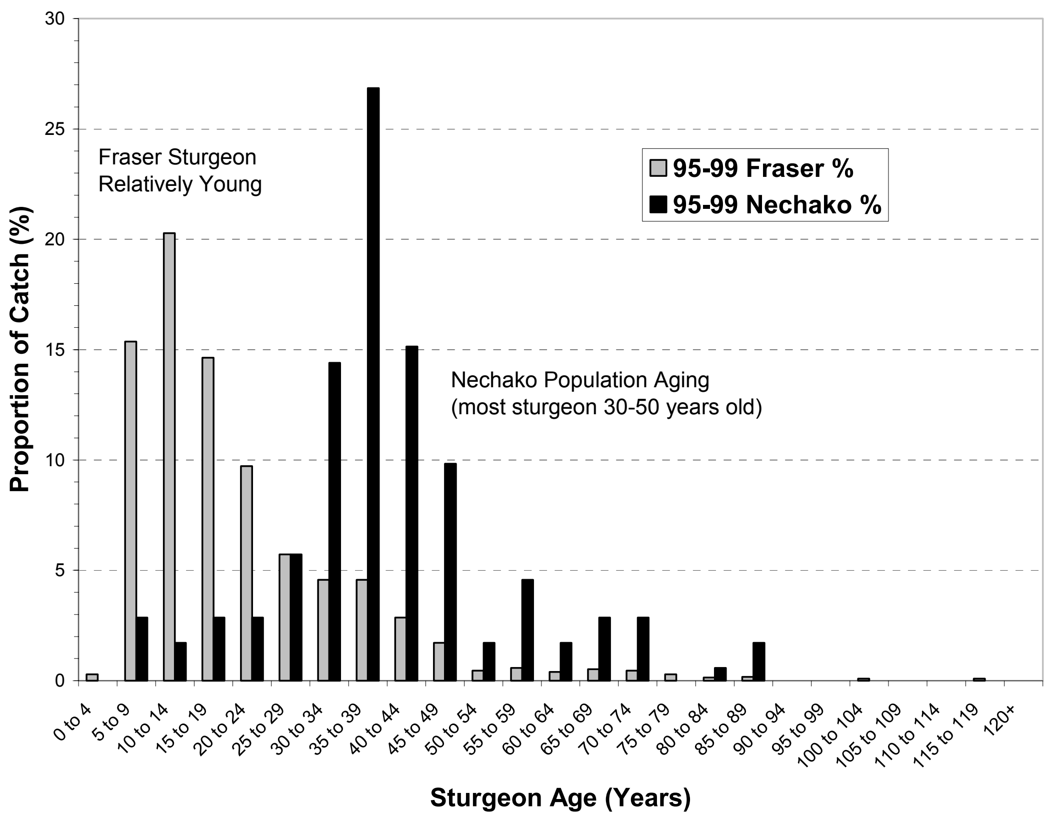

Figure 6. Comparison of age structure in surveys from mainstem Fraser River and the Nechako River (RL&L 2000). A similar age shift has occurred in the upper Columbia and Kootenay groups.

Generation time (average age of parents of the current cohort) in the lower Fraser River appears to be around 30-35 years; in the mainstem downstream of the Nechako River it seems to be in the range of 35 to 40 years of age, while in the Nechako River system the natural generation time could be 40 years. J. Yarmish (pers. comm.) estimates that it is in the range of 40 years in the upper Fraser River, but data are still limited. In the Columbia River, generation time is estimated at 30-35 years (C. Spence, B.C. Ministry of Water, Land and Air Protection, pers. comm.). The Kootenay fish appear to have a generation time of around 30 years (C. Spence pers. comm.). Generation times are roughly estimated based on age analyses conducted to date. Another factor that may affect estimates is the possibility of reproductive senescence (S. McAdam pers. comm.). Currently, the average age of adults in the three regulated systems lacking recruitment is greater than would be expected in a natural situation; this also affects the accuracy of the estimate for these populations.

Studies by Perrin *et al*. (1999 and 2000) in the lower Fraser River indicate spawning occurs in the spring or early summer (May to July) at water temperatures between 11.3^{o} and 18.4^{o} C, either at the peak of the freshet or as flows decline. In the upper Columbia River spawning events occur at temperatures 14^{o} to 21^{o} C (Hildebrand *et al*. 1999). Spawning in the Kootenay River population has occurred between 7^{o} and 17^{o} C. Sticky eggs are dispersed in fast flowing water, which prevents the eggs from clumping together and smothering (Perrin *et al*. 2000), and disperses them downstream. Scott and Crossman (1973) reported that fecundity varies with female size and can be as high as 4 million eggs in the largest spawners. Less than 0.1% will survive their first year (Columbia River Investigations webpage).

Data from Fraser River fish examined by RL&L (2000) showed the adult sex ratio was skewed to males and varied from 4 - 4.5:1 below Hell's Gate, to 7.6:1 in the middle Fraser, and 2:1 in the Nechako. In the Columbia River, current sampling (B.C. Ministry of Water, Land and Air Protection, unpubl. data) indicates the sex ratio is 1.35 males per female (n=94). In the Kootenay River the sex ratio was assumed to be equal, as reliable data are not available (Paragamian *et al.* in prep). There are no sex ratio data for upper Fraser River sturgeon. Adults survive spawning but do not spawn every year. Limited data from an earlier study indicated intervals between spawning in the lower Fraser River vary from 4 to 9 years (Semakula and Larkin 1968). In the Fraser River study, fewer than 10% of the females and 12% of the males examined in the adult size class were in the late reproductive stages (n=117), indicating that the proportion of reproductively mature individuals in a given year is quite low. The number of female spawners each year in the lower Fraser River is probably less than 100 (M. Rosenau, B.C. Ministry of Water, Land and Air Protection, pers. comm.). In the Nechako population the situation is dire; there are likely fewer than 15 female spawners per year at the present time. Sex maturity data on the Columbia River indicate that 4% of females would be capable of spawning in a particular year; in theory 14 -20 females may spawn each year, but the actual number is probably less (Hildebrand *et al*. 1999). The rate of spawning maturity is lower than seen in the mainstem Fraser River and may make recovery of Columbia River white sturgeon more difficult.

Survival

In impounded systems, the decrease in spring flows due to flow regulation is considered the major issue (Duke *et al*. 1999, Korman and Walters 2001). Kohlhorst *et al*. (1991, as cited in UCRRP 2002) reported that the strength of sturgeon year classes was positively correlated with discharge volume, and Anders and Beckman (1993, as cited in UCRRP 2002) related high spring flows to the amount of available spawning habitat, spawning success and rate of recruitment. Additionally, a lack of flushing flows can cause fine sediments to build up and decrease egg survival (Beamesderfer and Farr 1997, Duke *et al*. 1999, Korman and Walters 2001), food production (Duke *et al*. 1999) and juvenile habitat (Beamesderfer and Farr 1997, Duke *et al*. 1999, Korman and Walters 2001). The compounded effects of incremental increases in several mortality factors during early development may be enough to explain recruitment failures in the upper Columbia River (UCRRP 2002).

Flow diversion and impoundment have reduced turbidity, particularly in the Columbia and Kootenay rivers (Duke *et al*. 1999, Hildebrand *et al*. 1999, RL&L 2000, UCRRP 2002). Studies have predicted that increased water clarity may reduce the effectiveness of foraging by adults, change spawning behaviour and increase predation on sturgeon eggs and juveniles (Hildebrand *et al*. 1999, RL&L 2000, Gadomski *et al*. 2001, UCRRP 2002, Perrin *et al.* 2003).

Korman and Walters (2001) used an instantaneous natural mortality rate of 0.1 for the Nechako River in their model, based on Fraser River sampling data. The authors indicate that the estimated mortality is high for such a long living animal, unless mortality rate drops off very sharply for older, extremely rare fish. Korman and Walters (2001) gave three additional possibilities for the apparent high mortality: recruitment in the lower Fraser may be increasing (older fish may be rare due to poor recruitment following the peak of the historical fishery); larger, older fish may be less vulnerable to sampling; and the age of older fish may be underestimated. Another explanation for the apparent high mortality may be that relatively few fish actually achieve great age and size (Sulak and Randall 2002). Semakula and Larkin's (1968) age composition analysis for Fraser River white sturgeon also indicated a high total mortality rate (> 0.1). Most of their sample came from commercial salmon by-catch, and they indicate that gillnet mesh sizes likely biased the size and age of sturgeon captured. None of the fish in their study were aged at > 71 years of age, but they suggest that the presence of very large, old fish in the Fraser River could indicate a mortality rate around 0.05. Duke *et al.* (1999) estimated a mortality rate of 0.37 for Kootenay River sturgeon. RL&L (1994) used a natural mortality rate of 0.06 in calculations to determine the rate of decline for the upper Columbia River.

Environmental effects on physiology

Preliminary work on the lower Columbia River (Foster *et al*. 2001) indicates certain chemicals, such as organochlorides, chlorinated pesticides and PCBs may be contributing to population declines in areas subject to this type of contamination. Early data from this study indicate potential contaminant effects on plasma androgen concentrations and the induction of liver enzymes, and that contaminants may also be involved with reduced condition factor and altered gonad development.

Temperature effects may play a role in recruitment problems experienced in impounded rivers. Larval survival is optimal at 14-16^o C and decreases below 10^o and above 20^o C (Wang 1985). At the only known spawning site for upper Columbia River fish (the Pend d' Oreille River confluence; UCRRP 2002), water temperatures often reach 21^o C or higher during the spawning season, well above 18^o C where mortalities increase and abnormalities occur (Conte et al. 1988; Hildebrand *et al*.1999). Temperatures below HLK Dam tend to be warmer in winter and cooler in summer than before dam construction (UCRRP 2002). Changes to the natural temperature regime may affect juvenile survival by altering bioenergetic requirements (for example, by increasing metabolism at a time when food resources are limited).

Another water quality parameter that may impact larval survival, particularly in impounded rivers, is total dissolved gas pressure (TGP) (Counihan *et al*. 1998). Spills from dams can result in TGP levels >125% (Hildebrand *et al*. 1999). Conte *et al*. (1988) recommended a nitrogen gas pressure for cultured fish at <110%, which is now the standard. The swim-up stage following hatch may be the most sensitive period to gas bubble trauma (GBT) as larvae may be present near the surface where hydrostatic pressure can not compensate for excess TGP (Hildebrand *et al*. 1999). Apart from direct mortality, there is a potential for sublethal effects as the presence of gas bubbles in the head results in positive buoyancy and behavioural changes, which may increase vulnerability to predation (Counihan *et al*. 1998).

Movements/dispersal

In the Fraser River, movements related to spawning typically occur in the fall or in the spring to areas at, or near, suitable spawning habitat (RL&L 2000). Fall migrations to overwintering areas were sustained unidirectional movements, followed by a period of low activity. This period typically lasted from October to March. RL&L (2000) also noted a defined movement in spring to feeding areas throughout the Fraser River. Direction, distance and timing of this movement varied with food availability. In the upper Fraser River some individuals moved more than 30 km to suspected overwintering and feeding areas (Yarmish and Toth 2002). Kenney Dam is thought to be located at the upstream range of the historical distribution of sturgeon in the Nechako River and is not believed to be a migration barrier, although drastically lower flows in the section between Kenney Dam and the Nautley River (the outflow of Fraser Lake) may impact sturgeon use (S. McAdam pers comm.) and possibly food supply.

In the Columbia River, defined seasonal movements have not been identified; localized movements occur between adjacent high-use areas (Hildebrand et al. 1999). Movements to nearby shallower areas, associated with feeding, occur during the spring and summer. Limited movements downstream into the U.S. do occur, but have not been observed beyond the town of Kettle Falls, which is located just south of the border (Hildebrand *et al.* 1999; RL&L 1995). Similarly, a limited number of fish tagged in Lake

Roosevelt have been recaptured upstream during sampling operations in Canada (B.C. Ministry of Water, Land and Air Protection, unpubl. data). Long distance movements, in the late fall to overwintering habitat, have been monitored in the Kootenay River system (Apperson and Anders 1991). In this system white sturgeon regularly move back-and-forth across the British Columbia-Idaho border, to take up positions in deep holes in the mainstem or in Kootenay Lake.

Dams have formed migration barriers in the Columbia River (Fig. 3), blocking movements of individuals between habitats necessary for various life history stages (UCRRP 2002), such as migrations to spawning or feeding habitats (Rochard et al. 1990, Beamesderfer and Farr 1997). Using modeling, Jager *et al*. (2001) hypothesized that habitat fragmentation could significantly increase the extinction risk of sturgeon populations compared to non-fragmented populations.

The potential for natural dispersal to re-establish extirpated populations or bolster declining populations isolated above or between dams is limited. Natural dispersal from the lower Fraser River upstream to the river system above the barrier at Hell's Gate is unlikely. Tagging studies upstream of Hell's Gate indicate that areas of rapids, fast canyon sections and long shallow glides probably inhibit movement between various sections of the river (RL&L 2000). Genetic information (Nelson *et al*. 1999, Pollard 2000) also supports the demographic separation of white sturgeon from these areas. Columbia River fish are known to use the marine environment extensively and a few tagged fish picked up in the lower Fraser River do not have numbers from the local tagging program (T. Nelson, LGL Ltd., pers. comm.). Lower Fraser River fish also make some use of the marine environment (Veinott *et al*. 1999). However, mitochondrial DNA comparisons of fish from the two rivers indicate that they are genetically different (Brown *et al*. 1992) and that straying or dispersal between systems is low. For instance, Brown *et al.* (1992) found heteroplasmy was higher in Fraser River fish (54%) than in Columbia River (25%) fish ($\chi^2 = 13.33$, $P < 0.001$). Restriction site diversities at the population level (K_c) were 0.687 for the Fraser and 0.362 for the Columbia. Mean diversity in mtDNA length variation within individuals (K_b) was significantly higher for the Fraser River (0.223 ± 0.024) compared to the Columbia (0.127 ± 0.27) population (Student's $t = 2.639$; d.f. = 172, $P < 0.01$).

Nutrition and interspecific interactions

White sturgeon eat a variety of organisms from benthic invertebrates like crayfish, shrimp and clams to fish such as lamprey, salmon, eulachon and smelt (Semakula and Larkin 1968; Lane and Rosenau 1995, Echols 1995). Smaller sturgeon tend to eat smaller invertebrates, while larger sturgeon consume mainly fish. White sturgeon will readily take live prey as well as carcasses (Lane and Rosenau 1995).

Prior to dam construction on the Columbia River, white sturgeon likely relied on runs of spawning salmon as an important seasonal food source (Hildebrand *et al*. 1999, UCRRP 2002). The elimination of this regular supply of marine derived nutrients has likely had an effect on ecosystem productivity as well. The loss of salmon runs may have implications for sturgeon spawning frequency and fecundity (Hildebrand *et al*. 1999). The construction of dams has also disrupted nutrient transport downstream further reducing productivity and altering the food web (Ashley *et al*. 1999, UCRRP 2002). The result is a decline in several species of native fishes and invertebrates affecting prey availability for all life-history stages of sturgeon (Duke *et al*. 1999). Limited food supply for juveniles has been predicted to increase foraging time to meet energetic requirements and result in increased vulnerability to predation (Korman and Walters 2001).

Food supply and, possibly, sturgeon reproductive capability, throughout the Fraser River may have been periodically affected by low salmon cycles. Productivity in the lower river has also been affected by the drastic decline in the spring eulachon run since 1994 (Eulachon Research Council 1998).

Humans are the only significant predator of sturgeon adults in riverine systems (UCRRP 2002), although various species of fish prey on sturgeon eggs and juveniles (Anders *et al*. 2001, UCRRP 2002). Following impoundment, predation may rise with increasing predator numbers due to more stable hydraulic, temperature and water quality conditions. Populations of native predators such as suckers (*Catostomus* sp.) and northern pikeminnow (*Ptychocheilus oregonensis*) increased in the Columbia River system following impoundment (UCRRP 2002). The illegal introduction of non-native walleye (*Stizostedion vitreum*) into Lake Roosevelt has also affected the Canadian portion of the Columbia River mainstem, as these fish make annual feeding migrations upstream during June to August (UCRRP 2002). Although this migration coincides with the downstream dispersal period for larval white sturgeon, it is not known whether walleye have an impact on larval abundance.

Behaviour/adaptability

White sturgeon are specifically adapted to the large river systems of western Canada and the U.S. where they have evolved for millions of years. Their size and opportunistic behaviour have allowed them to take advantage of widely scattered seasonal resources (UCRRP 2002). Dam construction has blocked movement and restricted these fish to river fragments and reservoirs that in some cases no longer provide the full array of habitats or conditions necessary to complete their life cycle. Flow regulation has limited or changed cyclical hydrological and temperature patterns that are believed to have provided behavioral cues at appropriate spawning and rearing conditions (Beamesderfer and Farr 1997, RL&L 2000, Korman and Walters 2001, UCRRP 2002). The long lifespan of sturgeon also suggests that they have a limited ability to adapt to rapid environmental changes.

POPULATION SIZES AND TRENDS

General information

Birstein (1993) summarized the status of 27 Chondrostean species (sturgeon and paddlefishes) worldwide, based on the literature. Two species had populations that were considered extirpated and 13 species were classified as endangered, using IUCN categories or, for American species, the U.S. Office of Endangered Species categories. The 2002 IUCN Redlist lists 30 species, 17 stocks and two populations: 6 species and 2 stocks are Critically Endangered; 11 species, 10 stocks and one population are Endangered; 11 species, 3 stocks and one population are listed as Vulnerable; 2 stocks are shown as extinct; 2 species are shown as Near Threatened (including white sturgeon).

Declines have likely occurred in all Canadian populations of white sturgeon, and recruitment appears to be weak or lacking in half of the populations (Duke et al. 1999, RL&L 2000, Korman and Walters 2001, UCRRP 2002). In some cases, e.g. lower Fraser River, declines may be reversing as suggested by a more natural age distribution (RL & L 2000). Although the age distributions of some Fraser River populations indicate steady recruitment (Fig. 6), they may not have as high a proportion of immature fish as in the lower Columbia River, below Bonneville Dam. This population appears to be the largest and most healthy (USFWS 2001), with the proportion of immature fish estimated at 95% (DeVore *et al*. 1999, Anders *et al.* 2001). Even in the lower Fraser River, the proportion of immature fish in the sample is closer to 85% (Nelson 2002) indicating full recovery may not have occurred. In the Nechako, Kootenay and upper Columbia rivers age distributions are strongly skewed to older fish (Duke *et al.* 1999, RL&L 2000, UCRRP 2002). RL&L (2000) found very few fish in the Nechako River younger than 30 years (Fig. 6), in spite of a directed effort at younger age classes. Most Nechako River sturgeon were between the ages of 31 and 50, and the most common group was 31 to 45 years of age (60.3% of the catch). No sturgeon younger than 17 years old have been sampled in the upper Columbia River; most are older than 34 years of age. All naturally produced fish in the Kootenay River are older than 20 years of age.

Fragmentation has occurred in both the Columbia and Kootenay rivers (Hildebrand *et al*. 1999, UCRRP 2002). There may still be a very limited exchange in a downstream direction past the dams. UCRRP (2002) reported that dams have fragmented Columbia River sturgeon into at least 30 separate reaches (Fig. 3). White surgeon in five of the seven reaches, in Canadian waters, are considered functionally extirpated (fewer than 80 fish with no evidence of successful spawning). Genetic studies have shown that Fraser River populations are relatively isolated from each other (Pollard 2000, RL&L 2000, Smith *et al.* 2002). Genetic diversity decreases in an upstream direction and there appears to be very limited movement between populations (Nelson *et al*. 1999, Anders *et al*. 2000, Pollard 2000).

Information on the potential for sturgeon populations to act as population sources (which produce excess juveniles that may disperse to other areas) or sinks (which attract immigrants because the rate of recruitment is lower than the mortality rate) is not available. These sorts of population dynamics would only be possible in the Fraser River drainage where normal movement can occur. The lower Fraser River may effectively act as a sink since it is not likely to return immigrants to the rest of the river, due to the upstream barrier at Hell's Gate; it could act as either a source or sink for other populations on the Pacific Coast. However, movement between river systems is considered rare. Because upstream populations consist of few individuals that have not been shown to intermingle with other populations, their capacity to act as sources is thought to be low.

Historical data on fluctuations in population size or density are generally lacking. Studies in all systems are relatively recent and deal only with the current situation (see Table 2). Some populations may have naturally low numbers, as exploitation does not appear to be a factor and habitat remains largely intact. Based on the commercial statistics (Fig. 7) for the lower Fraser River, large declines occurred in the past related to overfishing.

Table 2. Estimated population size with density of individuals and the number of adult individuals.

Population	No. of individuals	95% Confidence interval[7]	No. of Adults	Density (indiv./ km^2)[10]	References
SP1[1]	47,431[4]	44,026 - 50,836	7,650[8]	94.9	Nelson *et al*. (2002)
SP2	3,745[5]	3,064 - 4813	749[9]	3.8	RL&L (2000)
SP3	815[6]	677 - 953	185[9]	11.6	Yarmish & Toth (2002)
SP4	571[5]	421 - 890	457[9]	1.2	RL&L (2000)
SP5 Lower[2]	1,427	1,295 - 1580	942	3.3	L. Porto (pers. comm.)[2, 3]
SP5 Upper[3]	42	26 - 87			
SP6	760	430 - 1090	752	1.6	C. Spence (pers. comm.)
TOTAL	54,791	49,939 – 60,249	10,735		

[1]SP1 is Fraser River mouth to Yale.
[2]SP5 Lower is stretch of river between HLK dam and the U.S border.
[3]SP5 Upper is above HLK dam.
[4]Estimates are for fish > 40 cm fork length
[5]Estimates are for fish > 50 cm fork length
[6]Estimates for fish > 70 cm fork length
[7]Confidence interval applies to number of individuals.
[8]Estimate of individuals ≥ 150 cm fork length
[9]Based on proportion of total captures in adult size class of >150 cm total length used in RL&L (2000).
[10]Density estimates calculated using area of occupancy data provided by S. Cheesman, B.C. Ministry of Sustainable Resource Management Victoria.

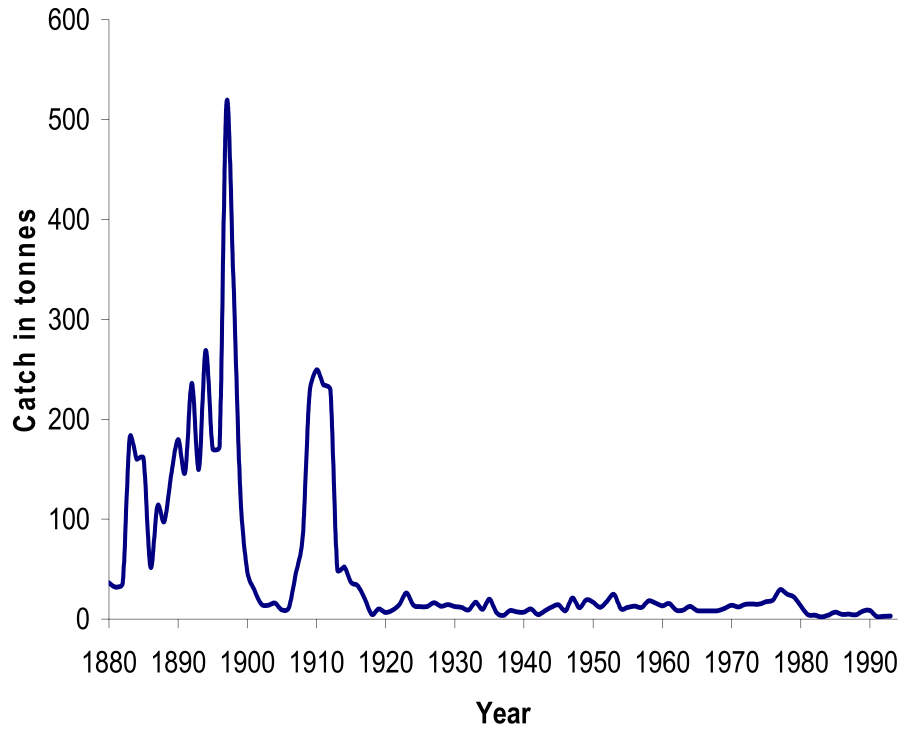

Figure 7. Historical commercial catch statistics for white sturgeon on the Fraser River, 1880 to 1993 (Figure taken from Echols 1995).

Lower Fraser River (SP1)

Monitoring has been underway since 1985 and has been more intensive since 1995. Techniques used have included radio telemetry, commercial and recreational catch statistics, mark-recapture and life history studies (e.g. Lane 1991, Swiatkiewicz 1992, RL&L 2000). Total population size for fish > 40 cm fork length was estimated by Nelson *et al*. (2002) for the area from the mouth of the river to Yale. A great deal of effort went into this mark/recapture study over 2 years (more than 100 volunteers captured tagged and released over 10,000 sturgeon). Because Nelson *et al*. (2002) did not assess age or maturity, the number of adult individuals of both genders was calculated by using the proportion of adult individuals from RL&L (2000) (0.675) and applied to the Nelson *et al*. (2002) population estimate (Table 2).

Good historical information on population trends is not available. Echols (1995) reviewed the available data (1983-94) on the First Nations fisheries, but commented that these data were collected sporadically and only approximate harvest estimates could be calculated. Estimates of monthly catches fluctuated widely from 0 during the winter to over 1000 fish during summer months, in some years. The highest portion of the total catch was observed in non-tidal waters from Mission to Hope. The largest database is commercial catch statistics dating back to 1880 (Semakula and Larkin 1968). Fraser River white sturgeon were an important commercial species in the late 1800s and early 1900s (Echols 1995). After 1880 the annual harvest increased by an average of 27 tonnes per year, peaking at 517 tonnes in 1897, before falling drastically to 20 tonnes in 1905 (Echols 1995; Fig. 7). A short recovery occurred soon after, but after 1917 the annual harvest rarely exceeded 15 tonnes prior to the closure of the fishery (Echols 1995; Fig. 7).

This pattern implies a substantial decline in the population due to the fishery. However, interpretation of commercial harvest data is problematic (Echols 1995). Changes in fishing patterns and lack of consistency make comparison of the historical catch to more recent catches difficult. Although there was a directed fishery for sturgeon near the beginning of the 20th century (Echols 1995), for the next 80 years the commercial catch was incidental to the salmon fishery. It has only been since 1994 that retention of sturgeon by-catch has been prohibited. Commercial fishery data, which include green sturgeon, were collected by weight, not number of individuals, and data collection did not begin until many years after the inception of the fishery. Also poaching has been a consistent problem over the years leading to under estimation of the catch (Echols 1995). In spite of these difficulties, it is reasonable to conclude that there was a large decline in the white sturgeon population in the lower Fraser around the beginning of the 20th century similar to the coincidental decline seen in the Columbia and Sacramento rivers (Hanson *et al*. 1992, as cited in Echols 1995, UCRRP 2002).

The commercial fishery on the lower Columbia River peaked in 1892 (Craig and Hacker 1940), although the peak catch (2700 tonnes) was much higher than on the Fraser River (517 tonnes). White sturgeon populations in the lower Columbia River declined due to over fishing but have since increased and are now considered healthy (Beamesderfer and Farr 1997, USFWS 2001). In 2000, population numbers were estimated at more than 1.3 million fish in the unimpounded section of the river below Bonneville Dam (USFWS 2001, DeVore *et al*. 1999). The unimpounded section of the Columbia River is larger in area than the section of the Fraser River below Hell's Gate. Although the river length is similar (about 211 km below Hell's Gate and 230 km below Bonneville Dam), mean annual discharge for the lower Columbia at The Dalles is 5389 cms (U.S. Geological Survey) while the Fraser River at Hope has an average of 2724 cms (Water Survey of Canada). The 25-fold difference in population size suggests that the lower Fraser River has a smaller population than it could potentially support. This is supported by Semakula and Larkin's estimate of historical harvest, taken between 1892 and 1920 (about one generation time), which is six times the current estimate of biomass in the river downstream of Yale (Nelson *et al.* 2002). Even assuming that the unexploited population consisted of larger fish, on average, than found in the current sample, the decline is probably well over 50%.

Additional catch data are available that may identify occasional recruitment problems or fishing impacts (mortalities from incidental catch and/or poaching) on undersized fish in the lower Fraser River. Recreational angler catch-per-unit effort of sub-legal size fish (50 – 100 cm) fell from 0.34 to 0.17 fish per trip between 1985 and

1990 (Inglis and Rosenau 1994). Bennett *et al*. (1998) also reported a decline in the number of juvenile sturgeon caught from 1985 to 1993. In another study, standardized multi-panel gill nets set at the same site at the same time of year showed a similar reduction between 1985-87 and 1992-93 (Lane and Rosenau 1995). A comparison of the fish community in the lower Fraser between 1972-73 and 1993-94 also showed an apparent decrease in sturgeon abundance (Richardson *et al*. 2000). These studies all indicate a possible decline in juvenile density from the mid-80s to the late 90s.

During the summer/fall period of 1993 and 1994 an unexplained die-off of adult white sturgeon occurred (McAdam 1995). All dead fish observed were of reproductive age. The recovered carcasses (38) ranged in size from 2.16 to 3.86 m total length (mean = 3.18) and were primarily female. The age of the smallest fish was estimated at 27-30 years. Several potential contributing factors were investigated including pollution, disease, low oxygen levels, and elevated water temperatures. Post-mortem analyses and timing reconstruction did not reveal a definitive cause.

Middle Fraser River (SP2)

Monitoring has been underway since 1994. Techniques used have included radio telemetry, mark-recapture and life history studies (RL&L 2000). Length frequency and age distribution indicate that regular recruitment is occurring (RL&L 2000). Population estimate for fish > 50 cm FL is about 3800, but it is not possible to determine whether the number of sturgeon in this population has declined or remained stable over the last 3 generations. Recolonization from sturgeon populations in the lower Fraser River or the U.S. is unlikely due to the barrier formed by Hell's Gate (location of barrier supported by tagging and genetic studies). Recolonization from upstream would also be difficult, based on the minimal amount of downstream movement that has been detected.

Upper Fraser River (SP3)

Monitoring has been underway since 1997 (RL&L 2000, Yarmish and Toth 2002). Techniques used have included radio telemetry, mark-recapture and life history studies. Length frequency distribution of sturgeon is skewed towards smaller fish, indicating a fairly natural population structure. There is no habitat information or fishery data to suggest potential population declines in this area. Abundance is lower (Table 2); however, the river is smaller and there are fewer returning salmon to provide marine derived nutrients.

Nechako River (SP4)

Monitoring began in 1982 and became more intensive in 1995 (Dixon 1986, RL&L 2000). Techniques used have included radio telemetry, recreational catch statistics, mark-recapture estimates and life history studies. This population has declined to fewer than 600 individuals (RL&L 2000). From age and size data it is clear that there has been very little recruitment since the 1960s. RL&L (2000) found that length-frequency and age distribution is highly skewed to older individuals (Fig. 6). Very few fish less than 30 years of age were caught in spite of a directed sampling effort on this life stage. Only 4% of individuals sampled were less than 100 cm total length.

Korman and Walters (2001) developed a model to evaluate historical trends in recruitment and to predict natural population age structure, track possible changes in population size associated with recruitment failure, and predict population recovery rates if recruitment is reestablished. The model predicted age composition for data collected in 1982 and from 1995 to 1999, if a steep decline in recruitment was initiated in the early 1960s. This indicates a link to changes in the flow regime that occurred at that time. In another scenario, the authors attempted to fit age composition data, by using spawning season flows at Vanderhoof to simulate reproductive success, and obtained simulated age compositions very similar to those observed in 1982, but shifted by - 5 years for 1995-1999. The time lag could be explained if changes to channel morphology, subsequent to changes to the hydrological regime, are a contributing factor (S. McAdam pers. comm.). This scenario also predicted an increase in recruitment following flooding in 1976, which has not been observed. The authors hypothesized that it may take more than one year of adequate flow conditions to stimulate spawning. The model shows that the situation is complex and needs additional clarification.

The estimated number of adult females in the population is 150 (RL&L 2000, Korman and Walters 2001). Korman and Walters (2001) predicted a decline to 25 females by 2025 (an 83% decline) in the absence of a change in the rate of recruitment. (In the Nechako drainage, 25 years represents about half the current generation time.) It is important to note that immediate recruitment of juveniles into the population will not alter the prediction due to the minimum 25 year lag between recruitment and maturity (Korman and Walters 2001). The authors state that the model forecasts underscore the urgency for initiating population recovery efforts as soon as possible. The urgency is amplified by the understanding that only a small percentage of adult females are capable of spawning in any given year. The current number of spawning females that are available annually is probably between six and 15. To protect natural genetic variation, breeding programs for Columbia and Kootenay culture programs have stipulated a minimum of five or six different families each year, over the life of the program (currently expected to be >25 years). If recruitment is to be augmented through conservation fish culture, the numbers of reproductively mature fish available per year poses obvious field difficulties, and the longer the delay the fewer the females that will be available.

Upper Columbia River (SP5)

Monitoring has been underway since 1990 (Hildebrand *et al*. 1999, UCRRP 2002). Techniques used have included radio telemetry, recreational catch statistics, mark-recapture and life history studies (Hildebrand *et al*. 1999, UCRRP 2002). Population size estimates are provided separately for the populations above and below HLK Dam (Table 2). The estimate for the area below the HLK Dam is incomplete as it does not include the Lake Roosevelt reservoir, in Washington State. However, monitoring has indicated very little movement upstream across the international border, which suggests the sturgeon in Lake Roosevelt form a distinct population that may not mix with the sturgeon further upstream. Sampling in Lake Roosevelt has also been inadequate to accurately estimate the population, but numbers are thought to be low (Hildebrand *et al*. 1999, UCRRP 2002). Despite anecdotal reports to the contrary, efforts to confirm the occurrence of sturgeon in areas upstream of Arrow Reservoir have been unsuccessful to date (RL&L 1996b, Hildebrand *et al*. 1999).

Detailed information on trends in population size is not available, but there is strong evidence that recruitment has consistently failed for several decades. Extensive study has confirmed spawning at one location (UCRRP 2002). However, despite regular spawning events, age structure analyses have shown that recruitment began to decline in 1969, and has likely failed entirely since 1985 (RL&L 1994, Hildebrand *et al*. 1999). Changes in length-frequency distribution follow a similar pattern, with a dramatic reduction in the percentage of smaller fish in ongoing sampling programs (RL&L 1996*a*, Hildebrand *et al*. 1999, UCRRP 2002). Sampling in Lake Roosevelt, although less intensive, shows a similar recruitment failure pattern (DeVore *et al*. 1999, UCRRP 2002). Recruitment to the upper Columbia has failed to the point where continued existence of the population is at risk. Current data indicate that numbers will decline by an additional 50% within 10 years, 75% within 20 years and reach functional extinction (< 50 fish) around the year 2044 (UCRRP 2002).

Some movement of individuals downstream across the border into the U.S. has been observed during telemetry studies (UCRRP 2002), but appears to be rare. The fish upstream of the border, in Arrow Lakes and the mainstem below HLK Dam, may be more closely related to each other than they are to fish in the U.S., because a natural barrier on the U.S. side may have prevented upstream movement before it was backflooded by Grand Coulee Dam (Fig. 3). Whether the Roosevelt Lake population could act as a source population to provide new immigrants to Canada, if the Canadian portion of the population were extirpated, is doubtful as both groups appear to be suffering similar recruitment failures. White sturgeon in the Arrow Lakes Reservoir are physically separated from the fish downstream by the HLK Dam. There is a boat lock to move boaters around the dam and the possibility of entrainment through HLK; however, there is little evidence of movement between the two areas as only one fish has been caught in the lower Arrow Lake during the sampling work (UCRRP 2002). Most of the fish are concentrated in Upper Arrow Lake and have been monitored moving upstream towards Revelstoke or the Beaton Arm and the Incommappleux River (UCRRP 2002). Consequently, the probability is low that Arrow Lakes could be naturally recolonized.

Kootenay River (SP6)

Surveys began in 1977 and became more intensive after 1990 (Duke *et al*. 1999, Anders *et al*. 2001). Techniques utilized have included radio telemetry, recreational catch statistics, mark-recapture estimates and life history studies (Duke *et al*. 1999, Anders *et al*. 2001). Population size estimates provided in Table 2 are for fish on both sides of the Canadian border (Paragamian *et al*. 1997), as this is a transboundary group that moves freely between Canadian and American waters.

Detailed information on population trends is not available, but there is strong evidence of recruitment failure. Age analysis indicates natural recruitment of juveniles into this population began to decline in the mid-1960s (Partridge 1983, as cited in Duke *et al*. 1999), and has been extremely low and intermittent since 1972, at the time Libby Dam was constructed (Duke *et al*. 1999).

Duke *et al*. (1999) reported that recruitment failure was primarily due to flow regulation. Other possible contributing factors were additional loss and degradation of habitat (through dyking) and poor water quality. Because males spawn every 2-3 years and females about every five years, it is possible that there has been a shortage of females available for spawning in some years (Duke *et al*. 1999, Anders *et al*. 2001). In the few years when spawning has been documented, post-spawning mortality appears to be significant.

LIMITING FACTORS AND THREATS

White sturgeon are especially vulnerable to overharvest and changes in their environment due to their delayed age of maturation, slow growth and long life span (Birstein 1993, Echols 1995, UCRRP 2002). Vulnerability to overharvest has been well demonstrated by population crashes that occurred soon after periods of heavy fishing pressure on the Fraser and Columbia rivers around the end of the 19th century (Semakula and Larkin 1968, UCRRP 2002).

Sustainable Exploitation Rates (SERs) have been estimated for various sturgeon populations. SER was defined by Echols (1995) as: SER = (MSY) / (MSY + Escapement), where MSY (Maximum Sustainable Yield) is the maximum annual harvest that does not impede a stock's ability to sustain itself indefinitely. Rieman and Beamesderfer (1990) estimated an SER of 0.05 for the lower Columbia River. The authors felt that this was the maximum SER for long-lived fish species that have been extensively harvested in the past. It was also estimated that in such cases an SER of 0.15 would collapse the population. Currently, the harvest rate appears to be about 0.03 of the population for fish larger than 60 cm (0.225 or 40,000 fish in the legal size range of about 107 to 152 cm). In contrast, Lukens (1985) estimated an SER of 0.24 for the population in the free-flowing portion of the Snake River, in Idaho. Two other studies have attempted to estimate SER, but both authors acknowledged they were based on problematic assumptions – they assumed density independent recruitment from an unexploited stock, which was identified as unrealistic (Echols 1995). SER estimates in these studies were 0.13 (Fraser River; Semakula and Larkin 1968) and 0.32 (Columbia River; DeVore *et al*. 1993).

Currently there are no data available on mortality caused by either the recreational catch-and-release fishery or the by-catch in the commercial salmon fishery. These studies have yet to be done; funding is currently being sought to conduct catch-and-release mortality studies in the lower Fraser River. The mark-recapture study in the lower Fraser River suggests catch-and-release mortality is relatively low. Over 1100 fish have been recaptured in the lower Fraser River during the population assessment, many of them more than once (about 110), several in the same day, with no apparent harm (Nelson *et al.* 2002). A preliminary study on the First Nation's gill net fishery suggested a potential mortality of 10 - 14% on gilled sturgeon; the vast majority of the fish captured were in the 50 – 79 cm size range (T. Nelson pers comm.). Reported by-catch in the First Nation's fishery varied between 3 - 17 kept and 1435 – 2312 released during the last three years (B. Ennevor, Fisheries and Oceans Canada, pers. comm.).

Poaching activity in the lower Fraser River is a concern. The numbers of fish poached is unknown, but calls reporting the activity are received by federal and provincial enforcement officers on a regular basis. A recent article in a local sport fishing magazine (Pollon 2002) provides some information. Black market prices for sturgeon steaks are high at $7 to $10 per pound in Vancouver, B.C. At this price, a large sturgeon has considerable value. Some recent investigations have linked sturgeon poaching to marijuana grow-operations, raising concerns of serious criminal involvement. An organized poaching ring, known to be operating in the Pacific Northwest, has provided large quantities of white sturgeon caviar to retailers, much of it marketed to the public as beluga caviar (Waldman 1995).

Human activities also threaten and limit sturgeon populations through changes to habitat. Common forms of human development include the damming of rivers and flow regulation, construction of dykes, dredging of channels and gravel mining. Indirect effects include contamination from industry, farming and urbanized areas, and changes to the species composition of rivers.

Sturgeon populations on the Columbia, Kootenay and Nechako rivers have been impacted by dams (Duke *et al*. 1999, Hildebrand *et al*. 1999, RL&L 2000, Anders *et al*. 2001, Korman and Walters 2001, UCRRP 2002). Habitat changes associated with these dams appear to have severely limited sturgeon populations. The hypothesized effects of dams are wide ranging, including changes in: water quality, the natural flow regime, nutrient inputs, benthic habitats, and alterations to the make-up of aquatic communities (Duke *et al*. 1999, Hildebrand *et al*. 1999, RL&L 2000, Anders *et al*. 2001, Korman and Walters 2001, UCRRP 2002). Although it is clear that flow changes have had an important influence, there has been little agreement on the exact mechanisms linked to dams that are limiting sturgeon populations (Hildebrand *et al*. 1999, Anders *et al*. 2001, Korman and Walters 2001).

The mainstem of the Fraser River has not been dammed. However, sturgeon populations in this drainage, as well as those in the Columbia and Kootenay drainages, have likely been limited by human activities (Echols 1995, Duke *et al*. 1999, Hildebrand *et al*. 1999, Nelson *et al*. 2001, UCRRP 2002). In the lower Fraser River, dyking and channelization have been common practices to increase land available for agriculture and control flooding. Dredging of channels also occurs regularly to keep waterways navigable and to mine gravel. In addition, due to the amount of land that has been made impervious, run-off from urbanized areas can contribute to the contamination of waterways. Contamination of white sturgeon from pulp mill effluent in the Fraser River downstream of Prince George has occurred (MacDonald *et al*. 1997). Human activities also affect other species, including important prey, predators or competitors of sturgeon.

If not managed properly the new commercial aquaculture industry could also pose additional genetic, health and ecological risks to wild sturgeon populations. A provincial white sturgeon aquaculture policy is under discussion to address the issues. The concerns include: 1) containment and placement of facilities to ensure no wild contact with either fish or effluent; 2) security of facilities; 3) access to broodstock is scientifically based and does not impair recovery; and 4) sale of cultured fish, caviar or meat does not create a market for illegally caught wild sturgeon.

SPECIAL SIGNIFICANCE OF THE SPECIES

The scientific and appreciative values of this large, ancient species as part of our natural heritage can not be quantified. This white sturgeon is representative of an ancient lineage that is largely extinct and almost all of the remaining species are at risk. The white sturgeon was once a valuable commercial species and is still highly valued for societal and cultural reasons, both recreationally and traditionally. Some First Nations peoples have harvested white sturgeon for subsistence purposes since long before Europeans arrived (Echols 1995, Cadden 2000, UCRRP 2002). There are, however, very few data available on First Nations' fisheries, and none of it provides effort data for sturgeon alone because the catch data include salmon and steelhead as well as sturgeon. Data for the freshwater recreational fishery, in the lower Fraser River, indicated the number of permits issued per annum varied from about 1000 in 1986 to over 3000 in 1991 (permits to take sturgeon were no longer required after this period).

Even though the fishery in the lower Fraser River is catch-and-release, there is an active commercial guiding industry in this area. An internet search found over 20 guiding businesses offering sturgeon fishing outings at a range of about $300 to $1000 per day.

In 1998 white sturgeon were approved for commercial aquaculture in B.C. after Malaspina College, in Nanaimo, had successfully spawned several fish obtained from private ponds. These offspring became available in limited numbers to commercial growers. Future growth of the industry is, however, dependent upon the availability of a limited number of white sturgeon from the wild. Cultured white sturgeon are just beginning to reach the food market in the lower mainland. It is reasonable to assume that as the industry grows international trade in sturgeon products will develop.

EXISTING PROTECTION OR OTHER STATUS

On the U.S. side of the border, the Kootenai fishery has been closed since 1979 in Montana and became catch-and-release in Idaho in 1984. All harvest was prohibited in the Kootenai River beginning in 1990. In B.C., the section of the Columbia River downstream of HLK Dam became a catch-and-release fishery in 1993. In 1994, the recreational fishery in the rest of the province became catch-and release and retention of commercial by-catch of sturgeon was prohibited. Also in 1994, the fishery was totally closed in the Columbia system above HLK Dam and in the Kootenay system, in B.C. In Washington, the upper Columbia River fishery became catch-and-release in 1995. In 1997, the Canadian portion of the Columbia River downstream of HLK Dam was closed to all angling for sturgeon. The Nechako and its tributaries were totally closed in 2000. The upper Columbia, in Washington, was closed to sturgeon angling in 2002.

In September 1994, under the authority of the U.S. Endangered Species Act of 1973, the Kootenai River population was listed as endangered. Studies intended to further define ESUs in the U.S. are ongoing. The conservation status ranks for white sturgeon in adjacent jurisdictions are S1 in Montana, S1 in Idaho and S3 in Washington State. The IUCN lists white sturgeon globally as LR/nt (near threatened).

White sturgeon are listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and require an export permit issued by the exporting country in order to be moved across an international boundary.

Recovery processes are under way for all populations. Recovery efforts for sturgeon in the upper Columbia River and Kootenay River are closely coordinated with U.S. agencies. Completion of the recovery plan for the Nechako River population is targeted for 2004. The upper Columbia River plan is complete. Recovery planning for populations in the Fraser River is in the preliminary stages. The development of the Kootenai River white sturgeon recovery plan (completed in 1999) was led by the U.S. Fish and Wildlife Service and it is now in the implementation phase. Recovery efforts have brought together: provincial and local governments; First Nations; experts in sturgeon biology, fish culture, recovery of endangered species, effects of hydroelectric dams, and habitat restoration; public and industrial stakeholders; and U.S. regulatory and tribal agencies for transboundary rivers. In an attempt to compensate for failing recruitment, an experimental conservation culture facility has been established for the Kootenay and upper Columbia rivers' populations at Fort Steele, B.C. This facility was originally developed as a backup to the facility operated by the Kootenai Tribe of Idaho, at Bonner's Ferry, Idaho, for Kootenai (Kootenay) River sturgeon, and now includes upper Columbia River white sturgeon. The first release of Kootenai (Kootenay) River juveniles occurred near Bonner's Ferry in the fall of 2000. The current release site is in the Kootenay River near Creston, B.C. The first upper Columbia River juveniles were released in 2002 from a temporary facility at Hill Creek, B.C. The recovery of these populations is a long-term commitment; significant adult recruitment of naturally spawned fish and the development of a stable age distribution may take 50 years, or more.

SUMMARY OF STATUS REPORT

White sturgeon are found in the Fraser, Columbia and Kootenay river systems of British Columbia, in Canada. This species has suffered population declines due to historical overfishing and the loss of habitat quality and quantity. Genetic, life history and movement data have shown that the province contains six populations: three in the mainstem Fraser River (the lower, middle, and upper Fraser River) and one in a major tributary (Nechako River); one in the Columbia River system and another in the Kootenay River system. The lower Fraser River fish have not recovered from overfishing that occurred at the turn of the last century. Three populations, found in impounded rivers, are at serious risk due to a continued failure of any offspring to reach the adult stage. Nearly all of the sturgeon in the Nechako, Columbia and Kootenay river systems are aging adults. As these fish die, they are not replaced by younger fish. Their long life span may be the only reason white sturgeon are still found in some parts of their historical range. Recovery teams have been formed to deal with recruitment failures. The Kootenai Recovery Plan (developed under the auspices of the Endangered Species Act, in the U.S.) is in the implementation phase. The recovery plan for upper Columbia River white sturgeon is complete, while the Nechako River plan is expected to be completed in 2004. Recovery planning for these populations has brought together provincial and local governments; First Nations; experts in sturgeon biology, fish culture, recovery of endangered species, effects of hydroelectric dams, and habitat restoration; public and industrial stakeholders, and include U.S. regulatory and tribal agencies, for the Columbia. Work on the recovery plan for the Fraser River groups is in the early stages.

TECHNICAL SUMMARY
(by population)

Acipenser transmontanus

White Sturgeon — Esturgeon Blanc

Range of Occurrence in Canada: B.C.

Proposed nationally significant populations (See Fig. 5 for range of occurrence*):*

SP1: Lower Fraser River - downstream of Hell's Gate (km 211)
SP2: Middle Fraser River - Hell's Gate to Prince George (km 212 to km 790)
SP3: Upper Fraser River - upstream of Prince George (km 790 to 1042)
SP4: Nechako River (tributary of Fraser River)
SP5: Upper Columbia River
SP6: Kootenay River

Extent and Area Information	**SP1**	**SP2**	**SP3**	**SP4**	**SP5**	**SP6**
• *Extent of occurrence (EO)* in km² *(See* Table 1)	2,360	9,700	2,970?	10,720	12,190	6,780
• *Trend in EO*	Stable?	Stable?	Stable	Decline	Decline	Decline
• *Are there extreme fluctuations in EO?*	No	No	No	No	No	No
• *Area of occupancy (AO)* in km² (*See* Table 1)	500	980	70	470	440	480
• *Trend in AO*	Decline	Stable?	Stable	Decline	Decline	Decline
• *Are there extreme fluctuations in AO (> 1 order magnitude)?*	no	No	No	No	No	No
• *Number of extant locations*	1	1	1	1	3	2
• *Trend in # locations)*	Uncertain	Stable?	Stable	Decline	Decline	Decline
• *Are there extreme fluctuations in # locations?*	No	No	No	No	No	No
• *Trend in area, extent or quality of habitat*	Decline	Stable?	Stable	Decline	Decline	Decline
Population Information						
• *Generation time (average age of parents in the population)* in years	≈ 30-35	≈ 35-40	≈ 40	≈ 40	≈ 30-35	≈ 30

• *Number of Mature Individuals* (*See* Table 2) N.B. Not all mature individuals contribute in any given year. Sex ratios for all populations are > 1:1 and females only spawn once in 4-9 yr or less. (*See* text – Biology – Reproduction) • *Number of mature females* • *Number of females capable of spawning in a particular year.* *Despite the availability of females capable of spawning there is no recruitment in these populations	7650 ≈ 1500 < 100	749 ≈ 90 < 10	185 ≈ 60 < 10	457 ≈ 150 < 15*	942 ≈ 400 < 15*	752 ≈ 380 < 40*
• *Total population trend*	Decline	Unknown	Unknown	Decline	Decline	Decline
• *% decline over the last/next 10 years or 3 generations, whichever is greater*	Perhaps ≥ 50% (over the last 100 yrs)	Unknown	Unknown	Significant, but undetermined % since 1960s. Projected 83% in next 25 yrs	Similar to SP4	Similar to SP4 & SP5
• *Are there extreme fluctuations in number of mature individuals?*	Yes, historical	No	No	No	No	No
• *Is the total population severely fragmented?*	No	No	No	No	Yes	Partly
• *Trend in number of populations*	Stable	Stable	Stable	Stable	Decline	Decline
• *Are there extreme fluctuations in number of populations?*	No	No	No	No	No	No
• *specify trend in number of populations (decline, stable, increasing, unknown)*	Stable	Stable	Stable	Stable	Decline	Decline
• *list each population and the number of mature individuals in each*	N/A	N/A	N/A	N/A	Below HLK to U.S. border ≈ 1427; Arrow Lakes ≈ 42; Slocan ≈ 5	Kootenay Lake to Kootenai Falls ≈ 750; Duncan Reservoir ≈ 25
Threats (actual or imminent threats to populations and habitats)						
THREATS	**SP1**	**SP2**	**SP3**	**SP4**	**SP5**	**SP6**
Actual (with major impacts)						
• historic overfishing	X	X	X	X	X	X
• construction of dams				X	X	X
• habitat loss and/or degradation through elimination of wetlands by dyking, channelization, dredging, and	X			X		X
• contamination	X				X	X
• poaching and by-catches	X	X	X	X	X	X

Imminent (Within 1 Generation)						
• construction of proposed new dams, or upgrades to existing facilities				X	X	X
• future habitat loss and/or degradation through elimination of wetlands, dyking, channelization, dredging, mining, and	X			X	X	X
• contamination	X	?	?	X	X	X
• aquaculture – concerns include facility placement, contamination, security, access to wild broodstock, importation of non-native stocks, masking and enhancing markets for illegal wild fish and/or their products	X	X	X	X	X	X
• increased levels of poaching	X	X	X	X	X	X
Rescue Effect (immigration from an outside source)	Low	Minimal	Minimal	Nil	Nil	Nil
Status of outside populations. The status of all N. Am. populations is similar to those in Canada with the exception of the lower Columbia River and could provide immigrants to SP1.						
• *Is immigration known or possible?*	Yes	Not Likely	Not Likely	No	No	No
• *Would immigrants be adapted to survive here?*	Yes	Unknown	Unknown	N/A	N/A	N/A
• *Is there sufficient habitat for immigrants here?*	Yes	N/A	N/A	N/A	N/A	N/A
• *Is rescue from outside populations likely?*	No	No	No	No	No	No
Quantitative Analysis	N/A	N/A	N/A	N/A	N/A	N/A

TECHNICAL SUMMARY
(species *per se*)

Acipenser transmontanus

White Sturgeon — Esturgeon Blanc

Fraser and Columbia River Systems – British Columbia

Extent and Area Information	
• *Extent of occurrence (EO)* [see Table 1]	44,720 km^2
• *Trend in EO)*	Decline
• *Are there extreme fluctuations in EO?*	No
• *Area of occupancy (AO)* [see Table 1]	2,870 km^2
• *Trend in AO)*	Decline
• *Are there extreme fluctuations in AO?*	No
• *Number of known or inferred locations* (*See* previous, Figs. 2&5)	6
• *Trend in # locations*	Decline and projected future decline at 3 locations where there is no recruitment to maturity.
• *Number of historic locations from which the species has been extirpated*	Possibly 1
• *Are there extreme fluctuations in # locations ?*	No
• *Trend: in area, extent or quality of habitat*	Declining
Population Information	
• *Generation time (average age of parents in the population)*	≈ 35 yr
• *Number of mature individuals (capable of reproduction)* *See* Table 2. Recruitment in SP4-6 is 0. N.B. Not all mature individuals contribute in any given yr. Sex ratios for all populations are > 1:1 and females only spawn once in 4-9 yr or less. (*See* previous and text–Biology – Reproduction) • *Number of mature females* • *Number of females capable of spawning in a particular yr*	< 9000 < 2600 < 200
• *Total population trend*	Declining – recruitment failure and loss of older individuals
• *% decline over the last/next 10 years or 3 generations.*	> 50% last 3 generations; estimate ≈20% next generation
• *Are there extreme fluctuations in number of mature individuals?*	Last century due to overfishing
• *Is the total population severely fragmented?*	Yes
• *Trend in number of populations*	Populations will continue to decline if conditions for SP-4-6 are not stabilized.
• *Are there extreme fluctuations in number of populations?*	No

• *List each population and the number of mature individuals in each.* (*See* above) N.B. Not all mature individuals contribute in any given year. Sex ratios for all populations are > 1:1 and females only spawn once in 4-9 yr or less. (*See* text –Biology – Reproduction)	SP1-Lower Fraser = 7650 SP-2-Middle Fraser = 749 SP3-Upper Fraser = 185 SP4-Nechako = 457 SP5-Upper Colum. = 942 SP6-Kootenay = 752
• *Number of mature females* • *Number of females capable of spawning in a particular yr* (In brackets). *Despite the availability of females capable of spawning there is no recruitment in these populations	SP1 ≈ 1500 (<100) SP2 ≈ 90 (<10) SP3 ≈ 60 (<10) SP4 ≈150 (<15)* SP5 ≈ 400 (<15)* SP6 ≈ 380 (<40)*
Threats (actual or imminent threats to populations or habitats)	
Actual (with major impacts) - historic overfishing - construction of dams and their resultant habitat and ecosystem changes - loss or degradation of habitat through elimination of wetlands, dyking, channelization, dredging, gravel mining, and contamination - poaching and by-catch	
Imminent - construction of proposed new dams - future habitat loss and/or degradation through elimination of wetlands, dyking, channelization, dredging, mining and contamination - black markets may effect level of poaching - potentially the emerging commercial aquaculture industry, if it is not managed properly (concerns include facility placement and containment, security, access to wild broodstock or the importation of non-native stocks, and the possibility of masking and enhancing the market for illegally caught wild fish or their products)	
Rescue Effect (immigration from an outside source)	Negligible
Status of the outside population(s)? (*see* below). The status of all North American populations is similar to those in Canada with the exception of the lower Columbia River which might provide immigrants to SP1	
• *Is immigration known or possible?*	Not likely, but slight possibility in the Lower Fraser (SP1) only.
• *Would immigrants be adapted to survive in Canada?*	Perhaps in the Lower Fraser
• *Is there sufficient habitat for immigrants in Canada?*	Possibly in the Lower Fraser
• *Is rescue from outside populations likely?*	No
Quantitative Analysis	N/A
Current Status **COSEWIC** – Special Concern 1990 **Other** • CITES – Appendix II • U.S.A. – Protected Species (Endangered species Act • Canada – Wild species 2000 National Rank – 2; Provincial Rank – 3 • B.C. – listed as blue (=SC) **Nature Conservancy Rankings** • **Global** G3 • **National** **US** N4 **Canada** N2 • **Regional** **U.S.** AK – S3S4, AZ - SEH, CA – S4, ID – S1, MT – S1, OR – S2, WA, - S3BS4N **Canada** BC – S3	

Status and Reasons for Designation

Status: Endangered **Alpha-numeric Code:** A2(c-e),4(b-e)

Reasons for Designation:
A long-lived species with a 30-40 year generation time, and low survival to adulthood that has suffered over a 50% decline in the last three generations. Three of six populations are in imminent threat of extirpation. Extant populations are subject to realized threats of habitat degradation and loss through damming of rivers, channelization, dyking and pollution. Illegal fishing (poaching) and incidental catches are also limiting. In addition, a developing commercial aquaculture industry may also impose additional genetic, health and ecological risks to wild populations,

Applicability of Criteria

A1 – Historical commercial fishery ceased in 1915, but poaching is still suspected, as are other limiting factors. Thus, it is problematic to apply the conditions of criteria A1.

A2(c-e) – One population (SP1) declined by >50% in the past 100 years; we have no information on trends in SP2 and SP3, but the remaining 3 (SP4-6) have experienced significant decline since the 1960s with no sign of recovery. Future projections for these 3 indicate a greater than 83% decline in < l generation. The overall decline in the last 100 years is significant and > 50 %. There has been a marked decline in habitat quantity and quality throughout the range, and poaching and incidental catches remain limiting. Pollution has contaminated habitat in some areas and led to change in species assemblages impacting predator-prey relationships as well as inter and intra-specific competition.

A3: N/A – no information on projected decline over 3 generations. We do know that the overall rate of decline is projected to be in the order of 20% over the next generation and that 3 populations will decline by more than 83% in that same time frame. There are too many assumptions to be made to apply the criterion.

A4(a – e): Overall decline of >50% in the last three generations. The decline is continuing and is projected to be in the order of 20% over the next 25 years (<1 generation). One population declined by >50% in the past 100 years (<3 generations), and, although we do not have an actual estimate of decline for populations SP4-6, we do know that there was an historic (significant) decline in numbers since the 1960s and that the decline is continuing and projected to be in the order of 83% or more in the next generation. These populations do not currently exhibit any recruitment. Populations are fragmented due to habitat decline, degradation and contamination, and may be subjected to illegal exploitation through poaching. A developing commercial aquaculture industry may also impose additional genetic, health and ecological risks to wild populations.

B: Does not meet the B criterion because the size of the EO and AO exceed the minimal limits.

C: Meets the criterion for C1 – Threatened on the basis of <10,000 mature individuals and an estimated continuing decline of >10% over the next generation.

A case could be made for C1 - Endangered as well, if we accept that the number of mature individuals is less than 2000. Based on a sex ratio of more than one male per female, the effective populaiton may be in the range of ˜ 2600 females, which do not spawn each year (once every 4-9 years or less), so the effective spawning population could be as low as 260 females or less. The projected rate of decline over the next generation is estimated to be less than 20%, but may be greater than this over the next 3 generations.

D: N/A**.** Number of mature individuals and number of locations exceed the threshold values.

E: N/A. Insufficient data to perform quantitative analysis.

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