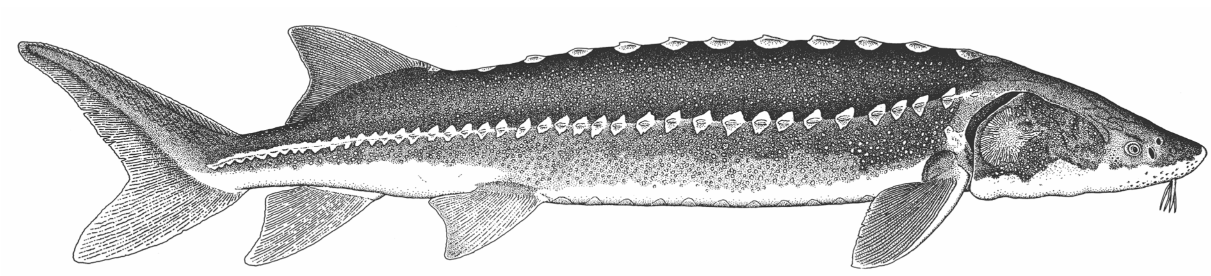
FRASER RIVER WHITE STURGEON CONSERVATION PLAN

Draft for Public Review



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The white sturgeon, *Acipenser transmontanus*. (Drawing by Paul Vecsei provided courtesy of Golder Associates Ltd.)

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Disclaimer
This draft plan outlines reasonable actions that are believed necessary to protect and recover Fraser River white sturgeon. The plan is a co-operative effort among provincial and federal agencies, First Nations, and others. It does not necessarily represent the views nor the official positions or approval of any individual or agency involved in drafting this document. The plan may be modified as new data are collected, when changes in species status occur, and upon completion of recovery tasks.

Acknowledgments
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COSEWIC Summary

Common Name: White Sturgeon
Scientific Name: *Acipenser transmontanus*
Current status and most recent date of assessment: Endangered (November 2003)
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, 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.
Occurrence: BC
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.

EXECUTIVE SUMMARY

The Fraser River White Sturgeon Conservation Plan (the Plan) addresses white sturgeon conservation in the Fraser River, excluding the Nechako River for which there is already a recovery plan. It is designed to be a high-level planning document that provides information on white sturgeon biology and conservation, identifies information gaps, and sets priorities for action by government and non-government organizations. It outlines general strategies and priorities for conservation, but is not highly-detailed or prescriptive. In short, the Plan presents "what to do" but not necessarily "how to do it." It is expected that detailed prescriptions for specific actions will be developed during future stages of conservation planning and management of white sturgeon across the full range of the species.

Biology.— White sturgeon, *Acipenser transmontanus*, is the largest, longest-lived freshwater fish species in North America (Scott and Crossman 1973). Fish of over 6 m in length and over 100 years of age have been reported in the Fraser River (Scott and Crossman 1973). Within the Fraser River, white sturgeon have been observed in the mainstem from the estuary upstream past the Morkill River, northwest of McBride, a distance of approximately 1,100 km (Yarmish and Toth 2002). Furthermore, they are found in a number of large tributaries and large lakes within the Fraser River watershed. The current distribution in the Fraser River is believed to reflect the historic distribution with the possible exception of the Seton and the Nechako Rivers.

Long-term trend data on fluctuations in population size or density are generally lacking for all populations, and most studies are relatively recent (Ptolemy and Vennesland 2003). Various lines of evidence can be used to infer that population declines have occurred in many parts of the Canadian range. In response to the population declines, white sturgeon were uplisted by COSEWIC in November 2003, from a species of "special concern" to "endangered." The legal listing process under SARA was officially initiated in July 2004 and is still underway. No trend data are available for white sturgeon stocks in the upper and middle Fraser, but abundance is believed to be naturally low in this region (Ptolemy and Vennesland 2003). Age structure of these stocks indicates that the populations are stable and recruitment is successful (RL&L 2000). Because the species is very long-lived the stable age structure implies no recent decline, but cannot speak to declines over the more distant past (i.e., prior to 1945). White sturgeon abundance in the lower Fraser River underwent a significant decline in the late 1800s and early 1900s due to aggressive harvesting by the commercial fishery (Echols 1995). Abundance monitoring in the lower Fraser has been underway since 1985, and has been intensive since 1995. Results indicate a natural age structure with about 85% of individuals in the immature life stage, and abundance of individuals >40 cm increasing over the last five years.

The intrinsic biologic factor that seems to be most limiting to white sturgeon population growth is the delayed maturity that characterizes this species. Even very small changes in the annual survival rate can have significant effects on the number of fish reaching maturity and thus the number of annual spawners (which is only a subset of all mature adults). If the survival rate drops slightly, the effect over multiple years can be large. Furthermore, delayed maturity means that even if juvenile recruitment starts to improve immediately, recruitment to the spawning population may be delayed for up to two decades or more. The effects associated with delayed maturation will be greatest in northern stocks where productivity and growth season are reduced, thus increasing age at maturity and perhaps spawning periodicity.

Values.— White sturgeon occupy a significant position in the spiritual, aesthetic and economic history of the peoples of British Columbia. Sturgeon have traditional cultural values to many First Nations in British Columbia and these values continue to be maintained. The predominant value of Fraser River white sturgeon to non-aboriginal communities has shifted considerably over the last century as general environmental awareness has increased; values have changed from one of a natural resource commodity to one in which white sturgeon are also appreciated in their own right (as a species), and as a component of a healthy ecosystem. There have been no long-term studies of the value of white sturgeon; however, a variety of data sources are used to describe some of the values over time, including First Nation's traditional uses, commercial fishing, recreational angling, guided angling, Aboriginal fishery, scientific inquiry, and aquaculture.

Threats.— Threats and challenges facing the species vary among the different stock groups of Fraser River white sturgeon. For the most part the threats can be described but not quantified. Despite difficulties with quantification, in many cases there is considerable evidence that a specific threat is real. Conservation threats to Fraser River white sturgeon most often involve one of the following mechanisms: changes in water quantity, changes in water quality, instream habitat alterations or harvest. Threats are presented and discussed here in detail. The following table summarizes high and medium priority threats:

Location	Threat Category	Threat
upper and mid Fraser	High	• Food supply • Hatchery effects (potential) • Spawning habitat
upper and mid Fraser	Medium	• Effects of small population size • Fishing effects • Mainstem rearing habitat (mid Fraser) • Off-channel rearing habitat (upper Fraser)
lower Fraser	High	• Fishing effects • Hatchery effects (potential) • Mainstem rearing habitat • Off-channel rearing habitat • Spawning habitat • Pollution
lower Fraser	Medium	• Food supply

Goals and Objectives.— The goal of this conservation plan is to ensure that naturally-reproducing populations of white sturgeon flourish over the long-term throughout the species' natural distribution in the Fraser River basin, and opportunities for beneficial use of each of the major stock groups are provided, if and when feasible.

To achieve this goal, a series of objectives and general strategies have been identified, including specific recovery measures, research, and ongoing monitoring. The objectives and timelines will be revisited as new information is collected and possible changes to priorities will be evaluated. The objectives are:

1. Reach and maintain a natural population age structure and reach biological targets throughout the species' natural distribution in the Fraser River.
2. Improve both the scientific and social basis for population targets for each of the major stocks of Fraser River white sturgeon. Refine these targets and identify appropriate time frames for achieving targets, through appropriate consultative processes.
3. Identify and quantify white sturgeon habitat availability and condition; make recommendations for critical habitat designation.
4. Track the status of white sturgeon populations and their response to management actions by developing and implementing scientifically-defensible monitoring programs for white sturgeon throughout the Fraser River.
5. Address basic biology data gaps (life history, habitat use, etc.) required to support conservation management approaches for this species.
6. Address specific data gaps to support improved assessment and prioritization of threats, and develop recommendations for specific management actions as required.
7. If consistent with SARA and conservation objectives, define the biological and social conditions that would allow for opportunities for beneficial use of Fraser River white sturgeon.
8. Support and implement recommendations in the Plan. Review and update the Plan at least every 5 years.

Population Targets.— The issue of population targets was considered carefully and it has been proposed that each stock should have its own target. The rationale for the targets is presented in detail, and a series of research tasks are proposed (see Section 7) to assess and refine the targets.

Habitat availability and food supply in the mid and upper Fraser are unlikely to support white sturgeon populations in excess of levels (COSEWIC 2005) that would permit downlisting of these stocks. Yet, abundance of white sturgeon in the mid and upper Fraser is believed to be at or near historic levels, age structure appears to be normal, and there is no evidence of a trend toward declining abundance or distribution (see Section 2.5). Population targets for the mid and upper Fraser River have therefore been set at current population levels: 750 mature adults in the mid Fraser, and 185 mature adults in the upper Fraser. Both targets assume a stable age distribution.

Habitat availability and population trends are quite different in the lower Fraser River. Abundance of white sturgeon in the lower Fraser is believed to be considerably lower than historic levels, age structure is skewed toward younger individuals, and there is evidence of a trend toward increasing abundance over recent years (see Section 2.5). White sturgeon are not rare in the lower Fraser, and habitat availability and food supply are thought to be sufficient to reach population levels (COSEWIC 2005) that would permit downlisting of these stocks. A population target for the lower Fraser River has been set at 10,000 mature adults, with an age distribution capable of supporting this number over the next 20 years. This target represents a level beyond which social decisions around beneficial use predominate. Below this level, there remain considerable conservation concerns, and beneficial use is expected to be of lower priority.

Critical Habitat.— Currently, we are able to delineate some habitats that are important, but we are as yet unable to provide a defensible demarcation of critical habitat. The Plan therefore proposes a series of tasks to allow delineation of critical habitat for white sturgeon in the Fraser River:

1. develop a good understanding of habitat use by different life stages of white sturgeon;
2. review of historic and current habitat availability;
3. review of historic and current population abundance;
4. undertake a review and analysis of life-stage specific population parameters (e.g., survival and fecundity);
5. undertake specific population modeling (e.g., elasticity analysis, see Gross et al. 2002) to explore which life stages are most limiting to Fraser River white sturgeon abundance;
6. to the extent possible, establish a functional relationship between habitat and abundance; and
7. use population targets and relationships between habitat types and abundance to determine how much of the different habitats is required to maintain viable populations of Fraser River white sturgeon.

The precise nature of each task will need to be developed during detailed planning stages in the future.

Recommended actions and implementation.— The general approach recommended in this conservation plan varies throughout the watershed, but includes protection of key habitats, ensuring adequate food supply for white sturgeon, minimizing impacts from fishing and other human activities, and undertaking specific research to clarify threats. The Plan lays out a series of broad strategies:

1. Identify habitat requirements for the major life stages of Fraser River white sturgeon, and ensure important habitats are adequately protected.
2. Make recommendations for critical habitat designation and protection.
3. Refine population targets for each of the major stock groups. These targets may include recovery targets, population status thresholds, and targets for beneficial use.
4. Clarify threats to Fraser River white sturgeon from different fishing activities.
5. Exercise caution (in favour of conservation) when planning/regulating/enforcing directed and interception white sturgeon fisheries (i.e., recreational angling, guided angling, commercial drift net, First Nation drift and set net),
6. Minimize illegal harvest of white sturgeon.
7. Clarify threats to Fraser River white sturgeon from pollution, and provide recommendations for management of these threats.
8. Develop and implement scientifically sound monitoring programs for Fraser River white sturgeon.
9. Incorporate the needs of healthy white sturgeon populations into the management of Fraser River eulachon and salmon.
10. Clarify and address risk to mainstem Fraser populations from release of hatchery-reared Nechako River white sturgeon.
11. Address information gaps that inhibit conservation of Fraser River white sturgeon.

A variety of recovery-related actions have been completed or initiated.

Anticipated Benefits, Conflicts and Challenges.— Potential benefits, conflicts and challenges associated with the execution of this Plan are wide-ranging, and are discussed in the document. Addressing the threats to white sturgeon abundance and distribution within the Fraser River mainstem is likely more straightforward than in any other portion of the species' natural range. The threats are significant, yet at the same time there are a number of reasons for greater optimism here than elsewhere. For example,

- the Fraser River mainstem is not regulated,
- white sturgeon abundance in the mid and the upper Fraser appears stable and is believed to be near historic levels,
- abundance in the lower Fraser, while lower than historic levels, appears to be increasing;
- habitat alterations have not been severe in the mid and upper Fraser,
- there has been considerable habitat alteration in the lower Fraser but present habitat conditions are sufficient to support a fairly healthy population,
- and most importantly, there is a diverse and highly motivated group of people willing to participate in conservation planning and implementation.

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1. PURPOSE OF THE CONSERVATION PLAN

The Fraser River White Sturgeon Conservation Plan (the Plan) addresses white sturgeon conservation in the Fraser River mainstem. Conservation planning processes have been conducted for white sturgeon in the upper Columbia, the Kootenay, and the Nechako Rivers. This Plan thus completes population-specific conservation planning for white sturgeon within its Canadian range.

The Plan is designed to be a high-level planning document that provides information on white sturgeon biology and conservation, identifies information gaps, and sets priorities for action by government and non-government organizations. It outlines general strategies and priorities for conservation, but is not highly-detailed or prescriptive. In short, the Plan presents "what to do" but not necessarily "how to do it." It is expected that detailed prescriptions for specific actions will be developed during future stages of conservation planning and management of white sturgeon across the full range of the species.

The Plan is needed because across much of their natural range in British Columbia, self-sustaining populations of white sturgeon have undergone severe decline. In some locations abundance has historically been low and remains low today. In April 1990 the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated white sturgeon a "vulnerable[1]" species. White sturgeon status was re-examined by COSEWIC and the species was uplisted to "Endangered" in November 2003.

The status of white sturgeon is currently being assessed under the Species at Risk Act (SARA), and the outcome of the listing process will determine legal obligations in Canada for conservation and restoration of this species. In part, the obligations will be determined by the status assigned to white sturgeon. For example, SARA requires development within specified timelines of a "management plan" for species of Special Concern, and a "recovery plan" for endangered, threatened or extirpated species. For endangered or threatened species there are also specific prohibitions under SARA that protect individuals and their residences, and critical habitat once it is defined.[2] A single SARA-compliant document will likely need to be produced for conservation of white sturgeon across their entire Canadian range — it is expected that such a document will rely heavily on this Plan and the documents already prepared for other populations of white sturgeon.

This plan will likely address many of the obligations for recovery planning required by SARA regardless of the ultimate decision on white sturgeon status, but it has been developed prior to completion of the SARA public consultation and listing process, so the precise nature of the actions required under SARA is not yet clear. In any case, the motivation for the Plan predates these obligations. White sturgeon occupy a significant position in the spiritual, aesthetic, and

[1] This translated to "Special Concern" status when COSEWIC changed their listing criteria.
[2] Readers should consult the legislation and supporting documents and communications if they wish to understand the specific requirements of SARA; individuals or groups may also wish to participate in or monitor the progress of the public consultation process associated with the SARA review of white sturgeon status (see http://www.sararegistry.gc.ca).

economic history of the peoples of British Columbia, and there has been broad support for conservation initiatives for this species over a long period of time. The Plan has thus been able to capitalize on a considerable history of research and management of white sturgeon in the Fraser River, and the Plan has benefited from the input of federal, provincial, and First Nations representatives, as well as a number of non-governmental representatives and stakeholders.

2. BACKGROUND

2.1 Species Description

White sturgeon, *Acipenser transmontanus*, is the largest, longest-lived freshwater fish species in North America (Scott and Crossman 1973). Fish of over 6 m in length and over 100 years of age have been reported in the Fraser River (Scott and Crossman 1973). The most distinguishing features of the white sturgeon include a mainly cartilaginous skeleton, long scaleless body covered with rows of large bony plates (called scutes) on the back and sides, shark-like (heterocercal) tail, and four barbels between the mouth and an elongated snout. It has no teeth, but instead has a protrusible mouth with which it creates suction to pull in food. Body colouration ranges from black, to olive or light grey on the dorsal surface and upper edge of plates, but is consistently white on the ventral surface (Scott and Crossman 1973).

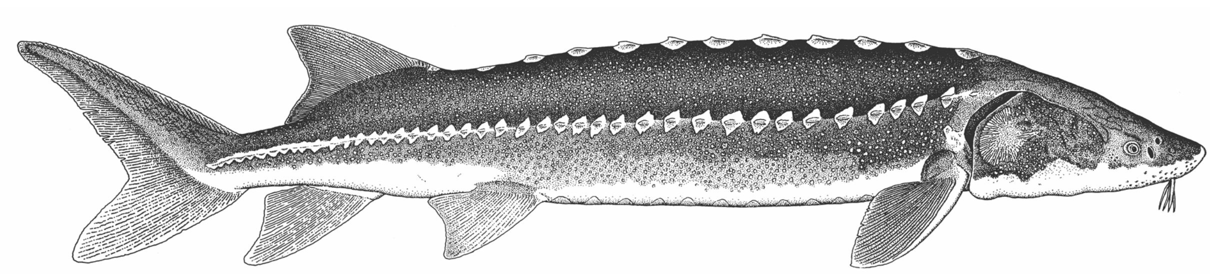

Figure 1. The white sturgeon, *Acipenser transmontanus.* (Drawing by Paul Vecsei provided courtesy of Golder Associates Ltd.)

2.2 Distribution

Globally, self-sustaining populations of white sturgeon are found in three major drainages on the north Pacific coast: the Fraser, Columbia and Sacramento river systems. In addition, white sturgeon can exhibit facultative anadromy and have been observed in several coastal inlets and estuaries on Vancouver Island, typically near creek and river mouths. These observations are believed to reflect transient individuals rather than self-sustaining populations.

Within the Fraser River, white sturgeon have been observed in the mainstem from the estuary upstream past the Morkill River, northwest of McBride, a distance of approximately 1,100 km (Yarmish and Toth 2002). Furthermore, they are found in a number of large tributaries including the Nechako and Stuart systems (a total of 400 km in length), the Harrison and Pitt rivers, as well as the lower reaches of the Bowron, McGregor and Torpy rivers (Ptolemy and Vennesland 2003). White sturgeon have also been reported in several large lakes associated with the Fraser River watershed including Fraser, Takla, Trembleur, Stuart, Williams, Seton,

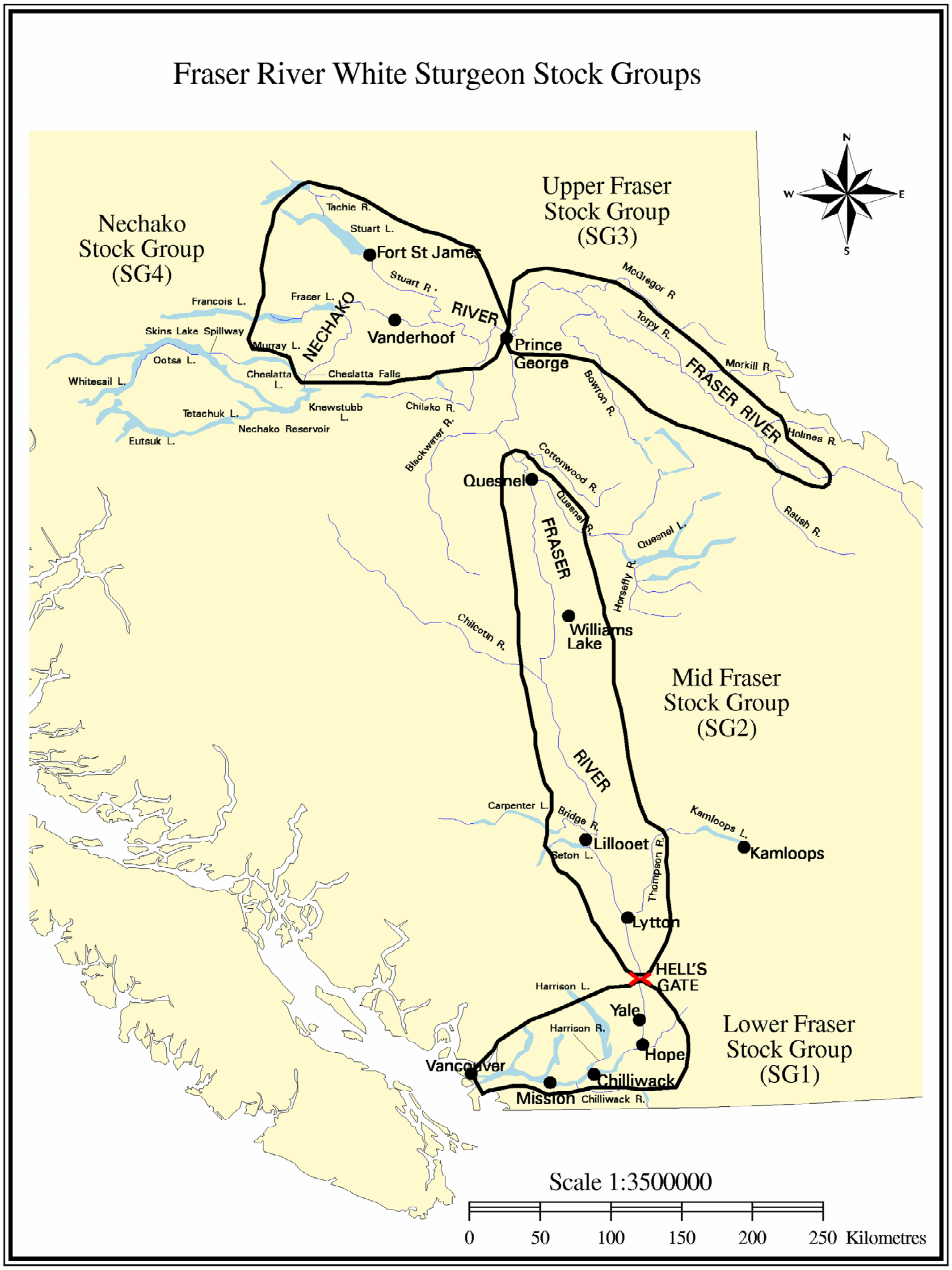

Figure 2. Map of the Fraser River basin showing the approximate ranges for each of the white sturgeon stock groups. Recent studies have indicated that white sturgeon are principally found in the mainstem habitats of the Fraser and Nechako rivers. However, sturgeon are often found in the lower ends of tributary systems and in some systems make extensive use of tributaries and large lakes (such as in the Harrison or Stuart watersheds). Anecdotal records indicate sturgeon being present in several watersheds beyond the described boundaries (see text for details). Sturgeon are occasionally found in the Fraser River between Prince George and the mouth of the Cottonwood River. These appear to be transient individuals and may belong to any one of the three surrounding stock groups.

Kamloops, Pitt, and Harrison lakes. Their current distribution in the Fraser River is believed to reflect the historic distribution with the possible exception of the Seton, Thompson, and Nechako rivers. In the Nechako system, current distribution may be limited by population declines and/or the alteration of flows (and related effects) below Kenney Dam (NWSRI 2004).

2.3 Genetic Diversity and Stock Structure

On a broad scale, the genetic diversity observed for Fraser River white sturgeon is similar to that observed in the Columbia system; genetic diversity within stock groups generally declines with distance upstream (Smith et al. 2002). This pattern can be explained by post-glacial dispersal, as well as the larger population size of the contemporary population downstream of Hells Gate and the potential for inter-migration between the lower Fraser and lower Columbia populations (Smith et al. 2002). Three mainstem stocks, and a Nechako River stock, have been identified based on recent genetic and movement data (Smith et al. 2002, RL&L 2000, Golder 2003a) and are being proposed as *Nationally Significant Populations* under COSEWIC (Ptolemy and Vennesland 2003). The Plan will consider the three stocks separately. As noted earlier, the Nechako River stock, while also distinct based on genetics and movement patterns, is being addressed by a separate recovery plan (see NWSRI 2004).

The three Fraser River mainstem stocks include:

1. Lower Fraser River – Fraser mainstem downstream of Hells Gate (0 to 211 km upstream) plus the Pitt River and Harrison River watersheds.
2. Middle Fraser River – Fraser mainstem from Hells Gate to the Cottonwood River confluence (211 to 670 km upstream).
3. Upper Fraser River – Fraser mainstem upstream of Prince George (790 to 1,100 km upstream).

Few fish have been encountered between the Cottonwood River confluence and Prince George; transients from the middle or upper Fraser or Nechako may be found there as a rare occurrence, so this zone is not defined as part of a single stock group.

2.4 Biology

In this section we review the general biology of white sturgeon, based on information collected in studies across the geographic range of this species. Although a considerable amount of research has been conducted on white sturgeon, the extent to which one can generalize from each study is not always clear, since there is potential for stock-specific behaviours. To date, research is insufficient to identify these stock-specific behaviours, so readers should remain aware of the potential for limited transferability of information across the species range.

2.4.1 Growth and Maturation

White sturgeon are slow-growing with a delayed onset of sexual maturity and an impressive longevity potential. One individual collected in 1993 from the Fraser River was aged at 138 years (M. Rosenau, MWLAP, pers. comm.), and another collected in 1996 was aged at 118 years (RL&L 2000). In terms of size, recent surveys have recorded fork lengths of up to 3.43 m in the Fraser River (Nelson et al. 2004), and one individual was measured at more than 3.95 m total length (M. Rosenau, MWLAP, pers. comm.). Average fork lengths for sturgeon captured by 'hook and line' from 1995-99 ranged from 0.95 m to 1.24 m depending on stock (not including the Nechako River), but most fish were significantly smaller than the maximum length (RL&L 2000). Growth rates and maturity vary significantly throughout the white sturgeon's range, and noticeable differences are observed throughout the Fraser River mainstem (Echols 1995). Growth rates are highest in the stock downstream of Hells Gate, and lower in more upstream sections of the river. The upper Fraser stock exhibits the lowest growth rate (similar to that observed in the Nechako River), likely reflecting a shorter growing season and differences in food availability (RL&L 2000). Recent analysis of an extensive capture-recapture monitoring program has developed a reliable growth curve for white sturgeon in the lower Fraser over the size ranges 50 cm to 250 cm (Nelson et al. 2004).

White sturgeon males tend to mature at a younger age and smaller size than females, but it is thought that age at first maturity increases with distance upstream. Females and males in the lower Fraser stock may spawn as young as 26 and 11 years, respectively (Semakula and Larkin 1968). Age at first maturity in the middle Fraser stock is estimated to be in the late 20s for females while males may be younger (Ptolemy and Vennesland 2003). The upper Fraser stock is probably significantly older at first maturity given the slower growth rates and reduced productivity of this section of river. White sturgeon are non-annual spawners and may spawn multiple times throughout their life. Limited data for the lower Fraser stock suggests that intervals between spawning for females may vary from 4 to 11 years, with the interval increasing with age (Semakula and Larkin 1968, Scott and Crossman 1973). It has been hypothesized that spawning frequency may be lower in the mid and upper Fraser, but this has not been assessed directly. Annual survival rates have been estimated at 90% or more (Ptolemy and Vennesland 2003); Gross et al. (2002) report a value of 91% for ages ≥ 1, but only 3.96×10^{-6} for young of the year. However, 10% annual mortality over the long term translates to very few numbers in the population reaching the old ages frequently cited.

2.4.2 *Spawning and Early Development*

White sturgeon are broadcast spawners, releasing large numbers of eggs and sperm into the water column of turbulent river habitats. Spawning occurs in the spring as water temperatures are rising, in fast water velocities, over coarse substrates, and in water depths of 3 m or more (Parsley et al. 1993, Parsley and Kappenman 2000, Paragamian and Wakkinen 2002, Parsley et al. 2002, Perrin et al. 2003, RL&L, 1994, Liebe et al. 2004), though there are deviations from this general pattern. Water temperatures during spawning are 10–18 ˚C (peak spawning 13–15 ˚C) in the lower Columbia and Middle Snake Rivers, 8–12 ˚C in the Kootenai River (Paragamian et al. 1997), and 10–18 ˚C in the lower Fraser River (Perrin et al. 2003). Spawning congregations in the Nechako River were observed when water temperatures exceeded 12˚C for the first time in the year (Liebe et al. 2004). In the mainstem Columbia and Snake Rivers and major tributaries the appropriate velocity conditions for spawning exist largely in the tailwaters of large dams. In the Fraser River, the only unregulated river examined, spawning has been documented both in side channels and mainstem habitats (Perrin et al. 2003, RL&L 2000).

Spawning events were documented between late June and early August for the lower Fraser stock (Perrin et al. 2003). Spawning is correlated with particular water temperatures, and generally occurs on the descending limb of the spring freshet; these relationships appear to vary among stocks. Mature fish gather in groups on the spawning grounds; rolling and breaching behaviour, believed to be associated with spawning, may be observed (Parsley et al. 1993). Although some researchers suggest that several males may spawn with a single female, genetic evidence from the Columbia River suggests that most families are formed by unique pairs of males and females (Rodzen and May 2004). Spawning period duration may be shorter in the more-northern, colder regions, such as the upper Fraser River (NWSRI 2004).

Fecundity is directly proportional to female body size, ranging from about 0.7 million eggs in a medium-size female to 3 or 4 million eggs in a large female (Scott and Crossman 1973). Eggs are fairly large (3.5 mm, Deng et al. 2002 cited in Coutant 2004), adhesive, and demersal. Suspended sediment sticks to the egg surface, possibly preventing clumping while eggs remain in the turbulent water, and eggs sink to the bottom substrate (Perrin et al. 2003). Coutant (2004) has hypothesized that submerged riparian habitat during seasonal high water is needed for egg attachment, incubation and early development. He notes that where recruitment is successful, channels are complex and floodable riparian vegetation or rocky substrate is abundant. Coutant (2004) reviews extensive empirical and anecdotal support for this hypothesis, however, other researchers have noted that the hypothesis may not be universally applicable (McAdam et al. 2004). The merits of this hypothesis for the Fraser River require additional review.

Larvae hatch after 5 to 10 days depending on water temperature, with temperatures in excess of 20˚ C leading to abnormal development (Wang et al. 1985). Approximately 20-30 days after hatching metamorphosis is complete and the young fish are miniature replicas of the adult form (Perrin et al. 2003).

2.4.3 Feeding

Feeding behaviour is specialized for use in dark, bottom-oriented habitats where prey are often located through direct contact, facilitated by highly sensitive taste receptors on barbels around their mouth (Brannon et al. 1985). Juvenile white sturgeon are primarily benthic feeders, feeding on a range of invertebrate and fish species. Diet varies throughout the year, and depends on location. Juveniles reportedly eat a variety of aquatic insects, isopods, mysids, clams, snails, small fish and fish eggs (Scott and Crossman 1973, McCabe et al. 1993). Adults feed predominantly on fish, particularly migratory salmonids where available although crayfish and chironomids are also consumed (Scott and Crossman 1973). The lower Fraser stock has access to a broader range of food sources compared to the middle and upper Fraser stocks, and these include marine and estuarine fish and invertebrates, anadromous fish, as well as seasonally abundant lower Fraser salmon runs. Salmon roe, especially that of mainstem spawners (pink and chum salmon), is likely a targeted source of food, taken directly from the often dense concentrations of redds in the lower Fraser. Eulachon and lamprey are also important food sources for white sturgeon in the lower Fraser.

After white sturgeon larvae exhausts their yolk sac, they begin exogenous feeding. The initial time of first feeding for fish larvae is considered to be a critical period because it influences their subsequent survival and growth. The highest daily mortality rate of young sturgeon occurs in the days of first and early feeding (Gisbert and Williot 2002). First feeding in white sturgeon varies from 8–16 days post-hatch, depending on water temperature (Doroshov et al. 1983, Buddington and Christofferson 1985, Gawlicka et al. 1995). During early development, a mixture of food organisms produces faster growth than diets of single species (Gisbert and

Williot 2002). Coutant (2004) speculates that sturgeon larvae and juveniles may obtain better nutrition from feeding on zooplankton and dipteran chironomids colonizing flooded riparian vegetation than from feeding on amphipods on river bottoms. This implies that natural side channels, sloughs, and floodplains provide more potential juvenile growth than mainstem habitats. Unfortunately, at present there is not a direct test of this hypothesis.

2.4.4 Movement and dispersal

Potential movement within the Fraser River mainstem is generally unrestricted with the possible exception of Hells Gate. This confined canyon section is a velocity barrier: no upstream movement has been documented, and movement downstream has been documented only infrequently (RL&L 2000). Although movements between stock groups are possible and have occasionally been documented (Lheidli T'enneh Band 2001, Golder 2003a), there is genetic differentiation among lower, mid and upper portions of the watershed (Smith et al. 2002), which indicates highly restricted movements among these regions. Furthermore, tagging and genetic data strongly suggest that white sturgeon from the Nechako River do not contribute significantly to the Fraser mainstem stocks (Smith et al. 2002).

Anadromy is an option for white sturgeon in the lower Fraser, but it is unclear to what extent this stock uses the estuarine and marine environments for food or dispersal to other coastal river systems. Long-range dispersal is certainly possible. Tagged individuals from the Columbia River have been captured in the Fraser (Nelson et al. 2004), but tagged Fraser River white sturgeon have not been captured outside their region of origin. Veinott et al. (1999) assessed strontium concentrations in pectoral fin rays of lower Fraser River white sturgeon and interpreted their results as evidence that some juveniles spent time in the estuary (brackish water with mixed salinities), and that a small percentage of juveniles may rear for some period of time in marine waters (or brackish waters with higher salinities). They concluded that "it is probable that the majority of white sturgeon in the lower Fraser River are not diadromous, but many spend extended periods of time in the Fraser River estuary as juveniles." Ongoing monitoring of a large sample of uniquely tagged white sturgeon in the lower Fraser River (Nelson et al. 2004) confirms that some individuals make inter- and intra-annual migrations into the section of the Fraser estuary where marine and fresh water mix (both the North Arm and the mainstem of the Fraser River, downstream of the eastern end of Annacis Island).

Early life stage.— Movement and dispersal during early development are complex. After hatching, free embryos tend to avoid illumination and seek cover (Loew and Sillman 1998). An initial, short (2 day) period of nocturnal dispersal was noted for Sacramento white sturgeon (Kynard and Parker 2004). Negative phototaxis appears to subside after the first week of life, and association with the substrate appears to subside after age 22 days (Kynard and Parker 1998). Short dispersal style and behaviour of white sturgeon larvae contrasts greatly with the intense, long-duration dispersal style and behaviour (photopositive and swimming far above the bottom) of other sturgeon species (Kynard and Parker 2004).

Duration and distance of juvenile dispersal is not known, although there is potential for large-distance dispersal. Kynard and Parker (2004) found that larvae foraged on the open bottom, swam <1 m above the bottom, aggregated, and did not disperse downstream. In contrast, day-50 early juveniles initiated intense downstream dispersal. Despite differences in dispersal patterns, diel activity did not change during ontogeny: dispersing free embryos and juveniles had the same activity pattern — day and night movement with a nocturnal peak.

Juveniles and Adults.— Movement and migrations for later life stages of Fraser River white sturgeon are linked to feeding, overwintering and spawning activities. Different movement patterns appear primarily related to food type and availability, and differences in habitat availability and distribution. Data on movements associated with feeding and overwintering are limited as most tracking studies focussed on larger fish and on determining spawning locations. There appear to be differences among stocks, but in general most individuals seem to remain on summer feeding grounds and exhibit relatively localized movements (RL&L 2000). Tagging results suggest that Fraser River stocks then migrate in fall or winter, followed by a period of relatively low activity during the winter, with the timing and length of inactivity variable among stocks (RL&L 2000, Nelson et al. 2004). Migrations to spawning grounds occur in either fall (often called staging) or spring; these movements are often more extensive than feeding and overwintering movements (RL&L 2000). The movement patterns specific to each stock are briefly summarized below.

In the lower Fraser, there are extensive movements throughout the Fraser Valley area, the lower Fraser, and its' estuary, movements that are consistent with availability of important food sources such as eulachon, salmon, and salmon roe (Nelson et al. 2004). There is a downstream migration just prior to and during the eulachon migration in April and May, a decrease in movement during June and July and then an upstream migration following the salmon migration from August to December (Nelson et al. 2004). Lower Fraser stocks (between Mission and Hells Gate) exhibited mainly localized movements during the fall. Several mature fish from the lower Fraser stock demonstrated spawning migrations that exceeded 40 km and in some cases exceeded 70 km (RL&L 2000). Mature fish from this stock that were collected from upstream sites (Hope to Yale) tended to migrate less distance although some exceeded 35 km.

In the mid Fraser, information on movements of white sturgeon is quite limited. Tagging work indicated the stock exhibited mainly localized feeding migrations of less than 10 km in the spring, although some moved more extensively downstream (> 20 km) and then moved back upstream in the fall (RL&L 2000). Movements to overwintering areas were varied, ranging from less than 10 km up to 37 km, likely reflecting proximity to overwintering habitat (RL&L 2000). Mature fish from the middle Fraser stock also demonstrated a significant range of spawning-related movements: they generally moved more than 10 km and up to 75 km (RL&L 2000).

The upper Fraser stock undergoes significant annual movement. This is thought to reflect the need for white sturgeon to move great distances to find sufficient food (Lheidli T'enneh Band 2001). For example, half of the 14 fish tagged in 1999 and recaptured in 2000 had moved distances greater than 32 km, and five of the 19 fish recaptured in 2001 had moved distances greater than 20 km from point of initial capture (Lheidli T'enneh Band 2001, 2002). The Fraser River section between the Willow River and Nechako River confluences appears to be a movement corridor possibly associated with the upstream migration timing of Stuart River sockeye. Of note is the single sturgeon originally captured at the Nechako River confluence in July 2000 and later detected 120 km up the Nechako River (Lheidli T'enneh Band 2002). This is the first documentation of a sturgeon tagged from this area moving more than 0.5 km up the

Nechako (Lheidli T'enneh Band 2002). Congregations of sturgeon have also been noted at the Bowron River confluence, which is thought to provide an over-wintering and high-water refuge, as well as feeding area (Lheidli T'enneh Band 2002).

Pre-spawning migrations in the upper Fraser are likely to be significant (Lheidli T'enneh Band 2001), but maturity was not specifically evaluated for studies conducted for the upper Fraser population, so it is not possible to attribute specific movements to spawning activity. Age structure suggests normal recruitment of juvenile fish and a healthy population (Lheidli T'enneh Band 2002), thus regular spawning events for this population must be occurring.

2.5 Population Abundance and Trends

Recent population estimates have been calculated for all Fraser River stocks (Table 1). Based on a size criterion of 150 cm minimum fork length [3] (FL), a total of at least 9862 adults were estimated to be present throughout the Fraser River: 8928, 749 and 185 adults in the lower, mid and upper Fraser, respectively (Ptolemy and Vennesland 2003, Nelson et al. 2004). Table 2 summarizes population estimates in the lower Fraser for different size classes based on capture-recapture studies over five years (Nelson et al. 2004).

From these estimates, it is evident that the majority of the total Fraser population (approximately 90%) occurs downstream of Hells Gate, and that this population appears to be increasing. Genetic differences and movement data suggest each stock is sufficiently isolated and independent that they should be considered separately when evaluating stock status. When evaluating status of each stock it is important to also consider that the actual number of adults reproducing in a given year is significantly less than the total number of adults, particularly in the less productive northern extent of the range. For example, the upper Fraser population of 815 fish would likely see fewer than 50 adults of both sexes spawning each year if females spawn every 4 to 11 years.

Table 1. Population estimates for white sturgeon >40cm in the Fraser River mainstem.

Stock	Number of fish	95% C.I.	Reference
Lower Fraser	62,611 [4]	57,579 – 67,643 [5]	Nelson et al. 2004
Middle Fraser	3,745	3,064 - 4,813	RL&L 2000
Upper Fraser	815	677 - 953	Yarmish and Toth 2002
total	67,161		

[3] This size criterion is somewhat arbitrary, but is assumed to be a reasonable indicator of mature adults. Males may be mature at 100 cm FL; females may not mature until 170 cm FL. Because it is difficult to accurately sex live white sturgeon, a fork length of 150 cm was used to estimate combined (male and female) adult populations for each stock.
[4] The white sturgeon population in the lower Fraser also includes individuals < 40 cm and > 220 cm, but population estimates cannot be generated due to the small number of tagged fish in these size groups (Nelson et al. 2004).
[5] Values for the lower Fraser describe the 95% highest density rather than a parametric confidence interval (see Nelson et al. 2004).

Table 2. Population estimates for white sturgeon in the lower Fraser River mainstem by size class[4] in two time periods (from Nelson et al. 2004). (MLE = maximum likelihood estimate; CV = coefficient of variation.)

	October 1999 to January 2002		January 2002 to February 2004	
Size Class (cm)	MLE	CV (%)	MLE	CV (%)
40-59	8,021	27.0	9,493	60.2
60-79	12,999	7.7	15,629	11.4
80-99	10,073	6.0	13,403	7.9
100-119	6,611	7.1	9,484	9.0
120-139	4,349	9.1	5,673	10.8
140-159	3,276	11.1	3,429	12.0
160-179	2,769	19.5	3,259	19.2
180-199	1,394	23.7	1,327	20.1
200-219	1,160	55.6	913	38.8
Total	50,654	5.8	62,611	17.2

Long-term trend data on fluctuations in population size or density are generally lacking for all populations, and most studies are relatively recent (Ptolemy and Vennesland 2003). Various lines of evidence can be used to infer that population declines have occurred in many parts of the Canadian range, particularly in the lower Fraser, Nechako, Columbia and Kootenay rivers. Outside of the Fraser River mainstem the cause of decline is primarily associated with dams and river regulation, whereas within the Fraser the cause is primarily related to historic harvest, ongoing incidental mortality as by-catch, and historic and present habitat destructions and alterations. In response to the population declines, white sturgeon were uplisted by COSEWIC in November 2003, from a species of "special concern" to "endangered." The legal listing process under SARA was officially initiated in July 2004.

Mid and Upper Fraser River.— No trend data are available for white sturgeon stocks in the upper and middle Fraser, but abundance is believed to be naturally low in this region (Ptolemy and Vennesland 2003). Evidence that the populations are within the range of historic abundance, is based largely on a lack of evidence suggesting otherwise. For example, there is no record of an intensive fishery or overharvest, and there is no evidence of widespread habitat alteration or destruction. Age structure of these stocks indicates that the populations are stable and recruitment is successful (RL&L 2000). Because the species is very long-lived the stable age structure implies no recent decline, but cannot speak to declines over the more distant past.

Lower Fraser River.—White sturgeon abundance in the lower Fraser River underwent a significant decline in the late 1800s and early 1900s due to aggressive harvesting by the commercial fishery (Echols 1995). Early annual catches were routinely above 100 metric tonnes and peaked at more than 500 tonnes in 1897. The stock crashed in the early 1900s. White sturgeon were no longer targeted by commercial fishers after the fishery crashed, and a commercial fishery no longer exists in the Fraser River. Until 1994, white sturgeon were routinely retained as by-catch in the salmon net fishery and sold commercially. Commercial harvest records, which included both white and green sturgeon catches, exceeded 25 tonnes only twice between 1924 and 1992 (in 1977 and 1978), with a mean annual harvest during this period of 11.7 tonnes (Semakula and Larkin 1968; Echols 1995).

Abundance monitoring in the lower Fraser has been underway since 1985, and has been intensive since 1995, using techniques such as radio telemetry, commercial and recreational catch statistics, mark-recapture, and life history studies (e.g., Lane 1991, Swiatkiewicz 1992, RL&L 2000, Nelson et al. 2004). Results indicate a natural age structure with about 85% of individuals in the immature life stage (Table 2), and abundance of individuals >40cm increasing over the last five years.

There is broad agreement that there has been a substantial decline in lower Fraser River white sturgeon abundance as a result of historic overfishing. However, it is uncertain whether there has also been a recent decline in the lower Fraser stock. Ptolemy and Vennesland (2003) cite evidence in Inglis and Rosenau (1994), Lane and Rosenau (1995), and Richardson et al. (2000), and conclude that these studies "all indicate a possible decline in juvenile density from the mid 80s to the late 90s."

Further review of the reports cited above suggests a more equivocal conclusion may be warranted. Richardson et al. (2000) compared two sampling efforts of the fish community in the lower Fraser, separated by 21 years (1972-1973 vs. 1993-1994). The authors' general conclusion was that "despite large changes in the lower Fraser River ecosystem in the past 21 years, the overall fish community has shown remarkably little change over that interval." They discuss the long-term decline of Fraser River white sturgeon resulting from historic overfishing, but the data in their study (shown in an appendix) actually indicate a higher abundance and density of white sturgeon abundance and density, rather than the reduction reported by Ptolemy and Vennesland (2003). It should be noted that the purpose of Richardson et al. (2000) was to compare community-wide patterns and that changes in abundance between the two time periods are inconclusive with respect to trends of individual species.

Inglis and Rosenau (1994) collated and analysed data from recreational angler cards from 1985 to 1991. A significant decline in CPUE for juveniles and small adults was observed over the sample period, but was not observed for other size classes. Although results from these data are intriguing, some caution should be exercised. For example, the number of active anglers more than doubled during the sample period yet the number of cards returned to the ministry never exceeded 50% and was often much less. It seems possible that each year's cards sampled a substantially different set of anglers, and the effect of this source of variance is not known. The target for the fishery was mature fish, not juveniles, and although anglers are expected to record all fish caught, it seems likely that less attention was paid to fish below the legal size limit. The type of pattern indicated by Inglis and Rosenau (1994) may be expected to show up as a gap in the age distribution, a pattern which is not supported by recent population assessments of this stock by the Fraser River Sturgeon Conservation Society (FRSCS), which is based on large sample sizes (Nelson et al. 2004). There are a number of potential reasons for this apparent conflict, but further analysis would be required.

2.6 Biological Limiting Factors

The intrinsic biologic factor that seems to be most limiting to white sturgeon population growth is the delayed maturity that characterizes this species. Even very small changes in the annual survival rate can have significant effects on the number of fish reaching maturity and thus the number of annual spawners, which is only a subset of all mature adults. If the survival rate drops slightly, the effect over multiple years is significant. Furthermore, delayed maturity means that even if juvenile recruitment starts to improve immediately, recruitment to the spawning population may be delayed for up to two decades or more. The effects associated with delayed maturation will be greatest in northern stocks where productivity and growth season are reduced, thus increasing age at maturity and perhaps spawning periodicity.

Gross et al. (2002) used a form of population modeling called "elasticity analysis" to assess the sensitivity of sturgeon population growth (or decline) to changes in age- and life-stage specific survival and fecundity. The analysis indicated that population growth is most sensitive to changes in early survival rates. Changes in survival of older fish and changes in fecundity had considerably less effect on population growth. The authors stress that since white sturgeon survival during the first year is extremely low, the overall opportunity for affecting population growth is strongest in that age class because of its exceptional potential for increased survival rates; older fish already have fairly high survival rates, so there is less potential for increases in survival of these age classes.

3. HABITAT

3.1 White Sturgeon Habitat Use

White sturgeon inhabit large rivers where they are associated with particular habitat features: slow, deep mainstem channels interspersed with a zone of swift and turbulent water, extensive floodplains with sloughs and side channels, and a snowmelt-driven hydrograph with prolonged spring floods (Coutant 2004). Historically, white sturgeon are thought to have moved extensively throughout mainstem and major tributary rivers, moving to feeding or spawning sites, sometimes dispersing widely, even to estuary or ocean habitat when accessible (Scott and Crossman 1973, Veinott et al. 1999). Natural barriers provided some level of population segmentation, leading to genetic differentiation among locations within some rivers (e.g., Smith et al. 2002).

Most habitat use studies for white sturgeon are recent and have come from regulated rivers, particularly the upper Columbia and Kootenay Rivers. The Fraser River is the only unregulated of three major river systems (Sacramento, Columbia, and Fraser) supporting spawning populations of white sturgeon, and the few studies completed on the Fraser indicate that habitat use there may be quite different. This may simply reflect the difference between present and historic habitat availability on regulated systems. If the "best" habitats are absent or altered, the preferences that fish are demonstrating may be an artefact of current availability of habitat types. Care must therefore be exercised when extrapolating observations and conclusions regarding sturgeon habitat and related behaviours from regulated systems to the Fraser watershed. A considerable amount of work is still required to properly describe habitat requirements for Fraser River white sturgeon.

Like many fish species, habitat use by white sturgeon varies with life stage and season. This section of the Plan summarizes what is currently known about habitat use by white sturgeon in general and, where information exists, specifically for the Fraser River.

3.1.1 Adult Habitat

RL&L (2000) divided adult habitat use into spawning, summer residency, and overwintering, with movements or migrations to and from these key habitats between each period. Most studies of adult habitat use have focussed on the physical features of spawning habitat; considerably less attention has been paid to other adult habitat requirements, such as overwintering, feeding and holding habitats, plus migration habitats. This seems to reflect a general belief that adult feeding and holding habitats are not limiting, whereas the availability of suitable habitats for spawning and early life stages are critical to population abundance (see Section 2.6).

Habitat use varies by stock group, season and activity (feeding, overwintering, etc), but Fraser River white sturgeon adults are frequently 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&L 1994 and 2000). Adults in less productive northern areas may be widely dispersed (including use of tributaries), and require longer migrations than in southern regions (Yarmish and Toth 2002).

Summer residency.— Summer residency of white sturgeon in the Fraser River drainage was defined as the period between spring movements to feeding areas and fall migrations for overwintering. This generally encompasses the period July to September. During this period, the movements of white sturgeon in most stocks were typically frequent but more localized than in the spring or fall. In systems like the lower Columbia River (RL&L 1994, Brannon and Setter 1992) and Kootenai River (Apperson and Anders 1991), white sturgeon were reported using shallower depths during the spring to summer period and exhibited frequent, short distance forays between shallow and deep-water areas to feed.

Information on summer residency of Fraser River white sturgeon is sparse. Generally, the movements of the non-spawning adult cohort in the lower Fraser River were localized and less than 5 km (RL&L 1998a, 1999a). These preliminary results suggest that during the summer period, most individuals do not move large distances to feed and may remain within the areas selected during the spring and early summer (RL&L 2000). Lane and Rosenau (1995), however, documented movement of juveniles from sloughs and backwaters to mainstem areas as summer progressed. Movement patterns in the middle Fraser were similar, indicating that there may not be a large geographic separation between habitats suitable for such activities as feeding and overwintering. Movement patterns in the upper Fraser are not well known.

Fall Movements to Overwintering Areas.— The fall migrations of white sturgeon in the Fraser River drainage is defined in RL&L (2000) as sustained, unidirectional movements (a movement in either an upstream or downstream direction but not both) likely for overwintering purposes. These movements were usually exhibited by individuals during the late summer to fall period. The fall migration was typically followed by a prolonged period of reduced activity (RL&L 2000).

The non-spawning adult cohort of white sturgeon in the lower Fraser River exhibited mainly localized movements during the fall (RL&L 1998a, 1999a). These results indicate that areas suitable for feeding and overwintering are likely in close proximity in the lower Fraser River.

Fall movements by white sturgeon in the middle Fraser were variable, although most did not exceed 10 km (RL&L 2000). Some white sturgeon in the middle Fraser River may not move much to feed and overwinter, whereas others may move extensively, possibly between preferred areas (RL&L 2000). Seasonal movement patterns in the upper Fraser are not well known.

As noted earlier, data from the Albion test fishery suggest that white sturgeon in the lower Fraser respond to salmon and eulachon resources, resulting in downstream movements in the spring, and upstream movements in the late summer and fall (Nelson et al. 2004). Tag recapture data collected under the Lower Fraser River White Sturgeon Monitoring and Assessment Program (FRSCS 2004) have illustrated directed upstream migrations of sturgeon in the fall, mostly from the extreme lower river and estuary into the mid and lower Fraser Valley (Stave River mouth to the Harrison River mouth). In addition, annual observations of adult sturgeon abundance in the fall occur in the Harrison River between the confluence with the Fraser River and the outlet of Harrison Lake. These concentrations of large sturgeon coincide with sockeye, chum, and pink salmon spawning and die-off events. Tag recapture data from sturgeon captured in the Harrison River confirms that many of these fish also reside in the Fraser mainstem (FRSCS 2004).

Overwintering.— Results of telemetry studies conducted during the winter indicate that some white sturgeon in the Fraser River move less than 2 km during this period, with only a few individuals moving more than 5 km (RL&L 2000). Reduced activity was generally observed from October to March (RL&L 2000, Nelson et al. 2004). Individuals in all stock groups tended to utilize deeper, lower-velocity areas during the winter period. In some portions of the Fraser River drainage (e.g., Nechako River, Sinkut Ranch area), white sturgeon also used these same areas for feeding activities (RL&L 1999d).

In the lower Fraser River, the abundance of white sturgeon intercepted in the Albion Test Fishery in October and November, and tag recaptures during these months (FRSCS 2004), suggest that white sturgeon can remain highly mobile until well into December. It appears that sturgeon in the lower river concentrate in deep or low energy locations and remain there for at least 2.5 to 3 months, from approximately mid-December to mid-March (T. Nelson, FRSCS, pers. comm.). Although only a few sturgeon “overwintering” locations have so far been identified in the lower Fraser, these locations appear to attract and hold large numbers of sturgeon annually.

White sturgeon in other watersheds have been documented as being relatively inactive (in terms of in-river movements) during the winter period (Apperson and Anders 1991, Brannon and Setter 1992, RL&L 1994). Apperson and Anders (1991) determined that Kootenai River white sturgeon used deeper, calmer habitats during the winter period to recover metabolic energy expended for spawning and migration. A similar behaviour was noted during studies of white sturgeon in the Columbia River in British Columbia (RL&L 1994).

3.1.2 Spawning and Incubation Habitat

White sturgeon are one of the few fish species in British Columbia that spawn during the peak freshet period in the spring. The timing of the freshet varies somewhat throughout the Fraser River watershed (
Figure 3), so spawning times may also vary among locations.

There has been a considerable amount of work done to characterize white sturgeon spawning habitats, but much of the information has come from regulated rivers (e.g., Parsley and Beckman 1994, Parsley et al. 1993, Paragamian et al. 2001). Those studies indicated strict requirements for deep, swift water and coarse substrates. Parsley et al. (1993) characterized spawning habitat in the Columbia River below McNary Dam as having a 0.8 to 2.8 m s^{-1} mean water column velocity, and boulder and bedrock substrates. Mean water column velocities typically range from 0.5 to 2.5 m s^{-1} at most sites studied. The recommended spawning velocity for the upper Columbia River is 1.7 m s^{-1} or greater with water depths of 4 m or greater (UCWSRI 2002).

As noted, Parsley et al. (1993) characterized spawning habitat in the Columbia River as having boulder and bedrock substrates. Spawning has occurred in the Kootenai River in an area characterized by large mobile sand deposits but this area is believed to result in extremely poor egg survival, since eggs collected from here have been coated in sand (Duke et al. 1999). Spawning was observed in 2004 in the Nechako River over substrates dominated by gravel and fines, and these substrate conditions appear to be associated with the ongoing recruitment failure (McAdam et al. 2005).

Evidence from the lower Fraser River indicates that white sturgeon utilize large side channels for spawning (Perrin et al. 2003) as well as more turbulent areas downstream of the Fraser canyon (RL&L 2000). Perrin et al. (2003) conducted extensive sampling for eggs and embryos in both mainstem and side channels, and found evidence for spawning only in side channels. Physical characteristics of the side channels included gravel, cobble and sand substrates, and mostly laminar flows with near-bed velocities averaging 1.7 m s^{-1}. Boulder and cobble predominated in the mainstem study site. All sites were within a portion of the lower Fraser that is unconfined and largely unaffected by floodplain development. Coutant (2004) noted that successful spawning is most often associated with turbulent or turbid river sections areas upstream of floodplains, and the fact that many floodplains are now unavailable or severely diminished may be largely responsible for recruitment failure in this species.

White sturgeon likely produce infrequent, strong year classes even under historical circumstances (Jager et al. 2002). Individuals have high fecundity, late maturation, and high mortality in early life stages. Species such as white sturgeon are sustained by infrequent episodes of highly successful recruitment, which occurs when annually varying environmental conditions are favourable (Winemiller and Rose 1992).

3.1.3 Juvenile Habitat

Lane and Rosenau (1995) described spring and summer juvenile (<1 m in length) habitat in the lower Fraser River as the lower reaches of tributaries, large backwaters, side channels and sloughs. They indicate a depth > 5 m, low velocities, 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/migration from sloughs and backwaters into mainstem areas as summer progressed. Data from the middle Fraser River (between Boston Bar and French Bar Canyon) indicate that larger juveniles occupy the same areas as those used by adult fish (RL&L 2000). This is similar to results from the Columbia River where smaller released hatchery-reared white sturgeon were observed in habitats similar to adult habitat (Golder 2003b); results from this study have not yet been published.

In the upper Fraser, young white 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). Parsley et al. (1993) defined physical habitat for juvenile white sturgeon in the lower Columbia River (downstream of McNary Dam) as 2 to 58 m depth, 0.1 to 1.2 m s^{-1} mean column velocity, and near-substrate velocity of 0.1 to 0.8 m s^{-1}. Young-of-the-year were collected at sites with the following characteristics: 9 to 57 m depth, 0.2 to 0.6 m s^{-1} mean water column velocity, and 0.1-0.6 m s^{-1} near-substrate velocity. These observations suggest that juvenile white sturgeon may be found at a range of depths, but that they prefer slow to moderate water velocities. Ktunaxa Nation elders have historically observed juvenile sturgeon (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). Unfortunately, there is not much information on juvenile habitat preferences in the Fraser watershed, and we do not know how well data from regulated systems reflects preferences in the Fraser.

3.2 Characteristics of the Fraser River

3.2.1 Physical Characteristics

The Fraser River stretches almost 1400 km from its source at Mount Robson in the Rocky Mountains to the metropolitan area of Greater Vancouver (
Figure 2). It drains approximately 240,000 km^2, or roughly one-quarter of British Columbia. The Fraser Basin is made up of 13 major sub-basins: upper Fraser, Stuart-Takla, Nechako, Quesnel, West Road-Blackwater, Chilcotin, Middle Fraser, North Thompson, South Thompson, Thompson-Nicola, Bridge-Seton, Lillooet-Harrison, and the Lower Fraser & Estuary. The Fraser River exhibits variable river conditions and surrounding topography. An overview of geophysical conditions based on RL&L (2000) is presented here.

The upper Fraser River between Tête Jaune Cache and Prince George is typified by a broad, relatively shallow channel where cobble/gravel bars and islands are prevalent. The river channel narrows and water velocities increase, in several localized sections of the river (e.g., the Grand Canyon area). In the middle Fraser section downstream of Prince George to Soda Creek, the channel is similar; however, it eventually becomes a series of tight meanders within a broad valley bottom. Water velocities and depths are generally moderate and turbulent and up-welling flows are present in only a few areas (e.g., Hawks Creek area, French Bar Canyon). Depositional areas, often associated with the capture of white sturgeon, are moderately abundant and found near broad bends in the river channel (RL&L 1998c).

Near Lillooet, the Fraser River enters a bedrock canyon and becomes tightly confined with fast and turbulent flows. Eddy and depositional areas are uncommon in this section. As the Fraser River exits Bridge River Rapids and flows south toward the confluence of the Thompson River, the valley widens and large channel meanders and depositional areas become more prevalent. Water velocities are generally lower and areas of turbulence and upwelling are less common compared with upstream sections. Large backwater and eddy areas are abundant and are usually found in association with depositional habitats (RL&L 1999b).

From the Thompson River confluence to Boston Bar, the Fraser River is often restricted by bedrock valley walls. The Thompson River adds considerable volume to the Fraser River, resulting in higher velocities, with an increased abundance of turbulent rapids. Nearshore depositional areas are moderately abundant throughout this section, but are usually found in areas where the channel is broader and water velocities are lower (RL&L 1999b).

Downstream of Boston Bar the Fraser River is narrowly confined by bedrock cliffs, and there are numerous areas with extreme high-flow conditions. Rapids are common, with depositional areas distributed sporadically downstream to Yale (RL&L 1999b). The Fraser River below Hope exhibits a low gradient and braided channel form as large side-channels, marshes, and backwater sloughs become more prevalent (RL&L 1999a). Substrates are more depositional, with higher concentrations of fine sediment and small gravel. Below Hope the Fraser River becomes a multi-threaded channel with wooded islands and gravel bars. Downstream of Chilliwack the morphology is similar, but dykes built for flood control are common, limiting access to the floodplain in all but extreme flow events. Municipal and agricultural development have taken over most of the floodplain below Chilliwack (Boyle et al. 1997).

3.2.2 Flow Regime

There are no dams or water diversions on the mainstem Fraser River, and there is currently provincial legislation prohibiting their construction on the Fraser mainstem. Dams and diversions do exist in two of 13 major sub-basins (the Nechako and Bridge-Seton watersheds) meaning that Fraser River discharge is somewhat influenced by regulated inflows; this influence is attenuated downstream from the confluence of these tributary rivers.

Flow in the Fraser River is influenced by precipitation and climate over a very large area, and can therefore be highly variable among years and locations. Flows follow a classic interior snowmelt-driven pattern, with stable low flows in the winter, increasing flows during the spring (as winter snows melt), high flows during the late spring and early summer, tapering through the summer and fall (as snowmelt subsides, Figure 3). Discharge increases substantially over the ~1400 km length of the river as the many sub-basins contribute to river flow; peak flows increase almost tenfold from McBride to the Greater Vancouver area. The general shape of the hydrograph is similar throughout the watershed, but the timing of peak snowmelt is somewhat later as one moves upstream. In contrast, the measured difference between high and low flows increases as one moves downstream (Figure 3).

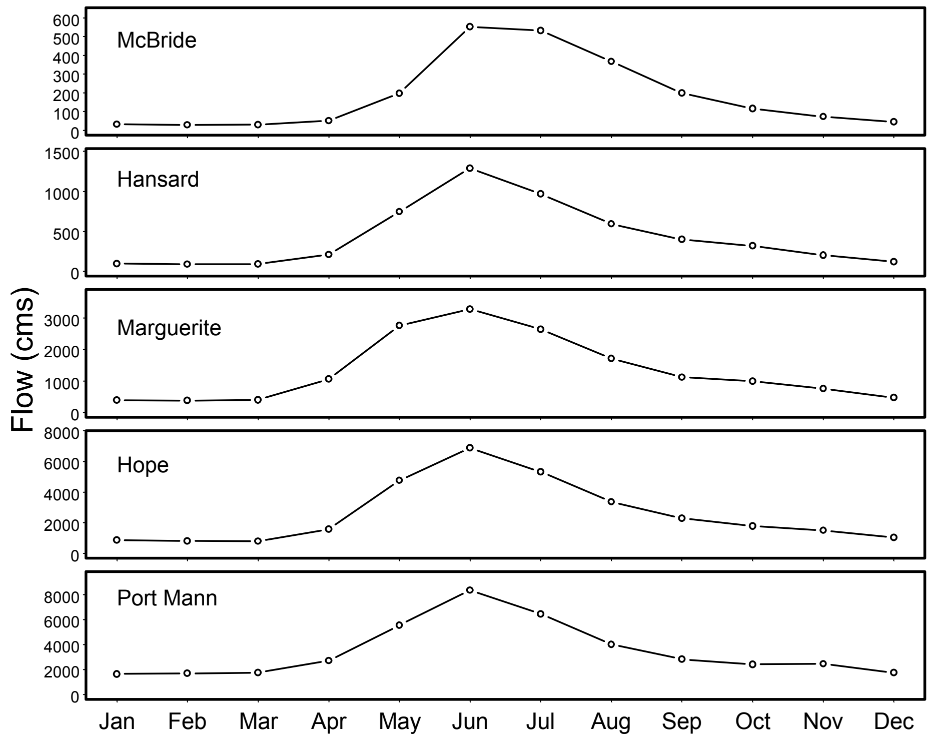

Figure 3. Streamflow (median monthly flows) at different points within the Fraser River mainstem. Note difference in Y-axis (Flow) scales among locations.

The historic flow record at Hope indicates that the timing of peak flows in the Fraser River has been getting earlier in the year (McAdam 1995). Climate change modeling indicates that this trend is expected to continue (Morrison et al. 2002). The modeling also indicates by 2080 a modest rise of 5% in annual runoff, a substantial decline in average peak flow (1600 $m^3 s^{-1}$), and a shift toward rainfall-dominated runoff in some years. The implications of these predicted flow changes for fish and fish habitat are uncertain.

3.2.3 Water Quality

The Fraser Basin is home to approximately two thirds of British Columbia's human population, and generates 80% of the province's economy. As a result, the Fraser River acts as the receiving waters for a wide variety of point and non-point source pollutants. These pollutants are introduced over a broad geographic scale. In the upper reaches of the watershed, effluents from pulp mills at Prince George, Quesnel, and Kamloops, treated municipal sewage effluents from Prince George, Quesnel, Williams Lake and Kamloops, and non-point sources of pollution from agriculture, forestry, and urban areas are the main human influences on water quality. In the lower river, industrial, agricultural and urban point and non-point discharges and spills are greater, related to the substantial human population densities, activities and use.

On the mainstem Fraser River a wide variety of water quality parameters (major ions, trace elements, nutrients, colour, dissolved and suspended solids, pH, temperature, fecal coliforms and adsorbable organo-halides [AOX, an indicator for chlorinated compounds such as chlorinated phenols, dioxins and furans]) are monitored at the following locations: Red Pass (near the headwaters); Hansard (confluence of the Bowron River); Stoner (~30 km downstream of Prince George); Marguerite (halfway between Quesnel and Williams Lake); Hope; and in the Lower Mainland. Recent analysis of water quality trends at these locations has been published by Ministry of Environment, Lands and Parks, and Environment Canada (1996a, 1996b, 1997, 2000).

Throughout the Fraser River, the water is considered well-buffered to acid inputs. There were no concerns or environmentally significant changes from 1985 through 1994 at Red Pass or Hansard, in the upper Fraser River. Improving trends in water quality were observed at Stoner, Marguerite and Hope; each of these locations showed an improving trend in adsorbable organo-halides (AOX) and chloride, a result of reduced concentrations in the effluents of upstream pulp mills. AOX and chloride compounds are toxic to aquatic life and have been substantially reduced in the Fraser River in recent years. For example, by 1995, chlorinated phenols in the Fraser River at Hope were no longer detectable and met MWLAP water quality objectives. Fraser River bottom sediments in the Lower Mainland also indicated a decline in lead concentrations from 1985 to 1996, a result correlated with the declining use of lead in gasoline.

The studies found no increasing trends through time that might jeopardize aquatic life, wildlife, drinking water, livestock, irrigation, or recreation; however, there is a trend toward declining water quality with distance downstream from the headwaters. For example, 14 water quality indicators (colour, fecal coliforms, non-filterable residues, ammonia, vanadium, molybdenum, turbidity, barium, nickel, chloride, sodium, phosphorus, copper and AOX) had higher values at Marguerite than the upstream station at Hansard.

Published work indicates the potential for a pollutant effect on white sturgeon. Some industrial pollutants have been shown to be particularly toxic to early life stages of white sturgeon. Didecyldimethyl-ammonium chloride (DDAC), used as an antisapstain, pesticide, and disinfectant by the lumber industry, is highly toxic for white sturgeon larvae (Teh et al. 2003). DDAC and other antisapstain fungicides, commonly used in lumber mills along the lower Fraser River, were about 1,000 times more toxic to white sturgeon fry than to rainbow trout (Bennett and Farrell 1998). Nener (1992) found that heavy metals associated with slag in the Columbia River proved toxic to juvenile white sturgeon. Susceptibility of white sturgeon to a wider variety of diet- or water-borne pollutants remains untested.

Despite the broad variety of pollutants present in the lower Fraser River, analysis of carcasses from the 1993/94 adult mortalities indicated relatively low levels of pollutants (McAdam 1995). This may be due to an adult diet that consists largely of salmon and eulachon (prey species that are predominantly marine), which may suggest that adult white sturgeon in the lower Fraser may be less prone to local pollutant effects that could be bioaccumulated through their food supply. However, since juvenile white sturgeon depend on locally-derived food supplies such as benthic invertebrates and young fish, they may be more susceptible to pollutants. Toxins from discharges or spills may also have sublethal effects such as reduced survivability or fertility, but these effects are difficult to assess.

In the mid-1990s, six white sturgeon were captured in the middle Fraser River downstream of major pulp mills and assessed for concentrations of mercury, dioxins, furans and coplanar PCBs (MacDonald et al. 1997). For all six fish the levels of mercury in white muscle and liver tissue exceeded the limit recommended for people with high weekly consumption rates, and levels in two of the fish exceeded the provincial tissue residue criteria for people who consume low quantities of fish (Ptolemy and Vennesland 2003). 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) were assessed in liver, white muscle, and red muscle. Many of the red muscle and liver samples exceeded the Health Canada working guidelines for the protection of human health (1990).

The effects of various other toxins and pollutants on the health of Fraser River white sturgeon are not known, but may constitute a threat based on the effects observed in developing embryos of other fish species (Walker et al. 1991, 1992, Spitsbergen et al. 1991).

3.2.4 Water Temperature

The metabolic rate of fishes is directly related to ambient water temperature, making temperature a key environmental variable that can affect the status of fish habitats. Prior to the initiation of spawning, white sturgeon appear to require water temperatures above certain threshold levels; these threshold values may vary by stock group and location across their range (UCWSRI 2002, US Fish and Wildlife Service 1999). Temperatures in excess of 20 ˚C are known to be stressful or harmful to many fish species in the Fraser River. One of the principle effects of altered temperatures on white sturgeon is a decline in egg viability at temperatures in excess of 20˚C (Wang et al. 1985). Elevated winter and summer temperatures may alter bioengergetic requirements, and thereby affect reproductive condition. Elevated temperatures may also affect susceptibility to disease. Higher-than-normal temperatures in 1993 and 1994 were implicated as one of the multiple causes responsible for adult mortalities in the lower Fraser River (McAdam 1995). Mid-summer sturgeon interception data from First Nation gill net monitoring activities in the mid-Fraser valley since 2000 suggests increasing mortality rates with increasing water temperatures (FRSCS 2004).

Summer water temperatures have been recorded at Hells Gate since the early 1940s, but other locations have been consistently monitored only relatively recently. Summer mean temperatures in the Fraser River at Hell's Gate range from 15 ˚C to 19 ˚C. Long-term trends indicate that the summer mean temperature has increased from 1941-98 (MWLAP 2002); based on data from 1953 to 1998 the rate of change is 0.022 ˚C per year, or 2.2 ˚C per century (Morrison et al. 2002). Trend data are available only for the Hells Gate site, but presumably reflect patterns in much of the watershed.

Climate change modeling indicates that this trend is expected to continue (Morrison et al. 2002). The modeling suggests that by 2080 extreme temperatures will become much more common, particularly below the Thompson River confluence (Morrison et al. 2002). The implications of increased summer water temperature may be severe for migrating salmon (Cooke et al. 2004); since sturgeon do not undertake obligatory long-range migrations during summer, the implications of increased summer water temperature for sturgeon are uncertain. However, reduced availability of salmon for food would likely affect sturgeon negatively.

3.3 Trends in Habitat

White sturgeon habitat has declined in both quality and quantity in British Columbia. The regulation of river flows has had a large influence on habitat in the Columbia, Kootenay and Nechako systems. The effects of dams are numerous, including creation of migration barriers, changes to water quality (temperature, turbidity, etc.), streamflow patterns, water temperature, physically suitable habitat, and, potentially, changes in species composition. Dams do not exist on the Fraser River mainstem; dams on tributary systems may have reduced accessible white sturgeon habitat (e.g., Seton River watershed, British Columbia Ministry of Fisheries et al. 2000), but have likely had little effect on white sturgeon habitat within the mainstem itself (Hatfield and Long 2004).

The loss and degradation of aquatic habitat from human activities other than dams has occurred throughout the Fraser Basin, but floodplain impacts have been greatest downstream of Hope. Historically, significant flooding occurred annually along the lower Fraser during the spring freshet, which resulted in large tracts of swampy or marshy land (North and Teversham 1984, Perry 1984 cited in Boyle 1997). Sumas Lake varied in size from 32 to over 100 km^2 depending on water levels in the Fraser River (Schaepe 2001, Woods 2001), and was drained completely in 1920 for development of agricultural lands. The lake was shallow and marshy, and likely used by most fish species in the lower Fraser. Boyle et al. (1997) estimate that wetland area has declined from about 10% of the land area downstream of Hope to about 1%, with most changes occurring before 1930 (Boyle et al. 1997). Dyking in the Fraser Basin started as early as 1864; most of the approximately 600 km of existing dykes were constructed during the first half of the 20^{th} Century (MWLAP 2002). Alteration and destruction from dredging, gravel mining and channelization have also occurred, and are ongoing particularly in the lower Fraser River (Lane and Rosenau 1995, RL&L 2000, Rosenau and Angelo 2000). Dyking and wetland drainage has not been widespread on the Fraser River mainstem upstream of Hope due to topography and the limited presence of wetland areas.

Contamination of water and sediments is a concern within, and downstream from, areas of high human use. With the Fraser Basin supporting most of the province's economy and human population, the Fraser River acts as the receiving waters for a wide variety of point and non-point source pollutants. Trends in water quality and contamination are discussed in Section 3.2.3.

3.4 Critical Habitat

Identification and protection of "critical habitat" is vital for management of species at risk. While defining critical habitat is one of the most challenging aspects of species management, it is vital to ensuring a species' long-term survival. This rationale is central to endangered species legislation in general, and specifically to the Species at Risk Act (SARA), where critical habitat is defined as:

> *"…the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in a recovery strategy or in an action plan for the species."* [s. 2(1)]

The need to designate and protect critical habitat is clearly recognized by scientists, resource managers, and the general public. However, definitions and guidance for identifying critical habitat remain vague, and there is at present only limited guidance for identifying critical habitat in practise.

Despite its complexity, the core issue is the same for all species: to determine the role of habitat in population limitation, and to answer the question, "How much of the different habitats is required to maintain viable populations of the species?" Time and resources are seldom available to assess all aspects of habitat's role in population limitation, so biologists should focus research efforts on examining those habitats most likely to be limiting the species of interest.

At this point in the process of conservation planning for Fraser River white sturgeon we are able to delineate some habitats that are important, but we are as yet unable to provide a defensible demarcation of critical habitat. We therefore propose a series of tasks that should be undertaken to allow delineation of critical habitat for white sturgeon in the Fraser River:

1. develop a better understanding of habitat use by different life stages of white sturgeon;
2. review of historic and current habitat availability;
3. review of historic and current population abundance;
4. undertake a review and analysis of life-stage specific population parameters (e.g., survival and fecundity);
5. undertake specific population modeling (e.g., elasticity analysis, see Gross et al. 2002) to explore which life stages are most limiting to Fraser River white sturgeon abundance;
6. to the extent possible, establish a functional relationship between habitat and abundance; and
7. use population targets and relationships between habitat types and abundance to determine how much of the different habitats is required to maintain viable populations of Fraser River white sturgeon.

The precise nature of each task will need to be developed during detailed planning stages in the future.

4. VALUES

White sturgeon occupy a significant position in the spiritual, aesthetic and economic history of the peoples of British Columbia. Sturgeon have traditional cultural values to many First Nations in British Columbia and these values continue to be maintained. The predominant value of Fraser River white sturgeon to non-aboriginal communities has shifted considerably over the last century as general environmental awareness has increased; values have changed from one of a natural resource commodity to one in which white sturgeon are also appreciated in their own right (as a species), and as a component of a healthy ecosystem. There have been no long-term studies of the value of white sturgeon; however, a variety of data sources can be used to describe some of the values over time, and these are outlined below.

4.1 Commercial Fishing

A commercial fishery for Fraser River white sturgeon crashed in the early 1900s, but white sturgeon were routinely retained as by-catch in the salmon net fishery and sold commercially. Since 1994 all sturgeon in the Fraser River and elsewhere in BC including by-catch, must be released, by regulation. Demand for sturgeon meat and caviar has apparently remained high, and this is underscored by evidence of continued poaching of white sturgeon (Long et al. 2004). It seems safe to conclude that there is sufficient demand for white sturgeon meat and caviar to support commercial fishing activities should a fishery ever be re-established for this species.

4.2 Recreational Angling

Recreational fishing in BC is regulated by DFO within tidal waters and MWLAP within non-tidal waters. The jurisdictional boundary between federal (tidal) and provincial (freshwater) is the Mission Highway 11 Bridge. Over the years, angling regulations for white sturgeon have varied considerably in the lower Fraser, partly as a result of these different jurisdictions. Since 1994 regulations have been coordinated, and now dictate that all recreationally caught sturgeon must be released in all tidal and non-tidal waters of British Columbia. Further, directed fisheries for sturgeon are not permitted in the Nechako, Columbia or Kootenay watersheds.

Prior to 1991 anglers required special sport fishing permits to fish for sturgeon in nontidal waters of the Fraser River. The sturgeon permits were primarily used to enforce an annual quota, as anglers were required to record any fish harvested. Inglis and Rosenau (1994) analysed angler cards for the lower Fraser to estimate fishing activity between 1986 and 1991. Over this six-year period the number of sturgeon fishing permits issued by the province almost tripled to more than 3,000, presumably reflecting an increase in demand for angling sturgeon. The total number of reported fishing days per year remained fairly constant over this period, at an average of 2,956 (range = 2,520 to 3,823) with less than 50% of the cards returned each year. Based on this return rate, an expanded estimated effort of 8,901 (range = 6,592 to 10,641) days was calculated (Inglis and Rosenau 1994). Following closure of the retention fishery for sturgeon in 1994, permits were no longer required and this source of data is not currently available, however, recreational angling effort for white sturgeon in the lower Fraser River is believed to be substantial and increasing (E. Stoddard, MWLAP, pers. comm.). Gislason (2004), using interviews and surveys with professional fishing guides and data from MWLAP guide reports, indicates that the Fraser River white sturgeon recreational fishery is substantial and growing. In the analysis, the non-guided recreational fishery is projected to have over 9,000 angler days in 2005, almost all of this in the lower Fraser. Historic data and casual observation of recreational angling activity confirm that the demand for catch and release white sturgeon angling is high and growing.

There are no data for recreational fishing in the upper Fraser (D. Cadden, MWLAP, pers. comm.), but recreational fishing directed at this population is assumed to be low or non-existent at present. In the mid Fraser there is considerable recreational fishing activity around the Lillooet area; however, no specific data are available in terms of angler days or fish caught (I. McGregor, MWLAP, pers. comm.). The Nechako River has been closed to sturgeon fishing since 2000.

4.3 Guided Angling

A large component of recreational angling for lower Fraser white sturgeon is the commercial guiding industry. The guiding industry for white sturgeon is estimated to represent 60% of the total recreational fishery for white sturgeon. The industry is regulated by MWLAP only in non-tidal waters, and guides must submit annual reports of their activities and obtain operating permits every year. There are currently 45 to 50 guiding operations with 50 to 60 operators projected for 2005 (Gislason 2004). Many of the guides target more than one species depending on time of year and client demands, but white sturgeon account for a considerable number of guided fishing days: 15,500 guided angler-days in 2004, with projections of 20,000 guided angler-days in 2005. The white sturgeon guiding industry is thought to generate considerable economic activity; 2005 revenues are projected at more than M$6.4, with additional "coat-tail" effects in the tourism industry (e.g., meals, accommodation, etc.) that are believed to be considerable (Gislason 2004). The industry has expanded at a rate of 30% to 40% in recent years (Gislason 2004) and is expected to continue to grow.

Most of the white sturgeon guiding industry is based in the lower Fraser; there is at present only a very limited guiding industry for white sturgeon above Hells Gate in the mid Fraser. In recent years, only two guides have operated on the mid-Fraser between Spuzzum and Bridge River. In 2002, a total of 60 BC resident days and 97 released sturgeon were reported for the mid Fraser (based on one guide). In 2003, a total of 54 BC and 14 Canadian resident angler-days, and 96 released sturgeon were reported (based on two guides). No numbers were reported for 2004 (I. McGregor, MWLAP, pers. comm., based on submitted guide reports).

Prior to the general closure for sturgeon fishing in the Nechako, a single licensed guide operated on the Nechako for 3 years. After the closure, this guide tried unsuccessfully to guide in the upper Fraser between Prince George and McBride for a very short period and is no longer operating (D. Cadden, MWLAP, pers. comm.).

4.4 Aboriginal Fishery

White sturgeon have long been important to First Nations in the Fraser Basin and remain significant in the culture, teachings and traditions of Aboriginal people today. In the lower Fraser River, sturgeon were harvested until 1994, when Sto:lo Nation, with support from member bands, expressed concern about stock status and initiated a moratorium on harvesting white sturgeon. Federal and provincial agencies followed suit shortly thereafter with "no harvest" restrictions on commercial and sport fisheries. White sturgeon are no longer targeted directly by aboriginal set or drift net fisheries, but they may be caught incidentally during salmon fisheries. Intercepted sturgeon are voluntarily released unharmed if they are in good condition, but dead sturgeon may be retained. The sturgeon component of the aboriginal net fishery prior to the 1994 decision was reported in Schubert (1984, 1985, 1986) and MacDonald (1987, 1988, 1989, 1990, 1991, 1992). Data from these reports clearly indicate that white sturgeon are a valued component of the aboriginal fishery and would be retained more readily in the future if conditions permit.

4.5 Scientific Inquiry

White sturgeon continue to fascinate scientists and there are a variety of ongoing studies into the biology of this species, and more broadly into sturgeons as a group. Active research is currently underway as part of the Columbia and Nechako Recovery plans. Recent funding for a white sturgeon research facility at Malaspina College is a further indication of the level of interest in this species. Using "white sturgeon" as search words, a query of the Aquatic

Sciences and Fisheries Abstracts database returned 322 scientific references on this species, and 2106 scientific references on sturgeon as a group.

4.6 Aquaculture

Sturgeon aquaculture is a relatively new endeavour in BC and there is only one commercial operator currently licensed. The industry has requested access to wild Fraser River white sturgeon to bolster their broodstock. Their present broodstock was obtained from Malaspina College, which itself obtained broodstock from captive sources, including fish that had been legally or illegally captured and held in ponds. To date, only a small amount of commercial product has been offered for sale and it is unclear whether BC could support a major sturgeon aquaculture industry given competition factors with US facilities that can take advantage of naturally warmer water sources.

4.7 Other Values

White sturgeon have a high intrinsic value to the public. As a result, outreach programs such as those that occur for the Nechako, Columbia and Kootenay stocks have been successful in developing broad public interest in conservation efforts. A further indication of this high intrinsic value has been the formation of and long-running interest in the Fraser River Sturgeon Conservation Society, with its large membership and substantial profile in the region.

5. THREATS AND REASONS FOR DECLINE

Fraser River white sturgeon are divided into four distinct stock groups (Smith et al. 2002; Figure 2), and the threats and challenges facing the species vary among these different stocks. For the most part the threats can be described but not quantified. Despite difficulties with quantification, in many cases there is considerable evidence that a specific threat is real.

Conservation threats to Fraser River white sturgeon most often involve one of the following mechanisms: changes in water quality, instream habitat alterations, or harvest. Each of these can affect white sturgeon in both direct and indirect ways. For example, river regulation can directly influence the abundance and distribution of physical habitat in a river, but it may also act in subtle ways that are more difficult to test such as the alteration of behavioural cues or changes to the broader ecological community. The threats are summarized in an influence diagram (Figure 4), which shows possible pathways linking human activities to consequences for white sturgeon. There are numerous potential pathways, but some are believed to be of greatest influence in limiting sturgeon abundance and distribution.

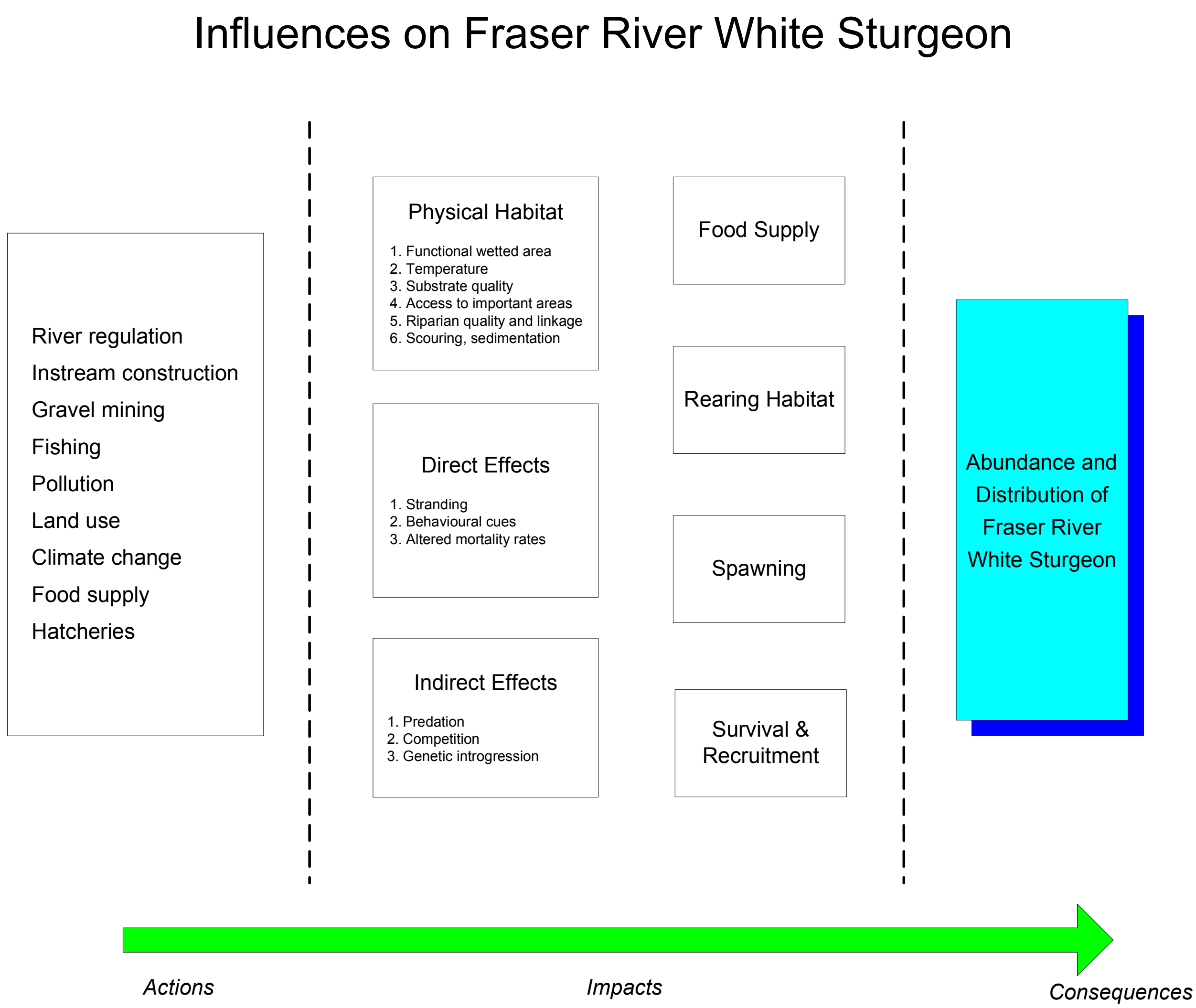

Figure 4. Influence diagram of hypothesized pathways linking an assortment of human activities to consequences for Fraser River white sturgeon. Changes in abundance and distribution of sturgeon may arise in a wide variety of ways. For example, river regulation can directly alter the available physical habitat, and it may also influence the behavioural cues for spawning. Since there are many possible pathways between actions and consequences all hypothesized pathways are not indicated.

5.1 Threats

Threats are presented and discussed here as 15 "impact hypotheses," hypothesized mechanisms that influence abundance, distribution and health of white sturgeon. Many of the impact hypotheses grew out of earlier work on white sturgeon in the Nechako, Columbia and Kootenay Rivers (Korman and Walters 2001, NWSRI 2004, UCWSRI 2002). The hypotheses are summarized in Table 3 and then presented individually (in alphabetical order). Additional discussion of these impact hypotheses is presented in Hatfield et al. (2004) and Hatfield and Long (2004). Not all impact hypotheses are equally valid for each stock group, and there are differing degrees of support for each impact and its ability to influence the abundance, distribution and health of white sturgeon in the Fraser River. Procedures and results of assessment and prioritization of the impact hypotheses are presented in Section 5.2.

Table 3. Summary of impact hypotheses considered for Fraser River white sturgeon. Impacts are listed by type, and the affected stock groups are indicated. Note: this plan does not discuss in detail the impacts and proposed management actions for Nechako white sturgeon, but the impacts are summarized in this table for reference since the Nechako is one of the major sub-basins within the Fraser.

Impact Hypothesis	Present relevance			
	Lower Fraser SG1	Mid Fraser SG2	Upper Fraser SG3	Nechako SG4
Change in ecological community	?	?	?	?
Disease	?	?	?	?
Effects of small population size		?	✓	✓
Fishing effects	✓	✓	✓	✓
Food supply	✓	✓	✓	✓
Habitat — In-channel rearing habitat	✓			✓
Habitat — Off-channel rearing habitat	✓			✓
Habitat — Spawning habitat	✓			✓
Hatchery effects	✓	✓	✓	✓
Hydrograph components				✓
Macrophyte development				✓
Pollution	✓	✓		
Sequential years of adequate flows				✓
Thermal regime	✓			✓
Turbidity				✓

5.1.1 Change in Ecological Community

Hypothesis.— Changes in the broader aquatic community lead to altered predation and competition with concomitant effects on white sturgeon survival and recruitment.

Potential Influences: Flow regulation, species introductions and movements, fishing effects, habitat alteration, climate change.

Description.— River regulation can affect a wide variety of species, altering relative abundance and distribution as a result of changes to flow patterns, temperature, and other factors. Increased abundance of predators or competitors of white sturgeon, for example an increase in some cyprinids is hypothesized in the case of the Nechako River. Predation on juvenile sturgeon may therefore have increased in comparison to historic levels.

Assessment.— This hypothesis was given a “high” plausibility rating at the Nechako River White Sturgeon Recovery Planning Workshop in October 2000 (Korman and Walters 2001) in part due to the observed time lag between dam construction and white sturgeon recruitment decline, which conformed with a time lag that would be expected for an increase in predators. The Nechako White Sturgeon Recovery Initiative (NWSRI) focussed on the predation aspect of this hypothesis and rated it as a moderate priority. This hypothesis does not explain any of the recruitment variation prior to the major changes in the 1960s. Predation risk would presumably increase with other factors affected by flow, such as increased fine sediment on the bed and reduced turbidity, and therefore may be one of several causes of declines in survival.

Uncertainties and Data Gaps.— The relative abundance and distribution of potential predators before and after Nechako flow regulation is not known. Studies that have been conducted in the Fraser watershed have focussed on salmon, which are not anticipated to have a direct interaction with white sturgeon other than a potentially significant reduction in food supply. We do not know the functional relationship between predation and successful sturgeon recruitment, or whether predators are capable of or responsible for a large reduction in sturgeon survival.

5.1.2 Disease

Hypothesis.— Disease poses a significant risk to Fraser River white sturgeon.

Potential Influences: aquaculture, thermal regime changes (e.g., climate change, river regulation), introduction of pathogens, introduction of toxic pollutant stressors.

Description.— Several parasites and diseases of white sturgeon are known to be present in British Columbia. We do not know the risks associated with other diseases and their vectors or mechanisms of spread. However, we do know that the risks of disease outbreak increase under conditions where fish are stressed (e.g., high temperature). The movement of large numbers of fish between watersheds (e.g., release from hatcheries) is probably the greatest potential threat, and is amenable to control.

Assessment.— This risk is not well-defined at this time. Work on wild white sturgeon in the Columbia River has shown that manifestations (epizootics) are generally not a threat to wild fish (S. Guest, Freshwater Fisheries Society of BC, pers. comm.). Artificial culture does increase the chance of disease, and some US hatchery programs have encountered disease problems, apparently due to culture conditions. Operations at provincial culture facilities near Cranbrook have not detected any sturgeon viruses during the course of an extensive screening program. It seems reasonable to assume that disease poses a potentially greater risk to small populations than to large ones. The continued persistence of upper mainstem populations indicates the ability of these relatively small populations to persist in conjunction with naturally-occurring diseases and parasites. Federal and provincial agencies jointly regulate the importation and movement of fish in British Columbia. Under draft policy developed by provincial agencies, the importation of sturgeon from outside of the province or the movement of sturgeon between major drainages will generally not be approved. Further, effluent from hatchery facilities must be managed to address potential disease transfer issues. These actions will greatly reduce disease risk associated with culture facilities.

Uncertainties and Data Gaps.— Relative to fish such as salmon, little is known about parasites and diseases of Fraser River white sturgeon. The risks posed to long-term persistence of each stock group are therefore unclear.

5.1.3 Effects of Small Population Size

Hypothesis.— Some stock groups of Fraser River white sturgeon are sufficiently small as to be limited by one or more "population size effects."

Potential Influences: historic forces leading to small population size (e.g., food supply, habitat availability, water quality, disease, etc.), anthropogenic factors causing recruitment failure.

Description.— When populations become sufficiently small there are a number of ecological effects that may prevent the population from increasing, even if resources are not limiting. For example, the Allee effect occurs when population levels decline to the point that individuals have difficulty locating a suitable mate. In this case suitable mates may exist in the population but the probability of finding one may be low enough that a significant proportion of the population goes unmated. Other effects of small population size include genetic effects such as founder effects, inbreeding depression, or loss of genetic variance due to small effective population size. The genetic effects of small population size are similar to the problems faced by some captive breeding programs.

Assessment.— The effects of small population size have been well-studied in the fields of theoretical and empirical population genetics. The effects are well-known, but there seems little that one can do to offset them in wild populations, except to ensure that natural abundance remains well above levels where these effects might be encountered. It is perhaps better to understand and communicate these effects as a cautionary note to provide motivation for maintaining reasonable abundance of Fraser River white sturgeon.

Uncertainties and Data Gaps.— The general effects of small population size are well known. Factors such as longevity, iteroparity, and the potential for genetic mixing between many year classes may act to diminish the potential effects of small population sizes for white sturgeon. However, the precise mating patterns of each stock group of Fraser River white sturgeon is not sufficiently well-known to develop stock-specific relationships for different components of the effect of small population size. For example, we do not know at what abundance level the Allee effect becomes relevant for each stock group, nor do we know the rate at which genetic variance is lost in relation to population size.

5.1.4 Fishing Effects

Hypothesis.— Fraser River white sturgeon abundance is limited by injury or mortality induced by activities associated with specific fisheries: recreational angling, aboriginal net fisheries (drift gill net, set gill net, and seine net), commercial gill net fisheries, and illegal harvest (poaching).

Potential Influences: Recreational catch and release of sturgeon, aboriginal and commercial net fishery interception and release of sturgeon, aboriginal retention, and poaching of sturgeon.

Description.— Fraser River white sturgeon are caught both intentionally and incidentally by distinct fisheries that use a range of capture methods and gear. It is important to differentiate between the fisheries and gear types because their effects on white sturgeon abundance and distribution likely range from low to high.

Recreational Fishery - The recreational fishery for white sturgeon is a non-retention fishery. By regulation, all sturgeon must be released following capture. The levels of injury and latent mortality (released fish that die as a direct result of angling-related injuries or stress) associated with the fishery have not been studied.

Aboriginal Fisheries – In the Fraser River, aboriginal fisheries associated with food, social, and ceremonial purposes use drift gill nets (mostly downstream of Mission) and set gill nets (mostly upstream of Mission). The majority of in-river aboriginal fisheries target migrating runs of Pacific salmon, with no directed harvest of white sturgeon since 1994. Most sturgeon intercepted in aboriginal net fisheries are released unharmed if the fish are in good condition; some fish are retained when they are found dead or in very poor condition. Experience indicates that injury and mortality levels vary significantly between the two major gear types, with soak time and water temperature being two important factors. Drifted gill nets likely have low mortalities associated with white sturgeon interceptions because of the short soak time, whereas set nets tend to have a higher level of mortality because they are often left fishing overnight or longer. Sturgeon caught in set nets are more likely to suffer minimal injuries if they are lightly tangled, but many are not. Mortalities are more likely if fish are heavily tangled and not removed from the net within a few hours of capture, especially if water temperatures are high. There have been no studies to date to quantify mortality associated with gill nets.

Commercial Fisheries – Commercial net fisheries that target specific runs of Pacific salmon are regularly permitted in the lower Fraser by order of Fisheries and Oceans Canada. Although these fisheries are typically short in duration, they can be intensive. All in-river commercial net fisheries occur downstream of Mission and utilize drift gill nets. White sturgeon are captured as by-catch during these fishery openings, and by regulation, all sturgeon must be released. The number of white sturgeon captured by commercial net fisheries on an annual basis varies with the number of commercial fishery openings, and the timing and duration of these openings. There have been no quantitative assessments of the levels of injury and mortality associated with the various in-river commercial net fisheries.

Illegal Harvest (Poaching) - White sturgeon are harvested illegally (poached) for both personal consumption and for sale on the black market. White sturgeon are valued both for their meat and their roe (caviar). Capture methods used by poachers include set line, rod and reel (with legal or illegal terminal gear), and gill net. Because the intent of this fishery is retention, the mortality rate for captured sturgeon is assumed to be 100%. The actual numbers of sturgeon illegally harvested from the Fraser River on an annual basis is unknown, although estimates produced by enforcement personnel in the lower Fraser indicate that the minimum number may be several hundred animals per year. There have been no estimates of the injury rate for sturgeon that encounter illegal capture gear yet escape.

Assessment.— There have been no direct studies of injury or latent mortality levels for Fraser River white sturgeon released from recreational, commercial, or Aboriginal fisheries. There appears to be good compliance to the request to release white sturgeon from aboriginal fisheries (voluntary agreement), and recreational and commercial fisheries (regulation). The extent of poaching (i.e., number of sturgeon killed illegally on an annual basis) is not known.

Uncertainties and Data Gaps.— There are no data available to accurately assess white sturgeon injury and mortality levels associated with Fraser River recreational and commercial fisheries, and no reliable estimates of annual harvest and injury associated with illegal retention. Limited information regarding injury and mortality levels associated with First Nation net fisheries has been gathered since 2000 (FRSCS file data). Reliable information regarding injury and mortality levels is essential for all fisheries and gear types that capture sturgeon in the Fraser River, especially in light of restrictions that may come into effect if the species is listed as "endangered" under SARA. As part of an "allowable harm assessment," researchers are currently using FRSCS capture-recapture data to try to estimate mortality rates associated with the different fisheries.

Inference can be drawn from a number of sources that injury and latent mortality rates for sturgeon released from the non-retention recreational fishery are low, but this has not been specifically investigated. There is evidence of measurable mortality levels associated with aboriginal net fisheries, but the extent of this information is limited, and there has been limited effort to investigate temporal or spatial variations in mortality rates. Although sturgeon interceptions are reported during most commercial net fishery openings in the Fraser, there is no information available regarding the respective levels of mortality and injury associated with these openings. Reliable assessment programs need to be developed to address and quantify the levels of mortality and injury associated with all in-river fisheries. Assessments should determine whether there is a seasonal component associated with injury/mortality levels. For example, observed mortality levels in the 2001-03 aboriginal set gill-net fishery in the lower Fraser steadily increased from May through August with increasing water temperatures (T. Nelson, FRSCS, pers. comm.). In addition, observations at Malaspina University College suggest that wounds may heal slowly for cultured sturgeon at water temperatures < 10 ˚C (D. Lane, Malaspina University College, pers. comm.).

5.1.5 Food Supply

Hypothesis.— Abundance of Fraser River white sturgeon is proportional to the available food supply.

Potential Influences: Commercial, Aboriginal, and recreational fishing, land use (e.g., dyking), and climate change.

Description.— Diets are not fully understood for all age classes of Fraser River white sturgeon, and effects of food supply on population abundance may occur via many pathways. Humans exploit a number of anadromous and resident fish species in the Fraser River. Many of these same species form part of the food base for Fraser River white sturgeon. For example, eulachon and salmon are known to be an important food source for white sturgeon, yet are also harvested in considerable numbers. Activities other than direct exploitation in a fishery may also lead to decreased food supplies. Loss of floodplain habitat in the lower Fraser River may have contributed to decreased salmon production. The regulation of Nechako River flow has also been suggested as a cause of salmon declines in the Nechako River relative to pre-dam abundance (Jaremovic and Rowland 1988).

Assessment.— This impact hypothesis could be explored by comparing trends in sturgeon abundance with catch statistics of fish species utilized by both sturgeon and humans. Unfortunately, there are no such long-term records. As a surrogate, one could examine sturgeon growth as indicated in otoliths, fin rays, or similar structures, in relation to catch and escapement records for salmon. Growth comparison between different stock groups is being pursued to examine this sort of hypothesis for white sturgeon in the Columbia and Nechako Rivers.

Uncertainties and Data Gaps.— We do not know the extent to which abundance of each stock group is currently limited by its food supply, or the functional relationship between sturgeon abundance and food supply. There has been speculation by some sturgeon experts in BC with respect to the effects of the commercial fishery on food supply for sturgeon throughout the Fraser watershed, but the magnitude of this effect is not known.

5.1.6 Habitat — In-channel Rearing Habitat

Hypothesis.— Changes have occurred to key in-channel rearing habitats with concomitant effects on Fraser River white sturgeon abundance and distribution.

Potential Influences: Flow regulation, gravel and sand extraction, bank protection, and instream construction.

Description.— Rearing habitat for sturgeon can be directly impacted by river regulation in two important ways: changes in abundance and distribution of hydraulically suitable habitat, and geomorphic changes to instream habitats. Flows directly affect the hydraulic conditions in a river, determining the abundance and distribution of areas with suitable velocities and depths. If the regulated regime is sufficiently different from the natural flow regime then there is a potential for loss of key rearing areas. Alternatively, when flows become regulated there are often geomorphologic responses, such as changes in the river form and the substrate composition of the bed. If the responses to river regulation include physical alterations to key rearing areas then sturgeon survival may decline. For example, in the Nechako River elevated levels of sand and finer material on the bed is directly related to the lack of high flows. The resulting embeddedness and loss of interstitial spaces has the potential to reduce juvenile survival.

Gravel and sand extraction from the lower Fraser River has been occurring for many years. A moratorium on gravel extraction in the lower Fraser River was lifted in 2004 with the adoption of a five year gravel management and monitoring plan by federal and provincial authorities. The extraction process (by suction dredging in the wetted perimeter, or surface mining in the floodplain) may kill sturgeon directly via entrainment, and may disrupt or alter habitats of importance to sturgeon.

There are a variety of developments that require instream construction or ongoing use of instream habitats. For example, footings for bridges, instream log storage, streambank protection, and river marinas displace or alter instream habitats. These habitats are either permanently removed from the supply of available habitat, or the suitability of the remaining habitat is reduced. It is assumed that reductions in habitat translate into a lower carrying capacity for Fraser River white sturgeon.

Assessment.— Shifts toward a sand substrate have been identified for the Nechako River (Northwest Hydraulic Consultants 2003, Northwest Hydraulic Consultants and McAdam 2003) and the Kootenai/y River (USFWS 1999, Paragamian et al. 2001). While increased sand in the substrate clearly limits the availability of interstitial spaces, the mechanism by which this may affect white sturgeon has not been demonstrated. Interstitial spaces may be used as refuges from predators, or may provide important food sources. The Nechako recovery plan rates this as a moderate priority (NWSRI 2004), but based on more recent information (see McAdam et al. 2005) this is now regarded as a high priority. There has been little direct study of the biological effects of suction dredging (Harvey and Lisle 1998) on the Fraser River or elsewhere. One study in the lower Fraser River identified apparent young of the year white sturgeon in an area with potential for sand extraction (Perrin et al. 2003).

A tally of direct habitat losses due to industrial, agricultural, and urban development has not been conducted for the Fraser River. However, the effects are expected to be cumulative with other effects.

Uncertainties and Data Gaps.— There remains significant uncertainty about the early life history of white sturgeon and especially the habitats that they use. While changes in physical habitat have been noted for the Nechako and Kootenai/y Rivers, the linkages to white sturgeon juvenile habitat utilization have yet to be examined. This sort of effect seems less likely elsewhere in the Fraser River.

The direct effects of entrainment into suction dredges may affect sturgeon of various size classes; the extent of this effect is not known. The extent of habitat loss in the Fraser River due to gravel and sand extraction is also not known, but the key areas of present and historic extraction are well known. The importance of these areas to white sturgeon is similarly unresolved.

The functional relationship between habitat and white sturgeon abundance and distribution is not known, but it is generally assumed that abundance is proportional to the availability of limiting habitats.

5.1.7 Habitat — Off-channel Rearing Habitat

Hypothesis.— Lost access to side channel and floodplain habitats for rearing juvenile sturgeon causes declines in juvenile survival and recruitment.

Potential Influences: Flow regulation, gravel and sand extraction, and land development and use including dyking and infilling.

Description.— The use of side-channels and other floodplain components during early life history is a common feature of species that spawn during high flow periods. While limited information is available about white sturgeon habitat use during their first year, there are indications that floodplain habitats are used and are important (Lane and Rosenau 1995, Coutant 2004). The loss of these habitats can occur due to dyking, flow regulation, and modifications to the available floodplain.

Assessment.— Dyking in the lower Fraser for urban and agricultural development led to a considerable loss of floodplain wetland and side channel habitat by the 1930s (Boyle et al. 1997) with relatively smaller losses since then. However, dyking and channelization continues and current infilling is limiting or eliminating future opportunities for floodplain restoration. For the Nechako River an 85% loss of type 1 side channels occurred in the 1960s (Rood and Neil 1987), with reasonable correspondence between white sturgeon recruitment failure and the timing of these habitat changes (Northwest Hydraulic Consultants and McAdam 2003, McAdam et al. 2005). Similar patterns are also apparent for the Kootenay River (S. Ireland, Kootenai Tribe of Idaho, pers. comm., McAdam unpublished), lending support to the hypothesis that off-channel habitats are important.

Uncertainties and Data Gaps.— Coutant (2004) investigated factors affecting white sturgeon recruitment, and results indicated support for the importance of both in-channel and off-channel habitats. Although we do not know the functional relationship between shallow water habitat and sturgeon abundance, it is reasonable to assume that habitat losses translate into reduced capacity for sturgeon. To some extent off-channel and in channel impacts are associated, particularly in the lower Fraser, where dredging has coincided with dyking, so in some cases it is difficult to differentiate between the effects of each.

5.1.8 Habitat — Spawning Habitat

Hypothesis.— Alterations to key spawning habitats has had negative influences on Fraser River white sturgeon abundance and distribution.

Potential Influences: Flow regulation and diversions, land development and use including dyking, and gravel mining.

Description.— River regulation can affect spawning areas for sturgeon in two important ways: changes in abundance and distribution of hydraulically suitable habitat, and alterations to geomorphologic processes that create and maintain spawning habitat. Flows directly affect the hydraulic conditions in a river, determining the abundance and distribution of areas with suitable velocities and depths. If the regulated regime is sufficiently different from the natural flow regime then there is a potential for loss of key spawning areas. Alternatively, when flows become regulated or significant flows are diverted, there are often geomorphologic responses; for example, sand deposition has been noted in the Nechako and Kootenay Rivers. If the responses to river regulation include physical alterations to key spawning areas then reproductive success will likely decline if such areas are limiting.

Evidence from the lower Fraser River also indicates that white sturgeon spawn in large side channels (Perrin et al. 2000). This type of habitat was historically severely affected by channel modifications such as dyking and other river engineering (Ellis et al. 2004), which likely also affected both the quantity and quality of spawning habitat. Some sites within large extant side channels some with known sturgeon spawning areas are currently being mined for their gravels.

Assessment.— The hypothesis has not been tested directly in the Fraser watershed. Studies on the Nechako River identified sand accumulation in the vicinity of the recently identified spawning site near Vanderhoof (Liebe et al. 2004, McAdam et al. 2005).

Uncertainties and Data Gaps.— There are several knowledge gaps, including the historic and present abundance and distribution of spawning habitats.

5.1.9 Hatchery Effects

Hypothesis.— Hatchery fish will have negative influences on the genetic integrity of Fraser River white sturgeon stocks, if conservation or commercial aquaculture programs are initiated.

Potential Influences: Conservation aquaculture, and commercial aquaculture.

Description.— Hatchery effects are well-known for salmon, and for some other species. These effects include population effects, genetic effects, and disease transfer. Population effects occur when hatcheries release fish in sufficient numbers to displace fish of wild (i.e., non-hatchery) origin. In this case the hatcheries do not supplement wild populations, they merely replace them. This effect is well-described in the scientific literature (e.g., Hilborn 1999, Hilborn and Eggers 2000). Genetic effects occur due to a variety of processes common to many captive breeding programs including, but not limited to small effective population size, unintentional character selection, founder effects, and inbreeding depression. Ultimately, these effects lead to less genetic variation than is observed in wild populations.

There are specific risks that can and should be addressed for Fraser River white sturgeon if conservation or commercial aquaculture programs are initiated. Escapes from aquaculture operations are known to occur; escapes of a large number of closely-related individuals into sturgeon-bearing waters could have a negative impact on the genetic integrity of the wild population. For the commercial program, there is a risk that the establishment of a local market for white sturgeon meat and caviar will encourage poaching by stimulating demand, and make it easier to disguise illegally-harvested wild fish. Finally, there has not been an evaluation with respect to implications to the wild population if wild broodstock were removed from the Fraser for use in commercial aquaculture.

Assessment.— There is a significant distinction between commercial aquaculture and conservation aquaculture. Conservation aquaculture is intended to be a hatchery breeding program established for the express purpose of maintaining and enhancing the genetic integrity of a population. A conservation aquaculture program would be initiated as a step to avoid extinction, and may have a defined lifetime as part of a study program and would typically include the intentional release of cultured sturgeon into the watershed to mix with the wild population. Commercial aquaculture is a for-profit venture aimed at producing white sturgeon either as a source of fish for human consumption or as a source of eggs for caviar. Commercial aquaculture does not include the intended release of cultured sturgeon into the environment.

The proposed Nechako conservation fish culture program has been designed around a breeding plan (Pollard 2002) that would create a founder population of specific size. In so doing it also aims to maximize genetic diversity being contributed to subsequent generations. Mating would follow a structure with checks to minimize problems such as inbreeding. The breeding plan expands on a format similar to plans developed for the Columbia River (Pollard 2002) and the Kootenai/Kootenay River (Kincaid 1993).

A further consideration for the Nechako River conservation fish culture program is the potential for mixing among the four stock groups within the Fraser River, as cultured sturgeon released in the Nechako watershed can enter the mainstem Fraser River. Genetic risks have been evaluated (Williamson et al. 2003), and are considered to be low. NWSRI has deemed the risk of extinction to be greatly in excess of risks associated with conservation fish culture. In the event that cultured sturgeon are purposely released into the Nechako River, monitoring has been recommended to provide ongoing evaluation of this risk.

To date there has been little direct assessment of the threats posed by commercial aquaculture to wild white sturgeon populations in the Fraser River or elsewhere. However, provincial fisheries agencies have compiled and consulted on a comprehensive list of perceived threats associated with aquaculture and are developing policies to deal with each of these. Changes have already been made in several identified areas. There is currently only one commercial sturgeon aquaculture operation in British Columbia, located in the Sechelt area. Given its location, outside of the Fraser watershed and separated by saltwater, it is not considered to pose a high risk at this time to wild sturgeon in the Fraser River.

Uncertainties and Data Gaps.— Uncertainty regarding white sturgeon movement patterns, including use of saltwater habitats, affects the risk of genetic transfer to other stock groups, and monitoring is needed to evaluate this risk. With respect to genetic effects, the scale of the conservation fish culture program will influence its ability to avoid such affects. For example, difficulties with the capture of sufficient broodstock may limit the ability to form a sufficiently large founder population, and the effectiveness of, and commitment to, a long-term monitoring program are uncertain. Delays and uncertainty regarding funding act to increase the risks.

Existing conservation fish culture programs on the Columbia and Kootenay Rivers are enjoying good success, with excellent growth rates in released fish and monitoring plans that are working well. Improvements in brood capture and handling are adding to the success, and the long generation time of sturgeon greatly reduces the risk of genetic founder effects.

Specific quantification of the risks posed by commercial aquaculture will be difficult, but the assessment of risks from conservation aquaculture can guide a qualitative assessment. Population genetics modeling may help quantify some of the genetic risks associated with the proposed Nechako conservation program.

5.1.10 Hydrograph Components

Hypothesis.— Specific features of the natural hydrograph (e.g., a spring freshet) are biologically significant for Fraser River white sturgeon.

Assessment.— This hypothesis is believed to be not relevant at present to white sturgeon in the mainstem Fraser River. It will, however, be an issue if damming of the mainstem Fraser River or any of its major tributaries is considered. Readers interested in the relevance of this impact to stocks in the Nechako River should consult (NWSRI 2004).

5.1.11 Macrophyte Development

Hypothesis.— Macrophyte development affects juvenile sturgeon survival due to increased night time or under-ice oxygen demand in the river.

Assessment.— This hypothesis is believed to be not relevant at present to white sturgeon in the mainstem Fraser River. See NWSRI (2004) for additional information on the relevance of this impact to Nechako River stocks.

5.1.12 Pollution

Hypothesis.— Survival and recruitment of Fraser River white sturgeon is influenced by toxic pollutants in the Fraser River.

Potential Influences: Toxic spills, industrial, municipal or agricultural discharges or runoff.

Description.— The Fraser River acts as the receiving waters for a wide variety of point and non-point source pollutants, which are introduced over a very broad geographic scale. In the upper reaches of the river the main point sources are pulp mill effluent in Prince George and Quesnel, and community sewerage. In the lower river there is a wide variety of sources from industrial, urban and agricultural use. Industrial toxins such as antisapstain fungicides (including DDAC), which are highly toxic to juvenile white sturgeon, are commonly used at lumber mills in the Fraser River; in 2003, 11 of the 16 lumber mills on the mid- and lower Fraser River used chemical products that contained DDAC (Teh et al. 2003).

Assessment.— Adult white sturgeon in the lower Fraser may be less susceptible to local pollutants than juveniles because much of the adult diet is marine-derived (e.g., salmon and eulachon). Since juvenile and upstream adult white sturgeon depend more on locally-derived food supplies (e.g., benthic invertebrates and resident fish), they would likely be more susceptible to pollutants. Contaminant loads are likely to differ among different parts of the Fraser depending in part on proximity to pollutant sources (see Section 3.2.3).

Uncertainties and Data Gaps.— Susceptibility of white sturgeon, and particularly juveniles, to a wide variety of pollutants remains untested. Further analysis of juvenile white sturgeon diets, with investigation of the pollutant levels in these food sources may provide additional useful information. Toxic pollutants from discharges or spills may also have sublethal effects such as reduced survival or fertility, but these effects would be difficult to assess. In addition, toxins may influence the availability of important prey species, which could impact sturgeon growth and distribution.

5.1.13 Sequential years of adequate flows

Hypothesis.— A single year of suitably high flows is insufficient to stimulate successful white sturgeon spawning.

Assessment.— This hypothesis is believed to be not relevant at present to white sturgeon in the mainstem Fraser River. See NWSRI (2004) for additional information on the relevance of this impact to Nechako River stocks.

5.1.14 Thermal Regime

Hypothesis.— Successful spawning and rearing of Fraser River white sturgeon requires a specific range of water temperatures during critical time periods.

Potential Influences: Flow regulation and climate change.

Description.— River temperatures are dictated by the interaction of river flow and climate, so changes in either have the potential to alter water temperatures. Scientific evidence clearly indicates that climate is changing and animal and plant distributions are responding to these changes (Parmesan and Yohe 2003). Since climate affects water flow and temperature in many ways, it may also affect white sturgeon abundance and distribution. Global climate change may affect temperature in the whole Fraser River, but the effect would likely be greatest in the lower Fraser due to the greater distance from the cooling sources.

Dams can also alter the temporal pattern and range of water temperatures observed in a river. A dam's influence is generally dependent on the storage characteristics of the reservoir and the depth from which water is withdrawn.

One of the principle effects of altered temperatures on white sturgeon is a decline in egg viability at temperatures in excess of 20 ˚C (Wang et al. 1985). Elevated winter and summer temperatures may also alter bioengergetic requirements, and thereby affect reproductive condition. Elevated temperatures may also affect susceptibility to disease. Some dams cool downstream waters through the release of hypolimnetic water, and this could affect white sturgeon; however, this is not considered an issue on the Fraser.

Assessment.— Long-term trends indicate that the summer temperature of the Fraser River has increased from 1941-98 (MWLAP 2002). This might create a long term threat, but the rate of change is about 0.01 ˚C/year, though extreme conditions may become more common. In this respect it is important to note that higher than normal temperatures in 1993 and 1994 were implicated as one of the multiple causes responsible for adult mortalities in the lower Fraser River (McAdam 1995).

The extent to which climate change poses a risk to Fraser River white sturgeon is difficult to determine. Factors that influence white sturgeon reproduction and productivity (e.g., food supply, river temperatures) will likely be affected by climate change, and the net effect may be negative. The response of white sturgeon populations to climate change is of concern, however, these changes would be relatively slow and due to their global cause they are outside the scope of this conservation planning effort.

The Nechako diversion is not likely to have caused much change in Fraser River temperatures. The similarity between the surface withdrawal at Skins Lake Spillway and a natural lake outlet would likely lead to a similar discharge temperature regime, though this assumption has not been tested. Lower river volume during the summer is known to affect downstream summer temperatures in the Nechako (Triton 2001). Implementation of Summer Temperature Management flows (STMP) limits elevated temperatures during July and August, but temperatures during June could be 2 to 3 ˚C higher than natural in warm and hot years (Triton 2001), but this effect would be rapidly diluted downstream of the Nechako confluence. Flows in May were not tested, but may not have changed markedly from natural due to the later onset of spring in this northern area.

Experience at Malaspina University College indicates strong temperature effects on spawning and rearing success, and general health of sturgeon (D. Lane, Malaspina University College, pers. comm.). Embryos and larvae from a single female spawned at 7-10 ˚C had very high mortality in comparison to females spawned at 15–17 ˚C. Fry and fingerlings reared in captivity showed increased growth with temperature up to 25 ˚C. Optimal temperature for rearing and survival appears to be 15–18 ˚C. Recovery from surgery also appears to be temperature dependent. Wounds on cultured sturgeon in captivity heal more rapidly at 12–20 ˚C than at 10–12 ˚C. In addition, mortality rates for sturgeon intercepted in set gill nets increase with increasing water temperatures (T. Nelson, FRSCS, pers. comm.). These observations that both healing and mortality levels change with water temperature may be relevant for management of recreational, aboriginal, and commercial fisheries.

Uncertainties and Data Gaps.— Despite previous and ongoing research there is uncertainty in temperature modeling of the Nechako and Fraser. Some changes to historic river temperatures have been noted, but they don't appear to have been large. The biological effects of these changes are uncertain, and still require further investigation. In particular, there is uncertainty regarding direct effects of thermal regime on adult fish, and for all life stages, additive effects of temperature and other stressors.

There is strong scientific evidence that climate is changing and that species distributions are changing in response. However, there remains considerable uncertainty in predicting how individual species will respond to the changes.

5.1.15 Turbidity

Hypothesis.— Successful recruitment of white sturgeon requires concentrations of suspended sediments in excess of a threshold level during a critical time window.

Assessment.— This hypothesis is believed to be not relevant at present to white sturgeon in the mainstem Fraser River. See NWSRI (2004) for additional information on the relevance of this impact to Nechako River stocks.

5.2 Overall Assessment and Priorities

Threats to Fraser River white sturgeon were assessed and prioritized using an expert panel: a group of resource managers with specific expertise in white sturgeon biology or habitat management. Subjective judgements of impact and action priorities were captured using a questionnaire, a formal scoring procedure for the questionnaire responses, and structured discussion at a follow up technical workshop (Hatfield and Long 2004). The expert panel was assembled with representation from Fisheries and Oceans Canada, Ministry of Water, Land and Air Protection, First Nations, consultants, fishing guides, and the FRSCS. We made a concerted effort to obtain representation from throughout the watershed, but participants had most experience in the lower Fraser. This bias reflects the fact that most white sturgeon research has occurred in this region.

Threats were first presented and discussed as 15 "impact hypotheses." A questionnaire focusing on the impact hypotheses was then distributed to the expert panel. The questionnaire listed the impact hypotheses for each of the four stock groups in the Fraser River. For each impact hypothesis experts were asked a series of six questions:

1. Is this impact hypothesis relevant to this stock group?
2. How large is the geographic area over which this impact occurs?
3. What is the magnitude of this impact?
4. How frequently does this impact occur?
5. How sensitive is this impact to species-specific management actions?
6. What is the value of additional data for this impact?

Answers were restricted to either a yes or no (for question 1) or a numerical response between 0 and 5 (for all other questions). Definitions were provided to guide numerical responses. Impact, action and information scores were calculated separately for each respondent and then compiled for the group.

A technical workshop was held in Vancouver on January 22, 2004 with the same group of experts. At the workshop the group's questionnaire responses were used to stimulate and guide discussion. During discussion the scores were reviewed and impacts, management actions, and information needs were categorized into bins of high, medium and low priority. The procedure used to develop the scoring algorithms, the process of the technical workshop, and results from the expert elicitation are presented in Hatfield and Long (2004).

Shortly after the technical workshop in Vancouver a public forum on Fraser River white sturgeon was held on January 29, 2004 at Skway Hall, Chilliwack (Long et al. 2004). The forum presented an initial opportunity for people outside the working group to provide input to this Plan. Results from the technical workshop were presented at the public forum and input was solicited on the threats as discussed and prioritized by the technical experts. Feedback from participants at the forum supported the general conclusions of the technical panel and offered minor alterations to priorities. The Working Group reviewed results from both the technical workshop and public forum and prioritized threats to white sturgeon in the upper, mid and lower Fraser (

Table 4).

Table 4. Categorization of threats for Fraser River white sturgeon, as determined by the expert panel, public workshop, and Working Group. Priorities were developed separately for the upper, mid and lower Fraser. Since results for the upper and mid Fraser are very similar they are combined here into a single table.

UPPER / MID FRASER	
Category	**Threat**
HIGH	- Food supply - Hatchery effects (potential) - Spawning habitat
MEDIUM	- Effects of small population size - Fishing effects - Mainstem rearing habitat (Mid Fraser) - Off-channel rearing habitat (Upper Fraser)
LOW	- Change in ecological community - Disease - Hydrograph components - Macrophyte Development - Pollution - Sequential years of adequate flows - Thermal regime - Turbidity

LOWER FRASER	
Category	**Threat**
HIGH	- Fishing effects - Hatchery effects (potential) - Mainstem rearing habitat - Off-channel rearing habitat - Pollution - Spawning habitat
MEDIUM	- Food Supply
LOW	- Change in ecological community - Disease - Effects of small population size - Hydrograph components - Macrophyte Development - Sequential years of adequate flows - Thermal regime - Turbidity

6. GOALS AND OBJECTIVES

6.1 Goal

The goal of this conservation plan is to ensure that naturally-reproducing populations of white sturgeon flourish over the long-term throughout the species' natural distribution in the Fraser River basin, and opportunities for beneficial use of each of the major stock groups are provided, if and when feasible.

To achieve this goal, a series of objectives and general strategies have been identified, including specific recovery measures, research, and ongoing monitoring. The objectives and timelines will be revisited as new information is collected and possible changes to priorities will be evaluated.

6.2 Objectives and Strategies

1. Reach and maintain a natural population age structure and reach biological targets throughout the species' natural distribution in the Fraser River.
2. Improve both the scientific and social basis for population targets for each of the major stocks of Fraser River white sturgeon. Refine these targets and identify appropriate time frames for achieving targets, through appropriate consultative processes.
3. Identify and quantify white sturgeon habitat availability and condition; make recommendations for critical habitat designation.
4. Track the status of white sturgeon populations and their response to management actions by developing and implementing scientifically-defensible monitoring programs for white sturgeon throughout the Fraser River.
5. Address basic biology data gaps (life history, habitat use, etc.) required to support conservation management approaches for this species.
6. Address specific data gaps to support improved assessment and prioritization of threats, and develop recommendations for specific management actions as required.
7. If consistent with SARA and conservation objectives, define the biological and social conditions that would allow for opportunities for beneficial use of Fraser River white sturgeon.
8. Support and implement recommendations in the Plan. Review and update the Plan at least every 5 years.

6.3 Population Targets

Much has been written about setting population targets for conservation because the probability of population persistence is usually proportional to population size (Morris et al. 1999, Soulé 1987, Thomas 1990). The setting of targets may consider genetics, population structure, and population variability, including occasional catastrophes. Population viability analysis (PVA) is often used to calculate extinction probabilities under different scenarios. PVA generally requires very detailed biological information, which is often not available for species at risk. Some have argued that even in relatively data-rich situations the calculated extinction probabilities are so uncertain as to be essentially meaningless (Ludwig 1999). However, PVA can be of utility for the learning that comes from exploration of multiple scenarios and sensitivity analysis of parameters, rather than the use of a single calculated extinction probability (Morris et al. 1999). For this reason, PVA for Fraser River white sturgeon stocks has been proposed as a recommended research activity (see Section 7).

Alternatives to full-blown PVA include guidelines or rules-of-thumb (e.g., Soulé 1987, Thomas 1990, Reed et al. 2003). Minimum viable population (MVP) sizes for vertebrates tend to be on the order of 1,000 to 10,000 breeding pairs. These values tend to apply to single closed populations. Since many aquatic species occupy "islands" with little or no migration among populations these rules-of-thumb recovery targets may be applicable to each disjunct population that is a conservation priority. Various conservation assessment groups, including COSEWIC, utilize guidelines for population size, trends, and distribution to assess the status of species at risk (COSEWIC 2005). Such guidelines tend to be somewhat rigid to maintain consistency across taxa.

The issue of population targets was considered carefully and it has been proposed that each stock should have its own target. A series of research tasks have been proposed (see Section 7) to assess and refine the targets.

Mid and Upper Fraser.— Habitat availability and food supply in the mid and upper Fraser are unlikely to support white sturgeon populations in excess of levels (COSEWIC 2005) that would permit downlisting of these stocks. Yet, abundance of white sturgeon in the mid and upper Fraser is believed to be at or near historic levels, age structure appears to be normal, and there is no evidence of a trend toward declining abundance or distribution (see Section 2.5). In other words, white sturgeon are and will likely remain somewhat rare in the mid and upper portions of the Fraser River watershed. The higher risk of extinction due to their relatively small populations justifies specific management actions to address threats to long-term persistence, such as those proposed in Section 7. There is at present no compelling reason to engage in activities to enhance white sturgeon populations in the mid and upper Fraser beyond their current abundance.

Population targets for the mid and upper Fraser River have therefore been set at current population levels: 750 mature adults in the mid Fraser, and 185 mature adults in the upper Fraser [6]. Both targets assume a stable age distribution.

Lower Fraser.— Habitat availability and population trends are quite different in the lower Fraser River. Abundance of white sturgeon in the lower Fraser is believed to be considerably lower than historic levels, age structure is skewed toward younger individuals, and there is evidence of a trend toward increasing abundance over recent years (see Section 2.5). White sturgeon are not rare in the lower Fraser, and habitat availability and food supply are thought to be sufficient to reach population levels (COSEWIC 2005) that would permit downlisting of these stocks. Indeed, downlisting is believed to be achievable, and is a stated goal of this Plan.

[6] It would be preferable to state these targets as number of mature females, since females are assumed to be the limiting sex. However, current methods for sexing white sturgeon give highly uncertain results. This issue has been flagged as one requiring additional research effort.

A population target for the lower Fraser River has been set at 10,000 mature adults [7], with an age distribution capable of supporting this number over the next 20 years. This target represents a level beyond which social decisions around beneficial use predominate. Below this level, there remain considerable conservation concerns, and beneficial use is expected to be of lower priority. It is explicitly acknowledged that this threshold is conservative and based on rules-of-thumb developed from reviews of biological information of other species (e.g., Thomas 1990, Reed et al. 2003), and the Plan proposes that this threshold be explored and refined through further analysis (see Section 7). Present expectations are that results of the analysis will nevertheless support a value fairly similar in magnitude to this value. In addition to refining this threshold, the Plan proposes a series of tasks that will help determine the overall capacity of present-day habitats, and thus the potential for beneficial uses. Until this work is complete it is difficult to anticipate the potential for beneficial use.

7. Recommended Actions and Implementation

The general approach recommended in this conservation plan varies throughout the watershed, but includes

- delineation and protection of key spawning and rearing habitats,
- ensuring adequate escapement of commercially harvested fish as food supply for white sturgeon,
- minimizing impacts from directed, incidental or illegal fishing activities,
- designing and implementing sound monitoring programs, and
- undertaking specific research activities to clarify threats.

A description of the recommended approaches and actions is presented in Table 5. The Nechako River population of white sturgeon will require considerable additional effort, and the actions to support recovery in that system are presented in detail in NWSRI (2004).

[7] see footnote 6.

Table 5. Description of recommended approaches and actions for conservation of Fraser River white sturgeon.

Priority	Broad Strategy	Research Activities	Management Activities
Primary	**Identify habitat requirements** for the major life stages of Fraser River white sturgeon, and ensure important habitats are adequately protected. Relevant locations: upper, mid & lower Fraser Relevant threats: All	1. Identify habitat requirements for major life stages. 2. Quantify abundance and distribution of available habitats for each stock (using air photo analysis or other appropriate methods). 3. Quantify condition of available habitat. 4. Quantify historic habitat availability (this information will be used to provide context for discussions regarding population targets).	1. Identify regulatory bodies with influence or jurisdiction over white sturgeon habitat. 2. Communicate with regulators, First Nations and stakeholders regarding characteristics and locations of important white sturgeon habitat. 3. Develop and communicate best practices for activities that impact white sturgeon habitats. Identify, and where appropriate implement, habitat restoration opportunities.
Primary	**Make recommendations for critical habitat designation and protection**. Relevant locations: upper, mid & lower Fraser Relevant threats: All	1. Define the limiting habitats of major life stages of Fraser River white sturgeon. See Section 3.4 for description of steps required to define critical habitat. 2. Assess whether Plan objectives can be met with currently available critical habitat.	1. Support activities to define critical habitat by making available appropriate experts and other resources. 2. Develop and implement a strategy to protect critical habitat. 3. Develop strategy to guide actions if there is insufficient critical habitat to meet objectives of the Plan.
Primary	**Refine population targets** for each of the major stock groups. These targets may include recovery targets, population status thresholds, and targets for beneficial use. Relevant locations: upper, mid & lower Fraser Relevant threats: All	1. Undertake appropriate research to define viable population sizes, historic and present habitat capacity, for each stock. 2. Requirements for this analysis may include: a. population viability analysis (PVA), including exploration of genetic and demographic effects, and sensitivity analysis of population structure and reproductive parameters, b. forecasting population trends, c. assess historic population and habitat abundance, d. assess current habitat capacity.	1. Support activities to refine population targets. 2. Establish and participate in a process to define First Nation and stakeholder preferences for Fraser sturgeon management, once recovery targets are reached.

Priority	Broad Strategy	Research Activities	Management Activities
Primary	**Clarify threats to Fraser River white sturgeon from different fishing activities**. **Exercise caution** (in favour of conservation) when planning/regulating/enforcing directed and interception white sturgeon fisheries (i.e., recreational angling, guided angling, commercial drift net, First Nation drift and set net), **Minimize illegal harvest** of white sturgeon. Work is underway on to assess fishing mortality on the lower Fraser, which may be used to assist in the management of stocks throughout the Fraser River. Relevant locations: upper, mid & lower Fraser Relevant threats: Fishing effects	Undertake appropriate research to clarify threats, including: 1. Allowable harm assessment: a. Develop an "acceptability threshold" for each fishery b. Quantify fishing effort and effects for each fishery. 2. Undertake empirical studies of fishing effects (e.g., latent mortality rates), as required. 3. Assess effects of fisheries outside the Fraser basin.	1. Adjust fishing regulations as required to meet objectives of the Plan. 2. Support efforts to minimize illegal harvest. 3. Limit expansion of fishery for white sturgeon, unless research indicates it is safe. 4. Develop best practices for all fisheries (e.g., fish handling and release). 5. Partner with US agencies to obtain relevant data regarding effects of US fisheries on Fraser River stocks. 6. Build on work underway on the lower Fraser, to guide management of stocks in the mid and upper Fraser.
Primary	**Clarify threats** to Fraser River white sturgeon **from pollution**, and provide recommendations for management of these threats. Relevant locations: upper, mid & lower Fraser Relevant threats: Pollution	Undertake appropriate research to clarify threats, including: 1. Identify the major pollutants that affect each white sturgeon life stage. 2. Develop an understanding of the lethal and sublethal effects of these pollutants on each white sturgeon life stage.	1. Adjust pollutant discharge regulations as required to meet objectives of the Plan. 2. Support efforts to minimize point and non-point pollutant discharges into the Fraser River. 3. Support pollutant monitoring work underway throughout the Fraser basin.

Priority	Broad Strategy	Research Activities	Management Activities
Primary	**Develop and implement scientifically sound monitoring programs** for Fraser River white sturgeon. Relevant locations: upper, mid & lower Fraser Relevant threats: All	1. Develop monitoring plans for the following high priority items: a. population abundance, b. population structure (size/age/sex), c. effective migration rates among stocks, d. sex ratios, e. bioaccumulation in sturgeon tissues and effects of pollution on sturgeon populations, f. trends in habitat quantity and quality.	1. Help design, coordinate and prioritize monitoring activities throughout the Fraser basin. 2. Evaluate need for additional management activities arising from results from monitoring activities. Communicate findings of monitoring plans to agencies, First Nations and other interests.
Secondary	**Incorporate the needs of healthy white sturgeon populations into the management of Fraser River eulachon and salmon.** The food source of greatest importance in the upper and mid Fraser is mature anadromous salmon. In the lower Fraser, both salmon and eulachon are of importance. Relevant locations: upper, mid & lower Fraser Relevant threats: Food supply	1. Identify white sturgeon food sources by life stage (post-larval to 2 years of age, and adult) and stock (lower, mid, and upper Fraser). 2. Evaluate availability and/or threats to these food sources. 3. Understand the functional relationship between sturgeon indicators (e.g., survival, growth, reproduction, etc.) and food supply.	1. Incorporate white sturgeon needs into Integrated Fisheries Management Planning processes for all relevant prey species. 2. Develop and implement protection measures for key food items (in addition to salmon and eulachon) as necessary. 3. Communicate findings to fisheries managers regarding other important food items as they become evident.
Secondary	**Clarify and address risk to mainstem Fraser populations from release of hatchery-reared Nechako River white sturgeon**. Relevant locations: upper, mid & lower Relevant threats: Hatchery effects	1. Conduct population genetics modeling of potential gene flow from conservation fish culture hatchery releases in the Nechako River.	1. Monitor and evaluate the movement of white sturgeon hatchery releases and adjust Nechako White Sturgeon Recovery Strategy if appropriate. 2. Finalize policy on the commercial culture of white sturgeon aquaculture in British Columbia.

Priority	Broad Strategy	Research Activities	Management Activities
Secondary	**Address information gaps that inhibit conservation of Fraser River white sturgeon.** Relevant locations: upper, mid & lower Fraser Relevant threats: All	Address key information gaps including: 1. reliable assessment of sex ratios for each stock group, 2. relation between body size, fecundity and sexual maturity, 3. immigration and emigration rates for each stock (to define whether populations are open or closed and level of diadromy), 4. information on early life history ecology, 5. causes of mortality during early life stages (e.g., temperature, pollutants, predation, etc.) 6. frequency of spawning in each population 7. effects of small population size 8. diets of major life stages 9. use of tributary habitats in different portions of the watershed 10. limiting factors to population growth 11. reliable techniques for determining sex, age, and stock identity.	None at present. Specific management activities may be proposed in response to results from research activities.

A list of low priority threats and potential responses is presented in Hatfield and Long (2004). This conservation plan recommends that high- and medium-priority activities be completed before addressing lower-priority threats.

8. ACTIONS COMPLETED OR UNDERWAY

A variety of recovery-related actions have been completed or initiated.

1. Fisheries management actions have been implemented to limit or prevent harvest of Fraser River white sturgeon in all fisheries.
2. The Fraser River White Sturgeon Working Group was formed with representation from Fisheries and Oceans Canada, British Columbia Ministry of Water, Land and Air Protection, Sto:lo First Nation, BC Aboriginal Fisheries Commission, Fraser Basin Council, and the Fraser River Sturgeon Conservation Society. The Working Group developed this Conservation Plan.
3. A COSEWIC assessment and listing is complete and up to date. The status report (Ptolemy and Vennesland 2003) is available through the SARA public registry web site.
4. The SARA listing process has been initiated. Public consultations are ongoing; progress can be monitored through the SARA public registry web site.
5. An expert panel met on January 22, 2004 to assess and prioritize issues and threats by stock group.
6. A public forum on Fraser River white sturgeon was held on January 29, 2004 at Skway Hall, 44860 Schweyey Road, Chilliwack. The forum presented an initial opportunity for people outside the expert panel and Working Group to provide input to this Plan. The forum was well-attended with over 90 participants representing a diversity of interests.
7. Public awareness and education about Fraser River white sturgeon has been ongoing through a number of efforts by agencies and NGOs. Efforts include the publication of a white sturgeon brochure in the Wildlife in British Columbia at Risk series, and ongoing communications through the Fraser River Sturgeon Conservation Society.
8. Communications, programs and partnerships are underway between the Fraser River Sturgeon Conservation Society and some First Nations in the lower Fraser.
9. A Lower Fraser River First Nations Stewardship Program has been initiated to promote resource conservation and general awareness in First Nations fishing communities in the lower Fraser. Best practices have been developed and communicated to First Nations fishermen that intercept sturgeon while targeting Pacific salmon.
10. A Fraser River white sturgeon education program is being developed by the FRSCS for delivery to schools and communities.
11. A Fraser River First Nations catch monitoring program has been initiated, with training starting in February 2005.
12. Efforts to quantify and qualify mortality levels and sources have been initiated by MWLAP; this research is using the FRSCS monitoring program mark-recapture and other data to conduct these analyses.
13. Support for the core FRSCS programs (Lower Fraser River White Sturgeon Monitoring and Assessment Program, First Nations stewardship activities, and conservation plan/recovery plan activities initiatives) has been confirmed for 2005-06 (Living Rivers Trust Fund).
14. A wide variety of scientific investigations have been completed and/or are ongoing including:
    a. monitoring of white sturgeon abundance in the lower Fraser River,
    b. genetics research to identify stock groups,

c. ecological research (e.g., habitat use, movements and migration, diets, growth and feeding, behaviour),
d. habitat research (spawning habitat research, effects of dredging in the lower Fraser River mainstem).
e. numerous scientific documents and publications have been written about Fraser River white sturgeon (Appendix A).

9. ANTICIPATED BENEFITS, CONFLICTS AND CHALLENGES

Addressing the threats to white sturgeon abundance and distribution within the Fraser River mainstem is likely more straightforward than in any other portion of the species' natural range. The threats are significant, yet at the same time there are a number of reasons for greater optimism here than elsewhere. For example,

- the Fraser River is not regulated,
- white sturgeon abundance in the mid and the upper Fraser appears stable and is believed to be near historic levels,
- abundance in the lower Fraser, while lower than historic levels, appears to be increasing;
- habitat alterations have not been severe in the mid and upper Fraser,
- there has been considerable habitat alteration in the lower Fraser but present habitat conditions are sufficient to support a fairly healthy population,
- and most importantly, there is a diverse and highly motivated group of people willing to participate in conservation planning and implementation.

Potential benefits, conflicts and challenges associated with the execution of this Plan are wide-ranging, and are discussed briefly below.

Benefits: The primary goal of the Plan is to ensure the long-term persistence of Fraser River white sturgeon. Achieving this goal will benefit white sturgeon, the Fraser River, and other species that rely on this ecosystem. There are likely to also be direct and indirect benefits to local human communities that rely on the Fraser River.

The biological benefit of achieving this objective is the protection of a unique and key component of the Fraser River's aquatic biodiversity, and protection of the only successfully reproducing populations of white sturgeon in Canada. Activities associated with the Plan are also expected to have spin-off benefits for other aquatic species in the Fraser River, particularly through habitat protection and the maintenance of good water quality. In addition, it is expected that general environmental awareness in the local community will increase as activities are undertaken and residents become informed of the Plan.

The white sturgeon has been an important part of many Fraser basin First Nations, particularly with respect to ceremonial activities and as a food source, and this plan recognizes that aboriginal rights of access do exist. Successful management and conservation may produce conditions under which the harvest of sturgeon does not represent a conservation risk, an important goal as stated by some of the basin's First Nations. The Plan addresses current non-harvest uses such as recreational fishing that can provide multiple social and economic benefits, if managed correctly. If conservation activities are successful, there may ultimately be opportunity for additional beneficial uses (outside First Nations requirements) and the plan lays out the necessary studies and information requirements needed to support future decisions. Thus, this Plan will also benefit the local fishing community, including guides, outfitting companies, supporting industries, and recreational anglers.

From a broader sustainability perspective, conservation activities associated with the Plan are expected to have spin-off benefits for other aquatic species in the Fraser River, particularly habitat protection and the maintenance of good water quality. In addition, it is expected that general environmental awareness in the local community will increase as activities are undertaken and residents become informed of the conservation plan.

Finally, the Plan provides a planning structure to create an orderly sequence of events and expected timeframes. This process in turn enables longer-term planning and prioritization, particularly for limited funding resources.

Conflicts: Conservation of Fraser River white sturgeon is not without potential conflicts; indeed it is likely that some stakeholders will disagree with aspects of the Plan. The fairly large numbers of fish currently present in the lower Fraser and the absence of significant decline in the mid and upper Fraser may make it difficult to convince some members of the public and industry that there is a conservation concern. Achieving the conservation actions recommended in the Plan may require limiting some activities and this may not be acceptable to some stakeholders.

There is potential for conflict between the objectives of the Plan and those of development, industrial, agricultural and urban developments and use may impact water quality and important habitats, and there will be conflicts if habitat protection requires limiting certain activities. For example, off-channel rearing and spawning habitats are vulnerable to gravel and sand extraction, dyking, and dredging; managing these impacts is currently a significant issue in the lower Fraser River, where industrial, agricultural, and urban development is greatest and under expansion. These issues are common to many projects that have the potential to affect aquatic habitat and fish populations. Another example is the case of fishery impacts; it is likely that all fishing activities (recreational, commercial, First Nation) contribute to some level of impact on Fraser River white sturgeon, but each sector may have different views on the level and significance of impact and what conservation measures are “reasonable.” For this and other potential conflicts it will be essential to provide credible information to decision-making processes so that any restrictive actions taken to protect white sturgeon are socially-acceptable and do not exceed what is needed to achieve established objectives.

Challenges: The Plan faces a number of challenges including those of a biological, social and financial nature. It is usually very demanding to recover a species once depressed. In this case there are a number of biological challenges specific to white sturgeon: the species is difficult to study, it is challenging to manipulate or restore white sturgeon habitat on a realistic scale, and it is difficult to detect responses to management actions due to the species’ long life and late maturation. One of the biggest biological challenges will be to identify critical habitat. Limited resources, a large geographic range, difficult study conditions on a large river, and data gaps in the general biology of the species, combine to make it difficult to pinpoint specific habitats as critical for long term persistence. The species' widespread distribution will make it especially difficult to monitor the species and biotic responses to the Plan. Until a larger body of scientific studies is available many of the recommendations in the Plan must be based on theory and professional judgement, and as such will be uncertain and vulnerable to criticism.

There are likely to be substantial financial challenges to implementing many of the recommendations in the Plan. Obtaining reliable data for Fraser River white sturgeon is expected to take a long time, and measuring biotic responses to management actions and adjusting future actions will require a long-term commitment to a biological sampling program. Funding will also be required for enforcement activities and numerous research initiatives. One of the key uses of the Plan is that it helps prioritize activities so that resources can be directed where they are needed most. To help address some of the financial challenges there will likely need to be partnerships with various groups and agencies and this may present its own set of challenges.

The widespread geographic distribution of the species also presents some social challenges, the foremost being that is difficult to undertake meaningful consultation throughout the Fraser watershed. It may be difficult to obtain agreement on planned activities and priorities, and to communicate the results of the Plan over the full geographic range of the species.

10. Literature Cited

Apperson, K.A. and P.J. Anders. 1991. Kootenai River white sturgeon investigations and experimental culture. Annual progress report for FY90 by Idaho Department of Fish and Game. Report DOE/BPA 93497-2. Portland, OR: U. S. Department of Energy, Bonneville Power Administration. Available at: http://www.efw.bpa.gov/cgi-bin/efw/FW/publications.cgi

Bennett, W.R. and A.P. Farrell. 1998. Acute toxicity testing with juvenile white sturgeon. Water Quality Research Journal of Canada 33: 95-110.

Boyle, C.A., L. Lavkulich, H. Schreier, and E. Kiss. 1997. Changes in land cover and subsequent effects on Fraser Basin Ecosystems from 1823 to 1900. Environmental Management, 21(2):185-196.

Brannon E. and A. Setter. 1992. Movements of white sturgeon in Lake Roosevelt. Final Report 1988-1991. Prepared for Bonneville Power Administration, Portland, OR. Project No. 89-44 Contract No. DE-BI79-89BP97298

Brannon, E., S. Brewer, A. Setter, M. Miller, F. Utter, and W. Hershberger. 1985. Columbia River white sturgeon (*Acipenser transmontanus*) early life history and genetics study. Final report August 1, 1985 to December 1985 (Project Number 83-316), Report DOE/BP-18952-1. Portland, OR: U. S. Department of Energy, Bonneville Power Administration, Available at http://www.efw.bpa.gov/Publications/R18952-1.pdf

British Columbia Ministry of Fisheries, British Columbia Ministry of Environment, Lands and Parks, Fisheries and Oceans Canada., British Columbia Hydro and Power Authority. 2000. Bridge Coastal Fish and Wildlife Restoration Program Strategic Plan. Prepared by Regional Consulting Ltd., Vancouver, BC. 2 volumes, 393 pp.

Buddington, R.K. and J.P. Christofferson. Digestive and feeding characteristics of the chondostreans. Environ. Biol. Fishes, 14:31–41 (1985).

Cooke, S.J., S.G. Hinch, A.P. Farrell, M.F. Lapointe, S.R.M. Jones, J.S. Macdonald, D.A. Patterson, M.C. Healey and G. Van Der Kraak. 2004. Abnormal migration timing and high en route mortality of sockeye salmon in the Fraser River, British Columbia. Fisheries 29(2): 22-33.

Coutant, C.C. 2004. A riparian habitat hypothesis for successful reproduction of white sturgeon. Reviews in Fisheries Science, 12:23–73

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2005. COSEWIC's assessment process and criteria. Available at: http://www.cosewic.gc.ca/eng/sct0/Assessment_process_tbl2_e.cfm

Deng, X., J.P. Van Eenennaam, and S.I. Doroshov. 2002. Comparison of early life stages and growth of green and white sturgeon. pp. 237–247. In: Van Winkle, W., P. J. Anders, D. H. Secor, and D. A. Dixon (eds.). Biology, management, and protection of North American sturgeon. Symposium 28. American Fisheries Society, Bethesda, MD

Doroshov, S.I., W. H.J. Clark, P.B. Lutes, R.L. Swallow, K.E. Beer, A.B. McGuire, and M.D. Cochran. 1983. Artificial propagation of white sturgeon, *Acipenser transmontanus*. Aquaculture, 32: 93–104.

Duke, S.D., P. Anders, G. Ennis, R. Hallock, J. Hammond, S. Ireland, J. Laufle, R. Lauzier, L. Lockhard, B. Marotz, V.L. Paragamian, and R. Westerhof. 1999. Recovery plan for Kootenai River white sturgeon (*Acipenser transmontanus*). Journal of Applied Ichthyology 15: 157-163.

Echols, J.C. 1995. Review of the Fraser River white sturgeon, *Acipenser transmontanus*. Canada Department of Fisheries and Oceans, Vancouver, BC:

Ellis, E., M. Church, and M. Rosenau. 2004. Characterization of 4 floodplain side channels of the lower Fraser River. Department of Geography, University of British Columbia, Vancouver, Canada. 104 pp. & appendices.

Fraser River Sturgeon Conservation Society (FRSCS). 2004. Lower Fraser River white sturgeon monitoring and assessment program – white sturgeon mark-recapture data base. Managed by the FRSCS (Vancouver BC) in partnership with the Ministry of Water, Land and Air Protection, Victoria, BC.

Failing, L. and R. Gregory. 2003. Discussion Paper: Using traditional ecological knowledge to improve water use planning decisions - Final Report. Compass Resource Management and Value Scope Research. 56 p.

Gawlicka, A., S.J. The, S.S.O. Hung, D.E. Hinton, and J. de la Noüe. 1995. Histological and histochemical changes in the digestive tract of white sturgeon larvae during ontogeny. Fish Physiol. Biochem. 14: 357–371.

Gislason, G.S. and Associates. 2004 – in draft. Socio-Economic Implications of SARA. Interior Fraser coho, white sturgeon, bocaccio. Discussion document – Draft. Prepared for Fisheries & Oceans Canada, Vancouver, BC.

Golder Associates Ltd. 2003a. Nechako River White Sturgeon Spawning Program Region 7 (Omineca-Peace) 2001-2002 Data Report.

Golder Associates Ltd. 2003b. Upper Columbia River juvenile white sturgeon monitoring, Phase I investigations, fall 2002. Report prepared for BC Hydro, Castlegar, B.C.

Gisbert, E. and P. Williot. 2002. Advances in the larval rearing of Siberian sturgeon. J. Fish Biol., 60: 1071–1092.

Gross, M.R., J. Repka, C.T. Roberston, D.H. Secor and W. Van Winkle. 2002. Sturgeon conservation: insights from elasticity analyses. Pages 13-29 in Biology, Management, and Protection of North American Sturgeon, eds., W. Van Winkle, P. Anders, D.H. Secor, and D. Dixon. Bethesda, MD: American Fisheries Society (274 pp).

Harvey, B.C. and T.E. Lisle. 1998. Effects of suction dredging on streams: a review and an evaluation strategy. Fisheries 23 (8): 8-17.

Hatfield, T. and G. Long. 2004. Impacts to abundance and distribution of Fraser River white sturgeon. Results of expert elicitation survey and technical workshop. Report prepared for the Fraser River White Sturgeon Working Group.

Hatfield, T., S. McAdam, and T. Nelson. 2004. Impacts to abundance and distribution of Fraser River white sturgeon. A summary of existing information and presentation of impact hypotheses. Report prepared for the Fraser River White Sturgeon Working Group.

Hilborn, R. 1999. Confessions of a reformed hatchery basher. Fisheries 24: 30-31.

Hilborn, R. and D. Eggers. 2000. A review of the hatchery programs for pink salmon in Prince William Sound and Kodiak Island, Alaska. Transactions of the American Fisheries Society 129: 333-350.

Inglis, S.D. and M.L. Rosenau. 1994. Non-tidal sturgeon angler fishery of the lower Fraser River – angler card analysis. Regional Fisheries Report LM 241. BC Ministry of Environment, Surrey, BC.

Jager, H.I., W. Van Winkle, J.A. Chandler, K.B. Lepla, P. Bates, and T.D. Counihan. 2002. A simulation study of factors controlling white sturgeon recruitment in the Snake river. pp. 127–150. In: Biology, management, and protection of North American sturgeon. Symposium 28. (Van Winkle, W., P. J. Anders, D. H. Secor, and D. A. Dixon, Eds.). Bethesda, MD: American Fisheries Society.

Jaremovic, L. and D. Rowland. 1988 Review of chinook salmon escapements in the Nechako River, British Columbia. Can. MS. Rep. Fish. Aquat. Sci. 1963, 135 pp.

Kincaid, H. 1993. Breeding Plan to Preserve the Genetic Variability of the Kootenai River White Sturgeon. Final Report to Bonneville Power Administration, U.S. Fish and Wildlife Service. Project 93-27. Contract Number DE-AI79-93B002886. Portland, Oregon.

Korman, J. and C. Walters. 2001. Nechako River white sturgeon recovery planning: summary of stock assessment and Oct. 2-3 2000 Workshop. Prepared for Ministry of Water, Land and Air Protection, Victoria, BC. 26 pp.

Kynard, B. and E. Parker 2004. Ontogenetic behavior and dispersal of Sacramento River white sturgeon, *Acipenser transmontanus*, with a note on body color. Manuscript.

Lane, E.D. 1991. Status of the white sturgeon in Canada. The Canadian Field Naturalist 105:161-168.

Lane, E.D. and M. Rosenau. 1995. The conservation of sturgeon in the lower Fraser River watershed. A baseline investigation of habitat, distribution, and age and population of juvenile white sturgeon (*Acipenser transmontanus*) in the lower Fraser River, downstream of Hope, BC. Conservation Fund Project-Final Report, Surrey, BC. 172 p

Lheidli T'enneh Band 2002. 2001/2002 Assessment of upper Fraser River white sturgeon. Prepared for Upper Fraser Nechako Fisheries Council and Fisheries Renewal British Columbia UFNFC File: 0201-119. 37p.

Lheidli T'enneh Band 2001. 2000/2001 Assessment of upper Fraser River white sturgeon. Prepared for Upper Fraser Nechako Fisheries Council and Fisheries Renewal BC. Prince George. 38p + 8 appendices.

Liebe, R., W. Rublee, G. Sykes, and R. Manson. 2004. Adult White Sturgeon Monitoring-Nechako River 2004. Report by Triton Environmental Consultants for Alcan Primary Metal, Kitimat, B.C.

Loew, E.R. and A.J. Sillman. 1998. An action spectrum for the light-dependent inhibition of swimming behaviour in newly hatched white sturgeon, *Acipenser transmontanus*. Vision Res. 38:111-114.

Long, G., J. Bratty, and T. Nelson. 2004. Forum on the future of Fraser River white sturgeon. Meeting report, from January 29th, 2004, Skway Hall, Chilliwack.

Ludwig, D. 1999. Is it meaningful to estimate a probability of extinction? Ecology 80:298-310.

MacDonald, D.D., M.G. Ikonomou, A. Rantalaine, H. Rodgers, D. Sutherland and J. Van Oostdam. 1997. Contaminants in white sturgeon (*Acipenser transmontanus*) from the upper Fraser River, British Columbia, Canada. Environmental Toxicology and Chemistry. 16(3):479-490.

MacDonald, A.L. 1987. The Indian food fishery of the Fraser River: 1986 summary. Canadian Data Report of Fisheries and Aquatic Sciences No. 623.

MacDonald, A.L. 1988. The Indian food fishery of the Fraser River: 1987 summary. Canadian Data Report of Fisheries and Aquatic Sciences No. 690.

MacDonald, A.L. 1989. The Indian food fishery of the Fraser River: 1988 summary. Canadian Data Report of Fisheries and Aquatic Sciences No. 725.

MacDonald, A.L. 1990. The Indian food fishery of the Fraser River: 1989 summary. Canadian Data Report of Fisheries and Aquatic Sciences No. 787.

MacDonald, A.L. 1991. The Indian food fishery of the Fraser River: 1990 summary. Canadian Data Report of Fisheries and Aquatic Sciences No. 836.

MacDonald, A.L. 1992. The Indian food fishery of the Fraser River: 1990 summary. Canadian Data Report of Fisheries and Aquatic Sciences No. 876.

McAdam, S. 1995. Report on the mortalities of Fraser River white sturgeon (*Acipenser transmontanus*) during the summer-fall period of 1993-94. Ministry of Environment Unpublished Report.

McAdam, S.O., C.J. Walters, and C. Nistor. 2004. Linkages between white sturgeon (*Acipenser transmontanus*) recruitment and altered bed substrates in the Nechako River, Canada. Trans. Am. Fish. Soc. *in press*.

McCabe, G.T. Jr., R.L. Emmett and S.A. Hinton. 1993. Feeding ecology of juvenile white sturgeon (*Acipenser transmontanus*) in the lower Columbia River. Report O. pp. 245-263 in: R.C. Beamesderfer and A.A. Nigro (eds.). Vol. 2: Status and habitat requirements of the white sturgeon populations in the Columbia River downstream from McNary Dam. Final Report to Bonneville Power Administration. Portland, Oregon.

Ministry of Environment, Lands and Parks and Environment Canada. 1996a. State of water quality of Fraser River at Red Pass (1984-1995). Available at http://wlapwww.gov.bc.ca/wat/wq/quality/wqfrrp/wqfrrp.html

Ministry of Environment, Lands and Parks and Environment Canada. 1996b. State of water quality of Fraser River at Marguerite (1984-1995) Canada - British Columbia Water Quality Monitoring Agreement. Available at http://wlapwww.gov.bc.ca/wat/wq/quality/sowqofr2/sowqofr2.html#41

Ministry of Environment, Lands and Parks and Environment Canada. 1997. State of water quality of Fraser River at Hope 1979-1995. Available at http://wlapwww.gov.bc.ca/wat/wq/quality/hope/index.htm

Ministry of Environment, Lands and Parks, and Environment Canada. 2000. Water quality trends in selected British Columbia waterbodies. Available at http://www.env.gov.bc.ca/wat/wq/wqhome.html. 176 pp.

Ministry of Water, Land and Air Protection. 2002. Indicators of climate change for BC. Available at http://wlapwww.gov.bc.ca/air/climate/indicat/pdf/indcc.pdf. 50 pp.

Ministry of Water, Land and Air Protection. 2002. Flood Hazard Information: Lower Fraser River Floodplain. April 2002. Pamphlet.

Morris, W., D. Doak, M. Groom, P. Kareiva, J. Fieberg, L. Gerber, P. Murphy, and D. Thomson. 1999. A practical handbook for population viability analysis. The Nature Conservancy.

Morrison, J., M.C. Quick and M.G.G. Foreman. 2002. Climate change in the Fraser River watershed: flow and temperature projections. Journal of Hydrology 263: 230-244.

Nechako White Sturgeon Recovery Initiative (NWSRI). 2004. Recovery plan for Nechako white sturgeon. Prepared by Golder Associates Ltd. 82 pp + App.

Nelson, T.C., W.J. Gazey, K.K. English and M.L. Rosenau. 2004. Status of white sturgeon in the lower Fraser River. Report on the findings of the lower Fraser River white sturgeon monitoring and assessment program, 1999-2004. Prepared by LGL Limited for Fraser River Sturgeon Conservation Society, Vancouver, BC.

Nener, J.C., 1992, Survival and water quality of bioassays on five species of aquatic organisms exposed to slag from Cominco's T rail operations, Department of Fisheries and Oceans, Vancouver, B.C.

North, M.E.A., and J.M. Teversham. 1984. The vegetation of the floodplain of the Fraser, Serpentine and Nicomekl rivers, 1859–1890. Syesis 17:47–66.

Northwest Hydraulic Consultants and S. McAdam. 2003. Nechako River Geomorphic Assessment Phase II: Detailed analysis of potential white sturgeon habitat sites. Prep. For BC Min. Water, Land and Air Protection. 17 pp. +app.

Northwest Hydraulic Consultants. 2003. Nechako River Geomorphic Assessment Phase I: Historical analysis of the lower Nechako River. Prep. For BC Min. Water, Land and Air Protection. 31 pp. + app.

Paragamian, V.L., V.D. Wakkinen, and G. Kruse. 2002. Spawning locations and movement of Kootenai River white sturgeon. J. Appl. Ichthyol. 18:608-616.

Paragamian, V.L., and G. Kruse. 2001. Kootenai River white sturgeon spawning migration behavior and a predictive model. N. Am. J. Fish. Manage., 21:10–21.

Paragamian, V.L., G. Kruse, and V. Wakkinen. 1997. Kootenai River white sturgeon Investigations. Annual Progress Report FY 1996. Prepared for U.S. Department of Energy, Bonneville Power Administration. Contract No. DE-AI79-88BP93497; Project No. 88-6.

Paragamian, V.L., G. Kruse, and V. Wakkinen. 2001. Spawning habitat of Kootenai River white sturgeon, post-Libby Dam. N. Am. J. Fish. Management 21:22–33.

Parmesan, C. and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421: 37-42.

Parsley, M.J. and L.G. Beckman. 1994. White sturgeon spawning and rearing habitat in the lower Columbia River. N. Am. J. Fish. Manage., 14: 812–827.

Parsley, M.J., L.G. Beckman, and G.T. McCabe, Jr. 1993. Habitat use by spawning and rearing white sturgeon in the Columbia River downstream of McNary Dam. Trans. Am. Fish. Soc., 122: 217–227.

Parsley, M.J., P.J. Anders, A.I. Miller, L.G. Beckman, and G.T. McCabe, Jr. 2002. Recovery of white sturgeon populations through natural production: understanding the influence of abiotic and biotic factors on spawning and subsequent recruitment. pp. 55–66. In: W. Van Winkle, P. J. Anders, D. H. Secor, and D. A. Dixon (eds.) Biology, management, and protection of North American sturgeon. Symposium 28. American Fisheries Society, Bethesda, MD

Parsley, M.J. and K.M. Kappenman. 2000. White sturgeon spawning areas in the lower Snake River. Northwest Sci., 74: 192–201.

Perrin, C.J., A. Heaton and M.A. Laynes. 2000. White sturgeon (*Acipenser transmontanus*) spawning habitat in the lower Fraser River, 1999. Report prepared by Limnotek Research and Development Inc. for BC Ministry of Fisheries. 65 p.

Perrin, C.J., L.L. Rempel and M.L Rosenau. 2003. White sturgeon spawning habitat in an unregulated river: Fraser River, Canada. Transactions of the American Fisheries Society 132: 154-165.

Perry, T.E. 1984. Land use of the Matsqui Prairie region of the lower Fraser Valley in southwestern British Columbia 1858–1892. Master's thesis. Western Washington University, Bellingham, Washington.

Pollard, S. 2002. Upper Columbia white sturgeon conservation fish culture breeding plan. Prepared for Ministry of Water, Land and Air Protection, Victoria, BC. 21 p.

Ptolemy, J. and R. Vennesland. 2003. Update COSEWIC status report on white sturgeon *Acipenser transmontanus*. Prepared for Committee On the Status of Endangered Wildlife In Canada.

Reed, D.H., J.J. O'Grady, B.W. Brook, J.D. Ballou, and R. Frankham. 2003. Estimates of minimum viable population sizes for vertebrates and factors influencing those estimates. Biological Conservation 113:23-24.

Richardson, J.S., T.J. Lissimore, M.C. Healey and T.G. Northcote. 2000. Fish communities of the lower Fraser River (Canada) and a 21-year contrast. Environmental Biology of Fishes 59: 125–140.

Rosenau, M.L. and M. Angelo 2000. Sand and gravel management and fish habitat protection in British Columbia salmon and steelhead streams. Background Paper No. 200/3, prepared for the Pacific Fisheries Resource Conservation Council.

RL&L Environmental Services Ltd. 2000. Fraser River White Sturgeon Monitoring Program - Comprehensive Report (1995 to 1999). Final Report Prepared for BC Fisheries. RL&L Report No. 815F: 92 p + app.

RL&L Environmental Services Ltd. 1994. Status of white sturgeon in the Columbia River, BC. Prepared for BC Hydro, Environmental Affairs. Vancouver BC. 377F: 101 p.

RL&L Environmental Services Ltd. 1998a. Fraser River White Sturgeon Monitoring Program. Region 2 (Lower Mainland) – 1997 Data Report. Prepared for BC Ministry of Environment, Lands and Parks, Fish and Wildlife Section, Surrey, BC. 564F: 27 p.

RL&L Environmental Services Ltd. 1998b. Fraser River White Sturgeon Monitoring Program. Region 3 (Thompson-Nicola) – 1997 Data Report. Prepared for BC Ministry of Environment, Lands and Parks, Fish and Wildlife Section, Kamloops, BC. 563F: 30 p.

RL&L Environmental Services Ltd. 1998c. Fraser River White Sturgeon Monitoring Program. Region 5 (Cariboo-Chilcotin) – 1997 Data Report. Prepared for BC Ministry of Environment, Lands and Parks, Fish and Wildlife Section, Williams Lake, BC. 589F: 32 p.

RL&L Environmental Services Ltd. 1999a. Fraser River White Sturgeon Monitoring Program. Region 2 (Lower Mainland) – 1997 Data Report. Prepared for BC Fisheries and Fraser River Sturgeon Conservation Society. 671F: 22 p.

Rood, K and C. R. Neill. 1987. A study of some aspects of the geomorphology of the Nechako River. Reid Crowther and Partners Ltd. And Northwest Hydraulic Consultants Ltd. Prepared for Fisheries and Oceans Canada, Vancouver, B.C. DSS File #FP501-6-0142/01-SB. 84 pp. + app.

Rodzen, J. and B. May. 2004. Estimation of family structure within white sturgeon spawning locations. Unpublished report, Genomic Variation Laboratory, University of California, Davis.

Schaepe, D.M. 2001. The maps of K'hhalserten, c. 1918. In: A Sto:lo- Coast Salish historical atlas. K. T. Carlson (ed.). Douglas and McIntyre and the Sto:lo Nation, Vancouver and Chilliwack.

Schubert, N.D. 1984. The Indian food fishery of the Fraser River: 1983 summary. Canadian Data Report of Fisheries and Aquatic Sciences No. 479.

Schubert, N.D. 1985. The Indian food fishery of the Fraser River: 1983 summary. Canadian Data Report of Fisheries and Aquatic Sciences No. 512.

Schubert, N.D. 1986. The Indian food fishery of the Fraser River: 1985 summary. Canadian Data Report of Fisheries and Aquatic Sciences No. 560.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Bulletin 184. Fisheries Research Board of Canada.

Semakula, S.N. and P.A. Larkin. 1968. Age, growth, food and yield of the white sturgeon (*Acipenser transmontanus*) of the Fraser River, British Columbia. Fisheries Research Board of Canada. 25:2589-2602.

Smith, C.T., R.J. Nelson, S. Pollard, E. Rubridge, S.J. McKay, J. Rodzen, B. May and B. Koop. 2002. Population genetic analysis of white sturgeon (*Acipenser transmontanus*) in the Fraser River. Journal of Applied Ichthyology 18: 307-312.

Soulé, M.E. 1987. Viable populations for conservation. Cambridge University Press, Cambridge, UK.

Spitsbergen, J.M., M.K. Walker, J.R. Olson and R.E. Peterson. 1991. Pathologic alterations in the early life stages of lake trout, *Salvelinus namaycush*, exposed to 2,3,7,8,-tetrachorodibenzo-p-dioxin as fertilized eggs. Aquatic Toxicology 19:41-72.

Swiatkiewicz, V.J. 1992. Lower Fraser River white sturgeon studies from 1985-1987. Regional Fisheries Report No. LM209. B.C. Ministry of Environment. Fish and Wildlife Management, Surrey, BC. 40 pp.

Teh, S.J., C. Wong, V. Furtula, and F. Teh. 2003. Lethal and sublethal toxicity of didecyldimethylammonium chloride in early life stages of white sturgeon, *Acipenser transmontanus*. Environmental Toxicology and Chemistry 22:2152-2158.

Thomas, C.D. 1990. What do real population dynamics tell us about minimum viable population sizes? Conservation Biology 4:324-327.

Triton Environmental Consultants. 2001. Estimation of natural water temperatures in the Nechako River. Prepared for Nechako Environmental Enhancement Fund. Draft report.

U.S. Fish and Wildlife Service. 1999. Recovery plan for the Kootenai River population of the white sturgeon (*Acipenser transmontanus*). Region 1, USFWS, Portland, OR.

Upper Columbia White Sturgeon Recovery Initiative. 2002. Draft upper Columbia River white sturgeon recovery and management plan. prepared by the Upper Columbia River Recovery Team, January, 2002. 88 pp.

Veinott, G., T. Northcote, M. Rosenau, and R.D. Evans. 1999. Concentrations of strontium in the pectoral fin ray of the white sturgeon (*Acipenser transmontanus*) by laser ablation – inductively coupled plasma – mass spectrometry as an indicator of marine migrations. Canadian Journal of Fisheries and Aquatic Sciences 56: 1981-1990.

Walker, M.K., J.M. Spitsbergen, J.R. Olson and R.E. Peterson. 1991. 2,3,7,8-Tetracholorodibezo-p-dioxin (TCDD) toxicity during the early development of lake trout (*Salvelinus namaycush*) . Canadian Journal of Fisheries and Aquatic Sciences 48:875-883.

Walker, M.K., L.C. Hufnagle, Jr., M.K. Clayton and R.E. Peterson. 1992. An egg injection method for assessing early life stage mortality of polychlorinated dibenzo-p-dioxins, dibenzo-furans, and biphenyls in rainbow trout (*Oncorhynchus mykiss*). Aquatic Toxicology 22:15-38.

Wang, Y.L., F. P. Binkowski, and S. Doroshov. 1985. Effect of temperature on early development of white and lake sturgeon, *Acipenser transmontanus* and *A. fulvescens*. Environmental Biology of Fishes 14:43–50.

Williamson, C.,D. Cadden and S. McAdam. 2003. Genetic hazards and risks associated with the recovery of Nechako white sturgeon. Prepared for the Nechako River white sturgeon recovery team. 15 pp.

Winemiller, K.O. and K.A. Rose. 1992. Patterns of life-history diversification in North American fishes: implications for population regulation. Can. J. Fish. Aquat. Sci. 49: 2196–2218.

Woods, J.R. 2001. Sumas lake transformations. *In*: A Sto:lo-Coast Salish historical atlas. K.T. Carlson (ed.). Douglas and McIntyre and the Sto:lo Nation, Vancouver and Chilliwack.

Yarmish, J.A. and B.M. Toth. 2002. 2001/20002 Assessment of upper Fraser River white sturgeon. Report Produced by Lheidli T'enneh First Nation for Upper Fraser River Nechako Fisheries Council and Fisheries Renewal BC. 37 p.

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Appendix A
Bibliography for Fraser River white sturgeon (excluding Nechako River)

Bennett, W.R. and A.P. Farrell. 1998. Acute toxicity testing with juvenile white sturgeon. Water Quality Research Journal of Canada 33: 95-110.

Echols, J.C. 1995. Review of the Fraser River white sturgeon, *Acipenser transmontanus*. Canada Department of Fisheries and Oceans, Vancouver, BC:

Ellis, E., M. Church, and M. Rosenau. 2004. Characterization of 4 floodplain side channels of the lower Fraser River. Department of Geography, University of British Columbia, Vancouver, Canada. 104 pp. & appendices.

Fraser River Sturgeon Conservation Society (FRSCS). 2004. Lower Fraser River White Sturgeon Monitoring and Assessment Program – white sturgeon mark-recapture data base. Managed by the FRSCS (Vancouver BC) in partnership with the Ministry of Water, Land and Air Protection, Victoria, BC.

Gislason, G.S. and Associates. 2004 – in draft. Socio-Economic Implications of SARA. Interior Fraser coho, white sturgeon, bocaccio. Discussion document – Draft. Prepared for Fisheries & Oceans Canada, Vancouver, BC.

Hatfield, T. and G. Long. 2004. Impacts to abundance and distribution of Fraser River white sturgeon. Results of expert elicitation survey and technical workshop. Report prepared for the Fraser River White Sturgeon Working Group.

Hatfield, T., S. McAdam, and T. Nelson. 2004. Impacts to abundance and distribution of Fraser River white sturgeon. A summary of existing information and presentation of impact hypotheses. Report prepared for the Fraser River White Sturgeon Working Group.

Inglis, S.D. and M.L. Rosenau. 1994. Non-tidal sturgeon angler fishery of the lower Fraser River – angler card analysis. Regional Fisheries Report LM 241. BC Ministry of Environment, Surrey, BC.

Lane, E.D. 1991. Status of the white sturgeon in Canada. The Canadian Field Naturalist 105:161-168.

Lane, E. D. and M. Rosenau. 1995. The conservation of sturgeon in the lower Fraser River watershed. A baseline investigation of habitat, distribution, and age and population of juvenile white sturgeon (*Acipenser transmontanus*) in the lower Fraser River, downstream of Hope, BC. Conservation Fund Project-Final Report, Surrey, BC. 172 p

Lheidli T'enneh Band 2002. 2001/2002 Assessment of upper Fraser River white sturgeon. Prepared for Upper Fraser Nechako Fisheries Council and Fisheries Renewal British Columbia UFNFC File: 0201-119. 37p.

Lheidli T'enneh Band 2001. 2000/2001 Assessment of upper Fraser River white sturgeon. Prepared for Upper Fraser Nechako Fisheries Council and Fisheries Renewal BC. Prince George. 38p + 8 appendices.

Long, G., J. Bratty, and T. Nelson. 2004. Forum on the future of Fraser River white sturgeon. Meeting report, from January 29th, 2004, Skway Hall, Chilliwack.

MacDonald, D.D., M.G. Ikonomou, A. Rantalaine, H. Rodgers, D. Sutherland and J. Van Oostdam. 1997. Contaminants in white sturgeon (*Acipenser transmontanus*) from the upper Fraser River, British Columbia, Canada. Environmental Toxicology and Chemistry. 16(3):479-490.

McAdam, S. 1995. Report on the mortalities of Fraser River white sturgeon (*Acipenser transmontanus*) during the summer-fall period of 1993-94. Ministry of Environment Unpublished Report.

Nelson, T.C., W.J. Gazey, K.K. English and M.L. Rosenau. 2004. Status of white sturgeon in the lower Fraser River. Report on the findings of the lower Fraser River white sturgeon monitoring and assessment program, 1999-2004. Prepared by LGL Limited for Fraser River Sturgeon Conservation Society, Vancouver, BC.

Perrin, C.J., A. Heaton and M.A. Laynes, 2000. White sturgeon (*Acipenser transmontanus*) spawning habitat in the lower Fraser River, 1999. Report prepared by Limnotek Research and Development Inc. for BC Ministry of Fisheries. 65 p.

Perrin, C.J., L.L. Rempel and M.L Rosenau. 2003. White sturgeon spawning habitat in an unregulated river: Fraser River, Canada. Transactions of the American Fisheries Society 132: 154-165.

Ptolemy, J. and R. Vennesland. 2003. Update COSEWIC status report on white sturgeon *Acipenser transmontanus*. Prepared for Committee On the Status of Endangered Wildlife In Canada.

RL&L Environmental Services Ltd. 2000. Fraser River White Sturgeon Monitoring Program - Comprehensive Report (1995 to 1999). Final Report Prepared for BC Fisheries. RL&L Report No. 815F: 92 p + app. [note: there are multiple data reports for each year of this study]

Semakula, S.N. and P.A. Larkin. 1968. Age, growth, food and yield of the white sturgeon (*Acipenser transmontanus*) of the Fraser River, British Columbia. Fisheries Research Board of Canada. 25:2589-2602.

Smith, C.T., R.J. Nelson, S. Pollard, E. Rubridge, S.J. McKay, J. Rodzen, B. May and B. Koop. 2002. Population genetic analysis of white sturgeon (*Acipenser transmontanus*) in the Fraser River. Journal of Applied Ichthyology 18: 307-312.

Swiatkiewicz, V.J. 1992. Lower Fraser River white sturgeon studies from 1985-1987. Regional Fisheries Report No. LM209. B.C. Ministry of Environment. Fish and Wildlife Management, Surrey, BC. 40 p.

Teh, S.J., C. Wong, V. Furtula, and F. Teh. 2003. Lethal and sublethal toxicity of didecyldimethylammonium chloride in early life stages of white sturgeon, *Acipenser transmontanus*. Environmental Toxicology and Chemistry 22:2152-2158.

Veinott, G., T. Northcote, M. Rosenau, and R.D. Evans. 1999. Concentrations of strontium in the pectoral fin ray of the white sturgeon (*Acipenser transmontanus*) by laser ablation – inductively coupled plasma – mass spectrometry as an indicator of marine migrations. Canadian Journal of Fisheries and Aquatic Sciences 56: 1981-1990.

Yarmish, J.A. and B.M. Toth. 2002. 2001/20002 Assessment of upper Fraser River white sturgeon. Report Produced by Lheidli T'enneh First Nation for Upper Fraser River Nechako Fisheries Council and Fisheries Renewal BC. 37 p.