Upper Columbia White Sturgeon Recovery Plan - 2012 Revision

Revised December 2013

(Original November 2002)

DISCLAIMER

Recovery plans delineate reasonable actions that are believed necessary to recover or protect the species. This plan has been prepared as a cooperative effort among Canadian and U.S. Federal, Provincial, and State agencies, Canadian and U.S. tribes, and other stakeholders. Objectives will be obtained and any necessary funds made available subject to budgetary and other constraints affecting parties involved, as well as the need to address other priorities. The recovery plan does not necessarily represent the views nor the official positions or approval of any individuals or agencies involved in the plan formulation. The original plan developed in 2002 was considered a living document subject to modification as needed. This document represents the first revision to the original Plan and has been modified to incorporate new findings, changes in species status, and update the recovery measures.

Suggested Citation: Hildebrand, L. R. and M. Parsley. 2013. Upper Columbia White Sturgeon Recovery Plan – 2012 Revision. Prepared for the Upper Columbia White Sturgeon Recovery Initiative. 129p. + 1 app. Available at: www.uppercolumbiasturgeon.org

Acknowledgements

This revision of the Recovery Plan is based on the original document produced in 2002 and edited by Ray Beamesderfer. The following members of the Upper Columbia White Sturgeon Recovery Initiative are gratefully acknowledged for their contributions to this plan.

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The following entities are gratefully acknowledged for direct funding of this Recovery Plan update:

BC Hydro

Columbia Power Corporation

Colville Confederated Tribes

Spokane Tribe of Indians

Teck Metals Ltd.

Executive Summary

White sturgeon are a unique and precious component of the biodiversity and cultural heritage of the Upper Columbia River but are currently threatened with extirpation from this geographic area. The current population of adult White Sturgeon in the Canadian and U.S. portions of the Upper Columbia River above Grand Coulee Dam is close to the endangered status criteria of 2,500 identified by the World Conservation Union. This coupled with an almost complete failure of natural recruitment to the population since the early 1970s led to the formation of the Upper Columbia White Sturgeon Recovery Initiative (UCWSRI) in 2001, the development of the first Recovery Plan in 2002, and the listing of this population as endangered in Canada by the Canadian Species at Risk Act (SARA). The original plan focused on short term measures designed to supplement the existing population through a conservation aquaculture program and to investigate potential causes of recruitment failure.

This revised plan is the product of the UCWSRI Technical Working Group, composed of Canadian, U. S., and aboriginal governments, industrial and environmental organizations, stewardship groups, and citizens and a Community Working Group that serves as a public liaison with the broader community of affected and interested parties. The recovery plan is also intended to serve as a master plan for sturgeon restoration efforts in the U.S. portion of the Columbia River upstream from Grand Coulee Dam consistent with implementation of the Columbia Basin Fish and Wildlife Program under the 1980 Northwest Power Act. The initial development and Implementation of this plan represents a proactive approach to species recovery and in its present form, is complimentary to the recovery and action planning activities under the Canadian Species at Risk Act.

The present document represents the first major revision to the original plan. To provide a context for recommended recovery actions, this revised plan summarizes information obtained through the numerous studies conducted in the past decade on the biology and status of Upper Columbia River White Sturgeon. This information forms the basis for updates on the reasons for decline, existing conservation measures, and likely causes of recruitment failure. Objectives, targets, strategies, and measures for arresting the decline of White Sturgeon, promoting the persistence and viability of naturally-reproducing populations, and restoring opportunities for beneficial use if feasible, also are discussed. Viability refers to the ability to sustain a diverse, naturally-reproducing population as a functional component of the river ecosystem. The efficacy of restoration of natural spawning and rearing habitats will determine whether natural populations can support subsistence or recreational fishing. The degree to which naturally reproducing populations will be able to support harvest or the impacts of a future catch and release fishery will depend on the success of efforts to restore habitat conditions suitable for spawning and rearing. Therefore, the primary objectives of this revised plan are to 1) continue to monitor the status and trends of populations within the recovery areas, 2) continue supplementation to rebuild abundance and maintain genetic diversity, and 3) identify and address factors limiting natural recruitment.

The short-term objectives identified in the original plan focussed on an assessment of population status and actions to prevent further reductions in White Sturgeon distribution, numbers, and genetic diversity. Many of these objectives have been met through intensive studies and the success of the conservation hatchery program. The original medium-term objectives were to determine survival limitations (bottlenecks) for remaining supportable populations and establish feasible response measures. Due to the difficulty in identifying reasons for recruitment failure, many of these objectives have not been met. The original long-term objectives to re-establish natural population age structure, achieve target abundance levels, and restore beneficial uses through self-sustaining recruitment, have not been achieved.

Recovery efforts will focus on three areas that continue to provide suitable habitat: Arrow Lakes Reservoir Reach (from Revelstoke Dam to HLK), the upper Transboundary Reach (HLK to the Canada-U.S. boundary), and the

lower Transboundary Reach (Canada-U.S. boundary to Grand Coulee Dam). This approach will be continually evaluated as numbers of fish present in the entire Transboundary reach increase through recovery efforts on both sides of the Canada-U.S. boundary. The Kinbasket Reach will continue to be considered as either an additional recovery area or a possible location for a failsafe population.

The updated recovery targets (i.e., interim benchmarks by which progress toward recovery will be measured) for the Upper Columbia River White Sturgeon are:

- Minimum interim adult population sizes of 2,000 adults in the Upper Transboundary Reach (Canada) and 5,000 adults in the lower Transboundary Reach (U.S.)
- Naturally-produced recruitment and juvenile population sizes sufficient to support desired adult population sizes in at least two of the three potential recovery areas identified above.
- Stable size and age distributions in each population.
- Genetic diversity (including rare allele frequencies) is preserved.
- Abundance and natural production rates are sufficient to support beneficial uses including subsistence harvests by First Nations, Native American Indians, and recreational fishery uses.

Recovery goals, objectives, and targets will be addressed using a combination of strategies and associated measures. These include continued control of direct sources of adult mortality, continued hatchery intervention to preserve population diversity and replace wild recruitment, improvements in recruitment and survival based on habitat, flow, and/or water quality restoration, and continuing adaptation based on research and monitoring of sturgeon status, limiting factors, and potential recovery actions. Specific recovery measures are identified consistent with these recovery strategies for fishery regulations, entrainment, hatchery production, water management, water quality, contaminants, habitat diversity, population connectivity, system productivity, assessment, monitoring, research, information, education, planning, coordination, and implementation. Timeframes for each measure reflect short (0-5 year), medium (5-10 year), and long (10- 50 year) term commitments for implementation of measures and expectations of results.

The Recovery Plan is based on an adaptive management approach that involves the continued modification of the program based on results of research on limiting factors and monitoring of stock status and its response to recovery actions. Additional knowledge gained since the original recovery plan has increased our knowledge of what changes have affected sturgeon, but it is still unclear what specific and feasible actions will be effective at stimulating natural recovery. Currently, recovery planning is hampered by a lack of understanding of key factors limiting natural recruitment. Laboratory studies combined with field research and monitoring will continue to provide information on means to alleviate ecological impediments to recovery.

The next 20 years represent a critical period in recovery of Upper Columbia River White Sturgeon. The existing wild population will continue to decline while supplementation efforts will continue to replace natural recruitment until hatchery fish reach adulthood and supplement or replace wild spawners. Restoration targets of adult and juvenile population levels will continue to be assessed on a regular basis. At present, model projections suggest achievement of target adult populations for the Transboundary Reach between 2060 and 2080.

Multiple measures will be required to achieve a naturally reproducing, self-sustaining population and to increase or restore opportunities for beneficial use, if and when feasible. Although there is some uncertainty as to when and how natural recruitment will be achieved, the coordinated efforts of the UCWSRI since 2002 has substantially increased overall knowledge of the species, protected wild adults, and increased the abundance of juveniles in both the Transboundary Reach and ALR Reach.

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1.0 INTRODUCTION

1.1 Background

White Sturgeon (*Acipenser transmontanus*) is the largest, longest-lived freshwater fish in North American (Scott and Crossman 1973) and is highly adapted to the large river systems where they evolved (Plate 1). The largest White Sturgeon on record weighed approximately 682 kg and was caught in the Snake River in 1898 (Simpson and Wallace 1982). Ages up to 104 years have been reported (Rien and Beamesderfer 1994).

Longevity and high fecundity have allowed White Sturgeon to withstand variable environmental conditions and to capitalize on favorable feeding and spawning conditions when they occurred. The species has the ability to forage widely and take advantage of highly dispersed and seasonally-available food resources. These attributes, which have proven adaptive for millions of years, are now a liability (Beamesderfer and Farr 1997). Large size and high fecundity makes White Sturgeon a valuable fishery commodity but longevity, delayed maturation, and intermittent spawning make them extremely vulnerable to overfishing and also complicate research and recovery. Long life span and benthic feeding also makes White Sturgeon potentially susceptible to bioaccumulation of industrial and community pollutants with possible detrimental effects on health, growth, maturation, and recruitment.

Key White Sturgeon habitats also have been altered. Dam construction has blocked movements and restricted sturgeon to river fragments that may no longer provide the full spectrum of habitats necessary to complete the life cycle. Flow regulation has altered seasonal and annual fluctuations that provide behavior cues and suitable spawning or rearing conditions. Numerous exotic species [e.g., Walleye (*Sander vitreus*), Northern Pike (*Esox lucius*), and freshwater shrimp (*Mysis relicta*)] have been introduced into the Upper Columbia River system. All of these changes have produced a much different community of aquatic predators, prey, and potential competitors.

White Sturgeon are a unique and precious component of the biodiversity and cultural heritage of the Upper Columbia River, defined as the Columbia River drainage upstream from Grand Coulee Dam in Washington State, USA to the Canadian headwaters, excluding the Kootenay River upstream of Bonnington Falls (Figure 1). This species is an integral component of the native riverine ecosystem and historically supported productive traditional and recreational fisheries. Research conducted in the 1980s and 1990s indicated all population segments in the Upper Columbia River were experiencing recruitment failure and were threatened with extirpation from this area unless rigorous restoration and protective measures were implemented.

Sturgeon are at risk almost everywhere they occur in North America, Europe, and Asia, and White Sturgeon in the Upper Columbia River are no exception. Habitat fragmentation, habitat degradation, and historical fisheries have combined to drastically reduce the global range and numbers of sturgeon. The Upper Columbia River White Sturgeon population now consists of several known or suspected population segments that have been isolated from each other and from historical habitats (Figure 1). Natural recruitment has failed for all Upper Columbia River wild populations, which now consist solely of aging cohorts of mature fish that are gradually declining as fish die and are not being replaced by wild produced progeny. Only the longevity of this species and complete fishery closures have forestalled extirpation that will be inevitable without effective intervention.

White Sturgeon were first designated as vulnerable in 1990 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), and reassessed as Endangered in 2003. The Columbia River population in British Columbia was assigned to the provincial Red List in 1993 based on a BC Conservation Data Centre (CDC) status review that described the species as “critically imperilled.” In 2006, the Upper Columbia River population of White Sturgeon, along with three other White Sturgeon populations in Canada, were listed as endangered under the federal *Species at Risk Act* (SARA). The Kootenay River (spelled Kootenai in the USA) population of White Sturgeon was listed in 1994 as endangered under the U.S. Endangered Species Act (ESA). Upper Columbia River White Sturgeon are not currently listed under the ESA.

The wide distribution and transboundary movement of Upper Columbia River White Sturgeon requires effective inter-jurisdictional coordination of recovery efforts. This was achieved through the development in the early 2000s of a cooperative effort by Canadian and U.S. governmental aboriginal, industrial and environmental organizations, stewardship groups, and citizens, collectively, the Upper Columbia White Sturgeon Recovery Initiative (UCWSRI). The UCWSRI developed the Upper Columbia White Sturgeon Recovery Plan (UCWSRP) that described strategies and measures to arrest the decline of White Sturgeon in the Upper Columbia River Basin, prevent extirpation, remove threats to long-term survival, and restore opportunities for beneficial use if feasible (UCWSRI 2002). The UCWSRP was a technical document produced through discussion and consensus. The implementation of the original plan represented a proactive approach to species recovery in that the structure was designed to be compatible with pending SARA legislation and the existing U.S. ESA.

The UCWSRP addresses White Sturgeon recovery in the Upper Columbia River above Grand Coulee Dam, with the exception of the Kootenay Lake and River above Bonnington Falls (Figure 1). The selection of Lower Bonnington Dam as the separation point between the Kootenay River and Columbia River systems reflects the location of Bonnington Falls that historically, was an impassable barrier to upstream fish passage into the remainder of the Kootenay River (spelled Kootenai in the U.S.) system. The Kootenay River population of White Sturgeon was listed in 1994 as endangered under the U.S. Endangered Species Act (ESA), and is covered by a separate recovery plan (USFWS 1999).

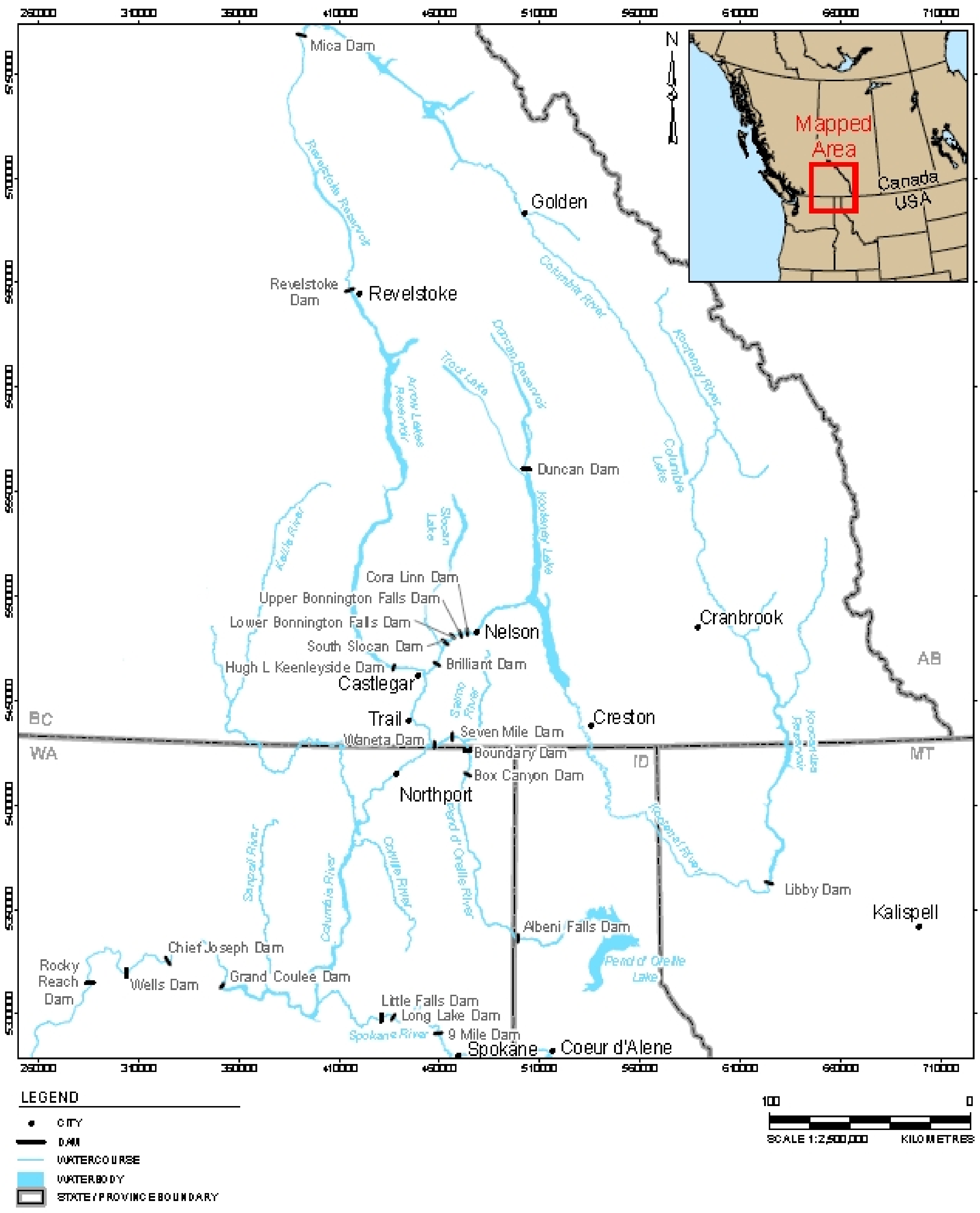


Figure 1: Upper Columbia River White Sturgeon recovery area, Columbia Lake to Grand Coulee Dam.

This document represents the first revision to the original 2002 UCWSRP and reflects the “living document” status of that plan and the adaptive nature of the recovery process. Research referenced in the 2002 version was either from early study programs conducted on White Sturgeon in the Upper Columbia River recovery area or general information obtained from the literature on other populations within the species range. Since that time, numerous studies have been conducted on White Sturgeon within the Upper Columbia River and throughout the species range. This document focuses on information specific to White Sturgeon in the Upper Columbia River but also includes relevant information from other sturgeon research and recovery programs.

Although White Sturgeon are the main subject of this plan, actions proposed for their stabilization could also benefit other native aquatic species and contribute to overall health of the Upper Columbia River ecosystem.

The Upper Columbia River White Sturgeon recovery area is comprised of several geographic areas that are referred to throughout this document). These are defined as follows:

Upper Columbia River recovery area: The Columbia River mainstem from Columbia Lake to Grand Coulee Dam including the lower Kootenay River from Brilliant Dam to the Columbia River confluence (Figure 2). At present, this recovery area is divided into four primary reaches:

Kinbasket Reach: Columbia Lake, the unimpounded portion of the Upper Columbia River, and Kinbasket Reservoir formed by Mica Dam (Figure 1).

Revelstoke Reach: The reservoir from Mica Dam downstream to Revelstoke Dam (Figure 1).

Arrow Lakes Reservoir (ALR) Reach: The unimpounded and impounded sections of the Columbia River between Revelstoke Dam and Hugh L. Keenleyside Dam (HLK; Figures 1 and 2). Referred to as the Mid-Columbia River in Canada by BC Hydro for Water Use Planning requirements.

Transboundary Reach: The Columbia River between Grand Coulee Dam in Washington State and HLK in British Columbia including the lower Kootenay River from Brilliant Dam to the Columbia River confluence, the lower Pend d’Oreille River upstream to Waneta Dam, the lower Kettle and Sanpoil rivers, and the lower Spokane River upstream to Little Falls Dam (Figure 2). The Transboundary Reach is further subdivided into two additional reaches based on geopolitical considerations:

Keenleyside Reach: The Columbia River between HLK and the Canada-U.S. boundary including the lower Kootenay River upstream to Brilliant Dam, and the lower Pend d’Oreille River upstream to Waneta Dam.

Roosevelt Reach: The Columbia River between the Canada-U.S. boundary and Grand Coulee Dam), the lower Kettle and Sanpoil rivers, and the lower Spokane River upstream to Little Falls Dam.

Other areas in the Transboundary Reach that historically may have been used by White Sturgeon are the lower Kootenay River between Brilliant Dam and Upper Bonnington Dam (including the Slocan River and Slocan Lake) and the lower Pend d’Oreille River between Waneta Dam and Boundary Dam). These areas are not presently considered as potential White Sturgeon recovery areas but may be in the future.

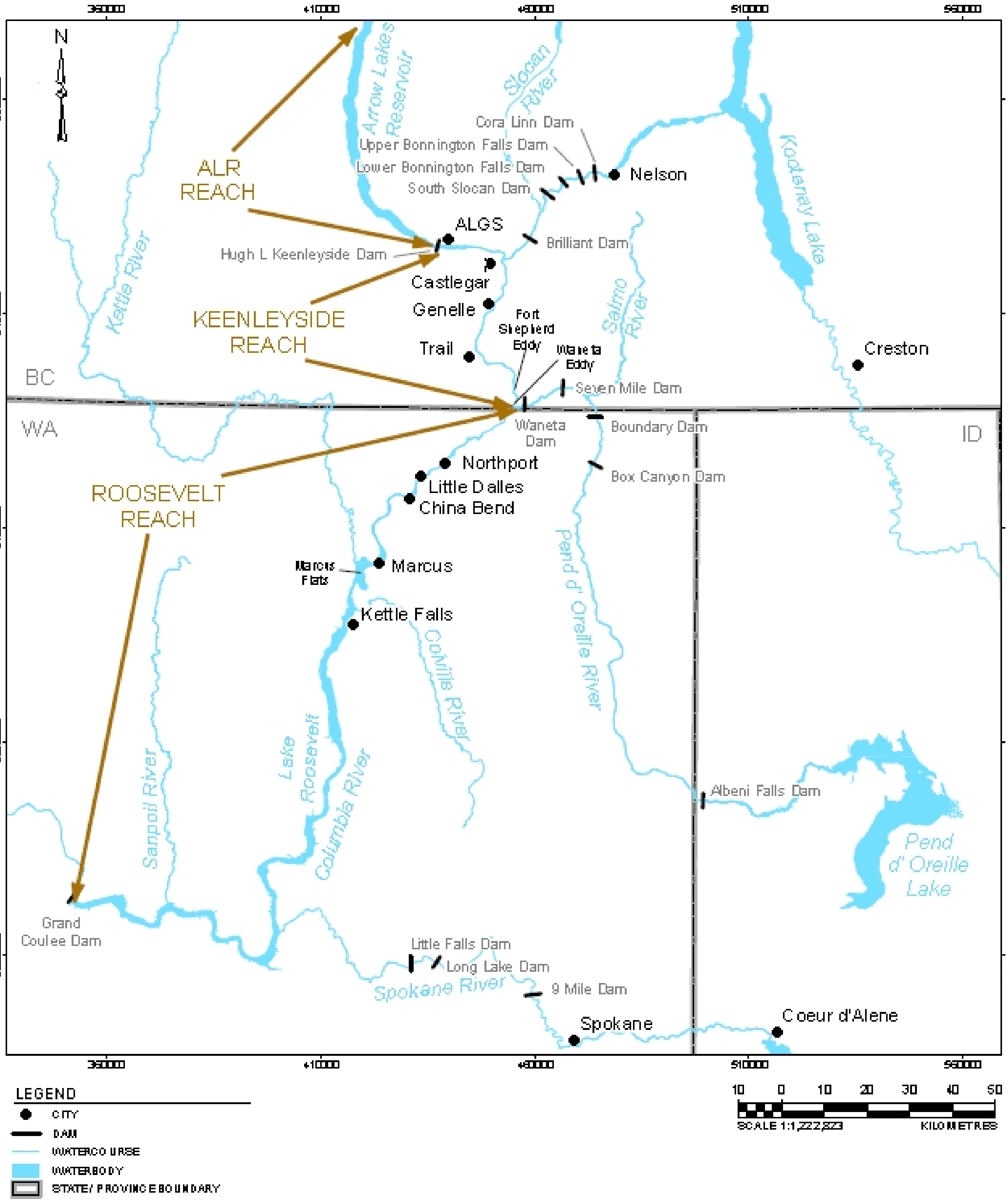


Figure 2: Upper Columbia River White Sturgeon recovery area. The Roosevelt and Keenleyside reaches combined comprise the Transboundary Reach.

1.2 Outlook Without Intervention

The intrinsic biologic factors most limiting to White Sturgeon population growth are very low early life stage survival and delayed maturation (Gross et al. 2002; NRTWS 2007). Without intervention, the Upper Columbia White Sturgeon population will continue to decline, eventually reaching critical thresholds from which recovery may be difficult even with intervention (Wood et al. 2007).

The World Conservation Union (IUCN 1994) and COSEWIC (2003) classify sturgeon populations of fewer than 2,500 mature individuals as endangered. Adult numbers of 500 and 50 have been identified as population benchmarks associated with irreversible consequences in U. S. Endangered Species assessments (Thompson 1991; McElhany et al. 2000; Rieman and Allendorf 2001). Numbers lower than 500 result in bottlenecks that can rapidly reduce genetic diversity as not all individuals are available to breed annually. Numbers lower than 50 result in severe genetic impacts related to inbreeding. However, due to polyploidy and their unique life history traits of long life, late maturation, intermittent spawning, and spawning site fidelity, White Sturgeon likely have a buffer against loss of genetic material at low population levels. More recent findings from other sturgeon species suggest that a larger degree (as compared to other fish species) of population level diversity is represented by fewer individuals (Walsh et al. 2001; Waldman et al. 2002; Grunwald et al. 2002; Wirgin et al. 2005).

In the 2002 UCWSRP, the natural wild White Sturgeon population in the Keenleyside Reach was estimated at approximately 1,500 individuals and was projected to decline to lower than 500 fish within 14 years and to lower than 50 fish by 2044 (UCWSRI 2002). This prediction was based on a 7% annual mortality rate (RL&L 1994a) and without intervention in the form of supplementation through conservation aquaculture programs and other recovery efforts. This information contributed to the listing of the species in Canada under SARA, regulatory protection measures in the U.S., and development of the UCWSRP.

More recent data indicate that approximately 3,100 adult wild White Sturgeon reside in the Transboundary Reach when fish in the Keenleyside Reach and the Roosevelt Reach are considered collectively. Based on an annual mortality rate of 2.9% (Irvine et al. 2007), this wild population is projected to decline to lower than 500 fish within 50 years and to lower than 50 fish by 2140. However, the rate of decline after 2050 is expected to increase as most fish approach 100 years of age, which is assumed to represent their approximate maximum life span. For this and other reasons (see Section 2.4.1), there is still considerable uncertainty surrounding these projections. There is also concern that the possible presence of present/historical stock structure will further reduce the effective population size, which increases conservation risk.

The decline of the Upper Columbia White Sturgeon began with recruitment failure in the 1960s and 1970s, which was not recognized until the early 1990s. Many of the actions outlined in the 2002 UCWSRP, which were intended to slow or arrest this decline, have been implemented in the past decade. However, in upcoming decades, fewer adult fish will remain to take advantage of suitable natural recruitment conditions (if they occur) and it will become increasingly difficult to capture the broodstock needed to sustain an artificial supplementation program. Continued uncertainty about the nature of the recruitment problem(s) will likely delay identification of potential solutions to restore natural recruitment. The current critical status of Upper Columbia River White Sturgeon belies a notion that their longevity provides an extended opportunity for implementation of this revised recovery plan. In fact, White Sturgeon longevity ensures that near term actions or inaction in the following decade will have long term consequences for the future of the species in the Upper Columbia River.

1.3 The Upper Columbia White Sturgeon Recovery Initiative

The original White Sturgeon recovery planning process was initiated by Canadian organizations and built upon a Canadian Columbia River White Sturgeon stock stabilization document (Hildebrand and Birch 1996). A common commitment to a recovery program was formalized by Fisheries and Oceans Canada, BC Environment, BC Fisheries, and BC Hydro (BCH) with an August 17, 2000 Letter of Understanding. The agreement also defined a process for engaging First Nations and stakeholders (interested parties) in recovery planning in order to build understanding and support for the plan and to explore possible sources of funding for full implementation of the plan. This process led to active U.S. participation by the Spokane Tribe of Indians, Confederated Tribes of the Colville Reservation, U.S. Geological Survey, U.S. Fish and Wildlife Service, Bonneville Power Administration, and the State of Washington and the subsequent development of the formal UCWSRI.

The UCWSRI recovery planning process for Upper Columbia White Sturgeon was initiated in September 16, 2000. An initial priority of the UCWSRI was the development of a formal recovery plan (UCWSRI 2002). An Action Planning Group and a Recovery Team were formed in late 2000 as an outcome of the September 16 workshop. These groups interacted but were not hierarchically organized and their respective roles and responsibilities were described in a “terms of reference.” These two groups were subsequently reorganized and renamed in 2005 as the Community Working Group (CWG) and the Technical Working Group (TWG), respectively to align the UCWSRI with the Canadian federal government’s National Recovery Strategy Process for species listed as endangered under SARA. At the local planning and implementation level, the UCWSRI is supported by both the CWG and TWG committee processes.

The CWG constitutes the ‘main table’ with representation by the Canadian provincial, federal, and regional governments, First Nations, members of the public, environmental and industrial stakeholders. A CWG has to date only been established in Canada. Their primary tasks are to develop a common vision for sturgeon recovery and to act as a public liaison with the broader community of affected and interested parties. The Terms of Reference for the CWG and TWG can be found at: http://www.uppercolumbiasturgeon.org/. Specific responsibilities of the CWG include:

- outreach education in schools and in the community;
- acting as a "sounding board" for TWG ideas and for community ideas;
- serving as a liaison from the community and industry to the TWG and from the TWG to the community and industry (bridging function);
- accessing funding for programs, education, outreach and public communication that may not be available through regular TWG channels;
- serving as a community advisory group to regulators/agencies;
- seeking local and traditional knowledge to support recovery strategy development;
- providing reporting services to federal and provincial authorities as required;
- developing, revising and maintaining a communication plan that details strategies, tactics, and budgets for outreach education and communication;
- working with other basin-level CWGs, as requested;
- providing advice on potential social and economic impacts of proposed recovery actions; and
- fostering support for long term sturgeon recovery through all of the above.

The TWG has been formed to lead recovery actions for Upper Columbia White Sturgeon Recovery. The primary role of the TWG is to offer scientifically sound recovery advice to government and non-government agencies, as well as to the National Recovery Team for White Sturgeon in Canada; however, ultimate responsibility and accountability for management decisions based on this advice rests with the responsible jurisdictions. The TWG also oversees implementation and monitoring of recovery plans in cooperation with the regulatory agencies. The TWG is comprised of individuals with technical expertise in relevant areas of sturgeon biology and fish culture, recovery of endangered species, genetics, hydraulic operation of Upper Columbia hydro facilities, and habitat remediation. The TWG provides detailed planning and implementation for White Sturgeon conservation and recovery activities and a mechanism for collaboration and coordination among various parties with interests in White Sturgeon within the Upper Columbia. Public input into the plan is achieved through on-going communication with and feedback from the CWG. Specific responsibilities of the TWG include:

- assembling accurate baseline data and reviewing reasons for population declines;
- defining the recovery goals and short, medium, and long-term objectives for white sturgeon recovery;
- establishing criteria to evaluate the recovery plan and to define success;
- designing technical strategies, measures, and supporting research programs to achieve recovery goals and objectives; and,
- establishing priorities for recovery implementation based on technical criteria and input from the CWG.

As required, the TWG establishes sub-committees to provide information or recommendations on specific subjects such as water management, habitat restoration, early life history, contaminants, fish culture, genetics, and database management.

1.4 Species at Risk Act

The Canadian *Species at Risk Act* (SARA) was proclaimed in 2003 to prevent indigenous wildlife from becoming extirpated or extinct, to secure the recovery of endangered and threatened species, and to prevent species of special concern from becoming more seriously at risk. Species listed under SARA as threatened or endangered are immediately protected from killing, harm, harassment, capture, take, possession, collection, buying, selling, and trade by a series of general prohibitions. Species' residences and critical habitats, once identified, must be protected from destruction. The Canadian federal government is also required to undertake recovery and action planning activities within mandated timelines. Fisheries and Oceans Canada (DFO) is the federal department responsible for White Sturgeon recovery under SARA.

Four populations of White Sturgeon were listed as Endangered under the SARA's List of Wildlife Species at Risk (Schedule 1) in 2006 – upper Fraser River, Nechako River, upper Kootenay River and Upper Columbia River. A national Recovery Strategy for White Sturgeon in Canada, which includes an identification of the species' critical habitat, is currently under development. Following finalization of the recovery strategy, DFO, together with partners, will begin development of a SARA action plan for the species; timelines for action plan development will be established in the recovery strategy.

1.5 Northwest Power Planning Council Fish and Wildlife Program

U.S. White Sturgeon recovery efforts in the Upper Columbia River are being conducted under the auspices of the Northwest Power and Conservation Council's Fish and Wildlife Program. The Upper Columbia White Sturgeon Recovery Initiative provides the opportunity to develop a comprehensive plan for both sides of the Canada-U.S. boundary. This recovery plan is not intended to replace the formal planning process for the U.S. Columbia River Basin Fish and Wildlife Program but should provide a technical basis for sturgeon recovery strategies and measures addressed in that program. This recovery plan may also serve as a master plan for any supplementation-based recovery measures identified for the U.S. portion of the Upper Columbia River.

The Pacific Northwest Electric Power Planning and Conservation Act passed by the U.S. Congress in 1980 authorized the states of Idaho, Montana, Oregon, and Washington to create the Northwest Power and Conservation Council. The Act directs the Council to prepare a program to protect, mitigate, and enhance fish and wildlife of the Columbia River Basin that have been affected by the construction and operation of hydroelectric dams while also assuring the Pacific Northwest an adequate, efficient, economical, and reliable power supply. The Act also directs the Council to inform the public about fish, wildlife, and energy issues and to involve the public in its decision-making.

Through its fish and wildlife program the Council provides guidance and recommendations to the Bonneville Power Administration. Bonneville then uses these recommendations to fund fish and wildlife projects to mitigate for the impacts of the federal hydropower system within the Columbia basin. A series of fish and wildlife programs have been adopted, revised, or amended between 1982 and 2009. The current Fish and Wildlife Program incorporated specific measures and objectives for the mainstem Columbia and Snake Rivers in 2003, adopted sub basin management plans in 2004-2005, and includes amendments added in 2009 to update the sub basin management plans and Program objectives to reflect recent monitoring, evaluation, and planning developments (NPCC 2009). The mainstem plan incorporated in 2003 provides a vision, objectives, and priorities for White Sturgeon populations in the U.S. portion of the Columbia River, which are consistent with the recovery of the Upper Columbia White Sturgeon population.

Upper Columbia River White Sturgeon are considered native resident fish in the current Fish and Wildlife Program. The Council expects U.S. Federal operation agencies, in conjunction with relevant state and Federal fish and wildlife agencies and tribes to implement actions to stabilize and improve Columbia River White Sturgeon. This is to be achieved through consideration of hydro system operations, fish passage efforts, habitat improvement investments, and other actions directed toward optimizing sturgeon survival by protecting, enhancing, restoring, and connecting natural river processes and habitats, especially spawning rearing, resting, and migration habitats.

2.0 BIOLOGY AND STATUS

The following sections provide an update on available information about White Sturgeon in the Upper Columbia River with an emphasis on research findings conducted since the 2002 recovery plan was written. For more general information on White Sturgeon biology, the reader is encouraged to review the original 2002 version of the Recovery Plan (UCWSRI 2002) or consult previously published sources that provide more general information on the species (Scott and Crossman 1973; PSMFC 1992; McPhail 2007). Sturgeon recovery activities outside of this recovery area are also considered if they affect Upper Columbia River sturgeon.

In the interests of brevity, references are restricted to the most relevant and/or recent reports or publications that provide the information presented. However, these reports often provide summaries from a series of related research programs (e.g., ongoing annual or regular study programs related to supplementation through conservation aquaculture programs, spawn monitoring, stock assessments, etc.). To ensure the detail in the supporting reports is identified for potential future review or re-analysis, a bibliography of reports from all research programs conducted in the Upper Columbia River since 1990 has been prepared and is available on the UCWSRI website (http://www.uppercolumbiasturgeon.org).

The following summary also includes information on juvenile hatchery origin White Sturgeon that have been released annually in the Transboundary Reach since 2001 and in the Arrow Lakes Reservoir since 2007. In the 2002 recovery plan, information on juvenile White Sturgeon was extremely limited due to a near absence of juveniles in the Upper Columbia River.

2.1 Species Description

Although the order Acipenseriformes originated ~200 million years ago, phylogenetic research suggests White Sturgeon have existed as a species for about 46 million years (95% CI 18 to 85 MY; Peng et al. 2007). The White Sturgeon is one of nine North American and 30 total sturgeon species that inhabit temperate large river systems throughout the Northern Hemisphere (World Sturgeon Conservation Society http://www.wscs.info/).

White Sturgeon are characterized by a cartilaginous skeleton and persistent notochord (Scott and Crossman 1973). They possess a tube-like mouth and four barbels located on the ventral surface of a hard protruding snout. All have at least five rows of bony plates (scutes): one dorsal, two ventral, and two lateral rows. Denticles make the skin feel rough between the rows of scutes. Additional information on the physical appearance and basic biology of White Sturgeon can be found on the UCWSRI website (http://www.uppercolumbiasturgeon.org).

2.2 Distribution & Movements

2.2.1 Wild Origin White Sturgeon

White Sturgeon inhabit large rivers, estuaries, and the near-shore ocean of western North America from Ensenada, Mexico to the Aleutian Islands (Figure 3). Reproducing White Sturgeon populations are present in the Columbia, Fraser, and Sacramento River systems (Scott and Crossman 1973; Lee et al. 1980; Lane 1991). Some members of these populations do enter the ocean and occasional movement of tagged fish has been observed among the three main river systems (DeVore et al. 1999; Welch et al. 2006; pers. comm., Nelson, T., Fraser River Sturgeon Conservation Society, Vancouver, BC, 2011). Movements of White Sturgeon are influenced by the geographic separation between suitable habitats required for various life requisite functions such as feeding, spawning, and overwintering (Apperson and Anders, 1991; Brannon and Setter, 1992).

The construction of dams on the Columbia River mainstem and tributaries has fragmented the once contiguous riverine habitat for wild White Sturgeon and resulted in the formation of numerous isolated population segments. Many of these population segments, particularly those in the upper and middle portions of the basin, are experiencing recruitment failure or low recruitment success (Figure 3).

Virtually all of the research on these population segments has been conducted since 1980, well after most of the dams were constructed (post-regulation). As such, the movement patterns and certain population metrics of White Sturgeon in the Transboundary Recovery Area that are discussed in the following sections reflect post-regulation conditions. While some information on these population metrics are available from wild populations in unregulated systems like the Fraser River, in most cases the comparability of the data is limited due to substantial physical, chemical, and biological differences between the Columbia and Fraser river systems.

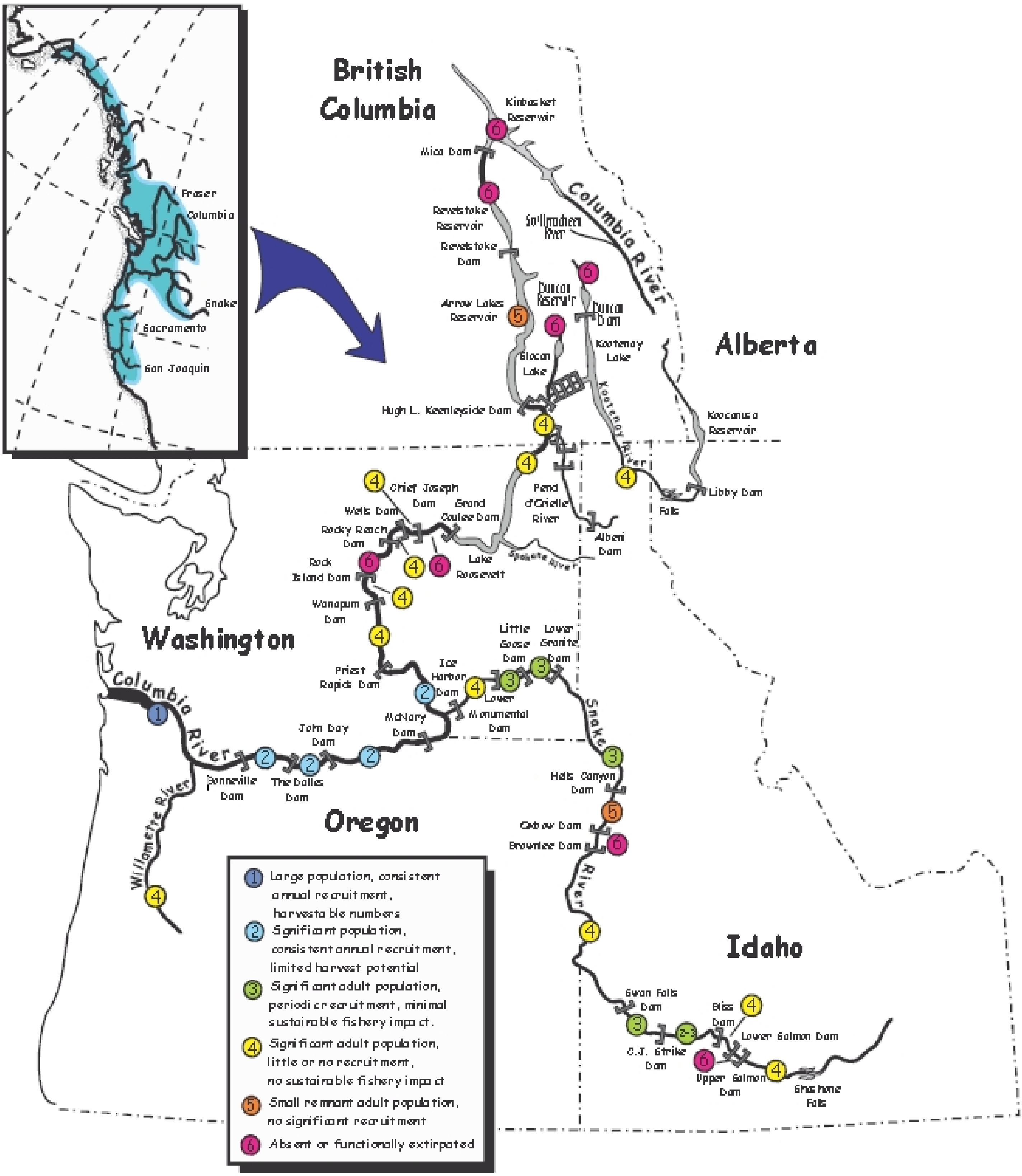


Figure 3: Freshwater and saltwater (inset) range of White Sturgeon and the distribution and status of Columbia River Basin population segments.

White Sturgeon in the Upper Columbia River were most likely resident and historically inhabited the Columbia River mainstem, lower Spokane River, lower Pend d'Oreille River, and Kootenay River to Upper Bonnington Falls (Figure 1). They probably also used portions of the Sanpoil, Kettle, Slocan, and Salmo rivers (Hildebrand and Birch 1996; Prince 2001). Distribution was probably patchy with fish concentrated in areas of favourable habitat. Anecdotal sightings were reported during the early 1900s in the lower Kootenay River and in the Columbia River near Castlegar, Arrow Lakes, near Revelstoke, and the present site of Mica Dam (Prince 2001).

Two defined White Sturgeon population segments (i.e., former contiguous populations now separated physically by dams) are present in the Upper Columbia River: one in the Transboundary Reach and the other in the ALR Reach (Figure 2). The largest population segment resides in the 296 km long Transboundary Reach. The two genetics studies conducted to date have used different methods and provided different results; consequently, there is uncertainty and differing interpretations regarding historical stock structure within the Transboundary population segment and the ALR Reach (see Section 2.3). Other remnant population segments that consist of a few individuals occur, or are suspected, throughout other portions of their historical range in the Upper Columbia River (Figure 1).

2.2.1.1 Transboundary Reach

Intensive annual studies in the Roosevelt Reach, initiated in 1998, indicated wild sub-adults (100 to 150 cm FL) and adults (>150 cm FL) were distributed throughout the area upstream from Gifford in Lake Roosevelt (DeVore et al. 2000; Howell and McLellan 2007a, 2007b, 2008, 2011, *in prep*) whereas juveniles (<100 cm FL; primarily hatchery origin) were concentrated in the river-reservoir transition zone from Marcus upstream (Figure 2; Howell and McLellan 2011; Howell and McLellan *in prep*). High use areas are present at the Little Dalles and Marcus Flats and most adults occur in the river-reservoir interface area and in the mainstem river upstream to the Canada-U.S. boundary. Juveniles showed little distributional seasonal differences but older fish (>100 cm FL) were more widely distributed in the summer than during the early spring (i.e. at the tail-end of overwintering) when fish were most heavily concentrated in the area between the Colville River mouth upstream through the Marcus Flats area.

White Sturgeon in the Keenleyside Reach have been intensively studied annually since 1990 (RL&L, 1994a, 1994b, 1995a, 1995b, 1996d,1997a, 1998a, 1998b, 1998d, 1999a, 2000b; Golder 2002, 2003, 2005, 2006a, 2008, 2009a, 2009b,2010, 2011c; Hildebrand et al 1999; BC Hydro unpubl. data). Sturgeon in the Keenleyside Reach are concentrated throughout the year in deep, low velocity habitats that represent high use areas for White Sturgeon (Hildebrand et al. 1999; RL&L 1994a; Golder 2006a; BC Hydro *in prep*). The primary areas of use are the 7 km long section downstream from HLK, at the Columbia Kootenay rivers confluence, Fort Shepherd Eddy, and Waneta Eddy at the Pend d'Oreille River confluence (Hildebrand et al. 1999).

Considerable information on the extent of White Sturgeon movements and mixing in the Transboundary Reach has been collected since 1990 (Golder 2006a, 2009a; Howell and McLellan 2007b; Irvine et al. 2007; Van Poorten and McAdam 2010; Clarke et al. 2011; Nelson and McAdam 2012; Howell and McLellan *in prep*.). These data indicate that White Sturgeon reside throughout the Keenleyside Reach and in the upper half of the Roosevelt Reach. In general, most fish tend to remain in relatively localized areas for extended periods but some move frequently among areas within the river system for spawning, feeding, or overwintering. Analysis of telemetry data from 2008 to 2012 indicated the mean proportion of time spent at a single location (residency time) was 0.62 years ± 0.21 (mean ± 1 SD) for individual White Sturgeon, with higher residency time (0.65 years ± 0.20) exhibited by females compared to males (0.58 years ± 0.21; BC Hydro *in prep*). Additionally, fidelity levels greater than 90% were identified based on analysis at the sub-reach scale (Hildebrand et al. 1999; Nelson and McAdam 2012). Although these movements are indicative of present habitat use, long term movement patterns are poorly understood, including the relationship between current and historical movement patterns.

In the Transboundary Reach, movements of fish likely engaged in spawning migrations tend to be greater on average than movements for non-spawning related activities (Table 1). During the summer period, White Sturgeon also exhibit frequent but more localized movements, likely related to feeding, than in the other seasons (Hildebrand et al. 1999). White Sturgeon use shallower depths during the spring to summer period and often exhibit frequent, short distance forays between shallow and deep-water areas to feed. In general, sturgeon in the Transboundary Reach ranged most widely during the period May-October with few long distance movements observed from November-April (Howell and McLellan 2011; Golder 2006a, 2009a). White Sturgeon typically become inactive during the winter period when water temperature drops below 15°C (Haynes et al. 1978). In the Upper Columbia River, sturgeon selected specific overwintering areas and typically remained in these areas all winter (Hildebrand et al.1999; Howell and McLellan 2007b). Feeding does occur during the winter although foraging activity is greatly reduced.

Table 1: Net movements of adult White Sturgeon monitored in the Keenleyside and Roosevelt reaches from 2003 to 2006 (Golder 2006a).

Movement Details	*n*	Movement Range (km)		
		Mean	Minimum	Maximum
Detected only in the Keenleyside Reach	**28**	**20.1**	**0.0**	**70.9**
Not believed to have spawned	22	12.1	0.0	55.9
Likely spawned	6	49.3	3.4	70.9
Detected in the Keenleyside Reach and the Roosevelt Reach	**10**	**101.5**	**19.3**	**179.9**
Detected only in the Roosevelt Reach	**39**	**67.6**	**35.4**	**124.6**
Not believed to have spawned	26	59.1	35.4	104.6
Likely spawned	13	84.6	59.0	124.6

In the Transboundary Reach, spawning migrations typically occur in the spring. White sturgeon putative spawners in the Keenleyside Reach moved lesser distances on average (49.3 km) than their counterparts in the Roosevelt Reach (84.6 km; Table 1). A portion of adults captured and tagged in each reach exhibited putative spawning migrations to the adjoining reach (Table 2).

From 2002 to 2005, 78 wild White Sturgeon in the Transboundary Reach (range of 104 to 256 cm FL; mean = 189.7 cm FL) were outfitted with acoustic tags; 40 in the Roosevelt Reach and 38 in the Keenleyside Reach (Howell and McLellan 2008; Golder 2006a). These tags had a nominal operational lifespan of four years and all expired by the end of 2009. Tagged fish were tracked with a longitudinal array of automated acoustic receivers deployed at various locations in the Transboundary Reach between the Columbia-Spokane confluence and HLK from 2003 to 2009. For the 76 sturgeon that were detected by the Transboundary array following release, detection history durations ranged from 0.1 to 6.3 years (mean = 3.6) and the detected longitudinal range of movement for individual fish at large varied from 0.0 to 186.4 km (mean = 69.6).

Table 2: Proportion of White Sturgeon adults (N = 44) that undertook putative spawning movements during the June to August period within and outside their original capture area within the Keenleyside Reach, 2008 to 2011(data from BC Hydro).

River Section where Movement Originated [a]	River Section (Known or Suspected Spawning Area)		
	Upper (Keenleyside)	Middle (Suspected – Kinnaird)	Lower (Waneta)
Upper	0.80	0.20	0.00
Middle	0.06	0.59	0.35
Lower	0.08	0.00	0.92

[a] Upper = HLK to Kootenay River mouth; Middle = Downstream of Kootenay R. mouth to Birchbank; Lower = Beaver Creek to Waneta

For the 73 sturgeon with detection history durations greater than two years (at large 2.5 to 6.3 years; mean = 3.8 years), the furthest downstream that sturgeon were ever detected was the receiver at the Columbia-Spokane confluence although only two sturgeon were detected this far downstream (Figure 2). Twelve (16.4%) sturgeon were detected further downstream than the Gifford station although only two fish ever spent more than a few days in this area over the entire course of their tag life. Ignoring temporary movements during suspected spawning migrations, sturgeon habituated to either the Keenleyside (n = 28; 38.4%) or Roosevelt Reach (n = 41; 56.2%) during the study with only four fish (5.5%) utilizing habitat in both reaches for substantial periods (months to years) of time. Including temporary movements for putative spawning migrations, 28.8% of fish were detected in both the Roosevelt and Keenleyside reaches (Howell and McLellan *in review*). Collectively, these data indicate some movement and mixing of sturgeon throughout the Transboundary Reach (Figure 2).

Finer scale (<10 m) White Sturgeon movement data from a VR2W Positioning System (VPS) study in the Marcus Flats area during 2009 to 2010 also indicated seasonal differences in habitat use (McLellan et al. 2011). In the winter and spring, sturgeon occupied the original Columbia River channel for significantly longer periods than adjacent flooded river terrace areas whereas habitat use was more dispersed in summer and fall.

2.2.1.2 Arrow Lakes Reservoir Reach

The ALR Reach supports a small population segment of adult White Sturgeon (estimated at ~50 individuals; see Section 2.4.1.3) that has experienced total recruitment collapse (RL&L 1996b, 1998c, 1999b, 2000a, 2000b; Golder 2006b, 2011a, 2011b). Sturgeon are distributed mainly in the upper half of ALR. The Beaton Flats area (at the confluence of Beaton Arm and the main body of ALR have been identified as an important feeding and overwintering areas for wild adults. Sturgeon remain in this area throughout the winter but move upstream during spring and summer to below Revelstoke Dam for feeding and/or spawning or into Beaton Arm for feeding. Movements to downstream areas near the middle ALR are occasionally observed, mainly in late summer and early fall, likely feeding on Kokanee (*Oncorhynchus nerka*) spawning in tributaries to ALR. Anecdotal reports suggest White Sturgeon were historically present in the former Lower Arrow Lake (now the lower half of ALR), but assessment fisheries in the lower ALR have captured only one sturgeon (Prince 2003), which suggests a low level of use of this area. Occasionally, dead White Sturgeon are recovered downstream from HLK; these fish were untagged and died of injuries that may have been sustained during passage through the dams water release structures (Golder unpubl. data). One sturgeon, tagged in upper ALR on 28 October, 1998, was recaptured downstream from HLK on 9 May 2003, which indicated that some fish do use or travel through the lower section of ALR and are able to successfully pass downstream through HLK (either through the dams water release structures or the boat lock; Golder 2006b). Fin ray microchemistry analysis was recently investigated as a means to provide a longer term analysis of past movement patterns and habitat use for adult and juvenile stages of White Sturgeon (Clarke et al. 2011). That analysis showed that 11 of the 12 samples collected from fish captured directly downstream of Keenleyside Dam (HLK group) showed distinct shifts in their chemical signatures at about 10 years of age, but ALR fish did not show a similar shift. These findings suggests that many of the HLK group fish apparently spent the majority of their first 10 years in areas similar to the ALR group, which is also consistent with the genetic similarity of fish from these two areas (Nelson and McAdam 2012).

2.2.1.3 Other Areas

Other small remnant White Sturgeon population segments occur throughout the historical Upper Columbia River range. Two adult White Sturgeon have been collected during systematic investigations in Slocan Lake (RL&L 1996b, 2000a). Anecdotal reports suggest of White Sturgeon were historically present in Seven Mile Reservoir on the Pend d'Oreille River (RL&L 1995b), Revelstoke Reservoir (RL&L 2000a), and Kinbasket Reservoir (CCRIFC 2010; Westslope 2011). However, past attempts to capture White Sturgeon in these reservoirs have been unsuccessful, which either suggests they are not present or present only at very low population densities.

2.2.2 Hatchery Origin White Sturgeon

To supplement existing wild populations of White Sturgeon in the Upper Columbia River, the UCWSRI initiated a broodstock collection program and a conservation aquaculture program in 2001. This program involves the collection of wild pre-spawning adults, transporting them to a conservation aquaculture hatchery where the eggs are spawned, fertilized, and subsequently reared at facilities in British Columbia and Washington until release. In the Keenleyside Reach, the majority of broodstock (70%: Table 3) have been captured in the lower section from Trail to the Canada-U.S. boundary (Figure 2).

Juvenile hatchery reared White Sturgeon have been released annually into the Keenleyside Reach since 2002, into the Roosevelt Reach since 2004, and into the ALR Reach since 2007. Most of these fish are the progeny of wild adult broodstock collected in the Transboundary Reach and most have been released as 5 to 10 month old juveniles. There also have been some experimental releases of fed and unfed larval sturgeon in the ALR Reach. Since 2011, supplementation in the Roosevelt Reach has relied solely on the capture of wild larvae, rearing these individuals in a conservation aquaculture hatchery, and releasing them as juveniles.

Table 3: The proportion of White Sturgeon adults (n = 128) used in the broodstock collection program captured from the different areas of the Columbia River in the Keenleyside Reach, 2001 to 2011.

River Section[a]	Proportion
HLK to Norns Creek	0.18
Lower Kootenay River	0.09
Kinnaird to Trail	0.04
Trail to Canada-U.S. boundary	0.70

[a] See Figure 2 for river section locations

As of 1 January 2012, the conservation aquaculture program has released 159,198 hatchery reared juveniles (5 to 10 months of age, excluding larval releases) into the Upper Columbia River recovery area: 122,555 into the Transboundary Reach (93,524 in the Keenleyside Reach and 29,031 in the Roosevelt Reach), and 36,643 into ALR Reach (see www.uppercolumbiasturgeon.org for updates on annual stocking numbers). In addition, approximately 1.5 million larvae have been released into the ALR Reach. All juveniles have been marked using a PIT tag (primary mark) and scute removal (secondary mark). In addition, 325 juveniles have been implanted with sonic tags in the Keenleyside Reach (50 per year from 2002 to 2006 and 25 in 2008), 98 in the Roosevelt Reach (8 in 2005 and 90 in 2008), and 250 in the ALR Reach (50 per year from 2008 to 2012). Although indexing of the hatchery juvenile population has been conducted regularly in all reaches where they were released, up-to-date summaries of the data are presently only available for the ALR Reach (Golder 2011a).

2.2.2.1 Transboundary Reach

To assess the dispersal patterns of hatchery juveniles following release into the Transboundary Reach and to identify locations and characteristics of rearing habitats, 90 juveniles were implanted with sonic tags and their movements monitored (Golder 2009a). Sonic tagged fish released in the Keenleyside Reach exhibited two general movement patterns based on where they were released. Fish released below HLK remained between there and Sturgeon Island (a 6 km section of river with thalweg depths in excess of 15 m, near-bottom current velocities lower than 0.5 m/s, and substrates consisting mainly of fines). Fish released at Beaver Creek (a small localized and shallow eddy) exhibited a downstream dispersal to habitats with conditions similar to those described above, such as Fort Shepherd Eddy and Waneta Eddy (Keenleyside Reach) or Little Dalles and Marcus Flats (Roosevelt Reach). Based on this information, the release pattern was modified in 2010; 25 sonic tagged juveniles were released at 11 km intervals from HLK to the Canada-U.S. boundary (5 individuals released at each of five locations) and their post release movements examined. The majority of juveniles remained within 5 km of their release location with the exception of those released downstream of Genelle. Those individuals exhibited rapid downstream movements, stopping only when they reached Fort Shepherd and Waneta eddies or small eddy habitats in-between. These movements, combined with direct capture data, suggest habitat use throughout the Keenleyside Reach occurs over a variety of habitat types with the exception of areas with very large substrate or bedrock. Data collected to date indicate the selection of suitable release locations is important since these determine the ultimate dispersal and distribution of the stocked juveniles.

Gill net sample programs conducted in the Keenleyside Reach in the early years of the juvenile White Sturgeon release program (i.e., 2002 to 2006) captured fish mainly in the upper and lower sections (Table 4; Golder 2009a). Although sample effort was not equal among river sections and sample years, sufficient effort was expended in the middle section to indicate a low overall use of this area, likely due to a low availability of deep thalweg or eddy habitat. Underwater video systems identified concentrations of several hundred juvenile White Sturgeon below HLK and in Waneta Eddy (Golder 2009a). These fish were typically lying on the bottom in close proximity to or touching other juveniles or adults, and oriented facing into the current.

Table 4: Relative distribution of hatchery juvenile White Sturgeon captured in the Keenleyside Reach by gill nets from 2002 to 2006 (data from Golder 2009a) and from 2009 to 2011(data from BC Hydro). See Figure 2 for locations.

	2002 to 2006[a]		2009 to 2011[b]	
Location in the Keenleyside Reach	**Catch**	**Proportion of Catch**	**Catch**	**Proportion of Catch**
Upper (HLK to Kootenay Confluence)	166	0.31	584	0.37
Middle (Kootenay Confluence to Beaver Creek)	9	0.02	102	0.06
Lower (Beaver Creek to Canada-U.S. boundary)	365	0.67	892	0.57

[a] Data from Golder 2009a; effort was not consistent within river sections and across years

[b] BC Hydro, unpublished data; consistent effort was applied annually in each river section

Sampling in the Keenleyside Reach from 2009 to 2011was conducted by a combination of gill nets and set lines and sample effort was applied in a standardized manner throughout the Keenleyside Reach. The proportional distribution of the catch was similar to that recorded in the 2002 to 2006 period. The substantially greater numbers of juveniles captured in the middle section in the later survey period indicated an increase use of this section as the overall population of juveniles in the reach increased and some members of the population started using other, possibly less suitable habitats.

Only 55 (4.2%) of 1,309 juvenile sturgeon (hatchery and wild) captured in the Roosevelt Reach during setline and fall gill net stock assessment surveys from 1998 to 2009 were captured downstream from the Hwy 395 Bridge at Kettle Falls (Figure 4). This could represent either an ontogenetically based preference for the river-reservoir transition zone or, since the vast majority of distributional observations for the juvenile size class were from hatchery fish, may simply reflect a propensity for remaining in habitat into which these fish were initially introduced (Howell and McLellan *in review*).

In the Roosevelt Reach, the results of fall gill net surveys and setline surveys to date indicate the highest captures of juvenile hatchery sturgeon are from the approximately 40 km section between Little Dalles and the downstream end of Marcus Flats (Figure 4). Changes in gear type and sample effort make comparisons of temporal changes in distribution difficult but the catch distribution in the 2009 setline survey suggests a more widespread distribution than was recorded in the 2005 to 2007 gill net surveys.

Data from both the Roosevelt and Keenleyside reaches indicate a trend towards the presence of juveniles in areas where they were not previously recorded and increased catch rates in areas where they were formerly only occasionally recorded. This suggests that as more juveniles are introduced into the Transboundary Area, distribution into formerly unused or underused habitats is occurring.

2.2.2.2 Arrow Lakes Reservoir Reach

Since May 2007, a telemetry receiver array has been used to monitor the movements of sonic-tagged fish released into different portions of the ALR Reach (Golder 2011a). Analyses of release locations indicated minor differences in the movement parameters examined. In all study years, juveniles released in more upstream riverine areas typically exhibited rapid downstream movement to lower velocity habitats in ALR, at which point there was an overall reduction in movements. Fish released in more downstream areas, within the influence of ALR, exhibited less downstream movement. This was interpreted as a selection for deeper, lower velocity habitat. In all years, juveniles exhibited greatest use of the uppermost section of ALR.

Analysis of movement data indicated that the month of the detection of an individual was important for the evaluation of release site effects (Golder 2011a). Initially, juvenile sturgeon released from all sites moved downstream. The tendency for fish to move upstream increased as the season progressed. The time spent on station (i.e., near a telemetry receiver station) also increased as the season progressed into fall. Although most juvenile movements occurred at night, neither time of day (day/night) nor Revelstoke Dam discharge at the onset of these movements had a significant impact on their magnitude or direction, or the time spent on station. Operations of Revelstoke Dam appeared to have little effect on juvenile White Sturgeon habitat use because use of the riverine portion of the ALR Reach is limited.

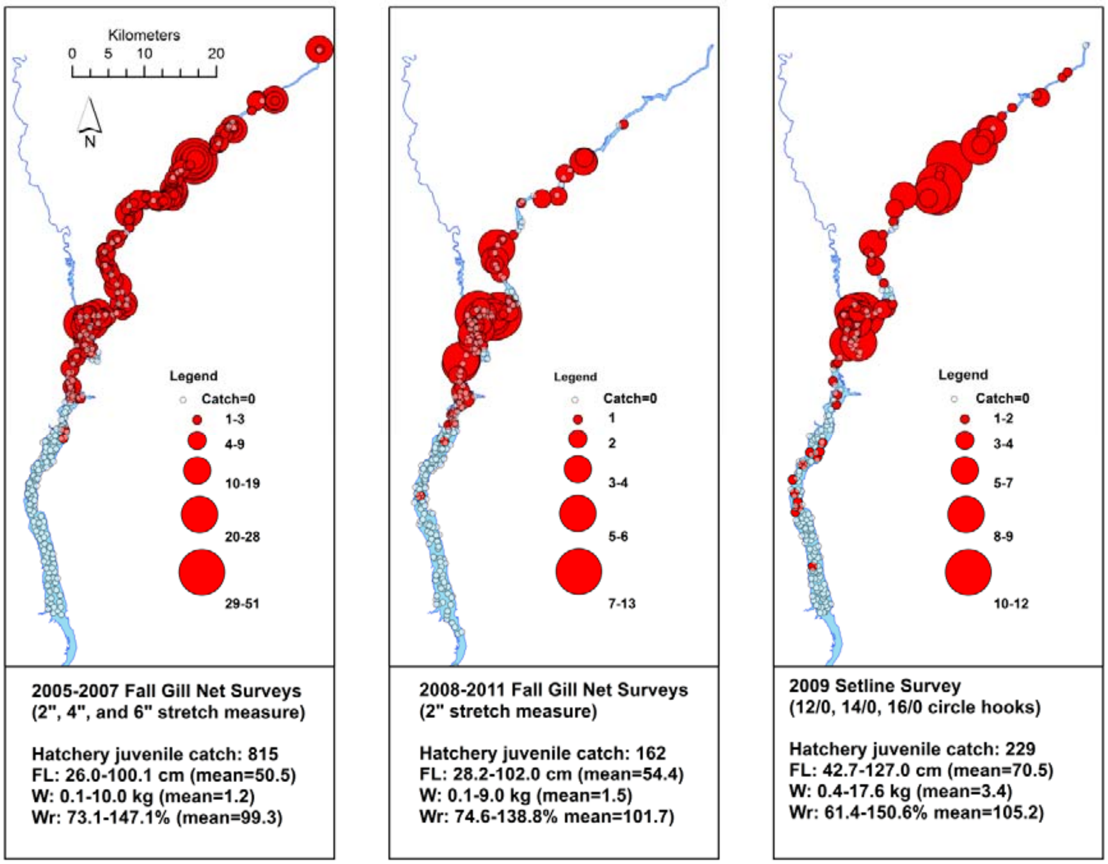


Figure 4: Distribution of hatchery juvenile White Sturgeon in the Roosevelt Reach during gill net surveys conducted in 2005 to 2007 (left panel) and 2008 to 2011 (center panel) and setline surveys in 2009 (right panel). Data from Howell and McLellan (in review).

2.3 Genetics & Stock Structure

The White Sturgeon is part of a Pacific clade of species that includes Kaluga *Huso dauricus*, Sakhalin Sturgeon *A. mikadoi*, Green Sturgeon *A. medirostris*, Chinese Sturgeon *A. sinensis*, and Amur Sturgeon *A. schrenkii* (Birstein and DeSalle 1998; Ludwig et al. 2001; Birstein et al. 2002; Peng et al. 2007; Krieger et al. 2008). The recent phylogenies of Peng et al. (2007) and Krieger et al. (2008) also include Yangtze Sturgeon *A. dabryanus* in this group. The four most recently proposed phylogenies suggest the Amur Sturgeon as the sister species of White Sturgeon (Ludwig et al. 2001; Birstein et al. 2002; Peng et al. 2007; Krieger et al. 2008).

A recent study documenting the inheritance of microsatellite loci in White Sturgeon (Drauch Schreier et al. *in prep*) supports the hypothesis that the species is of octoploid origin.

Earlier work on White Sturgeon population structure across their range provided preliminary evidence of genetic structure on a regional scale (Bartley et al. 1985; Setter and Brannon 1992; Brown et al. 1992; Rodzen et al. 2004) but the markers used did not provide enough resolution to examine fine-scale population structure. Drauch Schreier et al. (*in prep*) incorporated a more exhaustive collection of White Sturgeon from throughout their range and data from thirteen polysomic microsatellite loci to further examine White Sturgeon population structure. Drauch Schreier et al. (*in prep*) confirmed that population structure varied regionally and within major river basins (Figure 5). However, Smith et al. (2002) identified population structure within the Fraser River using a combination of mDNA and nDNA. Recent analysis by Drauch Schreier et al. (*in prep*) confirmed that population structure varied regionally and also found that it varied within major river basins (Figure 4).

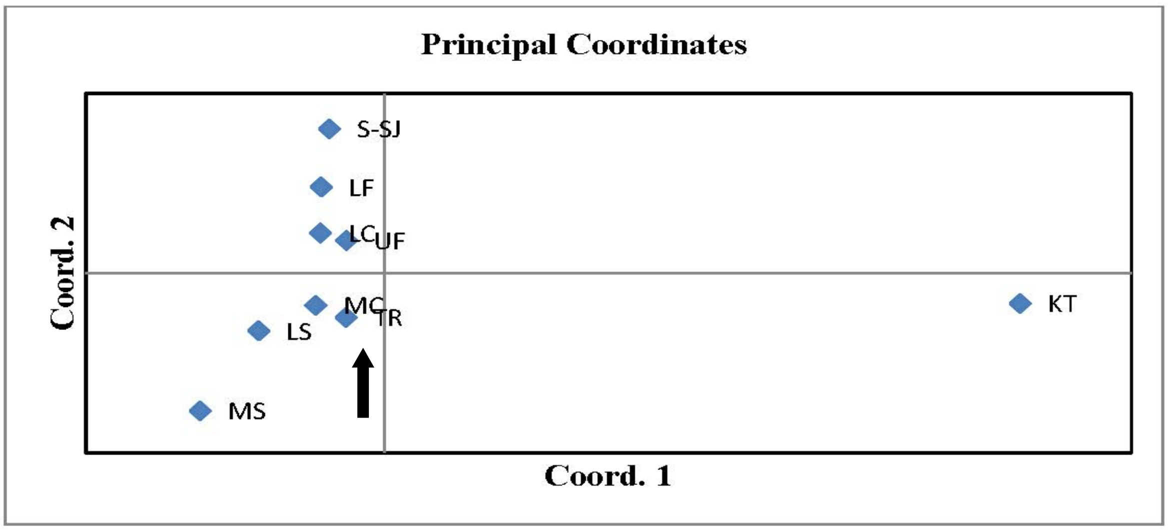


Figure 5: Principle coordinates analysis illustrating genetic relationships among White Sturgeon inhabiting different regions throughout their range. S-SJ = Sacramento-San Joaquin, LC = Lower Columbia, MC = Middle Columbia, TR = Transboundary Reach, KT = Kootenai, LS= Lower Snake, MS= Middle Snake, LF= Lower Fraser, and UF= Upper Fraser. An arrow depicting the Transboundary Reach (TR) was added for emphasis. Reproduced with permission from Drauch Schreier et al. (in prep).

Drauch Schreier et al. (2011d) observed little genetic difference between the middle Columbia, Transboundary Reach, and Lower Snake River White Sturgeon. Drauch Schreier et al. (*in prep*) reported that the pattern of isolation-by-distance revealed in the Columbia and Snake rivers suggests that there is gene flow between geographically proximate White Sturgeon populations as opposed to many genetically discrete spawning populations. However, similar to Smith et al. (2002) who identified different results using mtDNA and nDNA, Nelson and McAdam (2012) identified substructure within the Upper Columbia River Basin using mtDNA sequence data coupled with individual fish distribution information from telemetry and recapture information. Although White Sturgeon from spatially distant locations were not always genetically different, Nelson and McAdam (2012) suggest that White Sturgeon using the known spawning areas within the Transboundary Reach addressed by this Recovery Plan are semi-isolated sub-populations (Figure 6). The apparent differences between these two studies are likely due to the combined effect of the faster drift rate of mtDNA (see Zink and Barrowclough 2003) and limitations in the ability to identify weak structure using the program “Structure” (Waples and Gaggiotti 2006). While the level at which possible historical separation has been maintained in the now modified river still needs to be determined, it is clear that modifications to the riverine habit could make it difficult to maintain the historical patterns

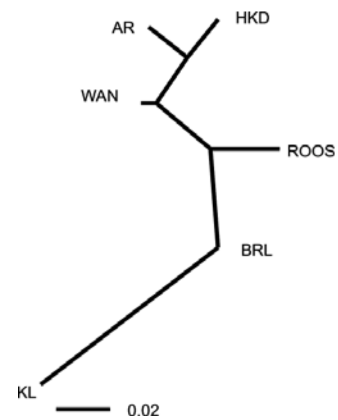


Figure 6: Neighbour joining tree showing overall genetic relationship among Arrow Lakes Reservoir (AR), Hugh Keenleyside Dam (HKD), Waneta (WAN), Brilliant Dam (BRL), Lake Roosevelt (ROOS) and Kootenay Lake (KL). Cavalli–Sforza distance bar is shown to allow for comparison of distance between groups. Reproduced from Nelson and McAdam (2012).

2.4 Abundance & Population Trends

2.4.1 Wild White Sturgeon

White Sturgeon in the Upper Columbia River recovery area were first isolated from downstream populations by the construction of Rock Island Dam in 1933. Grand Coulee Dam was closed in 1941 and the recovery area was further fragmented by the construction of HLK in 1968, Mica Dam in 1973, and Revelstoke Dam in 1983 (Hildebrand et al. 1999). In 2008, the abundance of wild White Sturgeon in the entire Transboundary Reach was estimated at approximately 3,000 fish (Irvine et al. 2007), of which approximately 79% were adults >165 cm FL (Howell and McLellan 2007b). White Sturgeon recruitment collapse in the Keenleyside Reach was identified during the early 1990's (UCWSRI 2002) and was corroborated in the Roosevelt Reach in 1998 (Devore et al. 2000; Kappenman et al. 2000). More recent studies show a continuation of failed recruitment in the Transboundary Reach (Lee and Pavlik 2003; Golder 2006a, 2010a; Howell and McLellan 2007a, 2008).

As the population of wild White Sturgeon in the Transboundary Reach has aged, size and maturity distribution has steadily shifted from a wild population dominated by juvenile and subadult fish less than 150 cm FL to one dominated by adult fish greater than 150 cm FL (Hildebrand et al. 1999; Irvine et al. 2007; Howell and McLellan 2008). Comprehensive stock assessment surveys were last conducted in the Keenleyside Reach in the early 2000's and in the Roosevelt Reach in 2009 and are scheduled to be repeated in 2013.

Setline and gill net sampling conducted in the Transboundary Reach has captured very few wild sub-yearling or older juvenile White Sturgeon (Lee and Underwood 2002; Lee and Pavlik 2003; Golder 2009a; Howell and McLellan 2011; Howell and McLellan *in review*). Between 2000 and 2011, juvenile indexing surveys have captured nine wild juveniles (i.e., untagged/unmarked fish <150 cm TL) in the Keenleyside Reach (Golder 2009a; BC Hydro *in prep*) and 37 wild juveniles (<100 cm FL) in the Roosevelt Reach (WDFW, unpublished data). In 1998, WDFW captured 2 wild juveniles (<100 cm FL) sturgeon. Collectively, these survey data confirm that natural recruitment of White Sturgeon in the Transboundary Reach is a rare event, consistent with recruitment collapse.

2.4.1.1 Roosevelt Reach

Since 2001, assessments of population status in the Roosevelt Reach have been completed through a combination of setline, gill net, and acoustic telemetry. Stock assessment using standardized baited setlines have been conducted annually from 2004 to 2009, except 2006. Surveys in 2004 and 2005 surveys were done in early spring (April and May) and only in the upper third of the Roosevelt Reach (Howell and McLellan 2007a; Howell and McLellan 2007b). Abundance of wild White Sturgeon (>70 cm FL) in the Roosevelt Reach estimated from these surveys was 2,037 fish (1,093 to 3,223 95% CI) using mark-recapture data (Howell and McLellan 2007b; Table 5).

Table 5: The estimated abundance (N) and survival of wild White Sturgeon and survival of hatchery origin sturgeon in the Transboundary Reach of the Upper Columbia River (RESCAT 2012).

Reach	Origin	N	95% CI	Survival	95% CI
Roosevelt (RR)	Wild (>70 cm FL)	2037	1,093-3293	-	-
Keenleyside (KR)	Wild (>34 cm FL)	1151	414-1900	0.97	0.92-0.99
RR & KR	Hatchery (6 mo Post-release)	-	N/A	0.28	0.11-0.54
RR & KR	Hatchery (2-5 yr Post-release)	-	N/A	0.88	0.35-0.99

Surveys in 2007 to 2009 were undertaken to address the potential sources of bias in the 2004 and 2005 surveys and evaluate previous assumptions about sturgeon distribution within the Roosevelt Reach. Whereas the 2004 and 2005 surveys used a haphazard sampling strategy in order to maximize catch rates, surveys in 2007 to 2009 incorporated a spatially balanced, general random tessellation stratified design (GRTS; Stevens and Olsen 2003). The 2007 survey covered the lower third of the Roosevelt Reach (Grand Coulee Dam to the Spokane River confluence, including the Sanpoil River Arm), the 2008 survey covered the middle third of the Roosevelt Reach (Spokane River confluence to Gifford, including the Spokane River Arm), and the 2009 survey covered the upper third of the Roosevelt Reach (Gifford to the Canada-U.S. boundary).

Fall (October) gill net surveys have been conducted annually in the Roosevelt Reach since 2001 to monitor levels of natural recruitment and collect data on hatchery juveniles released as part of ongoing supplementation efforts. Gear type and survey area have varied through time. For most surveys, effort was generally limited to the upstream third of the Roosevelt Reach; however, in 2008 the entire Roosevelt Reach was sampled.

The length distribution of Roosevelt Reach sturgeon captured in the 2004 and 2005 stock assessments was similar to earlier studies although the presence of a small cohort (<10%) of wild juveniles (~100 cm FL) indicated recent recruitment (Figure 7). Preliminary ageing of this cohort indicated most were from the 1997 year class, a year when spring and summer river discharge was abnormally high in the Columbia River basin. Additional evidence to support that these fish were born in 1997 was the incidental capture of wild juveniles (<40 cm FL) during routine fish monitoring surveys in Lake Roosevelt in 1998 (STOI unpubl. data; WDFW, unpubl. data).

The length of these fish was similar to those of age-1 sturgeon in other areas of the Columbia and Snake rivers, as well as the age-1 Upper Columbia River hatchery sturgeon (Howell and McLellan 2011). Data from the 2009 stock assessments showed this component of the population was larger (range 100 to150 cm FL), but still identifiable in the length frequency distribution. The median length of the adult cohort (≥150 cm FL) was greater than documented in previous surveys, which demonstrated ongoing limited recruitment (Figure 7).

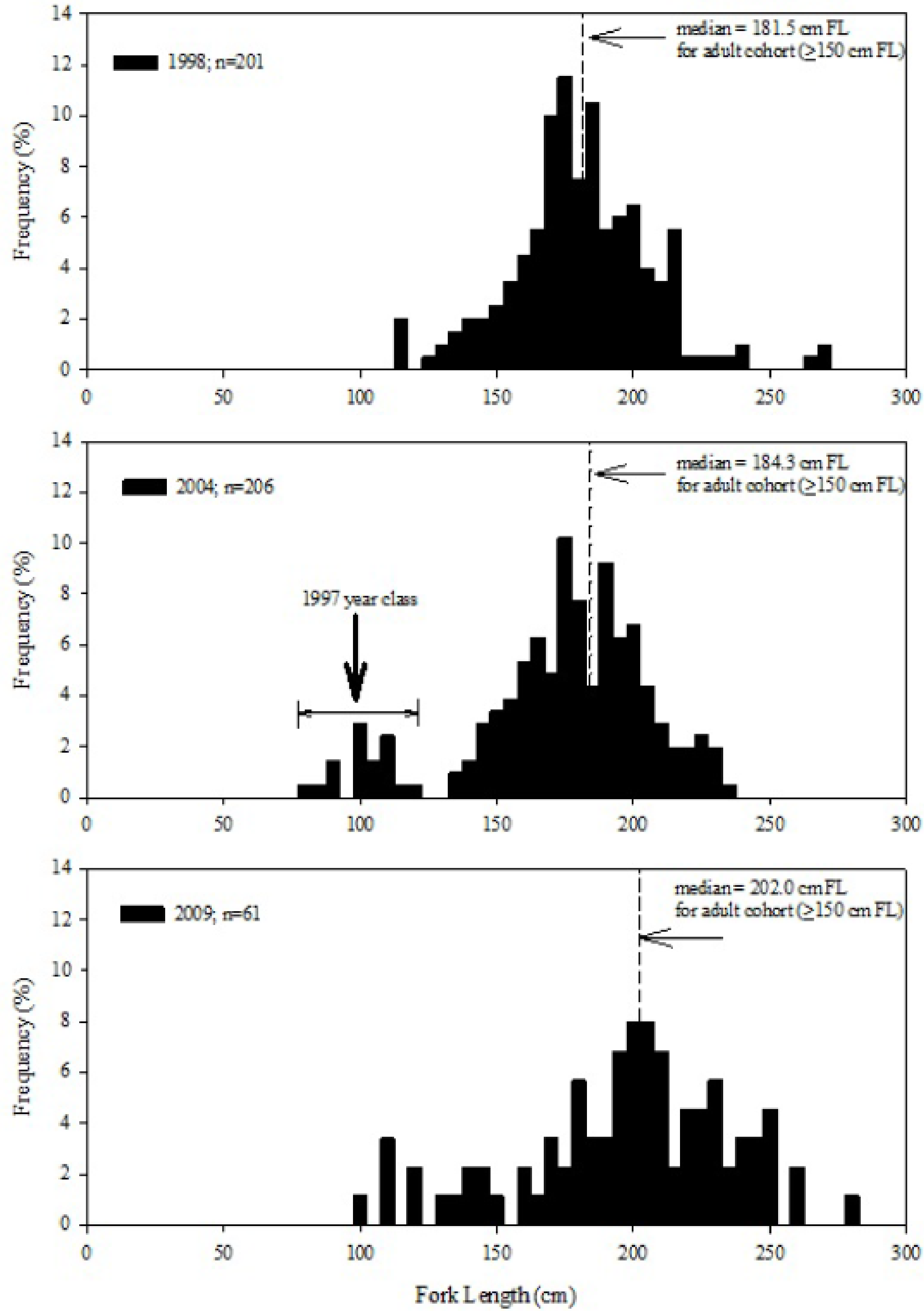


Figure 7: Length- frequencies of wild White Sturgeon captured during setline surveys of the Roosevelt Reach in 1998, 2004, and 2009 (from Howell and McLellan in prep).

2.4.1.2 Keenleyside Reach

The 1990 to 2004 mark-recapture data were re-analysed in 2004 using the POPAN model type, which produced an estimated abundance for this population segment of 1594 fish (703 to 2483) in 1983 and 1151 fish (95% CI = 414 to 1900) in 2004 (Golder 2005; Irvine et al. 2007). The 1993 estimate was considered the most accurate starting point for the Keenleyside Reach population segment (Golder 2005). Using the 1993 estimate and applying the survival estimates (and 95% CIs) for post-1993 sturgeon produces the predicted population trajectory shown in Figure 8. The survival estimates clearly have a substantial impact on subsequent population trends and as such, there is still considerable uncertainty as to the longevity of the current adult population of White Sturgeon in the Lower Columbia River.

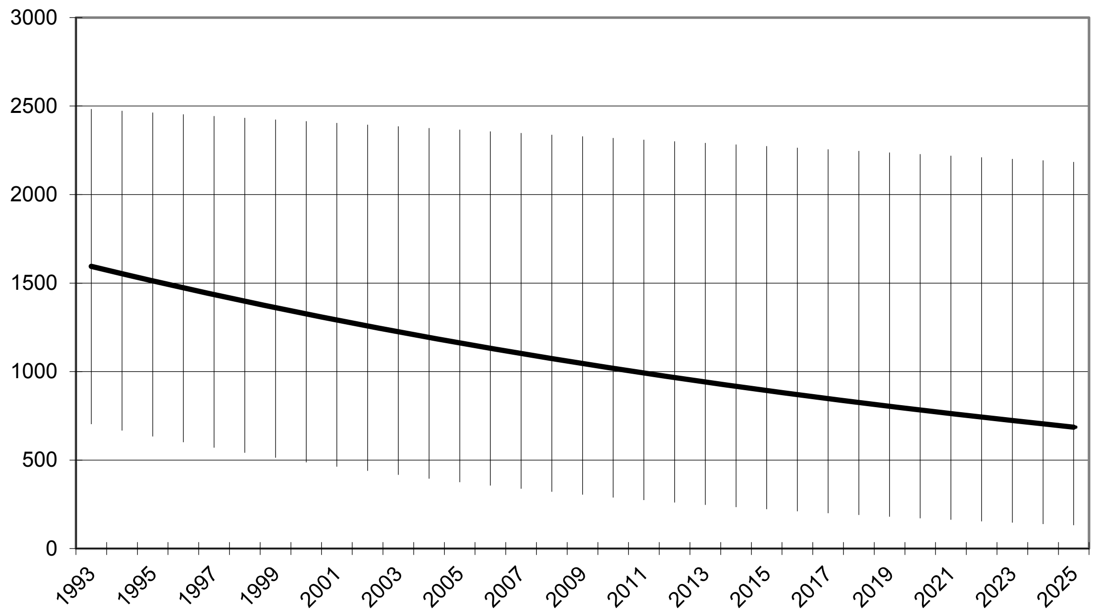


Figure 8: Projection of wild White Sturgeon abundance in the Keenleyside Reach from 1993 to 2025. Number of Fish is shown on the Y-axis and Year on the X-axis. Vertical lines represent the annual survival estimates applied to the 95% Confidence Intervals of the 1993 population estimate (Golder 2005).

Systematic stock assessments of the wild White Sturgeon population in the Keenleyside Reach have not been conducted since 2004. Information obtained during annual adult broodstock collection programs and incidental captures of wild adults during the juvenile indexing programs (Figure 9) indicates a length frequency distribution similar to that shown for the Roosevelt Reach in Figure 7. A systematic assessment of the existing wild and hatchery population in the Transboundary Reach is planned for 2013. As discussed in Section 2.4.2, since it's initiation in 2001, the conservation aquaculture program is having the desired effect of back-filling missing year classes of wild sturgeon in the Transboundary Reach.

2.4.1.3 Arrow Lakes Reservoir Reach

Mark-recapture data from 1995 and 1997 to 2003 were used to generate a population estimate of 52 (95% CI = 37 to 92) wild fish (all adults) in the ALR Reach (Golder 2006b). This population estimate is relatively robust, being based on a 29% recapture rate of (i.e., 13 of 45 total captures).

In total, 21 (95.5%) of the 22 fish for which ages were obtained were spawned prior to the closure of HLK in 1968 (Golder 2006b), which indicated these fish either were trapped in the reservoir following construction of HLK in 1968, or had since moved upstream into the reservoir via the boat lock at HLK. During a series of Recruitment Failure Hypothesis workshops held by members of the UCWSRI in 2007 and 2008, this age structure combined with the low suitability of spawning conditions in the pre-regulated ALR Reach, led to a conclusion that historically, recruitment did not likely occur in the ALR Reach (Gregory and Long 2008). Recent mtDNA analysis (Nelson and McAdam 2012) and examination of fin ray microchemistry (Clarke et al. 2011) may suggest that some fish below HLK originated from the ALR Reach. The fin ray microchemistry results are preliminary and would benefit from correlation with water chemistry data.

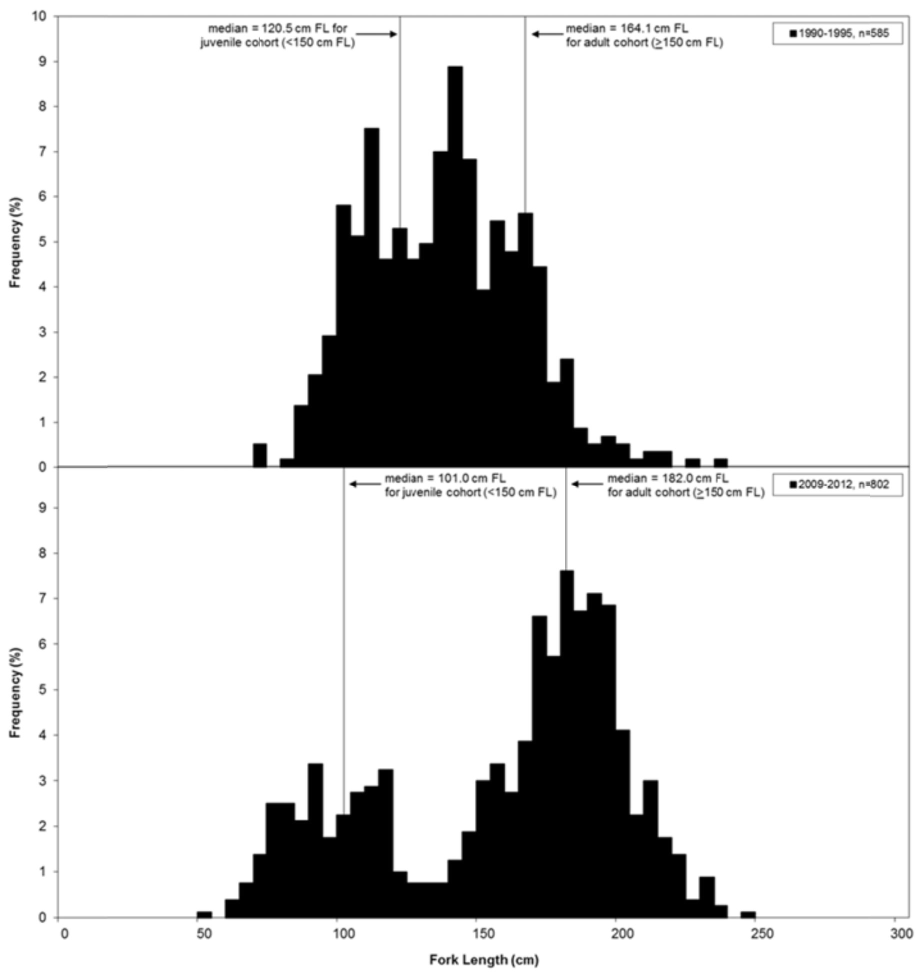


Figure 9: Length-frequencies of White Sturgeon captured during setline surveys conducted in the Keenleyside Reach during 1990 to 1995 and 2009 to 2012. (Unpublished data from Golder and BC Hydro).

Like the wild population segment in the Transboundary Reach, the wild ALR Reach fish are all large adults. Although spawning below Revelstoke Dam has been documented by members of this population segment, the absence of young wild fish in the ALR Reach indicates natural recruitment has not occurred in this area since completion of HLK in 1968 (Golder 2011a).

2.4.2 Hatchery White Sturgeon

As discussed in Section 2.2, 159,198 hatchery juvenile White Sturgeon have been released in the Upper Columbia River as of 1 January 2012,. Using survival estimates derived for wild adult White Sturgeon and for hatchery juveniles released into the Keenleyside Reach and recaptured in either the Keenleyside Reach or the Roosevelt Reach between 2001 and 2006 (Golder 2009a), an estimated 22,124 juvenile hatchery sturgeon were present in the Transboundary Reach as of 1 January, 2012 (see Section 2.5.2).

At present, data indicates an increasing population of hatchery juveniles in the Transboundary Reach. This is based on increasing catch rates in areas of high use and captures of fish throughout the Keenleyside reach and upper Roosevelt reach (Section 2.2.2). However, very low captures of hatchery juveniles released in the ALR Reach preclude accurate assessments of abundance or population status in that reach. With the continuation of planned releases of hatchery juveniles into the Transboundary and ALR reaches, the hatchery-origin component of the population will likely continue to increase in abundance in these areas.

2.5 Growth, Condition, Maturation, & Survival

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

Throughout the species range, the more abundant and productive White Sturgeon population segments are found in lower portions of the Sacramento-San Joaquin, Columbia, and Fraser river basins (Hildebrand et al. *in prep*). Greater productivity in the lower rivers is presumably due to diverse estuarine and marine food resources and favourable water temperatures for maximizing growth. White Sturgeon growth rates and weight–length relationships generally decrease as distance inland increases, with headwater residents typically showing the slowest growth (Hildebrand et al. *in prep*). In regulated rivers, this upstream growth gradient is often accompanied by increased modification of the riverine ecosystem by multiple anthropogenic stressors. This results in changes to flow and temperature regimes, water quality, physical habitat, and the biotic community, all of which can affect White Sturgeon productivity (Paragamian et al. 2001; Parsley et al. 2002; Anders et al. 2002; Van Poorten and McAdam 2010).

2.5.1 Wild White Sturgeon

The maximum size recorded for wild White Sturgeon in the Upper Columbia River was 270 cm FL (3.3 m TL; RL&L 1996b). On average, wild White Sturgeon in the Transboundary Reach have been estimated to grow at 3 to 5 cm/yr through age-30 and 2 to 3 cm/yr for age-30 to age-50 based on ages assigned from fin ray sections. These data should be interpreted with some caution as there are varying levels of confidence among researchers as to the accuracy of using fin rays to age White Sturgeon. Growth rates reported for the

Keenleyside Reach (k = 0.027; RL&L 1996b) were lower than those reported for the Roosevelt Reach (k = 0.035; DeVore et al. 1999).

Individual growth rates are highly variable. Many tagged fish appeared to grow at two or three times the average rate while others did not grow at all even after several years at-large (RL&L 1996b; BC Hydro *in prep*.; Howell and McLellan *in prep*). The mean annual growth of adult wild White Sturgeon >150 cm FL in the Roosevelt Reach was 2.8 cm/yr (Howell and McLellan *in prep*.) and 2.6 cm/yr in the Keenleyside Reach (BC Hydro *in prep*). These rates were lower than the 5.0 cm/yr (for fish > 137 cm FL) reported for the John Day reservoir by Kern et al. (2002) but greater than the 1.5 cm/yr (116 to 160 cm FL) and 0.6 cm/yr (>160 cm FL) reported by Paragamian and Beamesderfer (2003) for the Kootenay River population (Figure 10). In the Keenleyside Reach, for fish caught at least 4 times between 1993 and 2011 (n = 179) average growth was 2.3 cm/yr for females and 2.5 cm/yr for males (BC Hydro *in prep*).

Devore et al. (2000) found that the mean relative weight [W_r] = 91% (Beamesderfer 1993) of Roosevelt Reach wild sturgeon was the lowest for any Columbia River population. They attributed this slow growth (from their VBG analyses) and poor condition to the northerly location of the population (reduced growing season, colder average water temperature) and lack of food resources such as an anadromous forage base, as well as the large seasonal drawdowns and low water retention times characteristic of the Roosevelt Reach that tend to decrease densities of benthic invertebrates (Griffith and Scholz 1991).

Subsequent studies have found the condition of wild sturgeon in the Roosevelt Reach has improved and since 2003, has ranged between 93% and 177% (Howell and McLellan 2007b; Howell and McLellan *in prep*). The low mean W_r reported in 1998 was likely an artifact resulting from sampling only in the summer months when recently spawned out fish were likely present in the catch (Howell and McLellan *in prep*).

Condition factor reported for sturgeon in the Keenleyside Reach is near average for White Sturgeon but considerably lower than reported in downstream populations (RL&L 1996b). Recent estimates of W_r were 90, 84, 85, and 85%, for adults captured during broodstock collection efforts prior to spawning in 2009, 2010, 2011, and 2012, respectively (BC Hydro, unpubl. data). Females generally had higher, though more variable, relative weights (86% in 2012) compared to males (83% in 2012). Variation in female relative weights was attributed to the development stage (See Appendix A, Table A1 for developmental stage descriptions) of the individual with F4's being highest (95% in 2012) and F1's being the lowest (83% in 2012).

Growth and metabolic differences between wild White Sturgeon that were captured in the upper versus lower sections of the Keenleyside Reach highlighted the interaction between habitat selection and population productivity (Van Poorten and McAdam 2010). Bioenergetic simulations, using recapture field data to estimate model parameters, suggested that White Sturgeon occupying habitats with limited food resources and/or water temperatures approaching thermal maxima may experience a reduced energy intake and this could potentially lower lifetime fecundity because of slower growth, prolonged maturity, and increased spawning intervals (Van Poorten and McAdam 2010). Similarly, bioenergetics modeling in the middle Snake River found that only small increases in temperature significantly slowed growth, increased spawning intervals, and reduced lifetime egg production (Bevelhimer 2002).

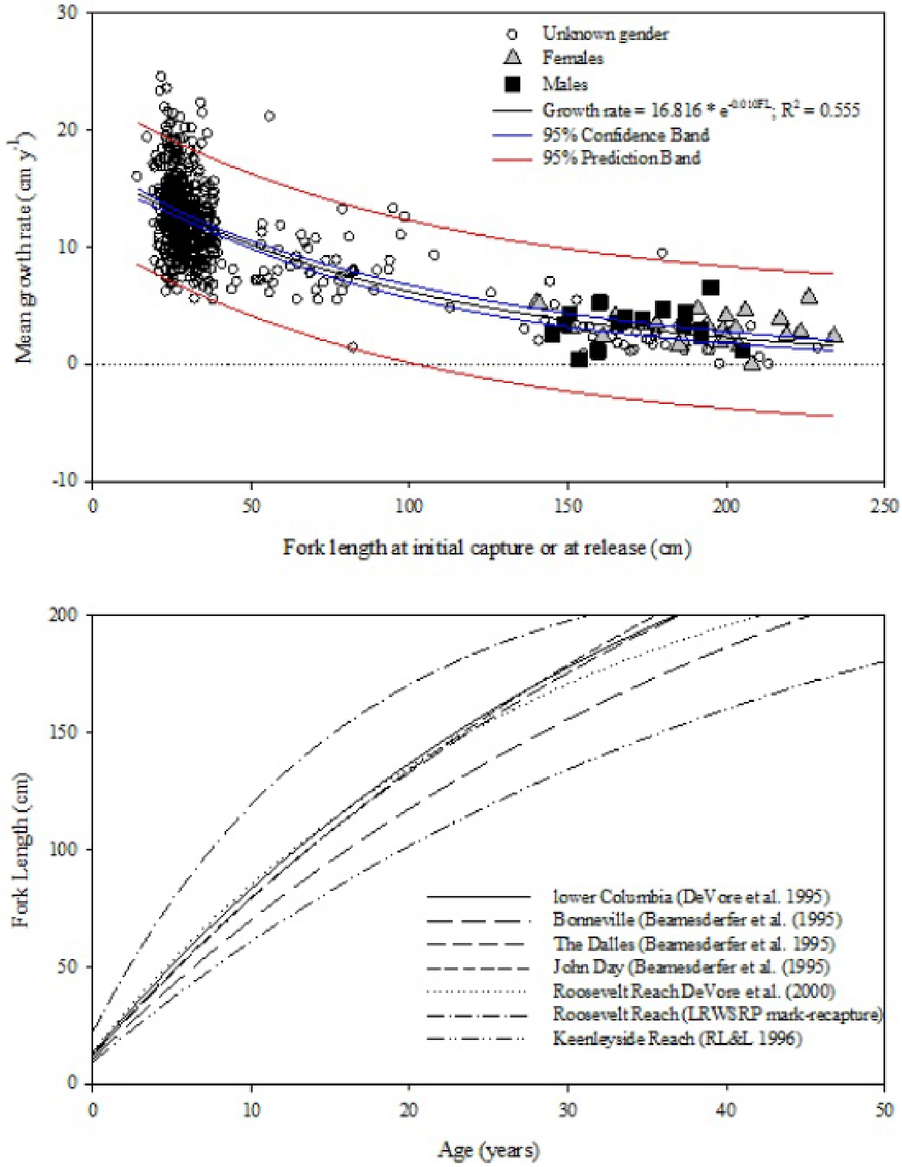


Figure 10: Upper panel: Estimates of mean annual growth in length for hatchery White Sturgeon (n = 610) captured or released and subsequently recaptured in the Roosevelt Reach 1998 to 2009 (Howell and McLellan in prep). Time at large ranged from 1 to 11 years (mean = 2.8 yrs). Lower panel: Comparison of von Bertalanffy growth curves for Columbia River wild White Sturgeon populations based on aging from fin rays (Beamesderfer et al. 1995; DeVore et al. 1995; DeVore et al. 2000; RL&L 1995a) and mark-recapture data (Howell and McLellan in prep).

Annual survival rates for long-lived fish like White Sturgeon are typically quite high in the absence of fishing and often exceed 90% (Semakula 1963, Cochnauer 1983, Kohlhorst et al. 1991, Beamesderfer et al. 1995, DeVore et al. 1995). In the Transboundary Reach, maximum ages of 65 and 96 years were reported for the population (RL&L 1996b; DeVore et al. 1999a), respectively. Because sturgeon are so long-lived, population trends are extremely sensitive to very small changes in survival.

The POPAN model (Scwarz and Arnason 1996) was used to estimate the survival for wild adult White Sturgeon in the Keenleyside Reach based on mark-recapture data from 1993 to 2004 (Irvine et al. 2007). Due to the uneven distribution of the population (concentrated in upper and lower segments of the reach with few individuals in between) and the low migration levels between the two groups (~3-5%), separate survival estimates were developed for each group and for both groups combined. Survival estimates were 95.6% (95% CI = 91.1% to 97.9%) for the upper group (HLK Dam to Kootenay River), 98.3% (95% CI = 89.0% to 99.0%) in the lower group (Kootenay River to the Canada-U.S. boundary) and 97.3% (95% CI = 91.8% to 99.1%) for both groups combined.

2.5.2 Juvenile Hatchery White Sturgeon

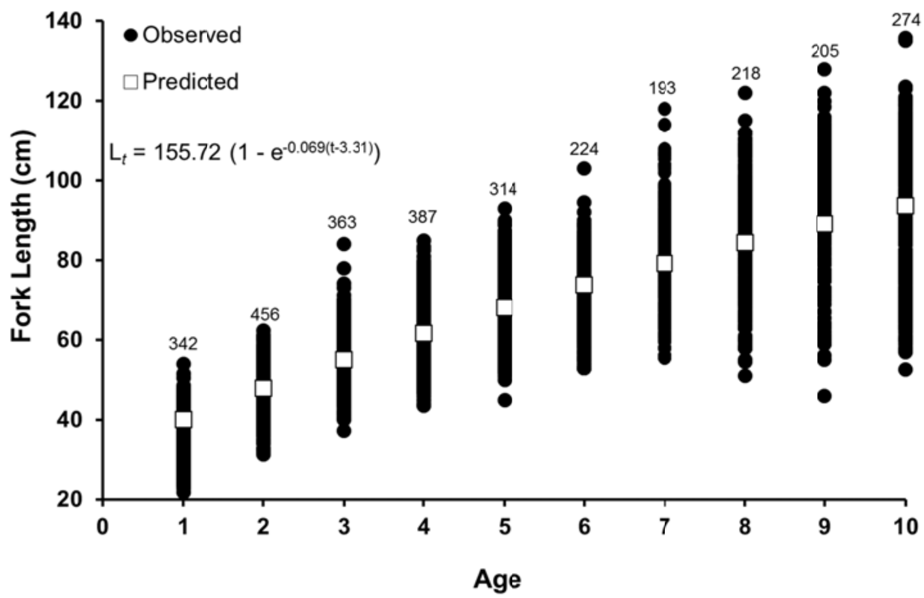
Juvenile hatchery White Sturgeon grow rapidly in length the first few years of life and exhibit a high degree of variability in growth rates, with same age fish exhibiting a wide range of sizes (Table 6; Figure 11). Rates of weight gain did not follow this same pattern.

Table 6: Mean fork lengths and weights of juvenile White Sturgeon captured in the Keenleyside Reach from 2002 to 2011 (data from Golder 2009a; BC Hydro unpubl. data).

Age	Sample Size	Fork Length (cm)		Weight (g)	
		Mean	Range	Mean	Range
1	335	35.4	21.8 to 51.6	299	64 to 710
2	434	46.0	31.4 to 62.3	640	160 to 1641
3	277	53.3	40.0 to 74.2	1060	414 to 3123
4	227	61.8	43.5 to 85.0	1815	550 to 5000
5	223	67.8	50 to 93.0	2090	700 to 5200
6	224	71.7	53.0 to 103.0	2500	750 to 7550
7	195	80.5	55.5 to 118.0	3630	850 to 12,050
8	221	85.1	54.0 to 122.0	2500	700 to 12,150
9	205	92.2	51.5 to 128.0	2500	700 to 16,100
10	270	91.6	53.0 to 135.7	2500	900 to 17,050

In the first 3 to 4 years of the juvenile hatchery program, fin deformities were very common; however since that time, there have only been minor incidences of fin deformities reported (R. Ek, FFSBC, pers. comm.). The fin deformities were not related to the aquaculture practices since juveniles from the Kootenai River raised at the same facility under identical methods had a very low incidence of fin deformities. The deformities appeared to be family related as some families had a high rate of deformities and some families had none at all. The cause(s) of the deformities are still unknown.

The mean growth rates of juveniles (age-1 to age-5 fish captured from 2002 to 2006) with and without pectoral fin deformities were similar, which indicated that at least in the early years of life, the deformities did not have a negative effect on growth (Golder 2009a).



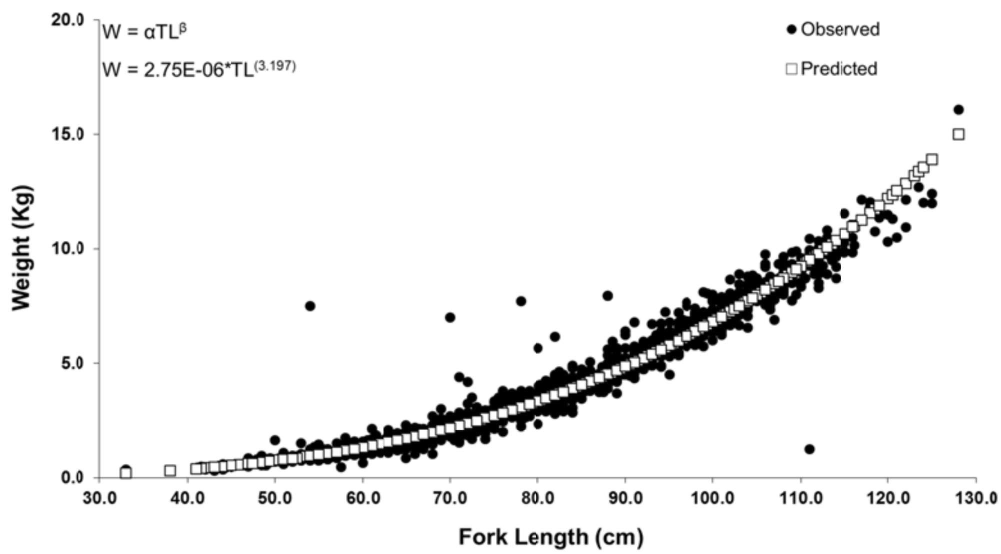


Figure 11: Von Bertalanffy length (top) and weight (bottom) growth curves for hatchery juvenile White Sturgeon captured in the Keenleyside Reach, 2009 to 2011 (data from BC Hydro). Estimates of parameters used: t0 = 0.

The relative weight (W_r) of hatchery juvenile White Sturgeon captured from 2002 to 2006 were higher than 50%, and the substantial majority showed W_r values higher than 75% (Golder 2009a). Most fisheries management perspectives propose to manage populations to achieve relative weights of 75% or greater (Murphy et al. 1991). By these standards, juvenile White Sturgeon in the study area were performing well during this period. The minimum/maximum W_r of all juveniles included in the analysis (n = 1304) at the point of release was 84.7%/187.7% and at the point of capture was 60.2%/162.3% (Golder 2009a). In total, between release and capture the W_r of 1276 (98%) juveniles decreased and the W_r of 28 (2%) juveniles increased. This general post-release decrease in W_r likely reflects changes in body shape that result in the shift from a hatchery to a riverine environment.

The data from the fall recapture programs and the spring releases in the Keenleyside Reach from 2002 to 2006 were analysed to assess survival and probability of capture for hatchery released juveniles (Irvine et al. 2007; Golder 2009a). The relative rate of recovery of the tags among years was used to develop a Cormack-Jolly-Seber (CJS) survival model for the hatchery juvenile population. Survival values increased substantially after the first 6 months in the river for all cohorts. The survival was estimated to be approximately 28% for the first 6 months in the river and was approximately 85% for the older fish. As the exact number of fish released and incorporated into the analysis was known, the CJS survival parameters were used to calculate an estimate of 22,124 juveniles surviving in the Transboundary Reach as of January 2012 (Table 7).

Table 7: Estimated numbers of White Sturgeon hatchery juveniles (by year class) released and surviving in the Transboundary Recovery Area as of 1 January, 2012.

Year Class	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	All Years
Number Released	8,671	11,803	11,576	16,503	20,218	15,587	14,298	7,678	7,820	8,401	**122,105**
Estimated Number Surviving[a]	1,337	1,876	1,897	2,788	3,521	2,798	2,646	1,495	1,696	2,070	**22,124**

[a] Age-0 to age-1 survival = 0.28 (Golder 2009a); Age-2 to age-5 survival = 0.85 (Golder 2009); Age-6 to age-11 survival = 0.9 [interpolated value based on data from Golder (2009a)].

In the ALR Reach, only 10 hatchery juvenile sturgeon have been recaptured out of the 28,533 hatchery juvenile White Sturgeon (including 200 implanted with sonic tags) that were released into the area from 2007 to 2010 (Golder 2011a). Four of the ten juveniles captured have been fish that were equipped with sonic tags at release. These fish were larger at release and grew faster compared to the six fish without sonic tags, which may suggest that in the ALR Reach, size at release may influence growth and possibly survival. Low sample size of juveniles from the ALR Reach precludes meaningful comparisons of growth rates with other population segments.

2.6 Food & Feeding

White Sturgeon are primarily benthic feeders on invertebrates and fish. Food items are detected with chemo and electro receptors located on four sensory barbels and the snout rather than by sight (Brannon et al. 1985; Buddington and Christofferson 1985). Foraging is achieved by rapid expansion of the buccal cavity and the associated negative pressure allows the fish to draw material from the river bed with its protrusible mouth. Foraging activity by large fish can result in visible pits on the riverbed (Plate 2). White Sturgeon also pursue and consume fish throughout the water column (RL&L 2002).

The onset of exogenous feeding in the larval stage constitutes a critical period of potentially high mortality for White Sturgeon (Parsley et al. 2002). According to the habitat "Match-Mismatch" hypothesis (Cushing 1974, 1990; Houde 2008), dispersing larvae must arrive at the right location at the right time to ensure survival. Braaten et al. (2008) suggested that it is important for sturgeon to settle in habitat patches with abundant food resources as they transition to exogenous feeding. Most of the food items were chironimids (Howell and

McLellan 2011; Howell and McLellan *in review*). However, the percentage of empty stomachs found in the few fish that had exhausted their yolk reserves was 100%, 84%, 74%, and 77% during 2005, 2006, 2007, and 2008, respectively (Howell and McLellan 2007b, 2011, *in review*). Prey items found in in the guts of 27 first-feeding sturgeon larvae (19.1 to 21.5 mm TL; median = 20.6 mm) collected in the Roosevelt Reach were primarily Dipteran larvae (62.9% of fish that contained prey); Copepods and dipteral pupae were also eaten. Five sturgeon measuring 20.0 to 21.5 mm TL (median = 20.8) contained both yolk and prey items i.e. they exhibited mixed feeding (WDFW unpublished data).

Plate 2: Examples of feeding pits made by White Sturgeon in the reservoir upstream from Bonneville Dam. Water level in the reservoir had been temporarily drawn down about 1 m, exposing the pits on a shallow bar. The glove was placed by the pits for scale (photos by M. Parsley).

In contrast, Muir et al. (2000) examined 64 larvae of a similar size and stage of development as the larvae collected in Roosevelt Reach and found only one empty stomach (1.5%). Although this seemed to suggest that prey availability, feeding success, or both in the river-reservoir transition zone of the Roosevelt Reach was comparatively low, the larvae collected by Muir et al. (2000) were captured with actively towed trawl gear fished for a short duration (typically 30 min or less) while those collected in the Roosevelt Reach were captured in passively fished plankton nets fished overnight. Individuals with empty stomachs may have been disproportionately represented in the catch of stationary gear if larvae with empty stomachs more actively seek suitable foraging habitat. There was also greater potential for prey digestion in larvae captured in the stationary sets in the Roosevelt Reach.

In addition, the White Sturgeon larvae captured in the Roosevelt Reach may not have been old enough to exhibit the effects of starvation. The oldest sturgeon larvae captured in the Roosevelt Reach to date were approximately 15 dph and relatively few fish had exhausted their yolk supply. Mortality of food-deprived green sturgeon (Acipenser medirostris), larvae was not appreciable until 28 to 31 dph (Gisbert and Doroshov 2003) and food deprived White Sturgeon larvae reared in a laboratory under a thermal regime that mimicked that of the Transboundary Reach exhibited 50% mortality within 13 to 21 dph and 100% mortality within 22 to 29 dph (Parsley 2010; Parsley et al. 2011). Rearing conditions experienced by yolksac larvae may also increase mortality of feeding larvae and therefore carryover effects might also contribute to observed mortality at this stage (Boucher 2012; S. McAdam, BCMOE, pers. comm.).

Mortality of food-deprived green sturgeon (*Acipenser medirostris*) larvae was not appreciable until 28-31 dph (Gisbert and Doroshov 2003) and food deprived White Sturgeon larvae reared in a laboratory under a thermal regime that mimicked that of the Transboundary Reach, exhibited 50% mortality within 13-21 dph and 100% mortality within 22-29 dph (Parsley 2010; Parsley et al. 2011). Current information, while not sufficient to suggest starvation is a primary cause of larval mortality, does indicate more investigation is required. Rearing conditions experienced by yolksac larvae may also increase mortality of feeding larvae and therefore carryover effects may contribute to observed mortality at this stage (Boucher 2012; S. McAdam, BCMOE, pers. comm.).

Juvenile (<60 cm TL) White Sturgeon are known to feed on tube-dwelling amphipods, mysids, isopods, Corophorium, and other benthic invertebrates such as chironomids, as well as on the eggs and fry of other fish species (Cochnauer 1983; Partridge 1983; PSMFC 1992; Parsley et al. 2010). As White Sturgeon grow to ~60 to 80 cm TL, their diets diversify and they begin to eat fish (Muir et al. 1988; PSMFC 1992) along with benthic invertebrates. Items found in their diet include small amphipods, isopods, mysids, clams, snails, small fish (such as sculpins and assorted fry), crayfish, and fish eggs (McKechnie and Fenner 1971; McCabe et al. 1993; Muir et al. 2000). In the Keenleyside Reach, *Mysis relicta* (entrained from ALR and Kootenay Lake) comprised 93% of the total prey items in hatchery juvenile (age-1 to age-3) stomach contents (Golder 2009a). Preliminary analysis of juvenile sturgeon diet data collected from the Keenleyside Reach in 2012 indicated the contribution of Mysis in the stomach contents of juveniles of all age classes (age-1 to age-10) declined with increased distance downstream from HLK (BC Hydro, unpubl. data). Mysis were the primary component of the diet in fish from the upper third of the Keenleyside Reach whereas Trichoptera nymphs comprised the majority of prey items in juveniles from the lower third. Other prey items encountered (in decreasing order of abundance) were Ephemoptera nymphs, snails, Dipterans, fish parts, Gammarids, Hemipterans, and Plecopterans. Predominant food items in the diet of hatchery juveniles (n = 4) in the ALR Reach were *Mysis relicta*, Chironomid larvae, Tricoptera larvae, Ephemeroptera larvae, and unidentifiable fish (Golder 2009a, 2011a).

A recent study by Parsley et al. (2010) of the diet of hatchery-origin juveniles from upper Lake Roosevelt showed that the fall diet was benthic in origin and quite diverse. Individual fish had consumed 1 to 11 different taxa. The most frequently consumed prey included isopods, larval chironomids, clams, and larval caddisflies. Gut fullness indexes suggested that foraging was not synchronous among individuals and was discontinuous over time. Non-edible material consumed while foraging averaged 58% of the diet. McLellan and Howell (2009) also reported that insects (primarily Trichoptera) were the most abundant prey in the diet of 15 juvenile White Sturgeon from Lake Roosevelt. Freshwater mussels have been identified as a potentially important food resource for White Sturgeon in Lake Roosevelt (Lake Roosevelt Management Team 2009). Entrained fish and invertebrates provide food for White Sturgeon residing downstream from dams.

Information on food habitats of wild adults in the recovery area is limited to observations of stomach contents from occasional mortalities. Prey found in these mortalities included adult Mountain Whitefish (*Prosopium williamsoni*), clams, snails, invertebrates (Gammarids, Plecopterans, Tricopterans), unidentified fish remains, algae, and detritus (Golder unpub. data). Diet can vary substantially during the year as White Sturgeon take advantage of seasonally abundant prey items. Observations of numerous large White Sturgeon in the vicinity of Rainbow Trout (*Oncorhynchus mykiss*) spawning areas in the mainstem Columbia River near Castlegar, BC in the spring (J. Crossman, BC Hydro, pers. comm.) and the capture of adult White Sturgeon at the mouths of Kokanee spawning tributaries in the early fall in ALR (Prince 2003), suggests that resident salmonids or their eggs are seasonal components of the diet. Loss of anadromous fish runs into the Upper Columbia River eliminated an important food source with potential implications for over-wintering fitness and spawning frequency and fecundity (Hildebrand and Birch 1996).

Feeding occurs over a wide range of water depths. Though targeted studies of feeding ecology of White Sturgeon in the recovery area have not been done, adult sturgeon occupy low velocity habitats for feeding. These high-use areas are typically depositional environments adjacent to fast water where forage is locally produced or deposited from upstream production areas (Hildebrand et al. 1999). In the lower Columbia Basin, White Sturgeon have been observed congregating in water less than 1 m deep during winter (Parsley et al. 2007) and feeding pits were observed in depositional areas at depths less than 1 m during January (Plate 2; M. Parsley, USGS, pers. comm.). In the recovery area, wintering areas are often the same as those used during summer although upstream migrations to wintering areas have been reported for population segments in other river reaches (Parsley et al. 2007; Parsley et al. 2008).

Many of the localized movements exhibited by Upper Columbia River White Sturgeon are likely related to feeding. White Sturgeon are capable of moving frequently and ranging widely in search of scattered or mobile food resources. These feeding behaviours reflect the plasticity in sturgeon life history that has enabled species to persist. Fish in riverine sections of the Upper Columbia River, which consists of interspersed rapids and pools where fish can hold and feed on prey delivered by the river, tend to be more sedentary. Several high use areas are situated below dams (i.e., Keenleyside Eddy, Kootenay Eddy, Waneta Eddy) and in these areas, entrained fish likely represent an important food source for White Sturgeon. Reservoir-river interface zones in ALR and Roosevelt Reservoir also represent high use feeding areas.

2.7 Spawning Behavior & Habitat

White Sturgeon are broadcast spawners and eggs released by one or more females are fertilized by one or more males. Descriptions of White Sturgeon spawning behaviour consist mainly of reports of breaching, rolling, and surface-oriented behaviour by one or more fish in known spawning areas and periods (Anders and Beckman 1993; Israel et al. 2009). However, whether this behaviour is related to courtship or actual spawning activity is unknown. One observation of spawning in the Nechako River recorded on video showed what looked like a spawning pair releasing gametes (Liebe et al. 2004). Female White Sturgeon are believed to spawn all their eggs within a short period of time because all eggs are ovulated simultaneously. Captures of mature females have not shown evidence of partial spawning.

All reported observations of putative spawning behaviour were during daylight but it is suspected that spawning also occurs at night based on back-calculated ages of eggs (Golder 2002, 2008). Given the few observations of spawning behaviour and wide range of water depths from which eggs have been found, questions still remain regarding where in the water column the female releases eggs during spawning. Anders and Beckman (1993) observed spawning activity (rolling and splashing behaviour) in relatively deep (>10 m) water while video-recorded observations in the Nechako River showed gamete release occurring in 1 to 2 m of water. Release of eggs near the water surface over deeper water would likely result in a wider dispersal of eggs over the river bottom. However, reports of highly aggregated egg captures on egg collection mats placed on the river bed (Parsley and Kappenman 2000; Golder 2008, 2011c) suggest that egg release may occur near the river bottom. Parentage analysis suggests a parental ratio near 1:1 for larvae at an Upper Columbia spawning area (unpubl. data, S. McAdam, BCMOE, unpubl. data).

Sexual maturity of White Sturgeon does not occur until relatively large sizes and advanced ages (Semakula and Larkin 1968; Chapman 1989; Welch and Beamesderfer 1993). Maturation occurs over a wide range of sizes and ages and substantial differences occur among populations depending on growth. Males typically mature at smaller sizes and ages than females, and may spawn in all or most years following maturation. Females typically mature at larger sizes and older ages and do not spawn every year. Females in the lower Columbia River reportedly spawn every 3 years (Welch and Beamesderfer 1993). Data from the Keenleyside Reach collected since 1997 suggests that while sex ratios of captured wild fish can change from year to year, the overall sex ration for all years is approximately 1:1 (Table 8). Sex ratios for White Sturgeon populations elsewhere are typically 1:1 (Hildebrand et al. *in prep*).

Table 8: Sex ratios for White Sturgeon in the Keenleyside Reach captured during tagging programs (1997 to 1998) and from the broodstock acquisition program (2001 to 2011).

Year	Number of Males	Number of Females	Sex Ratio (Males:Females)
1997	3	3	1:1
1998	7	6	1.2:1
2001	58	46	1.3:1
2002	21	31	0.7:1
2003	25	36	0.7:1
2004	39	50	0.8:1
2005	33	41	0.8:1
2006	26	17	1.5:1
2007	35	32	1.1:1
2008	15	18	0.8:1
2009	38	51	0.7:1
2010	41	63	0.7:1
2011	45	64	0.7:1
Total	**396**	**458**	**Mean = 0.9:1**

In the Keenleyside Reach, mature male White Sturgeon were 106 to 219 cm FL at age-16 to age-46 (RL&L 1996b; BC Hydro *in prep*). Most males greater than 150 cm and age-25 were mature. Mature females have been observed at sizes of 137 to 271 cm FL and age-27 to age-65. Most females greater than 170 cm and age-30 were mature. Size of maturation in the Upper Columbia River was similar to that reported by Welch and Beamesderfer (1993) for lower Columbia River populations. Information on adults that have been selected as hatchery candidates from 2001 to 2011 (BC Hydro *in prep*), indicated hatchery candidates were typically larger than 140 cm FL with the exception of one small female that was 91 cm FL (Figure 12). Males had a mean length of 176.5 cm FL (range 143.0 to 213.0 cm) and a mean weight of 46.4 kg (range 24.0 to 98.0 kg). Females had a mean length of 195.3 cm FL (range 91.0 to 234.5) and a mean weight of 70.0 kg (range 34.1 to 130 kg).

Since 2009, over 100 adults have been sexed annually during the broodstock collection program in the Keenleyside Reach (Table 9). An average (± 1 SD) of 19.0% (± 0.04%) of females collected have been in spawning condition (Stage F4 or F5). This proportion is assumed to represent the available spawning population as the broodstock program sampling is selective towards adults (large hooks and bait size) and has been spatially balanced throughout the Keenleyside Reach. Adults residing in the Roosevelt Reach are likely poorly represented in this estimate as sampling is conducted prior to spawning, when some adults in the Roosevelt Reach move up to the Keenleyside Reach to spawn. Based on an approximate 1:1 sex ratio (Table 8) and an estimated 1,157 adults in the Keenleyside Reach (Irvine et al. 2007), 87 of an available 578 females (~15%) could potentially be in spawning condition on an annual basis. The estimated annual proportion of females in spawning condition is within the range (0.11 to 0.20) reported during the 2009 to 2011 broodstock collection programs in the Keenleyside Reach (Table 9). If an estimated 87 of an available 578 females spawned annually, this would equate to a spawning interval of 6.7 years per female. Over the last 11 years of sampling, however, only one female spawner has been captured twice (first in 2001 and again in 2010). Over this same period, three males spawned previously at the hatchery have been captured a second time in spawning condition. Genetic work is underway to verify assessments of White Sturgeon spawning periodicity in the Transboundary Reach.

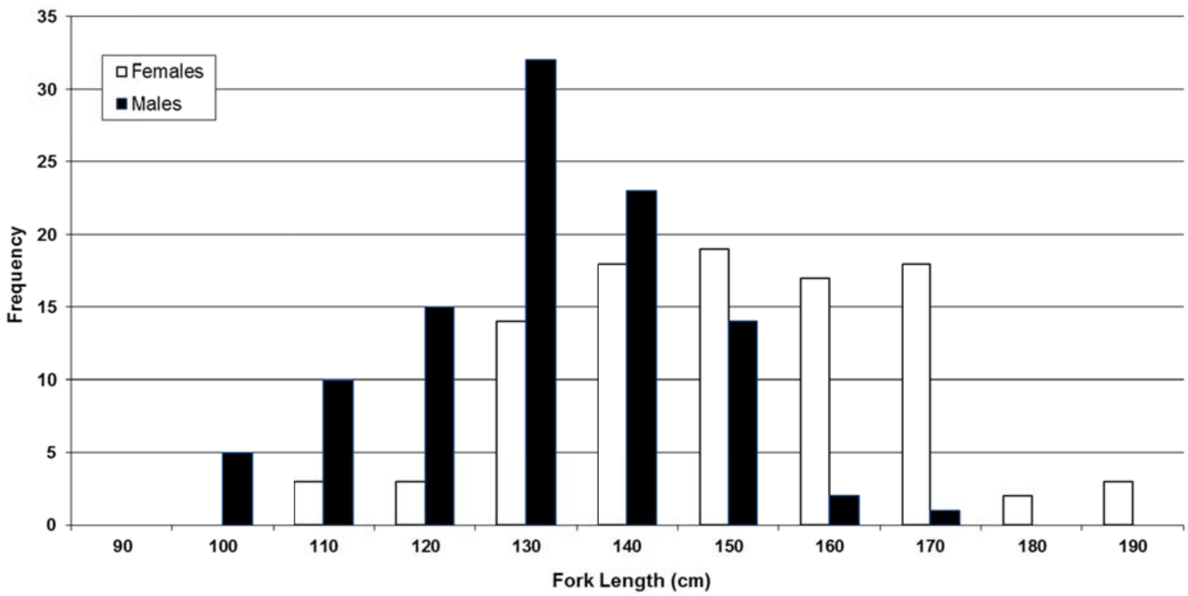


Figure 12: Length-frequency of mature male and female White Sturgeon captured in the Keenleyside Reach and used in the Canadian conservation aquaculture program, 2001 to 2011.

In the Roosevelt Reach, preliminary assessments of sex and maturity characteristics indicated that size at first maturity and the reproductive cycle of females in the Transboundary Reach may be similar to that observed in the mid-Columbia impoundments (Howell and McLellan 2007b; Beamesderfer et al. 1995). During the stock assessments in 2004 and 2005, 147 sturgeon were surgically examined for sex and stage of maturity and the male/female sex ratio was approximately 1:1; all females had reached reproductive maturity and the smallest mature female measured 156 cm FL. For females >167 cm FL, 38 were vitellogenic and 16 were post-vitellogenic. Theoretically, the ratio of vitellogenic to post-vitellogenic females at the time of the surveys should provide an indication of the duration of the reproductive cycle and hence spawning periodicity. Thus, these data suggest adult females in the Roosevelt Reach spawn on average once every 3 to 4 years.

This periodicity is supported by fifteen females that made putative spawning migrations at intervals ranging from two to four years. White Sturgeon in lower Columbia reservoirs are physiologically capable of spawning every three years, with the spawning cycle consisting of a two-year period of oocyte development and a one-year resting period prior to re-initiation of gonadal development (Welch and Beamesderfer 1993)

White Sturgeon throughout their range typically spawn at temperatures between 10 and 18°C, with most spawning at temperatures between 13 and 18°C (Figure 13). Spawning has been reported to occur at temperatures above 18°C, but work by Wang et al. (1985, 1987) showed reduced survival of progeny incubated at temperatures above 18°C. RL&L (1997a) incubated wild-caught eggs *in situ* and showed generally lower hatch success at temperatures exceeding 18°C.

Table 9: Sex ratios and sexual developmental stage of White Sturgeon captured from 2009 to 2012 during broodstock collection programs in the Keenleyside Reach.

Sample Year	No. Known Sex Adults	No. Each Sex		Proportion of Females in Spawning Condition (F4 or F5)	Developmental Stage [a]								
							Females					Males	
		M	F		F0	F1	F2	F3	F4	F5	M0	M1	M2
2009	89	38	51	0.20	0	20	3	12	10	0	4	25	9
2010	104	41	63	0.16	11	24	11	7	9	1	4	26	11
2011	109	45	64	0.13	12	32	7	5	8	0	6	28	11
2012	120	49	71	0.11	24	26	6	7	8	0	15	24	10

[a] See Appendix A, Table A1 for developmental stage descriptions

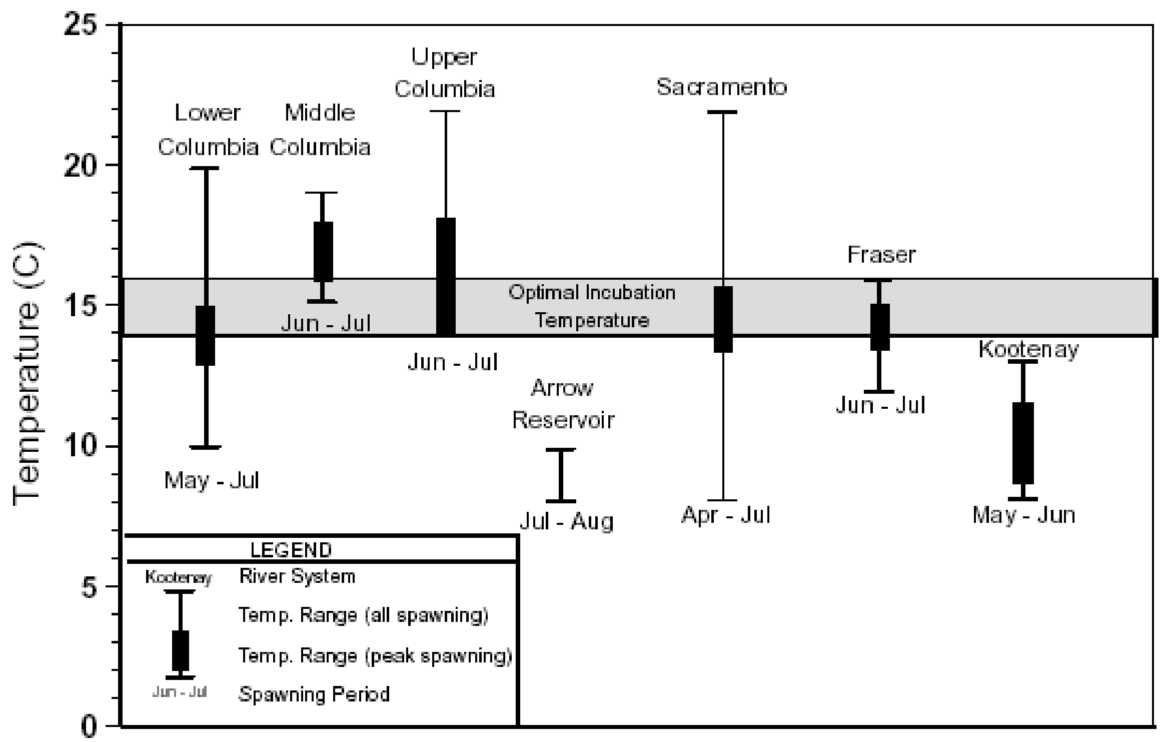


Figure 13: Reported water temperature ranges for White Sturgeon spawning (UCWSRI 2002). The Upper Columbia data are from the Transboundary Reach.

Fish in spawning condition migrate to spawning reaches and then select suitable spawning sites based on combinations of water velocity, turbulence, depth, and substrate composition. Spawning throughout the species range generally occurs in areas with fast-flowing waters over coarse substrates (Parsley et al. 1993; Hildebrand et al. 1999; Parsley and Kappenman 2000; Perrin et al. 2003) that have hydraulic complexity such as turbulent areas of the mainstem or major tributary confluences (Hildebrand et al. 1999; Parsley and Kappenman 2000; Howell and McLellan 2007b), high velocity runs near rapids (Lepla and Chandler 2001), or downstream from dams (Parsley and Kappenman 2000; Golder 2003, 2004a, 2004b, 2006b, 2008). Spawning in the Herrling side channel of the unimpounded lower Fraser River is a notable exception to this pattern (Perrin et al. 2003; Paradis et al. 2011.

Potential benefits from spawning in fast, turbulent waters with coarse substrates include suitable attachment surfaces for the negatively buoyant adhesive eggs, removal of fine sediments that could suffocate eggs, enhanced egg viability by dispersal of adhesive eggs to prevent clumping and disease, and reduced egg predation (Parsley et al. 1993; McCabe and Tracy 1994; Parsley et al. 2002; Perrin et al. 2003). High water velocity is a key attribute of spawning site selection. Mean water column velocities typically range from 0.5 to 2.5 m/s. Parsley et al. (1993) also observed consistently greater spawning success in reaches and high-discharge years that provided higher velocities. Lower spawning velocities (0.2 to 1.0 m/s) have been reported for Kootenay White Sturgeon (Paragamian et al. 2001). High water velocities may also improve suitability of early rearing habitats for yolk-sac larvae and help disperse feeding larvae. Habitat suitability criteria developed for U.S. populations of White Sturgeon identify 0.8 m/s as a minimum and 1.7 m/s or greater as optimum (Parsley et al. 1993; Parsley and Beckman 1994). RL&L (1996a, 1996b, 1996c), in reviewing available information on sturgeon spawning requirements, recommended mean column water velocities of greater than 1.5 m/s to provide for sturgeon spawning in the Upper Columbia River.

White Sturgeon spawning has been documented from several locations within the Upper Columbia River recovery area (Figure 14). Spawning in the Transboundary Reach typically occurs in late June through July (Golder 2006d, 2008, 2011c; Howell and McLellan 2007b, 2008, 2011). Similar to other areas of the Columbia, sturgeon spawning in the Transboundary Reach generally occurs when water temperatures reach about 14°C (Parsley et al. 1993; Parsley and Beckman 1994; Golder 2011c; Howell and McLellan 2007b, 2008, 2011). However, due to the higher latitude and cooler water, spawning in the Transboundary Reach occurs somewhat later than spawning in the lower Columbia (May to June; Parsley et al. 1993; Parsley and Beckman 1994).

Two White Sturgeon spawning areas have been identified in the Roosevelt Reach; one near Northport, WA and one near China Bend (Figure 14). The Northport site was first documented in 2005 (Howell and McLellan 2007b) and spawning at this location was confirmed in three subsequent years (2006 to 2008; Howell and McLellan 2008, 2011, *in review*). Although spawn monitoring ceased after 2008, the occurrence of spawning was implied from 2009 to 2011 through collections of larvae downstream from Northport (Howell and McLellan *in prep*; WDFW, unpublished data). Spawning near China Bend was documented in 2007 and again in 2008 (Howell and McLellan 2008, 2011, *in review*).

White Sturgeon have spawned in the tailrace of Waneta Dam at the confluence of the Pend d'Oreille and Columbia rivers in each of the 16 years that sampling was conducted between 1993 and 2011 (Figure 14; Golder 2002, 2011c). Spawning has occurred from early June to late July, with approximately 75% of spawning occurring before 10 July and 90% prior to 15 July (ASL et al. 2007). Based on an analysis of egg distributions on egg mats from 2000 to 2005, results of a 3D numerical model of the Waneta spawning area indicated that over 95% of the eggs were situated in areas with near-bottom flow velocities >1.0 m/s over the entire egg incubation period (ASL et al. 2007). This agrees with other researchers that indicate near-bottom velocities in egg deposition areas are typically >1 m/s (Parsley et al. 1993; Perrin et al. 2003).

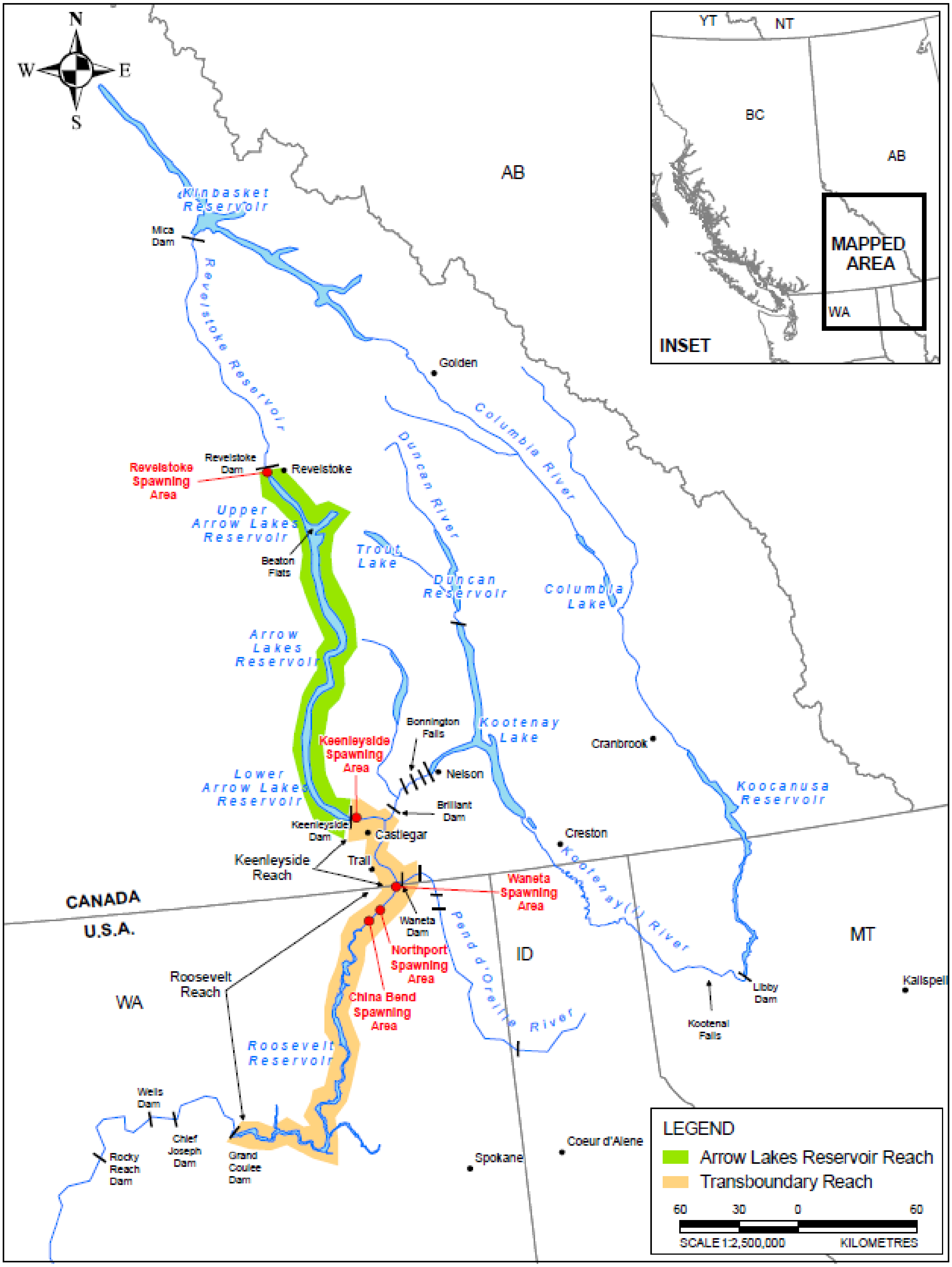


Figure 14: Locations of known White Sturgeon spawning areas in the Upper Columbia River recovery area.

In the early 1990s, the HLK tailwater area was identified as a suspected spawning area (based on suitable velocities and substrates and widespread observations of tailrace spawning in lower Columbia River impoundments); however, sampling at this location in 1992, 1993, and 1994 did not capture White Sturgeon eggs or larvae (RL&L 1996d). In 2007 and 2008, sampling in the upper Keenleyside Reach approximately 5 km below the Kootenay-Columbia confluence area led to the collection of White Sturgeon larvae (Golder 2009b). In 2010, White Sturgeon spawning was confirmed at the Keenleyside spawning area immediately downstream from HLK/ALGS (Figure 14; BC Hydro unpubl. data). Spawning at this location also occurred in 2011 (Terraquatic 2011). However, the ages of larvae collected below the Kootenay-Columbia confluence in these same years were not consistent with the hatch timing of spawning events at HLK/ALGS. Further, in both years, White Sturgeon eggs were collected in drift nets below the confluence area, which suggested another spawning area was located upstream of the Kootenay-Columbia confluence.

In the ALR Reach, spawning was first confirmed in 1999 downstream from Revelstoke Dam. This is the most northerly spawning location identified for White Sturgeon in the Columbia River Basin. However, spawning was only documented in four of the seven years that monitoring has been conducted since 1999 (Golder 2011b). Revelstoke Dam is a load following facility with hypolimnetic withdrawals and as a result, daily flow fluctuations variedy between to 0 and 1,700 cms and maximum summer water temperatures rarely exceed 11°C. Spawning occurs from late July to late August, which is the latest spawning documented for the species, at water temperatures between 8.5 and 11.1°C. This is at the lower end of the reported 10 to 18°C range for White Sturgeon in downstream areas of the Columbia River (Parsley et al. 1993), but similar to the 8 to14°C spawning range recorded for White Sturgeon in the Kootenai River (Paragamian et al. 1997).

Reported depths used by spawning White Sturgeon range from 0.5 to 25 m (Parsley et al. 1993; Parsley and Beckman 1994; RL&L 1996a, 1996b; Perrin et al. 1999, 2000). Depth does not appear to be a critical factor influencing spawning site selection.

2.8 Early Life History

Mature White Sturgeon eggs are large (2.5 to 4.0 mm in diameter) and dark grey in color. When released from the female, the eggs are negatively buoyant and rapidly sink at rates of approximately 5.4 cm/s (unpublished data, Kootenai Tribe of Idaho and U.S. Geological Survey). Within minutes after contact with water, the eggs become strongly adhesive (Wang et al. 1985) and typically adhere to substrate surfaces near where spawning occurred. Embryo incubation time is temperature dependant, varying from about 4 to 14 days and is inversely related to water temperature (Wang et al. 1985; Conte et al. 1988).

In the lab, optimal incubation temperatures range from 14 to 16°C; egg mortality increases at temperatures lower than 8°C and above 18°C. Wang et al. (1985) reported complete mortality at temperatures above 20°C. However, *in-situ* egg incubation experiments in the Upper Columbia River have shown hatch rates of 88% for eggs incubated at a mean temperature of 20.1°C (Golder 2010). Although the long-term viability of the larvae hatched at these temperatures is unknown, the results suggest there may be some stock specific variability in the upper lethal temperature. Hatch progresses rapidly but total hatch of eggs from a single female occurs over several days with peak hatch within 24 to 48 hours after the first eggs hatch. Field and laboratory studies and aquaculture experience show that hatch occurs during both day and night.

Ontogenetic behaviour of the yolk sac larvae is largely associated with interstitial hiding and downstream dispersal. As studies of this life stage are challenging in large rivers, laboratory studies have provided some understanding of this phase. Early laboratory studies reported an immediate swim-up phase resulting in drifting and downstream dispersal for 1 to 6 days (Brannon et al. 1985; Deng et al. 2002; Kynard and Parker 2005).

However, recent studies incorporating a variety of substrates showed a strong preference for small gravel (Bennett et al. 2007) and showed that both downstream drift and predation increased in the absence of suitable interstitial hiding habitat (McAdam 2011).

Field collections of yolk sac larvae made by sampling the drift also suggests a benthic orientation (Parsley et al. 1993; Howell and McLellan 2008) but no studies have been done to determine the distribution of yolk sac larvae within the water column as have been done for other species (Auer and Baker 2002; Smith and King 2005; Bratten et al. 2008; Duong et al. 2011). Studies in the Upper Columbia River have collected yolk sac larvae from the drift within about 2 km downstream of known spawning areas (Howell and McLellan 2008; Golder 2009b) and collections from the drift over greater distances from known egg incubation sites has been reported for the lower Columbia River and the Sacramento River (McCabe and Tracy 1994). In the lower Columbia River, drifting yolk sac larvae have been collected downstream of known spawning areas in surface tows and they have been found in near-shore interstitial habitats (van der Leeuw et al. 2006).

The yolk sac is absorbed within 10 to 15 days after hatch, whereupon the fish move out of the substrate and begin a downstream dispersal to feeding areas (Parsley et al. 2002). The larvae must find food or starve and greatest mortality in aquaculture facilities occurs at this critical period and likely in the wild as well. The larvae develop a full complement of fins and scutes and metamorphose into juvenile sturgeon over the next 30 to 60 days. In the Columbia River downstream from Bonneville Dam, White Sturgeon larvae undergoing metamorphosis have been captured in bottom trawls more than 175 km downstream from spawning areas (McCabe and Tracy 1994).

After metamorphosis, growth is typically rapid as the young juvenile stage usually coincides with the warmest water temperatures of the year. Age-0 White Sturgeon in warm productive riverine and reservoir habitats have been reported to achieve total lengths exceeding 220 mm by September or October (McCabe and Tracy 1994) when water temperatures typically begin to cool and growth would be expected to slow.

White Sturgeon year class strength in wild populations is generally believed to be set within 90 days after spawning. Estimated survival is very low during the first year with young-of-the-year survival of perhaps 5×10^{-5} (about one egg in 20,000 survives to age-1; Gross et al. 2002). While factors controlling year class strength are poorly understood, recruitment has been widely correlated with flow volume in many sturgeon species including White Sturgeon (Votinov and Kasyanov 1978; Kohlhorst et al. 1991; Anders and Beckman 1993). Kohlhorst et al. (1991) found a positive correlation between White Sturgeon year-class strength and the volume of freshwater flow through the Sacramento-San Joaquin River Estuary. In the lower Columbia River, high springs flows were also positively correlated with the availability of high velocity spawning habitat, spawning success, and subsequent age-0 abundance (Anders and Beckman 1993; McCabe & Tracy 1994). Differences in recruitment among several population segments with identical flow regimes are believed to be due to channel morphology and water surface gradient effects on water velocity at different flows within different spawning areas. A positive correlation between flow and recruitment success may be related to: 1) increased availability of suitable spawning sites; 2) reduced predation on eggs; 3) decreased predation on yolk sac embryos, larvae and juveniles; 4) dispersal to productive mainstem rearing areas; 5) increased flooding of side channel and slough areas that provide higher quality rearing habitats than mainstem areas; or 6) effects of related conditions such as temperature. A positive correlation between river flow and White Sturgeon recruitment success in the Upper Columbia River has been suggested based on a detectable pulse in natural recruitment following the high flow year in 1997, but due to the difficulties in capturing age-0 fish, within-year evidence to support flow-recruitment correlations has not been obtainable.

Despite documented spawning by White Sturgeon downstream from Revelstoke and HLK dams, and at Waneta, Northport, and China Bend, recruitment of juvenile sturgeon in the Transboundary Reach has been negligible since the 1970s (Figure 15) and no age-0 sturgeon have been captured during fall gill net surveys. However, capture efficiency of this size White Sturgeon is unknown and older juveniles believed to be of wild origin are occasionally caught (Howell and McLellan 2011).

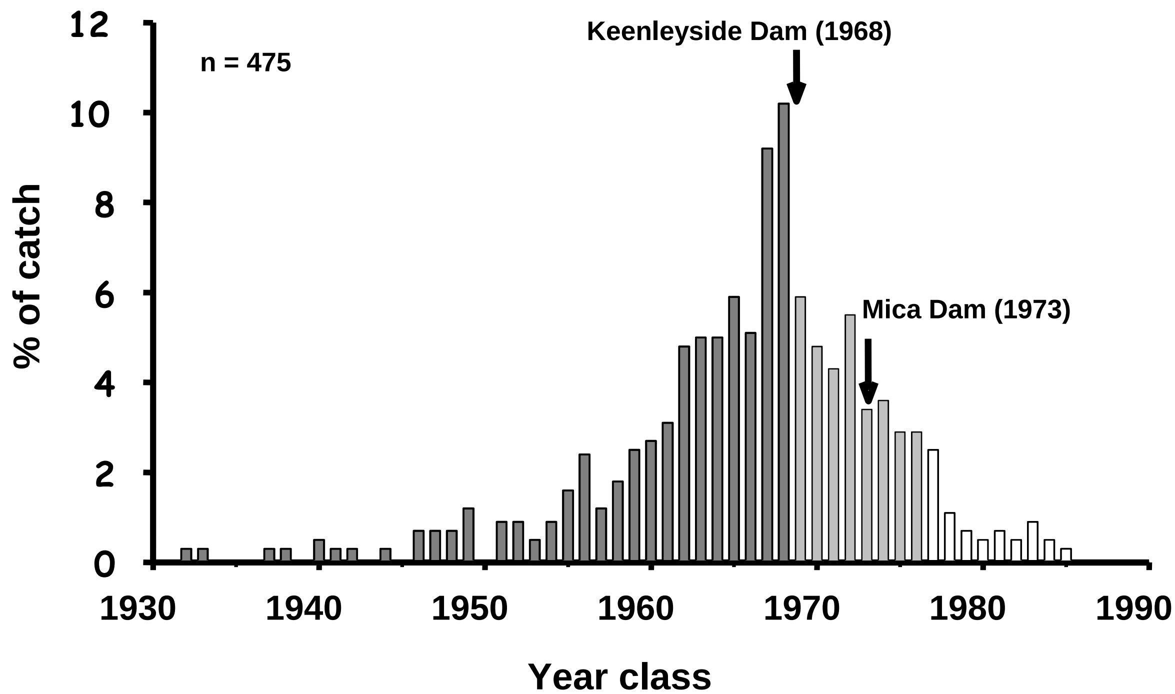


Figure 15: Reflection of historical recruitment and mortality rates of White Sturgeon in the Keenleyside Reach based on current age composition expressed in terms of year class (RL&L 1994a; Hildebrand and Birch 1996).

Golder (2006d, 2008, 2010) demonstrated high survival to hatch of embryos collected at the Waneta spawning area on egg mats and incubated *in situ* in incubation capsules. Post-hatch sturgeon up to the first feeding life stage have been captured in the riverine and upper river-reservoir transition zone areas of the Roosevelt Reach annually since 2004 (no sampling was conducted in 2009; Howell and McLellan 2008, 2011; WDFW, unpublished data). Total catch varied from 26 in 2004 to 10,391 in 2011. Variability in annual catch was attributed to: 1) increasing experience of the research team; 2) improvements in sampling equipment; and 3) differences in levels of effort and sample site location. Thus, conclusions cannot be drawn about annual larval production. However, plankton net catch data indicates that conditions in the Transboundary Reach, particularly downstream from the Canada-U.S. boundary, are suitable for successful incubation of embryos and that substantial numbers of larvae survive to the exogenous feeding stage in most years.

In the area between the Canada-U.S. boundary and the upper reaches of Lake Roosevelt, the substrate is typified by coarse sediments (gravel, cobble, boulder; Weakland et al. 2011; CH2M Hill 2006). Extensive areas of fine grained (sand/silt) sediments are typically found from the Marcus area downstream and bottom trawl efforts in this area to date have failed to capture larvae or age-0 White Sturgeon (Kappenman et al. 2000; Howell and McLellan 2011; Howell and McLellan *in prep*). Age-0 White Sturgeon have been captured in other areas of their range in bottom trawls and gill nets. Age-0 fish are often captured coincident with older juvenile sturgeon (van der Leeuw et al. 2006) and mixing of various sizes and ages of White Sturgeon has been observed in underwater video taken from many areas, suggesting that habitat partitioning by size or age does not occur.

2.9 Summary

As indicated above, considerable additional information on White Sturgeon biology in general and within the Upper Columbia River Recovery Area specifically has been collected since the original Recovery Plan was written in 2002. This information has been summarized in Table 10 and forms the basis for the discussion in subsequent sections of the present Recovery Plan.

3.0 POPULATION STRESSORS AND CAUSES OF ONGOING RECRUITMENT FAILURE

Worldwide, most sturgeon stocks are imperilled. They are particularly sensitive to overharvest and habitat degradation which has substantially influenced abundance and population productivity across most sturgeon species and populations (Birstein et al. 1997; Boreman 1997; Gross et al. 2002). Chronic recruitment failure has led to the listing of entire species or population segments of all sturgeon species in North America. However, identification of specific causes of the failure of some sturgeon populations, including White Sturgeon, to produce young fish to perpetuate the population has been difficult (Anders et al. 2002; Parsley et al. 2002; McAdam 2012).

Implicit in the 2002 Upper Columbia White Sturgeon Recovery Plan was the need to identify the recruitment failure bottleneck so that management actions could be implemented to recover the population segments. The phased approach to recovery outlined in the 2002 plan called for short term (~5 year) actions to halt further decline and to assess population status. The population status information was expected to inform medium term (the next 5 to 10 years) actions to determine recruitment failure bottlenecks and establish response measures. Research and monitoring conducted since publication of the original recovery plan has added substantial new information about habitat use, mortality rates, and genetic diversity of Upper Columbia River White Sturgeon populations.

On the basis of this new information, the TWG began to discuss causes of recruitment failure and potential remedial actions. These discussions revealed that widely varying points of view existed among members of the TWG concerning the interpretation of the new information and its implications for identifying and addressing bottlenecks to recruitment. Collectively, these bottlenecks became known as recruitment failure hypotheses, and the TWG initially identified over 100 hypotheses that could potentially explain recruitment failure.

In an attempt to focus White Sturgeon recovery efforts in the Upper Columbia River, the TWG conducted a review of all the hypotheses regarding recruitment failure with the following objectives:

1) Identify project objectives and competing hypotheses.

2) Screen out unlikely hypotheses that were not supported by the available data.

3) Prioritize hypotheses, identify uncertainty, and connect hypotheses to feasible in-river mitigation options.

4) Identify and prioritize high importance research projects required to verify hypothesis or initiate mitigation actions.

Table 10: Available knowledge and concerns for White Sturgeon life history stages in the Transboundary Recovery Area (adapted from Hildebrand and Birch 1996).

Life stage	Period	Synopsis of Available Knowledge and Concerns
Spawning	Late May to late July	Spawning occurs at five known areas within the flowing section of the Transboundary Recovery Area. Predation rates on eggs are unknown but selection of high velocity (typically > 1 m/s near bottom velocity) areas for spawning and egg incubation may result in similar pre- and post-regulation predation rates.
Incubation	Late May to late July	Eggs are successfully fertilized and incubate for 5-10 days depending on water temperature. Rates of survival to hatch are unknown but may be influenced by water quality (water clarity, contaminants) and substrate characteristics (suitable quality and quantity of interstitial spaces) that protect embryos from predation and physical damage.
Yolk sac larvae	Early June to late August	This stage begins following hatch. The endogenous feeding larvae seek hiding places within interstitial spaces in substrates or exhibit a swim-up and downstream dispersal to suitable rearing habitats. Sampling and in-situ egg incubation experiments indicate some portion of eggs hatch to this stage. Predation and energy expenditure required for hiding likely influence survival rates substrate characteristics (suitable quality and quantity of interstitial spaces)
Feeding larvae	Early June to Late August	Follows absorption of the yolk and the shift to exogenous feeding. Feeding larvae actively move onto substrate surfaces to seek food. This may be the most critical period in the recruitment cycle, where predation, starvation, and other factors influence survival rates.
Young-of-the-year	August to December	Generally refers to fish that have achieved their full complement of fins and scutes and resemble adults in miniature. No wild spawned young-of- the-year have been captured in the recovery area. Food abundance for this life stage has been influenced by many factors, that may have resulted in either increased (e.g., through reservoir fertilization and/or increased water clarity) or decreased (through changes in flow or substrate porosity) food availability. Increased predation associated with increased predator abundance, reduced flow volume, and increased water clarity may have reduced survival
Younger juveniles	All year	Represents age-1 to age-7 fish; low survival at the larval and YOY stages likely accounts for low abundance of wild younger juveniles; expected to be found in same habitats as older juveniles and adults. Changes in biotic productivity of the river may influence food availability and influence growth and survival.
Older juveniles	All year	Age- 8 to age-15; most fish > age-15; these fish are found in same habitats as adults; changes in biotic productivity of the river may influence food availability and influence growth and survival
Adult Feeding	All year; greater use from May to October	Represents immature sub-adults (15 to 30 years old) and mature adults (generally older than age-30;;; highest use in all seasons is for areas with depths over 15 m; food abundance/composition has likely changed in response to dam operations and exotic species introductions. Known feeding areas in BC include the HLK area, Kootenay, Fort Shepherd, and Waneta eddies and in the U.S. include areas near Kettle Falls, China Bend, and Dead Man's Eddy
Overwintering	November to March	In winter, fish tend to be found in deeper waters than during other times of the year. Since the availability of deep-water habitats in riverine reaches is limited, the importance of these areas during the winter period is increased; since regulation of the river, winter flows and water temperatures have increased, possibly reducing the suitability of overwintering habitats by increasing metabolic demands. Four known overwintering areas have been identified in BC (HLK area, Kootenay, Ft Shepherd, Waneta); overwintering areas in U.S. waters are upstream of China Creek and primarily near the Marcus and Seven Bays areas.
Staging (Pre-spawners)	November to late May	Represents locations selected by pre-spawning females (and possibly pre-spawning males) that provide suitable low velocity holding areas near spawning areas; flow fluctuations that increase velocities in staging areas and temperatures increases during the winter period may affect spawning intensity. Known staging areas are Ft. Shepherd eddy, Waneta eddy, and the HLK area; use of the Kootenay Eddy for staging has not been documented

Since recruitment failure hypotheses were distinct between the two main spawning areas known in 2006 (the Waneta/Northport and Revelstoke spawning areas), each geographic area was addressed separately but the same impact hypotheses were used. Of the initial 100+ hypotheses, a series of screening exercises pared the list down to 28 hypotheses (Gregory and Long 2008). This number was further reduced by grouping similar or related hypotheses. Influence diagrams were developed to describe each hypothesis pathway and facilitate discussion of each hypothesis (Figure 16). This approach required a compilation and review of the available data to support or reject each hypothesis. This process resulted in the identification of 11 consensus hypotheses, 5 for the Transboundary Reach (Table 11) and 6 for the ALR Reach (Table 12).

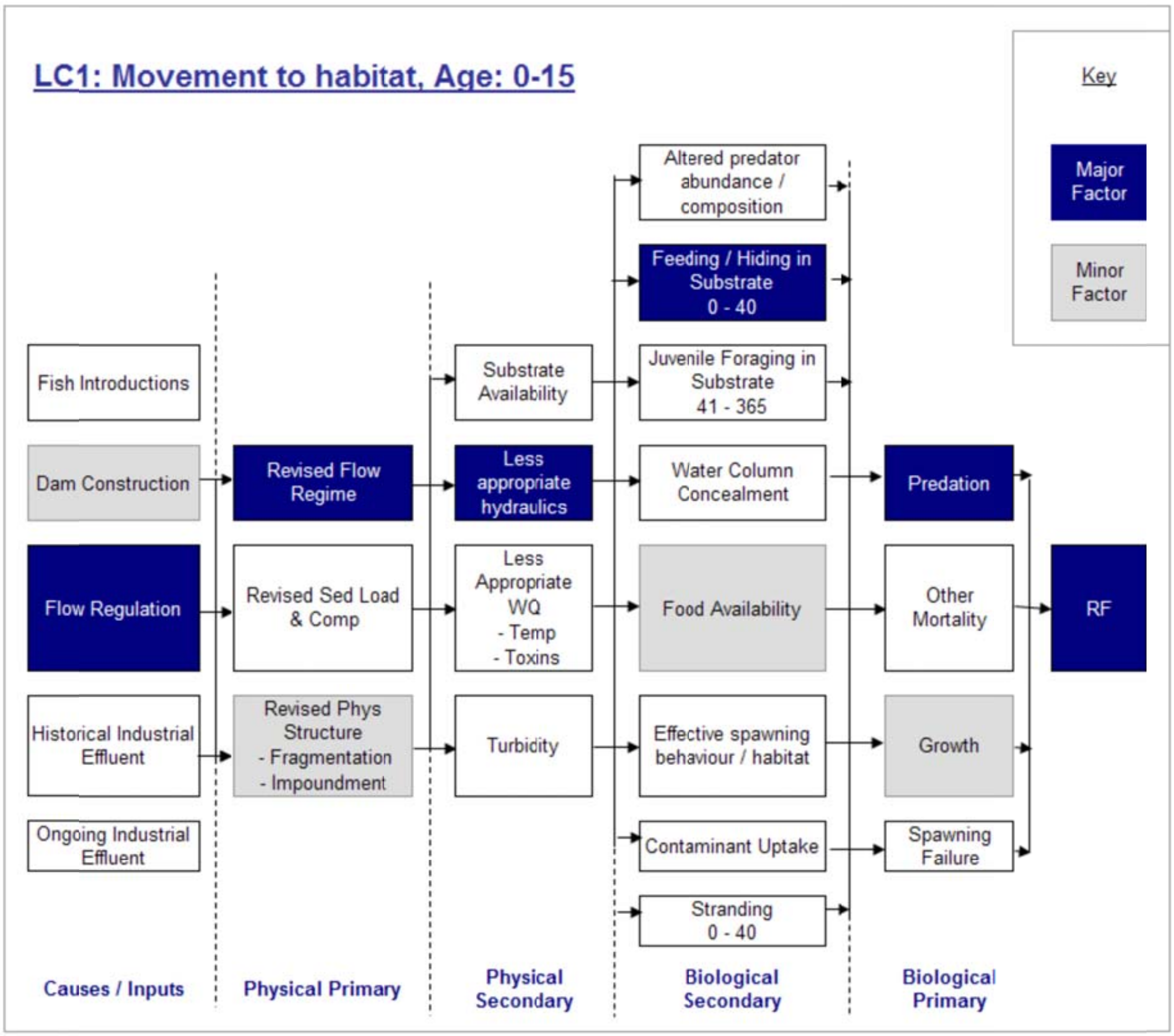


Figure 16: An example of an influence diagram showing pathways describing how a specific hypothesis may lead to recruitment failure. This influence diagram addresses recruitment failure at the post-hatch juvenile life stage in the Transboundary Reach. Figure adapted from Gregory and Long (2008).

Separate consideration was given to a hypothesis that concerned whether fish historically spawned upstream of Arrow Lakes or whether the sturgeon now present in ALR Reach were inadvertently trapped after construction of HLK while foraging in upstream reaches. Most members of the TWG felt that based on available data, fish did not historically spawn upstream of Arrow Lakes, but this opinion may change pending confirmation of initial findings from the finray microchemistry analysis (see Section 2.2.1.2; McAdam 2012).

Table 11: Consensus hypotheses regarding White Sturgeon recruitment failure in the Transboundary Reach, 2008.

Hypothesis	Life stage	Pathway description
Changes in flow patterns (magnitude and timing) and reduction in turbidity reduce the survival of young sturgeon	Age-0	Dam installation and operations cause reduced turbidity and altered hydraulics (flow volume and velocities). The altered hydraulics no longer serve to disperse newly hatched free embryos to suitable hiding habitat. Embryos suffer predation while searching for suitable habitat, and post-hiding phase juveniles also suffer predation while moving downstream. Increased predation occurs in part due to lack of cover associated with reduce flow volume and turbidity.
Diminished suitability and availability of habitat (primarily related to substrate conditions) downstream of spawning areas has led to reduced survival of early life stages	0 to 365 days; the smaller the juvenile the more likely the effect	Dam installation and operations combined with natural and industrial sources of sediments have in-filled substrate interstices or overlain substrates rendering them unsuitable for use by early life stages. Juveniles then succumb to a combination of reduced food availability (impacting growth) and predation (during search for food and habitat).
Changes to the fish community have resulted in increased predation on eggs, free embryos, larvae and juvenile sturgeon and significantly reduced survival	0 to 365 days	Dam installation and operations combined with fish introductions have altered the fish community and increased the number of predators. Since juveniles do not have suitable refuge habitat, they are more available for a longer time period to a larger predator population and their survival is substantially reduced.
Contaminated effluent from smelter and pulp mill sources leads to direct or indirect toxicity, impacted health, reduced spawning success, and reduced habitat and prey availability.	0 to 365 days	Industrial effluents introduced to the river contaminate prey items and fish. Sturgeon are directly or indirectly affected by contaminants accumulated from their prey. Sturgeon may succumb immediately, suffer reduced health and growth, have their gender or spawning capabilities impacted, or become more susceptible to predators.
Food of the appropriate type and size is not available at the right time and place to promote survival of young sturgeon.	Age-0	Substrate condition and availability has been altered by sediment additions and the inability of flows to clean the substrate. Invertebrates prey species are unable to find suitable substrate and die or succumb to sediment toxicity. Sub-yearling sturgeon cannot find suitable or sufficient prey, and they starve or their growth is reduced and they succumb to predation.

Table 12: Consensus hypotheses regarding White Sturgeon recruitment failure in the Arrow Lakes Reservoir (ALR) Reach, 2008.

Hypothesis	Life stage	Pathway description
Changes in flow and temperature patterns (magnitude and timing) reduce the success of or delay spawning, egg development, and post-hatch embryo growth and development. As a result, the over-wintering fitness of post-hiding phase juveniles is impacted and survival is reduced.	Pre-spawn and spawning adults, incubating eggs, and 0-365 day old juveniles	Dam installation and operations has altered the hydrograph (flow volume and velocities) and hypo-limnetic withdrawals have reduced overall river temperatures and delayed warming and cooling rates. Mature adults defer or postpone spawning while waiting for suitable cues. If adults do spawn, incubation and the post-hatch hiding phase of their progeny takes longer. Juveniles start feeding too late to build up metabolic reserves for adequate over-wintering fitness. Sub-yearling juveniles starve over the winter or suffer from increased predation.
Changes in flow patterns (magnitude and timing) and reduction in turbidity reduce the survival of eggs and young sturgeon.	Egg incubation and 0-40 days post-hatch	Dam installation and operations has reduced turbidity and altered hydraulics (flow volume and velocities) such that newly hatched embryos are no longer dispersed to suitable hiding habitat. Load shaping exposes incubating eggs and larvae to stranding mortality. Free embryos suffer predation while searching for suitable habitat, and post-hiding phase juveniles suffer predation while moving downstream. Increased predation occurs due to lack of cover associated with reduce flow volume and turbidity.
The suitability and availability of habitat (primarily related to substrate conditions) downstream of spawning areas has led to reduced survival of eggs and early life stages.	Incubating eggs, 0-40 day larvae, and 25-365 day larval/juvenile stages	Dam installation and operations (hydrograph changes and downstream reservoir backwatering) has resulted in substrate armouring of the riverine reach, and altered substrate conditions in the river-reservoir interface area rendering these areas unsuitable for egg incubation and the post-hatch hiding phase, or post-hiding feeding juveniles. Juveniles succumb to a combination of reduced food availability (impacting growth) and predation (during search for food and habitat).
The installation of HLK eliminated the ability of mature adults from below the dam to access spawning habitat in the mid-Columbia reach upstream of Arrow Lakes resulting in lost recruitment.	Mature adults (25+ years)	The construction of HLK without suitable passage facilities eliminated the ability of sturgeon residing below the dam either seasonally or during the interval between spawning events to move past the dam into ALR and upstream areas. This eliminated the potential for this segment of the population to spawn in the upstream Columbia River, which limited spawning to resident fish upstream of HLK.
Changes to the fish community have increased predation on eggs, free embryos, larvae and juvenile sturgeon and significantly reduced survival.	0-365 days	Dam installation and operations altered the fish community and increased predator abundance. Juveniles exhibit delayed development and do not have suitable refuge habitat, increasing their susceptibility to predation and reducing their survival.
Food of the appropriate type and size is not available at the right time and place to promote survival of young sturgeon.	11-365 days	Substrate condition and availability has been armoured below the spawning area and in the river-reservoir interface. Invertebrate prey species are unable to find suitable substrate. Sub-yearling sturgeon cannot find suitable or sufficient prey, and they starve or their growth is reduced and they succumb to predation.

Weighting factors for each hypothesis were derived using an opinion poll (Gregory and Long 2008). The hypothesis with the highest weight for the Transboundary Reach was related to the effects of altered substrate condition and contaminants on the availability of adequate prey for age-0 White Sturgeon. The hypothesis with the highest weight for the ALR Reach was related to impoundment effects of altered water flows and temperatures on all life stages. There was recognition by the TWG members who participated in the hypothesis review process that more than one hypothesis may have some validity and that recruitment failure may be the result of the cumulative impact of several hypotheses.

Mitigation options for each hypothesis were explored and research addressing key uncertainties about mitigation was identified. Research topics were refined and four key areas of research and mitigation interest were identified:

1) Substrate modification (additions and/or cleaning) to increase the quantity and quality of early rearing habitat.

2) Flow manipulations to address temperature concerns (ALR Reach) and flow volume effects (Keenleyside Reach).

3) Fertilization and feeding.

4) Turbidity augmentation.

Additional discussion refocused attention on the key implementation issues related to cost, research, and mitigation sequencing. The detailed level of analysis provided by Gregory and Long (2008) recognized existing limits on funding capabilities and provided an initial sequencing mechanism, with clear links to annual budgets and to future planning requirements.

A number of actions were identified during the Recruitment Failure Hypothesis Review process that would address key uncertainties or provide information needed before implementing restoration projects. Substantial progress has been made on several of these actions, while others are either in the process of being addressed or have yet to be addressed (Table 13).

In addition to studies specifically for White Sturgeon, the BC Hydro WUP also has implemented a series of investigations that will attempt to identify the effects of hydro operations in the Canadian section of the Upper Columbia River recovery area on resident fish populations, including White Sturgeon. These programs are described in Table 14 and relevant results will be incorporated into future evaluations of recruitment failure hypothesis. In addition, a weight-of-evidence evaluation of multiple recruitment failure hypotheses has also been conducted (McAdam 2012), but was not completed in time for inclusion into this revised recovery plan.

During the Recruitment Failure Hypothesis Review, two anthropogenic impacts were considered as the most likely to have resulted in White Sturgeon recruitment failure. The first was the construction of dams and formation of reservoirs with the primary effects being related to changes in flow, water temperature, predation, and food availability. This and other potential impacting factors that were considered less likely to be the prime causes of recruitment failure, but may have contributed cumulatively to recruitment failure, are described and discussed below.

Table 13: Summary of actions identified by the UCWSRI TWG to provide information needed to verify recruitment failure hypothesis in the Upper Columbia River recovery area and the status of those actions.

Action	Status	
	Completed	**In Progress or Planned**
Conduct stock structure analysis (genetics, fin ray microchemistry, age re-valuation)	- Two studies on genetic stock structure analysis - Fin ray microchemistry to assess spatial distribution at-age - Demographic analysis - Growth modeling	- Genetic evaluation of spawning parentage underway - Verification of microchemistry results through water chemistry analysis - Stock structure and population estimate underway
Develop impact timelines for hypothesized causes of recruitment failure	- See AMEC (2012) report - McAdam 2012	- Progress in ongoing research and monitoring programs will assist in further refinement of causes for recruitment failure and associated impact timelines
Develop a plan to identify responses to opportunistic flows provided under the BC Hydro WUP	- Not completed	- Annual monitoring program to develop database spanning multiple years (10) to address questions pertaining to the effects of different flow regimes on recruitment.
Conduct larval sampling to determine if early larvae are feeding	- WDFW and BC Hydro studies	- Annual larval monitoring underway at multiple locations in both US and Canadian reaches
Study successful habitat components for early feeding larvae	- Crossman and Hildebrand 2012	- Some hatchery experimentation planned - Further field assessments planned
Determine food availability and distribution for early feeding larvae	- Not completed	- In progress (samples collected and analyses in fall 2012)
Determine food availability and distribution for juveniles	- Not completed	- In progress (samples collected and analyses in fall 2012)
Conduct bathymetry mapping of key habitats in the Transboundary Recovery area	- Bathymetric surveys in Revelstoke, HLK/ALGS, Waneta, spawning areas	- Hydrographic surveys are planned for the upper Roosevelt Reach in 2013. - Mapping planned for HLK/ALH spawning area.
Conduct sediment facies mapping to determine the distribution and composition of substrates, particularly for free embryo hiding habitat	- Sediment mapping in Revelstoke spawning and early rearing area; data input into 3D numerical model - Sediment mapping of Waneta spawning and early rearing habitats	- Hydrographic surveys planned for the upper Roosevelt Reach in 2013; will include sediment facies mapping. - Sediment mapping at the HLK/ALH spawning area
Determine if free embryo hiding habitat is limiting	- Not completed	- Work dependant on sediment mapping results
Complete lab studies to examine substrate effects on free embryo/larvae survival	- Studies on the effects of yolksac larvae habitat on larval physiology and performance	- Completion of lab studies on larval quality. - Evaluation of quality indicators for wild caught feeding larvae - Hatchery experimentation with
Complete feasibility study for substrate enhancement	- Completed for Revelstoke spawning area; pilot substrate modification program in 2010; early larval rearing suitability assessed in 2011 (Crossman and Hildebrand 2012)	- Examine feasibility of enhancing substrate at the HLK/ALH spawning area
Synthesize existing literature on predator composition, distribution, behavior and diet, to assess the potential for consumption of larvae and small juveniles	- Not completed	- Will be partially addressed through the White Sturgeon egg predation studies at Waneta

Table 14: Summary of WUP projects to identify the effects of hydro operations on resident fish in the Canadian section of the Upper Columbia River White Sturgeon recovery area.[a]

Monitoring Programs	2007 WLR YR1	2008 WLR YR2	2009 WLR YR3	2010 WLR YR4	2011 WLR YR5	2012 WLR YR6	2013 WLR YR7 Interim Review	2014 WLR YR8	2015 WLR YR9	2016 WLR YR10	2017 WLR YR11	2018 WLR YR12	2019 WLR YR13 Final Review
CLBMON-42 Lower Columbia Fish Stranding	✓	✓	✓	✓	✓	u/w	■	■	■	■	■	■	■
CLBMON-43 Lower Columbia Sculpin and Dace			✓	✓	✓	u/w	■						
CLBMON-44 Lower Columbia Physical Habitat and Ecological Productivity		✓	✓	✓	✓	u/w	■	■	■	■	■	■	■
CLBMON-45 Lower Columbia Fish Indexing	✓	✓	✓	✓	✓	■	■	■	■	■	■	■	■
CLBMON-46 Lower Columbia Rainbow Trout Spawning Habitat Assessment		✓	✓	✓	✓	■	■	■	■	■	■		
CLBMON-47 Lower Columbia Whitefish Spawning Ground Topo					✓	u/w	■						
CLBMON-48 Lower Columbia Whitefish Egg Monitoring & Life History Study		✓	✓	✓	✓	■							
CLBMON-49 Lower Columbia Effects of Whitefish Flows on Great Blue Heron & Winter Use of Waldie by Great Blue Heron						■	■	■	■				

Legend:
■ = Program to be undertaken/initiated in identified year
u/w = Project is underway
✓ = Program completed for the year
× = Program started, but encountered operational or hydrological delays

[a] The table was produced from the BC Hydro website and detailed descriptions of each of the studies can be found at the following link: http://www.bchydro.com/etc/medialib/internet/documents/planning_regulatory/wup/southern_interior/2012q3/annual_report_august.Par.0001.File.CLB-MP8-Annual-Report-2012-08-31.pdf

3.1 Dams & Reservoirs

Dam and reservoir construction and operation affect White Sturgeon by:

1) blocking movements between widely-distributed spawning, rearing, and feeding habitats needed to complete the life cycle;

2) flooding productive riverine habitats;

3) eliminating anadromous fish runs that provided food and marine-derived nutrients;

4) reducing habitat suitability by changing temperature patterns, flow, substrate condition, water chemistry, nutrient transport, and water clarity;

5) increasing mortality either directly as a result of dam construction and entrainment, or indirectly as a result of gas supersaturation; and

6) changing species composition and abundance of prey, competitor, and predator species.

Upper Columbia River White Sturgeon were cut off from the lower basin population and anadromous food resources by construction of Grand Coulee Dam in 1941. These dams were among the first large mainstem dams in an intensive dam building phase that continued into the 1970s (Figure 17). Mainstem dams fragmented sturgeon habitat into short riverine sections connected by long impoundments. White Sturgeon in the Columbia and Snake rivers have been isolated into at least 30 separate reaches, functionally extirpated from eight reaches, and are likely to become extirpated in another 8 reaches without intervention (Hildebrand et al. *in prep*). Remaining population segments are primarily restricted to reaches with significant riverine habitat and subpopulations in marginal habitat areas have been lost or consist solely of a few remnant individuals.

In the Kootenay River, South Slocan Dam (1928) eliminated access to the base of Lower Bonnington Falls. Brilliant Dam (1944) restricted access to the lower 2.8 km of the river and cut off the Slocan River system while Duncan and Libby dams enabled seasonal flow regulation. Access into the Pend d'Oreille River was blocked by Waneta Dam (1954). Other Pend d'Oreille River dams including Box Canyon (1952), Albeni (1955), and

Boundary (1967), also had significant effects on water clarity, seasonal temperature ranges, dissolved gas saturation levels, and the aquatic community composition experienced by downriver populations of White Sturgeon. Hungry Horse Dam (1953) enabled seasonal flow regulation.

Recruitment failure in the Upper Columbia River White Sturgeon population coincides with the construction since 1968 of three large Columbia River mainstem dams (Figure 17). The construction of the HLK in 1968 isolated those sturgeon that were present in the former Arrow Lakes, cut off access by fish in the Transboundary Reach to potential habitats in the upper basin, and replaced a highly diverse and productive river lake ecosystem with a homogenous, oligotrophic reservoir. Mica Dam, constructed in 1973, further fragmented the river ecosystem above Arrow Lakes Reservoir, flooded over 250 km of the Columbia River mainstem that may have provided spawning and feeding habitats for White Sturgeon, reduced productivity by trapping nutrients, and increased water clarity by trapping sediments. HLK and Mica provide seasonal flow regulation. Revelstoke Dam (1984) effectively eliminated the 130 km section of flowing river between Mica Dam and Arrow Lakes Reservoir cut off access to the upper riverine habitat.

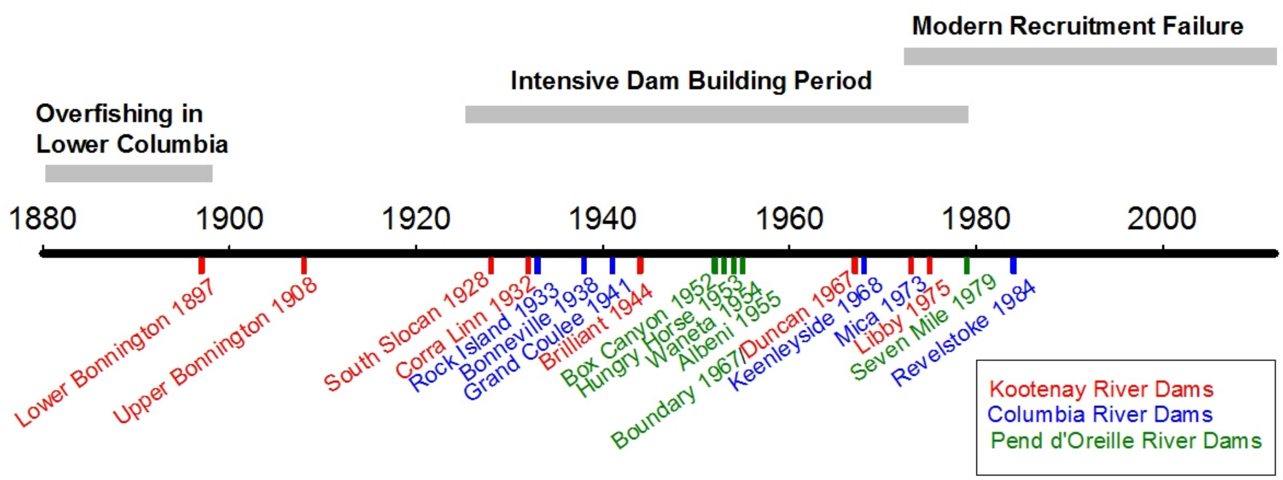


Figure 17: Time line of dam construction in the Columbia River basin and modern recruitment failure in the upper Columbia River.

The modern recruitment failure timeline is based on ageing of fin rays from captured White Sturgeon. White Sturgeon ages from fin ray sections should be interpreted with some caution, as there are varying levels of confidence among researchers as to the accuracy of this method. Consequently, developing accurate impact timelines for recruitment failure has been problematic. Fin ray microchemistry analysis and re-evaluation of past ageing work is underway and should assist with refining impact timelines.

The construction of dams and creation of reservoirs on the Upper Columbia River has resulted in unquestionable and substantive physical changes to the former natural riverine ecosystem. These changes have a numerous effects that could potentially negatively impact White Sturgeon recruitment. As such, dam construction, reservoir formation, and flow regulation are considered as primary causes of recruitment failure. The main changes that have occurred and their known or suspected impacts on White Sturgeon recruitment are discussed below.

3.1.1 Habitat Diversity & Geomorphology

The former riverine habitat structure of the Upper Columbia River has been altered by impoundment, channel modification, flood control, and flow regulation. The four mainstem reservoirs on the Upper Columbia River (Kinbasket = 100 km in length; Revelstoke = 130 km; ALR = 230 km; Lake Roosevelt = 240 km) flooded over 700 km of formerly diverse riverine habitat. Changes in river geomorphology as a result of flood control and flow regulation have been more subtle but no less significant (see Section 3.1.2). Floods help maintain channel diversity by periodically scouring and rearranging materials to create pool and backwater habitats. Regulated flows result in a more uniform river channel and an armoured substrate. These changes reduce aquatic habitat diversity, alter flow conditions at potential White Sturgeon spawning and nursery areas, and alter substrates in incubation and rearing habitats necessary for survival (Partridge 1983; Apperson and Anders 1991). Complex habitats may provide important seasonal forage areas and refuges from high discharges. Side channels and low-lying marshlands provide extremely productive habitats which may be used directly by sturgeon or by important food sources.

The locations or attributes of important White Sturgeon habitats prior to dam construction in the Upper Columbia River are uncertain, and limited information about historical habitat conditions makes it challenging to identify the apparent cause(s) of recruitment failure, and more importantly, the mitigation measures that can restore natural recruitment. Based on the apparent links between changes in physical habitat and recruitment failure (McAdam et al. 2005, Paragamian et al. 2009; McAdam 2012), the recent focus has been on laboratory studies to determine habitat requirements for larval and early life stage survival. Survival through the early life history period is specifically addressed as it has been identified by the TWG as the most likely recruitment bottleneck.

Laboratory studies have revealed new information on habitat for early life stages of White Sturgeon. Bennett et al. (2007) showed that White Sturgeon eleutheroembryos (yolk sac larvae) avoided bare or sand substrates and preferred 12 to 22 mm diameter gravels. McAdam (2011) further examined larval behavior in the presence of gravels and found a propensity for newly hatched larvae to hide rather than drift. Larvae from 1 dph to 6 dph also showed strong hiding responses when suitable interstitial habitats were available, although hiding responses diminished at 10 and 15 dph. These studies suggest that the behavioral responses of larval sturgeon are more complex than those identified by previous laboratory experiments, and these differences have a material effect on our understanding of links between larval behavior, substrate, and survival leading to recruitment.

In the Upper Columbia River, bathymetry and sediment facies have not as yet been mapped to the levels needed to enable estimation of suitable early rearing habitat. While the preponderance of drift by yolksac larvae may provide a biological indicator of substrate limitations (McAdam 2011), further sediment mapping is required to evaluate this suggestion. Studies are currently underway in both the Keenleyside and Roosevelt reaches to address this data gap. Recent laboratory studies have also provided new information regarding the effects of sediment particle sizes and resultant interstitial spaces on White Sturgeon early life history development and growth. Recently, available information regarding substrate condition and early life history survival has been used to design and build substrate enhancement projects for White Sturgeon in known spawning areas downstream from Revelstoke Dam, in the Nechako River, and the Kootenai River. In 2010, an experimental substrate modification program was implemented in the Revelstoke spawning area (Figure 14; Crossman and Hildebrand *in press*). Existing armoured riverbed conditions were modified using a mixture of larger and smaller angular rock to increase substrate complexity and availability of interstitial spaces. Post-hatch larvae were seeded into both the modified site and at an adjacent control site that represented existing armoured substrate conditions to determine (i) the extent that stocked larvae remained in both the modified and control sites immediately after release, (ii) the timing of subsequent dispersal of larvae from both sites, and (iii) how total length of dispersing larvae changed over time and by site. Results from this work indicated that the modified section of riverbed retained significantly higher numbers of larvae after release compared with the control site.

The larger variation in total larval length observed at the control site compared with the modified site indicated greater difficulty in hiding within the control substrate. These case studies (as well as those for Lake Sturgeon; Kerr et al. 2010) will inform future substrate enhancement projects if spawning, incubation, and hiding habitats are shown to be limiting population recovery.

3.1.2 Flow Regulation

Increased storage in the Upper Columbia River basin and hydro system operation have generally eliminated floods, reduced spring freshet flows, and increased late summer through winter discharges (Figure 18). Mica and HLK (Columbia River), Duncan and Libby (Kootenay/ai River) and Hungry Horse (Pend d'Oreille River) dams provide 22.2 million acre feet (MAF) of usable storage (7.0, 7.1, 1.4, 5.0, and 1.7 MAF, respectively). These storage reservoirs capture a large portion of the spring runoff for release to meet high power demands in fall and winter. Reservoirs are also drawn down and regulated for flood control from September through April. Unregulated spring runoff peaked during June and July in the Upper Columbia River, and about one month earlier in the Kootenay and Pend d'Oreille basin.

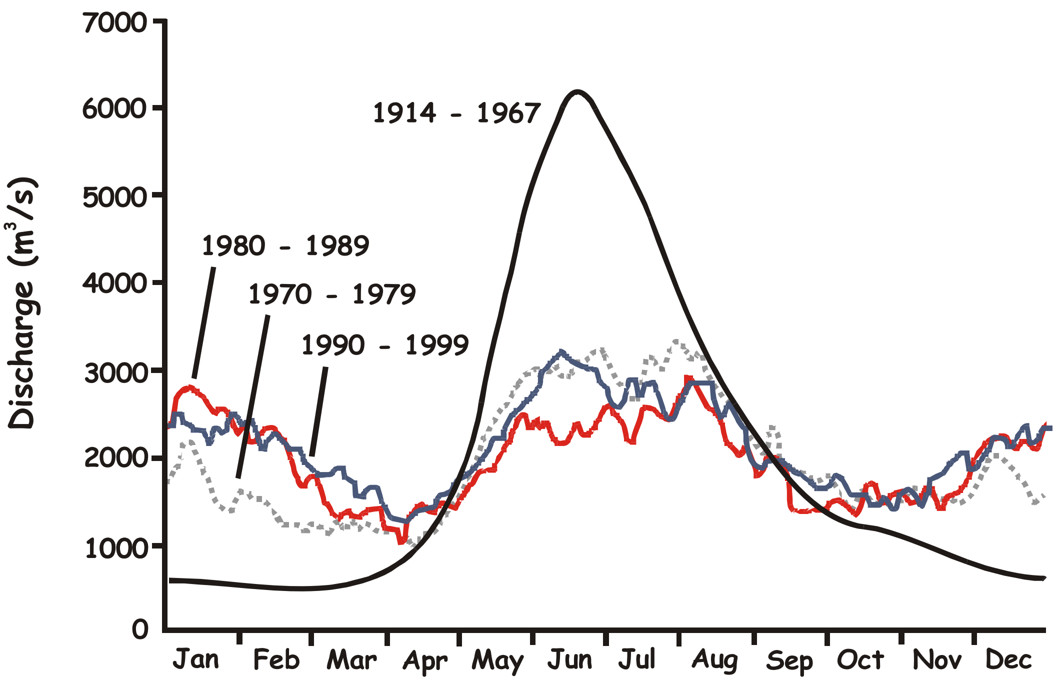


Figure 18: Mean daily discharge in the Columbia River at Birchbank during the pre-Keenleyside Dam period (1914 to 1967) and for three post-regulation periods, including 1970 to 1979, 1980 to 1989 and 1990 to 1998. Data from Water Survey of Canada gauging stations 08NE003 [Trail; for 1914-1937] and 08NE049 [Birchbank; for 1937 to 1998].

Historically, spring peak flows at the Canada-U.S. boundary often exceeded 4,500 cubic meters per second or cms (160,000 cubic feet per second or cfs) but currently average about 1,700 cms (60,000 cfs). Flood flows occurred primarily in spring as a result of snowmelt but also could occur in winter following rain on snow events. The largest recorded flood occurred in June 1894 as the result of rapid melting of an above-normal snow pack and produced an estimated 19,250 cubic meters per second (680,000 cfs) at the Canada-U.S. boundary. The lowest recorded historical flow at the boundary was 365 cms (12,900 cfs) in April 1968.

Flow regulation is suspected as a likely contributor to reduced recruitment of White Sturgeon in the Upper Columbia River. Recruitment of juvenile sturgeon has been correlated with spring flow volume (Beamesderfer and Farr 1997). White Sturgeon have adapted to and depend on riverine habitats and seasonal floods to provide suitable spawning conditions. Seasonal flow patterns likely cue maturation, migration, and spawning. Adhesive eggs are broadcast over rocky substrates in turbulent high-velocity habitat that accompanies high flow. High flows help disperse eggs and larvae, and reduce predation on early life stages. In addition, high flows in unimpounded floodplain systems increase access to food resources in newly inundated areas, and decrease predator densities. Periodic floods also flush fine sediment from river bed cobble and prevent armouring that reduce suitability for egg incubation, larval and juvenile fish rearing, and invertebrate diversity.

Flow effects can be complex because of interactions with temperature, turbidity, and a variety of other variables. Benefits of high flows in the Upper Columbia River recovery area are suggested by the noticeable recruitment pulse in 1997, when flows in the Transboundary Reach were near average pre-regulation flows and considerably above post-regulation average flows (Figure 19). Water temperatures at the Canada-U.S. boundary in 1997 reached 14°C (i.e., the optimal spawning temperature) in mid-late June 1997. First feeding larvae would likely have been abundant by mid-July, which coincided with a large secondary peak in discharge, which may have aided larval survival through more effective dispersal to nursery habitats further downstream in the Roosevelt Reach or by reductions in predation due to greater flow volumes and turbidity. However, it is also important to note that high flow events haven't always led to detectable recruitment, which further emphasizes that changes coinciding with high flows can lead to a complex set of secondary effects.

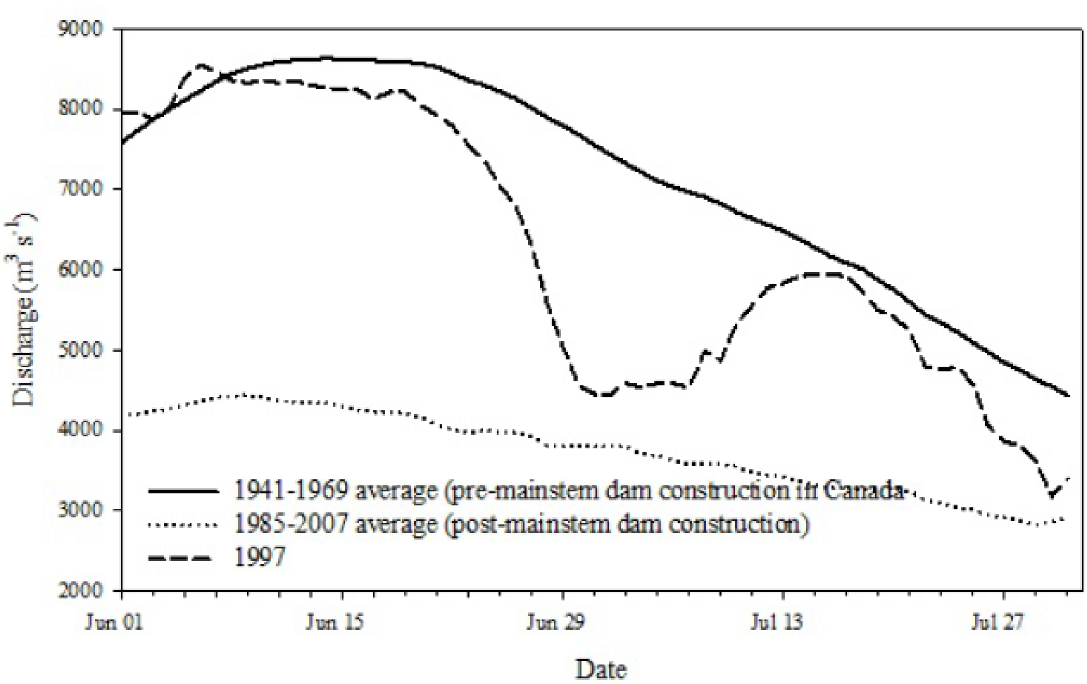


Figure 19: Comparisons of Columbia River discharge at the Canada-U.S. boundary pre- and post-mainstem dam construction in Canada, and in 1997 - a year when a detectable pulse of White Sturgeon recruitment occurred (from RESCAT 2012).

Hydro system operations also can result in weekly and daily flow fluctuations for power load but the effects of these peaking patterns on White Sturgeon are unclear. For peaking operations, discharge is generally increased during weekdays and daytime periods to meet increased power demands. In some years, peaking operations from Waneta Dam occur during the latter portion of the White Sturgeon spawning period and can affect flow conditions downstream in the Waneta spawning area at the Columbia-Pend d'Oreille rivers confluence (Figure 14). Spawning has occurred during periods of peaking at Waneta although egg deposition primarily occurs in areas of the confluence where flow velocities are determined by Columbia River flows (ASL et al. 2007; Golder 2011c). Although spawning in this area is not producing significant numbers of juvenile sturgeon, spawning in other areas of the Upper Columbia River that are not influenced directly by daily hydro-peaking operations (i.e., the Northport, China Bend, and the HLK/ALGS spawning areas) are also failing to produce substantive recruitment. Studies downstream of a lower Columbia River dam showed that peaking operations can result in scouring of White Sturgeon eggs and embryos from the riverbed (Counihan and Parsley 2001). However, successful spawning and recruitment of White Sturgeon has been observed downstream of lower Columbia River dams operated for peaking.

Negative effects of peaking operations on spawning Lake Sturgeon included increased time on the spawning grounds, reduced numbers of spawners, and decreased reproductive readiness (Auer 1996). Studies on Russian sturgeon have identified adverse changes in behaviour and maturation following highly fluctuating discharges during winter that required sturgeon to maintain an increased level of activity. Similar studies have not been conducted for White Sturgeon, but recent studies downstream from The Dalles Dam on the lower Columbia (Parsley et al. 2007) and below Waneta Dam in the Upper Columbia River (Golder 2005) showed that White Sturgeon position downstream of these dams were influenced by dam discharge.

The magnitude of the change in the river environment from the pre- to post-regulation flow regime and the known effects of flow on sturgeon recruitment, strongly suggest flow changes are a primary cause of recruitment failure. In the past 11 years, there have been 5 years when flows have exceeded the 5,660 cms (200,000 cfs) at the Canada-US boundary. This led the UCWSRI TWG to select this flow level as a reasonably attainable target flow that is within flood control considerations and may help stimulate natural sturgeon recruitment (Table 15). The flows in 2011 and 2012 have been exceptionally high and have approached the pre-regulated average flow at the Canada-U.S. boundary. The 2011 and 2112 flow volumes also were substantially higher for a greater length of time than that the 1997 flows, when a detectable recruitment pulse occurred. As such, they should provide a good test of the flow effects hypothesis. However, identification of recruitment success from the past two high flow years will likely not be identifiable for another two or three years, given the difficulties in sampling age-0 to age-2 juveniles in the Transboundary Reach.

Table 15: Summary of the last 11 years (2001 – 2012) where the Columbia River mean daily flow at the Canada/U.S. boundary exceeded 5,660 cms. Duration is presented as the total number of consecutive days that 5,660 cms was exceeded in each of the five years.

Year	Maximum (cms)	Duration (Days) >5,660 cms
2002	6,524	9
2006	6,435	11
2008	6,134	17
2011	7,560	50
2012	7,906	55

Hydro-operations in "normal" and "low" discharge years may inhibit the dispersal of early larvae to appropriate rearing habitats, which may be critical for recruitment. Kynard and Parker (2005) speculated that recruitment failure in White Sturgeon populations might be due to a habitat mis-match between the dispersal behavior and altered post-dispersal habitat. Disruption of the dispersal of Pallid Sturgeon (*Scaphirhyncus albus*) larvae has been implicated in that species' recruitment failure in the Missouri River system (Braaten et al. 2008). In a laboratory study, the dispersal of Kootenai River White Sturgeon early larvae was initiated earlier, of greater duration, and of greater intensity at higher velocities (0.169 m/s versus 0.234 m/s; Kynard et al. 2010). The bottom velocities at larval collection sites in the Roosevelt Reach during late July (period of larval dispersal) averaged 0.22 m/s in 2010 (discharge range = 1,921 to 3,329 cms) and 0.40 m/s in 2011 (discharge range = 4,003 to 4,543 cms; WDFW unpublished data). The flow year (peak discharge) was considered “normal” in 2010 and “high” in 2011. For comparison, the discharge during the same period (mid- to late-July) in 1997, when there was detectable recruitment, ranged from 4,587 to 5,947 cms. In “normal” and “low” discharge years, hydropower facilities have the ability to loadshape by mid-July, which results in reduced discharge, and velocities, at night when white sturgeon larval dispersal is greatest (Kynard et al. 2010; WDFW unpublished data). In addition, the larval capture site just upstream of China Bend is at the upper extent of the impoundment created by Grand Coulee Dam (river-reservoir transition zone) and Lake Roosevelt is at its full pool elevation in July, thus water velocities decline rapidly downstream from there (CH2M Hill 2006). So, when compared to the Kynard et al. (2010) study, velocities in the river-reservoir transition zone of the Roosevelt Reach in normal flow years may result in less intense, shorter duration, and delayed dispersal by early larvae that may result in a habitat mis-match, poor survival, and recruitment failure.

3.1.3 Water Temperature

Significant temperature changes have accompanied construction and operation of dams and reservoirs. In the Columbia River below Revelstoke Dam, water temperatures are similar in summer but warmer in fall and winter as compared to the pre-impoundment period (Figure 20). Downstream of HLK, average fall and winter temperatures are similar but temperatures from May through September are 2 to 3ºC warmer than occurred historically (McAdam 2001; Hamblin and McAdam 2003; Figure 20). Recent observations suggest that in the Keenleyside reach since 1990, winter temperatures are warmer and cold winter periods are briefer (Golder, unpubl. data.). Pend d’Oreille River temperatures currently rise faster and get much warmer (e.g. can reach 25ºC in some years) than in the Columbia River during the spawning season. Whether Pend d’Oreille temperature patterns are similar to historical conditions is unknown because pre-impoundment data are lacking. Lake Roosevelt provides a much wider range of temperatures and more complex thermal environment than historically occurred in the river it replaced.

Altered thermal environments can be expected to influence metabolic rates and population productivity of White Sturgeon. Effects of altered temperature patterns and their role in White Sturgeon population decline are poorly understood but are likely to be complex. Water temperature and seasonal patterns in water temperature affect sturgeon maturation, spawning, incubation, development, energy requirements, food production, growth rate, and survival rate. Changes in the timing of temperature-controlled processes could disrupt the synchrony between these and other processes affected by other environmental factors (McAdam 2001; Van Poorten and McAdam 2010).

Changes in water temperature due to river regulation are currently considered a less likely cause of recruitment failure than flow effects. In the Transboundary Reach, pre-versus post-regulation water temperature patterns have not exhibited the same magnitude of change as flow (Figure 20). Water temperature can vary from year to year, so suitable temperature conditions to support recruitment should have been present in some years since recruitment failure occurred in the early 1970s.

Water temperatures in the ALR Reach may have a greater effect on recruitment success and sturgeon recovery efforts in that area since available water temperature data indicate relatively cold water temperatures occurred during the sturgeon spawning, egg incubation, and early larval rearing period both pre-and post-regulation

(Figure 20). Recent studies on the effects low temperatures on White Sturgeon eggs and larvae indicate that egg incubation and larval development periods are substantially prolonged in comparison to development at more elevated temperatures at spawning areas further downstream (Parsley et al. 2011). This factor, combined with the later than normal spawn timing of White Sturgeon in the ALR Reach, results in reduced opportunity for young fish to grow sufficiently to enter the winter period at a size sufficient for survival.

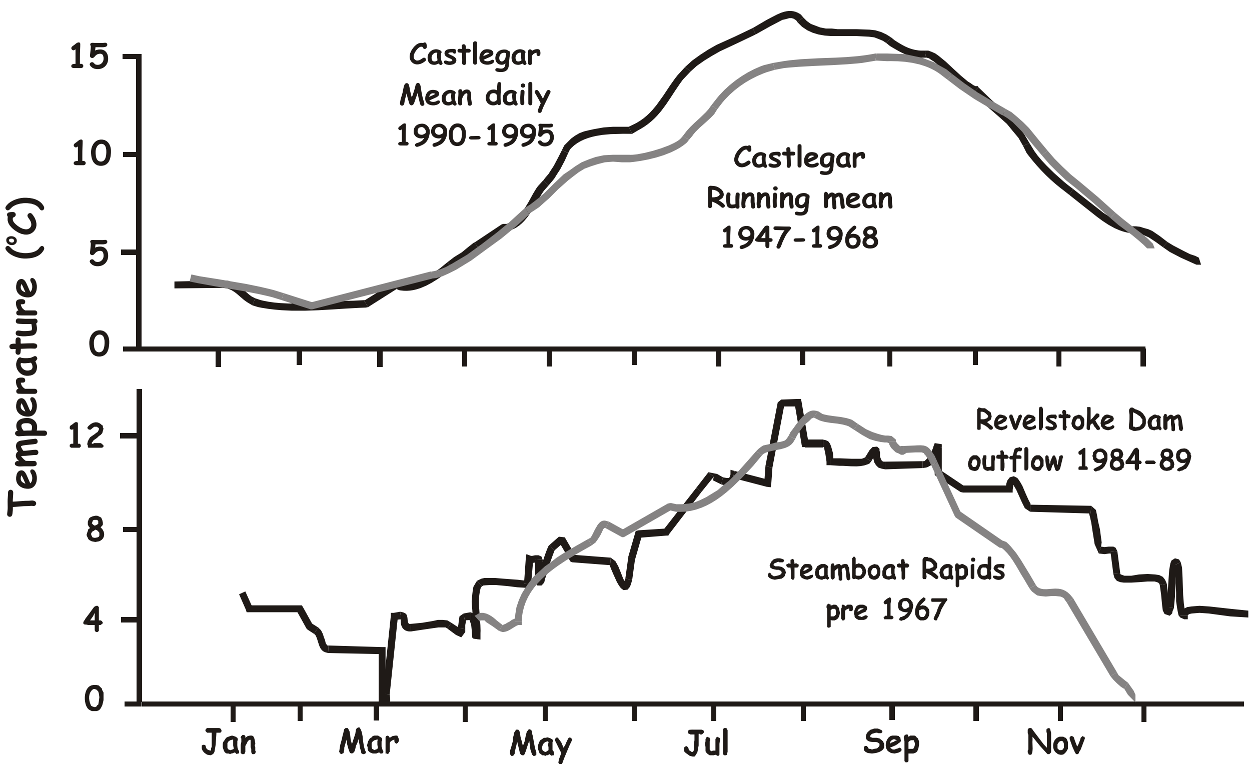


Figure 20: Changes in average Columbia River water temperature in the Keenleyside Reach (top) and in the Arrow Lakes Reservoir Reach (bottom; McAdam 2001).

Although water temperatures are not likely the primary cause of recruitment failure, at least in the Transboundary Reach, changes to the natural temperature regime has occurred post-regulation and these may be further exacerbated by climate change effects. This may result in future temperature changes that may have affect sturgeon recovery.

3.1.4 Water Clarity

Although information on pre-development levels of turbidity in the Transboundary Reach is limited, the construction of several upstream mainstem and tributary reservoirs has created large settling basins that undoubtedly have reduced downstream sediment transport and historical levels of river turbidity in this reach. These changes in turbidity may have significant implications for sturgeon. For instance, predation has likely increased with water clarity, especially during the larval dispersal and first few months of life. Laboratory studies by Gadomski and Parsley (2005a) documented higher predation rates by Prickly Sculpin (*Cottus asper*) on White Sturgeon yolk-sac larvae (1 to 2 wk. old) at low turbidities (30 and 23 larvae per trial at 0 and 20 NTU) than at high turbidities (18 larvae per trial at 60 and 180 NTU). The highest level of turbidity tested were not likely typically present in the Transboundary Reach, although present day turbidity levels in the Columbia River headwaters near Golden, BC averaged 126 NTU during the spawning period (Westslope and CCRIFC 2012).

Turbidities associated with successful White Sturgeon spawning and recruitment were 6 to 92 NTU in the lower Fraser River (Perrin et al. 2000) and 2.2 to 11.5 NTU in the lower Columbia River (McCabe and Tracy, 1993.) In the past four decades, turbidity in the Columbia River near Birchbank, BC and at Northport, WA, has generally been below 2 NTU year round (Figure 21). Data prior to 1968 is limited and sporadic but suggests that historical turbidity may not have been substantially higher at this location (McAdam 2012). The Pend d'Oreille River is typically more turbid than the Columbia River and during the June-July period, typically ranges from 1 to 4 NTUs; in the high flow year of 1997, 11 NTU was recorded on 4 June although this had declined to about 2 NTU when next sampled on 9 July (Golder 2006c). The higher turbidity levels at Northport (Figure 21) likely reflect greater suspended sediment inputs from the Pend d'Oreille River.

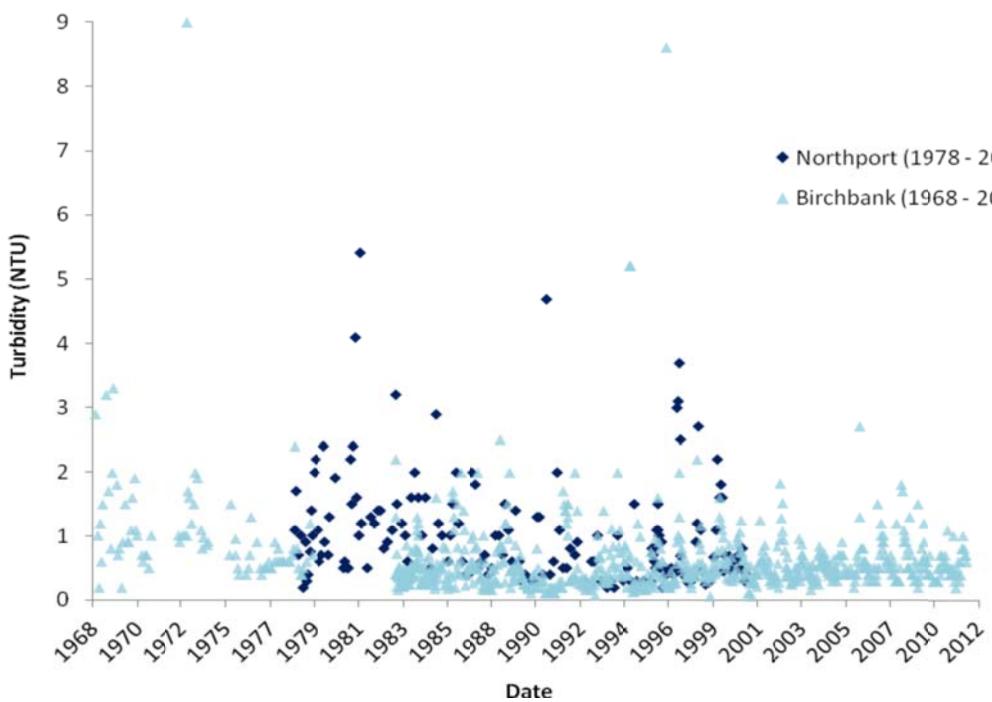


Figure 21: Historical turbidity spot measurements recorded in the Columbia River at Birchbank, BC (August 1968 to April 1979 data from Teck Metals Ltd.; May 1983 to August 2011 data from Environment Canada BC08NE0005;) and at Northport, WA (May 1978 to September 2000 data from USGS Station: 12400520). Adapted from AMEC (2012).

The range of visibility changes that results from slight differences in turbidity are sufficient to potentially account for very large changes in recruitment success, assuming the mortality rates for juvenile or larval sturgeon are proportional to the decrease in turbidity related visibility (Figure 22). When the June 1997 turbidity value is compared with all other years, the potential effect of turbidity on distance, area, and volume parameters is substantial.

Sturgeon larvae are likely dispersed over a broader area during periods of higher discharge. Benefits of this increased dispersion in terms of protection from predation may be reduced by the high fecundity of sturgeon and the relatively synchronous hatch of the large numbers of eggs deposited during each discrete spawning event. This would result in a "pulse" of larvae drifting downstream. This is supported by literature reports of aggregated lake sturgeon larvae during downstream dispersion (Auer and Baker 2002). This mass hatching may be a predator avoidance mechanism that may be highly successful where the probability of a predator locating a relatively high concentration of drifting larval sturgeon is low, but may substantially increase vulnerability during periods of high visibility.

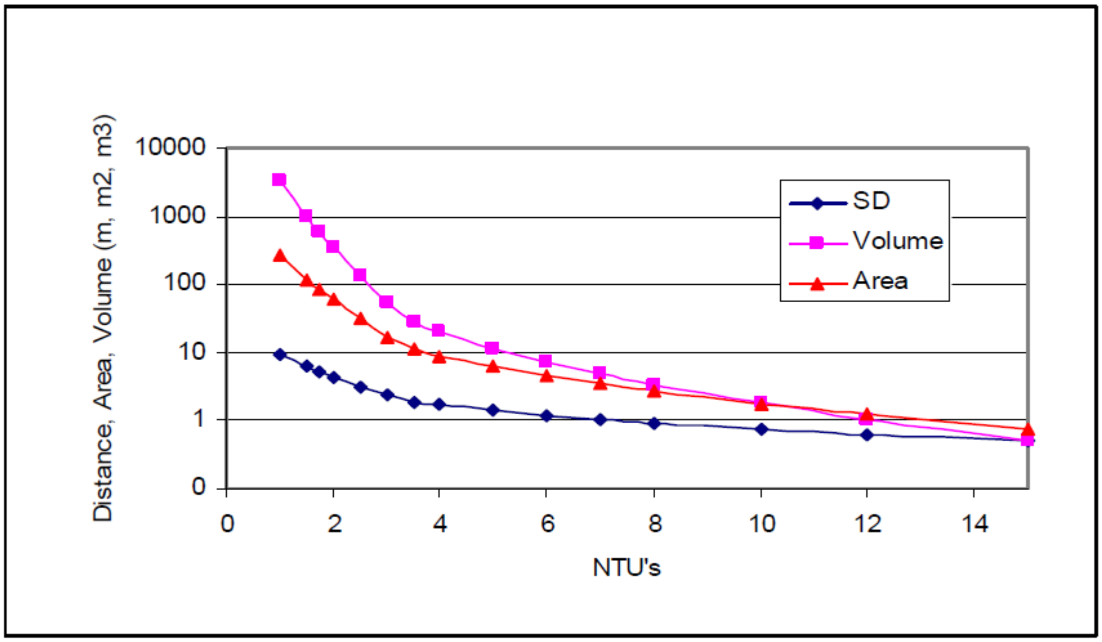


Figure 22: The relationship of NTUs to Secchi disk distance (SD), the volume of a sphere (radius=SD), and the area of a circle (radius=SD). This illustrates the potential effect of turbidity on the vulnerability (expressed as area or volume) of a young sturgeon being observed by a visual predator (from Golder 2006c).

If flow dispersion is a factor in reducing predation, the effect is likely a linear function of increased volume (discounting turbidity impacts), with the average distance between larvae increasing linearly with volume increases. The linear response in larvae distribution related to increased flows suggests that that this mechanism alone is unlikely to account for the near-absence of sturgeon recruitment that has occurred since flow regulation.

3.1.5 Total Dissolved Gases

Dam construction and operation has increased dissolved gas supersaturation levels downstream from several facilities including Mica, Revelstoke, HLK, Waneta, and Brilliant. Supersaturation occurs when plunging water entrains air which is dissolved into the water at depth. Dissolved gas levels are referred to as total dissolved gas (TDG) in the U.S. and total gas pressure (TGP) in Canada. During spring spills in the past, TGP levels in the Columbia, Kootenay, and Pend d'Oreille rivers have often exceed the BC guideline of 110% with levels up to 144% saturation reported below HLK (Clark 1977). TGP levels in excess of 135% have been observed below Waneta Dam primarily during spill periods from May through June (RL&L unpubl. data). Levels exceeding 125% can occur downstream of Brilliant Dam on the Kootenay River (RL&L unpubl. data).

High TGP levels cause gas bubble trauma (GBT) that involves the growth of gas bubbles internal or external to the animal (Weitkamp and Katz 1980; Fickiesen and Montgomery 1978; Ebel at al. 1975; Ash et al. 1981;

Fidler 1988). GBT occurs when fish exposed to high dissolved gas levels at depth move into shallower water where hydrostatic pressure is low and will not compensate for excess TGP.

Lower turbidities combined with reduced flows increase the effective search volume for predators hunting larval sturgeon. Consequently, changes to these parameters may have contributed to White Sturgeon recruitment failure in the past and have the potential to limit future natural recovery efforts.

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

White Sturgeon are most likely to be affected by GBT during the dispersal stage when larvae begin exogenous feeding and drift at variable depths in the water column (Shrimpton et al. 1993). Effects may include direct mortality, altered dispersal patterns, and increased susceptibility to predation. TGP levels exceed thresholds for gas bubble trauma for significant periods of time through the sturgeon spawning, incubation, and dispersion period. Both Brilliant and Waneta dams typically spill during the June to July period when dispersal occurs and spill can also occur at HLK.

In the past two decades, overall TGP levels in the Transboundary Reach have decreased due to powerplant upgrades at Brilliant and Waneta dams, the construction of expansion plants at Brilliant Dam and HLK, and modifications to spill procedures that reduce TGP production. The new generation capacity has allowed more water to be diverted through the powerplant turbines, which typically do not produce elevated TGP levels. Further reductions will be achieved in the near future with the completion of the Waneta Expansion plant at Waneta Dam. Despite these operational measures and increased generation capacity, elevated levels can still occur in the Upper Columbia River between June and September in high flow years.

The effects of TGP on White Sturgeon are expected to be low due to the general selection of all life stages for deeper water habitats. As such, TGP is not presently suspected as a primary cause of past recruitment failure and should not be a major impediment to future White Sturgeon recovery efforts. TGP remains a general concern, however, because of known harmful effects on other fish species and limited information on effects of larval sturgeon in the wild.

3.2 Contaminants

Exposure to contaminants may also cause reduced survival of early life stage White Sturgeon either directly or indirectly by affecting behavior. According to the UCWSRI (2002):

> *There are several sources of contaminants to the Upper Columbia River watershed in British Columbia and the United States, including Cominco Ltd. at Trail, BC, Celgar Pulp Company at Castlegar, BC, municipal sewage treatment plants, abandoned mines, and tailing dumps. Many of these sources have made substantial effort to establish cleaner operating procedures within the last 25 years; however, a great deal of contaminant input occurred prior to these upgrades and potential effects to sturgeon are unknown.*

Cominco has been operating since 1906 (MacDonald Environmental Sciences Ltd. 1997). However, over the past 25 years, the industry has initiated a long-term program to modernize and expand its operations at the Trail plant. Some of the major improvements include an effluent treatment plant, zinc electrolyte stripper, mercury removal plant, drainage control system, heat exchanger, elimination of phosphate-based fertilizer plant, and a slag containment facility. These modernization projects have significantly reduced loading of metals to the Columbia River. Accidental discharges currently comprise the majority of contaminant inputs. Between January 1987 and January 1993, there were a total of 56 spills from Cominco Ltd., into the Upper Columbia River. These spills released multiple tons of compounds containing sulphuric and phosphoric acid, zinc (various forms), gypsum, mercury, copper sulphate, ammonia, coal dust, furnace and compressor oils, sodium bisulphite, phosphate, ammonium sulphate, arsenic, cadmium oxide, chlorine, lead, slag, oxide dust, and various undetermined solutions.

Exposure to contaminants has been suggested to cause direct mortality of sturgeon larvae. Kruse and Scarnecchia (2002) suspected contaminant (copper and the PCB Aroclor 1260) exposure led to decreased survival of White Sturgeon eggs. Sand-sized water-granulated fumed slag released from the Cominco Ltd. (now Teck Metals Ltd.) lead and zinc smelter in Trail, British Columbia is distributed throughout the Roosevelt Reach, but primarily in the upper portion with a major depositional area at Marcus (CH2M Hill 2006). Slag contains elevated levels of several trace elements, such as arsenic, cadmium, copper, lead, and zinc (Majewski et al. 2003). Preliminary acute toxicity studies with larval (30 dph) White Sturgeon indicated LD50's at much lower concentrations of copper (3.1 to 4.9 µg/L) than similar aged rainbow trout (USFWS 2008). However, Vardy et al. (2011) reported that chronic concentrations (LC20) for White Sturgeon larvae (up to 66 dph) exposed to copper (5.5 µg/L), zinc (112 µg/L), and cadmium (1.5 µg/L) were similar to other sensitive salmonids. Smelter effluent (collected under atypical conditions) which contained lead (mean = 21.6 ug/L at 100%), zinc (mean = 166 ug/L at 100%), copper (mean = 2.5 ug/L at 100%), and cadmium (mean = 2.55 ug/L at 100%) was lethal to White Sturgeon larvae (11-14 and 32 to 35 dph) at high effluent concentrations of 100% and 50%, but in low concentrations (1%) mortality did not differ significantly from controls (Bruno 2004). There is likely no direct mortality from exposure to metals given the rapid dilution of effluent by several orders of magnitude in the Columbia River. The annual capture of relatively large numbers of free embryos and early larvae suggest that acute toxicity is not the root cause of recruitment failure. Contaminant exposure may result in sublethal effects that reduce survival of sturgeon during early life stages.

Exposure to elevated levels of copper from slag deposited throughout the upper Roosevelt Reach may impair the sensory function and behavior of larval White Sturgeon. Exposure to copper has been shown to impair the olfactory system of salmonids (Baldwin et al. 2003; Sandahl et al. 2007) and damaged peripheral mechanosensory (lateral line) cells of larval zebrafish (*Danio rerio;* Linbo et al. 2006). Similar to other fishes, larval White Sturgeon exposed to copper may have impaired sensory function that would inhibit their ability to locate food that could result in increased searching behavior or reduced growth and condition, both causing increased predation risk. Contaminant exposure may also alter a sturgeon's ability to detect or respond to predation risk. Coho salmon exposed to copper (>2.0 µg/L) did not initiate "predator avoidance behaviors" (Sandahl et al. 2007). The data suggest recruitment of sturgeon in the Transboundary Reach may be dependent on larvae being dispersed to nursery habitats downstream of the primary slag depositional zone (Marcus). The USGS initiated studies in 2012 to evaluate the effects of copper and zinc exposure on swimming performance (stamina) and predator avoidance of White Sturgeon larvae (C. Ingersoll, USGS, pers. comm.). These studies will address some of the questions regarding the role of contaminant exposure in recruitment failure, but additional investigations of sensory impairment are needed.

Heavy metal contamination in the upper Roosevelt Reach may also reduce the variety and abundance of food available to first feeding White Sturgeon larvae. Heavy metal contamination (copper and zinc) can negatively impact benthic macroinvertebrate diversity and abundance (Clements 2004). White sturgeon larvae in the lower Columbia River fed on amphipods (Corophium spp.), but also Copepods, Diptera, and Ceratopogonidae larva (Muir et al. 2000). As previously noted, investigations of macroinvertebrate food sources (abundance and diversity) available to first feeding are ongoing; however, there is a lack of data regarding the relationships between substrate composition, slag distribution, macroinvertebrate abundance, distribution, diversity and larval and subyearling juvenile sturgeon distribution and habitat use.

Concern has also been raised about the physical effects of slag on White Sturgeon free embryos and larvae. Slag particles are glass-like and very angular (CH2M Hill 2006) suggesting that contact with slag could result in physical trauma to sturgeon early life stages. Evidence of early larvae incidentally ingesting slag particles (attached to prey) has been confirmed through the examination of the gut contents of the D-ring plankton net catch (Howell and McLellan 2011; Plate 3), although whether slag ingestion results in physical trauma or reduced survival of sturgeon larvae is unknown.

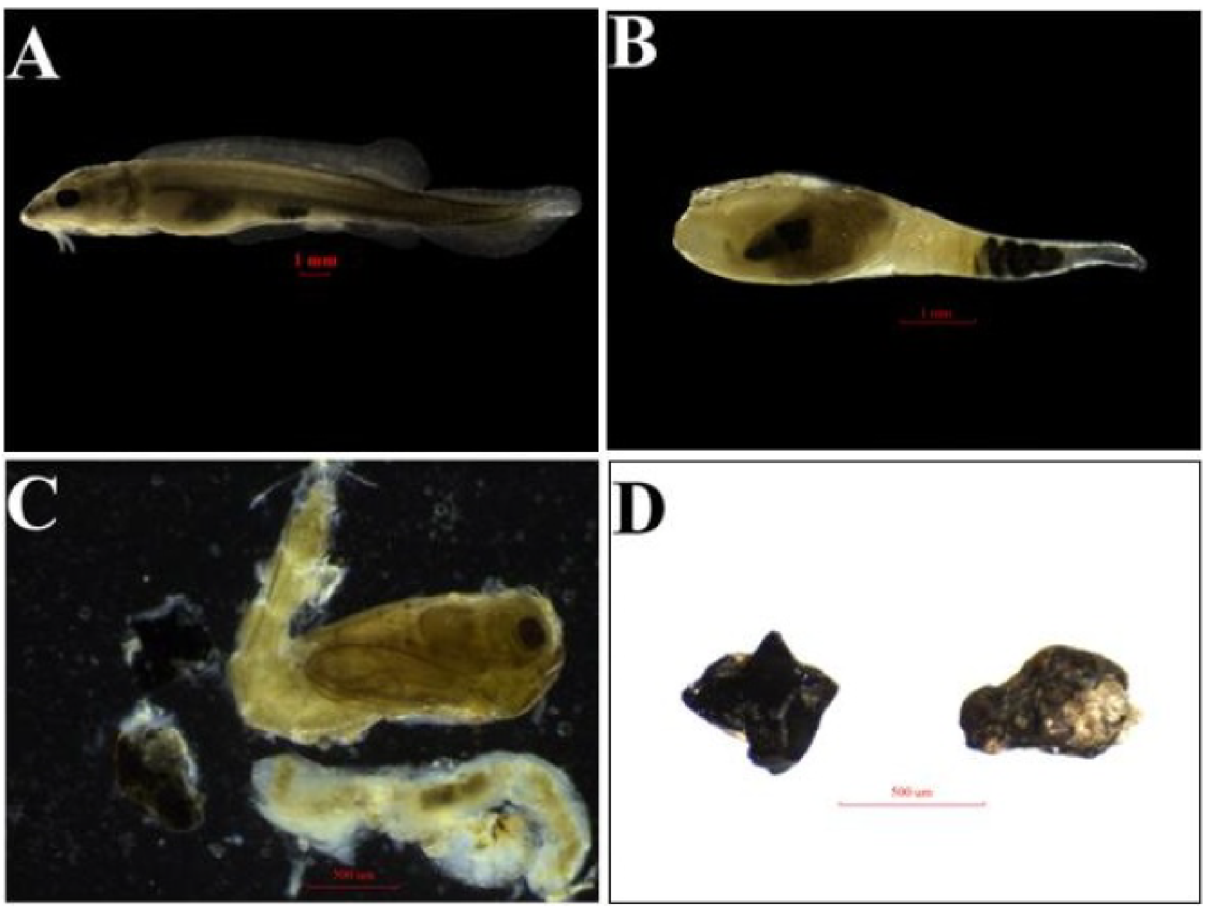


Plate 3: Granulated industrial slag particle found in the gut of a larval White Sturgeon. A) Stage 45 individual (19.9 mm TL) captured in a benthic plankton net. B) Left-lateral view of excised digestive tract; prey items and slag/sand grains can be clearly seen. C) Prey items and slag/sand grains removed from stomach. D) Detail of the slag (left) and sand (right) grains. (From Howell and McLellan, in review).

Juvenile sturgeon in the Upper Columbia River also ingested slag particles. Parsley et al. (2010) examined the gut contents of 37 hatchery origin juvenile White Sturgeon captured in upper Lake Roosevelt that had been at large for 1 to 4 growing seasons and 78% contained slag particles. Histological examination of the digestive tracts indicated significantly greater chronic inflammation relative to controls (fish reared without exposure to ingestible substrate). It is unknown if the inflammatory response would occur in sturgeons ingesting inert sand-sized substrate or if it results in reduced survival, growth, or condition. The relatively high survival, growth, and condition of hatchery sturgeon on the Transboundary Reach suggest that it does not.

The effects of contaminants on older life stages are unknown at this time. White Sturgeon are long lived, and thus they have greater risk of negative effects due to contaminants as a result of bioaccumulation (Beamesderfer et al. 1995). Exposure to some contaminants has been suggested to reduce reproductive potential of White Sturgeon (Feist et al. 2005). Kruse and Webb (2006) indicated that copper can bioaccumulate in the eggs of Upper Columbia River White Sturgeon. As discussed above, copper can have both acute and potentially sublethal effects on White Sturgeon early life stages that may result in low survival. Hatchery sturgeons from the Roosevelt Reach were provided to the USFWS in 2008 and 2009 for an analysis of contaminant burden; however, ongoing litigation has prevented public release of the results. Additional work is needed to determine the patterns and rates of contaminant bioaccumulation by sturgeon in the Transboundary Reach. Hatchery sturgeon of known age and origin provide an opportunity to monitor contaminant bioaccumulation and the effects on growth, condition, and reproduction (i.e. fecundity, egg size).

The availability of suitable substrate for the hiding phase of development has been implicated as a potential factor limiting recruitment of White Sturgeon in the Roosevelt Reach. Fine substrates, including slag, may have filled interstitial spaces and reduced hiding habitat for sturgeon free embryos. Brannon et al. (1985) noted that substrate composition may influence the settling response of free embryos such that coarser substrates provide more suitable cover for the hiding phase than fines. McAdam (2011) found that in a laboratory study, free embryos hid immediately when provided coarse substrate, whereas over sand they entered the drift, which suggested that free embryo drift was indicative of poor hiding habitat. Gravel was identified as the preferred hiding habitat of White Sturgeon free embryos (Bennett et al. 2007). However, the lower capture rate of free embryos, the short drift distance, and captures of substantial numbers of early larvae suggest that substrate conditions used for the hiding phase in Roosevelt are suitable for substantial free embryo survival. A comprehensive sediment facies map has not been completed for the upper Roosevelt Reach, so it is impossible to say how much coarse (gravel or cobble) substrate is available.

A summary of contaminants in the Upper Columbia River and their potential impact to White Sturgeon health was recently completed by the UCWSRI (AMEC 2012). Research to date does not indicate that any of the known contaminants in the Upper Columbia River recovery area have directly or indirectly caused White Sturgeon recruitment failure (see also McAdam 2012). Recruitment occurred in the 1940s to mid-1960s when contaminant loadings from the Cominco smelter were at peak levels. Metal loadings to the Columbia River from Cominco were reduced starting in 1981 and had ceased by 1997 (Duncan 2008). The Celgar pulpmill commenced operations in 1961 just prior to the onset of recruitment failure in the early 1970s and released approximately 14,000 kg/day of organic solids with attached hydrophobic organochlorine contaminants. Modernization of the Celgar pulp mill between 1989 and 1991 significantly reduced contaminant inputs from that source as well (Duncan 2008). The lack of a discernable sustained increase in recruitment coincidental with these reductions in contaminant loads does not support a direct link between contaminants and recruitment failure. Contaminant inputs into the Upper Columbia River are presently regulated by Federal, Provincial, and State agencies and adherence to these regulatory guidelines is assumed to be sufficient to protect existing White Sturgeon and should not impede future recovery efforts.

3.3 Availability of Food Resources

Historical nutrient inputs into the Upper Columbia River system have been reduced by the combined effects of elimination of anadromous fish runs, reservoir construction upstream, and reduced effluent discharges. Prior to the construction of Grand Coulee Dam, anadromous fish runs were likely a significant source of marine derived nitrogen, phosphorus, and trace elements in addition to a direct food source for White Sturgeon. Upstream reservoirs act as nutrient sinks and reduce downstream transport of nutrients from the upper basin. Matzinger et al. (2007) found that hydraulic modifications due to HLK reduced ALR productivity by up to 40%. This productivity loss was comparable to the reduction caused by nutrient retention behind Mica and Roosevelt dams upstream of ALR and the combined productivity loss from these reservoirs might well be responsible for the dramatic decline of Kokanee (*Oncorhynchus nerka*) the ALR in the 1990s. Historical effluent discharges from the Cominco fertilizer plant at Trail, BC artificially increased nutrient levels in the Transboundary Reach. Since the cessation of the phosphate rich discharge in 1994, the growth of periphyton and macrophytes in the Columbia River downstream of Trail has decreased dramatically (Golder 2007). Municipal and industrial sources of nutrients also have been substantially reduced by widespread construction of sewage treatment plants that provide primary and secondary treatment.

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

Reservoir fertilization programs were initiated in Kootenay Lake in 1992 and in ALR in 1999 and have been conducted annually since (Schindler et al. 2006; Schindler et al. 2009). These programs have resulted in increased productivity within these waterbodies in the form of increased Daphnia biomass and pelagic Kokanee numbers size and biomass. These increases were considered indicative of successful trophic level responses to nutrient additions. Increased abundance of Kokanee and other fish species may result in direct benefits to White Sturgeon in the ALR Reach and indirect benefits to sturgeon in the Transboundary Reach through increased entrainment of fish.

Other changes in the productivity of the Upper Columbia River also have occurred post-regulation. *Mysis relicta* were introduced into ALR in 1968 as a means to increase food for kokanee (Pieters et al. 2003), Although this objective was not achieved (mysids in ALR were direct competitors with Kokanee for food resources) their abundance in ALR results in substantial numbers being entrained through HLK into the Transboundary Reach where they serve as an important component of the diet of many fish species, including White Sturgeon (see Section 2.6). Increased flow stability and water clarity in the Transboundary Reach also have resulted in greater light penetration that has increased the photic zone of the river and produced a very abundant invertebrate population that supports a productive fishery. In addition, since 1990, there has been a substantial increase in the abundance of mainstem spawning Rainbow Trout and in recent years there has been a steady increase in the numbers of adult White Sturgeon observed on the rainbow trout spawning grounds, undoubtedly feeding on spawners and spawned eggs (BC Hydro, unpublished data). Adult White Sturgeon also prey upon the abundant Mountain Whitefish population as indicated by the recovery of a dead White Sturgeon with several fresh Mountain Whitefish spawners in its stomach (Golder, unpublished data).

Recent studies have focussed on the availability of food for larval sturgeon at the onset of exogenous feeding, with the premise that lack of suitable food at critical times could result in decreased larval or early juvenile survival. Capture of larvae downstream from the Northport and China Bend spawning areas and examination of the diet by WDFW has verified that larvae are feeding (Howell and McLellan *in review*).

Prey availability and distribution for early feeding larvae and juveniles has not been addressed. An investigation of the availability of potential prey for larval White Sturgeon in the transitional area between the Marcus Flats area and the Little Dalles was initiated by the Spokane Tribe of Indians in 2007 and samples are currently undergoing analysis. Studies initiated in 2012 in the Keenleyside Reach sampled the river for available food items and examined the diet of age-1+ juveniles; preliminary findings indicated a high proportion of stomachs were full and contained a wide variety of food items (BC Hydro, unpublished data).

Although nutrient transport and productivity in the Upper Columbia River have undoubtedly been impacted by river regulation, these changes are not considered as a primary reason for White Sturgeon recruitment failure in the Transboundary Reach. This conclusion is supported by documented feeding by larval stages, reasonable growth rates of juveniles and adults, and the apparent availability of suitable food resources for these life stages. For sturgeon in ALR, the effects of reduced productivity may be more significant, particularly when combined with cold water temperatures and a fluctuating reservoir environment.

3.4 Changes in Fish Species Composition and Predation

The current fish assemblage in the Upper Columbia River is a result of anthropogenic actions that have created an unbalanced, ever-shifting, hybrid lotic/lentic ecosystem. In the Transboundary Reach, substantial changes in the relative composition of fish species have accompanied dam development and the introduction of exotic species in the Upper Columbia River. The pre-development fish community included anadromous salmon (*Onchorhynchus* spp.) and a resident sport fish community was dominated by Mountain Whitefish (*Prosopium williamsoni*), Rainbow Trout (*O. mykiss*), Bull Trout (*Salvelinus confluentus*), and Burbot (*Lota lota*). The primary post-regulation changes have been the elimination of anadromous species, and an increase in introduced species. Walleye were first introduced into the Upper Columbia River in the 1960s and by the early 1990s, had become the third most abundant sport fish in the Transboundary Reach (Hildebrand and English 1991). In the past two decades, abundance of Smallmouth Bass (*Micropterus dolomieu*), Largemouth Bass (*M. salmoides*), and Yellow Perch, Black Crappie, and Pumpkinseed (many originating from the Pend d'Oreille River system), have increased steadily in abundance the Transboundary Reach. In 2009, Northern Pike (*Esox lucius*) were first documented in the Keenleyside Reach and have steadily increased since that time (Ford and Thorley 2012). Early life stages of White Sturgeon are very vulnerable to predation by native and non-native fish. Three laboratory studies conducted by the U.S. Geological Survey examined several facets of predation on young White Sturgeon. White Sturgeon from newly hatched larvae to about 170 mm TL were exposed to predatory fishes they might encounter in the natural environment (Gadomski and Parsley 2005b). Channel Catfish (*Ictalurus punctatus)* and Northern Pikeminnow (*Ptychocheilus oregonensis*) ate White Sturgeon up to mean sizes of 121 and 134 mm TL, respectively and juvenile Walleye ate White Sturgeon up to 59 mm TL. Prickly Sculpin (*Cottus asper*) ate White Sturgeon up to a mean TL of 50 mm. Additional studies only with Prickly Sculpin investigated predation at various turbidity levels and in the presence of cover. Gadomski and Parsley (2005a) found that significantly more White Sturgeon yolk sac larvae were eaten at lower turbidity levels. Significantly fewer White Sturgeon were eaten during trials that combined the lowest light level, cover, and the smallest larvae. McAdam (2011) found that substrates influenced predation on 1 day post hatch larvae in a laboratory experiment that also examined predation by Prickly Sculpin. A third laboratory study by Gadomski and Parsley (2005c) confirmed high rates of predation on young White Sturgeon by pikeminnow and prickly sculpin even when alternative prey was available. The studies collectively demonstrated that predation is a likely cause of mortality of age-0 White Sturgeon and may be contributing to recruitment failure.

Early sturgeon larvae actively searching for food could potentially experience an increased vulnerability to predation. Early life stages of White Sturgeon are subject to predation by other fishes (Miller and Beckman 1993;

Gadomski and Parsley 2005a, 2005b). However, predator diet studies to date do not suggest large numbers of White Sturgeon larvae or juveniles are consumed. Stomach samples (n = 520) from 13 species of potential predators collected in the upper Roosevelt Reach during the sturgeon spawning and larval dispersal period did not contain any White Sturgeon young (Howell and McLellan 2007a, 2007b). Examination of 165 stomachs from 11 species of potential egg predators captured in the Waneta spawning area during a period when incubating sturgeon eggs were known to be present, recorded four sturgeon eggs from two Largescale Sucker (Golder 2006d).Similarly, predator diet studies in lower Columbia River reservoirs have only identified one instance of predation on juvenile sturgeon (Gadomski and Parsley 2005a). However, these results do not definitively rule out predation as a limiting factor since electrofishing was the method used to capture potential predators. Electrofishing collects only fish distributed in near shore shallow habitats, while current data indicates most sturgeon larvae are located in deep, mid-channel habitats. Further, lab studies indicate larval sturgeon are digested more rapidly by predators than similar sized salmonids thereby limiting the likelihood of identifying them in diet sampling (Garner 2006).

The abundance of potential predators is relatively high in the upper Roosevelt Reach during the times when early life stages of sturgeon are present (Beckman et al. 1985; Hall et al.1985; Peone et al. 1990; Griffith and Scholz 1991; McLellan et al. 2002). Among those predators suspected to pose the greatest risk are Walleye and Sculpins. Walleye are one of the most abundant species of fish in the Roosevelt Reach (Peone et al. 1990; Griffith and Scholz 1991; Underwood and Shields 1996; Lee et al. 2006) and their proliferation corresponds with sturgeon recruitment failure (Nielsen 1975). In addition, the decline of numerous other native species populations in the Roosevelt Reach corresponds with the expansion of the Walleye population (Scholz et al. 1986). Consumption of age-0 sturgeon by Walleye has been demonstrated in the laboratory, and sturgeon of this age appeared to be preferred over both Rainbow Trout and Kokanee while age-1 sturgeon were not consumed (Garner 2006). In the Keenleyside Reach, three recently released 10-month-old juvenile sturgeon were recovered from the stomach of a large Walleye (L. Hildebrand, Golder, pers. comm.).

In 2008 an acoustic telemetry study of Walleye behavior was conducted to explore the spatio-temporal overlap between Walleye and early post-hatch life stages of White Sturgeon in the upper Roosevelt Reach (Howell and McLellan, *in review*). Walleye exhibited diel depth migrations occupying deeper water habitat during the day and shallower water at night. Night time depths were typically shallower than 15 m whereas in the same area, White Sturgeon larvae were most often captured in the main channel (>20 m) near the bottom and were more active at night (Howell and McLellan, *in review*). Since Walleye are bentho-pelagic by nature, this implies that while they seek depth during the day, they may remain in areas peripheral to the main channel, thereby potentially limiting interactions with sturgeon larvae.

Sculpin are abundant in the Keenleyside Reach (Ford and Thorley 2012) and the upper Roosevelt Reach (Howell and McLellan 2007b). A Mottled Sculpin (75 mm TL) captured in a plankton net set during the 2010 larval collection effort had consumed 13 sturgeon larvae (WDFW, unpublished data). Further, in November 2011, a subyearling sturgeon (~10 cm FL) was collected from the gut of a Walleye (31.5 cm TL; Plate 4; WDFW, unpublished data). Thus, predation on sturgeon early life stages does occur in the Transboundary Reach.

The ALR Reach fish community assemblage consists mainly of native species that include Rainbow Trout, Bull Trout, Mountain Whitefish, Burbot, Longnose Sucker (*Catosotomus catostomus*), Largescale Sucker *(C. macrocheilus*), Redside Shiner (*Richardsonius balteatus*), Peamouth (*Mylocheilus caurinus*), Northern Pikeminnow, and Prickly Sculpin (*Cottus asper*). Since impoundment there has been a trend towards increased abundance of Kokanee (stocked in the reservoir) and Bull Trout, with a corresponding decline in the abundance of Mountain Whitefish and Rainbow Trout. Longnose Sucker and Peamouth numbers increased dramatically from 1985 to 1995. Walleye have not been documented in the ALR Reach but low numbers of Yellow Perch

(*Perca flavescens*) have been recorded in the upper section (Ford and Thorley 2012). The predominant sportfish species in Revelstoke and Kinbasket reservoirs are Kokanee (introduced) and native Rainbow Trout, Bull Trout, and Mountain Whitefish.

Plate 4: A wild sub-yearling White Sturgeon (~10 cm FL) found in the gut of a Walleye (31.5 cm TL) captured in the Roosevelt Reach near China Bend on 4 November 2011 (from RESCAT 2012).

Changes in the level of predation on early life stages are very likely to be part of the mechanism of recruitment failure; however, it is challenging to differentiate whether such changes reflect increased vulnerability of the sturgeon prey or increased effectiveness of predators. Additionally, identifying whether such changes result from an altered fish species composition or the introduction of exotic predators is also challenging since early life stages are likely consumed by both resident and exotic species. The increase in Walleye in the Transboundary Reach roughly coincides with the recruitment failure timeline, although whether this is related to increased abundance of this species or increased predation by all potential predators due to changes in flow volumes, water clarity, and substrate alterations, is unknown.

3.5 Exploitation & incidental catch

As with other sturgeon species, White Sturgeon are vulnerable to overfishing because of their delayed age of maturation (15 years or greater) and longevity (up to 100 years) (Beamesderfer and Farr 1997). Only very low exploitation rates of 5% to 10% can be supported by productive sturgeon populations and unproductive populations cannot sustain any harvest (Rieman and Beamesderfer 1990). However, overharvest would be expected to produce a slow decline in recruitment, relative to the relatively rapid recruitment decline that has been detected in the Upper Columbia River (McAdam 2012). Although population declines due to overfishing might eventually decrease recruitment via mechanisms such as Allee effects, at current population levels such a mechanism is considered unlikely based both on theoretical evaluations (white sturgeon - Jager et al. 2010; lake sturgeon - Schueller and Hayes 2011) and the presence of sustained recruitment in even smaller populations (e.g. the upper Fraser River; Yarmish and Toth 2002).

Historically, White Sturgeon were used by native peoples although catches were probably low. Anecdotal information suggests that harvest of sturgeon in the Upper Columbia River basin remained low through the 1950s (Prince 2001). Catches of sturgeon during this period were noteworthy events, with accounts periodically published in local newspapers. Beginning in the late 1980s, several guiding outfits commenced operations on the Columbia River with sturgeon being a target species. Accurate annual harvest data are unavailable for Upper Columbia River sturgeon. Reported harvests between Lake Roosevelt and the Canada-U.S. boundary averaged 60 White Sturgeon per year from 1988 to 1995 (B. James, WDFW, unpublished data). Catch and harvest data for the Keenleyside Reach are limited to one survey in 1992 when an estimated 204 White Sturgeon were caught, of which 43 were harvested (ARA 1992).

Since 1996, harvest fisheries for White Sturgeon have been eliminated through protective regulations in both Canadian and U.S. portions of the Upper Columbia River recovery area. There is still a low degree of incidental catch of adult White Sturgeon and a high degree for juveniles in the Transboundary Reach. Dead individuals have been recovered with signs of hook injuries that may have been the cause of death. Anecdotal reports of anglers capturing juveniles are common. In 2012, the Angler Education and Information Sharing for Sturgeon Recovery Project interviewed almost 500 anglers in the Keenleyside Reach (G. Nellestijn, UCWSRI CWG Chair, pers. comm.). These anglers hooked and released 265 White Sturgeon over the 2010 to 2012 period, with most of the incidental sturgeon catch being reported by anglers that fished for walleye using bait.

At present, there is no data available to determine the effect of incidental angling catch on survival of either adult or juvenile White Sturgeon. There are numerous incidences of multiple captures of White Sturgeon in the Fraser River catch and release fishery individual sturgeon have been recaptured and sampled up to 14 times (Nelson et al. 2010). Multiple capture events for individual tagged sturgeon can occur on an annual basis, with some fish sampled up to five times in a single year. In parts the Snake River where an intensive recreational catch and release fishery occurs, White Sturgeon were hooked an average of 7.7 times in one year (Kozfkay and Dillon 2010).

Significant harvesting of sturgeon in the Transboundary Reach started in the mid-1970s and this popularity increased steadily to the 1990s. Although the timing of this increased angling activity and harvest coincide with the period of recruitment failure, harvest is not considered to be a primary cause of recruitment failure. However, past harvest has likely exacerbated the rate of population decline of wild fish and this may have implications to future recovery efforts. Data from other catch-and-release sturgeon fisheries suggests that if fish are properly handled and released, incidental catch may not be a significant factor in continued population decline in the Upper Columbia River.

4.0 REGULATORY FRAMEWORK AND EXISTING CONSERVATION MEASURES

4.1 Listings

COSEWIC first designated White Sturgeon as Vulnerable in April 1990, and reassessed the species as Endangered in 2003. In November 1991, the British Columbia Conservation Data Centre designated White Sturgeon in the province as BLUE listed (S3 Ranking) (Cannings 1993). This designation identifies a species that is rare, uncommon or susceptible to large scale disturbances (e.g., may have lost extensive peripheral populations). In December 1994, this ranking was upgraded to RED listed (threatened or endangered). At that time, four White Sturgeon populations were identified for monitoring purposes. These were the Fraser, Nechako, Kootenay, and Columbia populations. The Fraser River population was classed as S2 (imperilled). The Nechako, Kootenay, and Columbia stocks were classed as S1 (critically imperilled).

ESA

In the United States, the U.S. Fish and Wildlife Service listed the Kootenai River population of White Sturgeon as Endangered on September 6, 1994 (59 FR 45989) under the authority of the Endangered Species Act (ESA) of 1973, as amended. Individual listed fish that emigrate downstream from the Kootenai River into the Columbia River that subsequently re-enter U.S. waters of the Columbia River are afforded Federal protection under the ESA. The Upper Columbia River White Sturgeon populations are not formally listed in the U.S. by the Federal government.

SARA

The *Species at Risk Act* (SARA) came into force in 2003 and four populations of White Sturgeon (Upper Columbia River, upper Fraser River, Nechako River, and Kootenay River) were listed as Endangered in August 2006. In response to the listing decision, DFO initiated development of a National Recovery Strategy (NRS) for White Sturgeon in Canada, working together with the Province of British Columbia, First Nations, and other partners. A draft recovery strategy was released for public consultation in 2009, and is currently being finalized by DFO. The document provides recovery guidance for all four listed populations within Canada, including establishing population and distribution objectives, identifying critical habitat, and outlining approaches to recovery. The NRS, in combination with this revised recovery plan, provides objectives and direction for the TWG, although the NRS is the regulatory document for Canada.

Following completion of the NRS, DFO must also prepare one or more actions plans for White Sturgeon in Canada. SARA action plans are meant to facilitate implementation of species recovery strategies; they include measures to be taken to protect critical habitat, measures to monitor species recovery, and an evaluation of the socio-economic costs of the action plan and the benefits of its implementation. Timelines for the preparation of one or more action plans for White Sturgeon will be established in the final NRS.

SARA prohibits harm to White Sturgeon through general prohibitions that include: killing, harming, harassing, capturing, taking, possessing, collecting, buying, selling or trading an individual; destroying any part of the species' critical habitat. DFO may issue permits to allow certain activities to occur that would otherwise be prohibited. Researchers wishing to conduct scientific research or conservation activities that affect White Sturgeon, or persons undertaking activities that incidentally affect sturgeon, may be subject to SARA permitting provisions. Permits can be issued only for activities that meet certain pre-conditions, including that the activity does not jeopardize survival or recovery of the species. More information about SARA permitting, including a link to the application, can be found here: http://www.dfo-mpo.gc.ca/species-especes/permits-permis/application-eng.htm. Permit applications can take up to four months to process.

CITES

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) provides umbrella protection against illegal or unsustainable international trade. In 1998, parties to CITES including Canada and the U.S. placed all of the world's previously unlisted sturgeon and paddlefish species in Appendix II in response to increasing demands of the international caviar trade and collapse of Caspian Sea sturgeon fisheries. Commercial trade in Appendix II species across international borders is subject to regulation and allowed only if permits are obtained stating that trade is non-detrimental to the species' survival in the wild and that the species to be exported was legally acquired. A review process can result in country or species-specific recommendations for measures to maintain the species in its native range (TRAFFIC International, 2001). Implementation of CITES falls under the responsibility of the U.S. Fish and Wildlife Service and the Canadian Wildlife Service's CITES Office.

CITES and SARA primarily affect the Upper Columbia River White Sturgeon recovery effort by requiring appropriate permits to collect and/or transport White Sturgeon gametes, tissues, sperm, embryos, juveniles, or adults. CITES paperwork has been required to move juvenile sturgeon between rearing facilities on both sides of the Canada-U.S. boundary and to transport fertilized eggs from the KTH in Canada to various entities in the U.S. to conduct research related to restoration efforts. This constraint requires significant lead time in planning for research, culture, or supplementation efforts that will require the transport of White Sturgeon across the Canada-U.S. boundary.

4.2 Fishery Regulations

Fishing for White Sturgeon in the Upper Columbia River recovery area is prohibited. White Sturgeon caught incidentally while fishing for other species must be released immediately. The recreational sturgeon fishery in the Canadian portion of the Upper Columbia River basin has was first regulated in 1960 and was closed completely in 1996 (Table 16). Limited take was permitted until 1993. In 1994, commercial and sport harvesting of sturgeon became illegal in British Columbia, and many First Nations people voluntarily stopped their traditional sustenance and ceremonial harvests. Catch and release fishing was closed 1 April 1996. The closure included the Kootenay River downstream of Brilliant Dam and the Pend d'Oreille River downstream of Waneta Dam.

In the portion of the Transboundary Reach, recreational angling and harvest regulations prior to 1995 allowed the harvest of one sturgeon per day within a length slot limit with an annual limit of 10 fish per angler (Table 16). Sturgeon retention was prohibited beginning in 1995 but catch and release fishing was allowed until 2002 when WDFW prohibited all sturgeon angling.

4.3 Water Quality Protection & Restoration

During 1991 to 1993, a Columbia River Integrated Environmental Monitoring Program (CRIEMP) was initiated to define the status of the aquatic environment between HLK and the Canada-U.S. boundary. This survey incorporated water, sediment, and biological indicator parameters to identify influences of chemical constituents. The CRIEMP survey also set the stage for development of water, sediment, and tissue standards and monitoring objectives for the Upper Columbia River in Canada (MacDonald Environmental Sciences Ltd. 1997). CRIEMP continues and maintains on-going role in the monitoring, issues identification and reporting of Columbia River water quality issues to its partners and the public.

CRIEMP (2005) has summarized the past and present status of water quality in the Keenleyside Reach as follows:

> *"Water quality at Birchbank, located between Castlegar and Trail, has been rated as good to excellent since the early 1990s, which means that conditions are very close to ideal. Water quality at Waneta, located downstream of Trail near the US border, was rated as poor to marginal during the early 1990s, indicating that water quality was frequently impaired. Water quality rose to a "fair" ranking in the mid to late 1990s, and has been ranked as good for the last four years. The improvements in water quality at Waneta likely can be attributed to improvements, modernization, and termination of discharges at upstream industries, resulting in lower concentrations of contaminants in the Columbia River."*

Table 16: Historical and present White Sturgeon angling regulations in the Upper Columbia River in British Columbia and Washington State (Canada-U.S. boundary to Grand Coulee Dam).

Location	Period	Regulation
British Columbia (Keenleyside Reach)	1960s to 31 March 1978	one annually by permit (no size restriction)
	1 April 1978 to 31 March 1992	one annually by permit (none under 100 cm TL)
	1 April 1992 to 31 March 1993	one annually by permit (none under 100 cm or over 150 cm TL)
	1 April 1993 to 31 March 1996	catch-and-release only
	1 April 1996 to present	fishery closed; complete angling ban
Washington State (Roosevelt Reach)	Pre-1995	one per day; annual limit of 10 (1.22 m to 1.68 m TL)
	1995 to 2002	catch-and-release only
	2002 to present	fishery closed; complete angling ban

Continued protection and ongoing restoration of water quality in the Transboundary Reach is expected to provide positive benefits to White Sturgeon recovery. Environment Canada is responsible for regulating water quality through Section 36 of Fisheries Act in Canada, and the U.S. Environmental Protection Agency (EPA) and the Washington Department of Ecology are the regulatory authorities for water quality protection and restoration in the Columbia River in Washington State. Legacy sources of pollution and contaminants have largely been curtailed over the past 25 years. Contaminant input that occurred prior to enhanced treatment measures and the risk of accidental spills currently pose the greatest risk to White Sturgeon recovery. There are numerous abandoned mines and inactive mining districts throughout the Upper Columbia River watershed (Raforth et al. 2000). Inactive and abandoned mines, waste rock dumps, tailings, industrial outflows and municipal wastewater discharges can be sources of contaminated water which has the potential to impede White Sturgeon restoration.

There are two major municipal discharges to the Columbia River between HLK and the Canada-U.S. boundary. The City of Castlegar (population 7,816 in 2011) discharges secondary treated sewage to the Columbia River at Castlegar. The cities of Trail, Warfield and Rossland as well as the communities of Rivervale and Oasis (combined total population approximately 14,000) collect and discharge their primary treated sewage by outfall into the river near Trail. Treatment does not remove polluting chemicals such as metals and organic compounds that may interfere with endocrine function (Raloff 1998). Little information pertaining to organic and metal content of effluents is available for these sewage treatment plants or from other non-point sources of drainage, runoff, or septic tank seepage and little has been done to abate contaminant input from these sources. However, efforts are now being focused on both sides of the Canada-U.S. boundary to address these issues.

In the U.S., water quality standards are the foundation of the water quality-based pollution control program mandated by the Clean Water Act administered by the EPA. Separate water quality standards developed by the state of Washington and Tribes have been established to sustain public health and to protect fish, shellfish, and wildlife.

A ruling against the EPA in 1994 prompted a process for restoration of water quality in imperiled [303(d) listed] water bodies throughout Oregon, Washington, and Idaho, including the Columbia River. The Washington Department of Ecology, Confederated Tribes of the Colville Reservation, and Spokane Tribe of Indians have worked in coordination to develop total maximum daily loads (TMDLs) for the Columbia River between the Canada-U.S. boundary and Grand Coulee Dam. A TMDL is a written, quantitative assessment of water-quality problems and contributing pollutant sources (EPA 2002). It specifies the amount of a pollutant or other stressor that needs to be reduced to meet water-quality standards, allocates pollution-control responsibilities among sources in a watershed, and provides a basis for taking actions needed to restore an imperiled water body. TMDLs were approved for total dissolved gas in the Columbia River downstream from the border in 2004 and for dissolved oxygen in the Spokane River (a tributary to the Columbia River) in 2007. A TMDL for PCBs in the Spokane River is under development. More information can be found by visiting the EPAs website (www.yosemite.epa.gov).

Although the TMDLs described above primarily focus on water quality parameters such as dissolved gas, suspended solids, pH and temperature, the upper Lake Roosevelt watershed has also been slated for assessment of PCBs, arsenic, dioxins and sediment bioassays. These assessments will be used to establish and/or revise tissue and sediment guidelines as well as establish current distribution and effects on the aquatic environment.

In 2006, the U.S. EPA and Teck reached an agreement to conduct a Remedial Investigation and Feasibility Study (RI/FS) of the Upper Columbia which includes Lake Roosevelt. The purpose of the RI/FS is to investigate the nature and extent of contamination and to assess if there are unacceptable risks to human health and/or the environment as a result of past contamination. Depending on the outcomes of studies, the RI/FS will also evaluate potential cleanup actions and remedial alternatives. The Lake Roosevelt RI/FS is expected to be complete by 2018 to 2021.

Studies on sediment contamination and on contaminant effects on White Sturgeon are underway to inform the RI/FS process. Research has been done to describe trace-element concentrations and occurrence of metallurgical slag particles in bed sediments (Paulson et al. 2006; Cox et al. 2004) and to characterize slag (Hazen 2011). Laboratory experiments have also been conducted to ascertain the acute and chronic toxicity of metals to early life stages of White Sturgeon (Calfree et al. 2011; Little et al. 2011; Vardy et al. 2011). Results from these studies will help inform conservation measures.

4.4 Inventory & Monitoring

Relatively little was known about Upper Columbia River White Sturgeon in Canada prior to 1990 when studies were initiated as part of a five year BC Hydro inventory of fish composition, distribution, abundance, habitat use, and movements in the Columbia River below HLK (Hildebrand and English 1991; R. L. & L. 1995a). Based on initial findings of a skewed White Sturgeon size and age class composition, intensive annual studies commenced in 1992 on spawning, sex ratio, maturation, population size, and critical habitats (RL&L 1994a, 1995a, 1996a). In 1995, BC Environment began coordinating studies on White Sturgeon distribution and status throughout the Canadian portion of the Columbia River Basin to: 1) confirm the existence and determine population status of remnant populations of White Sturgeon in Kinbasket, Revelstoke, Duncan, and Arrow reservoirs, as well as Slocan and Kootenay lakes; 2) monitor the status of the known population in the Columbia

River below HLK; 3) monitor spawning frequency and success at the Waneta spawning site; and 4) radio or sonic tag pre spawning females to determine locations of other possible spawning areas.

In the Roosevelt Reach, there were few White Sturgeon inventory and research efforts prior to 2001. Small, directed sturgeon studies were conducted on four occasions. Sturgeon were collected from Lake Roosevelt for genetic analysis during the early 1980s (Brannon et al. 1985). A sonic telemetry study was conducted from 1988 to 1990 to track sturgeon movements (Brannon and Setter 1992). During 1998, 204 sturgeon ranging in size from 33 to 270 cm FL were captured from Lake Roosevelt to the Canada-U.S. boundary by the Washington Department of Fish and Wildlife (DeVore et al. 2000) and the U.S. Geological Survey using setlines, gillnets, and bottom trawls (Kappenman et. al. 2000). A gillnet survey for juvenile sturgeon in that same area was conducted by the Spokane Tribe in 2001.

Inventory and research on White Sturgeon in the US increased substantially following formation of the UCWSRI and studies have been undertaken primarily by the Washington Department of Fish and Wildlife, the Spokane Tribe and the Colville Tribe with funding provided through the Bonneville Power Administration. The Lake Roosevelt Sturgeon Recovery Project (LRSRP) is an ongoing project implemented to monitor population status and conduct recruitment failure research on White Sturgeon in the Roosevelt Reach of the Upper Columbia River. LRSRP stock assessment surveys using standardized baited setlines were conducted in in 2004, 2005, 2007, 2008, and 2009. The initial 2004 and 2005 surveys (Howell and McLellan 2007a; Howell and McLellan 2007b) were performed during the early spring (April and May) and were confined to the upper third of the Roosevelt Reach. Efforts were limited to this area based on: 1) insufficient funding to sample the entire reservoir; 2) the observation that the majority of fish (92%) were capture in this area during the 1998 summer/fall reservoir setline survey (DeVore et al. 2000); and 3) previous telemetry studies that indicated sturgeon overwinter in this area (Brannon and Setter 1992) and thus spring sampling would therefore likely provide a representative geographic sample of the general population.

Surveys in 2007, 2008, and 2009 were undertaken to address the potential sources of bias in the 2005 and 2006 surveys and evaluate previous assumptions about sturgeon distribution within the Roosevelt Reach. Whereas the 2004 and 2005 surveys utilized a haphazard sampling strategy in order to maximize catch rates, the 2007 to 2009 surveys incorporated a spatially balanced, general random tessellation stratified design (GRTS; Stevens and Olsen 2004). The 2007 survey covered the lower third of the Roosevelt Reach (Grand Coulee Dam to the Spokane River confluence, including the Sanpoil River Arm), the 2008 survey covered the middle third of the Roosevelt Reach (Spokane River confluence to Gifford, including the Spokane River Arm), and the 2009 survey covered the upper third of the Roosevelt Reach (Gifford to the Canada-U.S. boundary).

Fall (October) gill net surveys have been conducted annually in the Roosevelt Reach since 2001 to monitor levels of natural recruitment and, secondarily, collect data on hatchery origin juveniles released as part of ongoing conservation aquaculture supplementation efforts. Gear type and survey area have varied through time. Survey areas have generally been limited to the upstream third of the Roosevelt Reach for similar reasons given above for the 2004 and 2005 setline surveys. However, the 2008 survey sampled the entire Roosevelt Reach. Beginning in 2008 the gillnet surveys employed spatially balanced GRTS designs (Stevens and Olsen 2004).

Sturgeon movements, habitat usage, and spawning migrations have been further assessed using biotelemetry. Since 2003, approximately 450 sturgeon of various sizes and ages have been acoustic tagged and subsequently monitored with a longitudinal array of hydrophone receivers operated throughout the Transboundary Reach by various entities (Howell and McLellan 2011). Finer scale telemetry studies using the VEMCO positioning system (VPS; VEMCO, Halifax, Nova Scotia) application has also been employed to evaluate habitat use by sturgeon in the Marcus area (McLellan et al. 2011). Based on the success of VPS work in the Marcus area, in 2011 the

LRSRP conducted a pilot study to investigate the feasibility of installing a VPS system at the Northport spawn area to document habitat use and spawning behavior at a fine scale (WDFW, unpublished data).

4.5 Upper Columbia River Sturgeon Conservation Hatchery Program

The Upper Columbia sturgeon hatchery program was implemented in 2001 to help preserve wild genetic variability, help rebuild the natural age class structure, and prevent extinction until natural recruitment can be restored. This has been essentially achieved and as of January 2011, approximately 160,000 juvenile White Sturgeon and 1.5 million larval White Sturgeon have been released into the Upper Columbia River recovery area. These fish were the progeny of broodstock captured in the Transboundary Reach and transported to various hatchery facilities in BC and Washington State where they were spawned, fertilized, eggs hatched, and raised for release as larvae or older juveniles. From 2002 to 2011, 122,555 juveniles have been released in the Transboundary Reach (93,524 in the Keenleyside Reach and 29,031 in the Roosevelt Reach; Figure 23). Based on best available estimates of juvenile survival rates, an estimated 24,124 hatchery juveniles were present in the Transboundary Reach as of January 2012 (Table 7). Monitoring studies to date have indicated these fish are growing normally and to date, do not show any signs of density related changes in growth or survival rates (BC Hydro, unpublished data).

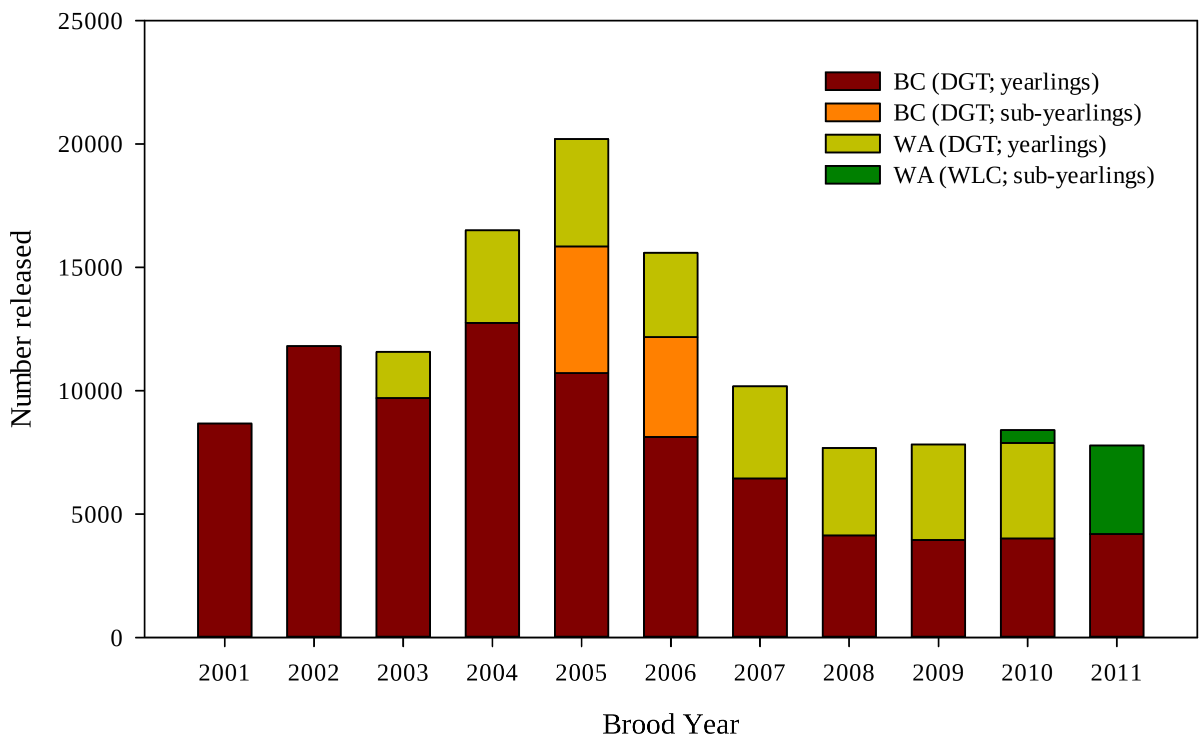


Figure 23: Number of juvenile hatchery sturgeon released in to the Transboundary Reach by brood year. Fish were sourced for rearing by direct gamete take (DGT) from broodstock collected in British Columbia (BC) and Washington (WA) and by wild larval collection (WLC) in Washington.

An additional 36,650 juveniles have been released into the ALR Reach since 2006 along with 1.5 million larval sturgeon. Survival estimates for these fish are not available and annual monitoring programs since 2006 have had very limited success in capturing released fish (Golder 2011a). The few fish captured have exhibited lower growth rates than their counterparts in the Transboundary Reach. Recent studies have focussed on identifying fine scale post-release movements of sonic tagged juveniles using a VPS system in the hopes of improving capture success and obtaining information on growth and survival.

More recently, wild larvae have been captured in the Roosevelt Reach, raised in the hatchery, and released back into the river as juveniles. The feasibility of a wild larval collection program in the Canadian section of the Transboundary Reach and rearing of these larvae in facilities adjacent to the Columbia River is also being investigated by the UCWSRI. The following sections briefly describe the history of the conservation aquaculture programs developed for White Sturgeon recovery in the Upper Columbia River.

Keenleyside and ALR Reaches

In 2000, a pilot culture facility for Upper Columbia White Sturgeon was developed by modifying the existing Hill Creek Hatchery located at Galena Bay, north of Nakusp, British Columbia. Broodstock collection and spawning began in 2001 and the first juveniles were released into the Keenleyside Reach in 2002. In addition, 272 wild eggs collected from egg mats set in the Waneta spawning area were brought to the hatchery and reared as an experimental program to assess the feasibility of capturing and rearing wild-spawned eggs; 22 of these survived and were released as juveniles.

In 2002, the Kootenay Sturgeon Conservation Hatchery, located in the Kootenay Trout Hatchery (KTH) near Wardner BC, was modified and expanded to meet the needs of the Upper Columbia White Sturgeon conservation aquaculture program. In 2003, the first complete year of broodstock collection, spawning, and rearing was carried out at the new facilities at the KTH. This new facility provided a more secure site with back up water and power along with additional experienced fish culturists providing 24 hour emergency response coverage. The facility has the capacity to hold up to 10 female and 10 male adult sturgeon brood until they are brought on to spawn, at which time they are crossed using a partial factorial breeding matrix plan.

Between 2002 and 2005, all White Sturgeon released in the Upper Columbia River recovery area were raised in the KTH from hatch in July until release in April or May of the following year. These juveniles typically weighed between 50 g and 75 g and were scute marked and implanted with a PIT tag before being released at various sites in the Keenleyside Reach. In early December 2005, ~5000 of the 2005 brood year were released at a mean size of 35 g to assess the effects of fall releases on subsequent survival and growth.

The target release goal for the KTH hatchery has remained at ~12,000 yearling juveniles since 2002. Since 2006, releases into the Keenleyside Reach have been reduced to about 4,000 juveniles with the remaining 8,000 juveniles released into the ALR Reach.

In addition to the yearly sturgeon juvenile production, larval sturgeon releases were initiated in the upper section of the ALR Reach in 2008 when ~600,000 unfed larvae were released below Revelstoke Dam as part of the BC Hydro WUP. Unfed larval releases continued in 2010 and 2011 with ~300,000 larvae released in each year. In 2010 and 2011 combined, ~235,000 fed larvae (on feed for 45 days) were released. Approximately 336,220 unfed larvae were released in 2010 below Revelstoke Dam as part of a substrate modification research project (see Section 3.1.1). Each year the juvenile releases have been incorporated into very large school and public events, organized by the Columbia Basin Fish and Wildlife Compensation Program and the UCWSRI Community Working Group.

Sturgeon gametes spawned and/or hatched at the KTH have also been used to support a large number of research projects. Some of these are:

- cold water egg incubation and early larval rearing;
- contaminant study of eggs and milt;
- contaminant and toxicity studies of larvae;
- cryopreservation of milt;
- larval and juvenile development at cold water temperatures;
- PCR diagnostic work;
- stable Isotope research;
- use of calcien for marking larvae;
- in stream incubation tests: and
- larval-substrate interactions.

From 2001 until 2005, a large number of fin deformities (mostly pectoral fins) occurred in most family groups raised at the Columbia Sturgeon at the KTH (from 9 % to 38 % of fish exhibited some type of fin deformity). Between 2006 and 2011, the incidence of fin deformities dropped to only 1 to 2% per year. The reason(s) for the high level of deformities in the early years of the culture program are unknown but are not thought to result from conditions at the hatchery since Kootenay Sturgeon, which are also reared at the hatchery using the same rearing containers, feed, and handling practices exhibited only low levels of fin deformities.

From 2007 to 2012 all adults that have been brought to the hatchery have been implanted with a Vemco acoustic tag prior to being returned to the river. These tags have a life span of 10 years and allow researchers to track their movements to identify important habitats and provide information on spawning periodicity.

In February 2004, approximately 2000 juvenile sturgeon were transported from the KTH to the Columbia Basin Hatchery in Washington. This allowed the US hatchery staff to become familiar with some of the aspects of sturgeon culture. Fertilized gametes were transported to the Columbia Basin Hatchery for the 2004 and 2005 year classes, from the KTH, where they were raised until the spring of the following years before being released into the USA portion of the Columbia River and Roosevelt Reservoir.

Roosevelt Reach

In 2003, the Spokane Tribe of Indians and WDFW implemented the White Sturgeon conservation aquaculture component of the BPA funded Lake Roosevelt Sturgeon Recovery Project (LRSRP) (BPA Project No. 1997-27-00). Initially, the U.S. program served as a failsafe for conservation aquaculture supplementation efforts in Canada that began in 2001. The WDFW Colville Hatchery (Colville, WA) was initially proposed as the interim U.S. rearing facility primarily due to its proximity to Lake Roosevelt but low water temperature at this facility (≈11oC) was not considered by the UCWSRI TWG as being suitable for adequate growth of juvenile sturgeon. The WDFW Columbia Basin Hatchery (CBH) near Moses Lake, WA was selected as the best alternative rearing facility. The CBH has sufficient space and water to rear 4,000 sturgeon to yearling size on an annual basis.

In February 2004, approximately 2,000 juveniles from BY 2003 were transferred from the KTH to the CBH. These fish gave the CBH staff an opportunity to gain experience rearing juvenile White Sturgeon. Rearing was successful and 1,881 juveniles were released in May 2004 representing the first introductions of sturgeon into the Roosevelt Reach.

In 2006, the U.S. aquaculture program suspended sourcing sturgeon from Canada in favor of developing its own broodstock collection and spawning program. WDFW's Sherman Creek Hatchery (SCH) was selected as an interim broodstock holding and spawning facility. SCH is located adjacent to Lake Roosevelt at the mouth of Sherman Creek near Kettle Falls, WA. The facility was constructed in 1991 to rear Kokanee salmon and Rainbow Trout. The primary reasons for using SCH include its proximity to the broodstock collection area and the potential for using ambient Lake Roosevelt water for holding and spawning.

Construction of the SCH holding facility began in early 2006. The facility comprised three-4 m diameter, 1.5 m deep fibreglass tanks supplied with river water from a redundant system of two submersible pumps. Water from the reservoir is pumped to a degassing tower and then gravity fed down to the holding tanks. The facility became operational in June 2006 and six pre-spawn adults from the vicinity of the Northport spawning area were successfully collected and transported to SCH. These fish were spawned and eggs were transported to CBH for incubation and rearing similar to previous years.

The U.S. program operated in this manner until 2011 when direct gamete take from broodstock was suspended in favor of collecting naturally produced larvae from the river and rearing them for supplementation purposes. This shift was variously motivated by: 1) early life history studies that indicated substantial numbers of post-hatch sturgeon could be collected alive and potentially reared in a hatchery environment; 2) research on Lake Sturgeon that showed offspring produced from direct gamete takes were more related and exhibited lower genetic diversity than offspring produced from larvae collected while dispersing from spawning areas; 3) collection of naturally produced eggs and post-hatch life stages for conservation aquaculture purposes was identified as a potential option in the UCWSRP; 4) broodstock collection would become more logistically challenging over time; and 5) concerns over the potentially deleterious effects of sampling procedures on the broodstock population.

A negative consequence for the U.S. program of a potential shift to wild larval collection was that it precluded the continued use of CBH as a rearing facility due to disease concerns. However, co-managers identified the SCH as an alternative site for rearing based on the Columbia River water supply system previously installed for broodstock holding which addressed disease concerns. To test the potential for SCH as a rearing facility, a pilot study was conducted in 2010 when 2,744 larvae were collected from the river between 11 and 25 July and transferred to SCH for rearing. Rearing was successful and resulted in the release of 522 sub-yearling juveniles in to the Roosevelt Reach in December 2010. U.S. brood collection efforts were suspended in 2011 in favor of larval collection as the primary method to meet program supplementation goals. The SCH infrastructure was upgraded to accommodate the rearing of 4,000 sturgeon to release size (~30 g) as sub-yearlings in early December. Rearing fish beyond December was not an option due to the potential freezing of the water supply system during the winter months. The retrofit included the installation of eight round tanks (1.5 m diameter), a UV filtration system, and an inline propane water heater to maintain rearing temperatures. From 26 July to 2 August 2011, a total of 10,295 larval sturgeon were collected from the river and transported to SCH. Rearing success in 2011 (34.9% survival to release) was substantially improved over 2010 (19.0% survival to release) and 3,590 sub-yearling juveniles were released into the Roosevelt Reach in December 2011. For the foreseeable future, the U.S. program will utilize naturally produced White Sturgeon larvae captured from the Upper Columbia River as its source for the conservation aquaculture program.

4.6 Hydro Facility Incidental Harm and Mitigation

White Sturgeon presence in the vicinity of Columbia Basin hydro stations has been documented over recent years. When units are off line, sturgeon have been observed swimming into hydro facilities (from downstream) and in the draft tubes below the turbines. There have been a number of incidents at Bonneville Dam on the lower Columbia River in recent years involving a large number of sturgeon mortalities when the turbines start up after a long period off-line. Idaho Power also has experienced White Sturgeon mortalities attributed to blade strike at one of their facilities on the Snake River (K. Lepla, Idaho Power Company, pers. comm.). Five dead sturgeon were recorded during the 2007 to 2010 period in the vicinity of the Brilliant Expansion Generating Station on the Kootenay River; some of these may have been associated with facility operations. The factors that make one facility more susceptible to mortality incidents than others are not completely understood but may be partially related to the type of turbine unit.

Columbia Power Corporation (CPC) has conducted research at the Brilliant Expansion and Arrow Lakes Generation Station facilities to better understand sturgeon interactions at Kaplan turbine facilities. Cameras were installed in the draft tube outlets of the Brilliant Expansion facility. Subsequent analysis of the video footage and a risk analysis of the turbine start up procedure led to modifications of the initial rotation of the unit and the rate of change of turbine water flow upon unit start up that help mitigate risks to sturgeon. A risk management approach also is used at the individual facilities to mitigate the risk of incidental harm. This involves knowledge of the higher risk periods and the operating characteristics of the individual facilities. Because sturgeon are known to enter draft tubes, inspection and salvage and removal of trapped sturgeon is common practice if draft tubes are isolated for prolonged periods or will be dewatered for maintenance. In new facilities, such as the Waneta Expansion Project, mitigation measures have been incorporated into the facility design. The draft tube design of the facility (currently under construction) incorporates a sturgeon exclusion gate that can be deployed in front of the draft tube outlets when the units go below a specified output.

Entrainment is not considered a current threat for the Upper Columbia population. Sturgeon populations do not presently exist above Brilliant or Waneta dams. Although there is a small population segment in the ALR Reach, most individuals apparently remain in the upper portion of the ALR Reach, although one member of this population did successfully move from ALR downstream through HLK. As the population in the ALR Reach is increased through supplementation efforts, downstream movement/entrainment may become an issue and will be the subject of future research. Research by Idaho Power, where downstream movement of White Sturgeon is commonly recorded, shows that the spillways are the primary method of downstream passage and that larger sturgeon are able to easily avoid entrainment through the power plant (Parsley et al. 2007; K. Lepla, Idaho Power Company, pers. comm.).

During the Environmental Impact Assessment for Cominco's Waneta Upgrade Project in the late 1990s, the flows from the regulated Pend d'Oreille River were recognized as having a potential influence on the Waneta White Sturgeon spawning area (Figure 14). Potential predation on incubating sturgeon eggs was identified as a potential project effect and led to the implementation of the 1998 White Sturgeon Flow Augmentation Program (WSFAP-1998). The intent was to enhance conditions for sturgeon spawning and egg incubation in the Waneta area during periods when mean daily flow in the Pend d'Oreille River decreased below the pre-upgraded generation capacity of 708 cms.

Under the WSFAP-1998, minimum day-time flows of 283 cms and night-time flows of 142 cms were established. The daytime flows were intended to provide sufficient flow velocity (0.8 m/s) in the upstream section of the Waneta spawning area during the day to stimulate spawning activity. The nighttime minimum flow was intended to provide White Sturgeon eggs with greater protection from predation at night than was provided by the pre-upgrade minimum flow of 34 cms. When mean daily Pend d'Oreille River flows were above 708 cms, a continuous minimum flow of 708 cms was established. These operational conditions were imposed annually on

Waneta Dam from 16 May to 31 July, which encompassed the White Sturgeon spawning period. Implementation of the WSFAP-1998 was dependent on the magnitude and timing of the spring freshet; however, in most years the flow protection was usually triggered by early to mid-July when between 20% and 50% of White Sturgeon spawning events in past years typically had occurred (ASL et al. 2007). In exceptionally high water years the WSFAP-1998 was not implemented until late July after which spawning is typically completed (Golder 2003).

During the EACA assessment of the Waneta Expansion Project in the mid to late 2000s, the WSFAP-1998 was modified and renamed the WSFAP Post-Project Enhancement (WSFAP-PPE). Key changes to the WSFAP-PPE were: 1) a change in the timing of the minimum flow implementation to more closely match the actual White Sturgeon spawning period and increase the number of spawning events that would benefit from the higher level of flow protection; and 2) the reduction of the level of the first protection flow (from 708 cms to 566 cms) to provide greater flows and resultant near-bottom velocities in the area of the egg deposition zone most affected by Pend d'Oreille River flows (ASL et al. 2007).

The WSFAP-PPE was accepted by the agencies as an improvement over the WSFAP-1998 and will be implemented following commissioning of the Waneta Expansion Project, which is currently under construction and scheduled for completion in 2014. As a condition for approval, the agencies required monitoring to confirm the environmental assessment conclusion that flow changes associated with the Project will not adversely affect the spawning habitat or spawning/incubation success of White Sturgeon during the June to July spawning period, and more specifically, that project related changes to the flow regime will not affect recruitment through significantly increased predation on White Sturgeon eggs. To verify the predictions of no net impact on sturgeon spawning activity or egg predation, CPC committed to a six year study of the relationshop between flow from Waneta Dam and White Sturgeon egg predation.

Water management recommendations of the present recovery plan will be an important consideration of the Water Use Planning (WUP) process in the Canadian portion of the Columbia Basin. The water use planning process for BC Hydro's Columbia River project was initiated in August 2000 and completed in June 2004. This program was developed by the BC provincial government to evaluate and refine the water operations throughout the province. BC Hydro has undertaken WUP processes for all of its facilities, including those in the Columbia Basin. Given that WUP processes are a means of examining and modifying system operations to address various interests in the watershed, including fisheries, the Columbia WUP process represents an important mechanism for consideration and implementation of Upper Columbia White Sturgeon recovery measures related to water management. In January 2007, the BC Comptroller of Water Rights approved the final WUP and issued an Order to BC Hydro to implement the conditions proposed in the Columbia River WUP and prepare terms of reference for multiple monitoring programs and physical works.

At the time of the development of the Columbia WUP, there were many uncertainties related to White Sturgeon recovery and an entire management plan was devoted to address links to operation of the Columbia River, gaps in knowledge (biological), and to facilitate recovery. A significant component of this management plan was the development and implementation of physical works that focus on conservation aquaculture as a means of supplementing the population until a time where recruitment failure is further addressed. Further, this management plan resulted in numerous monitoring studies focused on, but not limited to, determining how operations of river and reservoir levels influence sturgeon life history (e.g. spawning, movements, habitat use etc.), improving general knowledge about the species (e.g., early life history, adult demographics, etc.), and describing the success of juveniles released from conservation aquaculture programs. Work for White Sturgeon is split between the lower Columbia River (HLK to the Canada-U.S. boundary) and the mid-Columbia River, which includes ALR from HLK to Revelstoke Dam and Kinbasket Reservoir upstream of Mica Dam. The plan was divided as it was recognized that there were numerous uncertainties related to sturgeon restoration or recovery in the mid-Columbia River and that work needed to be approached in phases so the program could adapt to new information. White sturgeon work under the Columbia WUP is extensive and extends through the end of the WUP period, currently planned around 2019. The schedule of implementation for both monitoring programs and physical works is provided in Table 17. Details and results from these studies can be found online at:

http://www.bchydro.com/about/sustainability/conservation/water_use_planning/southern_interior/columbia_river/columbia-sturgeon.html

Table 17: Schedule of Columbia River WUP Monitoring Programs and Physical Works Implementation under the White Sturgeon Management Plan as of 2012.[a]

Monitoring Programs	2007 WLR YR1	2008 WLR YR2	2009 WLR YR3	2010 WLR YR4	2011 WLR YR5	2012 WLR YR6	2013 WLR YR7	2014 WLR YR8	2015 WLR YR9	2016 WLR YR10	2017 WLR YR11	2018 WLR YR12	2019 WLR YR13 Final Review
CLBMON-19 Kinbasket Sturgeon Inventory and Habitat Use		✓	✓	✓									
CLBMON-20 Mid Columbia River Spawning Habitat Assessment				×	✓	■							
CLBMON-21 Mid Columbia River Juvenile Sturgeon Detection and Habitat Program and Tracking of Existing Sonic Tagged Sturgeon	✓	✓	✓	✓	✓	■	■	■	■	■			
CLBMON-23 Mid Columbia River Sturgeon Egg Mat Monitoring and Underwater Videography Feasibility	✓	✓	✓	✓	✓	■	■	■	■	■			
CLBMON-24 Mid Columbia River Sturgeon Genetics									■				
CLBMON-25 Kinbasket Juvenile Sturgeon Detection and Habitat Use	C*												
CLBMON-26 Kinbasket Sturgeon Recolonization Risk Assessment and Habitat Suitability				✓	✓	■							
CLBMON-27 Mid Columbia River Sturgeon Incubation and Rearing Study			✓	✓	✓								
CLBMON-28 Lower Columbia River Adult Sturgeon Population Monitoring		✓	✓	✓	✓	■	■	■	■	■	■	■	■
CLBMON-29 Lower Columbia River Juvenile Sturgeon Monitoring		✓	✓	✓	✓	■	■	■	■	■	■	■	■
CLBMON-30 Lower Columbia River Opportunistic Assessment of High Flow Events			✓	✓	✓	■	■	■	■	■	■	■	
CLBMON-54 Mid Columbia Effects of REV 5 Flow Changes on Incubation & Early Rearing Sturgeon				×	✓	■							
Physical Works													
CLBWORKS-24 Mid Columbia Experimental Aquaculture		✓	✓	✓	✓								
CLBWORKS-25 Mid Columbia Sturgeon Conservation Aquaculture						■	■	■	■	■	■		
CLBWORKS-26 Mid Columbia Sturgeon Upgrade Hatchery		✓	✓										
CLBWORKS-27 Lower Columbia Bentonite Addition Experiment	C*												
CLBWORKS-28 Planning and Assessment of WSG Turbidity				u/w	✓	■							
CLBWORKS-34 Lower Columbia Sturgeon Aquaculture Program		✓	✓	✓	✓	■	■	■	■	■	■	■	■

Legend:
- ■ = Program to be undertaken/initiated in identified year
- u/w = Project is underway
- ✓ = Program completed for the year
- × = Program started, but encountered operational or hydrological delays
- C* = Program is on the conditional list

[a]http://www.bchydro.com/etc/medialib/internet/documents/planning_regulatory/wup/southern_interior/2012q2/clb_mp5_annual_report.Par.0001.File.CLB-MP5-Annual-Report-2012-05-31.pdf

4.7 Other Activities

Fertilization projects undertaken in Kootenay Lake (Schindler et al. 2009) and Arrow Reservoir (Schindler et al. 2006) may benefit sturgeon as well as other members of the aquatic community. Fertilization of Kootenay Lake was initiated in 1992 and in Arrow Lakes Reservoir in 1999 in response to dramatic declines in Kokanee escapement, spawner size, and low in-lake abundance. Zooplankton and mysid populations increased in abundance and biomass with high fertilization loading. Kokanee populations increased in both escapement and in-lake abundance Monitoring has shown that phytoplankton and Kokanee abundances appear to track the fertilizer loading fairly closely (i.e., decreased fertilizer loads causes reduced phytoplankton and Kokanee abundances). Since fertilization began, phytoplankton, zooplankton, and mysid densities in ALR have increased from pre-fertilization levels. Mysids entrained through HLK have proven to be a primary food source for juvenile sturgeon below HLK. Initial changes in Kokanee populations have been similar to changes observed in Kootenay Lake with improvements to in-lake abundance, escapement, spawner size, and fecundity (Schindler et al. 2006).

5.0 RECOVERY

5.1 Goal and Objectives

The UCWSRI began recovery efforts for sturgeon in 2000 with the goal of working together to build a healthy future for the sturgeon in the Upper Columbia River in British Columbia and Washington. The subsequent listing of White Sturgeon under SARA in 2006 broadened the goal for sturgeon recovery within Canadian waters of the recovery area to ensure that the populations are self-sustaining through natural reproduction and to increase or restore opportunities for beneficial use, if and when feasible. This recovery plan acknowledges that SARA recovery goals and objectives must be met within Canadian waters but recovery in U.S. waters is not subject to SARA.

The short-term objectives of the original 2002 Recovery Plan to assess population status and to prevent further reductions in White Sturgeon distribution, abundance, and genetic diversity within the current range have largely been met. Population monitoring and hatchery supplementation to replace the lack of natural recruitment are ongoing components of White Sturgeon restoration. These activities will continue as necessary to facilitate recovery.

Substantial progress has also been made towards identifying limitations to restoration of natural reproduction. However, knowledge gaps still exist and identification of feasible response measures to reduce or eliminate limitations is ongoing.

The degree to which naturally reproducing populations will be able to support harvest or the impacts of a future catch and release fishery will depend on the success of efforts to restore habitat conditions suitable for spawning and rearing. Therefore, the objectives of this White Sturgeon recovery plan are to:

1) Monitor status and trends of populations within the recovery areas.
2) Continue supplementation to rebuild abundance and maintain genetic diversity.
3) Identify and address factors limiting natural recruitment.

Recovery efforts will focus on three areas within the historical geographic range that continue to provide suitable habitat. These three potential recovery areas include the Arrow Lakes Reservoir Reach (from Revelstoke Dam to HLK) and the upper Transboundary Reach (HLK to the Canada-U.S. boundary) that are within Canadian jurisdiction and the lower Transboundary Reach (Canada-U.S. boundary to Grand Coulee Dam) in the U.S. jurisdiction. This approach will be continually evaluated as numbers of fish present in the entire Transboundary Reach increase through recovery efforts on both sides of the Canada-U.S. boundary.

At some point in the future, a failsafe population may also be established in an area of the Upper Columbia River basin with suitable habitat that either no longer contains sturgeon or that presently supports a non-sustainable sturgeon population segment. This would involve a release of hatchery fish in an area separate from existing recovery areas, which can be used as a future source of White Sturgeon to support population abundance and diversity in other recovery areas. Genetic and demographic risks to existing wild populations can be minimized by establishing the failsafe population where the potential for straying can be controlled and monitored.

At present, the ALR Reach is being investigated either as another recovery area or failing that, as a potential area for the failsafe population The Kinbasket Reach is also being investigated as either an additional recovery area or a possible location for a failsafe population.

The recovery plan is based on an adaptive management approach that involves the continued modification of the program based on results of research on limiting factors and monitoring of stock status and its response to recovery actions. Currently, long-term recovery planning is hampered by a lack of understanding of key limiting factors. Laboratory studies will continue to provide information necessary to evaluate field-scale recovery actions. Field research and monitoring will continue to provide information on ecological impediments to recovery. Additional knowledge gained since the original recovery plan was written has increased our knowledge of what changes have affected sturgeon, but it is still unclear what specific and feasible actions will be effective at stimulating natural recovery. Research and evaluation efforts need to be aggressive because of the critical status of some remaining population segments and the inherent time lag in implementation of research findings. Restoration of population levels of White Sturgeon to a point where recreational fishing or limited harvest is allowed is a significant goal of some of the parties involved in the development of the recovery plan. The feasibility of this goal is currently unclear given the SARA listed status in Canada, and will depend on progress in restoring natural recruitment and stock productivity in the U.S. and Canada. Opportunities for beneficial use fisheries will be considered at such time as appropriate based on recovery measures, evaluations, and monitoring data and consistent with the intent of recovery.

5.2 Targets

Recovery targets are interim benchmarks by which progress toward recovery will be measured. A minimum of 25+ years will be required to approach many of these recovery targets because of the long life span and generation time of sturgeon. Targets identified in this plan are based on population viability guidelines identified in the scientific literature and are similar to those adopted in the draft Canadian National Recovery Strategy for White Sturgeon and in recovery plans for other vulnerable sturgeon populations. The targets for the Upper Columbia River White Sturgeon are listed below:

1. ***Minimum interim adult population sizes of 2,000 adults in the upper Transboundary Reach (Canada), 5,000 adults in the lower Transboundary Reach (U.S.)***

   Periodic population assessments will inform progress on meeting and /or adjusting this target in each recovery area. The 2000 adults in the upper Transboundary Reach approximates the estimated historical adult population estimate and on this basis, is set as the interim target. The Lake Roosevelt co-managers have identified a long term objective of achieving an abundance of 5,000 adults for the lower Transboundary Reach with adequate rates of natural recruitment to maintain the adult abundance (LRMT 2009). These abundance numbers are interim targets pending studies of habitat carrying capacity in designated recovery areas and may change based on capacity assessments. Note that a target for ALR has not presently been established.

2. ***Naturally-produced recruitment and juvenile population sizes sufficient to support desired adult population sizes in at least two of the three potential recovery areas identified above.***

   Research on survival limitations may allow improvements to habitat that will increase natural spawning survival and production. Supplementation will continue to build juvenile abundance. Population monitoring will provide information on natural production and juvenile abundance. Multiple recovery areas provide the spatial diversity necessary to protect the species from local impacts.

3. ***Stable size and age distributions in each population.***

   Population monitoring will provide information on size and age distribution within recovery areas. Stable population numbers are required to demonstrate the effectiveness of long term recovery actions. Stable size and age distributions reflect the longevity and normal population structure of sturgeon as well as providing the population resilience needed to sustain these fish over the long term.

4. ***Genetic diversity (including rare allele frequencies) is preserved and is similar to that measured during the late 2000s.***

   Population monitoring and supplementation will provide information on efforts to maintain current levels of diversity (Drauch Schreier et al. 2011). Restoration of natural spawning and production will alleviate the need for supplementation. This will ensure that sufficient variability is preserved to allow sturgeon to use the available array of environments, protect against short-term spatial and temporal changes in the environment, and provide the raw material for surviving long term environmental changes (McElhany et al. 2000).

5. ***Abundance and natural production rates are sufficient to support beneficial uses including subsistence harvests by First Nations and Native American Indians and recreational fishery uses.***

   Population monitoring, supplementation, and reductions in limitations to natural production result in meeting recovery goals in U.S. and Canadian recovery areas. Natural reproduction rates sufficient to provide harvest or withstand other fishery impacts recognize a desire to restore historical fishing opportunities. Reproduction rates that provide a sustainable harvestable surplus also provide an additional safety factor from long term risks to population viability.

This recovery plan does not identify specific ecosystem function targets or benchmarks but recognizes that efforts to restore sturgeon populations through natural production are also likely to result from restoration of ecosystem function that in turn will benefit many other components of the native aquatic community.

5.3 Strategies and Measures

Recovery goals, objectives, and targets will be addressed using the following strategies and associated measures. These specific strategies and measures are consistent with the goals and objectives of this Recovery Plan and were developed by TWG subcommittees and adopted by the full TWG. Timeframes for each measure reflect short (0-5 year), medium (5-10 year), and long (10- 50 year) term commitments for implementation of measures and expectations of results.

5.3.1 Control Direct Sources of Adult and Juvenile Mortality

Strategies to reduce mortalities of wild and hatchery White Sturgeon will be accomplished using the following measures.

1) Continue to prohibit fishing for and retention of sturgeon.

All fishing for sturgeon in U.S. and Canadian waters of the Upper Columbia River is currently prohibited and must remain so for the foreseeable future.

Schedule: Short to Long term

2) Continue to limit incidental impacts and illegal harvest of sturgeon.

With current closures of the sturgeon fishery in the U.S. and Canada, the primary fishery threats are from poaching and incidental captures as by-catch in the increasingly popular Walleye or Rainbow Trout fisheries. Poaching is not presently considered a major threat but incidental handling of small sturgeon in these fisheries will increase as hatchery fish numbers increase or natural recruitment is restored. Education and enforcement initiatives will be required to mitigate these impacts.

Schedule: Short to Long term

3) Continue to monitor occurrence of sturgeon mortalities.

Sturgeon mortalities are periodically observed in the Upper Columbia River and the public is encouraged to report carcasses to the BC FLNRO, DFO, or the WDFW. Reports are investigated in an attempt to ascertain the cause of mortality and to obtain appropriate biological information.

Schedule: Short to Long term

4) Continue to monitor mortality or harm through the operations of dams and hydroelectric facilities and if deemed necessary, implement operational mitigation measures.

Entrainment through turbines and entry into draft tubes of off-line turbine units has been identified as a concern because mortalities can be high. Entrained fish also are passed downstream and unable to return to recovery areas. Monitoring and responding to potential problems as they are identified must continue. Hydro operations will likely increase risks to sturgeon as more young fish are introduced into the system and they begin to colonize previously underutilized habitats and disperse downstream. If entrainment levels become unacceptable, specific actions to reduce or eliminate the risk should be developed and implemented.

Schedule: Short to Long term

5.3.2 Rebuild Abundance through Hatchery Supplementation

Hatchery supplementation must continue into the foreseeable future to rebuild juvenile abundance while preserving the remaining population diversity. Hatchery methods, risks, and benefits require consistent and careful review at regular intervals throughout the recovery process to maintain genetic diversity and reduce selective pressures that may promote survival in a hatchery but not in the wild. Hatchery operations should strive to promote conditions that support riverine phenotypic expression by juveniles. Hatchery intervention is currently envisioned as a medium term strategy to be re-evaluated once hatchery fish begin to reach maturity. The aggressive hatchery measures presently in place have successfully replaced 11 year-classes juveniles that would not have been produced by the existing population of aging, wild mature fish. Hatchery fish also serve as test subjects in the wild or the laboratory, subject to applicable permitting provisions, to experimentally investigate natural recruitment limitations, mortality factors, critical habitats, and feeding. Strategies to rebuild the abundance of the White Surgeon population in the Upper Columbia River recovery area will be accomplished using the following measures.

1) Pursue a fish culture strategy to conserve existing population diversity.

Hatchery operations have and will continue to be conducted in a manner that recognizes the critical status of Upper Columbia River sturgeon and a shrinking window of opportunity for restoration. Hatchery intervention is currently the only demonstrated alternative for preserving the Upper Columbia River White Sturgeon population. An intensive post-release monitoring and evaluation program is on-going to determine whether the hatchery program is providing the intended benefits. Initial release goals were based on the best available information at the time of the 2002 plan, but subsequent monitoring and evaluation of survival rates, dispersal patterns, system carrying capacity, and ecosystem effects have provided information that has led to the reduction of stocking targets and the collection of wild larvae as a replacement of or supplement to the broodstock collection program.

Preservation of existing genetic diversity is a primary goal of the hatchery program but overly selective hatchery and rearing practices can reduce genetic diversity. Genetic risks can be minimized by careful design and implementation of hatchery practices. Hatchery breeding practices have been modified since the original 2002 breeding plan and are now based on a partial factorial mating strategy where multiple half-sib families are created by crosses of multiple females and multiple males is the best approach. Implicit in this design is that all fish must be in prime spawning condition with optimal fertilization capability at the time of spawning. In addition, egg and milt volumes must be of sufficient quantity to complete the factorial pattern. This plan has been examined using genetic analysis and has been shown to capture a high proportion of the existing genome that will foster phenotypic expression of traits characteristic of wild fish. Ongoing wild larvae capture and subsequent hatchery rearing and release of these naturally produced progeny should continue. Broodstock use plans should ensure that a) the founder population spawned in the hatchery will be large enough to preserve existing genetic diversity (including frequencies of rare alleles) and b) contributions of each family group in the next generation are balanced so as to avoid swamping the population with a few families.

Schedule: Short to Medium term

2) Use hatchery-reared offspring of wild adults to assist in research.

Hatchery releases are being used to provide experimental fish consistent with recovery plan objectives. Based on the low abundance of wild juveniles, hatchery releases provide an effective alternative to help identify causes of current recruitment failure and feasible alternatives for restoration of suitable conditions for natural recruitment. Release experiments have been designed to help identify limiting life stages and critical habitats. Comparisons among different release groups can help fine tune out-planting strategies to optimize survival. Subject to applicable permitting conditions, the hatcheries may also provide eggs, larvae, and juveniles for mechanistic research conducted *in situ* or *in vivo*. Hatchery releases also provide fish to assess limiting factors, monitor movements, understand food habits, and monitor contaminant uptake.

Schedule: Short to Medium term

3) Establish failsafe adult population(s) where feasible and acceptable.

Failsafe populations provide a reserve of fish as a contingency for future recovery efforts. These populations will be based on releases of hatchery-reared offspring of wild adults, and if deemed necessary in the future, will be established in areas where suitable conditions for natural spawning and recruitment are not likely to be restored, but adults can be expected to persist. Extra eggs are typically obtained from broodstock spawned in the hatchery but the available rearing space limits the numbers of juveniles that can be reared to optimal release sizes. In addition, careful management of risks to the existing wild population requires limitations on release numbers to balance genetic effects and the potential for over seeding of the available rearing area. Release of these “surplus” fish into a separate area would provide an additional population as a contingency for future needs and also avoids the apparent contradiction inherent in the sacrifice of fish from a sensitive species that is subject to intensive and expensive recovery efforts. Sites for consideration should ideally be within the historic range of Upper Columbia River White Sturgeon, provide significant food resources, and be buffered from remaining significant wild populations. Failsafe population management must consider genetic risks consistent with conservation goals but the lack of natural spawning conditions may provide some flexibility in hatchery release and marking strategies.

Schedule: Medium to long term

4) Use cryopreservation techniques to preserve White Sturgeon sperm.

Cryopreservation of sperm can provide a contingency for the hatchery program in the event that continued declines in the wild population make it difficult to ensure that ripe males and females are available at the same time. This technique has now been developed and should be employed as needed to preserve sperm from future male broodstock.

Schedule: Short term

5.3.3 Restore Natural Recruitment

Restoration of natural recruitment will likely require implementation of habitat restoration actions developed from an understanding of relations between White Sturgeon survival and habitat as defined by river flow, local hydraulics, river bed substrates, water temperature, and water quality. Restoration of natural recruitment is required to achieve long term recovery objectives. Necessary measures might involve modifications to the annual hydrograph in the Columbia and Pend d'Oreille rivers or improvement or enhancement of important habitats (e.g., spawning or rearing areas).

Strategies to restore natural production of White Sturgeon can be best achieved using the following water management, physical habitat, and water quality measures.

5.3.3.1 Water Management

As previously discussed, the Upper Columbia River watershed is heavily regulated for power generation and flood control. A complete return to the natural hydrograph of the system would be prohibitive in terms of economic (power) and social (flooding) costs and is not considered a viable option. As such, any changes to water management must consider these constraints plus existing international agreements (e.g., Columbia River Treaty, Non-Treaty Storage Agreement, Kootenay Lake IJC Order), provincial water licence requirements (WLRs), and existing or future environmental flow requirements designed to manage other ecosystem impacts (e.g., Rainbow Trout protection flows from HLK, Libby Dam sturgeon spawning flows, Roosevelt releases for downstream salmon transport). Due to these constraints, the following measures should be developed on an opportunistic basis as allowed by the water year.

1) Monitor and evaluate the effects of flow on natural recruitment using opportunistic flow years that will minimize impacts on other uses of basin waters.

River geomorphology and substrates in the Upper Columbia River can and have been altered through natural and anthropogenic processes. These alterations affect spawning, incubation, rearing, feeding, staging, and overwintering habitats of White Sturgeon. At present however, specific flow requirements needed to stimulate successful recruitment are unclear.

Sturgeon recovery may be assisted by alterations to current operations of dams above and including Grand Coulee Dam. The feasibility and efficacy of a partial return to more natural conditions (i.e., to the extent feasible), should be investigated on an opportunistic basis as determined by the water year. Following years with high freshet flow volumes above an established target threshold of 5,660 cms (200,000 cfs) at the Canada-US boundary, monitoring will be conducted to assess whether the increased flow volume or other associated physical parameters (e.g., temperature, substrate conditions, turbidity) results in increased recruitment of wild White Sturgeon.

A condition of the PAC for the Waneta Expansion Project (presently in construction) on the Pend d'Oreille River required the development and implementation of a monitoring program to assess the effects of flow changes that will result from the operation of the expansion power plant and also to evaluate effects of the WSFAP-PPE (see Section 4.6). Over a six year period commencing in 2012, the monitoring program will attempt to assess the relationship between flows and predation on White Sturgeon eggs in the Waneta spawning area to evaluate if flow changes arising from project operations have a detectable effect on White Sturgeon recruitment success.

Water Use Plans mandated by the British Columbia government in the form of Water Licence Requirements (WLRs) have been developed for the major Canadian Columbia River Treaty storage dams (and associated generating plants). In the present WLRs for the ALR Reach, provisions have been made for the provision of a minimum flow year-round and specified water releases during the spawning period to to promote spawning and survival. However, due to the high economic cost of the flow releases and the low expected benefits, implementation of these flow experiments is not being pursued at the present time. Specific flow releases have not been included in WLRs for the Keenleyside Reach although as discussed previously, there is a provision for opportunistic monitoring during or following high water years to assess the potential that experimental flow augmentation will result in detectable recruitment in the Transboundary Reach. In the next few years, results of the juvenile indexing program will provide an opportunity to determine if the high flow years in 2011 and 2012 resulted in an increase natural recruitment; this data will help inform the need for future flow augmentation programs.

Schedule: Short to Long term

2) Implement flow requirements that promote natural spawning, incubation, rearing, recruitment, and survival of Columbia River White Sturgeon.

If the data collected during opportunistic high flow years in the Upper Columbia River or from other White Sturgeon research programs indicates that flow manipulations are beneficial for sturgeon recruitment, then there will be a need for power producing entities and agencies to carefully examine current operational practices and assess the feasibility of modifying flows in a manner that will benefit White Sturgeon and other native fish species. This may involve specific water storage and flow augmentation during spawning and early life stage development periods to meet the biological objectives of sturgeon recovery.

Any experimental flow augmentation programs must be designed with consideration of the magnitude of potentially feasible flow increases, the ability to detect changes in early life stage survival rates and opportunities associated with unusually high and low discharge years. These programs may require changes to existing water licences and international agreements like the Columbia River Treaty.

Schedule: Short to Long term

3) Continue to assess impacts of dam discharge and reservoir operations on White Sturgeon early life stages.

High summer levels of the Roosevelt and Arrow Lakes reservoirs may impair the dispersal of White Sturgeon eggs and/or larvae to suitable incubation or rearing habitats. Low levels of these reservoirs in the winter may result in de-watering of rearing habitats for sub-yearling and yearling sturgeon. The de-watering may affect White Sturgeon juveniles directly or by reducing food production and availability. In the ALR Reach, WLR research programs, involving a combination field and laboratory research have been implemented to assess these impacts and provide a basis for recommendations for altered reservoir management regimes.

In some years, Revelstoke generating capacity may be used for load factoring operations during the sturgeon spawning period. In the past, this could result in periods of zero discharge from the dam overnight with potential impacts to White Sturgeon that included: (i) delayed or inhibited spawning; (ii) stranding or desiccation of eggs; (iii) increased egg predation rates, and (iv) reduced transport of larvae to suitable rearing areas. In 2010, a minimum Revelstoke flow of 141.5 cfs was established that resulted in an increase of total wetted riverbed area below the dam. Although egg stranding has been identified as a potential impact, it is unlikely to limit recruitment as dewatering events are infrequent under the current operating regime. Work is ongoing to determine the effects of reservoir elevation and dam discharge on spawning and incubation.

Revelstoke load-shaping restrictions are being considered within the development of Water Use Plans for the Mica, Revelstoke, and Arrow facilities, for the benefit of White Sturgeon and other fish species. A monitoring and research program should be designed and implemented, possibly involving experimental load-shaping restrictions mandated through Water Use Planning, to determine minimum summer flows required to support consistent spawning and adequate levels of egg and larval survival.

In order to evaluate the larval transport/habitat mis-match hypothesis (see Section 3.1.2), hydrographic surveys of the upper Roosevelt Reach should be conducted and a hydrodynamic model developed to determine relationships between habitat, hydro-operations, and historical recruitment. The results of these analyses may then be used to inform recovery alternatives and future management decisions. In addition, the larval transport/habitat mis-match hypothesis should also be investigated empirically through larval release experiments. Characterization of rearing habitat for late-larval and early-juvenile life stages should be completed and incorporated in the habitat modeling.

If studies suggest that river-reservoir transition zone contains limited suitable rearing habitat and that larval dispersal out of this area is key to promote successful recruitment, alternatives for achieving larval transport to suitable rearing areas or improving rearing conditions in the river-reservoir transition zone should be evaluated.

Schedule: Short to Long term

4) Future Treaties, agreements, or water licences should promote White Sturgeon recovery.

The Columbia River Treaty is scheduled to expire in 2024 and negotiations to renew and alter the Treaty will commence in 2014. The existing treaty imposes numerous restrictions of flow releases from Canadian storage and hydro facilities, many of which could potentially be detrimental to future flow changes needed to promote sturgeon recovery. Any renegotiation of the Treaty or other provincial or international agreements on water management policies must incorporate provisions for White Sturgeon recovery.

Schedule: Short to Long term

5.3.3.2 Water Quality

1) *Continue to assess the effects of altered thermal regimes, total dissolved gases, and water clarity on the timing of spawning, and metabolic rates, growth, and survival of egg through juvenile stages.*

River regulation (possibly in combination with other influences such as logging and climate warming) may have altered natural thermal regimes prior to and during spawning, and may have impacted juvenile survival, growth, and maturation through effects on seasonal metabolic rates. Research on the effects of low water temperatures on egg and larval development and survival has shown that at least in the ALR Reach, cold water temperatures may have negative effects on egg and larval development and survival. The effects of high winter water temperatures on metabolic demand, growth, egg maturation and/or release, and survival have not been investigated but may also impact recruitment success. Measures to mitigate temperature effects include alterations to reservoir operations and multi-level release structures at Revelstoke Dam to provide thermal control of downstream water temperatures. Preliminary Investigations of these measures indicates they will be very expensive (in the case of multi-level release structures) and potentially not achievable on an annual basis (in terms of altered reservoir operations). In addition, they may not result in sufficient increases in recruitment success to warrant the expenditure. However, examinations into the feasibility of these mitigation measures should continue until such time as sufficient information is available to allow an informed decision as to their feasibility and utility.

Mitigation measures to reduce dissolved gas levels have been implemented through operational changes to dam operations and spill or through construction of additional power plants adjacent to existing dams that pass more water through turbines and reduce spill volumes. These changes have likely benefited sturgeon directly by increasing survival during the larval stage and indirectly by increasing productivity of the entire river ecosystem. Additional measures to reduce spills are limited and considering the predicted low risk of TGP to sturgeon recruitment success, are not considered as a high priority for implementation at this time. In addition, summer flow augmentation during the larval sturgeon drift period must consider potential dissolved gas impacts and means for mitigating these impacts.

The construction and operation of dams and storage reservoirs may have resulted in reductions in turbidity levels in sturgeon spawning, egg incubation and larval rearing areas. Laboratory studies show that increased water clarity can increase larval predation rates. Additionally, preliminary assessments of the feasibility of artificially increasing turbidity through the addition of turbidity-inducing substances (e.g., bentonite), have indicated that these measures would be very costly, logistically complex, and of uncertain effectiveness. As such, the potential costs of turbidity augmentation programs outweigh the potential benefits of this type of program. Provision of natural turbidity increases through measures such as freshet spikes to increase erosion also have severe limitations in terms of delivery and scale of effect. Given these limitations, turbidity augmentation is not considered as a viable measure at this time.

Schedule: Medium to Long term

5.3.3.3 Contaminants

1) Determine concentrations of organic and inorganic contaminants in sturgeon, their foods, and habitats.

The Columbia River Integrated Environmental Monitoring Program (CRIEMP) and various Canadian and U.S. government agencies have conducted studies on water and sediment quality in the Columbia River between HLK and Grand Coulee Dam. Recent contaminant data in water, sediment, and tissues (fish and other aquatic organisms) have been reviewed and those suspected to have a negative effect on sturgeon have been identified. Tissues are presently being collected and archived from juvenile sturgeon as part of the juvenile monitoring programs and from adult sturgeon (opportunistically from mortalities) in order to allow testing for bioaccumulated levels of contaminants. Data on food composition and availability are also being investigated. Results from these studies will increase our understanding of contaminant bioaccumulation in aquatic organisms in the Upper Columbia River and their direct and indirect effects on sturgeon health and recruitment.

If contaminants are determined to be limiting White Sturgeon recovery, the UCWSRI would encourage the removal or reduction in the source of problem contaminants, although the agencies with legislative jurisdiction will determine the remediation measures that would be applied. Impacts to important White Sturgeon habitats should be given top priority for protection from contaminant sources.

Schedule: Short term

2) Encourage and support efforts by other entities to assess contaminant effects and monitor contaminant levels.

The lethal and sublethal effects of water and sediment chemical constituents known or suspected to have detrimental effects on sturgeon health are still largely undetermined for all life stages of White Sturgeon. The UCWSRI would provide expertise, data, or sturgeon eggs, larvae or tissues to continuing efforts to determine long-term effects of existing contaminants and supports the clean-up of legacy pollution. Evaluations may require laboratory studies on using eggs, larvae, and juveniles (preferably using cultured stocks) and additional analyses of sediment, periphyton, and suspended sediment samples. Periodic review of available literature, analytical methods, technological advances, and data gathered through the various monitoring programs or research projects, would provide a basis for future re-evaluation of contaminant effects.

Schedule: Long term

5.3.3.4 Habitat Diversity, Connectivity, and Productivity

1) Project future impacts and limitations associated with continuing large scale habitat changes due to basin development and climate change.

Changes in fluvial geomorphology and river temperatures associated with basin development and especially flow regulation and climate change can be expected to have continuing effects. Impacts can be identified by a comparison of pre and post development conditions to understand what habitat types may have been lost. Baseline conditions need to consider effects of other pre-dam influences including logging. Future changes can be forecast based on observed trends.

Schedule: Medium to Long term

2) Investigate means to restore habitats and natural functions of the Columbia River that are beneficial to sturgeon while also minimizing impacts on other uses of the river.

Reservoirs on the Upper Columbia River and bed degradation below dams have reduced the occurrence of overbank flows to the floodplain. As a result, side channels, wetlands, and oxbows that were once connected to the main channel are now separated. When connected, these floodplain habitats provided important nursery areas for native fishes. However, opportunities to restore river flows to presently-isolated floodplain habitats or modify/create these habitat types within existing riverine channels are severely limited in the Transboundary and ALR reaches due to the narrow valley and seasonal inundations from reservoir operations.

River regulation has resulted in the armouring of riverbed substrates. A habitat enhancement option that may have more direct benefits to White Sturgeon recruitment is the provision of clean coarse substrate in spawning, egg incubation, and early larval rearing areas. This technique has been employed successfully to increase spawning success for other sturgeon species where these substrates were limiting and most recently, in the Revelstoke spawning area to increase the suitability for early larval hiding and rearing. In addition, laboratory studies suggest substrate type and quality has a pronounced effect on larval growth and survival.

Meso-habitat experiments or field studies based on carefully-designed habitat manipulations including flow delivery hold promise for rapid application. Basic mechanistic research on limiting factors will provide ideas for restoration actions and provide a basis for support of restoration actions by regulatory agencies

Schedule: Short to Long term

3) Consider passage alternatives for restoring free movements of sturgeon at such time as new information demonstrates the feasibility, benefits, and lack of risk.

Restoration of population connectivity would theoretically benefit White Sturgeon where dams have impeded migration to and from traditional spawning areas and other important seasonal habitats. However, effective passage measures are unclear and passage risks likely exceed potential benefits at this time. Risks include passage of undesirable species such as Walleye and Northern Pike or movement of sturgeon into suboptimal habitats. Passage facilities are not proposed as recovery measures at this time but may be reconsidered in the future if warranted by new information.

Schedule: Long term

4) Evaluate feasibility, benefits, and risks of increasing sturgeon population productivity by increasing nutrient availability.

Alternatives to increase nutrient availability include controlled nutrient releases from point sources, localized embayment nutrient additions, and expansion of large lake or reservoir nutrient addition programs. The value of such programs is unclear for sturgeon and will require considerable research including site evaluations, modelling of response mechanisms, and pilot testing.

Schedule: Long term

5) Assess the impacts of predators, particularly exotic predators, on early sturgeon life stages.

Alternatives may include selective removal of predators using capture/population control programs. These may require evaluations of flow management options. Predator control programs for other species have been notably unsuccessful.

Schedule: Short to Medium term

6) Support the examination of toxic/abrasive sediments in suitable rearing habitats.

Downstream from the Cominco smelter in Trail, sturgeon feeding areas have accumulated potentially toxic and physically abrasive slag from past releases of this material from the smelter. These sediments may directly impact sturgeon as they interact with the bottom, or may indirectly impact growth and survival by reducing invertebrate prey abundance. The ongoing Remedial Investigation and Feasibility Studies (RI/FS) in Lake Roosevelt is investigating the nature and extent of contamination in the Roosevelt Reach and will assess if there are unacceptable risks to the environment as a result of the historical contamination from smelter operations. Depending on the outcomes of studies, the RI/FS will also evaluate potential cleanup actions and other remedies (called remedial alternatives) to safeguard human health and the environment. The UCWSRI supports the objectives of the RI/FS but does not consider these activities as core components of the recovery plan.

Schedule: Short to Long term

5.3.3.5 Population Assessment, Monitoring, & Research

1) Conduct periodic adult stock assessments.

In the Transboundary Recovery area, White Sturgeon population status and trends should be monitored with periodic stock assessments based on mark-recapture studies. Assessments should include basic biological information needed to monitor population status and productivity; invasive procedures should be limited to activities that provide must-have information. Present plans in the Roosevelt Reach call for annual stock assessments from 2013 to 2017. Plans in the Keenleyside Reach are not firmly established but full assessments will likely be repeated at least every 3 years with partial assessments conducted annually in association with broodstock collection efforts.

In the ALR Reach, the remaining adults in the ALR Reach have been intensively studied in the past and their status and movements are sufficiently understood at present. This decision should be re-examined every five years.

Schedule: Short term for Transboundary Reach; Medium term for ALR Reach

2) Continue to investigate the feasibility of establishing a failsafe population or an additional recovery area in the Upper Columbia River recovery area.

At present, it is still unclear whether restoration of natural recruitment in the foreseeable future is feasible. The existing wild population will continue to slowly decline but broodstock numbers should be sufficient to support hatchery stopgap measures for the next 20 to 30 years. Current hatchery release numbers appear sufficient to produce a significant adult population in the same period given the updated information on survival rates. The biggest uncertainty is whether or not the hatchery produced mature adults will ultimately spawn and if natural recruitment can be re-established before wild fish disappear. Thus, every reasonable effort should be undertaken to develop contingencies should any of the assumptions underlying proposed measures prove fallacious.

As discussed in Section 5.3.2, preliminary investigations into the feasibility of the ALR or the Columbia River upstream from Mica Dam are being conducted to assess the feasibility of establishing either a failsafe population or another recovery area in those areas. These investigations should continue.

Schedule: Short to Medium term

3) Conduct regular spawning investigations at key spawning sites.

Key White Sturgeon spawning areas like the Waneta (Pend d'Oreille-Columbia confluence) and Northport areas should be monitored regularly or as needed to answer specific questions (e.g., identify effects of unusual flow conditions, assess habitat modifications) or build upon the long-term databases. At the Waneta spawning area, this work would be an extension of monitoring that has been conducted at this site annually since 1993 using artificial substrate mats and D-ring drift nets to collect White Sturgeon eggs and larvae.

Conduct additional spawning assessments at recently discovered spawning areas to determine if these represent occasional use areas (e.g., only used during high flow years), recently established, or previously undetected areas.

Annual spawning data should be compared with information obtained from the juvenile sturgeon monitoring programs to identify physical factors that contribute to or inhibit recruitment success. Physical habitat parameters at egg collection sites should be measured annually, including water depth, temperature, substrate type, and mean water column velocity.

Schedule: Short to Long term

4) Conduct regular juvenile indexing.

Continue to employ standardized sampling protocols to monitor juvenile White Sturgeon year class abundance, survival estimates, and growth rates throughout the Transboundary and ALR reaches. These monitoring programs should be conducted at regular (yearly or every two years) intervals to allow the detection of density dependent responses of growth and survival that are necessary to adjust stocking rates. These programs also should be designed to detect wild White Sturgeon recruitment and help identify physical or biological factors that may contribute to natural recruitment success.

Schedule: Short to Long term

5) Determine recruitment bottlenecks.

Continue research to identify early life history stages where juvenile recruitment is failing. This investigation should use a combination of laboratory experiments and experimental releases of hatchery-reared juveniles at various stages of development, encapsulated egg or larval samples planted near spawning locations as *in situ* bioassays, sonic telemetry, spawning investigations, juvenile indexing, and habitat analyses.

Schedule: Short to Long term

6) Develop and improve population analysis methods.

Additional work is needed to address limitations in current assessment methods that have significant impacts on population prospects and recovery plan implementation including: a) validity of age estimates based on fin ray sections; b) population estimates based on mark-recapture methods; c) egg development rates used to back-calculate spawning date and to identify physical conditions that coincided with spawning; and d) impact assessment and response tools including computer production models for use in evaluating population viability and potential recovery actions.

Schedule: Short to Medium term

7) Improve the understanding of ecological interactions.

Population productivity and habitat capacity depend in part on food availability and predation mortality. Additional work is needed to evaluate potential limitations resulting from predation, food habits, and feeding behaviour. Predation during critical early life history periods is presently being investigated in the Waneta spawning area by means of a six-year study program to assess the effects of flow on White Sturgeon egg predation. This program also should provide information on the abundance of potential egg predators and identify which species represent the greatest predation threat. The availability of hatchery-released juveniles will continue to provide the opportunity in future years to obtain diet data without risk to wild fish. The effects of the stocking of large numbers of hatchery juveniles on other fish species should be examined using data from the juvenile monitoring programs, diet assessments, and results of on-going native fish indexing programs being conducted as part of BC Hydro's WLR programs in the Keenleyside and ALR reaches and by the Lake Roosevelt Fish Evaluation Project administered by the Spokane Tribe of Indians in the Roosevelt Reach. Appropriate actions will be considered as interactions are identified.

Schedule: Medium to Long term

8) Encourage and support applied biological research

Progress in understanding the likely causes of recruitment failure and potential restoration options have resulted from the combination of laboratory and field studies. Investigations of factors such as the substrate requirements and the various benefits that can result from substrate have provided important contributions to our understanding of sturgeon recovery needs. The need for laboratory studies of basic sturgeon biology is also emphasized by the many continued uncertainties regarding sturgeon biology (e.g. they are not nearly as well studied as groups of fish such as salmon) and the challenge of implementing experimental studies in the large river habitats occupied by white sturgeon.

Schedule: Short to Long term

5.3.3.6 Education and Outreach

Education and outreach are critical to maintaining public support for recovery activities, the Community Working Group (CWG) has been formed to develop and implement these activities.

1) Support active communication and coordination with interested stakeholders to raise awareness of the need to protect White Sturgeon.

Support coordination and funding of the CWG and their communication efforts, as well as outreach to the broader community. This includes implementation of the CWG communication plan and encompasses activities such as development and distribution of communication materials, annual reports, web site maintenance and updates, educational materials and infomercials, coordination of public release events, angler education efforts, and other activities as identified. Encourage, strengthen, and facilitate on-going coordination between the UCWSRI TWG and CWG.

Communication and coordination efforts will include a diverse range of interested stakeholders. These include, but are not limited to, federal, provincial, local and regional governments, First Nations, industrial and environmental interests, rod and gun clubs, US regulatory, and tribal agencies.

Schedule: Short to Long term

2) Pursue opportunities to link Upper Columbia River Sturgeon recovery activities with other efforts.

UCWSRI efforts should be coordinated with Initiative partners, local communities and organizations, and other White Sturgeon Recovery Initiatives (Kootenay and Nechako rivers) through co-shared meetings, linked web sites, and information brochures. Members of the recovery team are encouraged to participate in Basin and Transboundary events i.e., symposia, conferences, workshops, through public presentations, booth displays and outreach.

A representative implementation group of the Community Working Group should be established to provide key communications, public education, and outreach to actively communicate and obtain community, in-kind and financial support of the Recovery Plan. This group should also assist with integration of Recovery Plan information into other local and Transboundary Columbia Basin planning.

Schedule: Short to Long term

3) Implement regular recovery progress reporting to government, aboriginal communities, local agencies, communities, and the general public.

Develop a standardised reporting regime to communicate efforts being made to recover the Upper Columbia White Sturgeon population.

Schedule: Short to Long term

4) Develop coordinated data and reporting systems to facilitate program implementation.

Large numbers of tagged fish will be involved in this recovery effort. Given these numbers, the length of time over which recovery efforts will take place, and the number of different agencies/consultants involved in the program, a coordinated approach to data management and reporting will be required. This will include a comprehensive fish tag database, in which all marked fish and subsequent recaptures of these fish are tracked, along with descriptions to assist with interpretations of growth, survival, and habitat use. Web-based alternatives for maintaining and accessing this information should be examined. This effort should be integrated with other U.S. or BC provincial tagging databases as appropriate.

Schedule: Short to Long term

5) Support regulatory mechanisms and planning processes to protect White Sturgeon and their habitats.

A variety of existing regulatory and planning processes affect sturgeon and their habitats. Sturgeon considerations identified by this recovery plan should be incorporated into appropriate processes including water use and sub basin planning. Sturgeon risks should also be evaluated prior to introductions of new industries or developments.

Schedule: Short to Long term

6) Monitor sturgeon by-catch in the recreational fishery and develop angler awareness programs to reduce harm.

Programs are presently in place to evaluate the extent of by-catch and illegal fishing for White Sturgeon and also to educate anglers on proper handling and release techniques for sturgeon caught as by-catch in recreational fisheries. These programs should be continued as juvenile numbers in the river increase.

Schedule: Short to Long term

5.4 Expected Response

The next 5 to 20 years represent a critical period in recovery of Upper Columbia River White Sturgeon. The existing wild population will continue to decline in abundance while supplementation efforts will continue to replace natural recruitment until such time as the hatchery fish reach adulthood and supplement or replace wild adult spawners. Restoration target population levels will continue to be assessed on an annual basis based on data collected during the various monitoring and research programs in progress or planned in the near future. On-going studies on juvenile population levels and survival will be used to adjust future stocking rates.

The time to achieve this goal is unknown due to uncertainties in key population metrics that are currently being investigated. For example, slight changes in juvenile survival rates or female spawning intervals result in substantially different estimates in the number of years required to achieve the adult population targets. At present, model projections suggest achievement of target adult populations for the Transboundary Reach between 2060 and 2080.

Multiple measures will be required to achieve the goal of a naturally reproducing, self-sustaining population and to increase or restore opportunities for beneficial use, if and when feasible. Although there is some uncertainty as to when and how natural recruitment will be achieved, the coordinated efforts of the UCWSRI since 2002 has substantially increased overall knowledge of the species, protected wild adults, and increased the abundance of juveniles in both the Transboundary Reach and ALR Reach.

6.0 DEVELOPMENT AND IMPLEMENTATION OF OPERATIONAL PLAN

The activities described in Section 5 will be selected for implementation and incorporated into an Operational plan that will be developed by the UCWSRI on a regular basis consistent with the goals and objectives of this plan. Actual implementation schedules will be contingent upon new data collected as part of the monitoring and research activities and the resources available for plan implementation. Evolving knowledge, economic, social, and legal considerations will guide decisions on proceeding with any of the various elements in the implementation schedule.

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8.0 GLOSSARY

Acipenser transmontanus - Scientific name of the White Sturgeon.

Adult – maturity onward; there is no evidence of senescence in White Sturgeon.

Anadromous - Fish life history type involving freshwater spawning and migration to the ocean at some part of the life cycle.

Anthropogenic - Of human cause or origin.

APG - Action Planning Group consisting of policy representatives of government and stakeholders convened to aid in implementation of recovery plan.

Arrow Lakes Reservoir (ALR) Reach: See Upper Columbia River recovery area. Also known as the Mid Columbia River in Canada (BC Hydro designation for Water Use Planning).

BC FLNRO - BC Ministry of Forests, Lands and Natural Resource Operations.

Beneficial use - Typically used to refer to subsistence harvest, recreational fishery harvest, or recreational catch and release fishing.

Benthic - Bottom oriented.

Bioassay - Test for toxic effects on an organism typically conducted by exposure to varying concentrations in a laboratory.

BPA - Bonneville Power Administration.

By-catch - Incidental or unintended catch of non-target species.

CDC - British Columbia Conservation Data Centre.

CITES - Convention on International Trade in Endangered Species of Wild Fauna and Flora.

Condition factor – Body shape index of thinness or plumpness based on weight for a given length.

Conservation hatchery - An artificial fish production facility operated for the purpose of preservation of weak, threatened, or endangered fish species as opposed to the traditional hatchery practice of fish production for harvest or commercial purposes.

COSEWIC - Committee on the Status of Endangered Wildlife in Canada.

CRIEMP - Columbia River Integrated Environmental Monitoring Program.

Critical population benchmark - Effective population sizes corresponding to potentially irreversible genetic consequences that may threaten long term health and sustainability of a population.

Dph - Days post-hatch.

DDT - Dichlorodiphenyltrichloroethane.

Egg/embryo – these terms are often used interchangeably for the period between fertilization and hatch. Egg is more often used for the first portion of the period and can also refer to the unfertilized ovum.

Entrainment - Involuntary capture and downstream passage of water or fish at a dam.

ESA - U.S. Endangered Species Act.

Extirpation - Local extinction of a population or population unit.

Failsafe population - In this context, a sturgeon population established separate from the population units being recovered to provide a hedge for unforeseen circumstances. Failsafe populations are not expected to reproduce naturally and may be established in areas that historically produced sturgeon or in other areas where sturgeon are not present.

Feeding larvae – the period between the initiation of exogenous feeding and completion of metamorphosis. Detailed criteria for the initiation of this phase may include the ability to feed, the initiation of feeding, and release of the melanin plug; however, these events may not be simultaneous. This period ends when the full complement of fins is present.

FL – Fork length of the fish as measured from the tip of the snout to the fork in the tail along the lateral line.

F_{ST} - Fixation index; measure of population differentiation.

Functional Extinction - Small population size below which severe genetic and demographic bottlenecks make recovery unlikely.

GBT - Gas bubble trauma. Fatal or sublethal fish syndrome resulting from exposure to high levels of dissolved gas in the water.

Genetic risk - Threat to population composition and productivity as a result of loss of inherited diversity and potential inbreeding which may increase expression of deleterious recessive traits.

Geomorphology - Physical configuration of the river channel in relation to surrounding topography and geology.

Haplotype - Unique DNA sequence used to distinguish differences among individuals and populations.

Heterozygosity - Genetic diversity.

Hydrograph - Seasonal water flow pattern.

HLK - Hugh L. Keenleyside Dam, the current upstream boundary of the Transboundary Reach.

Juvenile – the period from metamorphosis to maturity. The first year in this period is referred to as age-0.

Keenleyside Reach - See Upper Columbia River recovery area.

KTH - Kootenay Trout Hatchery.

Longevity - Life span typically thought to approach or exceed 100 years of age for White Sturgeon.

mtDNA - Mitochondrial DNA.

nDNA - Nuclear DNA.

NPCC - Northwest Power and Conservation Council.

NWSRI - Nechako White Sturgeon Recovery Initiative.

PCB - Polychlorinated biphenyl.

PIT tag - Passive Integrated Transponder tag. An internal fish tag about the size of a grain of rice that can be used to individually mark fish. Tags are read by an electronic detector passed along the body.

Population segment – A component of a formerly contiguous population that has been fragmented and separated by a dam.

Recovery - For purposes of this plan, refers to a population level that ensures the persistence and viability of naturally-producing populations of White Sturgeon and provides opportunities for beneficial use, if feasible.

Recovery area - See Upper Columbia River recovery area.

Recovery goal - see Recovery.

Recovery measure - Specific task identified in the recovery plan as potentially beneficial to sturgeon recovery.

Recovery objective - Short, medium, and long term directions by which recovery goal may be accomplished.

Recovery strategy - Overarching approaches to sturgeon recovery described in more detail by objectives and measures.

Recovery target - Interim benchmarks describing population attributes by which progress toward recovery will be measured.

Recovery team - Group of technical convened to develop and oversee implementation of recovery plan.

Recruitment - Successful natural reproduction and survival of juvenile fish to a size or age where many are likely to survive contribute to future generations..

RFLP - Restriction fragment length polymorphism.

Rkm - River kilometre.

RI/FS - Remedial Investigation and Feasibility Studies: the methodology that the U.S. Superfund program has established for characterizing the nature and extent of risks posed by uncontrolled hazardous waste sites and for evaluating potential remedial options. http://www.epa.gov/superfund/policy/remedy/pdfs/540g-89004-s.pdf

Roosevelt Reach: See Upper Columbia River recovery area

SARA - Canadian Federal Species at Risk Act.

Staging - In this context, used to describe local migration and concentration near spawning sites prior to spawning.

Swim up - Dispersal life stage of sturgeon where larvae leave the bottom and enter the water column where they are transported downstream.

TDG - Total dissolved gas. Measure of gas pressure in water typically used in the U.S.

TGP - Total gas pressure. Measure of gas pressure in water typically used in Canada.

TMDL - Total maximum daily load. A written quantitative assessment of water-quality problems and contributing pollution sources typically associated with U.S. Enviromental Protection Agency.

Transboundary recovery area: See Upper Columbia River recovery area.

Transboundary Reach: See Upper Columbia River recovery area.

Transition Zone - The semi-riverine upper portion of the river-reservoir interface areas of Lake Roosevelt and Arrow Lakes Reservoir.

UCWSRI - Upper Columbia White Sturgeon Recovery Initiative.

UCWSRP – Upper Columbia White Sturgeon Recovery Plan.

Upper Columbia River recovery area - The Columbia River mainstem from Columbia Lake to Grand Coulee Dam including the lower Kootenay River from Brilliant Dam to the Columbia River confluence. This recovery area is divided into four primary reaches:

> **Kinbasket Reach:** Columbia Lake, the unimpounded portion of the Upper Columbia River, and Kinbasket Reservoir formed by Mica Dam.
>
> **Revelstoke Reach:** The reservoir from Mica Dam downstream to Revelstoke Dam.
>
> **Arrow Lakes Reservoir (ALR) Reach**: The unimpounded and impounded sections of the Columbia River between Revelstoke Dam and Hugh L. Keenleyside Dam (HLK). Also referred to as the Mid-Columbia River in Canada by BC Hydro for Water Use Planning requirements.
>
> **Transboundary Reach**: The Columbia River between Grand Coulee Dam in Washington State and HLK in British Columbia including the lower Kootenay River from Brilliant Dam to the Columbia River confluence, the lower Pend d'Oreille River upstream to Waneta Dam, the lower Kettle and Sanpoil rivers, and the lower Spokane River upstream to Little Falls Dam (Figure 2). The Transboundary Reach is further subdivided into two additional reaches based on geopolitical considerations:
>
> > **Keenleyside Reach:** The Columbia River between HLK and the Canada-U.S. boundary including the lower Kootenay River upstream to Brilliant Dam, and the lower Pend d'Oreille River upstream to Waneta Dam.
> >
> > **Roosevelt Reach:** The Columbia River between the Canada-U.S. boundary and Grand Coulee Dam), the lower Kettle and Sanpoil rivers, and the lower Spokane River upstream to Little Falls Dam.

USEPA - U.S. Environmental Protection Agency

USFWS - U.S. Fish and Wildlife Service

USGS - U.S. Geological Survey

WUP - Water Use Plan. Process initiated by British Columbia to evaluate and refine operations of water use projects throughout the province

WDFW - Washington Department of Fish and Wildlife

Yolk sac larvae – The period between hatch and the initiation of exogenous feeding. This phase has also been referred to as free embryo or eleutheroembryo

YOY - Young-of-the-year

APPENDIX A

Sexual Developmental Stages for White Sturgeon

Table A1: Sexual maturity codes used for White Sturgeon in the upper Columbia Recovery area (adapted from Bruch et al. 2001).

Sex	Code	Developmental State Description
Male	Mv	**Virgin male juvenile**; Testes are ribbon-like in appearance with lateral creases or folds , dark grey to cream coloured attached to a strip of adipose fat tissue.
	M1	**Developing male**; Testes are tubular to lobed, light to dark grey, and embedded in substantial amounts of fat. Testes moderately to deeply lobed have distinct lateral folds.
	M2	**Fully developed male**; Testes large, cream to whitish in colour, deeply lobed and filling most of the abdominal cavity. If captured during active spawning, may release sperm if stroked posteriorly along the abdomen.
	M3	**Spent/recovering male**; Testes size are much reduced, with very distinct lobes and whitish to cream colour.
	M0	**Male based on previous capture**; general unknown maturity
Female	Fv	**Virgin female juvenile**; small feathery looking, beige ovarian tissue attached to a thin strip of adipose fat tissue.
	F1	**Early developing female**; pinkish/beige ovarian tissue with brain-like folds and smooth to rough surface, imbedded in heavy strip of fat tissue. The visible whitish eggs are <0.5 mm in diameter. Ovarian tissue of F1 females that have previously spawned is often ragged in appearance.
	F2	**Early "yellow egg" female**; Yellowish/beige ovarian tissue with deep "brain-like folds embedded in extensive fat tissue giving it a bright yellow appearance. Eggs, 1 to 2 mm in diameter with no apparent greyish pigmentation.
	F3	**Late "yellow egg" female**; large yellowish ovaries with deep lateral folds and reduced associated fat. Yellow/greenish to grey eggs 2.5 mm in diameter. May indicate next year spawning.
	F4	**"Black egg" female**; Large dark ovaries filling much of the abdominal cavity. Exhibiting a distinct "bulls-eye". Very little fat, Eggs are still tight in the ovary, dark grey to black, shiny and large, >3 mm in diameter.
	F5	**Spawning female**; Loose flocculent-like ovarian tissue with eggs free in body cavity shed in layers from deep ovarian folds. Eggs large, from grey to black, similar to F4.
	F6	**Post spawn female**; ovaries immediately after spawning are folded with a mushy pinkish and flaccid appearance, with little or no associated fat. Post spawn females display a characteristic abdominal mid-line depression. Large dark degeneration eggs buried amongst small oocytes.
	F0	**Female based on previous capture**; general unknown maturity
Unknown	97	adult based on size, (i.e. 1.5 m FL or greater) no surgical examination
	98	juvenile/sub-adult based on size, (i.e. no surgical examination
	99	gonad undifferentiated or not visible during surgical examination