Fisheries and Oceans Canada
Ecosystems and Oceans Science

Pêches et Océans Canada
Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2021/064

Pacific Region

Recovery Potential Assessment for Lower Fraser River White Sturgeon (*Acipenser transmontanus)*

Karl K. English[1], Wendell Challenger[1], David Robichaud[1], and Josh Korman[2]

[1]LGL Limited
9768 Second Street
Sidney, BC V8L 3Y8

[2] Ecometric Research
3560 West 22nd Avenue
Vancouver, BC V6S 1J3

November 2021

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044
ISBN 978-0-660-40419-6 Cat No Fs70-5/2021-064E-PDF

Correct citation for this publication:

English, K.K., Challenger, W., Robichaud, D. and Korman, J. 2021. Recovery Potential Assessment for Lower Fraser River White Sturgeon (*Acipenser transmontanus*). DFO Can. Sci. Advis. Sec. Res. Doc. 2021/064. vii + 85 p.

Aussi disponible en français :

*English, K.K., Challenger, W., Robichaud, D. and Korman, J. 2021. Évaluation du potentiel de rétablissement de l’esturgeon blanc (*Acipenser transmontanus*) du bas Fraser. Secr. can. de consult. sci. du MPO. Doc. de rech. 2021/064. viii + 98 p.*

TABLE OF CONTENTS

ABSTRACT viii

1. INTRODUCTION 1

2. BIOLOGY, ABUNDANCE, DISTRIBUTION AND LIFE HISTORY PARAMETERS 1

2.1. ELEMENT 1: SUMMARIZE THE BIOLOGY OF WHITE STURGEON 1

2.2. ELEMENT 2: EVALUATE THE RECENT SPECIES TRAJECTORY FOR ABUNDANCE, DISTRIBUTION AND NUMBER OF POPULATIONS 7

2.3. ELEMENT 3: ESTIMATE THE CURRENT OR RECENT LIFE-HISTORY PARAMETERS FOR WHITE STURGEON 10

3. HABITAT AND RESIDENCE REQUIREMENTS 11

3.1. ELEMENT 4: DESCRIBE THE HABITAT PROPERTIES THAT WHITE STURGEON NEEDS FOR SUCCESSFUL COMPLETION OF ALL LIFE-HISTORY STAGES. DESCRIBE THE FUNCTION(S), FEATURE(S), AND ATTRIBUTE(S) OF THE HABITAT, AND QUANTIFY BY HOW MUCH THE BIOLOGICAL FUNCTION(S) THAT SPECIFIC HABITAT FEATURE(S) PROVIDES VARIES WITH THE STATE OR AMOUNT OF HABITAT, INCLUDING CARRYING CAPACITY LIMITS, IF ANY 11

3.2. ELEMENT 5: PROVIDE INFORMATION ON THE SPATIAL EXTENT OF THE AREAS IN WHITE STURGEON DISTRIBUTION THAT ARE LIKELY TO HAVE THESE HABITAT PROPERTIES 14

3.3. ELEMENT 6: QUANTIFY THE PRESENCE AND EXTENT OF SPATIAL CONFIGURATION CONSTRAINTS, IF ANY, SUCH AS CONNECTIVITY, BARRIERS TO ACCESS, ETC. 18

3.4. ELEMENT 7: EVALUATE TO WHAT EXTENT THE CONCEPT OF RESIDENCE APPLIES TO THE SPECIES, AND IF SO, DESCRIBE THE SPECIES' RESIDENCE 18

4. THREATS AND LIMITING FACTORS TO THE SURVIVAL AND RECOVERY OF WHITE STURGEON 19

4.1. ELEMENT 8: ASSESS AND PRIORITIZE THE THREATS TO THE SURVIVAL AND RECOVERY OF WHITE STURGEON 19

4.2. ELEMENT 9: IDENTIFY THE ACTIVITIES MOST LIKELY TO THREATEN (I.E., DAMAGE OR DESTROY) THE HABITAT PROPERTIES IDENTIFIED IN ELEMENTS 4-5 AND PROVIDE INFORMATION ON THE EXTENT AND CONSEQUENCES OF THESE ACTIVITIES 28

4.3. ELEMENT 11: DISCUSS THE POTENTIAL ECOLOGICAL IMPACTS OF THE THREATS IDENTIFIED IN ELEMENT 8 TO THE TARGET SPECIES AND OTHER CO-OCCURRING SPECIES. LIST THE POSSIBLE BENEFITS AND DISADVANTAGES TO THE TARGET SPECIES AND OTHER CO-OCCURRING SPECIES THAT MAY OCCUR IF THE THREATS ARE ABATED. IDENTIFY EXISTING MONITORING EFFORTS FOR THE TARGET SPECIES AND OTHER CO-OCCURRING SPECIES ASSOCIATED WITH EACH OF THE THREATS, AND IDENTIFY ANY KNOWLEDGE GAPS 29

5. RECOVERY TARGETS 30

5.1. ELEMENT 12: PROPOSE CANDIDATE ABUNDANCE AND DISTRIBUTION TARGET(S) FOR RECOVERY 30

5.2. ELEMENT 13: PROJECT EXPECTED POPULATION TRAJECTORIES OVER A SCIENTIFICALLY REASONABLE TIME FRAME (MINIMUM OF 10 YEARS), AND TRAJECTORIES OVER TIME TO THE POTENTIAL RECOVERY TARGET(S), GIVEN CURRENT WHITE STURGEON POPULATION DYNAMICS PARAMETERS 32

5.3. ELEMENT 14: PROVIDE ADVICE ON THE DEGREE TO WHICH SUPPLY OF SUITABLE HABITAT MEETS THE DEMANDS OF THE SPECIES BOTH AT PRESENT AND WHEN THE SPECIES REACHES THE POTENTIAL RECOVERY TARGET(S) IDENTIFIED IN ELEMENT 12 33

5.4. ELEMENT 15: ASSESS THE PROBABILITY THAT THE POTENTIAL RECOVERY TARGET(S) CAN BE ACHIEVED UNDER CURRENT RATES OF POPULATION DYNAMICS PARAMETERS, AND HOW THAT PROBABILITY WOULD VARY WITH DIFFERENT MORTALITY (ESPECIALLY LOWER) AND PRODUCTIVITY (ESPECIALLY HIGHER) PARAMETERS 34

6. SCENARIOS FOR MITIGATION OF THREATS AND ALTERNATIVES TO ACTIVITIES 34

6.1. ELEMENT 16: DEVELOP AN INVENTORY OF FEASIBLE MITIGATION MEASURES AND REASONABLE ALTERNATIVES TO THE ACTIVITIES THAT ARE THREATS TO THE SPECIES AND ITS HABITAT (AS IDENTIFIED IN ELEMENTS 8 AND 10) 34

6.2. ELEMENT 17: DEVELOP AN INVENTORY OF ACTIVITIES THAT COULD INCREASE THE PRODUCTIVITY OR SURVIVORSHIP PARAMETERS (AS IDENTIFIED IN ELEMENTS 3 AND 15) 35

6.3. ELEMENT 18: IF CURRENT HABITAT SUPPLY MAY BE INSUFFICIENT TO ACHIEVE RECOVERY TARGETS (SEE ELEMENT 14), PROVIDE ADVICE ON THE FEASIBILITY OF RESTORING THE HABITAT TO HIGHER VALUES. ADVICE MUST BE PROVIDED IN THE CONTEXT OF ALL AVAILABLE OPTIONS FOR ACHIEVING ABUNDANCE AND DISTRIBUTION TARGETS 35

6.4. ELEMENT 19: ESTIMATE THE REDUCTION IN MORTALITY RATE EXPECTED BY EACH OF THE MITIGATION MEASURES OR ALTERNATIVES IN ELEMENT 16 AND THE INCREASE IN PRODUCTIVITY OR SURVIVORSHIP ASSOCIATED WITH EACH MEASURE IN ELEMENT 17 38

6.5. ELEMENT 20: PROJECT EXPECTED POPULATION TRAJECTORY (AND UNCERTAINTIES) OVER A SCIENTIFICALLY REASONABLE TIME FRAME AND TO THE TIME OF REACHING RECOVERY TARGETS, GIVEN MORTALITY RATES AND PRODUCTIVITIES ASSOCIATED WITH THE SPECIFIC MEASURES IDENTIFIED FOR EXPLORATION IN ELEMENT 19. INCLUDE THOSE THAT PROVIDE AS HIGH A PROBABILITY OF SURVIVORSHIP AND RECOVERY AS POSSIBLE FOR BIOLOGICALLY REALISTIC PARAMETER VALUES. 40

6.6. ELEMENT 21: RECOMMEND PARAMETER VALUES FOR POPULATION PRODUCTIVITY AND STARTING MORTALITY RATES AND, WHERE NECESSARY, SPECIALIZED FEATURES OF POPULATION MODELS THAT WOULD BE REQUIRED TO ALLOW EXPLORATION OF ADDITIONAL SCENARIOS AS PART OF THE ASSESSMENT OF ECONOMIC, SOCIAL, AND CULTURAL IMPACTS IN SUPPORT OF THE LISTING PROCESS 46

7. ALLOWABLE HARM ASSESSMENT 46

7.1. ELEMENT 22: EVALUATE MAXIMUM HUMAN-INDUCED MORTALITY AND HABITAT DESTRUCTION THAT THE SPECIES CAN SUSTAIN WITHOUT JEOPARDIZING ITS SURVIVAL OR RECOVERY 46

8. SOURCES OF UNCERTAINTY AND FUTURE WORK 47

9. ACKNOWLEDGMENTS 48
10. REFERENCES CITED..48
APPENDIX A: SUMMARY OF LOWER FRASER RIVER WHITE STURGEON MONITORING AND ASSESSMENT PROGRAM, 2019 59
APPENDIX B: GRAVEL EXTRACTION SITES ALONG THE LOWER FRASER RIVER...........61
APPENDIX C: RECREATIONAL STURGEON FISHERY CATCH 62
APPENDIX D: STURGEON CATCH ESTIMATES FOR LOWER FRASER RIVER FIRST NATION GILLNET FISHERIES 68
APPENDIX E: OVERVIEW SUMMARY OF ISAMR MODEL..81

LIST OF TABLES

Table 1. Life history parameters for Lower Fraser River White Sturgeon DU 11

Table 2. List of identified threats associated with each COSEWIC threat category and the risk assessment associated with each threat 20

Table 3. Confirmed sturgeon spawning areas in the lower Fraser River, peak counts of spawning-sized sturgeon from side-scan sonar surveys at these sites, and the volume of gravel extracted from these sites from 1964-2010 22

Table 4. Survival threshold and candidate recovery thresholds for Lower Fraser White Sturgeon 31

Table 5. Examples of feasible mitigation measures and reasonable alternatives to threatening activities, and estimates of the relative benefits to juvenile and adult mortality and recruitment to Age 7 for each mitigation measure or alternative to threatening activity. 36

Table 6. Recruitment scenarios and settings used in forward population projections used to assess the survival and candidate recovery thresholds 41

Table 7. Results from population projections assessing the likelihood of meeting the survival threshold and candidate recovery abundance thresholds within a 50-year timeframe 44

LIST OF FIGURES

Figure 1. Location map for the Lower Fraser White Sturgeon DU ... 3

Figure 2. Average annual growth increments of 60-179 cm FL White Sturgeon in the lower Fraser River, by year and by 20-cm FL size group ... 7

Figure 3. Abundance estimates of Lower Fraser River White Sturgeon from 2000 to 2019 ... 9

Figure 4. Estimated age-7 abundances prior to and during the assessment period ... 10

Figure 5. Distribution of mainstem Region 2 and Region 3 White Sturgeon catch in the FRSCS monitoring and assessment program ... 14

Figure 6. The lower Fraser River downstream of Hatzic, illustrating Glova's juvenile White Sturgeon catch data ... 16

Figure 7. The lower Fraser River upstream of Hatzic, illustrating Glova's juvenile White Sturgeon catch data ... 17

Figure 8. Estimates of Chum Salmon and Eulachon escapement in the lower Fraser River from 1995-2016 ... 26

Figure 9. Estimates of the ratio of juveniles (age 7) per adult, as a function of Chum Salmon and Eulachon escapement in the lower Fraser River from 2000-2012 ... 26

Figure 10. Simulated trends in White Sturgeon abundances under current conditions ... 33

Figure 11. Observed age-7 to adult relationship within the assessment period ... 41

Figure 12. Simulated trends in juvenile (60-99 cm FL) abundances (A) and corresponding forecasts of adults (160-279 cm FL) and the total population (60-279 cm FL) abundances under the six recruitment hypotheses (B) ... 45

ABSTRACT

The Lower Fraser White Sturgeon (*Acipenser transmontanus*) population is genetically and spatially isolated from fish upstream of Hells Gate, and is without genetic structure within its range. The population inhabits a wide range of habitats within its range.

The population is undergoing declines in abundance, both overall and specifically in the juvenile and subadult size/age classes. The adult size/age class has been gradually increasing over the past 20 years, but is expected to start to decline within 5 years. Candidate recovery thresholds are set to 60,000 sturgeon in the 60-279 cm fork length (FL) size range (Age 7-55) and 20,000 adult sturgeon (160-279 cm FL, Age 23-55). We have also evaluated the potential for the abundance of adult sturgeon to remain above the previously defined threshold level of 10,000 adults.

The biggest threats to recovery include: the food available for all life stages of sturgeon; further reduction in the habitat available for sturgeon, bycatch mortalities associated with in-river gillnet fisheries; and sub-lethal factors that affect the spawning frequency and spawning success for adult sturgeon.

Potential and realized mitigation actions, in the order in which they are presented in the report, include: maintaining the current moratorium on gravel extraction from the lower Fraser River; managing dredging to minimize the impacts on sturgeon; reducing the effects of fisheries on sturgeon; improving access to juvenile rearing habitat (e.g. replacing old tidal/flood gates with “fish friendly” gates); and reducing fisheries (or fishery related impacts) on important species that directly or indirectly support the food supply for sturgeon (e.g. Fraser Chum Salmon, *Oncorhynchus keta*, and Eulachon, *Thaleichthys pacificus*).

Population projections suggest that both large natural improvements to survivorship and recruitment and substantive management actions will be required in order to reverse the declining trends for the population and to meet the candidate recovery threshold of 60,000 Age 7-55 sturgeon within a 50-year horizon.

Physical habitat availability had declined over the past century, but should be sufficient to support the candidate recovery threshold of 60,000 Age 7-55 sturgeon, an abundance level that was observed as recently as the early 2000’s. Food resources available to Lower Fraser White Sturgeon, such as Eulachon and Chum Salmon, have declined in a way that matches the observed declines in juvenile White Sturgeon, and the prey base may need to be recovered in order to support White Sturgeon at the abundance levels targeted for recovery.

1. INTRODUCTION

After the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses an aquatic species as Threatened, Endangered, or Extirpated, Fisheries and Oceans Canada (DFO) undertakes a number of actions required to support implementation of the *Species at Risk Act* (SARA). Many of these actions require scientific information on the current status of the species, threats to its survival and recovery, and the feasibility of recovery. Formulation of this scientific advice has typically been developed through a Recovery Potential Assessment (RPA) that is conducted shortly after the COSEWIC assessment. This timing allows for consideration of peer-reviewed scientific analyses into SARA processes including recovery planning.

An assessment of White Sturgeon (*Acipenser transmontanus*) in Canada (COSEWIC 2003) divided the species into six Nationally Significant Populations (NSP) based on geography and genetics: the lower, middle, and upper Fraser River; Nechako River; Columbia River; and Kootenay River. As a whole, White Sturgeon was assessed as endangered by COSEWIC, but only the last four populations were listed as endangered under SARA in 2006. Following the listing process, an RPA (Wood et al. 2007) was undertaken for the listed populations, followed by advice on the identification of critical habitat (Hatfield et al. 2013). Since 2009, a species plan has been in development by the BC Ministry of Forests, Lands, Natural Resource Operations & Rural Development (FLNRORD) and the Fraser River Sturgeon Conservation Society (FRSCS). The SARA recovery strategy for White Sturgeon in Canada was published in 2014 (DFO 2014a).

After 2003, COSEWIC replaced the “Nationally Significant Population” concept with the “Designatable Unit” (DU) concept. During a COSEWIC re-assessment in 2012 (COSEWIC 2012), the White Sturgeon in Canada were divided into four DUs. The boundaries for three of the DUs were the same as those for the previously-defined NSPs (Lower Fraser, Upper Columbia, and Upper Kootenay White Sturgeon), and the remaining three NSPs (Middle Fraser, Nechako, and Upper Fraser NSPs) were combined into one DU (Upper Fraser White Sturgeon). In 2012, COSEWIC assessed the Lower Fraser White Sturgeon DU as threatened (COSEWIC 2012).

In support of listing recommendations for the Lower Fraser White Sturgeon DU, DFO Science has been asked to undertake an RPA, based on the National Frameworks (DFO 2007a,b). The process was undertaken in 2015, but the Canadian Science Advisory Secretariat (CSAS) Working Paper on which it was based (i.e., Hatfield and Smyth, unpublished) was never finalized. In 2019, the RPA process was re-started, and the current document represents the scientific working paper that resulted.

The advice in the RPA may be used to inform both scientific and socio-economic elements of the listing decision, as well as development of a recovery strategy and action plan(s), and to support decision-making with regards to the issuance of permits, agreements and related conditions, as per section 73, 74, 75, 77 and 78 of SARA if listed. The advice generated via this process will also update and/or consolidate any existing advice regarding Lower Fraser White Sturgeon.

2. BIOLOGY, ABUNDANCE, DISTRIBUTION AND LIFE HISTORY PARAMETERS

2.1. ELEMENT 1: SUMMARIZE THE BIOLOGY OF WHITE STURGEON

Sturgeons are a family of fish species dating back to the Triassic Period (Birstein et al. 1997). Sturgeons have a mainly cartilaginous skeleton, a heterocercal caudal fin, and elongated scaleless body covered with rows of large bony plates called scutes. Sturgeon have sensitive barbels between a bottom-oriented mouth and an elongated snout. The family is restricted to rivers, lakes, and coastlines of the Northern Hemisphere (Bemis et al. 1997). Most sturgeons are anadromous bottom-feeders, though some species exclusively inhabit freshwater environments, and others primarily inhabit coastal marine environments (Bemis et al. 1997). Among the 27 species of sturgeon, there is a Pacific clade that includes White Sturgeon (Birstein and Desalle 1998).

White Sturgeon are distributed along the Pacific Coast of North America, with breeding populations in the Fraser, Columbia, San Joaquin, and Sacramento rivers (Hildebrand et al. 2016). White Sturgeon is long-lived and is the largest freshwater fish species in North America (Scott and Crossman 1973). Fish of over 6 m in length have been reported in the Fraser River (Scott and Crossman 1973), estimated to be over 100 years old. The species is identified by the two rows of four to eight ganoid bony plates between the anus and anal fin, with about 45 rays present in the dorsal fin. Coloring ranges from gray to brownish on the dorsal side, with gray fins, and is consistently white on the ventral surface (Scott and Crossman 1973). The barbels are situated anterior to the mouth, closer to the snout than the mouth.

Several populations of White Sturgeon are recognized. Using microsatellites, genetic differentiation is high enough to distinguish White Sturgeon among watersheds (Drauch Schreier et al. 2013), suggesting that among-basin movements (e.g., Welch et al. 2006) are limited. Within Canada, four Designatable Units of White Sturgeon are recognized by COSEWIC: Lower Fraser; Upper Fraser; Upper Columbia, and Upper Kootenay White Sturgeon (COSEWIC 2012). Comparisons among populations have suggested that physical differences (e.g., snout shape) exist among the Fraser River populations (Hildebrand et al. 2016).

Lower Fraser White Sturgeon occurs in the mainstem Fraser River from the marine estuary upstream to Hells Gate (Figure 1). It also occurs in the Harrison and Pitt rivers, Pitt and Harrison lakes, and the confluences or lower reaches of numerous large and small tributaries. This DU has unimpeded access to the marine waters but are not fully anadromous, with only a portion of the population showing evidence of marine movements (Lane 1991, Veinott et al. 1999, Robichaud et al. 2017), and only after a certain age (Shaughnessy et al. 2015). The extent and prevalence of marine habitat use is not well understood (Hildebrand et al. 2016, Robichaud et al. 2017). The habitats used by Lower Fraser White Sturgeon are discussed in ELEMENT 4.

2.1.1. Polyploidy

Genome duplication during sturgeon evolution has led to sturgeons being polyploid, containing more than two paired sets of chromosomes (Dingerkus and Howell 1976). A study of microsatellite inheritance in White Sturgeon supports that it is an ancestral octoploid, with 240 chromosomes (Drauch Schreier et al. 2011). Alternative ploidy states, the result of spontaneous autopolyploidy, have been documented in White Sturgeon (Schreier et al. 2013). Spontaneous polyploids, which are morphologically indistinguishable from individuals of ‘normal’ ploidy, can have fertility issues, or may produce infertile offspring, depending on the ploidy of the mate. Artificial spawning techniques (utilized in sturgeon aquaculture programs) can unintentionally result in the production of spontaneous autopolyploids.

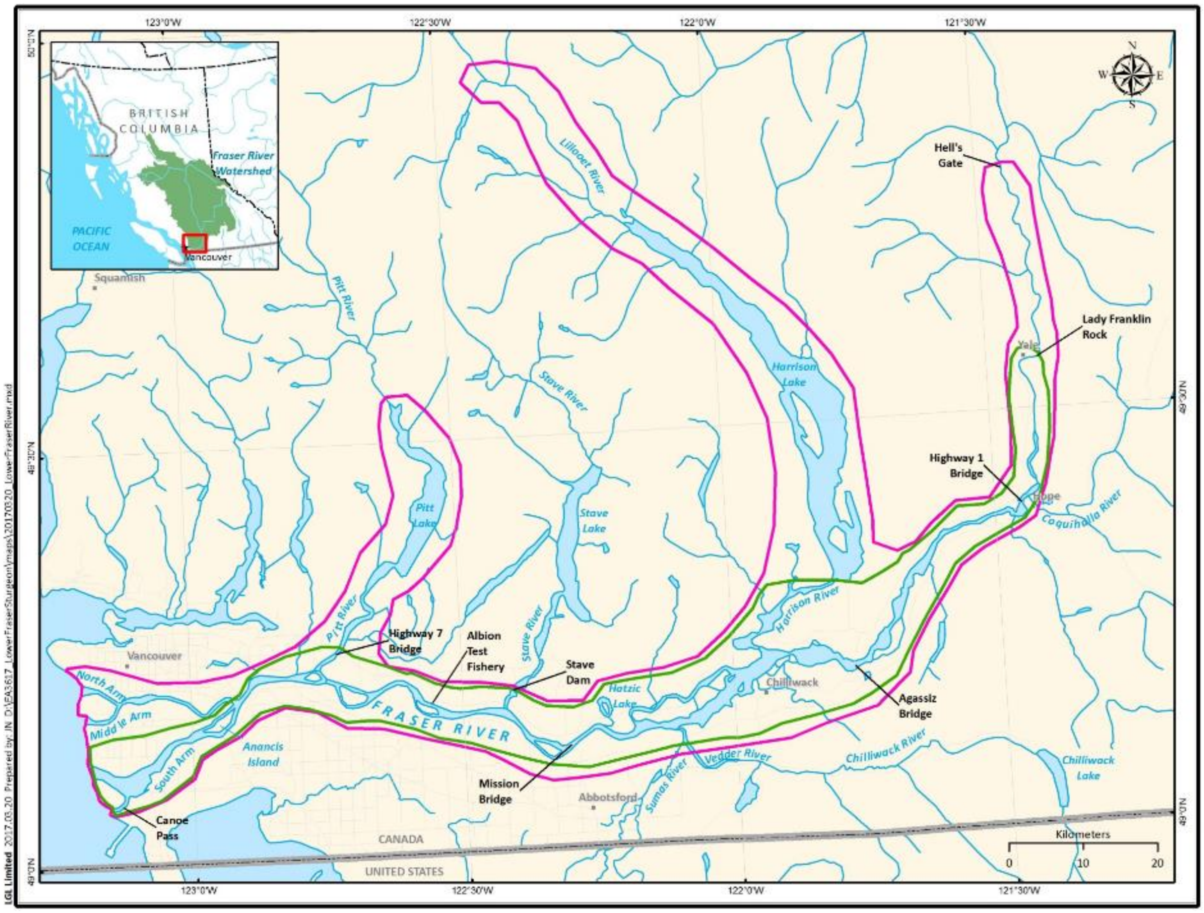

Figure 1. Location map for the Lower Fraser White Sturgeon DU. Area within red line presents the extent of known/observed distribution of the Lower Fraser White Sturgeon DU. The area inside the green line is the "core assessment area", used for the production of White Sturgeon abundance estimates presented in Nelson et al. (2020) and Challenger et al. (2020). Figure reproduced from Nelson et al. (2020).

2.1.2. Life Stages

White sturgeon are slow-growing with a delayed onset of sexual maturity. The DFO White Sturgeon Recovery Strategy (DFO 2014a) defines six life stages.

Egg/Embryo Stage — This life stage refers to the 'in-egg' incubation period from fertilization to hatch. Hatch occurs 5 to 10 days after fertilization depending on water temperature, with temperatures in excess of 20° C leading to abnormal development (Wang et al. 1985). This life stage ends at hatch.

Yolk Sac Larval Stage (0 to 12 days post-hatch) — At the beginning of this period some drift may occur until the larvae find appropriate habitat, after which individuals tend to remain within interstitial spaces of riverbed substrates (e.g., McAdam 2011). This life stage ends at the onset of exogenous feeding, after the yolk sac is exhausted.

Feeding Larval Stage (12 to 40 days post-hatch) — At the onset of this larval period individuals emerge from hiding habitats, show nocturnal drift, and initiate exogenous feeding. First feeding occurs from eight to 16 days post-hatch, after about 200 accumulated temperature units (Doroshov et al. 1983, Buddington and Christofferson 1985, Gawlicka et al. 1995, Boucher 2012). Feeding larvae forage on benthos, periphyton, and zooplankton (Buddington and Christofferson 1985, Muir et al. 2000). Under culture conditions, the highest daily mortality rate for larval sturgeon occurs in the earliest days of exogenous feeding (Gisbert and Williot 2002); and under wild conditions, predation induced mortality is common during this stage. This life stage ends at metamorphosis.

Early Juvenile Stage (40 days to 2 years) — After metamorphosis, all White Sturgeon life stages are morphologically similar (Buddington and Christofferson 1985, Deng et al. 2002). Diets and habitat use vary ontogenetically, primarily due to differences in body size. During the Early Juvenile stage, fish become less susceptible to predation. Age 1 individuals can be observed in habitats that are similar to those occupied by adults. The division point between this and the next life stage (i.e., at Age 2) is somewhat arbitrary.

Late Juvenile, Subadult, and Adult Stage (>2 years) — Individuals aged 2 or older differ in size and sexual maturity, but habitat use is similar. This life stage may include activities such as staging, overwintering, migration, and rearing. The size and age of sexual maturity varies among individuals and by sex (Semakula and Larkin 1968). The abundance models on which our projections are based (see ELEMENT 13) have used 160 cm fork length (Nelson et al. 2020) and age 23 (Challenger et al. 2020) as useful thresholds when defining adulthood (on average) in the Lower Fraser White Sturgeon population. Food resources shift during this stage, with an increasing trend toward piscivory in older fish. Juvenile White Sturgeon are mainly benthic feeders, foraging on aquatic insects, isopods, amphipods, clams, snails, and small fish or fish eggs (Scott and Crossman 1973, McCabe et al. 1993). Adult White Sturgeon feed on fish, crayfish, molluscs, and chironomids (Bajkov 1949, McKechnie and Fenner 1971, Scott and Crossman 1973, Galbreath 1979, Muir et al. 1988). In the lower Fraser River, White Sturgeon have access to a broader range of food sources, including marine and estuarine fish and invertebrates, and seasonally available migratory stocks of lampreys (Petromyzontidae), Pacific salmon (*Oncorhynchus* spp.), or Eulachon (*Thaleichthys pacificus*).

Spawning — This is the period of active reproduction for mature individuals. Typically, this is shortly after the peak of the spring freshet (Stoddard 2017), but the actual timing varies among locations. See the Reproduction and Recruitment section, below.

2.1.3. Reproduction and Recruitment

The size or age at which Lower Fraser White Sturgeon become sexually mature varies among individuals and by sex, whereby males tend to mature at a younger age (11 years or later) and smaller size than females (26 years or later; Semakula and Larkin 1968). Individual Lower Fraser White Sturgeon may spawn multiple times throughout their lifetime. The interval between a wild female's spawning events has been reported to vary from 4 to 11 years and increases with age (Semakula and Larkin 1968, Scott and Crossman 1973). More work on spawning periodicity is required. Hildebrand et al. (2016) argued that further study is needed to determine the roles of endogenous and environmental factors in spawning periodicity, given their importance for both aquaculture and conservation (Doroshov et al.1997).

Spawning occurs in the late spring and early summer (into early August, Perrin et al. 2003), as water temperatures are rising (Parsley et al. 1993, 2002, Parsley and Kappenman 2000, Paragamian et al. 2002, Perrin et al. 2003, Sykes et al. 2007). To spawn, White Sturgeon release large numbers of eggs and milt into the water column of turbulent river habitats. Some studies consider velocity and depth to be more important than substrate preferences during spawning (Paragamian et al. 2009, McDonald et al. 2010, Sykes 2010), despite the critical need for specific habitats for the survival of eggs and very early life stages (McAdam et al. 2005, Paragamian et al. 2009, McAdam 2011, Boucher 2012). In the Columbia and Snake rivers, spawning has occurred largely in the tailwater areas of large dams (e.g., Parsley et al. 1993, Parsley and Kappenman 2000, Lepla et al. 2001, Parsley and Beckman 2004, Terraquatic Resource Management 2011) or at the confluences of large tributaries. In the lower Fraser

River, spawning has been documented in the mainstem river and in large side channel habitats from ~ 5 km upstream of Hope to the confluence of the Harrison River, including at Minto, Jesperson, Peters, Herrling Island Side Channel, Seabird Side Channel, Ruby Creek Side Channel, Hunter Creek mouth, Hamilton Bar, Floods Bar, Bristol Island / Landstrom Bar & Side Channel, Coquihalla Fan & Side Channel, Mountain Bar, and Bar 289 (RL&L Environmental Services Ltd. 2000, Perrin et al. 2003, Johnson et al. 2016, 2017, 2018, Stoddard 2017).

The number of eggs produced by female White Sturgeon is proportional to body size. Hatchery White Sturgeon in San Francisco Bay produce 3,192 to 8,582 (mean 5,648) eggs per kilogram of body weight (Chapman et al. 1996). In Canada, Scott and Crossman (1973) reported egg quantities ranging from 700,000 to four million eggs per female. Eggs are approximately 3.5 mm in diameter, adhesive, and demersal (Deng et al. 2002), and size does not vary significantly with the length of the female (Chapman et al. 1996). Sex ratios in the wild are generally 1:1 (Chapman et al. 1996, Hildebrand and Parsley 2013, BC Hydro 2015).

Survival from egg to adulthood is very low. During the first year alone, survival is estimated at 1 in 250,000 (Gross et al. 2002). Yet, survival rates increase with age/size. At age 1-2 years, annual survival rates of hatchery-produced White Sturgeon can range from 18% (Robichaud et al. 2020) to 32% (Robichaud and Gingerich 2020), and can be density dependent (Justice et al. 2009), but estimates tend to be biased low in shorter-term studies. In a long-term study in the Columbia River, BC Hydro (2016b) found age 1-2 survival to be heavily influenced by size-at-release (47.6% at 100 g; 86.3% at 200 g; and 98.1% at 300 g), and found survival rates that were much higher than the original 27-29% assessments (Golder Associates 2007) that were made based on a shorter time series. In the later juvenile, subadult, and adult life stages, annual Fraser River survival rate estimates often exceed 90% (Semakula 1963, Walters et al. 2005, Challenger et al. 2020). Nevertheless, the combined effect of low early survival and the compounding of mortality over many years results in relatively few individuals surviving to adulthood.

2.1.4. Movements and Behaviour

Most movements in the Fraser River tend to be restricted to a particular river section, as ‘whole’ river migratory movements have not been observed (Beardsall and McAdam, BC Ministry of Environment, Vancouver, BC, unpublished data), and as evidenced by the genetic population structure that exists among the three Fraser River NSPs (Smith et al. 2002, Schreier 2012). Tagging studies have demonstrated movements of adult White Sturgeon among the middle Fraser, upper Fraser, and Nechako rivers (including some spawning migrations; Williamson et al. *in prep*[1]), several exchanges of fish have been detected between the Lower and Upper Fraser DU areas (Challenger and Robichaud 2018), and a few tagged individuals are known from recapture data to have made among-basin movements (e.g., Welch et al. 2006), yet these long-distance movements are thought to be exceptional cases.

Within the Fraser River mainstem downstream of Hells Gate, movements are generally unrestricted, and White Sturgeon display a complex set of movement patterns, exhibiting migratory behaviour that varies seasonally and among individuals (ECL Envirowest Consultants 1992, Robichaud et al. 2017, Golder Associates. 2019). Some individuals are relatively sedentary, and others make annual (or nearly annual) migrations, the distance varying among

---

[1] Williamson, C., Toth, B.M., and Gantner , N. Movements of White Sturgeon between putative population areas in the Upper Fraser Watershed 1995-2019. Report for Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, Williams Lake, BC. In prep.

individuals. Some individuals make repeated migrations each year, while others change their migratory behaviour from year to year (Robichaud et al. 2017).

Lower Fraser White Sturgeon are most sedentary during winter months when they are on their overwintering grounds (Robichaud et al. 2017, Golder Associates 2019). In general, activity levels decline in cold water temperatures (below 15 °C; Haynes et al. 1978), and though feeding occurs throughout the winter (Stoddard 2017), it is at greatly reduced rates. White Sturgeon in overwintering areas typically remain there all winter (RL&L Environmental Services 1994, Robichaud et al. 2017).

From spring to fall, juveniles and adults disperse widely. Most movements and migrations of White Sturgeon are linked to feeding. During these periods, sturgeon move extensively between holding and foraging areas. Movement patterns in the lower Fraser River suggest upstream and downstream movements in the spring and fall, associated with availability of migrating Eulachon and Pacific salmon (ECL Envirowest Consultants 1992, Robichaud et al. 2017, Nelson et al. 2020). During these movements, travel speeds are skewed toward slow movements (range 0.12-1.5 km/h, mean 0.32 km/h), and upstream speeds do not vary significantly in magnitude from downstream ones (Robichaud et al. 2017). Nevertheless, some faster movement rates have been detected (e.g., 60 km @ 2 km/d; 7 km @ 18 km/h; McDonald et al. 1987, Robichaud et al. 2017).

Other movements and migrations of White Sturgeon are linked to spawning. Cues that trigger spawning behaviour are not well understood, but temperature may play a role. In the Waneta area of the Columbia River, onset of initial spawning always occurred around the summer solstice, when mean water temperatures reached 14 °C, and on the descending part of the Pend d'Oreille River hydrograph (Golder Associates 2010). In the Kootenai River, spawning migrations were triggered when temperatures were 6 to 8 °C (March to April), ripeness was achieved at 10 to 12 °C (late May to June) as freshet levels descended (Ross et al. 2015, Hardy et al. 2016). In the Sacramento River, minimum flows were required for spawning (Schaffer 1997). In the Nechako River, clear and shallow water allowed spawning to be observed. There, spawning occurred in small groups (usually one female and 2-3 smaller males; Triton Environmental Consultants, 2004). The males will hold positions near the female. Eventually, a male will turn its ventral surface towards the female, and the pair will undulate in unison while moving upstream. Polyandry has been confirmed genetically (Jay et al. 2014). In the lower Columbia River, White Sturgeon are thought to be communal broadcast spawners (Anders and Beckman, 1993), thus it is possible that spawning behaviours vary with number of fish present (there are few spawning adults in the Nechako compared to the lower Columbia River).

2.1.5. Growth

White Sturgeon are slow-growing, with a delayed onset of sexual maturity. Growth rates vary ontogenically, and among populations. Their developmental rate is reduced for embryos and larvae reared in colder temperatures (BC Hydro 2016a), even when expressed by Accumulated Thermal Units. Growth rates for larval stages are significantly higher when interstitial habitat is available (Baker et al. 2014, Boucher et al. 2014, Crossman and Hildebrand 2014). Growth of juveniles is negatively impacted by lower temperatures (Lebreton and Beamish 2004). Juvenile growth rates, expressed as increases in length over time, are initially quick (e.g., average 158 mm/yr for age 1.5 fish in the Rocky Reach Reservoir, WA), but slow with age (108 mm/yr for age 2.5, 96 mm/yr for fish age 3.5-5.5, and 83 mm/yr for ages 6.5-9.5; Robichaud et al. 2020). Adult growth rates tend to be highest where waters are warmer, growing seasons are longer, and food is abundant. In the lower Fraser River, average White Sturgeon growth rates vary among years, but show declining trends (Figure 2). The average annual growth for 60-179 cm fork length (FL) White Sturgeon from 2016-2019 (3.4 cm/year) was 69% of that from 2010-2012

(4.9 cm/year; Nelson et al. 2020). Potential impacts of reduced growth (and hence) smaller size to female fecundity (both annual and lifetime fecundity) are currently unknown.

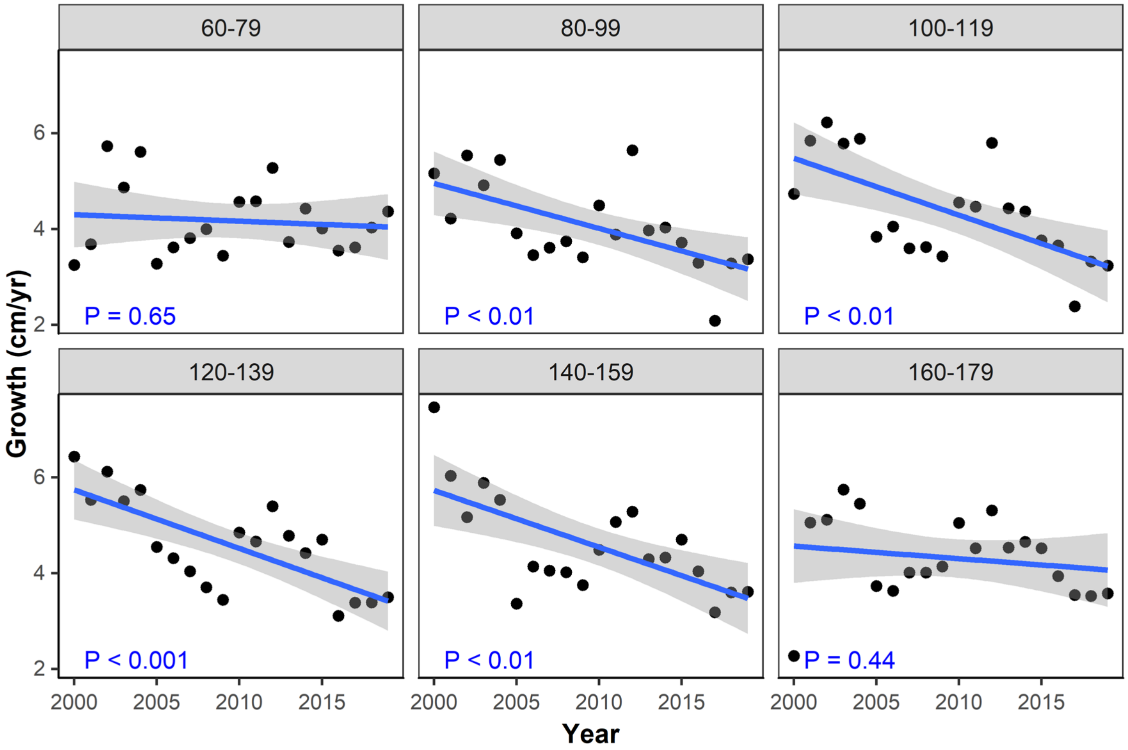

Figure 2. Average annual growth increments of 60-179 cm FL White Sturgeon in the lower Fraser River, by year and by 20-cm FL size group. The 95% confidence bounds around the linear trendlines are shown in grey shading.

2.1.6. Physiology & Stress

White Sturgeon are relatively tolerant to hypoxia (Burggren and Randall, 1978), and are CO_2 tolerant (Crocker and Cech 1998, Baker et al. 2009, Baker and Brauner 2012). Nevertheless, handling and air exposure cause a stress response, reflex impairment, and reduced post-release activity in Lower Fraser White Sturgeon (McLean et al. 2016, 2019, 2020), with effects exacerbated by warm water temperatures in summer. Tolerance of salinity appears to change ontogenically and with size, at least for Lower Fraser White Sturgeon. Amiri et al. (2009) exposed Age 1 fish to different levels of salinity, and observed complete mortality at ≥ 24 parts per thousand (ppt), and low mortality at ≤ 8 ppt, with larger individuals showing greater tolerance (McEnroe and Cech 1985, Amiri et al. 2009). After the fish are 2 years of age, though, they are fully capable of seawater acclimation (Shaughnessy et al. 2015).

2.2. ELEMENT 2: EVALUATE THE RECENT SPECIES TRAJECTORY FOR ABUNDANCE, DISTRIBUTION AND NUMBER OF POPULATIONS

2.2.1. Number of Populations

For the purposes of this RPA, we are assuming that the Lower Fraser White Sturgeon DU is comprised of a single panmictic population. White Sturgeon in the Fraser River are assessed as two DUs (Lower Fraser and Upper Fraser) under COSEWIC (COSEWIC 2012), with a geographic split based on Hells Gate, as justified by strong levels of genetic divergence across the barrier (Schreier 2012) and possibly physical differences (e.g., snout shape; Hildebrand et al. 2016). No additional population structure was detected below Hells Gate by Schreier (2012), though Nelson et al. (1999) showed a lack of Hardy-Weinberg equilibrium below Hells Gate, indicative of (probably weak) genetic substructure.

2.2.2. Distribution Trends

The Lower Fraser DU occurs in the mainstem Fraser River from the marine estuary upstream to Hells Gate. It also occurs in the Harrison and Pitt rivers, Pitt and Harrison lakes, and the confluences or lower reaches of numerous large and small tributaries (Figure 1). This DU also has unimpeded access to the marine waters, but the extent and prevalence of marine habitat use is not well understood (Hildebrand et al. 2016, Robichaud et al. 2017). Present distribution in the lower Fraser River is believed to be the same as that from recent history (Fraser River White Sturgeon Working Group 2005). Within that space, there have been declines in habitat availability that resulted from development, channelization, dyking, draining of floodplains, dredging, gravel mining, and land reclamation (Lane and Rosenau 1995, RL&L Environmental Services 2000, Rosenau and Angelo 2000, 2005).

White Sturgeon spawning has been confirmed at 14 sites in the lower Fraser River. The number of known spawning areas has increased greatly in recent years as a result of the application of novel survey technologies. Data from side-scan sonar surveys (Johnson et al. 2016, 2017, 2018) and acoustic telemetry has helped Stoddard (2017) direct the deployment of mats and D-rings (for collection of eggs and larvae, respectively). While the number of known spawning sites has increased (and additional sites may await discovery), this should not be interpreted as an increase in the spawning distribution of Lower Fraser River sturgeon. In-river gravel extractions (such as those permitted near Hamilton Bar and in the Seabird Island area between 2009 and 2015), and other in-river developments may have reduced the usefulness of some areas for spawning over the years. This possible effect has not been quantified.

2.2.3. Abundance Trends

Over the past 150 years, the White Sturgeon abundance in the lower Fraser River has declined dramatically. In the late 1800s and early 1900s, there was unsustainable White Sturgeon harvest in the lower Fraser River by a directed commercial fishery (Echols and Fraser River Action Plan [FRAP] 1995, Walters et al. 2005). Subsequently, retention of sturgeon (as bycatch) was not regulated in the commercial and First Nation salmon net fisheries, and there was a directed recreational kill fishery until the early 1990s (Walters et al. 2005). Additionally, habitat loss and reductions in prey availability may have contributed to sturgeon declines or hampered the population recovery (Rosenau and Angelo 2005) that was expected following reductions in catch. Reconstructions of former abundances using Stock Reduction Analysis have suggested that by 2004, the population vulnerable to the recreational fishery was at 66% of its pre-1900 levels (Whitlock and McAllister 2012), though English and Bychkov (2012) point out the many ways the analysis could be improved.

Since 2000, mark-recapture-based abundance monitoring of Lower Fraser White Sturgeon has been ongoing (Nelson et al. 2013, 2020). Sturgeon abundance has been analysed using two independent Bayesian mark-recapture models. One (‘BMR24’) model uses a 24-month rolling data window and is run separately for each set of 24 months; and the other (Integrated Spatial and Age-structured Mark-Recapture, or ‘ISAMR’) model considers all current and historical captures in a single age-structured model. Appendix E includes brief summary of the structure of the ISAMR model. Both the BMR24 (Nelson et al. 2020) and ISAMR (Challenger et al. 2017, 2020) models indicate that the abundance of 60-279 cm fork length (age 7-55) White Sturgeon in the lower Fraser River has been declining since 2006 (Figure 3, Appendix A). The 2019

ISAMR abundance estimate for 60-279 cm FL (age 7-55) White Sturgeon was 44,809 fish, which is 25% lower than the program's highest annual abundance estimate (in 2006).

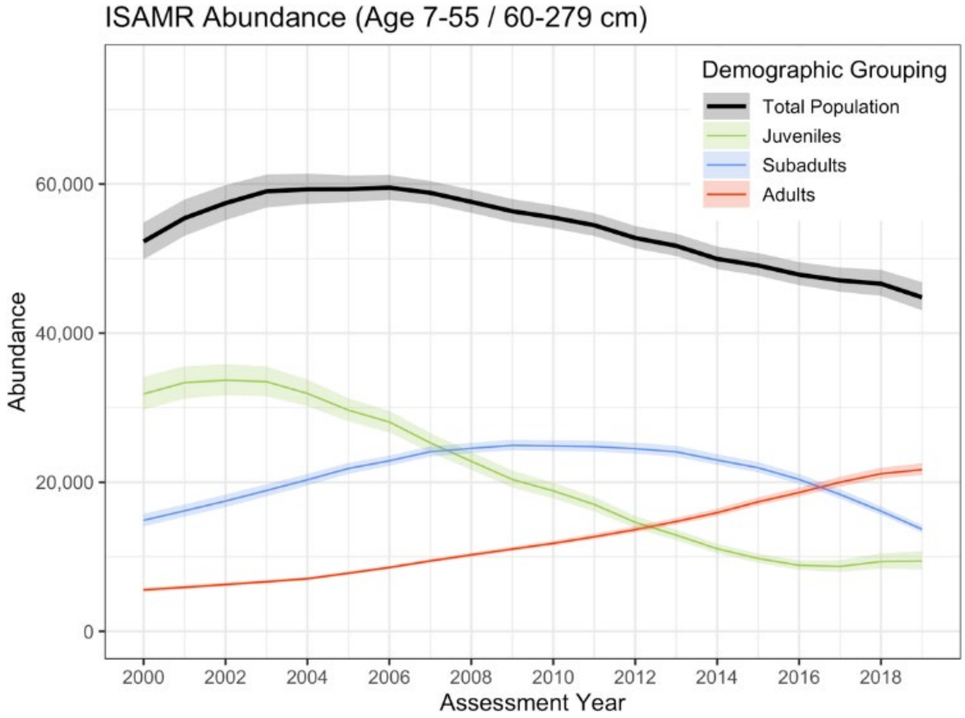

Figure 3. Abundance estimates of Lower Fraser River White Sturgeon from 2000 to 2019. Shading indicates 95% credible intervals. Total population was for 60-279 cm FL (age 7-55), juveniles were 60-99 cm FL (age 7-12), subadults were 100-159 cm FL (age 13-22), and adults were 160-279 cm (age 23-55). Figure adapted from Challenger et al. (2020).

Abundance trends for the different size/age categories were also estimated by Challenger et al. (2020; Figure 3) and Nelson et al. (2020). Both models estimated similar levels of decline in abundance over the past 15 years (2004-2019) for 60-99 cm FL juvenile White Sturgeon (BMR24: 77.9% decline; ISAMR: 70.5% decline). Both models estimated that significant declines in abundance have occurred for 100-159 cm FL subadult White Sturgeon in the past six years, 2013-2019 (BMR24: 50.9% decline; ISAMR: 43.1% decline). The BMR24 and ISAMR models differed regarding recent (2015-2019) abundance trends for adult (160-279 cm FL)[2] sturgeon: the BMR24 model indicated that adult abundance peaked in 2015, whereas the ISAMR model suggested that adult abundance continued to increase through 2019 (Challenger et al. 2020).

Aside from abundance model results, there are other concerning demographic indicators. For example, the proportion of juvenile White Sturgeon less than 100 cm FL in total annual measured samples captured by the Albion Test Fishery decreased 62.8% between 2000 and 2019 (Nelson et al. 2020). Also, the average annual growth rate for 60-179 cm FL White Sturgeon from 2016-2019 (3.4 cm/year) was 69% of that from 2010-2012 (4.9 cm/year; Figure 2; Nelson et al. 2020).

---

[2] This size criterion is assumed to be a reasonable indicator of mature adults. Males may mature at smaller sizes, and females perhaps at larger sizes; and since the fish cannot be sexed reliably in the field, a fork length of 160 cm was used as an estimate of 'sex unknown' adult size.

Recruitment into the Lower Fraser White Sturgeon population has varied over the last 20 years. The age-structured model (Challenger et al. 2020) permits the back-calculation of recruitment into the fishery (i.e., to age 7) for any given year in history based on the estimated age structure of captures during the study period (Figure 4). The age-specific estimates were derived by converting fish size into age using a fixed age-length relationship derived from data collected in the 1990s (RL&L Environmental Services 2000). Reconstructing historical abundances required the assumption that age-specific mortality rates prior to 2000 were the same as those estimated from the post-2000 data. Therefore, temporal changes in the length-at-age or age-specific-mortality relationships could impact the estimates of historical abundance. Further analyses have been recommended to assess the sensitivity of model estimates to temporal changes in these relationships.

Reconstructed age-7 recruitment showed a steady increase from 1980 through 2001 (estimated 8,499 individuals), followed by a steady and precipitous decline until it levelled-off from 2012-2015 at < 2,000 individuals (i.e., the lowest level of estimated age-7 abundances within the study period). Since then, there have been modest signs of recruitment improvement (albeit with an increasing level of uncertainty). If low levels of recruitment persist, ISAMR abundance forecasts suggest the overall population would continue to decline, with a possible leveling in approximately 40 years (i.e., early 2060s) at approximately 27,000 sturgeon (60-279 cm FL; Challenger et al. 2020).

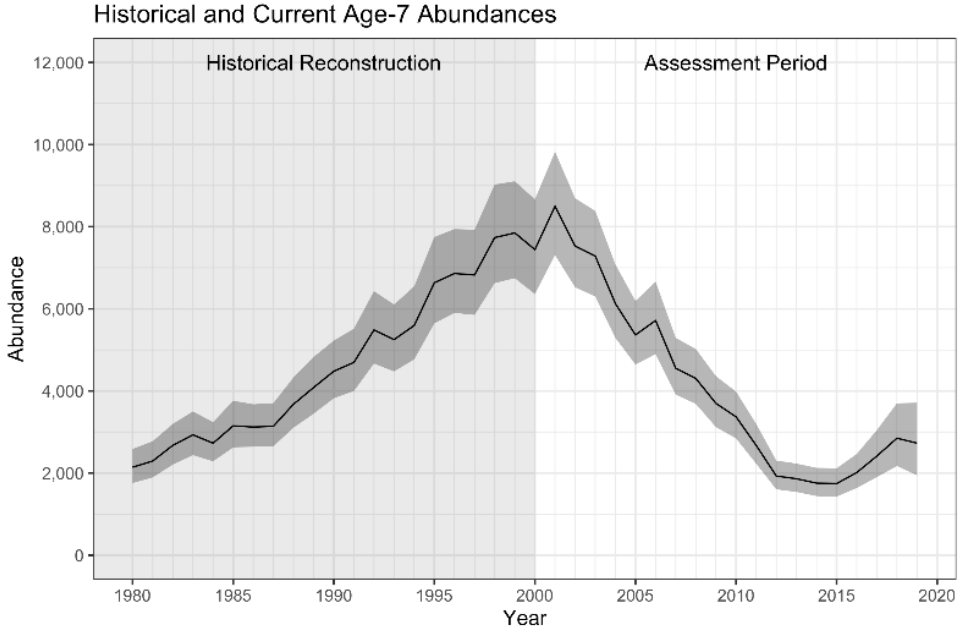

Figure 4. Estimated age-7 abundances prior to and during the assessment period. Dark grey shading indicates the 95% credible intervals. Light grey shaded region indicates historical estimates. Figure reproduced from Challenger et al. (2020).

2.3. ELEMENT 3: ESTIMATE THE CURRENT OR RECENT LIFE-HISTORY PARAMETERS FOR WHITE STURGEON

Estimates of life history parameters for the Lower Fraser DU are provided in Table 1. These parameter values come from recent models (e.g., Nelson et al. 2007, Challenger et al. 2017, 2020). Some of the parameters listed in 1 were included in or resulted from the population model that was used in ELEMENT 13 (projected population trajectories), ELEMENT 15 (probability of meeting abundance targets), ELEMENT 20 (effects of mitigation on abundance projections), and ELEMENT 21 (recommended parameter values to account for specialized scenarios). The life history parameters and estimates were provided to the RPA Steering Committee for review prior to model runs.

Table 1. Life history parameters for Lower Fraser River White Sturgeon DU. Some of these were baseline parameters used in White Sturgeon recovery simulations (see ELEMENT 13).

Parameter	**Description**	**Value**	**Used in Element 13 Modelling**	**Source[1]**
S	Annual survival rate of fish age ≥1	0.96	No	G
		Scales with age, max 0.97	Yes	A
σ_r	Standard deviation of age-1 recruitment	Different scaling	Yes	A
K	Brody growth (length-at-age) coefficient	0.025	Yes	E
L_∞	Asymptotic length (cm)	370.1	Yes	E
$A_{mat ♂}$	Age at first maturity (male)	11 – 22	No	F
		14	No	E
$A_{mat ♀}$	Age at first maturity (female)	26 – 34	No	F
		18	No	E
	Years between spawning for adult ♀	4 – 11	No	F
	Fecundity (eggs per kg of adult ♀)	3,192 – 8,582	No	C
	Mean growth of 60-179 cm fish	3.4 – 4.9 cm/yr	No	D
μ_v	Age at 50% vulnerability	6.9 – 7.2 (95% CI)	Yes	B
τ_v	Slope of age-vulnerability relationship	6.7	Yes	B
$N_{t=0}$	Adult population size for initialization year	20,984 – 22,552 (95% CI)	Yes	B

[1] Sources: A) Challenger et al.(2017); B) Challenger et al. (2020); C) Chapman et al. (1996); D) Nelson et al.(2020); E) RL&L Environmental Services (2000) and Nelson et al. (2007); F) Semakula and Larkin (1968); G) Whitlock and McAllister (2012).

3. HABITAT AND RESIDENCE REQUIREMENTS

3.1. ELEMENT 4: DESCRIBE THE HABITAT PROPERTIES THAT WHITE STURGEON NEEDS FOR SUCCESSFUL COMPLETION OF ALL LIFE-HISTORY STAGES. DESCRIBE THE FUNCTION(S), FEATURE(S), AND ATTRIBUTE(S) OF THE HABITAT, AND QUANTIFY BY HOW MUCH THE BIOLOGICAL FUNCTION(S) THAT SPECIFIC HABITAT FEATURE(S) PROVIDES VARIES WITH THE STATE OR AMOUNT OF HABITAT, INCLUDING CARRYING CAPACITY LIMITS, IF ANY

White Sturgeon in the Fraser River evolved in a natural large river system, including slow, deep mainstem channels, zones of swift and turbulent water, extensive floodplains with sloughs and side channels; and a snowmelt-driven hydrograph with prolonged spring floods (Coutant 2004). Today, the Lower Fraser White Sturgeon population occupies a wide variety of habitats from the strong currents of the Fraser Canyon near Yale to the tidal waters of the estuary near Steveston. Habitat use varies with life stage, as described below.

3.1.1. Habitat by Life Stage

Spawning and Incubation Habitat – White Sturgeon in the lower Fraser River spawn in a variety of habitats (Perrin et al. 2003), including side channels (gravel and cobble substrates, with laminar flows and velocities averaging 1.7 m/s), and turbulent mainstem areas downstream of the Fraser Canyon (RL&L Environmental Services 2000) near bars or river deltas (boulder and cobble substrates were dominant in the mainstem spawning areas; Perrin et al. 2003). The peak of White Sturgeon spawning usually occurs during the descending limb of the spring freshet, after peak flows (Stoddard 2017). There are many evolutionary benefits from spawning in fast, turbulent waters over coarse substrates. These habitats include suitable attachment surfaces for negatively buoyant adhesive eggs, and provide hiding habitat for hatched larvae (McAdam 2011). Fast and turbulent flows ensure the eggs are oxygenated; decrease the prevalence of fine sediments that could suffocate eggs; increase dispersal of eggs (prevents clumping and hence disease); and reduce egg predation (by exclusion of poorer-swimming predators; Parsley et al. 1993, 2002, McCabe and Tracy 1994, Gadomski and Parsley 2005). Spawning events may be triggered after temperature thresholds are reached (Paragamian et al. 2001, Golder Associates 2009), and egg and larval development and growth rates are temperature dependent (Lebreton and Beamish 2004, BC Hydro 2016a).

In the Fraser River, recent use of side scan sonar (English et al. 2014, Johnson et al. 2016, 2017, 2018) and acoustic telemetry have helped identify potential spawning sites based on the presence of adult aggregations during the spawning season. Egg and larval sampling has confirmed 14 spawning locations within the 57 km river corridor between Chilliwack Mountain and Bar 289. Use over multiple years has been confirmed for some locations (Perrin et al. 2003, Stoddard 2017).

Yolk Sac Larvae Habitat –Egg incubation habitat is primarily determined by adult spawning site selection. For the hatched yolk-sac larvae, interstitial spaces are the predominant habitat. During this stage, substrate quality affects survival (McAdam 2011, Baker et al. 2014, Boucher et al. 2014) and can affect stress response (Bates et al. 2014). When the interstitial habitat is not of suitable size (e.g. that provided by gravel), or when substrates are choked with fines, or when they are otherwise suboptimal, some fish will drift away from the hatch areas, thereby exposing themselves to an increased risk of mortality (McAdam 2011). While the grain size of the substrates dictates quality, the preferred substrate conditions probably include a mixture of particle sizes ranging from gravel to large cobble (McAdam 2011). Optimal temperatures for this phase are 14 to 18 ºC, where lower temperatures delay development (Wang et al. 1985, Parsley et al. 2011, Boucher 2012) and higher temperatures lead to increased deformities and mortality (Wang et al. 1985, Boucher 2012). White Sturgeon larvae are sensitive to contaminants such as copper (Vardy et al. 2013). The quality of the habitat conditions experienced during the yolk-sac phase can have strong carryover effects impacting the fish during the feeding larvae stage (Boucher et al. 2014).

Feeding Larvae Habitat – Little is known about the habitat requirements of the feeding larvae stage. The stage is characterised by nocturnal drift into feeding habitats where they forage over the open bottom. Brannon et al. (1985) found them to decrease use of cover with increased age. It is presumed that these fish require their habitat to be located downstream of spawning sites. It is also assumed that these fish use low velocity habitats such as side channels or floodplains. Ideal water temperatures for feeding larvae were the same as for yolk sac larvae (Wang et al. 1985). Feeding larvae are more sensitive to copper than yolk sac larvae (Vardy et al. 2013).

Juvenile Habitat – Juvenile White Sturgeon are found throughout the lower Fraser River with higher abundances detected at specific sites between Annacis Island and Hatzic (Glova et al. 2008, 2009, 2010, Schwindt and Yeung 2020, English and Robichaud 2020, Burns et al. 2020).

Compared to earlier life history stages, juvenile White Sturgeon occupy a wider range of depths (2 to 58 m), and prefer slow to moderate water velocities (0.1 to 0.8 m/sec near the bottom) and fine substrates (Parsley et al. 1993, Bennett et al. 2005, Glova et al. 2008, 2009, 2010). This includes deep, low velocity mainstem habitats (RL&L Environmental Services 2000, Golder Associates 2003, Neufeld and Spence 2004, Bennett et al. 2005, Glova et al. 2008, 2009, 2010), side channels, and sloughs (Bennett et al. 2005, Glova et al. 2008, 2009, 2010). In the Kootenay system, juveniles were found in lakes – something that could conceivably also happen in the lower Fraser River (DFO 2014a). Substrates range from clay to fines to boulders (Parsley et al. 1993, Young and Scarnecchia 2005). In a tank experiment, juvenile White Sturgeon exhibited a small preference for sand substrates, but occupied other substrates when food was present (Brannon et al. 1985). Preliminary results of a habitat association study (Burns et al. 2020) in the lower Fraser River found that juvenile White Sturgeon were more likely to be caught in deeper and warmer sites. Habitats provide access to food items such as chironomids, and a range of other invertebrate and fish species (Scott and Crossman 1973, McCabe et al. 1993, Bennett et al. 2005).

Subadult and Adult Habitat – Late juvenile, subadult, and adult White Sturgeon use a variety of habitats, depending on the time of year. In the lower Fraser River, adult habitat includes tidal areas, deep and slow-moving backwater areas, eddies, deep areas adjacent to heavy flows, tributaries, lakes, and depositional areas (Robichaud et al. 2017, Golder Associates 2019). Habitats provide access to prey items such as fish, including cyprinids, lamprey, Eulachon, and salmon, and benthic invertebrates such as shellfish, crayfish, and chironomids (Scott and Crossman 1973). During the spring and fall, when Eulachon, lamprey, and salmon are migrating or spawning, sturgeon may make long-distance movements (Robichaud et al. 2017, Golder Associates 2019, Nelson et al. 2020) between holding areas and the locations where prey are congregated, or to carcass depositional areas (RL&L Environmental Services 1994, 2000). In the summer, sturgeon may occupy shallower depths and make frequent short distance foraging trips into deep-water areas (Apperson and Anders 1991, Brannon and Setter 1992, RL&L Environmental Services 1994).

Overwintering – From mid-December to mid-March, a wide range of ages and sizes of sturgeon are known to concentrate at a few overwintering sites in the lower Fraser River, including Pitt River and Lake, Matsqui side-channel, and Hatzic Eddy (Robichaud et al. 2017, Robichaud and Johnson 2020). In the lower Fraser River White Sturgeon remain mobile well into December (Nelson et al. 2020), likely due to the availability of spawning salmon and their eggs for food. Overwintering habitat typically includes deep, low velocity habitats (Apperson and Anders 1990, Hildebrand et al. 1999). Reduced activity is generally observed during winter months (e.g., RL&L Environmental Services Ltd. 2000, Robichaud et al. 2017), though some sturgeon do still move and actively feed within these and adjacent habitats during that period (Stoddard 2017).

3.1.2. Water Quality

All of the above habitats can be impacted by industrial, agricultural, and urban pollutants, including detritus from log jams or sawmills, that are inputted into the river. Aquatic species can be at risk when water conditions degrade beyond specific thresholds for oxygen, temperature, pH, or pollutants (Little et al. 2012, Vardy et al. 2013). Even if water quality does not affect sturgeon directly, there could nevertheless be indirect effects via impacts to their prey base.

3.2. ELEMENT 5: PROVIDE INFORMATION ON THE SPATIAL EXTENT OF THE AREAS IN WHITE STURGEON DISTRIBUTION THAT ARE LIKELY TO HAVE THESE HABITAT PROPERTIES

In general, juveniles, subadult, and adult White Sturgeon are found throughout the lower Fraser River (Figure 5).

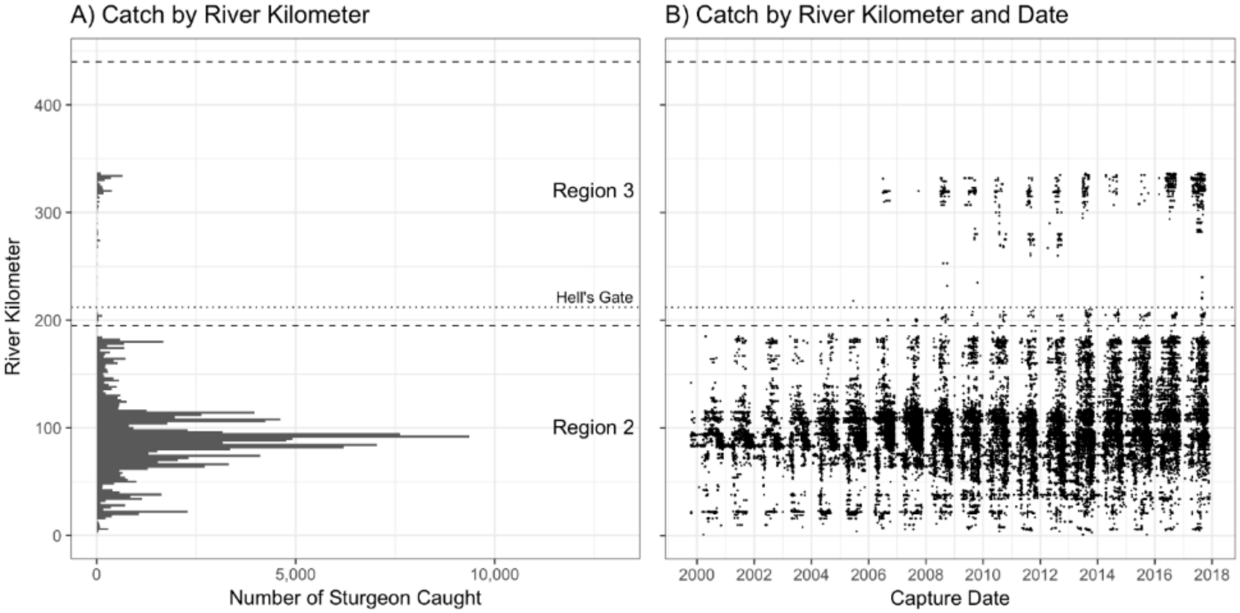

Figure 5. Distribution of mainstem Region 2 (BC Fishing Region - Lower Mainland) and Region 3 (Thompson-Nicola) White Sturgeon catch in the FRSCS monitoring and assessment program. Region 2 data are from 1999-2018; those from Region 3 span 2005-2018. Data are shown by A) river kilometer, and B) river kilometer and capture date. Region boundaries are indicated by horizontal dashed lines. The location of Hells Gate is indicated by the horizontal dotted line. The Lower Fraser White Sturgeon population occurs below Hells Gate. Data from upstream of Hells Gate were part of the reproduced figure, but are not pertinent to this RPA. Reproduced from Challenger and Robichaud (2018).

Extent of overwintering habitat – a wide range of ages and sizes of sturgeon are known to concentrate at three main overwintering sites between late November and April, including Pitt River, Matsqui side-channel, and Hatzic Eddy (Robichaud et al. 2017, Robichaud and Johnson 2020), though Stoddard (2017) may have identified additional sites. Robichaud and Johnson (2020) used side-scan sonar to define the geographic boundaries of two of the main overwintering sites (Hatzic Eddy, and Matsqui Side Channel).

Extent of spawning habitat – there are 14 confirmed spawning areas in the lower Fraser River (RL&L Environmental Services Ltd. 2000, Perrin et al. 2003, Johnson et al. 2016, 2017, 2018, Stoddard 2017), all restricted to the gravel reach upstream of Chilliwack Mountain (river km 101), though others may await discovery (Stoddard 2017). Spawning sites are located in side-channels or in the mainstem. Habitat features of the known spawning areas are described in ELEMENT 4. GIS analyses have not been undertaken to identify the spatial extent of the areas that include the habitats required.

Extent of juvenile habitat – Some juvenile White Sturgeon distribution and population data were initially collected for the lower Fraser River in the mid-1980's and early 1990's (Lane and Rosenau 1995). Since then, several studies have been conducted to describe the distribution of juvenile White Sturgeon in the lower Fraser River. Glova et al. (2008, 2009, 2010) sampled a variety of habitat types in the lower Fraser River to collect baseline distribution information. The areas of highest juvenile sturgeon concentration were near Annacis Island (~river km 20) and in the Hatzic Eddy (~river km 84), with modest concentrations near Barnston Island and Matsqui Island (Figures 6 and 7). More recently, efforts have been made to increase juvenile-targeted sampling effort in the lower Fraser River (at random and haphazard sites) in order to further develop the spatial extent of juvenile habitat (English and Robichaud 2020), and to develop a habitat suitability model (Burns et al. 2020), but these projects are just getting underway.

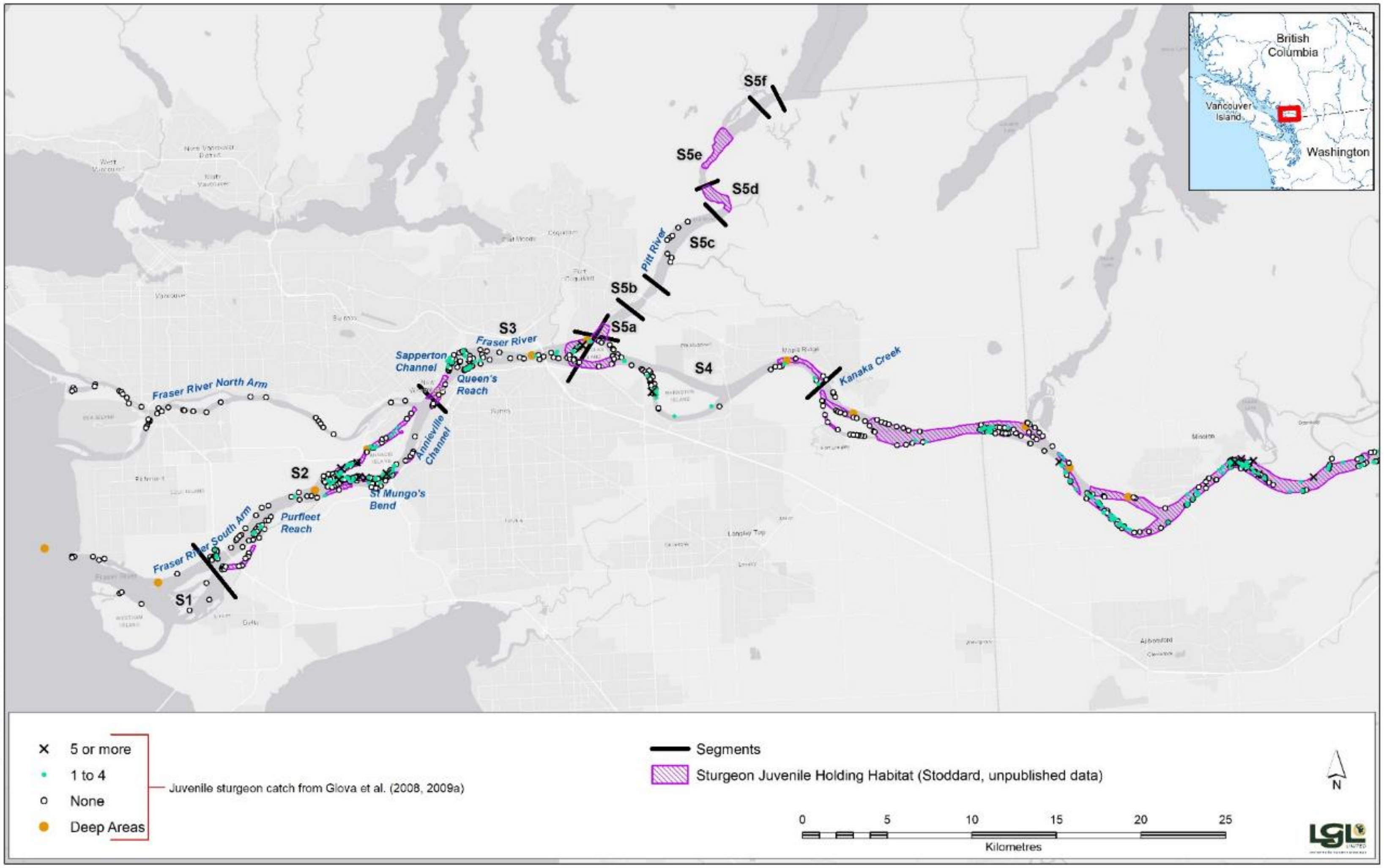

Figure 6. The lower Fraser River downstream of Hatzic, illustrating Glova's juvenile White Sturgeon catch data. Reproduced from English and Robichaud (2020), which included details (e.g., "Deep Areas") that are not germane to the RPA.

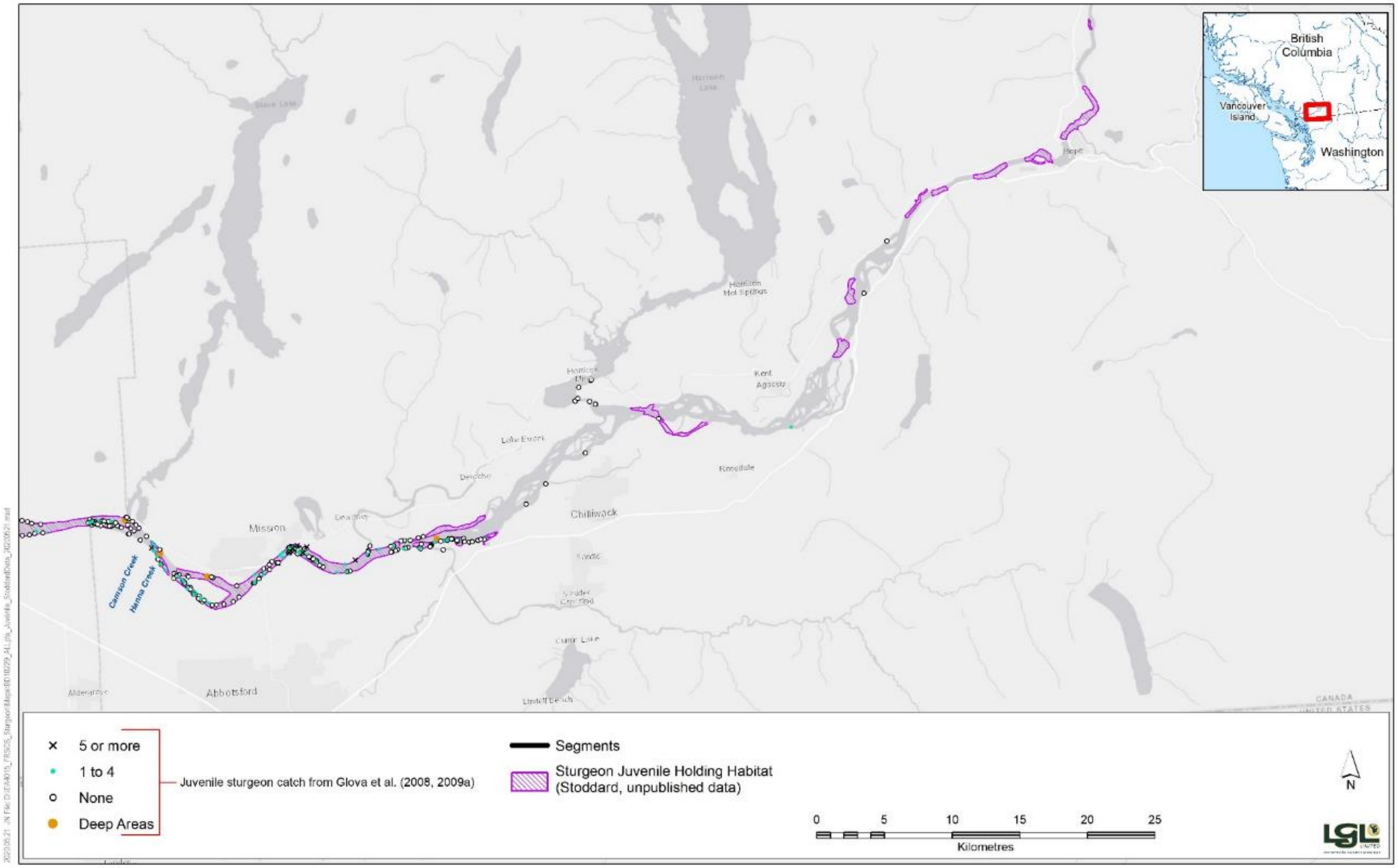

Figure 7. The lower Fraser River upstream of Hatzic, illustrating Glova's juvenile White Sturgeon catch data. Reproduced from English and Robichaud (2020).

Extent of feeding habitat – Lower Fraser White Sturgeon make use of feeding habitats that extend from the Fraser estuary upstream to Hells Gate and in Pitt and Harrison lakes, and it is assumed that they find forage throughout. That said, spring and fall movement patterns suggest upstream and downstream movements toward areas that host seasonally-availability migrating, spawning, or dead Eulachon and Pacific salmon (ECL Envirowest Consultants 1992, Robichaud et al. 2017, Nelson et al. 2020). GIS analyses have not been undertaken to identify the spatial extent of the seasonal hotspot areas.

3.3. ELEMENT 6: QUANTIFY THE PRESENCE AND EXTENT OF SPATIAL CONFIGURATION CONSTRAINTS, IF ANY, SUCH AS CONNECTIVITY, BARRIERS TO ACCESS, ETC.

Compared to other industrialized rivers within the range of White Sturgeon, the lower Fraser River has a relatively natural hydrograph and fewer barriers to connectivity, given that it is not dammed on the mainstem. Nevertheless, there have been declines in habitat availability in the lower Fraser River compared to historic levels that resulted from development, channelization, dyking, draining of floodplains, dredging, gravel mining, and land reclamation (Lane and Rosenau 1995, RL&L Environmental Services 2000, Rosenau and Angelo 2000, 2005). Dikes, tidal gates and flood boxes, built to protect shoreline developments and reduce flood risk, are believed to limit sturgeon access to a significant amount of off-channel rearing habitat in the lower Fraser River. A project initiated by Tide Canada to reintegrate vital wild salmon habitat by modifying and upgrading flood-control infrastructure has reported that “over 1500 kilometers of wild salmon habitat in the lower Fraser is fully or partially blocked by these floodgates and pumps” (Tides Canada 2020) . They have identified 11 locations between Mission and Upper Maria Slough on their short list for potential sites where access to off-channel habitat could be improved (e.g. Hatzic Pump Station, Lower Nelson Slough reconnection, Cheam Slough reconnection). Improving sturgeon access to productive off-channel habitat by replacing old tidal gates with “fish friendly” gates and reconnecting sloughs could increase productivity and survival for juvenile and subadult sturgeon.

3.4. ELEMENT 7: EVALUATE TO WHAT EXTENT THE CONCEPT OF RESIDENCE APPLIES TO THE SPECIES, AND IF SO, DESCRIBE THE SPECIES’ RESIDENCE

SARA defines a residence as “a dwelling place, such as a den, nest or other similar area or place that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding, or hibernating” (S.C. 2002, c.29).

The residence must support a life cycle function, there must be an element of investment in the creation or modification of the structure, and it must be occupied by one or more individuals. White Sturgeon are broadcast spawners and they do not modify their environment for the purpose of “breeding, rearing, staging, wintering, feeding, or hibernating”, thus the concept of residence does not apply.

4. THREATS AND LIMITING FACTORS TO THE SURVIVAL AND RECOVERY OF WHITE STURGEON

4.1. ELEMENT 8: ASSESS AND PRIORITIZE THE THREATS TO THE SURVIVAL AND RECOVERY OF WHITE STURGEON

Table 2 provides a list of the potential threats and the relative risk associated with each threat. The following paragraphs provide brief descriptions of the rationale for each identified threat.

Gravel extraction from locations close to potential and confirmed sturgeon spawning and larval rearing areas has been identified as a threat to the Lower Fraser Sturgeon population for many years (Glova 2008[3], Langer 201[4]1). The compaction of gravel by heavy equipment, increased erosion and siltation resulting from the removal of the armoring surface layers on gravel bars, and gravel removal can reduce the amount of habitat available for larval rearing and feeding in the substrate interstitial spaces. This loss of habitat could decrease growth and increase predation on larval sturgeon. Gravel extraction has occurred on bars and side-channels between Mission and Hope since the 1950s but has only been regulated since 1974 (Appendix B). Weatherly and Church (1999) provided information on the history of gravel removals from 1964-1998; and similar information associated with gravel sediment removals from 2000-2010 was obtained from a document submitted to the Cohen Commission dated 20 May 2011 (Anon. 2011). Most of the gravel removal that occurred in the 2000’s was related to an Emergency Management BC assessment that gravel removal would reduce the risk of floods. The benefits for flood protection were challenged for several years prior to a moratorium on gravel extraction being implemented in 2010. Despite this moratorium on gravel removal related to flood protection, some gravel extraction was permitted in the Seabird Island area from 2013-2017 but the only year when gravel was removed under this permit was 2014. Information on the volume of gravel extracted from locations close to confirmed sturgeon spawning sites, and the peak counts of spawning-sized sturgeon observed at these sites from 2013-2016 (Johnson et al. 2016, 2017, 2018) are provided in Table 3. Given the quantity of gravel removed from locations close to known sturgeon spawning areas and the years when these gravel extractions occurred, the disturbance to these sturgeon spawning and larval rearing habitats between 2000 and 2010 may have been an important factor in the observed decline in age 7 sturgeon recruitment from 2003-2015. Juvenile recruitment to age 7 showed its first signs of improvement in 2016 and 2017 (Figure 4), seven to ten years after gravel extraction was stopped at most sites near known sturgeon spawning areas in the lower Fraser River. These observations contributed to the Medium (3) threat risk rating for past and any future potential gravel extraction from known sturgeon spawning or rearing areas in the gravel reach. There is currently a moratorium on extraction of gravel from the lower Fraser River, but this could change with political pressure and the degree of legal protection offered by the moratorium is unknown.

---

[3] Glova, G.J. 2008. Assessment of potential impacts on White Sturgeon and their habitat from proposed gravel extraction in the Lower Fraser River during winter, 2009. Letter, dated 20 November 2008, submitted to Emergency Management BC.

[4] Langer, O. 2011. Inspection of gravel bars in the Lower Fraser Gravel Reach and commentary on recent past mining impacts - December 17, 2010. Letter prepared for the Fraser River Gravel Stewardship Committee and submitted 6 January 2011 to Emergency Management BC.

Table 2. List of identified threats associated with each COSEWIC threat category and the risk assessment associated with each threat. This table was developed using the threat-assessment methods that are outlined by DFO (2014b).

COSEWIC Threat Categories	Specific Threat	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
1. Residential and commercial development								
Threats discussed elsewhere (e.g., 7. Natural system modifications)								
2. Agriculture & aquaculture								
Threats discussed elsewhere (e.g., 9. Pollution)								
3. Energy production & mining								
3.2 Mining & Quarrying	Gravel extraction	Known	Medium	Medium	Medium (3)	Historical/ Current	Continuous	Extensive
4. Transportation & service corridors								
4.3 Shipping Lanes	Boat strikes, noise, wakes, dredging	Known	Low	Very low	Low (4)	Historical/ Current	Recurrent	Narrow
5. Biological resource use								
5.4 Fishing & Harvesting Aquatic Resources	Recreational fishing	Known	Low	Low	Low (4)	Current	Continuous	Broad
5.4 Fishing & Harvesting Aquatic Resources	Bycatch in Commercial fisheries [1]	Known	Low	Low	Low (4)	Current	Recurrent	Broad
5.4 Fishing & Harvesting Aquatic Resources	Bycatch in Food, Social, & Ceremonial fisheries	Known	Medium	High	Medium (2)	Current	Continuous	Broad
5.4 Fishing & Harvesting Aquatic Resources	Illegal harvests	Known	Unknown	Low	Unknown (4)	Current	Recurrent	Narrow
6. Human intrusions & disturbance								
6.1 Recreational / Boating Activities	Noise and boat strikes	Known	Low	Low	Low (4)	Current	Recurrent	Broad
6.3 Work & Other Activities / Science Activities	Handling stress from tagging	Known	Low	Very low	Low (5)	Current	Recurrent	Restricted

COSEWIC Threat Categories	Specific Threat	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
7. Natural systems modifications								
7.2 Dams & Water Management/use	Shoreline modifications, including tidal and flood gates	Known	Medium	Low	Medium (4)	Current	Continuous	Broad
7.3 Other Ecosystem Modifications	Modifications to catchment surfaces	Known	Unknown	Very low	Unknown (5)	Historical/ Current	Recurrent	Broad
7.3 Other Ecosystem Modifications	Food availability	Known	Medium	Medium	Medium (3)	Historical/ Current	Continuous	Extensive
8. Invasive & other problematic species & genes								
8.1 Invasive Non-native/alien Species	Invasive non-native/alien species	Known	Unknown	Very low	Unknown (5)	Current	Single	Narrow
8.2 Introduced Pathogens and Viruses		Remote	Unknown	Very low	Unknown (5)	Current	Recurrent	Broad
8.3 Introduced Genetic Material	Nechako Hatchery program	Likely to occur	Low	Very low	Low (5)	Anticipatory	Recurrent	Broad
9. Pollution								
9.1 Household Sewage & Urban Wastewater	Run-off	Known	Unknown	Low	Unknown (4)	Current	Recurrent	Broad
9.2 Industrial & Military Effluents	Run-off	Known	Unknown	Low	Unknown (4)	Current	Recurrent	Broad
9.3 Agricultural & Forestry Effluents	Run-off	Known	Unknown	Low	Unknown (4)	Current	Recurrent	Broad
10. Geological events								
10.3 Avalanches/landslides	Hells Gate impediment	Known	Low	Very low	Low (5)	Historical	Single	Restricted
11. Climate change & severe weather								
11.2 Droughts	Side-channel reductions	Known	Low	Very low	Low (5)	Anticipatory	Continuous	Extensive
11.3 Temperature Extremes	River temperature	Known	Low	Low	Low (4)	Anticipatory	Continuous	Extensive

[1] Commercial fishing includes: DFO Area E gillnet fishery, First Nations Economic Opportunity fisheries and Demonstration fisheries

Table 3. Confirmed sturgeon spawning areas in the lower Fraser River, peak counts of spawning-sized sturgeon from side-scan sonar surveys at these sites, and the volume of gravel extracted from these sites from 1964-2010. Peak spawner counts are from Johnson et al. (2016, 2017, 2018). Gravel volumes are from C. Schwindt (BC FLNRORD, unpublished data).

			Gravel Extraction (m³)		
Confirmed Spawning Sites	**Rkm**	**Peak Count 2013-16**	**< 1985**	**1985-1998**	**2000-2010**
Minto	108	27	-	-	-
Mountain Bar	110.0	53	-	-	262,615
Jesperson side channel	115.5	15	-	-	-
Hamilton Bar	118.0	44	3,800	44,130	143,900
Herring side channel	125.0	63	34,000	-	166,000
Seabird Island	134.5	60	-	-	110,000
Peters	139	17	-	-	-
Ruby Creek	144.0	19	76,000	-	-
Hunter Creek	147.5	20	-	-	-
Floods Bar	152	n/a	-	-	-
Bristol Island	154.4	62	-	42,000	-
Landstrom Bar	156.0	59	310,000	60,000	-
Coquihalla	160.5	21	-	-	-
Bar 289	164	37	-	-	-
Total		**497**	**423,800**	**146,130**	**682,515**

Dredging, and associated boat strikes, noise, and wakes were identified as potential threats to the Lower Fraser sturgeon population due to increasing amounts of boat traffic and dredging on the lower Fraser River, annual observations of sturgeon mortalities related to boat strikes (e.g., propeller damage), and the potential impacts on juvenile sturgeon rearing habitat that could be the result of dredging. While some mortalities have been observed, the numbers are low and the portion of the population vulnerable to these threats is relatively small. However, the available information on boat strikes are just observational reports of mortalities and not a systematic sampling program (i.e., trends can not be determined). Consequently, the risk associated with these threats was rated Low (5).

Recreational angling was identified as a potential threat to the Lower Fraser sturgeon population because of the substantial fishing effort and catch of sturgeon by anglers in the lower Fraser River and the observation that some individual sturgeon were caught multiple times in a single year. This potential threat is mostly related to the chronic stress associated with angling events which can be exacerbated by increased water temperatures, fight times and multiple recapture events. Data suggest acute mortality of an angling event is very low, but concerns are in the chronic impacts (McLean et al. 2016, 2019, 2020). The number of sturgeon caught by anglers has increased substantially in recent years as other targeted species (Chinook (*Oncorhynchus tshawytscha*), Sockeye (*O. nerka*), and Coho (*O. kisutch*) salmon, and steelhead (*O. mykiss*)) have declined, and angling opportunities for these species have been reduced or eliminated. Information derived from guide reports, angler questionnaire data, and some creel survey work done in 2016 (Robichaud 2018a,b) suggested that annual sturgeon catch by anglers was in the 25,000-34,000 range from 2010-2015, and increased to 50,000 in more recent years (see Appendix C1). However, tidal exclusive anglers (whether guided or not) are not captured in these reports and may represent a significant piece of missing catch and effort data.

Mark-recapture data obtained by the FRSCS provided clear evidence that some individual sturgeon were being captured multiple times in a given year (note that the FRSCS samples are a subset of the sturgeon caught by the whole recreational fishery, representing about 20-25% of the whole; see Appendix C1). Using the 2019 abundance estimate (44,809 sturgeon; Challenger et al. 2020), data on the 2019 rate of repeat recaptures of individual sturgeon (Nelson et al. 2020), and an assumed sampling rate of 25%, we estimated that ~25,000 fish (63% of the total catch of ~40,000 sturgeon) would be unique individual sturgeon captures (see Appendix C2). Of these unique fish, ~9,600 (38%) would have been caught multiple times in 2019 and contributed ~15,000 capture events to the total catch. If, instead of 25%, the sampling rate was assumed to be 20%, the estimated total catch increased to ~55,000, with ~31,000 (57%) being unique fish, of which ~15,800 (50%) would have been caught multiple times in 2019. Under the assumption that FRSCS data represents 20-25% of the overall fishery, the best available data indicated that 56-70% of the 60-279 cm FL (age 7-55) sturgeon in the lower Fraser River were caught by anglers in 2019, and 38-50% of the sturgeon caught by anglers were caught more than once in 2019.

The threat level for recreational angling was rated as Low (4) because of the very high survival rate of sturgeon caught in this catch and release fishery (Robichaud et al. 2006). However, multiple recaptures of individual fish in a single year could affect the growth rate and potentially maturation schedules and fecundity. Studies have found evidence of stress on fish as a result of catch and release angling but none of these studies have been able to quantify the impact of multiple releases on sturgeon growth, maturation, or fecundity (Cooke et al. 2013, McLean et al. 2016, Halvorson et al. 2018). Mitigative actions related to the current guidelines for handling sturgeon, seasonal closures for spawning, rearing and/or overwintering areas, or other actions to reduce fishing effort have been implemented or proposed to reduce the potential effects of angling on the sturgeon population.

Commercial fishing using gillnets in the lower Fraser River was identified as a potential threat because some sturgeon are caught and killed each year as bycatch in these commercial gillnet fisheries that target salmon. These fisheries include drift gillnetting methods by DFO Area E gillnet vessels in the Fraser River downstream of the Mission Railway Bridge, and First Nation Economic Opportunity and Demo fisheries using drift gillnets and set gillnets in the lower Fraser River between Steveston and Sawmill Creek. Reliable estimates for the bycatch of sturgeon in lower Fraser commercial fisheries were not available for this assessment. The threat level for commercial fishing was rated as Low (4) because most commercial fishing is conducted using driftnets and beach seines in recent years. Sturgeon released from drift nets have higher survival rates than those released from set net fisheries (Robichaud et al. 2006). Sturgeon released from beach seines should have higher survival than those released from gillnets, although some of the more intensive beach seine fisheries can catch individuals multiple times. Also, opportunities for commercial fisheries on the lower Fraser River have been more limited than those for FSC fisheries in the past 10-15 years and are expected to continue to be very limited for the next 5+ years (Dean Allan, DFO, pers. comm.).

First Nation Food Social and Ceremonial (FSC) fishing using gillnets in the lower Fraser River was identified as a potential threat because some sturgeon are caught and killed each year as bycatch in these FSC gillnet fisheries. These fisheries include driftnet and setnet fishing methods. Given the mortality rates observed for setnet fisheries (Robichaud et al. 2006), and the substantial amount of FSC setnet and drift net fishing effort in the Lower Fraser River compared to other FSC fishing methods, we conducted a detailed review and assessment of the FSC encounter rates and estimates of FSC sturgeon mortalities (Appendix D). We estimated that the annual bycatch of sturgeon has ranged from 1,795 to 3,764 for FSC driftnet fisheries, and from 1,474 to 8,977 for FSC setnet fisheries from 2000-2019 (Table D3). Using the observed range of mortality rates for these fisheries, we estimated that sturgeon mortalities in FSC fisheries were significant in some years (annual estimates ranged from a low of 91 to 284 in 2019 to a high of 1,181-1,661 in 2004). Conservative estimates of the number of sturgeon caught in lower Fraser River gillnet fisheries from 2000-2019 range from 87,830 to 146,400 (Table D4). Estimates of the number of sturgeon mortalities associated with First Nations gillnet and setnet fisheries from 2000-2019 range from 4,335-7,225 (assuming lower mortality rate for released sturgeon) to 8,752-14,587 (using the higher mortality rate for released sturgeon; Table D5). Depending on the combination of catch rate assumption (i.e., three to five times) and whether the high vs. low mortality rates were used for each gear type, total mortality associated with the First Nation gillnet fisheries (2,818-9,482 for 60-150 cm FL sturgeon) could account for 10-33% of the estimated 29,000 decline of 60-159 cm FL sturgeon from 2003-2019 (Challenger et al. 2020). The threat level was rated Medium (2) because the losses due to this fishery have likely been in the 11-30% range (consistent with a medium level of impact) and there is substantial evidence that this fishery has contributed to population declines and is likely affecting population recovery to the abundance levels observed as recently as 2005 (i.e., causal certainty is high). The fishing effort data for these fisheries also indicate that there has been a substantial decline in FSC effort in recent years due to poor salmon returns, the estimates of sturgeon bycatch are lower in years with reduced effort in these fisheries.

Illegal Harvest was identified as a potential threat because illegal nets and long-lines have been found along the Lower Fraser River by Fisheries Officers, Conservation Officers, and others active along the Fraser River. Dead sturgeon have been found in some of these illegal or lost nets, however, the number of sturgeon killed by these nets is unknown. The level of threat risk was rated Unknown (4) because of the lack of data to guide the assessment of the severity of this threat on the Lower Fraser Sturgeon population.

Noise and boat strikes associated with recreational activities were identified as potential threats because of the large amount of recreational boating activity on the lower Fraser River, and given that this type of activity in sturgeon spawning and rearing areas could have a negative effect on sturgeon. While boat strikes can occur at any time of the year, the threat level was rated Low (4) because a large portion of the recreational boaters use jet motors rather than motors with propellers and recreational boating activity is generally low during the May-July sturgeon spawning period when sturgeon would be more likely to be impacted by noises that are related to recreational boating activity.

Capture and Handling Stress Related to Sturgeon Research were identified as potential threats since the FRSCS Monitoring and Assessment (M&A) program for lower Fraser River sturgeon has sampled 165,524 sturgeon, and applied PIT tags to 74,167 sturgeon from 1999-2019 (Nelson et al. 2020). Juvenile sturgeon have been sampled using tangle nets from 2008 to 2018 (Glova et al. 2008, Schwindt and Yeung 2020) and acoustic tags have been applied to adult sturgeon in recent years (e.g., Robichaud et al. 2017, Golder Associates 2019, McLean et al. 2019, 2020), but the numbers of juvenile and adult sturgeon handled in these efforts have been very low compared to the annual PIT tag M&A program. The risk associated with this threat was rated as Low (5) because of the strict adherence to the guidelines for handling sturgeon and care taken by all FRSCS volunteer taggers to minimize stress during the sampling, measurement, and tagging process.

Shoreline modification was identified as a potential threat because of the extensive use of dikes, rip-rap, tidal gates and flood gates to protect shoreline developments or reduce flood risk. These shoreline modifications were identified as potential threats because most of those that are currently in place are believed to limit sturgeon access to a significant amount of off-channel rearing habitat in the lower Fraser River. The 15 April 2020 Resilient Waters Advisory Meeting Report (Tides Canada, 2020) provides a short-list of 20 sites where modifications to shorelines (e.g., flood gates, pump stations, dikes) would improve fish access to a substantial amount of off channel habitat (Ken Ashley, BCIT, pers. comm.). The level of threat risk was rated Medium (4) because there was a high probability that the loss of this off-channel habitat had resulted in a medium level of impact (11-30%) on the population. However, the causal certainty was low because there has been little change to these shoreline modifications during the recent period of population decline, and there is limited evidence that these threats are impacting recovery to abundance levels observed in 2005. However, the strategic replacement of some tidal and flood gates and/or slough reconnection could have a positive impact on sturgeon growth, survival, and recovery by providing access to a significant amount of off-channel habitat.

Catchment surface modification was identified as a potential threat because of the large amount of development (paved surfaces) to serve the large number of people living and working in the lower Fraser Valley. The large amount of paved surfaces will increase the amount of surface flow coming from the land and entering the Fraser River. These surface runoffs can affect the nearshore aquatic environment via increased siltation and pollution. The potential impact from pollution is assessed below. The level of threat risk was rated Unknown (5) because of the lack of prior knowledge, literature, or data to guide the assessment of the severity of this threat on the Lower Fraser Sturgeon population.

Food availability was identified as a potential threat because the growth and survival of juvenile sturgeon are certainly affected by the food available in the lower Fraser River. The growth of adult sturgeon is also affected by food availability, which likely affects the fecundity and maturation schedules of adult female sturgeon. Food for adult sturgeon include all species of salmon, Eulachon and many other fish species. Food for juvenile sturgeon include many species that are affected by the nutrients added to the ecosystem by Eulachon and salmon that spawn and die each year in the Lower Fraser River. Eulachon and Chum Salmon (*Oncorhynchus keta*) are two of the more important species because they are annual sources of food for sturgeon and nutrients for the lower Fraser ecosystem. Historical escapement estimates indicated that there has been a substantial decline in the biomass of Chum Salmon that could potentially spawn in the lower Fraser River (Figure 8). During the peak years of relatively high recruitment to Age 7 (1995-2003), the average annual escapement of Chum Salmon was 1.9 M which added approximately 9,865 tonnes of marine-derived biomass and nutrients to the lower Fraser River ecosystem each year. From 2004-2010, the estimated Chum Salmon biomass input declined to 6,709 tonnes, and then declined further from 2011-2016 to 5,617 tonnes (57% of the 1995-2003 estimate). During the same three periods, the biomass index for Fraser River Eulachon decreased from 482 tonnes to 52 tonnes, then increased to 113 tonnes (Figure 8). Furthermore, there appears to be a positive association between the number of juveniles (i.e., Age 7) produced per adult and these two food sources (Figure 9). Given the parallel but more substantial decline in the abundance estimates for Age 7-12 (juvenile sturgeon) during this period, it would be reasonable to assume that food availability was likely one of the contributing factors. The level of threat risk was rated Medium (3) because there was a high probability that reduced food availability could have a 11-30% level of impact on the population. The causal certainty was rated Medium because both sturgeon growth rates (Nelson et al. 2020) and juvenile abundances have declined during the years when there have been substantial declines in the biomass of Chum Salmon, Eulachon and other salmon species entering the lower Fraser River (PSC 2019; DFO 2020; Challenger et al. 2020).

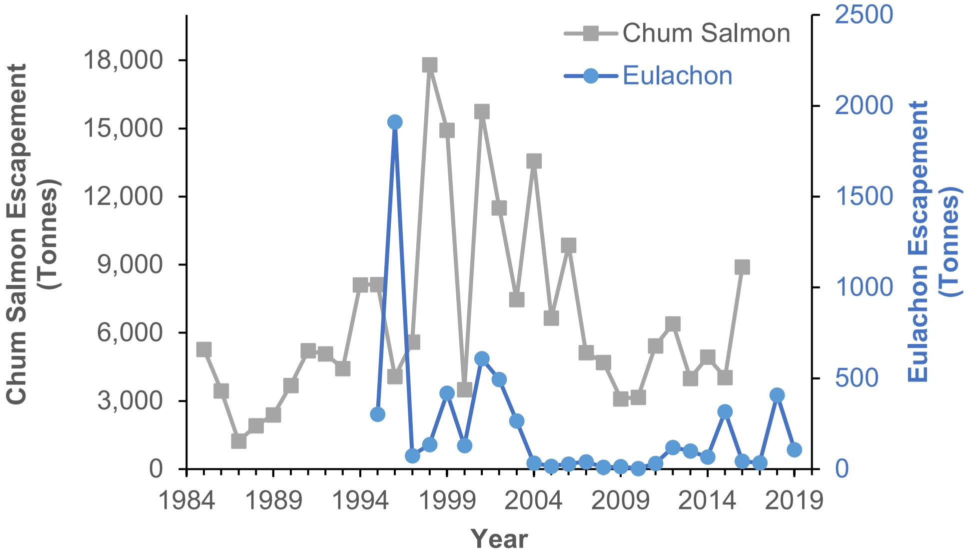

Figure 8. Estimates of Chum Salmon and Eulachon escapement in the lower Fraser River from 1995-2016. Chum Salmon escapement is based on index stocks (Harrison, Stave, Chilliwack, Inch Creek, Weaver Creek, Chehalis), plus a varying number of smaller streams in a given year. No expansion to these estimates is done for unassessed populations, with the exception of the Chilliwack mainstem, which has not been assessed since 2001. Escapement data are being reviewed and may be updated in the future. Chum Salmon data from 1985-2006 are from TFOG (2013), and those from 2007-2016 are from Table 3-11 in PSC (2019). Counts were converted to tonnes assuming an average weight of 5 kg. Eulachon biomass estimates are from Table 1 in DFO (2020).

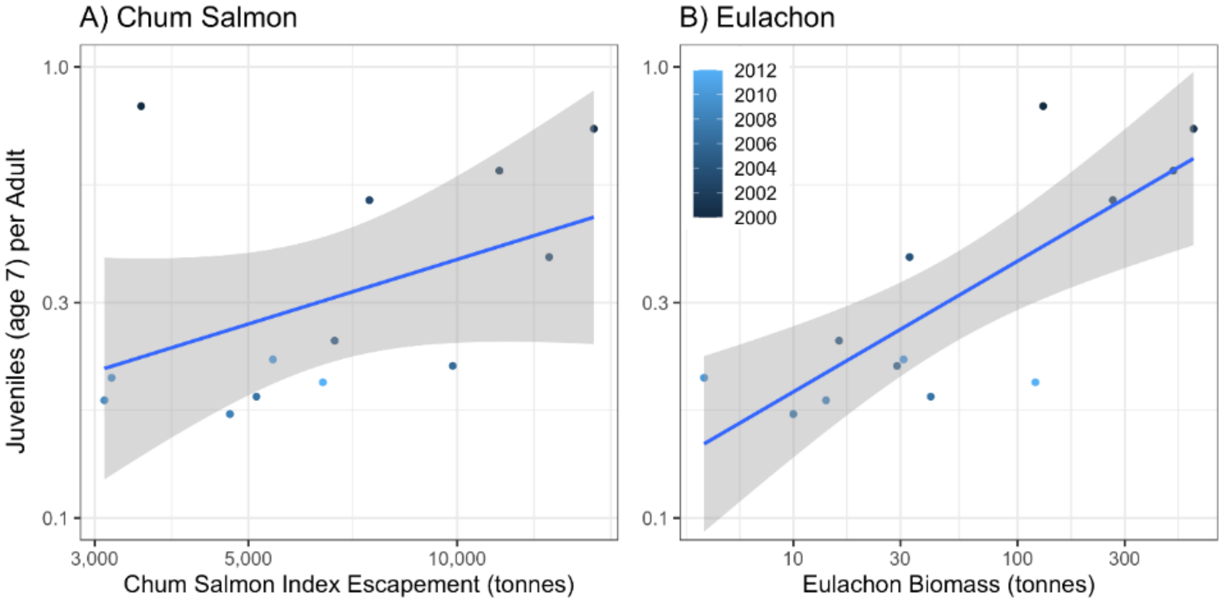

Figure 9. Estimates of the ratio of juveniles (age 7) per adult, as a function of Chum Salmon and Eulachon escapement in the lower Fraser River from 2000-2012. Solid line indicates simple linear regression fit, with shading indicating the 95% confidence region for the regression line. Axes are displayed on a logarithmic scaling. Adult and juvenile abundances are based on Figure 3 and Figure 4, with Chum Salmon and Eulachon escapement from Figure 8.

Invasive non-native/alien species were identified as potential threats because there are non-native species in the lower Fraser River that could prey on juvenile sturgeon (e.g. Centrarchid bass). The level of threat risk was rated Unknown (5) because of the lack of prior knowledge, literature, or data to guide the assessment of the severity of this threat on the Lower Fraser White Sturgeon population.

Introduced pathogens and viruses were identified as potential threats however we do not have any direct evidence of pathogens or viruses in the Lower Fraser White Sturgeon population. The level of threat risk was rated Unknown (5) because of the lack of prior knowledge, literature, or data to guide the assessment of the severity of this threat on the Lower Fraser White Sturgeon population.

Introduced genetic material was identified as a potential threat because juvenile sturgeon released from the Nechako Hatchery program have disbersed downstream in the Fraser River as far as Williams Lake (Colin Schwindt, FLNRORD, pers. comm.), and it is likely that some of these fish will be found in the lower Fraser River in the future. Once they reach spawning age, their genetic material could be introduced into the Lower Fraser sturgeon population. The level of threat risk was rated Low (5) because the level of impact was rated low (<10% of the population affected and this threat is unlikely to jeopardize the survival or recovery of the population) and the causal certainty was rated very low because there is no evidence that this threat has contributed to recent declines. There are nevertheless concerns that this may be a potential future threat to the population.

Pollution from various sources were identified as a potential threat because it is known that pollution associated with household sewage, urban wastewater, industrial & military effluents, and agricultural & forestry effluents has been entering the Lower Fraser River for many years. The level of threat risk was rated Unknown (4) because of the lack of prior knowledge, literature, or data to guide the assessment of the severity of this threat on the Lower Fraser White Sturgeon population, and the causal certainty was rated low. While pollution may be affecting the sturgeon recovery, we are not aware of recent changes in pollution levels that might have contributed to the recent decline in the sturgeon population.

The **Hells Gate impediment** was identified as an historical event that has restricted the upstream movement of sturgeon. The level of threat risk was rated Low (5). The level of impact was rated low (<10% of the population affected). The causal certainty was rated very low because there have not been any significant changes at Hells Gate since the fishways were built in the 1940’s. Therefore, it is unlikely that this impediment has contributed to the recent decline. While the recent major landslide at Big Bar has significantly affected salmon migrations past that site, it has not directly affected the Lower Fraser Sturgeon population.

Climate change and severe weather were identified as potential threats because droughts could reduce sturgeon access to off-channel habitat, and higher water temperatures would increase their metabolic rate and thus food requirements for sturgeon residing in the lower Fraser River, as well as exacerbate the impacts of angling, net encounters and handling (e.g., McLean et al. 2016). Thus far, droughts have not been a significant factor for the lower Fraser ecosystem due to the size of the watershed. While water temperatures have been increasing in recent years, they are rarely in the range where they could be a significant factor in sturgeon survival (i.e., >25 °C, Secor and Gunderson, 1998), and sturgeon generally reside in the deeper / cooler waters. For these reasons, the current threat risk associated with climate change and severe weather were rated as Low (5) and Low (4), respectively, but these threats are expected to be more important in the future.

4.2. ELEMENT 9: IDENTIFY THE ACTIVITIES MOST LIKELY TO THREATEN (I.E., DAMAGE OR DESTROY) THE HABITAT PROPERTIES IDENTIFIED IN ELEMENTS 4-5 AND PROVIDE INFORMATION ON THE EXTENT AND CONSEQUENCES OF THESE ACTIVITIES

In Table 2, we have identified major threats and types of activities that have affected sturgeon habitat in the past and/or could affect sturgeon habitat in the future. This section provides a summary of the link between these threats/activities and the habitat properties that White Sturgeon need for the successful completion of each life stage.

The most important properties of juvenile sturgeon habitat include the provision of food for growth, and availability of refugia for protection from predation. Activities that have directly affected these important properties for larval and juvenile sturgeon habitat include: 1) gravel extraction from areas close to sturgeon spawning areas where larval sturgeon can hide from predators and feed in the interstitial spaces between gravel and rocks in the river bed; 2) commercial and FSC gillnet fisheries that have resulted in substantial bycatch of juvenile sturgeon in fisheries targeting salmon; 3) tidal and flood gates that have prevented juvenile sturgeon from accessing productive off-channel habitat for feeding and avoiding predators; 4) shoreline modifications that have transformed natural shorelines into engineered river banks and dykes that are less productive; and 5) reductions in food availability due to the direct removal of key prey species by fisheries and reduction of the quantity of nutrients being deposited in juvenile rearing areas.

Information on the extent and timing of gravel extractions from locations close to known sturgeon spawning and rearing areas and reductions in the availability of key prey species (e.g. Eulachon and Chum Salmon) have been provided under Element 8. While it is always difficult to determine the consequences of specific actions, the timing of recent declines in juvenile sturgeon abundance in the lower Fraser River does align with the timing of substantial gravel extractions and reductions on prey availability for two important prey species and sources of nutrients for the lower Fraser River ecosystem. The other activities that likely have had some impact on the growth and survival of juvenile sturgeon have not changed substantially over the time frame when juvenile abundance has declined.

For all life stages of sturgeon growth and survival, important habitat properties are an abundant food supply, minimal disturbance during feeding, and fewer fishery encounters. Activities identified in Table 2 that have directly affected these important habitat properties include: 1) commercial and FSC gillnet fisheries that have resulted in substantial bycatch of subadult sturgeon; 2) recreational fisheries that can catch large numbers of subadult and adult sturgeon, with some individuals caught multiple times in a single year; 3) boat noise and boat strikes that can disturb and/or kill adult sturgeon; 4) reductions in food availability due to the direct removal of key prey species by fisheries, and reduction of the quantity of nutrients being deposited in feeding areas.

Information on the magnitude of the bycatch of sturgeon in FSC fisheries, the number of sturgeon caught and released in recreational fisheries, and reductions in the availability of key prey species have been provided under Element 8. While there have been recent declines in subadult sturgeon, these are the result of earlier declines in juvenile sturgeon (fewer small fish ageing into the subadult category), and are therefore not likely the direct result of changes in the habitat or of fishery-related impacts. Our best estimates of abundance for adult sturgeon indicate that this component of the population has been steadily increasing over the past 20 years as a result of higher abundances of juvenile sturgeon in the 1990’s and early 2000’s (Challenger et al. 2020).

Natural factors that could limit the survival and recovery of Lower Fraser White Sturgeon include: declines in abundance of key prey species and nutrient sources for the lower Fraser River ecosystem (e.g., salmon and Eulachon); increases in species that prey on sturgeon (e.g., seals, birds, and other fish species); siltation of sturgeon spawning areas; reduced inputs of gravel to the sturgeon spawning areas in the gravel reach; and natural changes in water temperature, river discharge, and flow through spawning, rearing, and overwintering areas. Available information on the biomass of Chum Salmon and Eulachon entering the lower Fraser River from 2000-2012 indicates a positive relationship between the biomass of these two species and the abundance of juvenile (age 7) sturgeon seven years later (see Figure 9). Other salmon species (e.g. Sockeye and Pink salmon) are also likely to be important source of food and nutrients for various life stages of White Sturgeon.

4.3. ELEMENT 11: DISCUSS THE POTENTIAL ECOLOGICAL IMPACTS OF THE THREATS IDENTIFIED IN ELEMENT 8 TO THE TARGET SPECIES AND OTHER CO-OCCURRING SPECIES. LIST THE POSSIBLE BENEFITS AND DISADVANTAGES TO THE TARGET SPECIES AND OTHER CO-OCCURRING SPECIES THAT MAY OCCUR IF THE THREATS ARE ABATED. IDENTIFY EXISTING MONITORING EFFORTS FOR THE TARGET SPECIES AND OTHER CO-OCCURRING SPECIES ASSOCIATED WITH EACH OF THE THREATS, AND IDENTIFY ANY KNOWLEDGE GAPS

The potential ecological impacts of the threats in Table 2 are described under Element 8. Abatement of the threats could benefit sturgeon and other co-occurring species. For example, protection of sturgeon spawning areas from gravel extraction could provide benefits to sturgeon (as described in Element 8), but also to Chum and Pink (*Oncorhynchus gorbuscha*) salmon that likewise spawn in these areas. The transition to more selective fishing methods (e.g., traps and fishwheels) could have significant benefits for sturgeon, but also for other non-target species commonly caught in lower Fraser River gillnet fisheries including: endangered Interior Fraser steelhead and several stocks / species of Fraser River salmon (e.g., Interior Fraser Coho Salmon, spring and summer Chinook Salmon, Early Stuart Sockeye Salmon, etc.). Reductions in fishing pressure on important prey species (e.g. Fraser Salmon and Eulachon) would help White Sturgeon indirectly, but would also directly help rebuild lower Fraser River Salmon stocks and the currently endangered Fraser Eulachon stock. Reductions in the quantity of pollutants entering the lower Fraser River would benefit sturgeon as well as juvenile salmon and other species that rear in the lower Fraser River. Time-area closures of the recreational fishery have been implemented to protect sturgeon from fishing related stress during their spawning period.

There are several existing monitoring efforts for Lower Fraser Sturgeon that are associated with the identified threats. The status and trends in the Lower Fraser Sturgeon population are currently being monitored by a Passive Integrated Transponders (PIT) tag mark-recapture program that has been conducted by the FRSCS since 1999 (Nelson et. al. 2020, Challenger et al. 2020). Returns of Salmon and Eulachon to the lower Fraser River are being monitored by DFO and lower Fraser First Nations. Catch monitoring programs for commercial and FSC fisheries are conducted by DFO and lower Fraser First Nations, but estimates of the bycatch of sturgeon and other non-target species require improvement. More on-water surveys are needed to observe the sturgeon bycatch rates and interview Food, Social, & Ceremonial (FSC) fishers during active fishing periods. Estimates of the number of sturgeon caught by anglers have been derived from guide reports and questionnaire data by FLNRORD, but individuals familiar with these data have identified serious concerns regarding biases in these estimates (Robichaud 2018a,b). Creel survey methods including angler interviews at landing sites to determine catch rates/angler and fishing activity patterns; and on-water or aerial surveys to obtain boat and angler counts are needed to derive more reliable estimates of sturgeon catch and effort by recreational anglers.

Significant knowledge gaps related to the threats for sturgeon include: 1) the identification of important rearing habitats for juvenile sturgeon in the lower Fraser River; 2) the key factors that affect the number of juvenile sturgeon in the lower Fraser River; 3) reliable estimates of the bycatch of sturgeon in lower Fraser River gillnet fisheries; and 4) reliable estimates of the number of sturgeon caught and released by lower Fraser River anglers.

5. RECOVERY TARGETS

5.1. ELEMENT 12: PROPOSE CANDIDATE ABUNDANCE AND DISTRIBUTION TARGET(S) FOR RECOVERY

The National Recovery Strategy for White Sturgeon (DFO 2014a) adopted McElhany et al. (2000)'s definition of a 'viable' population as one "that has a negligible risk of extinction due to threats from demographic variation (random or directional), local environmental variation, and genetic diversity changes (random or directional) over a 100-year time frame." While viability was defined on a 100-year time scale, measurable objectives for the population and distributional targets were listed as needing to occur within a 50-year timeframe. Thus, for the purpose of the modelling exercise (see ELEMENT 13), the population was projected over a 50-year time horizon. This shorter time frame has an important effect on our results. In many cases, recovery scenarios resulted in increases in abundance over time. However, owing to the 50-year time frame, in some cases the increasing population was on track to reach target (threshold) levels, and would have done so if a longer time frame had occurred.

5.1.1. Abundance

When defining abundance targets, the National Recovery Strategy provides a rule-of-thumb rationale for 10,000 mature individuals to ensure medium to long-term persistence. As such, we have used an abundance of 10,000 mature individuals as a survival threshold in the RPA (Table 4). In addition to the survival threshold, three candidate recovery thresholds were also considered, with abundance thresholds based on abundances attained in recent history. Two of these abundance thresholds have been suggested before (i.e., Challenger et al. 2017).

The first candidate recovery threshold was for 20,000 adults (Table 4). The current estimated abundance trends for Lower Fraser White Sturgeon suggest that the mature population (i.e., 160-279 cm FL) has recently reached 20,000 individuals, with abundance expected to peak in the next 5 years (Challenger et al. 2020). Selecting a threshold for adults that is substantially lower than current levels, given that the overall population has been declining for 15 years, may seem counterproductive. Currently, the juvenile recruitment rate is too low to maintain the adult population over time, and if it continues at its current pace into the future, adult abundances are expected to start to decline, dipping below 20,000 by 2030, and continuing to decline over the next 50 years (Challenger et al. 2020). Taking these factors together, 20,000 (rather than the 10,000 fish 'rule-of-thumb') was viewed as a more appropriate candidate abundance recovery threshold for the population and the analysis. That said, the ability of the population to maintain an adult population above a lower survival threshold 10,000 was also considered in addition to the proposed candidate recovery threshold.

A second candidate recovery threshold for 'total' abundance (individuals sized 60-279 cm FL) was set to 60,000 individuals (Table 4). In addition to the concerns about the adult segment of the population, there are also concerns about the rest of the age classes, and thus the total population as a collective. Low recruitment to the juvenile life stage has been identified as a primary source of concern for the long-term viability of the population (e.g., Nelson et al. 2020, Challenger et al. 2020). Without sufficient recruitment into younger age classes, older age classes are expected to undergo reductions, although at a relatively protracted rate given the long-lived nature of the species. Total abundance of 60-279 cm FL sturgeon was estimated to have peaked in the mid-2000s at an abundance of approximately 60,000 (Challenger et al. 2020). Given that this peak occurred in recent history (i.e., lower Fraser River habitat has recently supported this level of abundance), a total abundance of 60,000 individuals sized 60-279 cm FL was selected as the second candidate recovery threshold.

In addition to the fixed abundance thresholds, the third candidate recovery threshold was defined by *trends* in abundance. Specifically, a positive linear trend in juvenile abundance (i.e., 60-99 cm FL) were considered as additional candidate recovery thresholds.

Table 4. Survival threshold and candidate recovery thresholds for Lower Fraser White Sturgeon.

Name	Type	Abundance	Age/Size Categories	Description
Adult Survival Threshold	Survival Threshold	10,000	Age 22-55 (160-279 cm FL)	Mature adult abundance threshold suggested for medium to long-term persistence.
Adult Recovery Threshold	Candidate Recovery Threshold	20,000	Age 22-55 (160-279 cm FL)	This demographic represents mature sturgeon. While the adult abundance threshold is currently being met, we expect the numbers to fall below this level by the end of the decade (i.e., 2030; Challenger et al. 2020).
Total Recovery Threshold	Candidate Recovery Threshold	60,000	Age 7-55 (60-279 cm FL)	This demographic includes juveniles, subadults, and adults. The proposed threshold was estimated to have occurred within recent histories (i.e., 2005; Challenger et al. 2020) and therefore is believed to reflect abundances that are attainable under current environmental conditions.
Juvenile Trend Recovery Threshold	Candidate Recovery Threshold	Positive trend over the 50-year window	Age 7-12 (60-99 cm FL)	Increases in juvenile abundances are required to rebuild the population, therefore, a positive linear increase in juvenile abundances (age 7-12) over the 50-year period was proposed for the juvenile trend threshold.

5.1.2. Distribution

The distribution of the Lower Fraser White Sturgeon DU is described in ELEMENT 1 and trends in distribution are described in ELEMENT 2. The distribution target for this RPA is to maintain the current distribution. For the purposes of our modelling exercises (see ELEMENT 13 and onward), we have not considered distributional changes when determining population trajectories. This is because the upstream boundary for Lower Fraser White Sturgeon is Hells Gate, and movement in the Lower Fraser DU is not currently limited nor expected to be limited in the near future.

5.2. ELEMENT 13: PROJECT EXPECTED POPULATION TRAJECTORIES OVER A SCIENTIFICALLY REASONABLE TIME FRAME (MINIMUM OF 10 YEARS), AND TRAJECTORIES OVER TIME TO THE POTENTIAL RECOVERY TARGET(S), GIVEN CURRENT WHITE STURGEON POPULATION DYNAMICS PARAMETERS

Expected population trajectories were determined by projecting forward the posterior samples from Challenger et al. (2020). Each posterior sample contains a unique proposal of age-specific abundances and age-specific mortalities, which were then projected forward in order to derive a posterior predictive distribution of abundances up to the year 2070. Currently, the ISAMR model does not employ a spawner-to-recruit relationship, but instead directly estimates recruitment (Challenger et al. 2017). As a result, the baseline juvenile recruitment rate used in the forward projections assumed that future age-7 recruitment remained similar to recruitment over the last 10 years (i.e., 2009-2019; Figure 4).

Simply resampling the posterior sample of age-7 abundances will underrepresent uncertainty in future recruitment, as it assumes that the future average age-7 abundance will be similar to current levels (i.e., the mean of the 2009-2019 posterior age-7 abundances). As such, a posterior sample of age-7 abundances was used as a guidance for potential future recruitment in the forward projections (mean: 2,333, SD: 595). The probability-weighted values from the posterior sample of age-7 was used to assign a unique average age-7 recruitment value to each of the posterior projections. Year-to-year variation in future recruitment was based on the year-to-year variability the average yearly age-7 recruitment over the last 10 years (i.e., an estimate of process error; SD: 556). This follows the same procedure used in the 1x recruitment scenario of Challenger et al. (2020), resulting in a posterior predictive distribution of age-specific abundances up to the year 2070 (Figure 10).

Overall, if recruitment into age-7 persists at similar levels as over the last 10 years (i.e., 2009-2019) the juvenile demographic category (i.e., 60-99 cm FL) will remain at abundances in the lower end of values estimated from the previous two decades (Figure 10a). This lower level of juvenile recruitment is forecasted to result in a continued decline in the total population (i.e., 60-279 cm FL; Figure 10b top panel) and an eventual decline in adults (i.e., 160-279 cm FL; Figure 10b bottom panel). By 2070, both are expected to miss their respective candidate recovery thresholds (see Table 4), but adult abundance is also expected on average to be just below the survival threshold (mean: 9,072, SD: 2,507). While adults are forecasted to surpass the adult recovery threshold until approximately 2030, the population is forecasted to thereafter fall below the recovery threshold due to current estimated population structure, which lacks sufficient replenishment from younger ages. The long maturation times for sturgeon (see ELEMENT 1) indicate that changes in recruitment can take over 20 years before impacting the adult demographic category (i.e., 2040 and beyond). These forecasts indicate that under current conditions it is very unlikely for the recovery thresholds to be achieved without either natural improvements in juvenile recruitment or management intervention. Future scenarios considering these possibilities are explored further in ELEMENT 20.

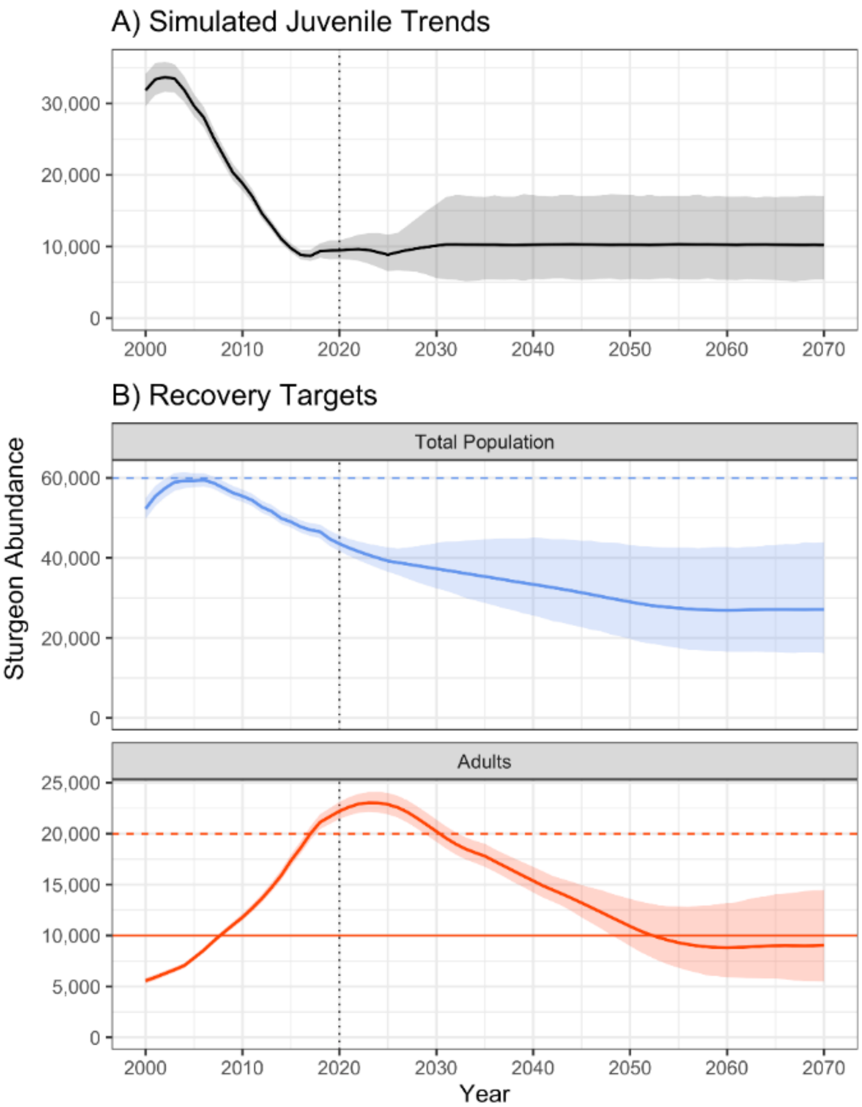

Figure 10. Simulated trends in White Sturgeon abundances under current conditions. A) simulated trends for juvenile (60-99 cm FL) abundances. B) forecasts for adult (160-279 cm FL) and the total population (60-279 cm FL) abundances. Vertical dotted lines indicate the start of the population projection. Horizontal dashed lines in panel B indicate candidate recovery thresholds for total population (blue) and adults (orange). Horizontal solid line (orange) in panel B indicates the adult survival threshold. Shading in (A) indicates the 95% percentiles in the simulated juvenile trends. Shading in (B) indicates the 95% credible interval from the posterior predictive distribution under assumed recruitment scenario.

5.3. ELEMENT 14: PROVIDE ADVICE ON THE DEGREE TO WHICH SUPPLY OF SUITABLE HABITAT MEETS THE DEMANDS OF THE SPECIES BOTH AT PRESENT AND WHEN THE SPECIES REACHES THE POTENTIAL RECOVERY TARGET(S) IDENTIFIED IN ELEMENT 12

Most of the physical habitat hypothesized to be important for White Sturgeon has not been substantially altered since the abundance levels were close to the total recovery threshold of 60,000 age 7-55 sturgeon observed in 2005 (see ELEMENT 2). Therefore, the supply of suitable habitat should be able to support the species both at the present level and at the proposed candidate recovery threshold. However, many of these important habitats are threatened by proposed developments and activities on the river that could be detrimental to sturgeon. In-river gravel extractions were permitted near four of the 14 confirmed White Sturgeon spawning areas (i.e., at Mountain Bar, Hamilton Bar, Herrling side channel, and in the Seabird Island area) between 2000 and 2015 (see Element 8). The impact of these extractions on sturgeon spawning is unknown. The current moratorium on in-river gravel mining and efforts to reduce fishing activity in known spawning areas during the spawning season will help maintain the integrity of spawning habitat.

The high abundances observed at a few sites (Pitt River, Matsqui side-channel and Hatzic Eddy) during winter months have made sturgeon highly catchable at these sites and indicate that these are important overwintering sites for Lower Fraser White Sturgeon (English and Robichaud 2019, Robichaud and Johnson 2020), and care should be taken to avoid impacts from future developments. Proposed developments near the Matsqui side-channel and Hatzic could affect these important overwintering areas.

Juvenile sturgeon can be readily found in high numbers in overwintering areas but are not as abundant in these areas during the spring and summer months. We suspect that these juveniles, along with many of the large sturgeon, disperse to other parts of the river for feeding (and some portion of the mature sturgeon migrate to spawning areas during the spring). The feeding and rearing habitat of juvenile sturgeon has likely been affected by dykes and exclusion from side-channels, but most of these impacts occurred much earlier than the recent peak abundances observed in 2005. However, the quantity of food available in the habitats important to juvenile sturgeon has likely been affected by the decline in abundance of salmon and Eulachon returns to the lower Fraser River (see Figure 8). This prey base could potentially need to be recovered to meet the demands of the species, both at present, and when the species reaches the proposed recovery threshold.

5.4. ELEMENT 15: ASSESS THE PROBABILITY THAT THE POTENTIAL RECOVERY TARGET(S) CAN BE ACHIEVED UNDER CURRENT RATES OF POPULATION DYNAMICS PARAMETERS, AND HOW THAT PROBABILITY WOULD VARY WITH DIFFERENT MORTALITY (ESPECIALLY LOWER) AND PRODUCTIVITY (ESPECIALLY HIGHER) PARAMETERS

Population projections under scenarios of higher and lower natural recruitment were considered as part of a larger suite of hypotheses in ELEMENT 20.

6. SCENARIOS FOR MITIGATION OF THREATS AND ALTERNATIVES TO ACTIVITIES

6.1. ELEMENT 16: DEVELOP AN INVENTORY OF FEASIBLE MITIGATION MEASURES AND REASONABLE ALTERNATIVES TO THE ACTIVITIES THAT ARE THREATS TO THE SPECIES AND ITS HABITAT (AS IDENTIFIED IN ELEMENTS 8 AND 10)

Table 5 provides an initial inventory of potential actions including feasible mitigation measures and reasonable alternatives to the potentially threatening activities listed in Table 2. The rationale for most of the proposed mitigation and reasonable alternative activities should be self-evident. For example, gravel extraction from in-river locations close to known and potential sturgeon spawning areas has been identified as a threat, so maintaining the current moratorium on gravel extraction in the lower Fraser River is a logical action to eliminate this threat. The rationale for some of the other suggested reasonable alternative activities, like those proposed for the various fisheries that encounter Lower Fraser White Sturgeon, may not be self-evident.

We have identified three alternative levels of actions that could be implemented to reduce the impact for each type of fishery. The Level 1 actions represent a relatively small change from current requirements for each fishery while, Level 2 and 3 actions would require more significant changes to the regulations regarding these fisheries. The relative benefits associated with each level of action is unknown, but it is reasonable to assume that Level 3 actions should provide more substantial benefits than Level 2 or Level 1 actions. Additional details on potential actions and the relative benefits associated with these actions are provided below.

6.2. ELEMENT 17: DEVELOP AN INVENTORY OF ACTIVITIES THAT COULD INCREASE THE PRODUCTIVITY OR SURVIVORSHIP PARAMETERS (AS IDENTIFIED IN ELEMENTS 3 AND 15)

Several of the reasonable alternatives to current activities related to recreational, commercial and First Nation fisheries should have a positive influence on the productivity and/or survival of sturgeon. Improving sturgeon access to productive off-channel habitat by replacing old tidal gates with “fish friendly” gates could increase productivity and survival for juvenile and subadult sturgeon. Reductions in fishing pressure on important prey species and sources of nutrients for the lower Fraser River ecosystem should increase the survivorship of Lower Fraser White Sturgeon.

6.3. ELEMENT 18: IF CURRENT HABITAT SUPPLY MAY BE INSUFFICIENT TO ACHIEVE RECOVERY TARGETS (SEE ELEMENT 14), PROVIDE ADVICE ON THE FEASIBILITY OF RESTORING THE HABITAT TO HIGHER VALUES. ADVICE MUST BE PROVIDED IN THE CONTEXT OF ALL AVAILABLE OPTIONS FOR ACHIEVING ABUNDANCE AND DISTRIBUTION TARGETS

As indicated in ELEMENT 14, the current physical habitat available to sturgeon should be sufficient to achieve the proposed candidate recovery thresholds. However, there are probably many areas along the lower Fraser River where habitat improvements would be beneficial to sturgeon and/or their prey species. The first step in any efforts to restore or improve habitats would be to identify the sites where restoration is needed and would have a significant benefit to sturgeon. The FRSCS has proposed that they work with Lower Fraser River First Nations, provincial and federal government agencies to identify a priority list of locations/habitats that should be considered for restoration and estimate the costs and benefits associated with any proposed restoration activity. Since recent declines in juvenile White Sturgeon abundance and growth rates have occurred during a period when the biomass of Salmon and Eulachon has also been declining in the lower Fraser River, reductions in fisheries for these prey species could help rebuild their populations while providing some substantial benefits for sturgeon. Fraser Eulachon has also been identified as an endangered species that requires rebuilding. The ability of managers to rebuild Fraser Eulachon will depend on the willingness to reduce the bycatch of Eulachon on coastal trawl fisheries and the protection of Eulachon spawning and rearing habitat in the lower Fraser River.

Table 5. Examples of feasible mitigation measures and reasonable alternatives to threatening activities, and estimates of the relative benefits to juvenile and adult mortality and recruitment to Age 7 for each mitigation measure or alternative to threatening activity.

				Anticipated Effects [2,3]			
				Mortality Reductions			
COSEWIC Threat Categories	**Specific Threat**	**Threat Risk**	**Examples of Mitigation / Reasonable Alternative Activities**	**Juvenile, Age < 7**	**Juvenile, Age 7-12**	**Adult,Age 22-55**	**Recruitment Increase**
1. Residential and commercial development							
Threats discussed elsewhere (e.g., 7. Natural system modifications)							
2. Agriculture & aquaculture							
Threats discussed elsewhere (e.g., 9. Pollution)							
3. Energy production & mining							
3.2 Mining & Quarrying	Gravel extraction	Medium (3)	Maintain moratorium on gravel extraction	0%	0%	0%	0-20%
4. Transportation & service corridors							
4.3 Shipping Lanes	Dredging, boat strikes, wakes	Low (4)	Manage boat traffic and dredging to minimize impacts on sturgeon and sturgeon prey species.	0-1%	0-1%	0-1%	0%
5. Biological resource use							
5.4 Fishing & Harvesting Aquatic Resources	Recreational fishing	Low (4)	Level 1: Ensure anglers follow handing guidelines; Level 2: Reduce fishing effort; Level 3: Complete closure of recreational fishery	0%	0%	0-1%	0-10%
5.4 Fishing & Harvesting Aquatic Resources	Bycatch in Commercial fisheries [1]	Low (4)	Level 1: Ensure fishers follow handing guidelines; Level 2: Seasonal closures to reduce sturgeon bycatch; Level 3: Only permit selective fishing methods	0-1%	0-2%	0-1%	0-10%
5.4 Fishing & Harvesting Aquatic Resources	Bycatch in Food, Social, and Ceremonial fisheries	Medium (2)	Level 1: All nets attended & sturgeon quickly released; Level 2: Seasonal closures to reduce sturgeon bycatch; Level 3: Only permit selective fishing methods	2-5%	2-5%	1-2%	20-50%
5.4 Fishing & Harvesting Aquatic Resources	Illegal harvests	Unknown (4)	Increased monitoring and enforcement	ne	ne	ne	ne
6. Human intrusions & disturbance							
6.1 Recreational Boating Activities	Noise and boat strikes	Low (4)	Level 1: Restricted time & areas for propeller motors; Level 2: no use of propeller motors	0%	0%	0-1%	0%
6.3 Work & Other Activities / Science Activities	Handling stress from tagging	Low (5)	Reduce sample size for adult sturgeon.	0%	0%	0-1%	0%

				Anticipated Effects [2,3]			
				Mortality Reductions			
COSEWIC Threat Categories	**Specific Threat**	**Threat Risk**	**Examples of Mitigation / Reasonable Alternative Activities**	**Juvenile, Age < 7**	**Juvenile, Age 7-12**	**Adult,Age 22-55**	**Recruitment Increase**
7. Natural systems modifications							
7.2 Dams & Water Management/use	Shoreline modifications (incl. tidal and flood gates)	Medium (4)	Replace tidal gates with sturgeon friendly gates.	1-3%	1-2%	0%	10-30%
7.3 Other Ecosystem Modifications	Modifications to catchment surfaces	Unknown (5)	Mitigate for any habitat loss.	ne	ne	ne	ne
7.3 Other Ecosystem Modifications	Food availability	Medium (3)	Reduce fisheries for prey species, Big Bar Slide passage	1-3%	1-2%	0%	30-50%
8. Invasive & other problematic species & genes							
8.1 Invasive Non-native/alien Species	Invasive non-native/alien species	Unknown (5)	Cull all invasive non-native/alien species	ne	ne	ne	ne
8.2 Introduced Pathogens and Viruses		Unknown (5)	Monitor pathogens and viruses	ne	ne	ne	ne
8.3 Introduced Genetic Material	Nechako Hatchery program	Low (5)	Reduce hatchery releases and cull all hatchery strays.	ne	ne	ne	ne
9. Pollution							
9.1 Household Sewage & Urban Wastewater	Run-off	Unknown (4)	Better mgt of sewage and wastewater	ne	ne	ne	ne
9.2 Industrial & Military Effluents	Run-off	Unknown (4)	Better controls on effluents	ne	ne	ne	ne
9.3 Agricultural & Forestry Effluents	Run-off	Unknown (4)	Better controls on effluents	ne	ne	ne	ne
10. Geological events							
10.3 Avalanches/landslides	Hells Gate, Big Bar impediment	Low (5)	Improve fish passage for sturgeon prey species	ne	ne	ne	ne
11. Climate change & severe weather							
11.2 Droughts	Side-channel reductions	Low (5)	Manage flows for important side-channels	1-2%	1-2%	0%	10-20%
11.3 Temperature Extremes	River temperature	Low (4)	Close fisheries during high temperature periods.	0%	0%	0-1%	0-10%
Maximum Total *				2-7%	1-5%	1-2%	70-200%

[1] Commercial fishing includes: Area E gillnet fishery, First Nations Economic Opportunity fisheries and Demonstration fisheries

[2] Anticipated effects were estimated on a relative basis for some examples mitigation/activities and reported as “ne” where the potential effect was “not estimated”

[3] Mortality Reduction and Recruitment Increase ranges capture the three levels of mitigation measures presented under the “Biological Resource Use” subheading

*Total effect would be lower for Level 1 or Level 2 actions related to the fisheries.

6.4. ELEMENT 19: ESTIMATE THE REDUCTION IN MORTALITY RATE EXPECTED BY EACH OF THE MITIGATION MEASURES OR ALTERNATIVES IN ELEMENT 16 AND THE INCREASE IN PRODUCTIVITY OR SURVIVORSHIP ASSOCIATED WITH EACH MEASURE IN ELEMENT 17

Table 5 has estimates of the relative reductions in juvenile mortality rates, reductions in adult mortality rates, and increases in productivity (recruitment to Age 7) estimated for each potential management action based on expert opinion using the available data. We have provided estimates of the range in potential reductions for two age categories of juvenile sturgeon (i.e., Age <7 and Age 7-12) in response to comments received on early versions of this table. The Age <7 category was added to show where we would expect some benefits from actions that could reduce the mortality rates for these ages of juvenile sturgeon, however, the method used to assess these potential benefits is through increased recruitment to Age 7. This is necessary since the analytical tool used to assess these benefits is the ISAMR model, and Age 7 is the first age that can be reliably assesed using the currently available data. Details on how the relative benefits of changes of management actions and/or natural productivity were modelled are described later in this document. The values presented in Table 5 are presented to provide our expert opinion of the relative importance of the mitigation and reasonable alternative activities that have been identified and the potential range of these benefits for the forward-looking assessment of the trends in the Lower Fraser Sturgeon population. The specific mitigation and reasonable alternative activities listed in Table 5 are examples of potential reasonable actions that should benefit sturgeon, but this is not intended to be a comprehensive list of potential actions. While the descriptions of these potential actions are brief, most are self-explanatory, but some do require further explanations. For example, maintaining the current moratorium on gravel extraction may not reduce the current juvenile or adult mortality rate, but permitting future gravel extractions could have negative effects. That said, with the moratorium in place, we may expect annual net increases in gravel deposits in the gravel reach which would likely have a positive benefit on recruitment through improved survival of larval sturgeon (as indicated in Table 5). The mechanism for these positive benefits would be improvements in the quality and quantity of spawning areas for sturgeon and salmon as new gravel is deposited in the gravel reach. Spaces between the gravel are important for larval sturgeon to escape predation and feed. Many studies have shown that gravel deposits are important for spawning salmon (Crisp and Carling 1989, Kondolf 2000). However, the benefits from increase productivity and food availability from spawning salmon may not be realized for many years after these new gravel deposits have mitigated for the previous damage from gravel extractions. The benefits from more salmon (i.e., eggs and nutrient additions from carcasses) will also be dependent on the number of adult salmon returning to these spawning areas.

All values included in Table 5 are our estimates of the relative change in the absolute estimates of mortality or recruitment. For example: a 2% improvement in juvenile mortality rates for Age 7-12 sturgeon would reduce the annual estimated mortality rate for each age in this category (e.g. from 16% to 14% for Age 7 sturgeon,11% to 9% for Age 12 sturgeon). The increased recruitment % values refer to recruitment to age 7 which could improve due to increased sturgeon fecundity or reduced mortality rates for Age <7 sturgeon. Examples of factors that could increase fecundity include higher growth rates for adult sturgeon (which could lead to the production of more eggs and/or more frequent spawning for individual females), the protection of sturgeon spawning habitat, and reductions in sub-lethal impacts on adult sturgeon (e.g., latent effects of handling and repeat captures). Examples of factors that could reduce the mortality rate for Age <7 sturgeon include: reduced bycatch in net fisheries, higher growth rates, and access to rearing habitats where predation rates are low.

The management of boat traffic (boat strikes) is expected to have small relative benefits in the mortality rate for adult sturgeon because the number of large sturgeon killed by boat strikes associated with shipping lanes is expected to be small. Improved management of dredging is expected to have some benefits for juvenile sturgeon (i.e., reduced annual mortality rates).

For fisheries, we identified three levels of management actions with potential increasing benefits from Level 1 to Level 3. The low end of the proposed range would apply to Level 1 actions and the upper end of the range would apply to Level 3 actions. For example: the suggestion that all FSC nets be attended and sturgeon quickly released (Level 1) should reduce the mortality rates for Age 7-12 sturgeon by at least 2%, while the relative benefit from a complete transition to selective fishing methods (Level 3) could be a 5% reduction in the annual mortality rate for Age 7-12 sturgeon. These estimates for the potential reduction in the annual mortality rate for Age 7-12 sturgeon are based on our estimates of the number of sturgeon caught in First Nation gillnet fisheries and the sturgeon mortalities associated with these fisheries from 2000-2019 (see Appendix D). These estimates suggest that these net fisheries could account for 10-33% of the estimated decline of Age 7-22 (60-159 cm FL) sturgeon. The total annual mortality rate for Age 7-12 sturgeon estimated using the ISAMR model is 12.6%. Therefore, the 2-5% change in the absolute mortality rate represents 16-40% of the estimated total annual mortality rate for Age 7-12 sturgeon. The benefits for Age 23-55 adult sturgeon would be less than that for juvenile sturgeon given the adult’s lower mortality rate and the lower encounter rates for adult sturgeon in these net fisheries. The benefits for improved recruitment would be the result of reduced mortality on sturgeon < Age 7 caught in these fisheries, and the potential for higher growth and more frequent spawning events that could result from reduced capture and handling stress in adults. Most of the improvement in recruitment would likely be related to reduced annual mortality rates for sturgeon < Age 7. The relative benefits for the alternative management actions proposed for other fisheries would be less than those for FSC fisheries given the differences in the gear types used in these fisheries.

Other potentially important actions identified are those related to: 1) the replacement of tidal and flood gates with “sturgeon friendly” gates that would allow for juvenile sturgeon to access more off-channel rearing habitat; and 2) the reduction of fisheries for important prey species for sturgeon. These actions would be expected to have a similar potential range in benefits for juvenile sturgeon. An increase in prey abundance could result in higher growth rates, more frequent spawning events, and higher fecundities for individual adult sturgeon – all of which could have positive impacts on recruitment. An increase in prey abundance could also improve juvenile growth rates leading to reduced mortality rates.

For all other threats, there is less information to assess the benefits of the identified actions. Benefits of these mitigations are expected to be small relative to those described for other threats above.

6.5. ELEMENT 20: PROJECT EXPECTED POPULATION TRAJECTORY (AND UNCERTAINTIES) OVER A SCIENTIFICALLY REASONABLE TIME FRAME AND TO THE TIME OF REACHING RECOVERY TARGETS, GIVEN MORTALITY RATES AND PRODUCTIVITIES ASSOCIATED WITH THE SPECIFIC MEASURES IDENTIFIED FOR EXPLORATION IN ELEMENT 19. INCLUDE THOSE THAT PROVIDE AS HIGH A PROBABILITY OF SURVIVORSHIP AND RECOVERY AS POSSIBLE FOR BIOLOGICALLY REALISTIC PARAMETER VALUES.

The probability of achieving proposed candidate recovery thresholds was assessed using abundance projections under different hypotheses of future recruitment (Table 6). Forecasts were generated based on the posterior distribution of age-specific abundances and mortality rates produced by the ISAMR model (Challenger et al. 2017, 2019, 2020), along with the recruitment scenarios under consideration (Table 6). The inclusion of age structuring in the ISMAR model makes forward abundance projections possible by combining age-specific abundance estimates with estimated age-specific mortality rates and future recruitment rates (i.e., age-7 recruitment) outline in Table 6.

Currently, the ISAMR model does not estimate a ‘adult-to-juvenile’ recruitment relationship, because population estimates to date do not provide a biologically reasonable or stable relationship between adult abundance and subsequent numbers of Age 7 recruits (Figure 11). Peak estimated recruitment to age-7 (currently used as the index for juvenile; see Challenger et al. 2020) occurred around 2001 (Figure 4), when adult abundances were estimated to be substantially lower that current levels (Figure 3). Thereafter, juvenile recruitment was estimated to decline, while adult abundances increased due the much high levels of Age 7 recruits that occurred prior to 2005 (Figure 4). An adult-to-juvenile relationship estimated from this time series of events would result in an inverted stock-recruitment curve (e.g., Figure 11), which could affect the effectiveness of any forward projections based on it. Lower Fraser White Sturgeon are known to exhibit interval breeding, with intervals as long as 11 years (Semakula and Larkin 1968). Given that adult population estimates are only available for the last 20 years (i.e., Figure 3), and recruitment may also be driven by food availability (i.e., Figure 9), it was felt that the current timeseries of data was insufficient to produce a meaningful adult-to-juvenile recruitment relationship that could be used in the forward population projections. Because we do not have a defensible adult-to-juvenile relationship, it should be noted that the survival changes to the adult population specified in Table 2 will not feedback to recruitments used in the projections.

Table 6. Recruitment scenarios and settings used in forward population projections used to assess the survival and candidate recovery thresholds. Settings considered include age-7 recruitment, juvenile and adult survival, along with lag to management action and the transition period before full effects are realized.

Hypothesis	**Type**	**Age-7 Recruitment**	**Survival Change**		**Lag**	**Transition**
			Juvenile	**Adult**		
H1: Chronic Low Recruitment	Naturally low stable recruitment	1.0 x (2010-2019 average)	–	–	–	10 years
H2: Chronic Moderate Recruitment	Naturally moderate stable recruitment	1.0 x (2005-2014 average)	–	–	–	10 years
H3: Recruitment Decline	Naturally declining recruitment	0.5 x (2010-2019 average)	–	–	–	10 years
H4: Recruitment Increase	Naturally increasing recruitment	2.16 x (2010-2019 average)	–	–	–	10 years
H5: Management Action	Improved recruitment and survival through management actions	1.475 x (2010-2019 average)	+ 4.5%	+ 1.5%	10 years	10 years
H6: Management & Recruitment Increase	Improved recruitment and survival through management actions combined with natural improvements in recruitment	2.635 x (2010-2019 average)	+ 4.5%	+ 1.5%	10 years	10 years

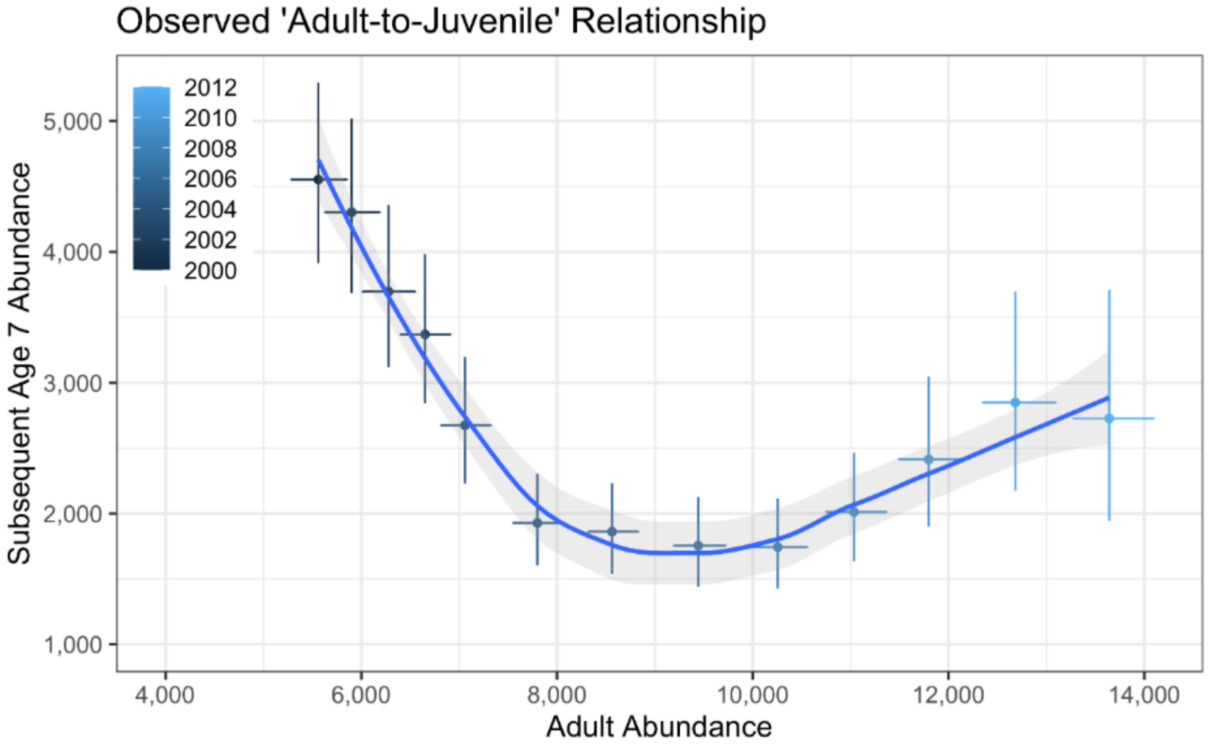

Figure 11. Observed age-7 to adult relationship within the assessment period. Vertical and horizontal bars indicate 95% credible intervals for abundance estimates. Solid line and grey shading indicate the 95% credible intervals from a local polynomial regression fit. Estimates are from Challenger et al. (2020). The line does not represent a meaningful relationship between adults and juvenile recruitment.

Six recruitment hypotheses were developed in order to explore a range of possible future recruitment scenarios and their effect on the probability of attaining the survival and candidate recovery thresholds. Hypotheses were designed to cover a variety of natural (e.g., see ELEMENT 13 and ELEMENT 15) and management scenarios (see ELEMENT 16), including a combination of both. The justification and details of the six hypotheses are as follows:

H1: Chronic Low Recruitment – Recent estimated recruitment rates into the sampled age-7 population has shown chronically low, but stable, rates since ~2011 at approximately 1,900 to 2,800 individuals (Figure 4). Although there are two estimates that suggest recruitment may be increasing, at this time there is insufficient data to support the existence of a real increasing trend. This scenario addresses ELEMENT 13.

H2: Chronic Moderate Recruitment – Prior to 2011 estimated recruitment into age-7 was much higher than at present, peaking in 2001 (Figure 4). Current low recruitment may not be indicative of future recruitment levels. Future increases above current lows may or may not persist but would increase average long-term recruitment over H1. To simulate a scenario of moderate improvements to recruitment, the average age-7 recruitment from 2005-2014 was used instead of 2010-2019, as the former period had moderately higher recruitment. A 10-year period was used to transition from current recruitment levels to recruitment under the moderate scenario.

H3: Recruitment Decline – Chronic low recruitment has persisted for approximately the last 10 years due to multiple factors that are difficult to quantify. Given the uncertainties regarding the factors that have contributed to the recent levels of recruitment, it is possible that recruitment may decline further. To simulate this possibility, the low recruitment hypothesis (H1) was halved with a 10-year transition period and then held stable for subsequent years.

H4: Recruitment Increase – For species that take years between spawning events, and that spawn large numbers of eggs per individual, occasional recruitment pulses are expected, especially if environmental factors can dictate reproductive success in any given year. The available data indicate that the Lower Fraser White Sturgeon population experienced higher recruitments to age-7 from 1998-2003 (Figure 4; Challenger et al. 2020), but the cause for this pattern is unknown. Nevertheless, the estimates suggest that in the recent past the population had the capacity for juvenile recruitment levels that were higher than current levels. Assuming that current environmental conditions could still support higher levels of recruitment, this scenario considers the impact of long-term natural recruitment improvements. The previous peak in age-7 recruitment (from 1998-2003) was approximately 3.24 times higher than recruitment in the last 10 years (i.e., 2010-2019). Because the scenarios are 50 years long, and it is unlikely that this peak in recruitment is sustainable for that duration, we used 66% of this historic peak (i.e., 2.16 times the 2010-19 average) to represent long-term natural recruitment improvements.

H5: Management Actions – Element 8 outlines key threats, and ELEMENT 16 details potential mitigative actions and their anticipated effects on recruitment, juvenile survival, and adult survival (assuming that multiple actions were implemented and effective for many years (see Table 5). While the list is reasonably exhaustive, it is unlikely that all the potential mitigative actions could be performed concurrently. This modelling scenario assumes that the actions undertaken would include: maintaining the gravel mining moratorium, changes to fisheries activities, and improve juvenile White Sturgeon habitat (e.g. replacement of some of the old tidal and flood gates with “fish-friendly gates”). It is also unlikely that these actions would be fully implemented to their maximum anticipated effect. Given this limitation, half of the maximum effect for juvenile survival (age 7-12), adult survival (age 23-55), and recruitment was used in the simulation. Juvenile survival improvements for ages under seven were already included in the estimated increase in recruitment and were therefore not included. There will also likely be a delay before mitigative actions can be implemented, plus a transition period before the full mitigative effect is realized. As a result, a 10-year lag period followed by a 10-year transition period was assumed.

H6: Management Actions and Recruitment Increase – The final scenario considers a combination of both natural improvements in addition to management actions. This scenario is a combination of H4 & H5, and therefore represents the "best case" scenario among the set of hypotheses under consideration.

To assess the population viability under each hypothesis, posterior samples of recruitment from the Challenger et al. (2020) model were projected forward under a given recruitment hypothesis in a manner similar to ELEMENT 13. The posterior distribution of age-7 recruitment over either the last 10 years (i.e., 2009-2019; mean: 2,333, SD: 595), or a different 10-year period (i.e., 2005-2014; mean: 3,522, SD: 1,415), depending on the scenario under consideration, was used as guidance for future recruitment. The probability weighted values from these posterior samples were used to assign a unique average age-7 recruitment value to each posterior projection. Year-to-year variation in the forecasted recruitment was based on the year-to-year variability in the posterior average of age-7 recruitment over the last 10 years (i.e., an estimate of process error; SD: 556). In all scenarios a period of 10 years was used to transition recruitment from current levels (i.e., the sample specific average recruitment value) to the recruitment scenario level (e.g., 2.16 times for H4). This procedure created a posterior predictive distribution of age-specific abundances up to 2070 for each recruitment scenario (Figure 12).

The probability of attaining the survival threshold and candidate recovery abundance thresholds (see Table 4), as well as the resulting trend in juvenile abundance, were assessed across six scenarios of recruitment and future survivorship (see Table 6) over a 50 year timeframe (results are in Table 7). Probabilistic outcomes summarized in Table 7 use the risk/certainty categories adopted by IPCC, which provide a descriptive and understandable language around probabilistic outcomes (Mastrandrea et al. 2010).

Under scenarios where recruitment did not improve substantially from current levels (i.e., H1, H2 and H3), it was unlikely or very unlikely that the candidate recovery abundance thresholds would be achieved (Table 7; Figure 12), but it was about as likely as not that the survival threshold was met if juvenile recruitment didn't decline further (i.e., H1 and H2; Table 7). If there is a further decline in juvenile recruitment then meeting the survival threshold is very unlikely and the long term persistence of the population could be threatened (i.e., H3). Scenarios with either natural improvements in recruitment or improvements in recruitment due to management actions (i.e., H4, H5, and H6) were very likely to surpass the survival threshold and had a 50% or better likelihood of achieving the candidate recovery thresholds within the 50-year timeframe (Table 7). As such, the population can be viewed of as currently existing on a balance point. If juvenile recruitment remains low or even moderately improves the population can be expected to persist into the foreseeable future, but medium to long-term persistence may be in jeopardy if juvenile recruitment declines further. Long-term achievement of recovery thresholds appears to only be achievable through either management intervention or substantive natural improvements in recruitment.

Table 7. Results from population projections assessing the likelihood of meeting the survival threshold and candidate recovery abundance thresholds within a 50-year timeframe.

		Adult Population			Total Population	
Scenario	**Juvenile Trend**	**Survival Threshold: 10,000†**	**Candidate Recovery Threshold: 20,000†**	**Trend**	**Candidate Recovery Threshold: 60,000†**	**Trend**
H1: Chronic Low Recruitment	Stable	About as likely as not	Very Unlikely	Negative	Very Unlikely	Negative
H2: Chronic Moderate Recruitment	Positive	About as likely as not	Unlikely	Negative	Unlikely	Negative
H3: Recruitment Decline	Negative	Very Unlikely	Very Unlikely	Negative	Very Unlikely	Negative
H4: Recruitment Increase	Positive	Very Likely	About as likely as not	Positive	About as likely as not	Positive
H5: Management Actions	Positive	Very Likely	Unlikely	Negative	Unlikely	Negative
H6: Management + Recruitment Increase	Positive	Very Likely	About as likely as not	Positive	Likely	Positive

† The International Panel of Climate Change adopted several risk/certainty categories that are now widely used to categorically describe probabilities of scenarios occurring. Very likely ≥ 0.90, Likely ≥ 0.66, About as likely as not 33-66 %, Unlikely ≤ 0.33, Very Unlikely ≤ 0.10.

Under the scenarios that considered the impact of management actions (i.e., H5 and H6), we found that management actions applied in isolation of recruitment improvements (i.e., H5) were unlikely to reach the candidate recovery thresholds (Table 7). However, when combined with notable natural improvements in recruitment (i.e., H6) there was a high probability of reaching the candidate recovery threshold for total population (i.e., a likely outcome). That said, the probability of reaching the adult recovery threshold did not substantially change between scenarios H5 and H6. This was due to a combination of long-lived nature of the species (see ELEMENT 1) and the lag in management action within the 50-year projection timeframe. As a result, the full effects of mitigation actions on adult abundances only began to be realized near the end of the 50-year projection window. These delays lead to management scenarios being assigned lower probabilities of success for adult thresholds, than would be realized over slightly longer timeframes (e.g., 70 years).

As a result of the delayed effectiveness of management actions, it could be instructive to also compare the 50-year outcomes to ones slightly longer in order to better gauge the overall efficacy of a particular scenario. For example, the trajectory of adult abundances under the `Management Action' scenario (i.e., H5) were positive and heading in the correct direction, but abundances were short of the recovery thresholds by 2070 (Figure 12). The 'Management + Recruitment Increase' scenario (i.e., H6) reached the recovery threshold for both total population and adults with 50% or greater probability, but the population trajectories required to achieve these thresholds will result in overshooting the thresholds over slightly longer time horizons (e.g., 70 years), even if management actions were terminated and natural productivity changes were reversed. The steep trajectories in younger abundances required to overcome the lag times within the 50-year timeframe implies that a large pool of younger sturgeon will continue to enter the adult age category long after the 50-year threshold has passed. That said, even initially aggressive actions can be abated over time if initial results are projecting clear signs of population recovery. Timeframes greater than 50 years would increase support for less aggressive trajectories. For example, while H4 and H5 were insufficient to attain the recovery thresholds with a high probability within the allotted timeframe, they were however fairly close and as such may represent viable scenarios over slightly longer assessment periods.

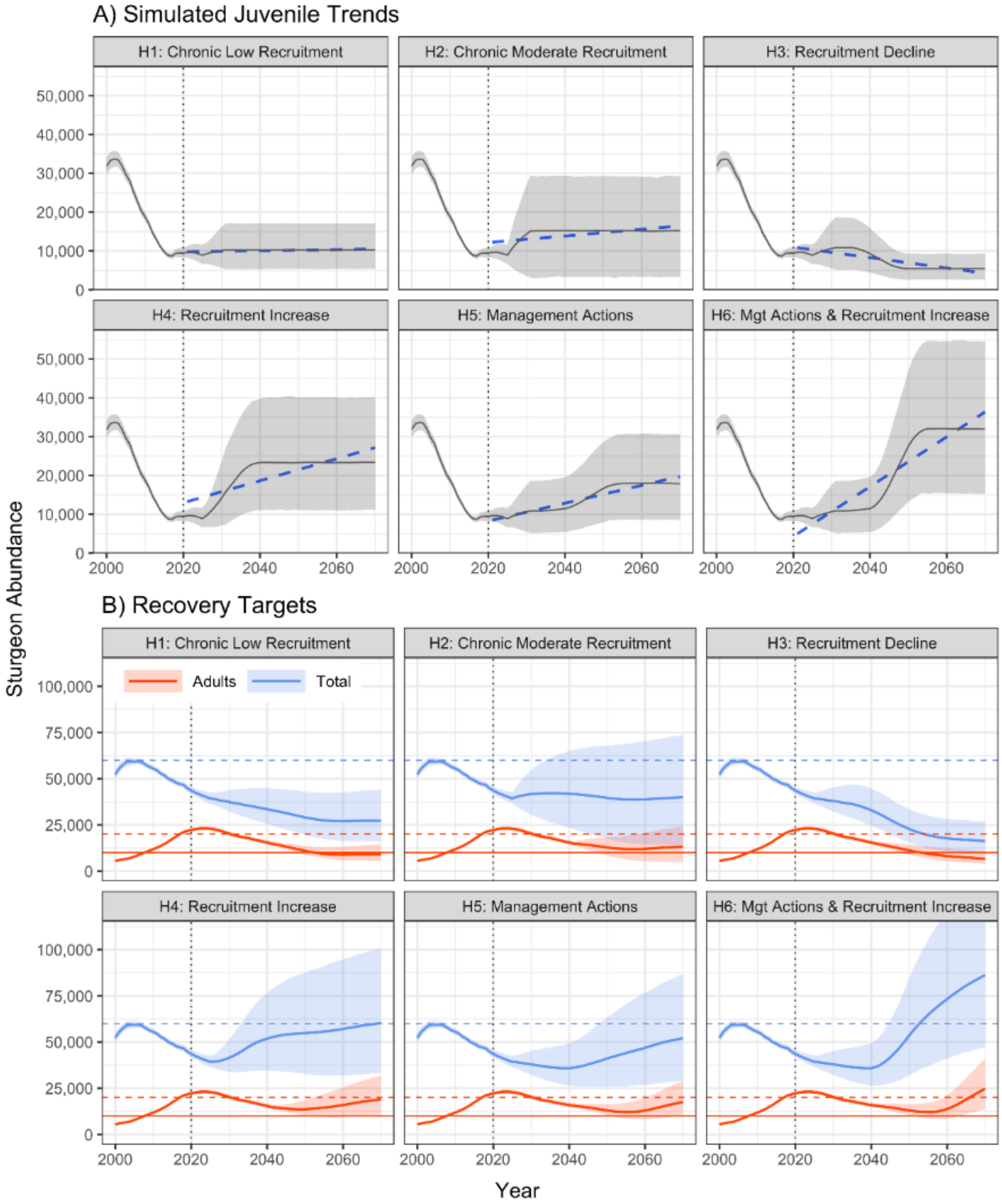

Figure 12. Simulated trends in juvenile (60-99 cm FL) abundances (A) and corresponding forecasts of adults (160-279 cm FL) and the total population (60-279 cm FL) abundances under the six recruitment hypotheses (B). Vertical dotted line indicates the start of the population projection. Horizontal dashed lines in panel B indicate candidate recovery thresholds for adults (orange) and total (blue) populations. Horizontal solid line (orange) in panel B indicates the adult survival threshold. Shading in (A) indicates the 95% percentiles in the simulated juvenile trends, with the dashed line indicating the average linear. Shading in (B) indicates the 95% credible interval from the posterior predictive distribution under the corresponding recruitment scenario.

While the optimal timeframe to assess population projections may need to be reconsidered, the outcome of the simulations all indicate that: 1) any further declines in recruitment will impact the medium to long-term persistence of the population; and 2) management actions and some improvements in natural productivity will be required in order to reach the recovery thresholds in less than 50 years. Scenarios that featured only moderate natural improvements (i.e., H2) were insufficient, but a substantial improvement in natural recruitment (i.e., a 2.16 times improvement over recent estimates) resulted long-term persistence and a moderate probability of achieving the recovery thresholds within 50-year timeframe (i.e., about as likely as not). Management actions in isolation produced improvements as well but were much more likely to achieve recovery thresholds within the timeframe when combined with natural increases in recruitment (or natural decreases in mortality). That said, improvements in adult abundances within the 50-year timeframe were more limited in management scenarios due to lags and transition times associated with executing these actions. If recovery thresholds are to be achieved within a 50-year timeframe, management actions should be rapidly implemented. The effectiveness of management actions may also need to be considered over longer timeframes due to the time delay between implementation and realized changes in adult abundance.

6.6. ELEMENT 21: RECOMMEND PARAMETER VALUES FOR POPULATION PRODUCTIVITY AND STARTING MORTALITY RATES AND, WHERE NECESSARY, SPECIALIZED FEATURES OF POPULATION MODELS THAT WOULD BE REQUIRED TO ALLOW EXPLORATION OF ADDITIONAL SCENARIOS AS PART OF THE ASSESSMENT OF ECONOMIC, SOCIAL, AND CULTURAL IMPACTS IN SUPPORT OF THE LISTING PROCESS

A limitation of the current analysis is the lack of adult-to-juvenile recruitment relationship. Currently, the available data do not support inclusion of this relationship. More information on the number of adult females in the population and frequency of spawning are needed to calculate annual spawning stock sizes for the stock-recruitment relationship. To work around this limitation a suite of potential recruitment changes were considered, but being able to directly link juvenile recruitment to a particular set of management actions that increases spawning stock would provide a notable improvement to projections.

Future analyses could also consider longer timeframes over which to assess the population projections. Currently, the National Recovery Strategy for White Sturgeon (DFO 2014a) has specified a 50-year timeframe for measurable objectives, but this could be too short of a timeframe for objectives that consider adult abundances, especially in the context of management actions. The long time to maturation, combined with lag and transition times associated with management actions, means that the actions only begin to affect adult abundances near the end of the 50-year timeframe. Thus, this timeframe will naturally select for more substantive management actions in order to achieve targets within the designated timeframe. That said, even initially substantive actions can be abated over time if initial results are projecting clear signs of population recovery.

7. ALLOWABLE HARM ASSESSMENT

7.1. ELEMENT 22: EVALUATE MAXIMUM HUMAN-INDUCED MORTALITY AND HABITAT DESTRUCTION THAT THE SPECIES CAN SUSTAIN WITHOUT JEOPARDIZING ITS SURVIVAL OR RECOVERY

As indicated by the modelling results, recovery to population levels observed in the mid-2000s is unlikely unless natural productivity increases and/or human-induced mortality decreases from recent levels. The survival of the Lower Fraser White Sturgeon population is an entirely different matter. This population has clearly survived substantial changes in habitat over thousands of years, and survived much higher human-induced mortality rates (i.e., in the late 1800s and early 1900s) than they experience today. To ensure the long-term survival of Lower Fraser White Sturgeon, adult abundance must not be allowed to go below the 10,000-adult survival threshold. Furthermore, two candidate recovery thresholds were identified as 20,000 adults, and 60,000 total (age 7 to 55) within a 50-year recovery window.

To achieve the candidate recovery threshold of 60,000 total abundance within a 50-year window, and to prevent further declines in the population, juvenile recruitment must be doubled from the average recruitment that was estimated from 2010 to 2019 (i.e., H4 in Table 6).

Critical to the sustainability of this population, we must ensure that harm is reduced at all life stages. This may be addressed through changes to habitat that would improve juvenile growth and survival, changes to fisheries, and increases in food availability (see *Scenarios for Mitigation of Threats and Alternatives to Activities* under Element 20 in this document).

8. SOURCES OF UNCERTAINTY AND FUTURE WORK

Significant knowledge gaps related to the threats for Lower Fraser White Sturgeon were identified, including:

- The identification of important rearing habitats for juvenile sturgeon in the lower Fraser River;
- Key drivers that affect juvenile sturgeon recruitment in the lower Fraser River;
- Reliable estimates of sturgeon bycatch in lower Fraser River gillnet fisheries;
- Reliable estimates of sturgeon caught and released by lower Fraser River anglers;
- Limited information about illegal harvest in the lower Fraser River;
- Limited knowledge around cumulative sub-lethal effects of capture events on survival and recruitment;
- Limited knowledge on the effects of other threats and limiting factors on the population (e.g., pollution, predation, temperature); and
- Limited information about key factors affecting juvenile recruitment, population viability, and extinction risk.

During the course of the regional peer review, several topics were identified for future work, including:

- Explore the relationship between other salmon species and juvenile recruitment;
- Sensitivity analysis on the effect of alternative growth curves on the ISAMR model;
- Additional data and analyses to relate age and length under more recent growth conditions;
- Currently ongoing juvenile monitoring program information should be incorporated into future analyses; and
- Maintain the annual monitoring and assessment program that has provided most of the information needed to assess status and trends for Lower Fraser White Sturgeon DU.

9. ACKNOWLEDGMENTS

We recognize the contributions of authors that worked on previous RPAs for this population, including Chris Wood, Dan Sneep, Steve McAdam, Todd Hatfield, and Eric Smyth. We thank the members of the Steering Committee, in alphabetical order, Dean Allan, Trevor Davies, Erin Gertzen, Paul Grant, Ahdia Hassan, Alain Magnan, Steve McAdam, Colin Schwindt, and Andy Witt for their assistance and guidance throughout the RPA process. The authors of this paper were also members of the Steering Committee for this RPA. We also thank Karen Burnett, who, in addition to the members of the Steering Committee, provided us with information and comments on draft sections of this report. Special thanks to Paul Grant and Alain Magnan for: recognizing the challenges associated with this RPA, assisting with contract amendments, organizing conference calls and obtaining data and comments from Steering Committee members.

We thank the Fraser River Sturgeon Conservation Society, specifically Rick Hansen, Troy Nelson and Sarah Schreier for providing the core data and reports needed to conduct the analyses presented in this report. We thank the past and present members of the FRSCS Board and the FRSCS Science and Technical Committee and the numerous volunteers who have assisted in the annual monitoring and assessment program for Lower Fraser River White Sturgeon over the past 20+ years. We thank the BC government and Habitat Conservation Trust Foundation for supporting research and assessment efforts for Lower Fraser White Sturgeon. Funding for this RPA was provided by Fisheries and Oceans Canada.

10. REFERENCES CITED

Anon. 2011. Policy and Practice Report. Gravel removal in the Lower Fraser River. Document dated 20 May 2011, submitted to the Cohen Commission.

Amiri, B.M., Baker, D.W., Morgan, J.D., Brauner, C.J. 2009. Size dependent early salinity tolerance in two sizes of juvenile White Sturgeon, *Acipenser transmontanus*. Aquaculture 286: 121-126.

Anders, P.J., and Beckman, L.G. 1993. Location and timing of White Sturgeon spawning in three Columbia River impoundments. Report B. *In* Volume I: Status and habitat requirements of the White Sturgeon populations in the Columbia River downstream from McNary Dam, Final Report. Edited by R.C. Beamdesderfer and A.A. Nigro. Report for Bonneville Power Administration, Portland, OR. pp. 47-59.

Apperson, K.A., and Anders, P.J. 1990. Kootenai River White Sturgeon investigations and experimental culture. Annual progress report FY 1989. Report for Bonneville Power Administration, Portland, OR. Report DOE/BPA 93497-2.

Apperson, K.A. and Anders, P.J. 1991. Kootenai River White Sturgeon investigations and experimental culture. Annual progress report for FY90. Report for Bonneville Power Administration, Portland, OR. Report DOE/BPA 93497-2.

Bajkov, A.D. 1949. A preliminary report on the Columbia River sturgeon. Fish Commission of Oregon Research Briefs 2: 3-10.

Baker, D.W., and Brauner, C.J. 2012. Metabolic changes associated with acid-base regulation during hypercarbia in the CO_2-tolerant chondrostean, White Sturgeon (*Acipenser transmontanus*). Comparative Biochemistry and Physiology - Part A 161: 61-68.

Baker, D.W., Matey, V., Huynh, K.T., Wilson, J.M., Morgan, J.D., and Brauner, C.J. 2009. Complete intracellular pH protection during extracellular pH depression is associated with hypercarbia tolerance in White Sturgeon, *Acipenser transmontanus*. American Journal of Physiology-Regulatory, Integrative, and Comparative Physiology 296: R1868-R1880.

Baker, D.W., McAdam, D.S.O., Boucher, M., Huynh, K.T., and Brauner, C.J. 2014. Swimming performance is altered by exposure to substrate at early life stages in White Sturgeon, *Acipenser transmontanus*. Journal of Applied Ichthyology 30: 1461-1472.

Bates, L.C., Boucher, M.A., and Shrimpton, J.M. 2014. Effect of temperature and substrate on whole body cortisol and size of larval White Sturgeon *Acipenser transmontanus*. Journal of Applied Ichthyology 30: 1259-1263.

BC Hydro. 2015. Lower Columbia River Adult White Sturgeon Monitoring Program (CLBMON-28). Years 5 & 6 Data Report. Report for BC Hydro, Castlegar, BC.

BC Hydro. 2016a. Lower Columbia River Juvenile Detection Program (CLBMON-29). Years 6 and 7 Data Report. Report for BC Hydro, Castlegar, BC.

BC Hydro. 2016b. Lower Columbia River Juvenile Detection Program (CLBMON-29): Year 8 Data Report. Report for BC Hydro, Castlegar, BC.

Bennett, W.R., Edmondson, G. Lane, E.D., and Morgan, J.D. 2005. Juvenile White Sturgeon (*Acipenser transmontanus*) habitat and distribution in the Lower Fraser River, downstream of Hope, B.C., Canada. Journal of Applied Ichthyology 21: 375-380.

Bemis, W.E., Findeis, E.K. , and Grande, L. 1997. An overview of Acipenseriformes. Environmental Biology of Fishes 48: 25-71.

Birstein, V.J., and DeSalle, R. 1998. Molecular phylogeny of Acipenserinae. Molecular Phylogenetics and Evolution 9: 141-155.

Birstein, V.J., Hanner, R., and DeSalle, R. 1997. Phylogeny of the Acipenseriformes: cytogenic and molecular approaches. Environmental Biology of Fishes 48: 127-155.

Boucher, M. 2012. The effect of substrate rearing on the growth, development, and survival of larval White Sturgeon (*Acipenser transmontanus*) during early ontogeny. M.Sc. Thesis. University of Northern British Columbia, Prince George, B.C. 84 p.

Boucher, M.A., McAdam, S.O., and Shrimpton, J.M. 2014. The effect of temperature and substrate on the growth, development and survival of larval white sturgeon. Aquaculture, 430: 139-148.

Brannon, E., and Setter, A. 1992. Movements of White Sturgeon in Lake Roosevelt. Final Report 1988-1991. Report for Bonneville Power Administration, Portland, OR. Project No. 89-44.

Brannon, E., Brewer, S., Setter, A. Miller, M. Utter, F., and Hershberger, W. 1985. Columbia River White Sturgeon (*Acipenser transmontanus*) early life history and genetics study. Final report, August 1, 1985 to December 1985 (Project Number 83-316). Report for Bonneville Power Administration, Portland, OR.

Buddington, R.K. and Christofferson, J.P. 1985. Digestive and feeding characteristics of the chondrostreans. Environmental Biology of Fishes 14: 31-41.

Burggren, W.W., and Randall, D.J. 1978: Oxygen uptake and transport during hypoxic exposure in the sturgeon, *Acipenser transmontanus*. Respiration Physiology 24: 171-183.

Burns, C.W., Robichaud, D., and English, K.K. 2020. Lower Fraser River juvenile White Sturgeon (*Acipenser transmontanus*) habitat assessment: year 1. Report for Fraser River Sturgeon Conservation Society, Vancouver, BC, and Vancouver Fraser Port Authority, Vancouver, BC.

Challenger, W., and Robichaud, D. 2018. Region 3 White Sturgeon mark and recapture data audit. Report for DFO, Ecosystems Management Branch, Vancouver, BC.

Challenger, W., English, K.K., and Carruthers, T. 2017. Integrated spatial and age mark recapture (ISAMR) model (v2.0) for Lower Fraser River White Sturgeon. Report for Habitat Conservation Trust Foundation, Victoria, BC.

Challenger, W., English, K.K., Robichaud, D., and Nelson, T.C. 2019. Status of White Sturgeon in the lower Fraser River in 2018 derived using an integrated spatial and age mark recapture model. Report for the Fraser River Sturgeon Conservation Society, Vancouver, BC.

Challenger, W., English, K.K., Robichaud, D., and Nelson, T.C. 2020. Status of White Sturgeon in the lower Fraser River in 2019 derived using an integrated spatial and age mark recapture (ISAMR) model. Report for the Fraser River Sturgeon Conservation Society, Vancouver, BC, and BC Ministry of Forest, Lands, Natural Resource Operations, and Rural Development, Surrey, BC.

Chapman, F.A., Van Eenennaam, J.P., and Doroshov, S.I. 1996. The reproductive condition of White Sturgeon, *Acipenser transmontanus*, in San Francisco Bay, California. Fishery Bulletin 94: 628-634.

Cooke, S.J., Donaldson, M.R., O'connor, C.M., Raby, G.D., Arlinghaus, R., Danylchuk, A.J., Hanson, K.C., Hinch, S.G., Clark, T.D., Patterson, D.A., and Suski, C.D. 2013. The physiological consequences of catch-and-release angling: perspectives on experimental design, interpretation, extrapolation and relevance to stakeholders. Fisheries Management and Ecology 20: 268-287.

COSEWIC. 2003. COSEWIC assessment and update status report on the white sturgeon *Acipenser transmontanus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 51 pp.

COSEWIC. 2012. COSEWIC assessment and status report on the White Sturgeon *Acipenser transmontanus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xxvii + 75 pp.

Coutant, C.C. 2004. A riparian habitat hypothesis for successful reproduction of White Sturgeon. Reviews in Fisheries Science 12: 23-73.

Crisp, D.T., and Carling, P.A. 1989. Observations on siting, dimensions, and structure of salmonid redds, Journal of Fish Biology 34: 119-134.

Crocker, C.E., and Cech Jr., J.J. 1998: Effects of hypercapnia on blood-gas and acid base status in White Sturgeon, *Acipenser transmontanus*. Journal of Comparative Physiology B 168: 50-60.

Crossman, J.A., and Hildebrand, L.R. 2014. Evaluation of spawning substrate enhancement of White Sturgeon in a regulated river: effects on larval retention and dispersal. River Research and Applications. 30: 1-10.

Deng, X., Van Eenennaam, J.P., and Doroshov, S.I. 2002. Comparison of early life stages and growth of Green and White sturgeon. *In* Biology, management, and protection of North American sturgeon. Symposium 28. Edited by W. Van Winkle, P.J. Anders, D.H. Secor, and D.A. Dixon. American Fisheries Society, Bethesda, MD. pp. 237-247.

DFO. 2007a. Revised Protocol for Conducting Recovery Potential Assessments. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2007/039.

DFO. 2007b. Documenting habitat use of species at risk and quantifying habitat quality. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2007/038

DFO. 2014a. Recovery strategy for White Sturgeon (*Acipenser transmontanus*) in Canada [Final]. In Species at Risk Act Recovery Strategy Series. 80 Ottawa: Fisheries and Oceans Canada. 252 pp.

DFO. 2014b. Guidance on assessing threats, ecological risk, and ecological impacts for species at risk. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/013. (Erratum June 2016).

DFO. 2020. Integrated Fisheries Management Plan, January 1 – December 31, 2020. Eulachon. Fraser River. Report by Fisheries and Oceans Canada, Ottawa, ON.

Dingerkus, G., and Howell, W. 1976. Karyotypic analysis and evidence of tetraploidy in the North American Paddlefish, *Polyodon spathula*. Science 194 (4267): 842-844.

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

Doroshov, S.I. Moberg, G.P., and Van Eenennaam, J.P. 1997. Observations on the reproductive cycle of cultured White Sturgeon, *Acipenser transmontanus*. Environmental Biology of Fishes 48: 265-278.

Drauch Schreier, A., Gille, D. Mahardja, B., and May, B. 2011. Neutral markers confirm the octoploid origin and reveal spontaneous autopolyploidy in White Sturgeon, *Acipenser transmontanus*. Journal of Applied Ichthyology 27: 24-33.

Drauch Schreier, A., Mahardja, B., and May, B. 2013. Patterns of population structure vary across the range of the white sturgeon. Transactions of the American Fisheries Society 142: 1273-1286.

Echols, J.C., and Fraser River Action Plan. 1995. Review of Fraser River White Sturgeon. Report for the Department of Fisheries and Oceans, Vancouver, BC.

ECL Envirowest Consultants. 1992. Fraser River White Sturgeon radio-tracking and tissue sampling 1989-1992. Report for BC Ministry of Environment, Lands and Parks, Surrey, BC.

English, K.K. and Bychkov, Y. 2012. Stock Reduction Analysis for Lower Fraser White Sturgeon – progress report for work completed in 2012. Report for Habitat Conservation Trust Foundation, Victoria, BC.

English, K.K., and Robichaud, D. 2019. Test of alternative methods for sampling and monitoring juvenile sturgeon abundance in the lower Fraser River. Report for Fraser River Sturgeon Conservation Society, Vancouver, BC, and BC Ministry of Forest, Lands, Natural Resource Operations and Rural Development, Victoria, BC, and the Freshwater Fisheries Society, Vancouver, BC.

English, K.K., and Robichaud, D. 2020. Lower Fraser juvenile White Sturgeon monitoring program: using size-selective angling techniques, 2019-2020. Report for Fraser River Sturgeon Conservation Society, Vancouver, BC, and Habitat Conservation Trust Foundation, Victoria, BC.

English, K. K., Beveridge, I., and Bychkov, Y. 2014. Side-scan sonar surveys of potential spawning areas for White Sturgeon in the lower Fraser River. Report for Fraser River Sturgeon Conservation Society, Vancouver, BC.

Fraser River White Sturgeon Working Group. 2005. Fraser River White Sturgeon conservation plan. Report for the Fraser River Sturgeon Conservation Society, Vancouver, BC.

Gadomski, D.M., and Parsley, M.J. 2005. Effects of turbidity, light level, and cover on predation of white sturgeon larvae by prickly sculpins. Transactions of the American Fisheries Society 134: 369-374.

Galbreath, J.L. 1979: Columbia River colossus, the White Sturgeon. Oregon Wildlife, March 1979: 3-8.

Gawlicka, A., The, S.J., Hung, S.S.O., Hinton, D.E., and de la Noüe, J. 1995. Histological and histochemical changes in the digestive tract of White Sturgeon larvae during ontogeny. Fish Physiology and Biochemistry 14: 357-371.

Gisbert, E. and Williot, P. 2002. Advances in the larval rearing of Siberian Sturgeon. Journal of Fish Biology 60: 1071-1092.

Glova, G., Nelson, T., English, K., and Mochizuki, T. 2008. A preliminary report of juvenile White Sturgeon habitat use in the lower Fraser River, 2007-2008. Report for the Fraser River Sturgeon Conservation Society, Vancouver, BC.

Glova, G., Nelson, T., English, K., and Mochizuki, T. 2009. A further report of juvenile White Sturgeon habitat use in the lower Fraser River, 2008-2009. Report for the Fraser River Sturgeon Conservation Society, Vancouver, BC.

Glova, G., Nelson, T., English, K., and Mochizuki, T. 2010. Investigations of juvenile White Sturgeon abundance and habitat use in the lower gravel reach of the lower Fraser River, 2009-2010. Report for the Fraser River Sturgeon Conservation Society, Vancouver, BC.

Golder Associates. 2003. Upper Columbia River juvenile White Sturgeon monitoring, Phase I investigations, fall 2002. Report for B.C. Hydro, Castlegar, BC.

Golder Associates. 2007. Upper Columbia River juvenile White Sturgeon monitoring: Phase 5 investigations, November 2006. Report for B.C. Hydro, Revelstoke, BC.

Golder Associates. 2009. Monitoring of juvenile White Sturgeon habitat use and movements of sonic-tagged sturgeon: 2008 investigations. Report for B.C. Hydro, Revelstoke, BC.

Golder Associates. 2010. White Sturgeon spawning at Waneta, 2009 investigations. Report for Columbia Power Corporation, Castlegar, BC.

Golder Associates. 2019. Lower Fraser River adult White Sturgeon acoustic telemetry data analysis. Report for Ministry of Forests, Lands, Natural Resource Operations and Rural Development, South Coast, Surrey, BC.

Gross, M.R., Repka, J., Roberston, C.T., Secor, D.H., and Van Winkle, W. 2002. Sturgeon conservation: insights from elasticity analyses. *In* Biology, management, and protection of North American sturgeon. Symposium 28. Edited by W. Van Winkle, P.J. Anders, D.H. Secor, and D.A. Dixon. American Fisheries Society, Bethesda, MD. pp. 13-29.

Halvorson, L.J., Cady, B.J., Kappenman, K.M., James, B.W., and Webb, M.A.H. 2018. Observations of handling trauma of Columbia River adult White Sturgeon, *Acipenser transmontanus* Richardson, 1836, to assess spawning sanctuary success. Journal of Applied Ichthyology 34:390-397.

Hardy, R., Rust, P., Stephenson, S., and Wakkinen, D. 2016. Kootenai River fish mitigation: White Sturgeon, Burbot, native salmonid monitoring and evaluation, annual progress report, May 1, 2014 – April 30, 2015. Idaho Department of Fish and Game Report 16-01.

Hatfield, T., Cooper, T., and McAdam, S. 2013. Scientific information in support of identifying critical habitat for SARA-listed White Sturgeon populations in Canada: Nechako, Columbia, Kootenay, and Upper Fraser (2009). DFO Can. Sci. Advis. Sec. Sci. Res. Doc. 2012/153. viii + 103 p.

Haynes, J. M., Gray, R. H., Montgomery, J. C. 1978. Seasonal movements of White Sturgeon, *Acipenser transmontanus*, in the mid-Columbia River. Transactions of the American Fisheries Society 107, 275-280.

Hildebrand, L.R., and Parsley, M. 2013: Upper Columbia White Sturgeon Recovery Plan – 2012 Revision. Report for the Upper Columbia White Sturgeon Recovery Initiative, Spokane, WA.

Hildebrand, L., McLeod, C., and McKenzie, S. 1999. Status and management of White Sturgeon in the Columbia River in British Columbia, Canada: an overview. Journal of Applied Ichthyology 15, 164-172.

Hildebrand, L.R., Drauch Schreier, A., Lepla, K. McAdam, S.O., McLellan, J., Parsley, M.J., Paragamian, V.L., and Young, S. 2016. Status of White Sturgeon (*Acipenser transmontanus* Richardson, 1863) throughout the species range, threats to survival, and prognosis for the future. Journal of Applied Ichthyology 32: 261-312.

Jay, K.J., Crossman, J.A., and Scribner, K.T. 2014. Estimates of effective number of breeding adults and reproductive success for White Sturgeon. Transactions of the American Fisheries Society 143: 1204-1216.

Johnson, S., Beveridge, I., and English, K. 2016. Side-scan sonar surveys of potential White Sturgeon (*Acipenser transmontanus*) spawning areas in the lower Fraser River, 2015. Report for Habitat Conservation Trust Fund, Victoria, BC.

Johnson, S., Beveridge, I., and English, K. 2017. Side-scan sonar surveys of potential White Sturgeon (*Acipenser transmontanus*) spawning areas in the lower Fraser River, 2016. Report for Fraser River Sturgeon Conservation Society, Vancouver, BC.

Johnson, S., English, K.K., and Beveridge, I. 2018. Side-scan sonar surveys of potential White Sturgeon (*Acipenser transmontanus*) spawning areas in the lower Fraser River 2017. Report for Habitat Conservation Trust Foundation, Victoria, BC, and Fraser River Sturgeon Conservation Society, Vancouver, BC.

Justice, C., Pyper, B.J., Beamesderfer, R.C.P., Paragamian, V.L., Rust, P.J., Neufeld, M.D., and Ireland, S.C. 2009. Evidence of density- and size-dependent mortality in hatchery-reared juvenile White Sturgeon (*Acipenser transmontanus*) in the Kootenai River. Canadian Journal of Fisheries and Aquatic Science 66: 802-815.

Kondolf, G.M. 2000. Assessing salmonid spawning gravel quality, Transactions of the American Fisheries Society 129: 262-281.

Lane, E.D. 1991. Status of White Sturgeon, *Acipenser transmontanus*, in Canada. Canadian Field Naturalist 105: 161-168.

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

Lebreton, G.T., and Beamish, F.W. 2004: Growth, bioenergetics, and age. *In* Sturgeons and paddlefish of North America. Edited by G.T.O. LeBreton, F.W.H. Beamish, and R. S. McKinley. Kluwer Academic Publishers, Dordrecht, Ned. pp. 195-216.

Lepla, K., Chandler, J.A., and Bates, P. 2001. Status of Snake River White Sturgeon associated with the Hells Canyon complex. Idaho Power Technical Report Appendix E.3.1-6 Chapter 1.

Little, E.E., Calfee, R.D., and Linder, G. 2012. Toxicity of copper to early-life stage Kootenai River White Sturgeon, Columbia River White Sturgeon, and Rainbow Trout. Archives of Environmental Contamination and Toxicology 63: 400-408.

Mastrandrea, M.D., Field, C.B., Stocker, T.F., Edenhofer, O., Ebi, K.L., Frame, D.J., Held, H., Kriegler, E., Mach, K.J., Matschoss, P.R., Plattner, G.K., Yohe, G.W., and Zwier, F.W. 2010. Guidance note for lead authors of the IPCC fifth assessment report on consistent treatment of uncertainties. Intergovernmental Panel on Climate Change (IPCC).

McAdam, S. 2011. Effects of substrate condition on habitat use and survival by White Sturgeon (*Acipenser transmontanus*) larvae and potential implications for recruitment. Canadian Journal of Fisheries and Aquatic Sciences 68: 812-822.

McAdam, S.O., Walters, C.J., and Nistor, C. 2005. Linkages between White Sturgeon recruitment and altered bed substrates in the Nechako River, Canada. Transactions of the American Fisheries Society 134: 1448-1456.

McCabe Jr., G.T., and Tracy, C.A. 1994. Spawning and early life history of White Sturgeon, *Acipenser transmontanus*, in the lower Columbia River. Fisheries Bulletin 92: 760-772.

McCabe, G.T., Jr., Emmet, R.L., and Hinton, S.A. 1993. Feeding ecology of juvenile White Sturgeon (*Acipenser transmontanus*) in the lower Columbia River. Report O. *In* Vol. 2: Status and habitat requirements of the White Sturgeon populations in the Columbia River downstream from McNary Dam. Edited by R.C. Beamesderfer and A.A. Nigro. Report for Bonneville Power Administration. Portland, OR. pp. 245-263.

McLean, M.F., Hanson, K.C., Cooke, S.J., Hinch, S.G., Patterson, D.A., Nettles, T.L., Litvak, M.K., and Crossin, G.T. 2016. Physiological stress response, reflex impairment and delayed mortality of White Sturgeon *Acipenser transmontanus* exposed to simulated fisheries stressors. Conservation Physiology 4: cow031.

McLean, M.F., Litvak, M.K., Cooke, S.J., Hanson, K.C., Patterson, D.A., Hinch, S.G., and Crossin, G.T. 2019. Immediate physiological and behavioural response from catch-and-release of wild White Sturgeon (*Acipenser transmontanus* Richardson, 1836). Fisheries Research 214: 65-75.

McLean, M.F., Litvak, M.K., Stoddard, E.M., Cooke, S.J., Patterson, D.A., Hinch, S.G., Welch, D.W., and Crossin, G.T. 2020. Linking environmental factors with reflex action mortality predictors, physiological stress, and post-release movement behaviour to evaluate the response of White Sturgeon (*Acipenser transmontanus* Richardson, 1836) to catch-and-release angling. Comparative Biochemistry and Physiology Part A 240: 110618.

McDonald, R., Nelson, J., Asce, M., Paragamian, V., and Baton, G. 2010. Modeling the effect of flow and sediment transport on White Sturgeon spawning habitat in the Kootenai River, Idaho. Journal of Hydraulic Engineering 136: 1078-1092.

McDonald, T.E., Swiatkiewicz, V.J., Lane, E.D., Dalziel, F., and Margolis, L. 1987. Release and recovery data for tagged Fraser River White Sturgeon, *Acipenser transmontanus*, in 1985. Canadian Data Report of Fisheries and Aquatic Sciences 639.

McElhany, P., Ruckelshaus, M. H., Ford, M. J., Wainwright, T. C., and Bjorkstedt, E. P. 2000. Viable salmonid populations and the recovery of evolutionarily significant units. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-42.

McEnroe, M., and Cech Jr., J.J. 1985: Osmoregulation in juvenile and adult White Sturgeon, *Acipenser transmontanus*. Environmental Biology of Fishes 14: 23-30.

McKechnie, R.J., Fenner, R.B. 1971. Food habits of White Sturgeon, *Acipenser transmontanus*, in San Pablo and Suisun Bays, California. California Fish and Game 57: 209-212.

Muir, W.D., Emmett, R.L., and McConnell, R.J. 1988. Diet of juvenile and subadult White Sturgeon in the lower Columbia River and its estuary. California Fish and Game 74: 49-54.

Muir, W.D., McCabe, G.T., Parsley, M.J., and Hinton, S.A. 2000. Diet of first-feeding larval and young-of-the-year White Sturgeon in the lower Columbia River. Northwest Science 74: 25-33.

Nelson, J., Smith, C., Rubidge E., and Koop, B. 1999. Genetic analysis of D-loop region and microsatellite DNA of White Sturgeon from British Columbia – population structure and genetic diversity. Report for BC Fisheries, Victoria, BC.

Nelson, T.C., Gazey, W.J., English, K.K., and Rosenau, M.L. 2013. Status of White Sturgeon in the lower Fraser River, British Columbia. Fisheries 38:197-209.

Nelson, T.C., Robichaud, D. Challenger, W., English, K.K., Mochizuki, T., Thibault, T., Rissling, J., and Gazey, W.J. 2020. Lower Fraser River White Sturgeon Monitoring and Assessment Program 2019: summary of sampling results, distribution, growth, and abundance estimates derived from 24-month Bayesian mark recapture modelling. Report for the Fraser River Sturgeon Conservation Society, Vancouver, BC.

Nelson, W.A., Levings, C.D., and Paul, A.J. 2007. Population growth and demography of white sturgeon in the lower Fraser River. American Fisheries Society Symposium 56: 381-396.

Neufeld, M.D., and Spence, C.R. 2004. White Sturgeon and Burbot recovery progress 2003-04. Report for Ministry of Environment, Lands and Parks, Nelson, BC.

Paragamian, V.L., Kruse, G., and Wakkinen, V.D. 2001. Spawning habitat of Kootenai River White Sturgeon, post-Libby Dam. North American Journal of Fisheries Management 21: 22-33.

Paragamian, V.L., Wakkinen, V.D., and Kruse, G. 2002. Spawning locations and movement of Kootenai River White Sturgeon. Journal of Applied Ichthyology 18: 608-616.

Paragamian, V.L., McDonald, R., Nelson, G.J., and Barton, G. 2009. Kootenai River velocities, depth, and White Sturgeon spawning site selection – a mystery unraveled? Journal of Applied Ichthyology 5: 640-646.

Parsley, M.J. and Beckman, L.G. 2004. White Sturgeon spawning and rearing habitat in the lower Columbia River. North American Journal of Fisheries Management. 14:812-827.

Parsley, M.J. and Kappenman, K.M. 2000. White Sturgeon spawning areas in the lower Snake River. Northwest Science 74: 192-201.

Parsley, M.J., Beckman, L.G., and McCabe Jr, G.T. 1993. Spawning and rearing habitat use by White Sturgeon in the Columbia River downstream of McNary Dam. Transactions of the American Fisheries Society 122: 217-227.

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

Parsley, M.J., Kofoot, E. and Blubaugh, T.J. 2011. Mid Columbia Sturgeon incubation and rearing study (year 2 – 2010). Report for B.C. Hydro, Castlegar, BC.

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

Pacific Salmon Commission (PSC). 2019. Pacific Salmon Commission Joint Chum Technical Committee 2016 Post Season Summary Report. Report No. TCCHUM (19)-01.

RL&L Environmental Services. 1994. Status of White Sturgeon in the Columbia River, BC. Report for B.C. Hydro Environmental Affairs, Vancouver, BC.

RL&L Environmental Services. 2000. Fraser River White Sturgeon Monitoring Program - comprehensive report (1995 to 1999). Report for BC Fisheries, Victoria, BC.

Robichaud, D. 2018a. Catch and effort in the Fraser River White Sturgeon recreational fishery, 2015-2016, with retrospective analysis of past data. Report for Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, South Coast Region.

Robichaud, D. 2018b. Catch and effort in the Fraser River White Sturgeon Recreational Fishery, 2016-2017. Report for Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, South Coast Region.

Robichaud, D., and Gingerich, A. 2020. White Sturgeon Supplementation and Management Plan Implementation in the Wells Reservoir, 2019. Report for Public Utility District No. 1 of Douglas County, East Wenatchee, WA.

Robichaud, D., and Johnson, S. 2020. Mission Force Main White Sturgeon Sonar Project, December 2019. Report for Palmer Environmental Consulting Group, Vancouver, BC.

Robichaud, D., English, K.K., Bocking, R.C., and Nelson, T.C. 2006. Direct and delayed mortality of white sturgeon caught in three gear-types in the Lower Fraser River. Report for Tsawwassen First Nation Fisheries, Delta, BC.

Robichaud, D., English, K.K., and Nelson, T.C. 2017. Annual movements of acoustic-tagged White Sturgeon in the lower Fraser River and its tributaries. Transactions of the American Fisheries Society 146: 611-625.

Robichaud, D., Wright, C., and Challenger, W. 2020. Rocky Reach Reservoir White Sturgeon Indexing and Monitoring Program 2019. Report for Public Utility District No. 1 of Chelan County, Wenatchee, WA.

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

Rosenau, M.L., and Angelo, M. 2005. Conflicts between agriculture and salmon in the eastern Fraser Valley. Report for Pacific Fisheries Resource Conservation Council, Vancouver BC.

Ross, T.J., Hardy, R., Rust, P., and Wakkinen, D. 2015. Kootenai River fish mitigation: White Sturgeon, Burbot, native salmonid monitoring and evaluation, annual progress report, May 1, 2013 – April 30, 2014. Idaho Department of Fish and Game Report 15-01.

Schaffter, R.G. 1997. White Sturgeon spawning and location of spawning habitat in the Sacramento River, California. California Fish and Game 83: 1-20.

Schreier, A.M. 2012. Use of polysomic genetic markers to address critical uncertainties in White Sturgeon biology and management. PhD Dissertation, University of California, Davis, CA.

Schreier, A.D., May, B., and Gille, D. 2013. Incidence of spontaneous autopolyploidy in cultured populations of White Sturgeon, *Acipenser transmontanus*. Aquaculture 416: 141-145.

Schwindt, C., and Yeung, A. 2020. Lower Fraser White Sturgeon juvenile monitoring program - 2012-2018 final report. Report for Ministry of Forests, Lands, Natural Resource Operations and Rural Development, Surrey, BC.

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

Secor, D. H., and Gunderson, T.E. 1998. Effects of hypoxia and temperature on survival, growth, and respiration of juvenile Atlantic sturgeon, *Acipenser oxyrinchus*. Fishery Bulletin 96:603-613.

Semakula, S.N. 1963. The age and growth of the White Sturgeon (*Acipenser transmontanus* Richardson) of the Fraser River, British Columbia, Canada. Masters Thesis, University of British Columbia, Vancouver, BC.

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

Shaughnessy, C.A., Baker, D.W., Brauner, C.J., Morgan, J.D., and Bystriansky, J.S. 2015. Interaction of osmoregulatory and acid-base compensation in White Sturgeon (*Acipenser transmontanus*) during exposure to aquatic hypercarbia and elevated salinity. Journal of Experimental Biology 218: 2712-2719.

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

Stoddard, E. 2017. Lower Fraser White Sturgeon spawning habitat confirmation project 2016-2017 Interim Report. Report for Ministry of Forests, Lands and Natural Resource Operations (MFLNRO), Fish & Aquatic Wildlife, South Coast, Surrey, BC.

Sykes, G.S. 2010. Nechako White Sturgeon Monitoring 2009. Report for the BC Ministry of Environment, Victoria, BC.

Sykes, G., Bond, J., and Liebe, R. 2007. Adult White Sturgeon monitoring - Nechako River 2007. Report by for Alcan Primary Metal, Kitimat, BC.

Terraquatic Resource Management. 2011. Arrow Lakes Generating Station White Sturgeon Spawn Monitoring Program. Report for Columbia Power Corporation, Castlegar, BC.

TFOG. 2013. Tsawwassen Fisheries Operational Guidelines – Updated and approved 24 Sep. 2013. Tsawwassen First Nation, Tsawwassen BC.

Tides Canada. 2020. Resilient Waters Advisory Meeting Report, 15 April 2020. Prepared by Tides Canada, now MakeWay Foundation, Vancouver, BC.

Triton Environmental Consultants. 2004. Adult White Sturgeon monitoring – Nechako River 2004. Report for the BC Ministry of Environment, Prince George, BC.

Vardy, D.W., Oellers, J., Doering, J.A., Hollert, H., Giesy, J.P., and Hecker, M. 2013. Sensitivity of early life stages of White Sturgeon, Rainbow Trout, and Fathead Minnow to copper. Ecotoxicology 22: 139-147.

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

Walters, C., Korman, J., and McAdam, S. 2005. An assessment of White Sturgeon stock status and trends in the lower Fraser River. DFO Can. Sci. Advis. Sec. Sci. Res. Doc. 2005/066. vii + 60 p.

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

Weatherly, H. and Church, M. 1999. Gravel extraction inventory of Lower Fraser River (Mission-Hope) - 1964-1998. Document submitted March 15, 1999 to District of Chilliwack.

Welch, D.W., Turo, S., and Batten, S.D. 2006. Large-scale marine and freshwater movements of White Sturgeon. Transactions of the American Fisheries Society 135: 386-389.

Whitlock, R., and McAllister, M. 2012. Incorporating spatial and seasonal dimensions in a stock reduction analysis for lower Fraser River White Sturgeon (*Acipenser transmontanus*). Canadian Journal of Fisheries and Aquatic Sciences 69: 1674-1697.

Wood, C., Sneep, D., McAdam, S., Korman, J., and Hatfield, T. 2007. Recovery potential assessment for White Sturgeon populations listed under the Species at Risk Act. DFO Can. Sci. Advis. Sec. Sci. Res. Doc. 2007/003. vi + 35 p.

Young, W.T., and D.L. Scarnecchia. 2005. Habitat use of juvenile White Sturgeon in the Kootenai River, Idaho and British Columbia. Hydrobiologia 537: 265-271.

APPENDIX A: SUMMARY OF LOWER FRASER RIVER WHITE STURGEON MONITORING AND ASSESSMENT PROGRAM, 2019

FRSCS Lower Fraser River White Sturgeon Monitoring and Assessment Program – *Program Summary 2019*

FRASER RIVER STURGEON CONSERVATION SOCIETY

Since April 2000, the FRSCS Lower Fraser River White Sturgeon Monitoring and Assessment Program has relied on trained volunteers to tag sturgeon and collect sampling data. Each year, FRSCS volunteers sample several thousand live sturgeon for the presence of uniquely numbered "PIT" tags. Sturgeon samples used for abundance and other analytical purposes are taken from a "core assessment area" that includes over 200 linear kilometers in the lower Fraser River watershed downstream of Lady Franklin Rock (near Yale).

Key Points and Findings

- More than 165,000 sturgeon have been sampled by program volunteers over the past 21 years (Figure 1).
- The program currently uses two models to generate abundance estimates: an Integrated Spatial and Age-structured Mark-Recapture (ISAMR) model and a Bayesian Mark-Recapture (BMR24) model. The trends for juvenile, sub-adult, and adult sturgeon are shown in Figure 2.
- The abundance of sturgeon in the lower Fraser River has been declining since 2006.
- Juvenile sturgeon (60-90 cm fork length/FL) abundance has declined substantially over the past 15 years.
- Sub-adult sturgeon (100-169 cm FL) abundance has been declining since 2012.
- Adult sturgeon (160-279 cm FL) abundance has increased gradually since the beginning of the program.
- The ISAMR model can be used to forecast future trends in sturgeon abundance.
- If recent trends continue, the Lower Fraser River White Sturgeon population is forecast to decline at an average annual rate of 1.4% per year over the next 30 years (see Figure 3 below).
- The average annual growth rate for 60-179 cm FL White Sturgeon in 2019 (3.6 cm/year) was 36.8% lower than the respective average annual growth rate in 2002 (5.7 cm/year).

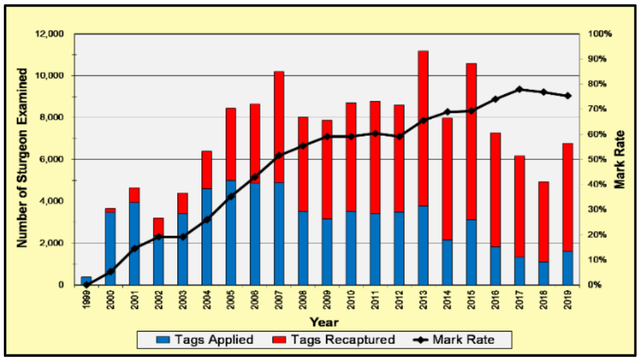

Figure 1. *Annual numbers of tags applied, the reported number of tag recaptures, and the annual mark rates (proportion of sampled fish that possessed a tag at the time of capture) for 60-279 cm FL White Sturgeon, 2000-2019. From Nelson et al. 2020.*

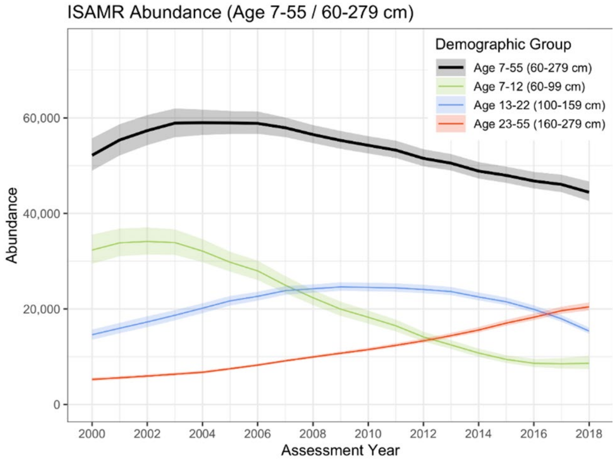

Figure 2. *ISAMR abundance estimates of age 7-55 (60-279 cm FL) Lower Fraser River White Sturgeon from 2000 to 2019. Shading indicates 95% credible intervals. From Challenger et al. 2020.*

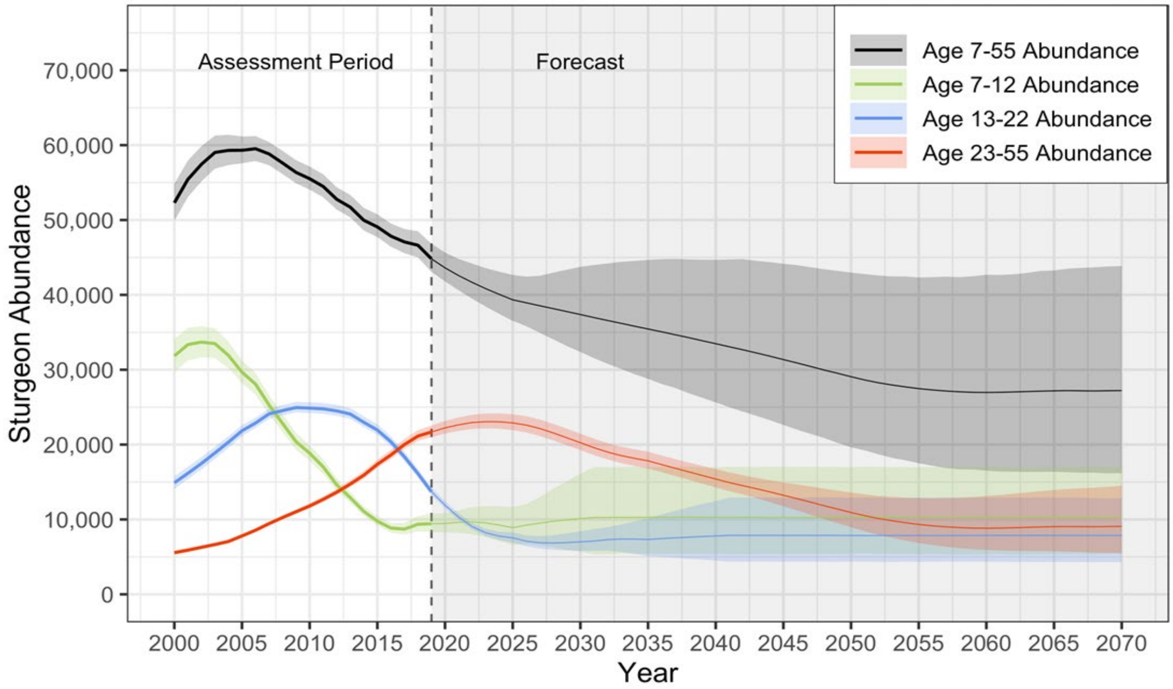

***Figure 3**. ISAMR abundance forecasts for Lower Fraser River White Sturgeon for 2019-2070, assuming that annual recruitment remains the same as recent estimates (i.e., 2012-2018 recruitment). Grey shading indicates forecasted years. From Challenger et al. 2020.*

Aside from abundance model results, there are other concerning demographic indicators:

- The proportion of juvenile (< 100 cm FL) White Sturgeon captured by the Albion Test Fishery decreased by 63% between 2000 and 2019
- The average annual growth rate for all size groups of White Sturgeon in 2019 (3.6 cm/year) was 37% lower than the respective average annual growth rate in 2002 (5.7 cm/year).

The future of wild Fraser River White Sturgeon – what can be done to help?

- Juvenile White Sturgeon recruitment rates in the lower Fraser River are currently below the level of population sustainability.
- The current and forecast abundance of mature adult fish in the population should be sufficient to increase juvenile recruitment rates over the next decade as long as specific actions are taken now to reduce impacts and improve environmental conditions.
- The authors recommend immediate actions to improve recruitment and survival rates for juvenile sturgeon.

Priority actions include:

- protection of overwintering, spawning, and juvenile rearing habitat;
- restricted fishing and boating activity across known sturgeon spawning areas during the spawning period;
- a reduction of the incidence of net interceptions from all net fisheries during all times of the year;
- a reduction in the annual capture rates in the recreational fishery; and
- the identification and protection of spawning and rearing areas for the prey species upon which juvenile and adult sturgeon depend (e.g., salmon and eulachon).

Detailed annual program reports that present both study methods and results are available at: Fraser River Sturgeon Conservation Society Research for Survival: Reports

APPENDIX B: GRAVEL EXTRACTION SITES ALONG THE LOWER FRASER RIVER

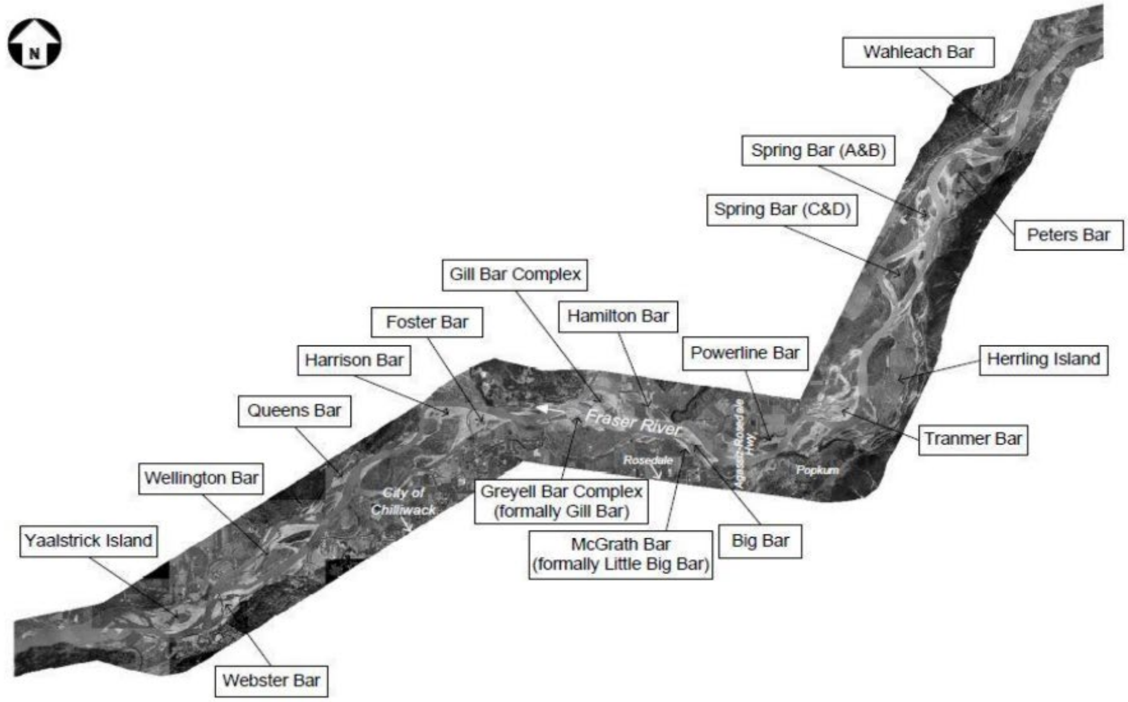

Figure 2. Location of gravel bars in the Fraser River.[67]

---

[67] British Columbia, Provincial Emergency Program, "Location of Gravel Bars in the Fraser River Hope to Mission, BC" (September 2010) online: PEP <http://www.pep.bc.ca/floods/sediment_docs/gravel_bars.pdf>.

Figure B1. Gravel extraction site along the lower Fraser River (from Anon. 2011).

APPENDIX C: RECREATIONAL STURGEON FISHERY CATCH

APPENDIX C1: CATCH ESTIMATES FOR THE LOWER FRASER RIVER RECREATIONAL FISHERY

Here, we describe the methods used to derive estimates of catch in the Fraser River White Sturgeon recreational fishery, and discuss the possible biases associated with the estimates.

Methods

Primary Values

Catch (2010-11, onwards) – FLNRORD has used paper, phone, and email questionnaires to collect responses from recreational anglers with the goal of estimating non-guided effort and catch for each licence year. When the non-guided catch is combined with guided catch (derived from a annual reports submitted by sturgeon angling guides), the total catch can be estimated for each year. Methods used to compile the catch for guided anglers and estimate non-guided catch for each year from 2010-11 to 2016-17 are described in Robichaud (2018b), along with the resulting catch estimates. Catch estimates for 2017-18 and 2018-19 are provided in Schwindt and Yeung (2020a,b). Values are shown in Table C1.

Adjusted Catch (2010-11 to 2016-17) – Robichaud (2018a) concluded that the catch estimates derived by expanding questionnaire data to represent all licenced anglers were biased high. For most years, the estimates of sturgeon catch were markedly higher than the total abundance of the Fraser River White Sturgeon population. Overreporting in the questionnaire data was assumed to result partly from recall bias and anglers who mistakenly reported the total catch per boat, rather than their individual catches. Also, guided anglers are less likely to return questionnaires, thereby producing a positive bias in the portion of the licences fished by non-guided anglers (Robichaud 2018a). Regardless of the source or reason of the bias, it was assumed that landing site interviews (asking people as they come back from fishing) would not be subject to the same level of reporting error, and that the CPUE from such a creel study would be more accurate than those derived from the questionnaire data.

During the 2016-17 licence year, a landing-site creel survey was conducted (Petra Wykpis, unpublished data), and a creel-derived CPUE was calculated. When comparing the creel-derived CPUE to the CPUE from the 2016-17 questionnaires, it was apparent that questionnaire methods were overestimating catch. Using AD (automatic differentiation) Model Builder (see Robichaud 2018b), each of the licence year catches estimated from the 2010-11 to 2016-17 questionnaires were adjusted downwards, taking into account effort by licence type, and CPUE from the 2016-17 creel survey. These estimates are shown in the adjusted column for non-guided catch in Table C1.

Guided Catch (2004-05 to 2008-09) and Total Catch (2009-10) – Colin Schwindt (FLNRORD, pers. comm.) provided guided catch totals from the 2004-05 to 2008-09 census data, and total catch for the 2009-10 licence year.

Derived Values

Guided Catch, 2009-10 – Guided catch was derived from the total catch value provided by Schwindt. The average of the ratios of non-guided to guided catch from 2010-11 to 2018-19 were used to estimate guided catch for the year. The derived value is shown in the grey shaded cell in the guided catch column in Table C1.

Table C1. Unadjusted and adjusted non-guided catch are presented along with guided catch, and unadjusted and adjusted total catch, by licence year. The data sources and methods used to derive these estimates are provided in this Appendix. Unadjusted catch estimates for non-guided anglers were derived from 2009-19 questionnaire data. Adjusted catch estimates for non-guided anglers for 2010-17 were adjusted for positive bias in the estimates derived from the questionnaire data (Robichaud 2018b). The catch estimates for guided anglers were derived from annual reports submitted by the licenced guides. Total catch is the sum of the annual estimates for non-guided and guided anglers. The estimates in grey shaded cells were not derived directly from questionnaire data and guide reports but derived using the available catch estimates for those years.

Licence Year	Non-Guided Catch		Guided Catch	Total Catch	
	Unadjusted	Adjusted		Unadjusted	Adjusted
2004-05	25,950	8,581	11,645	37,595	20,226
2005-06	40,798	17,123	23,237	64,035	40,360
2006-07	31,229	11,385	15,450	46,679	26,835
2007-08	38,663	15,774	21,406	60,069	37,180
2008-09	35,975	14,130	19,176	55,151	33,306
2009-10	26,102	7,824	10,617	36,719	18,441
2010-11	40,679	14,650	18,451	59,130	33,101
2011-12	30,875	12,886	17,542	48,417	30,428
2012-13	26,100	10,107	14,818	40,918	24,925
2013-14	42,149	16,648	17,239	59,388	33,887
2014-15	42,888	16,869	11,354	54,242	28,223
2015-16	58,536	23,073	16,547	75,083	39,620
2016-17	50,394	31,328	19,357	69,751	50,685
2017-18	41,539	17,451	28,479	70,018	45,930
2018-19	57,745	25,944	22,405	80,149	48,349

Adjusted Non-guided Catch (prior to 2010-11 and after 2016-17) – For the periods before and after the focus of Robichaud (2018b), the data needed to run the AD Model Builder were not available, thus alternative methods were needed to derive adjusted non-guided catch estimates.

Prior to 2010-11

To estimate adjusted non-guided catch for the period prior to 2010-11, the guided catch was multiplied by the average of the annual ratios of adjusted non-guided to guided catch. The ratios were showing an increasing trend over time, so, to better represent the earliest part of the time series, only the first three years of ratios were included in the average (2010-11 to 2012-13; mean 0.74, range 0.68 to 0.79). Derived values are shown in grey shaded cells in Table C1.

After 2016-17

To provide an approximate representation of adjusted catch for the period after 2016-17, a regression approach was used. Log-transformed adjusted non-guided catch from the 2010-11 to 2016-17 period were regressed against log-transformed unadjusted non-guided catch for the same period. The slope (1.2038) was statistically significant ($F_{1,5} = 18.6$, $P = 0.008$), and the relationship (with an intercept of -3.0345) had a strong fit (R^2 was 0.79). The regression formula was then used to derive adjusted non-guided catch values for each of the two years in question. Derived values for these years are shown in grey shaded cells in Table C1.

Unadjusted Non-guided Catch (prior to 2010-11) – To provide an approximate representation of unadjusted catch for the period before 2009-10, the same regression approach, described above, was used, except with the X and Y variables reversed. The regression formula (slope = 0.6549, intercept = 4.2323) was used to calculate unadjusted non-guided catch values from the adjusted values for each of the years in question. Derived values for years prior to 2010-11 are shown in grey shaded cells in the unadjusted non-guided catch column in Table C1.

Results

Unadjusted and adjusted non-guided catch are presented along with guided catch, and unadjusted and adjusted total catch in Table C1.

Likely Biases

The overall catch estimates were probably overestimated, especially in recent licence years, where catch was estimated to be markedly more than the total Lower Fraser River population size, as reported by Nelson et al. (2020). While Nelson et al. report abundances of fish in the 60-279 cm fork length size range between Yale and the mouth of the Fraser River, the questionnaires cover a larger geographic area (they include the Pitt and Harrison systems, areas upstream of Yale, etc.), and have no size stipulations, which could account for the very large number of fish estimated to have been caught. However, the overall catch reported from areas outside of the Nelson et al. ‘core area’ was small, and very little of the guided catch was reported from upstream areas, leaving a large discrepancy unexplained. It is possible that catch of very small or very large fish accounts for another portion of the discrepancy. Another possibility is the repeat capture of fish. English and Jesson (2013) showed that ~10% of fish sampled by the Lower Fraser White Sturgeon Monitoring and Assessment Program are caught more than once per year. Depending on how much of all Fraser River sturgeon catch that is included in the Monitoring and Assessment samples, the portion caught more than once in a year could be as high as 50% of the total catch of unique sturgeon (see Appendix C2 below). Nevertheless, there remains the likelihood of overreporting in the questionnaire data.

Overreporting in the questionnaire data could be substantial if anglers mistakenly reported the total catch per boat, rather than their individual catches. For example, an angler aboard a boat of four people that each lands a single sturgeon, should record a catch of one fish, but may erroneously record the boat’s catch of four fish. It is very common for boat-based anglers to report the total catch for the boat rather than each individual’s catch, especially since many have been ‘trained’ to do so after 30 years of creel surveys in BC, which have used the ‘boat trip’ as the unit of effort (English et al. 1986, 2002). It is unknown the extent to which this has occurred, and the wording of the questionnaire has been edited since the 2015-16 survey to make this important distinction more clear. Nevertheless, the average CPUE from a licence-year landing-site creel survey (Petra Wykpis, unpublished data from fall 2016) was 0.89 sturgeon per angler-day, or about 46% of the CPUE estimated from the questionnaire data for the same year, suggesting that there does appear to be some evidence for a potentially high level of overreporting by non-guided anglers. Attempts have been made to correct for this bias using a modelling approach, , yet the adjusted values may still be too high, given that the creel survey was carried out during a period of relatively good sturgeon fishing and only at two of the best locations, thus generating CPUE estimates that may be higher than the annual average.

Another source of bias could result from differential response rates among angler types. If non-guided anglers were more likely to respond to the questionnaire than guided anglers (guided anglers might think their data were being captured by the guide census), then the ‘completed response’ data set would include a disproportionate amount of non-guided anglers. This would result in an estimate of non-guided angling effort that is too high. Non-response bias assessments, conducted in association with the 2013-14 and 2014-15 email surveys, showed that anglers that didn't respond to the first prompt were different from those that did respond: non-respondents were less likely to have been non-guided anglers (Robichaud 2018b). While the pattern did not hold for the paper (mail-out) surveys (there appears to have been different response biases, depending on the survey method), this result indicates: 1) a possible source of bias does exist; and 2) the size of the bias could potentially have increased when the surveyors moved away from paper and toward email survey methods.

While overreporting may be occurring for the non-guided data, the guide-produced 'census' data may be underreported. By comparing reported catch from the census vs. that from datasheets showing individual recaptures of PIT-tagged fish as reported to the Lower Fraser White Sturgeon Monitoring and Assessment Program, English and Jesson (2013) found evidence for underreporting by several guides.

All types of misreporting could be avoided if daily log books are being kept, since recollection errors are easily made when filling out census forms well after the angling trips were conducted (Pollock et al. 1995). Regardless, an independent estimate of CPUE should be derived from an exit-survey type creel study, conducted throughout the year and throughout the lower Fraser River, in order to assess the degree to which questionnaire and census responses are biased.

Another large uncertainty associated with the catch and effort estimates for Fraser River White Sturgeon is related to the loose reporting requirements for designated tidal areas of the Fraser River downstream of the Mission Railway Bridge. BC regulations related to professional guides only apply to non-tidal waters, therefore, there is no requirement for guides to report their fishing effort and catch for Fraser River tidal waters if they are not licensed by the Province. Moreover, none of the non-guided anglers who fish strictly in tidal waters receive the Annual Fraser River White Sturgeon Angler Questionnaire, certainly biasing downwards the catch and effort results downstream of the Mission Railway Bridge. Tidal areas have large numbers of White Sturgeon, and there is an active population of anglers that exploit them (FRSCS, unpublished data).

References

English, K.K., and Jesson, D. 2013. Sturgeon catch and effort estimates for lower & middle Fraser River recreational fishery 2009-12. Report for Habitat Conservation Trust Foundation.

English, K.K., Shardlow, T.F., and Webb, T.M. 1986. Assessment of the Strait of Georgia sport fishing statistics, sport fishing regulations and trends in Chinook catch using creel survey data. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1375.

English, K.K., Searing, G.F., and Nagtegaal, D.A. 2002. Review of the Strait of Georgia recreational creel survey, 1983-1999. Canadian Technical Report of Fisheries and Aquatic Sciences No. 2414.

Nelson, T.C., Robichaud, D., Challenger, W., English, K.K., Mochizuki, T., Thibault, T., and Gazey, W.J. 2020. Lower Fraser River White Sturgeon Monitoring and Assessment Program 2019: Summary of sampling results, distribution, growth, and abundance estimates derived from 24-Month Bayesian Mark Recapture Modelling. Report for Fraser River Sturgeon Conservation Society, Vancouver, BC.

Pollock, K.H., Jones, C.M., and Brown, T.L. 1995. Angler survey methods and their applications in fisheries management. Rev Fish Biol Fisheries 5, 378–380.

Robichaud, D. 2018a. Catch and effort in the Fraser River White Sturgeon recreational fishery, 2015-2016, with retrospective analysis of past data. Report for Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, South Coast Region.

Robichaud, D. 2018b. Catch and effort in the Fraser River White Sturgeon Recreational Fishery, 2016-2017. Report for Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, South Coast Region.

Schwindt, C., and Yeung, A. 2020a. Lower and Middle Fraser Recreational White Sturgeon Fishery Monitoring Program (2017-2018 angling licence year), Technical Summary. Report for Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, South Coast Region.

Schwindt, C., and Yeung, A. 2020b. Lower and Middle Fraser Recreational White Sturgeon Fishery Monitoring Program (2018-2019 angling licence year), Technical Summary. Report for Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, South Coast Region.

APPENDIX C2: PORTION OF THE LOWER FRASER STURGEON POPULATION CAUGHT MULTIPLE TIMES IN A SINGLE YEAR

Data from the FRSCS Monitoring and Assessment Program for Lower Fraser White Sturgeon was combined with the 2019 abundance estimate (44,809) reported in Challenger et al. (2020) and assumptions regarding the FRSCS sampling rate to estimate the portion of the Lower Fraser Sturgeon population caught multiple times in a single year. In 2019, FRSCS guides and anglers sampled 7,034 sturgeon and 607 (9.6%) were sampled two or more times (Table C2, data from Nelson et al. 2020). The total number of unique fish sampled by angling in 2019 was 6,292 and 5,685 (90%) of these were only sampled once. If this represents 25% of the unique fish sampled by anglers, the remainder of the recreation fishery would catch 18,876 unique sturgeon or 42% of the 2019 abundance estimate. Using this catch rate, we estimate that 9,864 (52%) of the 18,876 sturgeon would be caught only once in 2019. Therefore, 15,549 (5,685+9,864) of the 25,168 (6,292+18,876) unique fish caught would be caught only once in 2019. The remaining 9,619 fish would be caught two or more times. Using the information on the number of times that the 24,461 unique sturgeon were encountered from 2016-2019 from Appendix D in Nelson et al. (2020), we apportioned the 9,619 encountered multiple times in 2019 between 2 and 12 encounters (Table C2). The analysis indicates that a total catch by anglers would need to be at least 39,760 sturgeon to catch 25,168 unique sturgeon. If the 6,292 unique sturgeon sampled by FRSCS guides and anglers represented 20% of the unique sturgeon caught by anglers, the total catch by anglers would be at least 55,458 sturgeon and about 50% of the 31,460 unique sturgeon caught would be caught two or more times in 2019.

Table C2. Summary of the FRSCS mark-recapture data used to estimate the potential number of multiple recapture events assuming FRSCS samples represented 20-25% of the number of unique sturgeon caught in 2019 by all anglers in the Lower Fraser River.

	FRSCS Sample = 25%			**FRSCS Sample = 20%**		
Value	**FRSCS Sample**	**Other Catch**	**Total Catch**	**FRSCS Sample**	**Other Catch**	**Total Catch**
Single Recaptures	5,685	9,864	15,549	5,685	9,956	15,641
Unique fish	6,292	18,876	25,168	6,292	25,168	31,460
2019 Population Est.	44,809	44,809	44,809	44,809	44,809	44,809
Sample or Catch rate (CR)	14%	42%	56%	14%	56%	70%
(1-CR)	86%	58%	44%	86%	44%	30%
Single Recapture %	90.4%	52.3%	61.8%	90.4%	39.6%	49.7%
Multiple Recapture %	9.6%	47.7%	38.2%	9.6%	60.4%	50.3%

Number of Recapture Events		**FRSCS Sample = 25%**			**FRSCS Sample = 20%**		
	FRSCS 2016-2019	**FRSCS 2019**	**Other Catch**	**Total Catch**	**FRSCS 2019**	**Other Catch**	**Total Catch**
1	18,320	5,685	9,864	15,549	5,685	9,956	15,641
2	4,200	510	6,164	6,579	510	10,404	10,819
3	1,240	75	1,820	1,942	75	3,072	3,194
4	413	14	606	647	14	1,023	1,064
5	173	5	254	271	5	429	446
6	57	1	84	89	1	141	147
7	20	1	29	31	1	50	52
8	19	-	28	30	-	47	49
9	10	-	15	16	-	25	26
10	6	1	9	9	1	15	15
11	0	-	0	0	-	0	0
12	3	-	4	5	-	7	8
Unique Fish	24,461	6,292	18,876	25,168	6,292	25,168	31,460
Multiple Recap	6,141	607	9,012	9,619	607	15,212	15,819
% Multi Recap	25%	10%	48%	38%	10%	60%	50%
Fish Caught	33,777	7,034	32,547	39,760	7,034	48,245	55,458
% Unique	72%	89%	58%	63%	89%	52%	57%

APPENDIX D: STURGEON CATCH ESTIMATES FOR LOWER FRASER RIVER FIRST NATION GILLNET FISHERIES

SOURCES OF INFORMATION

Reliable estimates of White Sturgeon caught in Lower Fraser River First Nation (FN) gillnet fisheries are needed to assess the potential effect of these fisheries on sturgeon, and to determine to what extent these fisheries are related to the recent (i.e., last 15 years) trends in juvenile sturgeon abundance, and if management decisions have the potential to facilitate future recovery.

The Department of Fisheries and Ocean Canada (DFO) has prepared estimates of the number of sturgeon kept and released from FN fisheries that target salmon on the lower Fraser River for 2000-2019. Most of the FN fishing effort in the Lower Fraser River is associated with fisheries where gillnets are fished from a boat while drifting downstream (i.e., driftnets) or fished in a stationary manner, either anchored from shore or from an anchored boat (i.e., setnets).

DFO has divided up the lower Fraser River into various reaches for each gear type with the most common being: 1) Fraser Mouth to Port Mann; 2) Port Mann to Mission; 3) Mission to Harrison; 4) Harrison to Hope; and 5) Hope to Sawmill Creek (Figure D1). The physical boundaries at Port Mann, Mission, and Hope are bridges that cross the Fraser River. For some years, adjacent strata were combined, thus estimates for individual stratum are not always available (e.g., a combined 'Mission-Hope' stratum was used to report sturgeon catch estimates for 2000-2003).

Sturgeon catch estimates reported by DFO for driftnet and setnet fisheries were derived by combining effort estimates for driftnet and setnet with estimates of the catch per unit effort derived from shore-based interviews of FN fishers. The primary focus for these interviews was to collect information on salmon catches, therefore the information on sturgeon catch is often incomplete. Moreover, most of the sturgeon caught since 2000 were released, and released fish can go underreported (the fish were not seen during the interview process at landing sites). In addition, fishers may have underreported the number of sturgeon kept because most communal licences required the release of sturgeon bycatch. The DFO estimates of sturgeon catch are therefore considered in general to be a significant underestimate of the number of sturgeon caught in FN gillnet fisheries.

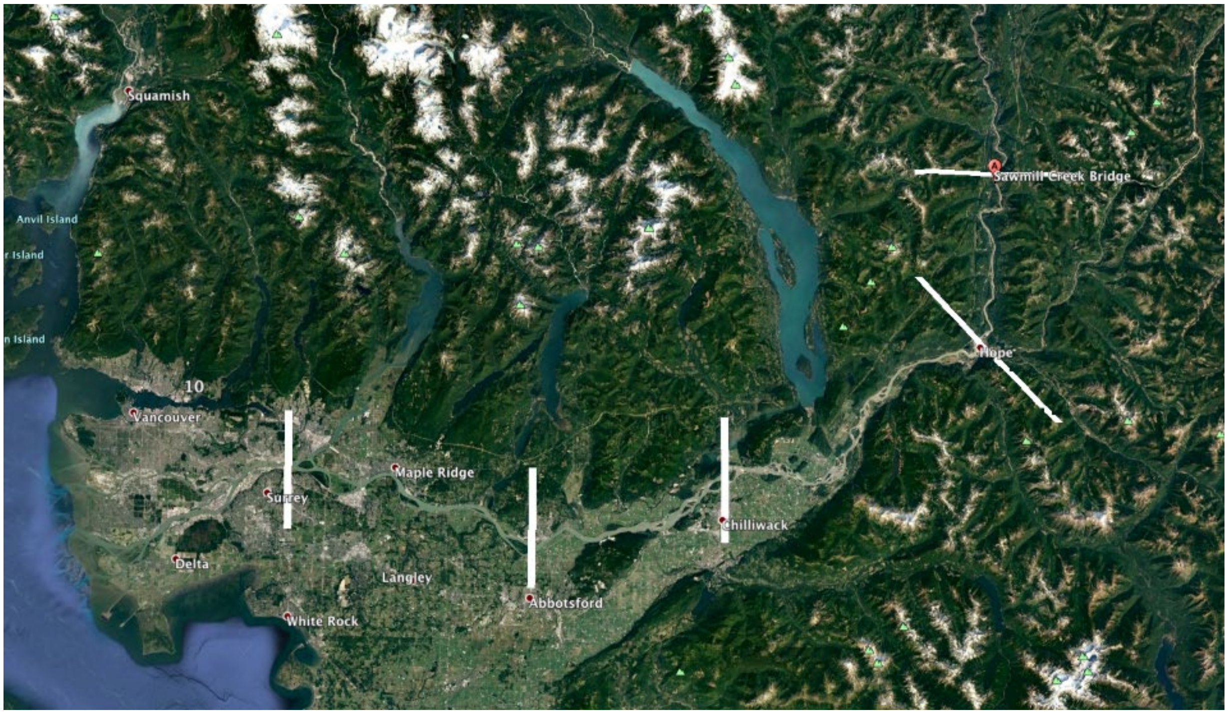

Figure D1. DFO catch monitoring reporting areas.

The sanctuary cage program run by the Fraser River Sturgeon Conservation Society (FRSCS) provides an additional source of information on White Sturgeon caught in FN setnet fisheries. The cage program was located in the Mission-Harrison stratum, and was run from 2000 to 2005. The goal was to protect as many White Sturgeon as possible from being caught multiple times in setnet fisheries targeting salmon (Nelson et al. 2005). Floating cages were deployed at two locations in the Mission to Harrison stratum. First Nation fishers participating in the program were asked to bring their bycatch of <150 cm White Sturgeon to sanctuary cages, where the fish would be temporarily held until the end of the weekend fisheries when FRSCS personnel would check the cages, examine all sturgeon, tag untagged fish, and release all the sturgeon from the cages. The fishers and locations represented a subset of the setnet fishing activity in the Mission-Harrison stratum, yet they were never intended to be representative (random sample) of the Mission-Harrison stratum as a whole. Indeed, the number of White Sturgeon observed in the cage program often exceeded the DFO estimate of the total number of White Sturgeon caught across all setnets in the Mission-Harrison stratum (Table D1).

The clear evidence of underreporting by DFO catch monitoring methods for sturgeon has led researchers to combine FRSCS data with setnet effort estimates to derive catch estimates for all setnet fisheries in the Mission-Sawmill Creek stratum (Walters et al. 2005). The resulting estimates were unreasonably high, and could not be extended to driftnet fisheries or beyond 2005, thus requiring that we develop a new method. In the following sections, we first describe why the Waters et al. (2005) method is not useable. Then, we describe a new method to estimate total sturgeon catch for lower Fraser River First Nation gillnet fisheries.

Table D1. DFO sturgeon catch and effort estimates for First Nation setnet fisheries, sturgeon delivered to FRSCS cages in the Mission to Harrison stratum. 2000-2003 DFO estimates were for Mission to Hope and have been adjusted to represent Mission to Harrison.

	DFO				FRSCS	
Date	**Effort (nets)**	**Fishery Duration (hr/wk)**	**Effort (net hours)**	**Catch**	**Catch (fish delivered to cages)**	**Diff.**
Jun 11, 2000	31	24	744	11	1	-10
Jun 18, 2000	40	24	960	60	17	-43
Jun 25, 2000	52	24	1248	13	21	8
Jul 2, 2000	74	48	3552	13	19	6
Jul 9, 2000	87	48	4176	16	25	9
Jul 16, 2000	84	48	4032	7	16	9
Jul 23, 2000	57	48	2736	165	73	-92
Jul 30, 2000	79	48	3792	171	156	-15
Aug 6, 2000	72	48	3456	105	120	15
Aug 13, 2000	69	48	3312	61	97	36
Aug 20, 2000	55	48	2640	15	11	-4
May 13, 2001	37	24	888	11.9	2	-9.9
May 20, 2001	41	24	984	13.3	15	1.7
May 27, 2001	45	24	1080	23.1	32	8.9
Jun 3, 2001	26	24	624	15.4	14	-1.4
Jun 10, 2001	40	24	960	11.2	8	-3.2
Jun 17, 2001	79	24	1896	34.3	36	1.7
Jun 24, 2001	85	24	2040	23.1	107	83.9
Jul 1, 2001	12	48	576	0	3	3
Jul 22, 2001	0	48	0	0	14	14
Jul 29, 2001	69	48	3312	91	150	59
Aug 5, 2001	109	48	5232	0	123	123
Aug 12, 2001	102	48	4896	84	139	55
Aug 26, 2001	71	48	3408	30.1	71	40.9
Jun 2, 2002	47	24	1128	9.1	3	-6.1
Jun 9, 2002	54	24	1296	42	14	-28
Jun 16, 2002	60	24	1440	20.3	10	-10.3
Jul 21, 2002	82	48	3936	34.3	156	121.7
Jul 28, 2002	106	48	5088	83.3	169	85.7
Aug 4, 2002	106	48	5088	142.1	273	130.9
Aug 11, 2002	106	48	5088	44.1	85	40.9
Aug 18, 2002	92	48	4416	56.7	36	-20.7
Sep 1, 2002	51	48	2448	0	19	19
Mar 30, 2003	14	24	336	8.4	1	-7.4
Apr 6, 2003	22	24	528	11.2	1	-10.2

	DFO				FRSCS	
Date	**Effort (nets)**	**Fishery Duration (hr/wk)**	**Effort (net hours)**	**Catch**	**Catch (fish delivered to cages)**	**Diff.**
Apr 20, 2003	36	24	864	16.8	4	-12.8
May 4, 2003	30	24	720	6.3	6	-0.3
May 11, 2003	38	24	912	0.7	3	2.3
May 18, 2003	54	48	2592	7.7	32	24.3
May 25, 2003	31	48	1488	13.3	5	-8.3
Jun 8, 2003	50	48	2400	26.6	3	-23.6
Jun 15, 2003	44	48	2112	26.6	2	-24.6
Jul 27, 2003	82	48	3936	8.4	161	152.6
Aug 3, 2003	94	48	4512	29.4	76	46.6
Aug 10, 2003	111	48	5328	25.9	42	16.1
Aug 17, 2003	113	48	5424	63	169	106
Aug 24, 2003	92	48	4416	27.3	73	45.7
Aug 31, 2003	79	48	3792	22.4	35	12.6
May 2, 2004	26	48	1248	18	2	-16
May 9, 2004	26	48	1248	15	30	15
May 16, 2004	35	48	1680	16	7	-9
May 30, 2004	40	48	1920	25	12	-13
Jun 6, 2004	36	48	1728	19	13	-6
Jun 20, 2004	36	48	1728	40	16	-24
Jul 4, 2004	46	48	2208	23	19	-4
Jul 11, 2004	50	48	2400	43	23	-20
Jul 18, 2004	83	48	3984	22	57	35
Jul 25, 2004	88	72	6336	11	59	48
Aug 1, 2004	127	72	9144	0	18	18
Aug 8, 2004	114	150	17100	0	31	31
Aug 15, 2004	94	72	6768	0	53	53
Aug 22, 2004	82	36	2952	13	48	35
May 1, 2005	20	24	480	0	10	10
May 8, 2005	17	48	816	1	7	6
May 15, 2005	28	48	1344	5	8	3
May 22, 2005	28	48	1344	5	23	18
May 29, 2005	25	48	1200	4	6	2
Jun 5, 2005	30	48	1440	0	8	8
Jun 12, 2005	32	48	1536	11	35	24
Jun 19, 2005	30	48	1440	8	33	25
Jun 26, 2005	42	48	2016	17	17	0
Jul 31, 2005	79	48	3792	48	35	-13
Aug 7, 2005	79	48	3792	0	23	23

	DFO				FRSCS	
Date	Effort (nets)	Fishery Duration (hr/wk)	Effort (net hours)	Catch	Catch (fish delivered to cages)	Diff.
Aug 14, 2005	102	48	4896	0	22	22
Aug 21, 2005	99	72	7128	0	15	15
Aug 28, 2005	112	80	8960	0	8	8
Sep 4, 2005	115	24	2760	0	6	6
			Average	**26.5**	**42.8**	**16.2**
	Period Averages		**2000-03**	**35.4**	**55.2**	**19.7**
			2004-05	**11.9**	**22.2**	**10.3**

Previous estimation methods (i.e., Walters et al. 2005) were not useful

Total catch estimates reported in Walters et al. (2005) were orders of magnitude higher than the DFO numbers. They were derived by combining estimates of the average number of nets fished each month in the Mission to Sawmill Creek stratum with monthly catch per effort (CPE) estimates derived from the 2000-2004 FRSCS sturgeon sanctuary cage program. These estimates for the Mission-Sawmill Creek fisheries would be reasonable if the CPE estimates from the cages were representative of the average sturgeon CPE for all FN fishing locations between Mission and Sawmill Creek. However, this is unlikely for the following reasons:

1. The sturgeon cages were strategically deployed in locations within the Mission to Harrison stratum (specifically Hatzic and Sumas) where sturgeon were more frequently caught by First Nation fishers (the FRSCS had a limited number of cages and the goal was to save as many sturgeon as possible from multiple recapture in the setnet fisheries). Therefore, the sturgeon catch rates in the locations where the cages were deployed would be higher than other locations in the Mission to Sawmill Creek stratum.
2. The number of nets that contributed sturgeon to the cages each week is not known but probably varied with the number of FN members fishing near the cage sites during each fishery. The Walters et al. (2005) estimates were based on the assumption that there was a fixed number of nets (3-6 depending on the cage location) that contributed sturgeon to the cages for each opening, regardless of the magnitude of the opening or the numbers of sturgeon found in the cages.
3. The Walters et al. (2005) assumption of a fixed number of nets resulted in sturgeon catch rates varying from 4-8 sturgeon/net during lower effort months (April-June) to 32-48 sturgeon/net during high effort months (July and August).
4. The combination of high sturgeon CPE values for the two cage sites in the Mission to Harrison stratum in July and August, with the peak fishing effort estimates during these months, caused the Walters et al. (2005) catch estimates to exceed 12,000 sturgeon in a single month for the Mission to Sawmill Creek stratum.

Therefore, the methods reported in Walters et al. (2005) likely produced substantial overestimates of the number of sturgeon caught and released by FN fisheries from Mission-Sawmill Creek. In addition, the Walters et al. (2005) methods cannot be applied to years after 2005 when no cage studies were conducted, and these methods do not provide estimates of the number of sturgeon kept and released from Lower Fraser River driftnet fisheries. Consequently, another approach needed to be developed for deriving estimates of the number of sturgeon kept and released by FN setnet and driftnet fishers in the Lower Fraser River for 2000-2019.

ADJUSTING DFO STURGEON CATCH ESTIMATES FOR UNDER REPORTING

Similar to the approach proposed by Walters et al. (2005), the FRSCS sanctuary cage program can be used to better understand the underreporting of sturgeon catch by the DFO catch monitoring. Examination of the monthly Mission-Harrison stratum catch that was reported as being released showed that both programs (i.e., DFO catch monitoring program, and FRSCS cage program) generally tracked well with each other across the six year period where the counts could be compared (Figure D2). The slope of the estimated simple linear regression to square-root transformed catch was not significantly different from a 1:1 relationship, though the FRSCS sanctuary cages generally produced higher catch estimates (i.e., the regression line was located above the 1:1 line; Figure D2). This indicates that the DFO catch monitoring and the FRSCS sanctuary cages scaled well together, and thus both appear to be indices of the true sturgeon catch, although the scaling factor to derive the true catch will need to be determined. While the two indices generally tracked one another, plotting the difference between the two catch indices indicates that magnitude of underreporting in the DFO data is larger later in the season, and larger during fisheries with higher fishing effort (Figure D3).

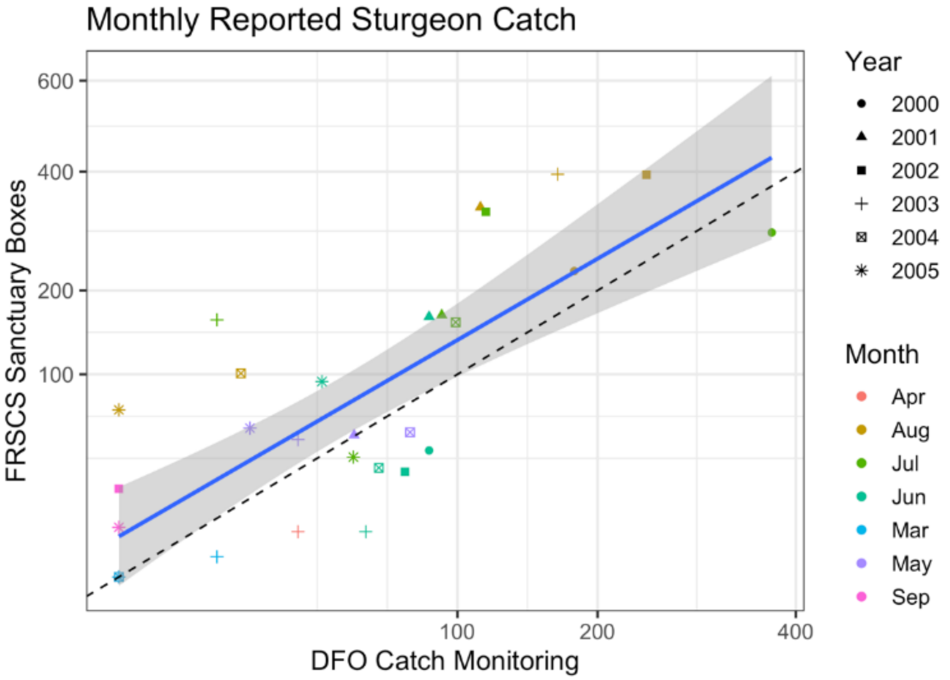

Figure D2. Comparison of the DFO sturgeon catch estimates in the Mission-Harrison stratum to the number of sturgeon reported in the FRSCS sanctuary cage program from 2000 to 2005. Dashed line indicates a 1:1 relationship, while the blue line indicates a fit from a simple linear regression line, with shading indicating the 95% confidence region for the regression line. Both axes are displayed on a square root scaling.

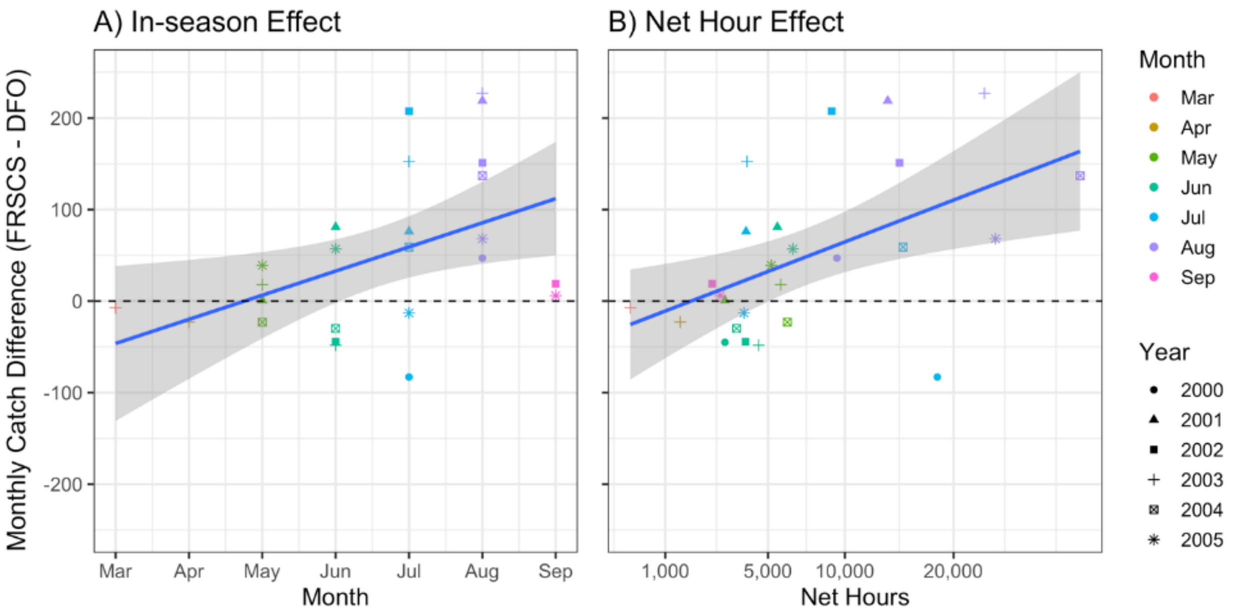

Figure D3. The difference between monthly FRSCS cage counts and DFO estimated sturgeon counts plotted against A) time and B) monthly net hours. The blue line represents a simple linear regression line, with shading indicating the 95% confidence region for the regression line. Square root scaling is used on the x-axis in the monthly net hours panel.

Table D2. AICc ranking of models predicting FRSCS sanctuary cage counts. Both DFO estimates and Net Hours were square root transformed and month was treated as a continuous variable (i.e., 1-12). K = number of parameters estimated.

Model	**K**	**AICc**	**ΔAICc**	**AICc Weight**	**Cumulative Weight**
DFO + Net Hours + Month	5	141.5	0	0.50	0.50
DFO + Net Hours	4	142.3	0.73	0.35	0.85
DFO + Net Hours * Month	6	144.9	3.32	0.09	0.94
DFO + Month	4	145.8	4.26	0.06	1.00
DFO	3	154.3	12.72	0.00	1.00

These factors can be combined in a multiple linear regression model, and the model can be used to assess the underestimation bias in the DFO Mission-Harrison catch estimates during years when the sanctuary program was not operational. Different combinations of these factors, including interactions, were considered and ranked using AICc (the small sample size corrected Akaike information criterion; Table D2; Burnham and Anderson 2002). Both the monthly FRSCS sanctuary cage counts and monthly DFO catch estimates, along with net hours, were square root transformed. Month was treated as a continuous variable (i.e., 1-12) so that the in-season trend could be represented as a linear effect over time. Using DFO catch estimates, without other information, was not supported (i.e., ΔAICc > 7), indicating that the difference between DFO catch estimates and the FRSCS cage was affected by other explanatory factors. Net hours as an additional factor had stronger support over including just time effects (i.e., month; ΔAICc >2). Overall, the top supported model included both net hours and month effects in an additive manner, but just including net hours without month effects had similar support (i.e., ΔAICc < 2). Including interactions between the net hours and months only had moderate support (i.e., 2 < ΔAICc < 5).

Since the number of sturgeon delivered to the FRSCS cages only represented a portion of sturgeon caught in the Mission-Harrison stratum, these estimates needed to be expanded to represent the total sturgeon catch within the stratum. Because the exact proportion of catch represented by the FRSCS sanctuary cage program is not known, a range of possible values was considered. We talked with the individuals that conducted the cage studies from 2000-2005 to determine the number of fishers that likely contributed sturgeon to the cages. They indicated that 2-10 First Nation fishers would have provided sturgeon to the cages each week, depending on the intensity of the fishery (Troy Nelson, FRSCS Executive Director 2000-07, pers. comm.; Jim Rissling, FRSCS field coordinator 2000-18, pers. comm.). This number of cage program participants was roughly equivalent to 10% of the 20-100 nets fished in the Mission-Harrison stratum each week (see Table D1). They also noted that the cages were located near sites where sturgeon were known to be more abundant and the fishers providing sturgeon to the cages likely caught more sturgeon than other FN fishers. Therefore, for a given catch rate, the stratum estimate would be:

$$\text{Stratum Estimate} = \text{Predicted FRSCS Catch} / (\text{catch rate} * 10\%).$$

A range of catch rates were considered, from a value of one (i.e., no difference in catch rates, assumed by Walters et al.2005) to five (i.e., fishers involved with the FRSCS cage program caught sturgeon at five times the rate as those fishers that did not participate in the cage program). A full set of calculations from DFO catch estimates, to expanded estimates and the resulting estimated mortalities is presented assuming a sturgeon catch rate of 3 times the rate of other fishers in the Mission-Hope stratum (Table D3). DFO has indicated that the method used to estimate sturgeon bycatch changed in 2007. Prior to 2007, DFO's sturgeon bycatch estimates were derived from a catch census system. From 2007-present, DFO's estimates were derived by combining total effort estimates with fisher interview data on bycatch rates by gear type (Karen Burnett, DFO, pers. comm.). Estimates of the sturgeon releases per 100 net-hours indicate that the average release rates for 2007-19 were roughly twice the average for 2000-06 (Table D3) and this is consistent with the change in how DFO derived their sturgeon bycatch estimates before and after 2007.

The relative catch rates considered ranged from a rate of one (i.e., FRSCS cage program fishers caught sturgeon at an equal rate as other fishers) to five (i.e., FRSCS fishers caught sturgeon at a rate five times higher than other fishers). Estimates of the total number of sturgeon caught in First Nation setnet and driftnet fisheries from 2000-2019 using the range of relative catch rates considered (1x to 5x) are provided in Table D4. This range of relative catch rates produce sturgeon catch estimates that range from 4.2 to 20.8 times the DFO catch estimates (see Table D4).

Estimates were generated for each stratum (Figure D1) for each of the months for which we had DFO catch estimates; and estimates were expanded using the stratum estimate equation. Monthly estimates were then summed by year, and the effective expansion factor was calculated for comparison purposes. Generally, setline catch had higher expansion factors over the DFO catch estimate due to higher net hours relative to drift nets.

Table D3. Yearly DFO sturgeon catch estimates along with expanded catch estimates and corresponding estimated mortalities using the assumption that the sturgeon catch rate for FRSCS cage program fishers was three times (3x) the catch rate for other fishers. Note the following abbreviations: Rel = Release; Exp F = Expansion Factor.

	DFO Estimate						**Expanded Estimate**						**Estimated Mortalities**							
	Setnet			Driftnet			Setnet			Driftnet			Setnet		Driftnet		Total		Rel/100 net-hrs	
Year	Net Hrs	Kept	Rel	Net Hrs	Kept	Rel	Exp F	Kept	Rel	Exp F	Kept	Rel	Low	High	Low	High	Low	High	Setnet	Driftnet
													6.2%	11.5%	0.0%	4.8%				
2000	249,545	14	1,453	65,259	12	859	6.2	86	8,977	4.4	53	3,764	643	1,119	53	233	696	1,352	3.6	5.8
2001	168,436	11	749	38,962	6	686	7.0	77	5,236	4.0	24	2,740	402	679	24	155	425	835	3.1	7.0
2002	194,183	4	856	47,251	1	661	7.3	29	6,242	3.8	4	2,540	416	747	4	126	420	873	3.2	5.4
2003	211,355	7	628	44,576	0	780	8.8	62	5,547	4.6	0	3,615	406	700	0	174	406	873	2.6	8.1
2004	329,153	73	627	43,775	0	683	10.6	771	6,620	3.9	0	2,693	1,181	1,532	0	129	1,181	1,661	2.0	6.2
2005	201,947	1	327	43,447	0	428	13.5	13	4,408	5.6	0	2,381	287	520	0	114	287	635	2.2	5.5
2006	283,777	16	386	43,909	14	547	16.1	257	6,209	5.0	70	2,725	642	971	70	201	712	1,172	2.2	6.2
2007	87,800	2	395	21,620	0	452	7.7	15	3,048	5.8	0	2,632	204	366	0	126	204	492	3.5	12.2
2008	135,775	12	519	37,296	1	565	8.6	103	4,474	4.8	5	2,708	381	618	5	135	386	753	3.3	7.3
2009	58,938	2	311	33,240	9	648	7.8	16	2,427	5.8	52	3,743	166	295	52	232	218	526	4.1	11.3
2010	134,928	6	317	39,258	1	259	13.8	83	4,385	9.2	9	2,370	355	587	9	123	364	710	3.3	6.0
2011	92,668	2	254	43,917	0	366	13.8	28	3,503	8.7	0	3,184	245	430	0	153	245	583	3.8	7.3
2012	102,756	2	567	30,968	0	489	8.3	17	4,682	6.6	0	3,233	307	555	0	155	307	710	4.6	10.4
2013	31,326	5	252	17,753	5	546	8.0	40	2,006	5.9	29	3,202	164	271	29	183	194	454	6.4	18.0
2014	141,747	1	299	51,569	0	513	14.4	14	4,318	6.9	0	3,560	282	511	0	171	282	682	3.0	6.9
2015	42,650	6	311	18,662	0	968	7.2	43	2,225	3.7	0	3,614	181	299	0	173	181	472	5.2	19.4
2016	37,176	1	296	12,474	0	276	7.2	7	2,127	6.5	0	1,795	139	252	0	86	139	338	5.7	14.4
2017	57,672	2	447	17,340	0	638	7.2	14	3,240	5.0	0	3,215	215	387	0	154	215	541	5.6	18.5
2018	92,013	0	588	24,864	0	397	7.5	0	4,387	7.1	0	2,823	272	505	0	136	272	640	4.8	11.4
2019	18,966	0	126	7,148	0	438	11.7	0	1,474	5.5	0	2,396	91	169	0	115	91	284	7.8	33.5
Totals	2,672,812	167	9,708	683,288	49	11,199	-	1,676	85,535	-	245	58,932	6,980	11,513	245	3,074	7,225	14,587	-	-
Average	133,641	8	485	34,164	2	560	9.6	84	4,277	5.6	12	2,947	349	576	12	154	361	729	4.0	11.0
Period Averages																				
2000-04	230,534	22	863	47,965	4	734	8.0	205	6,524	4.2	16	3,070	610	955	16	163	626	1,119	2.9	6.5
2000-06	234,057	18	718	46,740	5	663	9.9	185	6,177	4.5	21	2,922	568	895	21	162	590	1,057	2.7	6.3
2007-19	79,570	3	360	27,393	1	504	9.5	29	3,254	6.3	7	2,960	231	403	7	149	238	553	4.7	13.6

ASSESSING STURGEON MORTALITY

Once the number of sturgeon caught was estimated, the next step was to determine the proportion that were either killed (kept) or that died as a result of capture and handling stress. Mortalities associated with releases from setline and driftnet fisheries were computed based on high and low estimates of mortalities within each fishery type. Robichaud et al. (2006) estimated setnet mortality rates of 6.2% to 11.5%, and driftnet mortality rates of 0%-4.8%. The range in mortality rates for First Nation setnet fisheries is similar to values reported in the Walters et al. (2005) assessment of the mortalities for setnet fisheries (7%-13%). These post-release mortality proportions were applied to the estimated number of sturgeon released and combined with estimates of the number of sturgeon kept to calculate an estimate of total yearly mortalities associated with the First Nations gillnet fishery (Table D3).

Table D4. Estimates of the number of sturgeon caught in First Nations setnet and driftnet fisheries in the lower Fraser River from 2000-2019 under differing assumptions of the catch rates for FRSCS cage program fishers relative to other fishers and compared with the DFO estimates of the sturgeon caught in these fisheries. The 3x assumption was used as the default assumption for Table D3.

Gear Type	Catch Rate Assumption					DFO Estimates
	1x	2x	3x	4x	5x	
Catch Estimate						
Setnet	261,645	130,818	87,215	65,414	52,331	9,871
Driftnet	177,548	88,774	59,183	44,397	35,501	11,257
Total	439,193	219,592	146,398	109,811	87,832	21,128
Ratio Relative to DFO Estimate						
Setnet	26.5	13.3	8.8	6.6	5.3	–
Driftnet	15.8	7.9	5.3	3.9	3.2	–
Total	20.8	10.4	6.9	5.2	4.2	–

A large portion of the total mortality estimates were associated with sturgeon released from setnet fisheries. Thus mortality estimates were sensitive to underlying assumptions used in predicted of number of sturgeon released (Figure D3). The most significant was likely the assumption of the catch rate of fishers involved in the FRSCS sanctuary cage program relative to other First Nation fishers. The impact of the assumed relative catch rate on the catch estimates was investigated by considering a range of relative catch rates (see Table D4)). The estimates of total sturgeon mortality associated with First Nation gillnet fisheries from 2000-2019 using the relative catch rates considered are provided in Table D5. To assess the practicality of the alternative catch rate assumptions, these estimates were compared to those derived using unadjusted DFO catch estimates and the estimated decline in the abundance of sturgeon for the size range of sturgeon sampled through the FRSCS cage program.

Under the conservative assumption of FRSCS cage program fishers catching sturgeon at a rate five times higher than other fishers, the estimate of total mortality was 4.2 times higher than the DFO estimate for 2000-2019. This suggests that the DFO estimates represent significant underreporting of the sturgeon mortalities associated with these fisheries. Furthermore, the sanctuary cage program was restricted to sturgeon that were <150 cm FL, therefore these corrections do not account for the capture of larger sturgeon in these net fisheries. The least conservative assumption (i.e., other fishers captured sturgeon at the same rate as cage program fishers) resulted in estimates of total mortality that were 20.8 times the DFO estimates and represent an unrealistically high level of mortality, especially if the higher mortality rate limit is used.

Table D5. Estimates of the sturgeon mortalities associated with First Nation setnet and driftnet fisheries in the lower Fraser River for 2000-2019 under differing assumptions of catch rates for FRSCS cage program fishers, compared to estimates based only on DFO catch estimates. The 3x assumption was used as the default assumption for Table D3.

Size Group	Gear Type	Mortality	Catch Rate Assumption 1x	2x	3x	4x	5x	DFO Estimate
All sizes	Setnet	Low	20,939	10,469	6,980	5,235	4,188	769
		High	34,539	17,269	11,513	8,635	6,908	1,283
	Driftnet	Low	736	368	245	184	147	49
		High	9,222	4,611	3,074	2,306	1,844	587
	Total	Low	21,675	10,837	7,225	5,419	4,335	818
		High	43,761	21,880	14,587	10,940	8,752	1,870
60-159 cm FL	Setnet	Low	13,610	6,805	4,537	3,403	2,722	500
		High	22,450	11,225	7,483	5,613	4,490	834
	Driftnet	Low	478	239	159	120	96	32
		High	5,994	2,997	1,998	1,499	1,199	381
	Total	Low	14,089	7,044	4,696	3,522	2,818	532
		High	28,445	14,222	9,482	7,111	5,689	1,215

DISCUSSION

During the 2000-2005 FRSCS sanctuary cage program, roughly 65% of the sturgeon in the cages were 60-159 cm FL, with the rest being smaller. The abundance of the Lower Fraser White Sturgeon in the 60-159 cm FL size range has declined by 29,000 fish (Challenger et al. 2020) between 2003 and 2019. Therefore, a total bycatch related mortality estimate of 44,000, (28,400 sturgeon in the 60-159 cm range, Table D5), would account for nearly all of the estimated decline in the 60-159 cm sturgeon. This level of bycatch mortality (derived using the 1x catch rate assumption) is unlikely to be true given that other sources of mortality, including natural mortality, would also be expected to occur during this period. Given that this was the same catch rate assumption used by Walters et al. (2005), it is likely that this previous analysis greatly overestimated the 2000-2004 mortalities associated with the First Nation gillnet fishery.

Using more conservative assumptions about FRSCS fishers catch rates (i.e., that they ranged from three to five times that of the other First Nation fishers in the Mission-Hope stratum), the estimated mortalities are more biologically feasible (e.g., estimated mortality is below the estimated population decline). Under the ‘three times’ assumption, a high rate of mortality resulted in a total estimated mortality of 60-159 cm FL sturgeon was 9,482 (65% of 14,587) and this represents approximately 30% the estimated decline in this size group. Depending on the combination of catch rate assumption (i.e., three to five times) and whether the high vs. low mortality rates were used for each gear type, total mortality associated with the First Nation gillnet fisheries could account for 10-33% of the estimated decline of 60-159 cm FL sized sturgeon. If the same exercise is repeated using only the DFO catch estimate, the fishery would represent approximately 2-4% of the estimated decline. Clearly, this represents a potentially significant source of mortality in the population. Furthermore, these estimates only consider about 65% of First Nation sturgeon catch, since 35% of the sturgeon delivered to the FRSCS catches were <60 cm FL. The mortality of smaller sturgeon would reduce the number of sturgeon surviving to the >60 cm (age 7+) portion of the population.

The range in our mortality estimates is also generally reflective of the uncertainty in generating estimates for First Nation gillnet sturgeon catch, as well as the uncertainty in mortality rates associated with the capture and release method. Therefore, this range is a real indication of the lack of information about the direct impact the fishery is having on the Fraser River White Sturgeon population. While the estimates do demonstrate the potential size of the impact and the degree of underreporting regarding this impact, more direct observation First Nation bycatch will be required to accurately estimate the total sturgeon bycatch and mortality rates associated with these fisheries.

Finally, these estimates represent mortalities over the last 20 years (i.e., 2000-2019), but changes in how the gillnet fishery operates in the future may alter the significance of this threat moving forward. Generally, the size of the gillnet fishery has been declining over time, and if this general trend continues, the size of the threat can be expected lessen concomitantly (Figure D4). Overall, the number of net hours in both the driftnet and setnet have been steadily declining over the twenty year period (Figure D4a). While setnet sturgeon catch has been tracking the overall decline in effort, driftnet sturgeon catch has however remained steady (Figure D4b). Given that the driftnet fishery was associated with a much smaller portion of total estimated mortalities, it will likely be less of a concern relative to setnet catch, which may continue to decline if current trends hold.

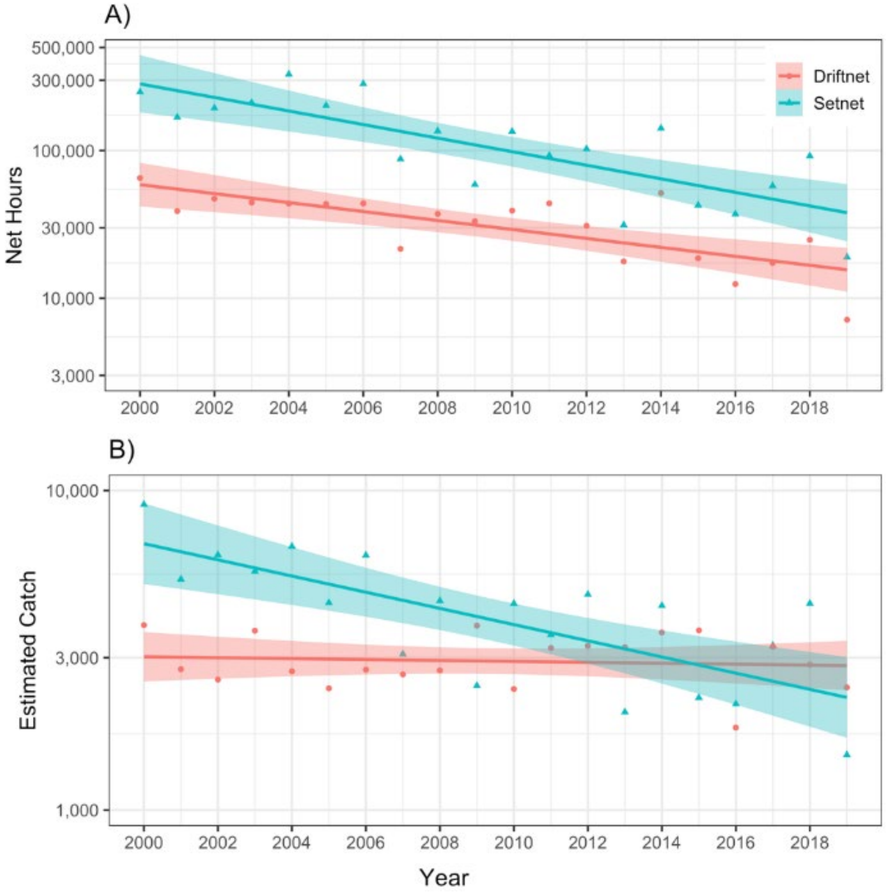

Figure D4. Long term trends in the setnet and driftnet effort (hours per year) and sturgeon catch (number of fish per year). Line indicates the fit from a linear regression, with shading indicating the 95% confidence region. Net hours axis is displayed using logarithmic scaling.

REFERENCES

Burnham, K.P., and Anderson, D.R. 2002. Model selection and multi-model inference: a practical information-theoretic approach. In 2nd edition. Springer-Verlag, New York.

Nelson, T.C., Gazey, W.J., English, K.K., and Rosenau, M.L. 2005. Status of White Sturgeon in the Lower Fraser River. Report for Fraser River Sturgeon Conservation Society, Vancouver, BC.

Robichaud, D., English, K.K., Bocking, R.C., and Nelson, T.C. 2006. Direct and delayed mortality of white sturgeon caught in three gear-types in the Lower Fraser River. Report for Tsawwassen First Nation Fisheries, Delta, BC.

Walters, C.J., Korman, J., McAdam, S. 2005. An assessment of white sturgeon stock status and trends in the Lower Fraser River. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/066. vi + 60 p.

APPENDIX E: OVERVIEW SUMMARY OF ISAMR MODEL

The following pages provide an overview summary of the Integrated Spatial and Age-structured Mark Recapture (ISAMR) Model used to estimate abundance for Lower Fraser White Sturgeon and assess the potential of achieving proposed candidate recovery thresholds, using figures presented to the review panel during the CSAS review process for this RPA document. Several of these figures are similar to ones described in Challenger et al. (2017). Others have been modified from those in previous documents to facilitate presentation and understanding. Prior to the development of the ISAMR Model, annual estimates of abundance for the Lower Fraser Sturgeon were computed using sequential 24 month periods of PIT tag release and recovery data using a Bayesian Mark-Recapture (BMR24) Model. Figures E1 and E2 provide an example of the difference between classical mark-recapture models (e.g., BMR24) and state space models (e.g., ISAMR). Figure E3 provided a flow diagram for the ISAMR Model showing the underlying model states, transitions between states and functional relationships (from Challenger et al. 2017). The ISAMR Model integrates the data from all study years into one analysis, unlike the BMR24 model which analyses sequential periods independently. The model includes a spatial component to adjust for different marking and sampling rates by area and age structuring to account for age-specific mortality rates and selectivity related to the primary sampling method (angling). The shape of the age-specific mortality curve is showing in Figure E4 and the parameter space of size/age selectivity curves are showing in Figure E5. The ISAMR Model estimates the parameters of these curves using Bayesian methodology based on observed mark-recapture data. Figure E6 demonstrates how gear selectivity will affect the number of sturgeon observed from a cohort over the range of ages, including ages where sturgeon are recruited into the sampling gear. Figure E7 shows estimates of Age 7 abundance for the 2000-2019 assessment period and the abundances of Age 7 sturgeon prior to 2000 required to produce the abundances of older sturgeon estimated during the assessment period. Based on the estimated selectivity curve about 50% of Age 7 sturgeon are vulnerable to sampling using normal angling gear and therefore this age has been used as an indicator of recruitment within the population. Figure E8 provides a comparison of abundance estimates for three different age/size categories of sturgeon derived using the BMR24 Model with those derived using the ISAMR Model. These two very different models produced similar long-term trends, but also differed in estimated abundances for specific years. The BMR24 model are more variable likely due to short-term changes in sampling, fishery behaviour, and temporary emigration. Figure 9 show the results from a model evaluation exercise where annual estimates and projections were generated from the ISAMR Model using a portion of the available data (i.e., 2000-2007, 2000-2010, 2000-2014) and then compared to the estimates produced when using all available data (i.e., 2000-2019).

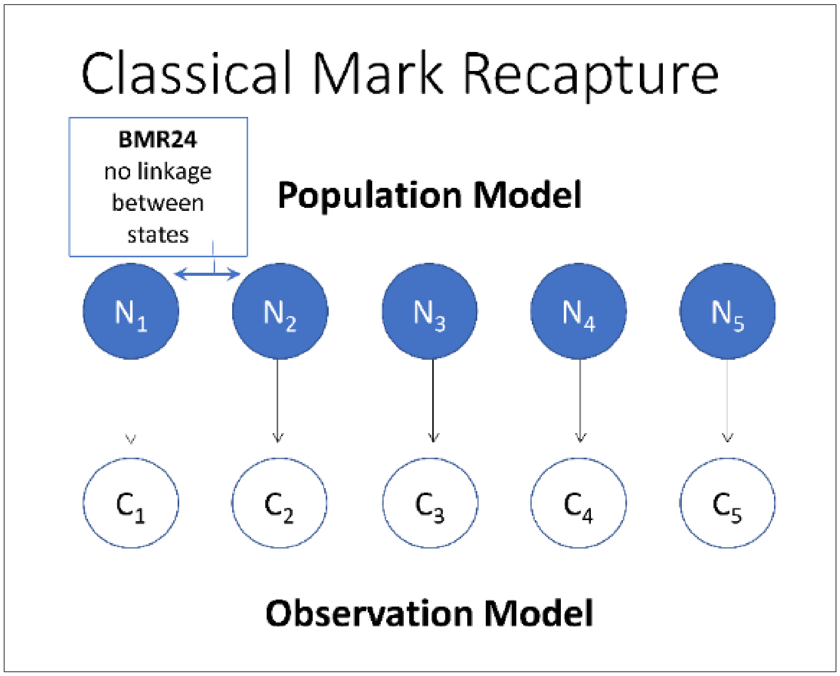

Figure E1. Classical mark-recapture model where there is no linkage between the population estimates for one period and those in previous or subsequent periods.

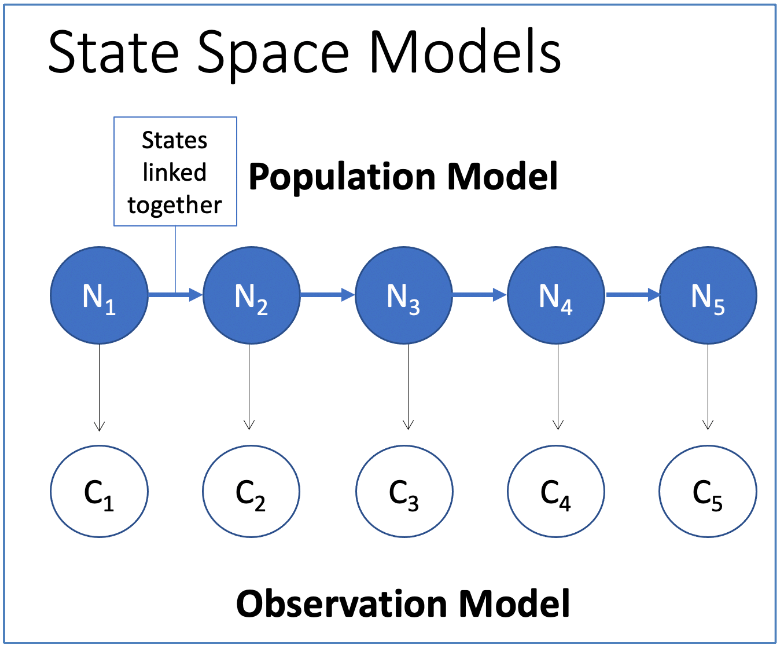

Figure E2. Example of a simple State Space Model where the population estimates are explicitly connected over time. In this type of model estimates for later years inform the estimates for all previous years. For example: a 10-year-old fish detected in the current year must have been alive in the population in each of the previous 9 years.

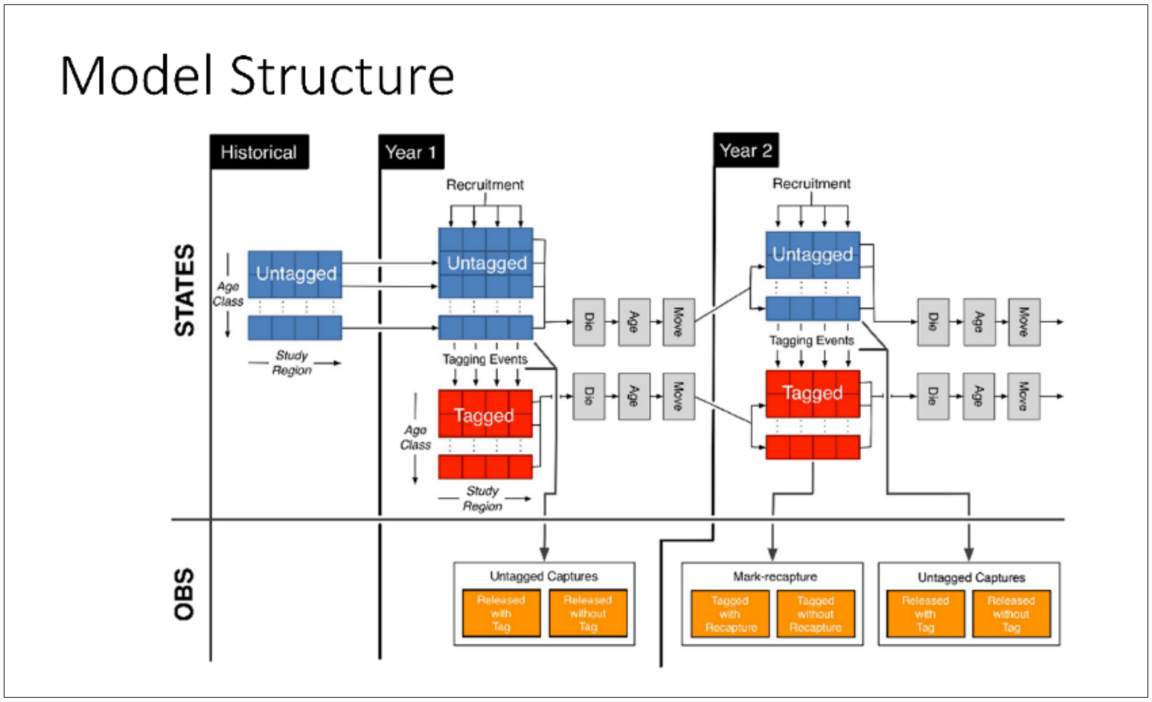

Figure E3. Flow diagram for the ISAMR Model showing the underlying model states, transitions between states and functional relationships (adapted from Challenger et al. 2017).

Figure E4. Shape of the age-specific mortality rate curve derived from the 2000-2018 data.

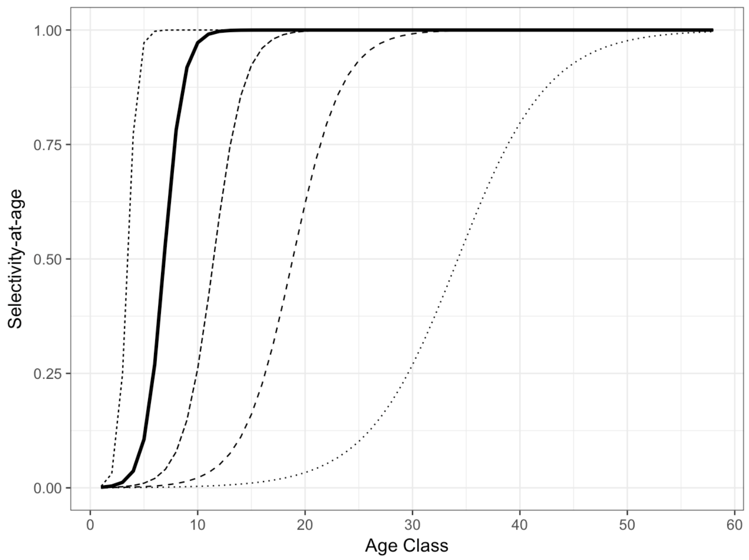

Figure E5. Examples of potential selectivity-at-age curves for the primary sampling gear. The model estimates the parameters for a sigmoidal curve. The solid line indicates the selectivity curve estimates from the data, relative to the full parameter space explored (dotted lines).

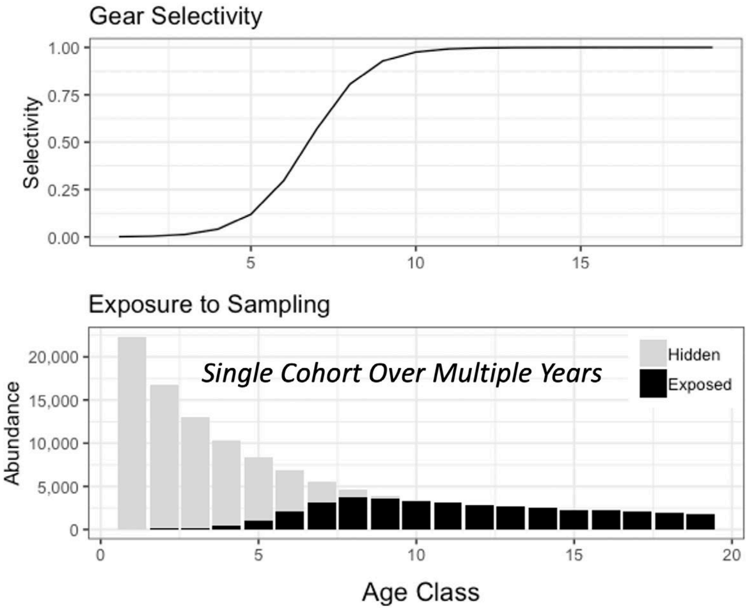

Figure E6. Relationship between gear selectivity and the portion of the a cohort exposed to sampling by age. Note that cohort abundance is expected to decline with age due to mortality.

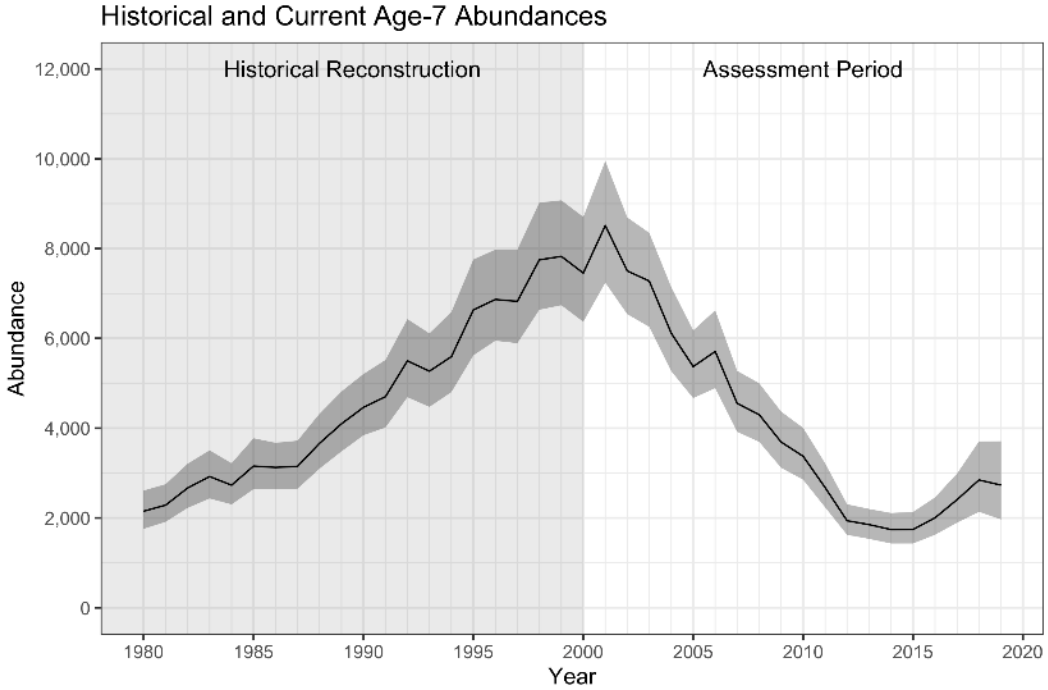

Figure E7. Estimates of the abundance of Age 7 sturgeon for the 2000-2019 assessment period and the abundances of Age 7 sturgeon prior to 2000 required to produce the abundances of older sturgeon estimated within the assessment period, with 95% credible intervals (from Challenger et al. 2020).

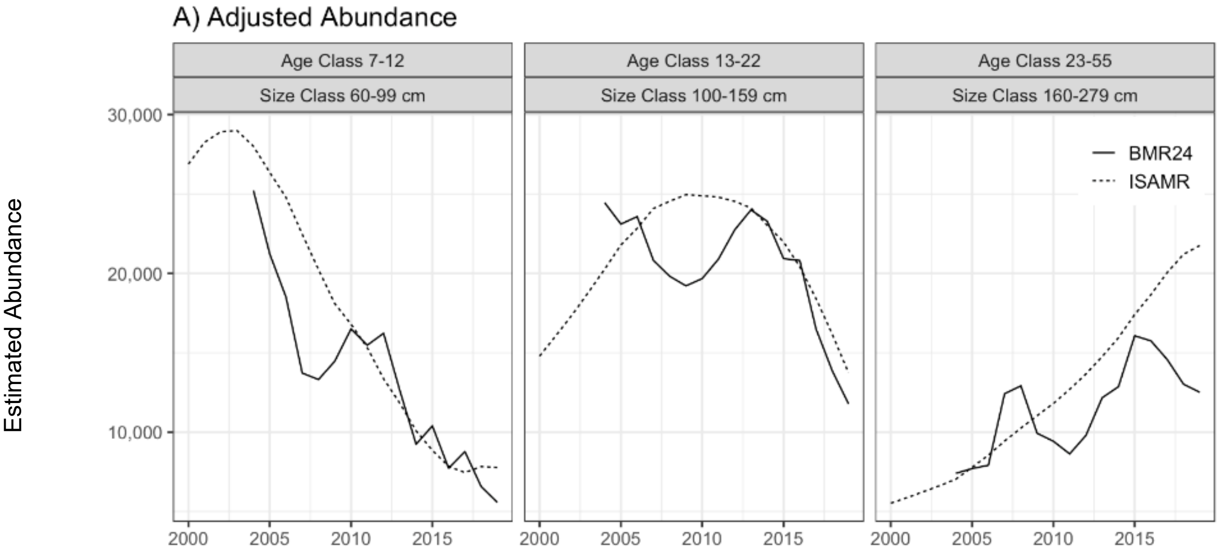

Figure E8. Comparison of abundance estimates for three different age/size categories of sturgeon derived from the BMR24 Model with those derived from the ISAMR Model (from Challenger et al. 2020). ISAMR abundance estimates were adjusted to remove the effect of age-specific selectivity for comparison with the BMR24 estimates which doesn't include selectivity adjustments.

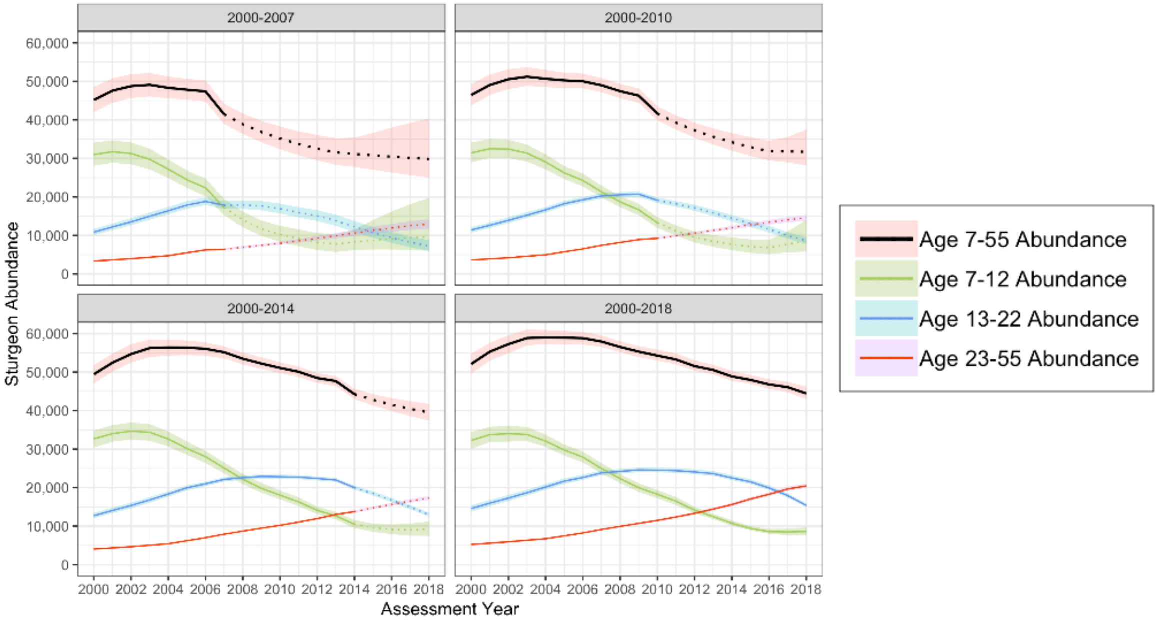

Figure E9. Results from a model evaluation exercise where annual estimates and projections from the ISAMR Model are derived from portions of the available data (i.e., 2000-2007, 2000-2010, 2000-2014) and compared with the estimates derived using all available data (i.e., 2000-2019). Dotted lines represent projections based on population estimates from the reduced data time series. Shaded areas indicated the 95% credible intervals.