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Lower Fraser River White Sturgeon Monitoring and Assessment Program: Status of White Sturgeon in the Lower Fraser River in 2018 With Abundance Estimates derived from 24-Month Bayesian Mark Recapture Modeling

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KEY POINTS AND FINDINGS

1. This is a long-term, large-scale, volunteer-driven assessment program

- The Lower Fraser White Sturgeon Monitoring and Assessment Program, delivered by the Fraser River Sturgeon Conservation Society, has been ongoing continuously since April 2000.
- White Sturgeon sampling data are collected by over 60 trained volunteers within a core assessment area that covers over 200 linear river kilometers of the lower Fraser River and its tributaries downstream of Hells Gate; over 98% of samples collected are from within this area.

2. Two separate abundance models are run each year

- The program uses two separate models to generate abundance estimates: 1) a Bayesian mark-recapture model (BMR24, described in this report); and 2) an Integrated Spatial and Age-structured Mark-Recapture (ISAMR) model, reported separately (Challenger et al. 2019).
- The BMR24 model uses a 24-month rolling data window (run separately over 24-month sets), while the ISAMR model considers all current and historical captures in a single analysis.
- For 2018, the BMR24 model was modified with a 30-day minimum time-at-large (30-d minTAL) restriction; this was applied retroactively to all assessment years from 2001 through 2018 such that BMR24 abundance estimates reported here differ from those previously reported.
- Heterogenous sampling biases have arisen in the past two years which affect the BMR24 model more than the ISAMR model; as such, we suggest that the ISAMR model currently provides the best estimates of abundance of Lower Fraser River White Sturgeon.

3. Both models agree that the Lower Fraser White Sturgeon population is in a state of decline

- Both the BMR24 and ISAMR models indicate that the abundance of 60-279 cm fork length (FL) White Sturgeon in the lower Fraser River has been in a continual state of decline since 2004.
- The ISAMR model, which provides abundance forecasts based on recruitment rates and standing age structure, predicts that at current juvenile recruitment rates the downward trend in abundance for 60-279 cm FL White Sturgeon will continue at an average annual rate of 1.2% per year from 2018 onward.
- The 2018 ISAMR abundance estimate for 60-279 cm FL (age 7-55) White Sturgeon was 44,430 fish, which is 24.7% lower than the respective 2004 ISAMR estimate, and 3.6% lower than the 2017 ISAMR estimate. The equivalent 2018 BMR24 abundance estimate was 45.3% lower than the respective 2003 BMR24 estimate, and 16.0% lower than the 2017 BMR24 estimate.
- Both models agree that in the past 15 years (2003-2018) significant declines in abundance have occurred for 60-99 cm FL juvenile White Sturgeon (BMR24: 78.2% decline; ISAMR: 75.7% decline).
- The BMR24 and ISAMR models differ regarding recent (2015-2018) abundance trends for adult (160-279 cm FL) sturgeon: the BMR24 model indicates that adult abundance peaked in 2015, whereas the ISAMR model suggests adult abundance continued to increase through 2018. Forecasts generated by the ISAMR model predict an increase of approximately 2,100 adult sturgeon from 2018 to 2023, followed by a continual decline into the foreseeable future (the predicted adult decline from 2023 to 2060 will average 2.4% per year and equate to ~13,500 adult sturgeon over this time period).
- Juvenile recruitment rates are currently below the level of population sustainability; the authors recommend immediate implementation of strategic actions to improve the rate of recruitment.

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

- The proportion of juvenile White Sturgeon less than 100 cm FL in total annual measured samples captured by the Albion Test Fishery decreased 60.1% between 2000 and 2018.
- The average annual growth rate for all size groups of White Sturgeon in 2018 (3.5 cm/year) was 39.9% lower than the average annual growth rate in 2002 (5.7 cm/year).
- The number of reported and confirmed sturgeon mortalities in the lower Fraser River in 2018 (46) was the highest observed in the program. Of sampled mortalities (31), 77% were mature adult fish over 160 cm FL, 52% were large mature adults over 200 cm FL, and 54% were tagged (recaptures).

EXECUTIVE SUMMARY

The Fraser River Sturgeon Conservation Society (FRSCS), a not-for-profit charitable organization founded in 1997, has a mandate to conserve and restore wild Fraser River White Sturgeon, raise public awareness of Fraser River White Sturgeon and their ecosystem, and produce reliable information regarding the status of Fraser River White Sturgeon and their habitat. This report summarizes the FRSCS' Lower Fraser River White Sturgeon Monitoring and Assessment Program activities for 2018.

Originally developed in 1999, this program uses a true "stewardship" approach to address objectives and generate field data. Since April 2000, the program has relied on the volunteer contributions of angling guides, recreational, commercial, and Aboriginal fishermen, test fishery and enforcement personnel, and various fishery monitors. Volunteers from these sectors were trained to sample and tag White Sturgeon, and record and transfer data. By January 2019, volunteers had conducted 155,806 sampling events (6,175 in 2018), tagged and released 70,539 sturgeon (1,954 in 2018), and documented 78,729 recapture events of tags applied by FRSCS volunteers within the general study area in the lower Fraser River (4,140 in 2018). The core assessment area for this project includes 187 km of the lower Fraser River mainstem downstream of Lady Franklin Rock (near Yale), the lower sections of the Pitt and Stave rivers, and the Harrison River downstream from Harrison Lake. Although White Sturgeon are captured and sampled by FRSCS volunteers throughout the general study area, 99.2% of all samples collected since 2000 have been taken within the core assessment area.

Abundance Models: BMR24 and ISAMR

The mark recapture data collected under the Monitoring and Assessment Program are inputted into two separate models to generate abundance estimates. The methods and outputs of one model, a Bayesian mark-recapture model (BMR24), are described in this report, whereas those of the second model, the Integrated Spatial and Age-structured Mark-Recapture (ISAMR) model, are reported elsewhere (Challenger et al. 2019). Both the BMR24 and ISAMR models only use sampling data that were collected from the core assessment area, and only consider sturgeon of 60-279 cm fork length (FL). Both models use Bayesian estimation to provide abundance estimates and credible intervals; however, the two models have very different population modelling structures: 1) the BMR24 model employs size groups while the ISAMR model uses age classes; and 2) the BMR24 model assigns individual fish to a size-class for each 24-month analysis period, while the ISAMR model reconstructs and tracks the transition of fish through the available age classes over time. The two models also differ in how sampling selectivity is handled: 1) the BMR24 model does not include differential selectivity by age, and assumes that selectivity within a size group is consistent over the 24-month sampling period; and 2) the ISAMR model applies a selectivity-at-age relationship that is estimated based on the data. In addition, the BMR24 model uses a 24-month rolling data window and is run separately for each set of 24 months, while the ISAMR model considers all current and historical (2000-2018) captures in a single analysis. New this year, we have applied a 30-day minimum time-at-large (30-d minTAL) restriction to the BMR24 model, a restriction that was also applied retroactively to all assessment years from 2001 through 2018; thus, abundance estimates published in previous annual project assessment reports will differ from those reported here.

Heterogenous sampling biases have arisen in the past two years, which affect the BMR24 model more than the ISAMR model. As such, we suggest that the ISAMR currently provides the best estimates of abundance of Lower Fraser River White Sturgeon within the core assessment area, and refer readers to Challenger et al. (2019) for details regarding ISAMR model methods and results for 2018.

Abundance Estimates, Trends, and Forecasts

Recent abundance estimates generated by both the BMR24 and ISAMR models indicate that the abundance of 60-279 cm FL White Sturgeon in the core assessment area of the lower Fraser River is well below historic levels and has been declining continually since 2004. The 2018 BMR24 abundance estimate for 60-279 cm FL White Sturgeon was 45.3% lower than the program's highest annual abundance estimate in 2003, and 16.0% lower than the 2017 estimate. Comparatively, the 2018 ISAMR abundance estimate for 60-279 cm FL (age 7-55) White Sturgeon was 24.7% lower than the model's highest respective annual abundance estimate in 2004, and 3.6% lower than the 2017 estimate. The ISAMR model, which produces abundance forecasts by size/age group with a high level of reliability, indicates that at current (2018) recruitment rates this downward trend in population abundance will continue at an average rate of 1.2% per year from 2018 onward (Challenger et al. 2019).

The current (2018) abundance estimates for 60-279 cm FL White Sturgeon in the core assessment area were 33,461 fish (95% CLs ± 9.5% of the estimate) for the BM24 model, and 44,430 fish (95% CIs ± 4.5% of the estimate) for the ISAMR model. Currently, the ISAMR estimate is considered to be the more reliable of the two estimates (due to heterogenous sampling biases that have arisen in the past two years, which affect the BMR24 model more than the ISAMR model). The size/age structure of the White Sturgeon population in the lower Fraser River in 2018 was comparable for the two models, with relatively few (19.2% - 19.6%) juveniles (60-99 cm FL), and more (34.6% - 41.5%) sub-adults (100-159 cm FL) and (38.9% - 46.1%) adults (160-279 cm FL).

Both the BMR24 and ISAMR models suggest that the observed decline in the total abundance of White Sturgeon in the core assessment area of the lower Fraser River since 2003 has been driven mostly by declines in juvenile recruitment into the population. Both models agree that in the past 15 years (2003-2018) significant declines in abundance have occurred for 60-99 cm FL juvenile sturgeon (BMR24, 78.2% decline; ISAMR, 75.7% decline). Both models also agree that the abundance of sub-adult White Sturgeon (100-159 cm FL) has declined significantly in the past 5 years (2013 to 2018; BMR24, 57.8% decline; ISAMR, 65.0% decline). In addition, both models indicate that the abundance of adult sturgeon (160-279 cm FL) within the core assessment area trended upward from 2000 to 2015, as surviving sub-adult sturgeon (100-159 cm FL) grew into the adult size group over this time period. However, the two models differ on the recent (2015-2018) trend of adult sturgeon (>160 cm FL). The estimates from the BMR24 model suggest that the abundance of adult sturgeon declined from 2015 to 2018, while those from the ISAMR model indicate that the abundance of adult sturgeon has continued to increase during this time period.

The Albion Test Fishery provides additional evidence of significant reductions in the abundance of juvenile sturgeon since 2004. The proportion of juvenile White Sturgeon less than 100 cm FL in the total measured sample captured by the Albion Test Fishery decreased 60.1% between 2000 and 2018. As in previous reports, we emphasize the importance of taking immediate actions to improve both recruitment of age-1 fish and survival rates for age 1-6 fish. Actions should include: 1) the protection of sturgeon spawning and juvenile rearing habitat; 2) the removal of all fishing gear, and restrictions of boating activity, from known sturgeon spawning areas during the spawning period; and 3) the protection of the spawning and rearing habitats of sturgeon prey species (e.g., salmon species and Pacific Eulachon). Recent efforts to improve sturgeon handling techniques by sturgeon anglers (and for net fishers that intercept sturgeon as bycatch while targeting other species) are expected to positively impact both survival and spawning rates and should continue to be supported.

Recaptures

Recaptures of tagged sturgeon during this study confirmed that movements and migrations occur throughout the entire lower Fraser general study area. Recapture locations of any given individual varied, and were sometimes several kilometers apart, even when the fish was at large for a relatively short time period. Moreover, White Sturgeon can and do move across the supposed boundary between sturgeon populations (Upper and Lower Fraser River populations) at Hells Gate (rkm 212). Sturgeon that were tagged and released upstream of Hells Gate (including fish tagged near Lillooet in Region 3, over 120 kms upstream of Hells Gate) have been recaptured in the lower Fraser River; and sturgeon tagged and released in the lower Fraser River have been recaptured near Lillooet.

Many individual tagged sturgeon have been recaptured and sampled numerous times. For example, by December 2018, 5,836 individual fish had been sampled five times, 536 fish had been sampled 10 times, and 21 fish had been sampled 20 times; the highest number of sampling events for an individual sturgeon was 27. Several individual tagged sturgeon have been sampled multiple times during the same year (up to seven times in 2018) and over consecutive years (up to 18 times over a five-year period). The number of times each individual sturgeon is captured is likely higher than the number for which we have records. Program volunteers include only a fraction of the total number of active sturgeon anglers, and annual numbers of capture events from gill net fisheries are not known.

Growth

Average annual growth rates for most size groups of 60-279 cm FL White Sturgeon were greater before versus after 2005. The average growth rate for all size groups in 2018 (3.5 cm/year) was the second-lowest annual growth rate observed since the beginning of the program and is 39.9% lower than the average annual growth rate of 5.7 cm/year estimated for 2002.

Mortalities

Each year, observations of dead sturgeon are reported by program volunteers, enforcement officers, recreational anglers, First Nations fishers, and the general public. The number of reported and confirmed sturgeon mortalities in the lower Fraser River in 2018 (46) was the highest since the beginning of the program. The majority (n = 31) of reported sturgeon mortalities were sampled (scanned for the presence of a PIT tag and measured) by program volunteers. For sampled mortalities, 54% had been tagged, and some of these had been previously sampled by program volunteers from 1-7 times prior to the mortality event. All sturgeon mortality sampling events in 2018 occurred in either July, August, September, or November, and the likely cause of death could not be determined for 64% of the fish sampled.

Cover Photo: "***Confirming PIT tag code prior to release***" *photo by Chad Hammond, Volunteer - Lower Fraser River White Sturgeon Monitoring and Assessment Program.*

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INTRODUCTION

Given conservation concerns for White Sturgeon (*Acipenser transmontanus*) in the lower Fraser River (e.g., COSEWIC 2012) there is a need for long-term monitoring of the population, including comprehensive and scientifically rigorous estimates of abundance. To that end, the Lower Fraser River White Sturgeon Monitoring and Assessment Program was initiated by the Fraser River Sturgeon Conservation Society (FRSCS) in April 2000 and has continued into 2019. The primary objectives of the program are to: 1) obtain abundance estimates of White Sturgeon in the lower Fraser River; 2) produce reliable information regarding seasonal abundance of White Sturgeon, by location, in the lower Fraser River; 3) ascertain seasonal migration and movement patterns of White Sturgeon in the lower Fraser River; and 4) increase public awareness regarding the conservation and preservation of White Sturgeon in British Columbia. The program uses a volunteer-based "stewardship" approach, initially developed in 1999 (Nelson et al. 2000), to address objectives and generate field data. Since 2000, the program has relied on the contributions of volunteers from several sectors, including recreational anglers, angling guides (including licensed, unlicensed, and assistant guides), First Nations and commercial fishers, test fishery staff (including the Albion and Pacific Salmon Commission test fisheries), fishery monitors (First Nation and federal), enforcement officers (First Nation, provincial, and federal), students, academic researchers, and provincial staff from the BC Ministry of Forests, Land, Natural Resource Operations and Rural Development (FLNRORD) and the BC Ministry of Environment (MOE).

This summary report presents the findings of the Lower Fraser River White Sturgeon Monitoring and Assessment Program for the 2018 assessment year. For additional information regarding the biology of White Sturgeon and history of Fraser River White Sturgeon, see Hildebrand et al. (2016) and Nelson et al. (2013a).

FIELD AND ANALYTICAL METHODS

Study Area

The general study area for the Lower Fraser River White Sturgeon Monitoring and Assessment Program includes the Fraser River watershed downstream of Hell's Gate (located at river kilometer (rkm) 212 on the mainstem Fraser River), the Harrison River and Harrison Lake, and the Pitt River and Pitt Lake (Figure 1). The general study area is essentially the extent of known and observed White Sturgeon distribution in both the mainstem Fraser River and all tributaries and lakes connected to the lower Fraser River, downstream of Hell's Gate. For the purpose of abundance estimation associated with this project, we have defined a "core assessment area" within the general study area; this area includes 187 km of the lower Fraser River mainstem downstream of Lady Franklin Rock (near Yale), the lower sections of major tributaries (Pitt and Stave rivers), and the Harrison River (Figure 1). The core assessment area is a subset of the general study area; it excludes areas of known White Sturgeon distribution, including all marine waters, the entire North Arm and adjacent Middle Arm of the Fraser River, the lower Pitt River upstream of the Highway 7 Bridge, Pitt Lake, Harrison Lake, and the section of the upper Fraser Canyon between Lady Franklin Rock and Hell's Gate. Although White Sturgeon are captured and sampled by FRSCS volunteers throughout the general study area, 99.2% of all samples collected since 2000 have been taken within the core assessment area. Since the beginning of the program in 2000, sampling data used for abundance modeling have been limited to those samples collected within the boundaries of the core assessment area, thus allowing direct comparison of annual abundance estimates among assessment years.

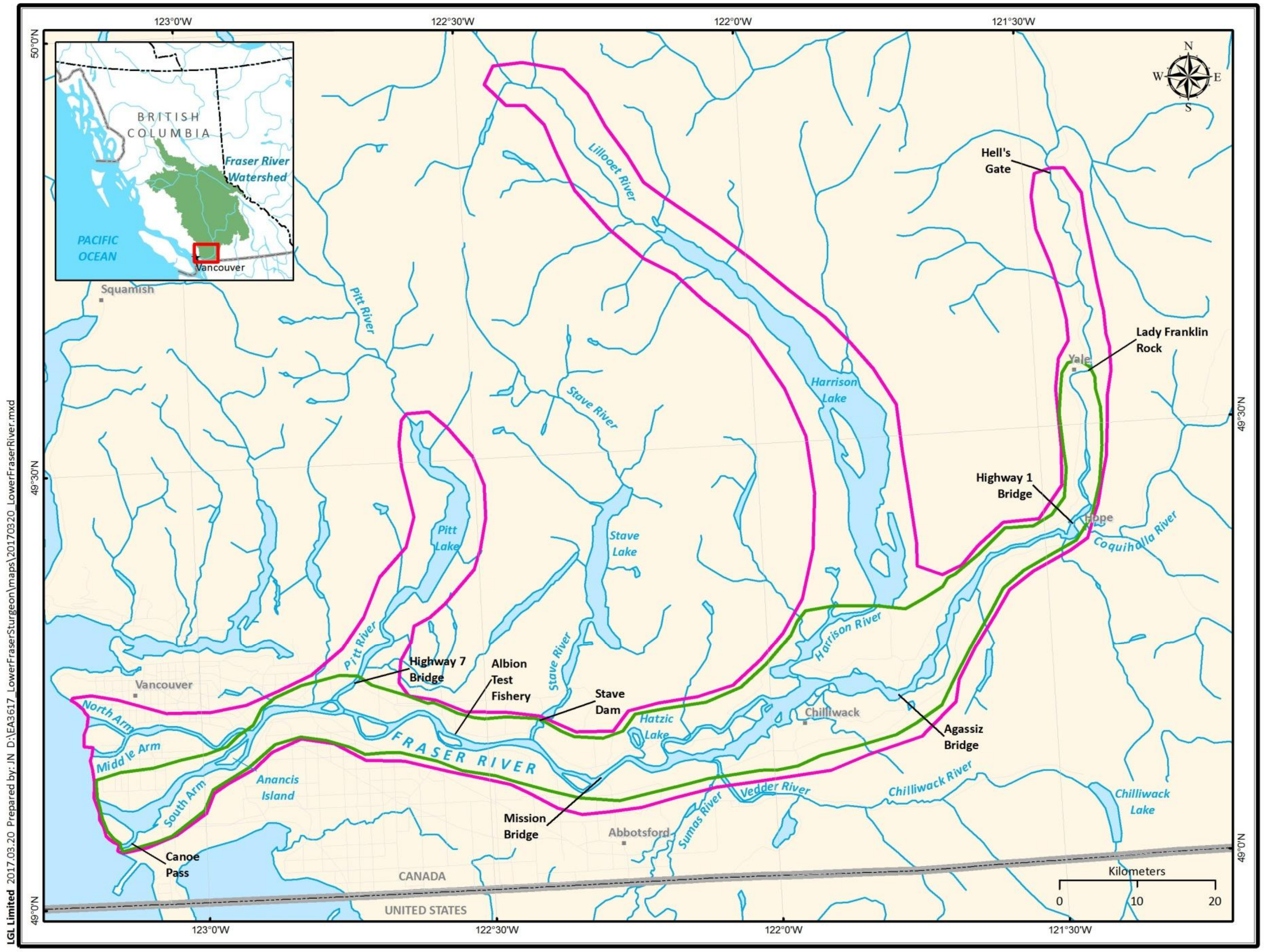

Figure 1. General study area (area within red line), and the core assessment area (area within green line; used for the production of White Sturgeon abundance estimates presented in this report). The general study area as illustrated presents the extent of known/observed White Sturgeon distribution in the lower Fraser River watershed downstream of Hell's Gate.

Sturgeon Capture and Handling Procedures

Program staff trained all volunteers that contributed to the tag and recapture database. Volunteers were trained in the field, typically on their own boat. Sturgeon capture, handling, and sampling procedures, designed to minimize stress and injury (McLean et al. 2016), were developed in partnership with provincial biologists. Scientific sampling permits, issued by both provincial and federal regulatory authorities, included the specified handling procedures as conditions of the respective permits. Accordingly, program volunteers were trained to use specific handling procedures when sampling live sturgeon. The sampling and tagging of at least one sturgeon was required to fulfill the training requirements, but in most cases several sturgeon were captured and tagged during training exercises.

Volunteers were trained to scan captured sturgeon for the presence of a Passive Integrated Transponder (PIT) tag, record all tag recapture data (from any PIT tag or external tag), apply new PIT tags (if one is not already present), measure fork length (FL) and girth (see PHOTOGRAPHS), complete a standard sampling data sheet (Appendix A), and secure and transfer data. Although volunteers were trained to sample all sturgeon captured, some sturgeon were not sampled due to time constraints and conflicting priorities (e.g., safety concerns). Volunteers who captured sturgeon by angling were required to use adequate fishing equipment (strong rods and reels, line test of at least 130-pound breaking strength), and to keep all sturgeon over 150 cm FL in the water while sampling. Sturgeon less than 150 cm FL were placed in a custom "sturgeon sling" (much like a stretcher) that contained water and supported the fish being sampled. For volunteers involved with commercial and First Nations net fisheries, emphasis was placed on exercising extra care when extricating sturgeon from gill nets (including the cutting of net, if needed) to reduce capture impacts and increase the rate of post-release survival. From 2000-2005, field data collections included sturgeon sampled as part of the FRSCS' Lower Fraser River First Nations White Sturgeon Stewardship Program; those sturgeon, intercepted in salmon gill nets, were placed in floating enclosures (provided by the FRSCS and anchored in close proximity to the fishing locations) and were removed, sampled, and released by program personnel on a daily basis (Nelson et al. 2008).

Green Sturgeon (*Acipenser medirostris*) are also present in the lower Fraser River and volunteers were provided with information to assist species identification (there have been only seven confirmed Green Sturgeon observations by this program since 2000).

Documentation of Capture Location

A simple mapping system was established to facilitate the documentation of capture locations to the nearest 0.5 rkm. Waterproof maps, delineated with rkms, were provided to all volunteers as part of the tagging equipment kit. Documentation of sturgeon capture location at this scale (closest 0.5 rkm) was important to confirm sturgeon presence at specific locations and habitat types, by season.

In order to document the general location of applied angler effort and catch, a series of sampling zones (adjacent sections of the river) was established within the core assessment area (Table 1). Zone boundaries were established based mainly on stationary geographical elements such as channel intersections, bridge crossings, and tributary confluences. Each sampling zone comprised a unique set of rkms, and was assigned to a specific sampling region (A, B, C, and D; Table 2, Figure 2). Two of the sampling regions (A and B; Figure 2) were in the designated “tidal” waters downstream of the Mission Railway Bridge, where recreational fisheries are managed by Fisheries and Oceans Canada. The remaining two sampling regions (C and D; Figure 2) were in the designated “non-tidal” waters upstream of the Mission Railway Bridge, where FLNRORD manages the recreational fisheries.

Table 1. Sampling zones used for abundance estimation of White Sturgeon, 2000-2018.

Zone	River Km	From	To
S*	0-25	Garry Point	Eastern Annacis Island
3, 5**	26-56.5 & P0-P4	Eastern Annacis Island	McMillan Island (Glover Road)
6, 7***	57-78	McMillan Island (Glover Road)	Mission Railway Bridge
8****	79-93	Mission Railway Bridge	Mouth of Sumas River
10	H0-H21	Confluence Fraser River	Outlet of Harrison Lake
12	94-122	Mouth of Sumas River	Agassiz Bridge
13	123-158	Agassiz Bridge	Hwy 1 Bridge (Hope)
14	159-187	Hwy 1 Bridge (Hope)	Lady Franklin Rock (Yale)

* Zone S is the Main (South) Arm of the Fraser River including Canoe Pass
** Zone 5 includes the lower 4 kms of the Pitt River, from the Fraser mainstem to the Hwy 7 Bridge (rkm P0-P4)
*** Zone 7 is the lower 2 kms of the Stave River, downstream of the dam (rkm ST0-ST2)
**** Zone 8 includes Hatzic Slough downstream of the water control weir located approximately 1.5 km from the Fraser confluence

Table 2. Sampling regions (A, B, C and D) used for abundance estimation of White Sturgeon, 2000-2018. Individual sampling regions are comprised of unique sampling zones (Table 1). The core assessment area is comprised of all four sampling regions (Figure 2) and includes the Harrison River and portions of the lower Pitt and lower Stave rivers (Figure 1).

Region	Zones	Description
A	S	South Arm of Fraser River; Garry Point to Eastern Annacis Island including Canoe Pass
B	3, 5, 6, 7	E. Annacis Is. to Mission Railway Bridge; lower 4 km of Pitt River (below Hyw 7 bridge); lower Stave River (below dam)
C	8, 10, 12, 13	Mission Railway Bridge to Hope including Hatzic Slough and the Harrison River
D	14	Hwy 1 Bridge (Hope) to Lady Franklin Rock (Yale)

Tagging

The marking of White Sturgeon with PIT tags has been used for movement and abundance analyses by researchers and resource managers since the early 1990s (Rein et al. 1994, Nelson et al. 2013b). PIT tags used in the study (distributed by Biomark Inc., Boise, Idaho) were injected beneath the skin of sturgeon with a specialized hand-held syringe and hypodermic needle. PIT tag models used in this study were TX1400L, BIO12.A.02, and BIO12.A.03V1 (12 mm long), and TX1405L (14 mm long); all tag types were 2 mm in diameter. When scanned with a tag reader, these glass-bodied tags emit a unique 10-digit alphanumeric code at a frequency of 125 kHz. PIT tags were kept in small glass or plastic jars that contained ethyl alcohol for sterilization purposes. Hypodermic needles, used to apply the tags, were also kept in small jars that contained ethyl alcohol.

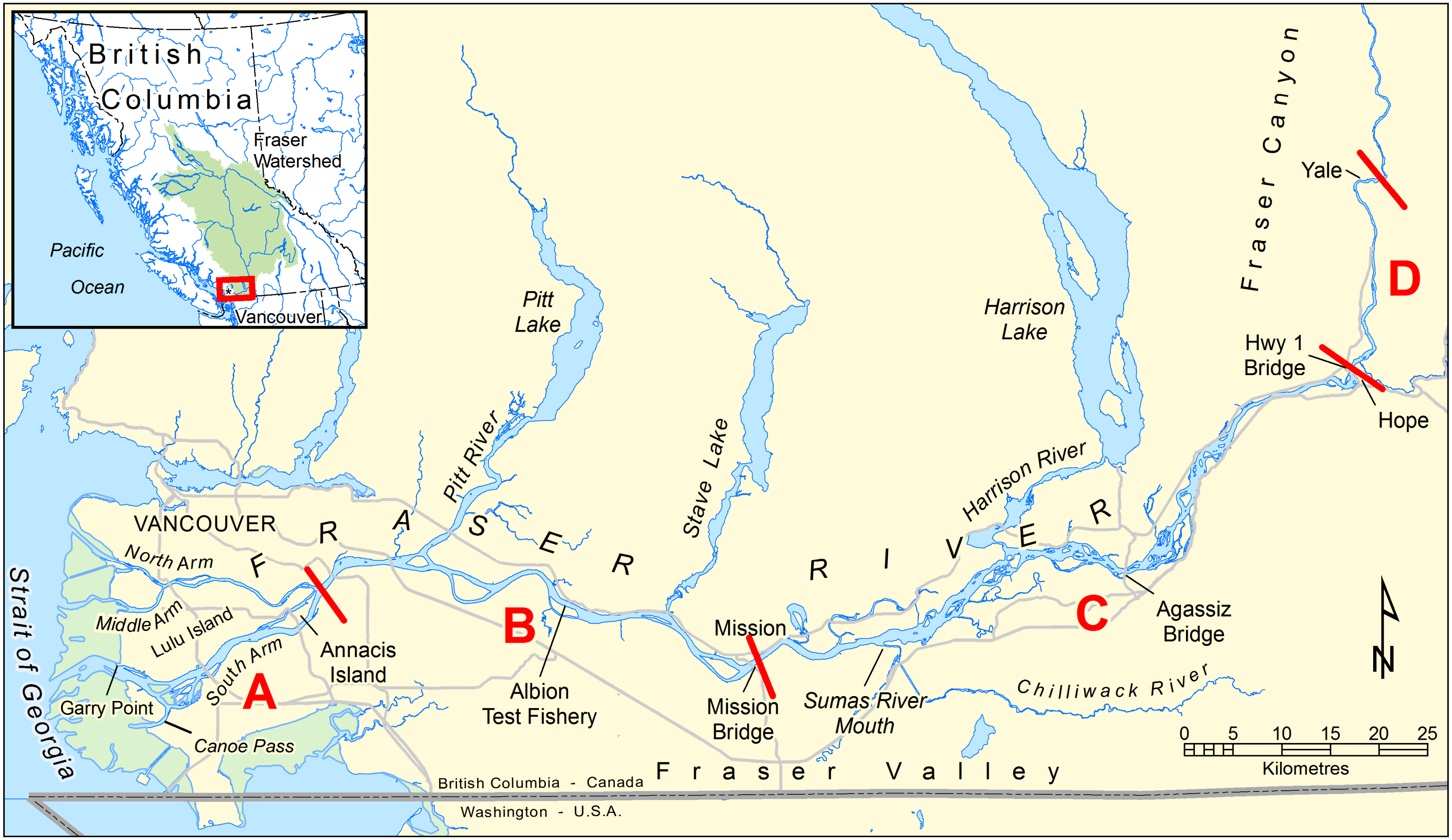

Figure 2. Boundaries of the four sampling regions (A, B, C, and D) that comprise the core assessment area used to generate abundance estimates of White Sturgeon presented in this report. Each sampling region is made up of individual sampling zones used in the analytical model to stratify tag release and recapture data; see Table 1 for a description of sampling zone locations. See Table 2 for a description of the boundaries for each sampling region. See Figure 1 for an illustration of the core assessment area.

PIT tags were injected just posterior to the sturgeon's bony head plate, left of the dorsal line, near the first dorsal scute. This PIT tag insertion location, referred to as the "head" location (see PHOTOGRAPHS), has been used by sturgeon researchers in both Oregon and Washington, and measured tag retention has been close to 100% (T. Rien, Oregon Dept. of Fish and Game, pers. comm.). Not all West Coast sturgeon tagging studies have applied PIT tags to the head location; other tag locations include the dorsolateral area, or body cavity near the dorsal fin. Volunteers were trained to scan all alternative areas, and sturgeon recaptured during this study that had a PIT tag in a non-standard location received a new tag in the head location. Tag-recapture data for all tags, regardless of tag type or body location, were recorded and entered in the recapture database.

The tag readers (scanners) used for the program were hand-held models from Biomark, Inc.; model MPR (125 kHz), and models GPR Plus and HPR.LITE.01V1 (both dual-frequency 125 kHz and 134.2 kHz). The program also used hand-held tag readers from AVID Canada distributed by PETIDCO, Calgary, Alberta; model Power Tracker (125 kHz) and Power Tracker V (dual-frequency 125 kHz and 134.2 kHz). The tag readers were battery-powered and displayed the tag numbers on a small screen. PIT tags were detected by the reader at a maximum distance of approximately 15 cm; an audible beep was emitted by the reader when a tag was detected. When a captured sturgeon was ready for sampling, a reader was activated and slowly passed over the length of the sturgeon, close to the body. If a tag was detected in the head location, the tag number was recorded on a data sheet as a "head" recapture. If a PIT tag was detected in any other location on the sturgeon, the number was recorded and a comment was made regarding the physical location of the tag, and a new PIT tag was applied in the head location. If no tags were detected, a new PIT tag was applied in the head location. The readers were also used to scan PIT tags prior to tag application (so that the tag number could be recorded), and, once inserted into the sturgeon, to confirm the active status and number of the applied tag (prior to the release of the sturgeon).

Tag Recoveries

An essential element of the abundance models used in this program was the positive identification and documentation of both tagged and non-tagged sturgeon in the sample. These data provide information on capture history (including movement), proportion of recaptures and non-tagged individuals, as well as growth and survival through time. PIT tag readers were used exclusively to determine the presence of a PIT tag. The only sturgeon used in the mark-recapture analyses were sturgeon that had been properly scanned for the presence of a PIT tag. In addition, the only recaptures used in the analyses were tags applied in the head location by this program. Other sturgeon tagging projects in the Fraser River, the Columbia River (Oregon and Washington), and elsewhere (California) have applied PIT tags and various types of external tags to both White Sturgeon and Green Sturgeon. Volunteers were trained to record all PIT tag and external tag information observed; for external tags, they recorded the tag type, color, attachment location, and all legible text/numbers. Recapture data from tags applied outside of this program were entered into the core program database, and in most cases the agencies and/or research programs that applied the tags were identified and contacted such that original tag release data were obtained (and entered into the database) and, reciprocally, all recapture details were shared.

Biosampling

All sturgeon included in the sampling program were measured with a flexible measuring tape for:

1) fork length to the nearest 0.5 cm, measured from tip of snout to fork in tail, measured along the side (lateral line); and
2) girth to the nearest 0.5 cm, measured around the body with the tape placed posterior to the insertion point of the pectoral fins (see PHOTOGRAPHS).

The general condition of each sturgeon was assessed prior to tagging, and a record was made of the condition of each fish at the time of release (ranking of 1 to 5: 1 = "vigorous, no bleeding;" 2 = "vigorous, bleeding;" 3 = "lethargic, no bleeding;" 4 = "lethargic, bleeding;" and 5 = "dead"). In addition, all visible wounds, scars, and physical deformities were identified on the data form, and comments were provided to document uncommon or unique observations regarding individual fish (specific morphological features, deformities, injuries, parasites, markings, etc.). A small number of captured sturgeon that exhibited serious wounds or deformities, or were assessed to be in some state of poor condition that could be potentially fatal or affect their normal movement and behaviour, were scanned and measured, but released without a tag.

Mortalities – When dead sturgeon were encountered by program volunteers, FLNRORD staff were contacted to conduct necropsies. When FLNRORD staff were unavailable, volunteers followed a sampling protocol that was developed in coordination with FLNRORD: sturgeon were scanned for the presence of a PIT tag, measured, and often sexed, assessed for level of maturity, and examined for stomach contents. Comments were provided regarding the state of the mortality (e.g., approximate number of days since death, any obvious wounds or cause of death) prior to "marking" the mortality carcass (as having been properly sampled) by removing the tail and opening the body cavity (the latter enables the carcass to more easily sink). PIT tag numbers recorded from dead sturgeon were marked in the database such that they were not considered to be available for recapture (by abundance models) following the mortality sampling event.

Data Management

Volunteers were trained to secure data sheets at the end of each sampling day. Data sheets were transferred to the field program manager for review; copies of data sheets were retained by the respective volunteer for filing. It was important that all volunteers retained a copy of the data that they provided, not only as a data security measure but also for future reference. The original (paper) data were reviewed by the field program coordinator and transferred to a data management technician for electronic entry. The electronic data were backed up on a secure hard drive; database updates were transferred back to the program manager on a regular basis for review. Annually, a complete (updated) database was provided to the provincial data managers at FLNRORD, typically in February, as per the partnership and program permitting conditions.

Abundance Estimation

We derived abundance estimates using two different mark-recapture models: 1) a Bayesian mark-recapture (BMR24) model that uses data from 24 consecutive months (Nelson et al. 2004, 2013a, 2016); and 2) an Integrated Spatial Age Mark Recapture (ISAMR) model (Challenger et al. 2017, 2019, Nelson et al. 2018) that uses the full 18-year time series of data (i.e., 2000-2018) to derive annual estimates of abundance by area and size category. Comparison of the estimates from these two models has revealed similar trends for small- and medium-size sturgeon, although there were notable differences in some years. By contrast, estimates for 2017 and 2018 showed some substantial differences between the two models for large (160-279 cm FL) sturgeon, which warranted further investigation.

The differences in abundance estimates between the two models in 2017 and 2018 prompted us to assess the potential for biases in the sampling data to affect the estimates derived from each model. One important difference between these two models is the BMR24 model uses every sampling event within a rolling two-year (24-month) sampling period whereas the ISAMR model only uses a single recapture event for each tagged fish in a given year. Therefore, a single individual marked sturgeon can only contribute once to the ISAMR model analysis in a given year, whereas it can contribute multiple times to the mark rates used in the BMR24 model. This difference could create a bias in the BMR24 model if there are repeated captures of individual fish, or repeated sampling of productive fishing sites within a 24-month period. If marked fish are not given the chance to mix with the population of unmarked fish, and the same locations are frequently sampled, then there is an increased risk of repeatedly catching the same fish, which would increase the overall mark rate, and bias the abundance estimates.

A data review revealed that over the last few years the mark rates of anglers that provided high numbers of samples (≥ 100 samples per year) were in some cases significantly higher than those of anglers that produced fewer annual samples; this indicated that our most productive volunteers had a higher probability of catching the same sturgeon multiple times within the assessment period. To reduce the potential bias of multiple recaptures of the same sturgeon prior to adequate mixing, we applied a minimum time-at-large (minTAL) restriction to the model, such that marked fish must be "at-large" (and allowed time to mix within the population) for a period of 30 days before they were included in the mark-rate sample. Our findings indicated that the 30-d minTAL model restriction provided reasonable estimates, albeit higher than those produced in our previous reports, for which minTAL was set to 1 day (e.g., Nelson et al. 2018). See the DISCUSSION section of this report for additional information regarding the selection and application of the 30-d minTAL restriction to the BMR24 model.

<u>24-month Bayesian Mark Recapture Model</u>

Detailed data assembly procedures and mathematical descriptions of the BMR24 mark-recapture model and model assumptions are provided in Nelson et al. (2004, 2013a, 2016); in the text that follows we present a brief overview of the methodology:

Abundance estimates were generated for each assessment period (a rolling data window of two years; e.g., the 2018 estimate consists of data extracted from 1 January 2017 to 31 December 2018) from 2000 to 2018. Note that a sturgeon had to be encountered at least twice in the two-year window to be deemed a recapture; valid recaptures were thus defined as either of the following occurring within a defined 24-month sampling period: 1) an initial tag application/release and one (or more) subsequent recapture(s) of that tag, or; 2) two (or more) separate recapture events for the same tag.

For any given 24-month assessment period, the BMR24 model inputs were limited to:

1) samples from the core assessment area;
2) samples of White Sturgeon that would have been within the 60-279 cm FL size range at some point during the 24-month assessment period;
3) samples collected via gear types that had been deployed relatively consistently over the assessment period (specifically, because there was an increase at the end of 2018 in the use of set lines and angling gear that specifically targeted small/juvenile sturgeon, these two gear types were excluded from the 2018 assessment year analyses; no other gear restrictions were applied for any other assessment year); and
4) samples for fish that had been at large for more than the minTAL.

As described in Nelson et al. (2004), estimates of the number of sturgeon sampled, tagged sturgeon available for capture, and recaptures by sampling zone (see Table 1) and day were based on deterministic (assumed known) representations of growth, movement, mortality, and non-detection of marked sturgeon. As is standard practice, we assumed that growth followed a von Bertalanffy curve (see Fabens 1965). Growth parameters were estimated from the mark-recapture data (length-at-release, length-at-recapture, and time-at-large). The estimated growth parameters (Table 3) were used to define an increasing size criterion for sampled sturgeon over the two-year window. Movement was defined by the distribution of recaptured tags, weighted by number of sturgeon examined, in eight sets of sampling zones over the two-year window.

Table 3. Parameter estimates for non-linear von-Bertalanffy sturgeon growth model (estimated from the 2008-2009 dataset) applied to abundance analyses for assessment year 2018.

Parameter	Estimate	Std Error
L_∞	532.6	15.8
g	2.076E-05	1.003E-06

Abundance estimates for each sampling region have been produced annually since 2001 (the first year that a complete set of 24 months of sampling data was available). Prior to 2018, all BMR24 analyses had been conducted using a minTAL parameter value set equal to 1 day. In this report, a 30-d minTAL restriction was applied when estimating the abundance for the 2018 assessment year. In addition, we have recalculated all annual abundance estimates for all assessment years from 2001 onward using the same 30 d minTAL criterion for all years. This consistent methodology allowed for fair and direct comparisons of abundance estimates among years, thereby permitting assessments regarding changes in abundance over time.

Abundance estimates for 60-279 cm FL White Sturgeon in the core assessment area of the lower Fraser River are presented in this report as follows:

1) "regional estimates": abundance estimates for each of the four sampling regions: A, B, C, and D (in this report, we present results for the 2018 assessment year only);
2) "total abundance estimates": total abundance for the core assessment area. The regional estimates were summed to calculate the total abundance for the core assessment area. Confidence intervals were calculated by invoking a normal distribution under the central limit theorem with a variance equal to the sum of the variances of the regional estimates. Estimates were produced for each year from 2001 onwards;
3) "size-specific regional estimates": because sample sizes were large, we were able to subdivide the dataset, and produce abundance estimates for each of three size groups (60-99 cm FL, 100-159 cm FL, and 160-279 cm FL) within each sampling region. Within each region in each year, the three size-specific relative abundances were scaled such that they summed to the "regional estimate" for the given region in the given year. Estimates were produced for each year from 2004 onwards; and
4) "size-binned estimates": abundance estimates by 20-cm size group. When the dataset was divided into such small bins, sample sizes were insufficient for spatial stratification, hence the sampling regions were disregarded for this analysis. Within each year, the relative abundances of the size-binned estimates were scaled such that they summed to the "total abundance estimate" for the given year. Estimates were produced for each year since 2004.

Because the core assessment area included four sampling regions (A-D; see Table 2 and Figure 2), two of which were located downstream of the "tidal" boundary at the Mission Railway Bridge (sampling regions A and B), the program also produced separate abundance estimates of White Sturgeon for the "tidal" and "non-tidal" sections of the lower Fraser River.

<u>Integrated Spatial and Age Mark Recapture (ISAMR) Modeling</u>

In addition to abundance estimates produced by the BMR24 model, the program generates separate abundance estimates from a second model, the Integrated Spatial and Age-structured Mark-

Recapture (ISAMR) model, which was developed under this program from 2015-17. See Challenger et al. (2017, 2019) for a description of the ISAMR model. Both the BMR24 and ISAMR models only use sampling data that were collected from the core assessment area, and only consider sturgeon of 60-279 cm FL. Both models use Bayesian estimation to provide abundance estimates and credible intervals; however, the two models have very different population modelling structures: 1) the BMR24 model employs size groups while the ISAMR model uses age classes; and 2) the BMR24 model assigns individual fish to a size-class for each 24-month analysis period, while the ISAMR model reconstructs and tracks the transition of fish through the available age classes over time. The two models also differ in how sampling selectivity is handled: 1) the BMR24 model does not include differential selectivity by age, and assumes that selectivity within a size group is consistent over the 24-month sampling period; and 2) the ISAMR model applies a selectivity-at-age relationship that is estimated based on the data. In addition, the BMR24 model uses a 24-month rolling data window, and is run separately for each set of 24 months, while the ISAMR model considers all current and historical (2000-2018) captures in a single analysis.

Growth Analyses

Fork length data for individual recaptured (tagged) sturgeon were analyzed to determine daily growth rates, based on the number of days-at-large between release and subsequent recapture events. Daily growth rates were expanded to provide estimates of annual growth, and these estimates were pooled and averaged by size group for comparative purposes. Exploratory analyses determined how the years of growth data would be pooled: by minimizing least squares, we determined when the breaks between groupings would occur, and whether three, four, or five groupings would be used.

RESULTS

Sampling Effort

From October 1999 through December 2018, program volunteers working in the general study area of the Lower Fraser River White Sturgeon Monitoring and Assessment Program (Figure 1) performed a total of 155,806 unique sturgeon sampling events that included the inspection (scanned with a PIT tag reader) of White Sturgeon (all sizes, and captured by all sampling gear types) for the presence of a PIT tag (Appendix B). Of this total sample from the general study area, 70,539 sturgeon were tagged with a PIT tag (in the head location) and released. The total sample also includes 78,729 recapture events. In addition, the total sample includes 5,365 sturgeon that were sampled (examined for the presence of a PIT tag and measured), but were either: 1) not tagged due to a shortage of available PIT tags or due to safety concerns; 2) not released (i.e., a mortality); or, 3) not tagged prior to release due to poor physical condition of the fish (the bulk of these cases were for sturgeon removed from gill nets; Appendix B).

Appendix C presents a summary of White Sturgeon sampled in the core assessment area of the lower Fraser River that were 60-279 cm FL when sampled, by month and year. A total of 145,725 60-279 cm FL White Surgeon were sampled in the core assessment area since 1999. This total includes 63,312 sturgeon that were tagged with a PIT tag (in the head location) and released, and 76,662 recaptures of sturgeon with a PIT tag in the head location. The number of 60-279 cm FL White Surgeon samples collected annually from 2000-2018 has ranged from a minimum of 3,785 in 2000 to a maximum of 11,238 in 2013 and has averaged 7,670 samples per year over the 19-year

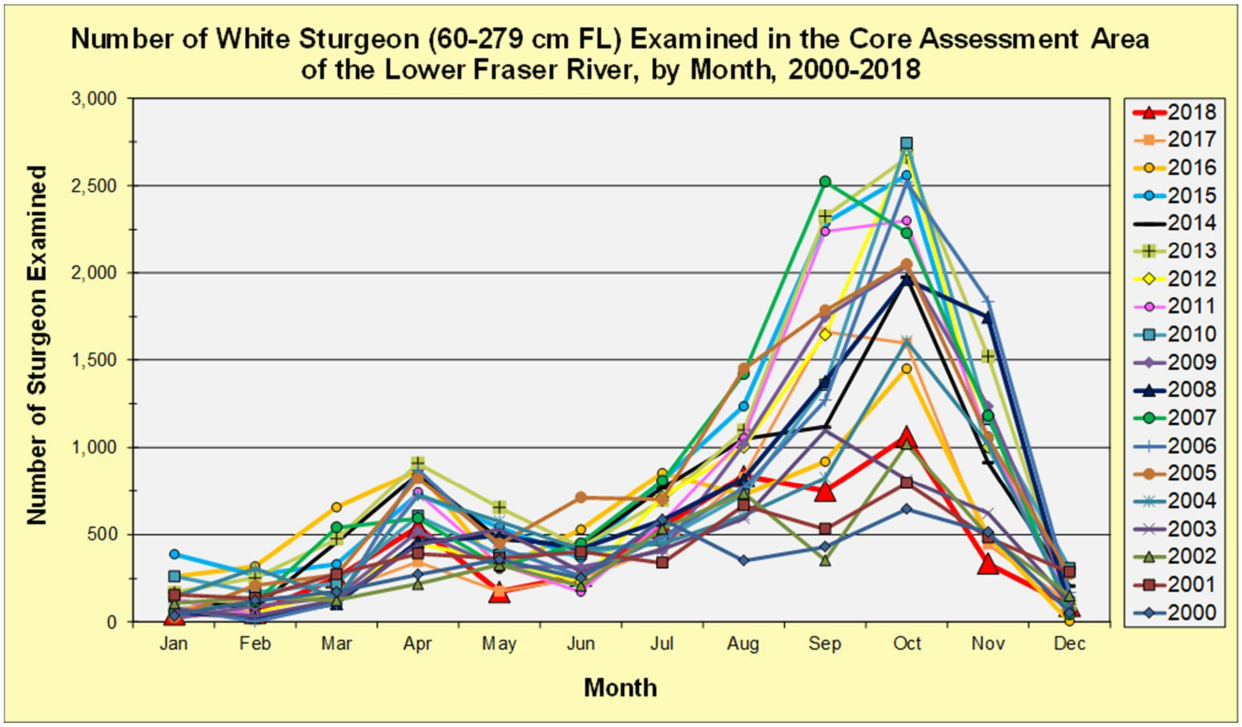

Figure 3. **Number of White Sturgeon (60-279 cm FL) examined for the presence of a PIT tag in the core assessment area of the lower Fraser River, by month, 2000-2018.**

span. The number of samples collected within the core assessment area has declined in recent years from 7,368 samples in 2016, to 6,203 samples in 2017, and down again to 4,940 in 2018 (Appendix C). The relative monthly contribution to respective annual total samples (Figure 3) has remained relatively consistent throughout all years (2000-2018). The variability of sample size among months is the result of variability in two main factors: fishing effort applied, and sturgeon catchability.

Recaptures of Tagged Sturgeon

Recapture data provided positive determination of both direction and distance of movements for individual tagged sturgeon. In many cases, multiple recapture events over years provided patterns of movement and migration. For the BMR24 model, movements (defined by the distribution of recaptured tags, weighted by number of sturgeon examined, in eight zones over the 24-month window) were incorporated in the analytical processes, as were the spatial distribution of samples over time (see Nelson et al 2013a). Recaptures of tagged sturgeon during this study confirmed that movements and migrations occur throughout the entire lower Fraser general study area. Recapture locations of any given individual varied, and were sometimes several kilometers apart, even when the fish was at large for relatively short time periods. In addition, several tagged White Sturgeon have been observed to move across the supposed boundary between sturgeon populations (Upper and Lower Fraser River populations) at Hells Gate (rkm 212), either being tagged upstream of Hells Gate and recaptured downstream, or the reverse (see DISCUSSION section).

Many tagged sturgeon have been recaptured and sampled multiple times. Since 2000, 5,836 sturgeon have been sampled five times, 536 sturgeon have been sampled 10 times, and one sturgeon has been sampled 27 times. The number of times each individual sturgeon is captured is likely higher than the number for which we have records. Program volunteers include only a fraction of the total number of active sturgeon anglers, and annual numbers of capture events from gill net fisheries are not known (see DISCUSSION section).

Mark Rates

An illustration of the annual numbers of tags applied, and reported number of tag recaptures, for 60-279 cm FL White Sturgeon sampled within the core assessment area, is provided in Figure 4. The proportion of recaptures recorded in a given 12-month sampling period (i.e., the annual mark rate) has steadily increased each year over the 19 years of monitoring (Figure 4). Concomitantly, the proportion of newly released tags has declined over time, as the pool of marked fish available for recapture has increased. Over 86% of the samples included in the 2001 abundance model calculations (samples from 2000 and 2001) were new tags applied, whereas only 21% of the samples used to produce the 2018 abundance estimates (samples from 2017 and 2018; Appendix C, Figure 4) were new tags applied.

In 2018, FRSCS volunteers applied 1,093 PIT tags and recaptured 3,791 tagged sturgeon (60-279 cm FL) in the core assessment area (Appendix C, Figure 4). The overall mark rate for the core assessment area in 2018 was 76.7% (Figure 4). Mark rates for sub-locations within the core assessment area differed from the respective overall mark rate; for example, the mark rate for sturgeon sampled from the Harrison River in 2018 was 92.2% (Figure 5). The adult (160-279 cm FL) group has the highest mark rate (89% possess a PIT tag applied under this program), followed by the sub-adult (100-159 cm FL) group (approximately 80% are tagged).

Monthly variation in White Sturgeon mark rates within the core assessment area was evident for each of the assessment years (Appendix C, Figure 6), and patterns have emerged that suggest an

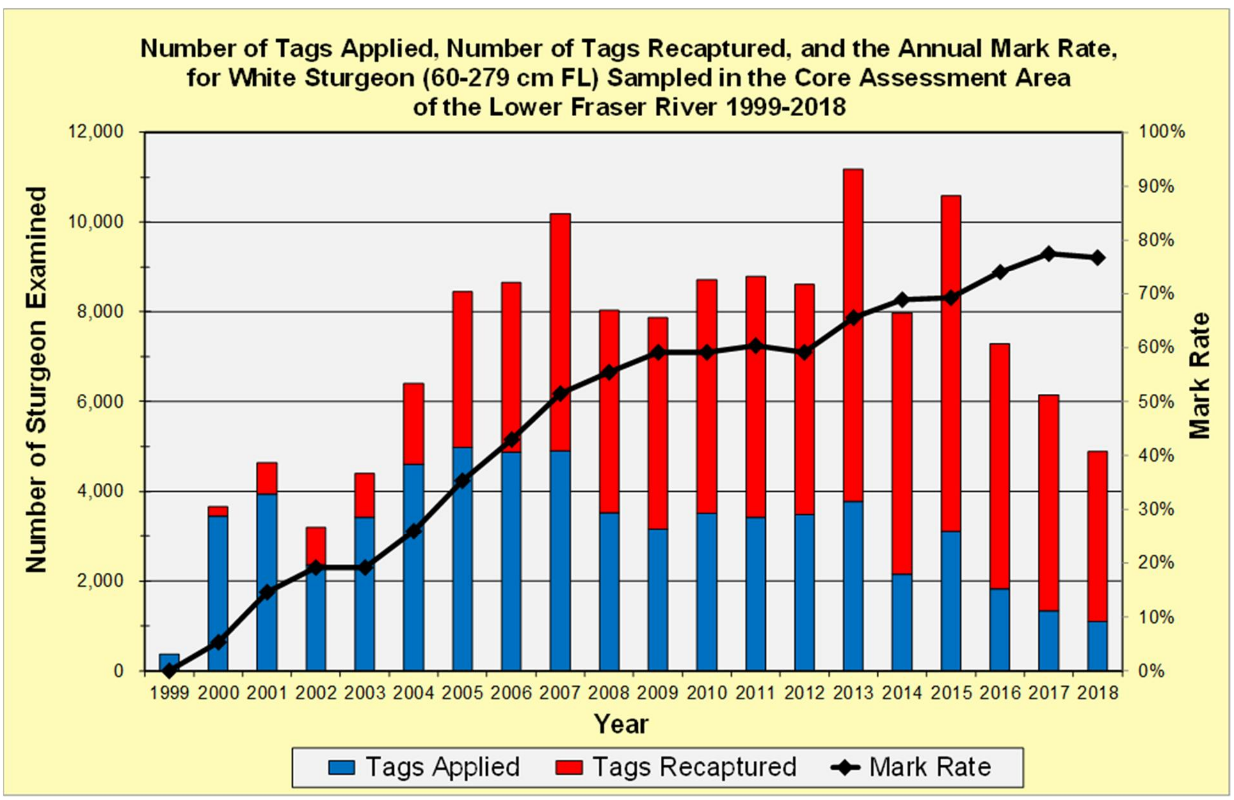

Figure 4. Number of tags applied, reported number of tags recaptured, and the annual mark rate for White Sturgeon (60-279 cm FL) sampled in the core assessment area, by year, 1999-2018.

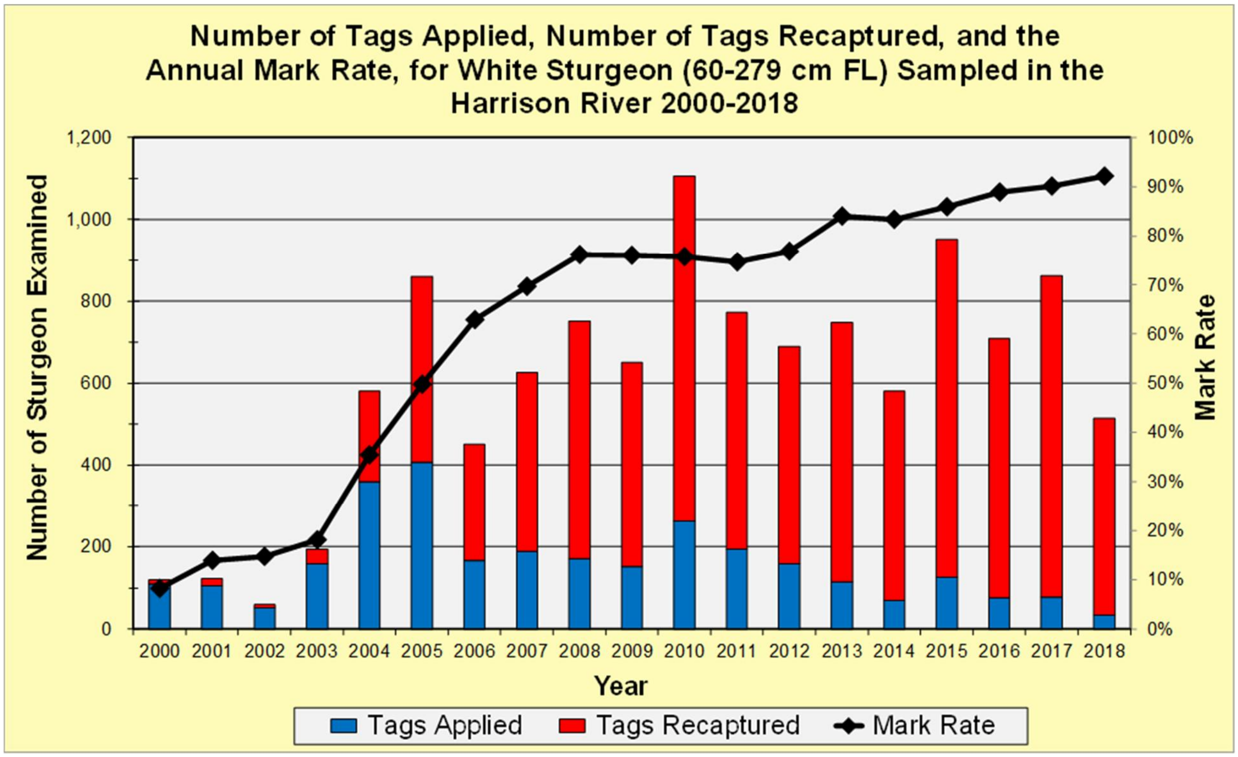

Figure 5. **Number of tags applied, reported number of tags recaptured, and the annual mark rate for White Sturgeon (60-279 cm FL) sampled in the Harrison River, by year, 2000-2018.**

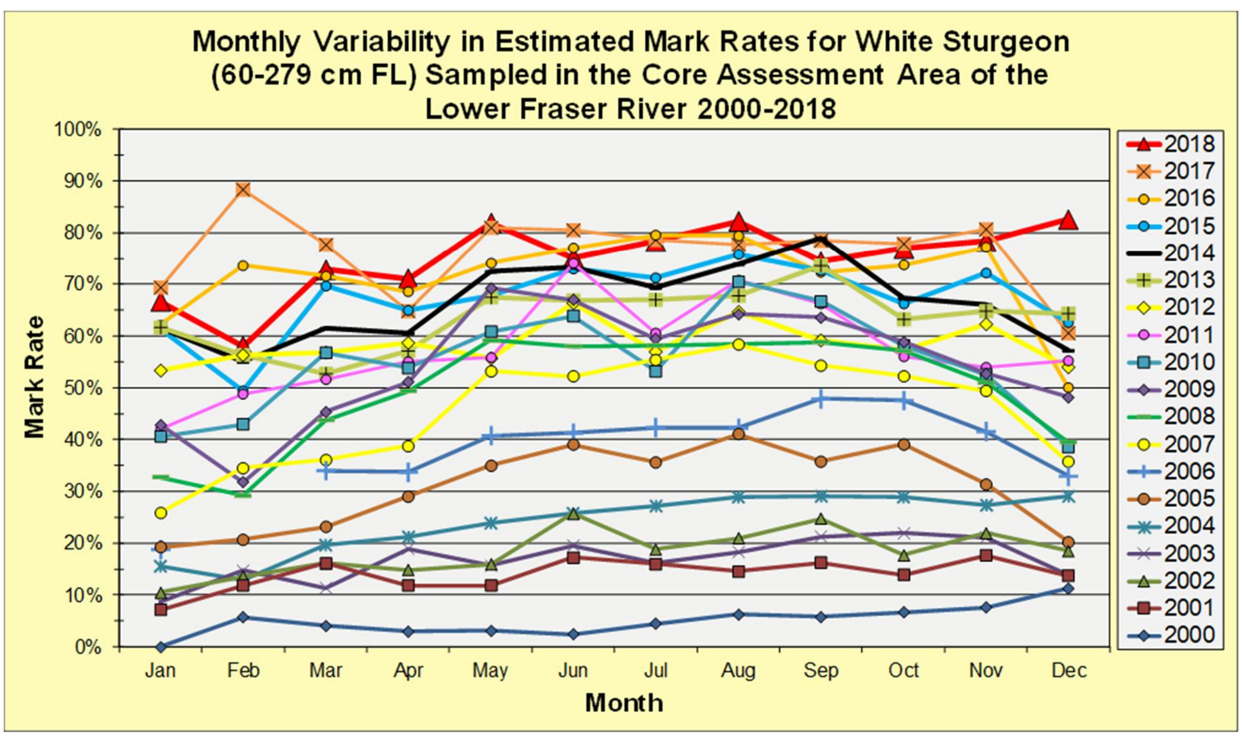

Figure 6. **Monthly variability in estimated mark rates for White Sturgeon (60-279 cm FL) sampled in the core assessment area of the lower Fraser River 2000-2018.**

influence of season on mark rates. For example, winter mark rates (January-February) after 2009 have in some years been 10-20% lower than summer mark rates (July-September; Appendix C, Figure 6). The mark rate for the core assessment area in 2018 varied from a low of 58.0% in February to a high of 86.2% in December (Appendix B, Figure 6). Seasonal variation could be linked to varying use of habitats (especially overwintering habitat) combined with seasonal changes in angling effort and techniques (e.g., hook size and bait type) by program volunteers.

Abundance Estimates

<u>24-month Bayesian Mark Recapture Model</u>

Sample sizes for the BMR24 model were a subset of the overall dataset (Appendix B). Appendix C represents an approximation of the samples used in the BMR24 modeling. While Appendix C summarizes only samples collected in the core assessment area, it does not exclude samples based on time-at-large, it does not account for gear-related exclusions, and it does not account for growth (the BMR24 model allows samples to be included if the fish would have been in the 60-279 cm FL size range at any point during the 24-month assessment period, whereas the data in Appendix C include only those fish that were within the 60-279 cm FL size range at the time of measurement).

The BMR24 model produced an abundance estimate for 60-279 cm FL White Sturgeon of 33,461 (95% CLs ± 9.5% of the estimate; Table 4) as of January 2018 in the core assessment area of the lower Fraser River. The estimated abundance of White Sturgeon within the core assessment area downstream of the Mission Railway Bridge (sampling regions A and B; see Figure 2) was 15,433 fish (46.1% of the total abundance estimate; Table 4, Figure 7). In the core assessment area upstream of the Mission Railway Bridge (to Lady Franklin Rock near Yale; sampling regions C and D; see Figure 2), the abundance estimate was 18,028 fish (53.9% of the total abundance estimate; Table 4, Figure 7).

The 2018 total abundance estimate was 16.0% lower than the respective 2017 estimate, and 45.3% lower than the program's peak abundance estimate in 2003 (Table 5, Figure 8). Annual abundance estimates for the first two years of the study were similar to each other (difference of 2.9%) and were followed in 2003 by an increase of 25.6% (Table 5, Figure 8). Since 2003, total annual abundance estimates indicated a general population decrease, with significant decreases between 2003 and

Table 4. BMR24 abundance estimates of 60-279 cm FL White Sturgeon in the lower Fraser River, by sampling region, from 1 January 2017 to 31 December 2018.

	Sampling Region		Zone			95% HPD[2]		
	From	To	Codes[1]	Mean	Mode	Low	High	Std. Dev
A	Georgia Strait	East Annacis Island	S	3,711	3,284	2,108	5,657	965
B	East Annacis Island	Mission CPR Bridge	3, 5, 6, 7	11,722	11,456	9,404	14,192	1,227
C	Mission CPR Bridge	Hwy 1 Bridge (Hope)	8, 10, 12, 13	16,190	16,160	15,305	17,087	451
D	Hwy 1 Bridge (Hope)	Yale	14	1,838	1,827	1,657	2,030	94
			Total	33,461		30,270	36,652	1,628

[1] See Table 1

[2] HPD - Highest Probability Density. See Nelson et al. 2004 for explanation of this statistic.

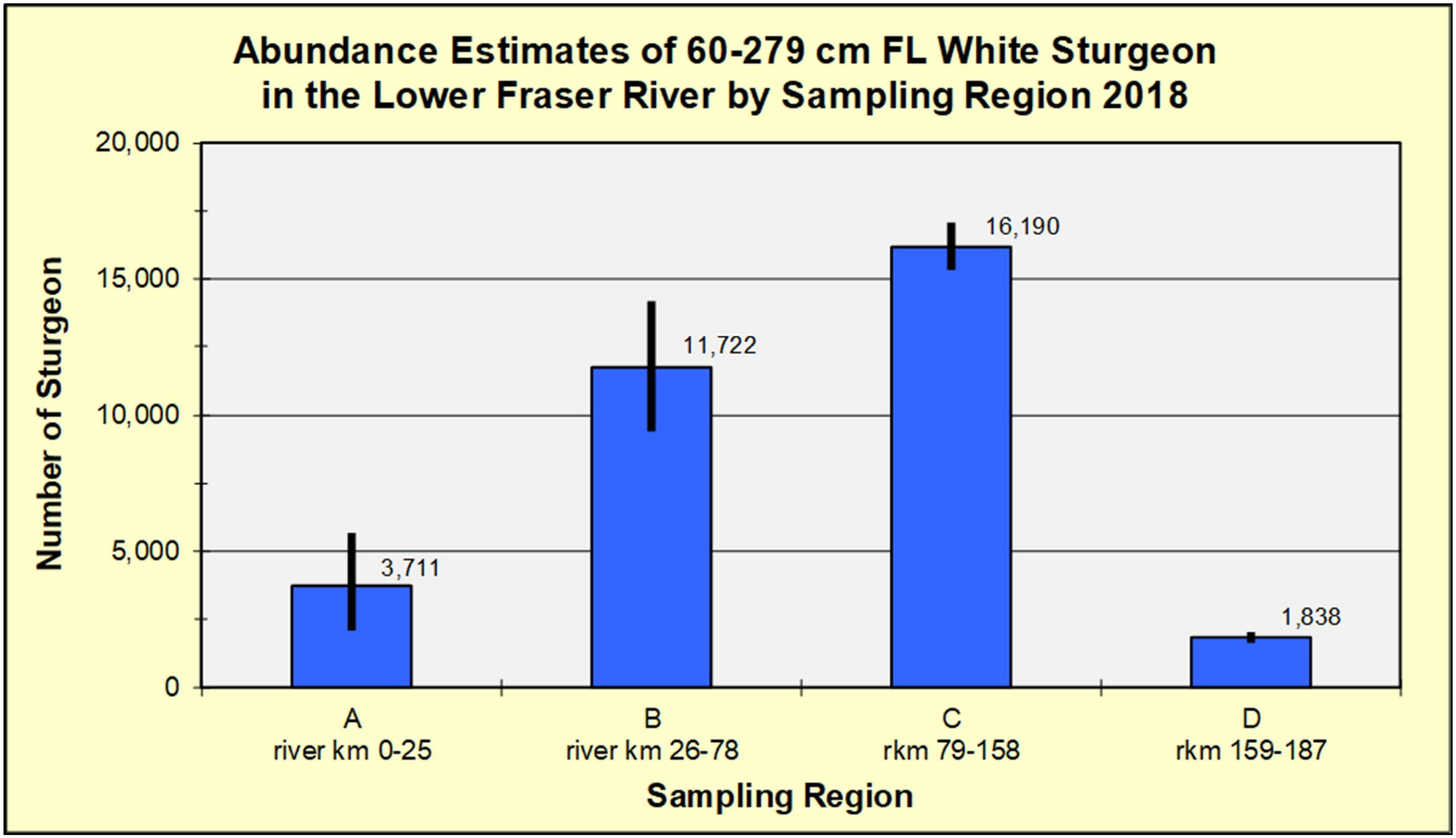

Figure 7. BMR24 abundance estimates of White Sturgeon (60-279 cm FL) in the lower Fraser River, by sampling region (A, B, C, and D, 2018; see Table 4 and Figure 1). Ranges show the 95% Highest Probability Density. Sturgeon movement and migration within the core assessment area will result in a proportional redistribution of these mean abundance estimates, by season.

Table 5. BMR24 abundance estimates of 60-279 cm FL White Sturgeon in the core assessment area of the lower Fraser River, by assessment year, 2001-2018.

Assessment Year	Sampling Period	Abundance Estimate	95% HPD[1] Low	95% HPD[1] High	Bounds as % of Abundance Estimate	CV (%)[2]	Annual % Change
2001	2000-2001	47,320	43,319	51,321	8.5%	4.31%	
2002	2001-2002	48,690	44,708	52,672	8.2%	4.17%	2.9%
2003	2002-2003	61,135	55,383	66,887	9.4%	4.80%	25.6%
2004	2003-2004	57,084	52,967	61,201	7.2%	3.68%	-6.6%
2005	2004-2005	52,046	49,183	54,909	5.5%	2.81%	-8.8%
2006	2005-2006	50,002	47,131	52,873	5.7%	2.93%	-3.9%
2007	2006-2007	46,965	44,319	49,611	5.6%	2.87%	-6.1%
2008	2007-2008	46,050	43,113	48,987	6.4%	3.25%	-1.9%
2009	2008-2009	43,614	40,640	46,588	6.8%	3.48%	-5.3%
2010	2009-2010	45,604	42,318	48,890	7.2%	3.68%	4.6%
2011	2010-2011	45,015	42,699	47,331	5.1%	2.62%	-1.3%
2012	2011-2012	48,772	45,789	51,755	6.1%	3.12%	8.3%
2013	2012-2013	48,792	46,038	51,546	5.6%	2.88%	0.0%
2014	2013-2014	45,380	42,918	47,842	5.4%	2.77%	-7.0%
2015	2014-2015	47,399	42,433	52,365	10.5%	5.35%	4.4%
2016	2015-2016	44,289	40,442	48,136	8.7%	4.43%	-6.6%
2017	2016-2017	39,841	34,076	45,606	14.5%	7.38%	-10.0%
2018	2017-2018	33,461	30,270	36,652	9.5%	4.87%	-16.0%

[1] HPD - Highest Probability Density

[2] CV - Coefficient of Variation

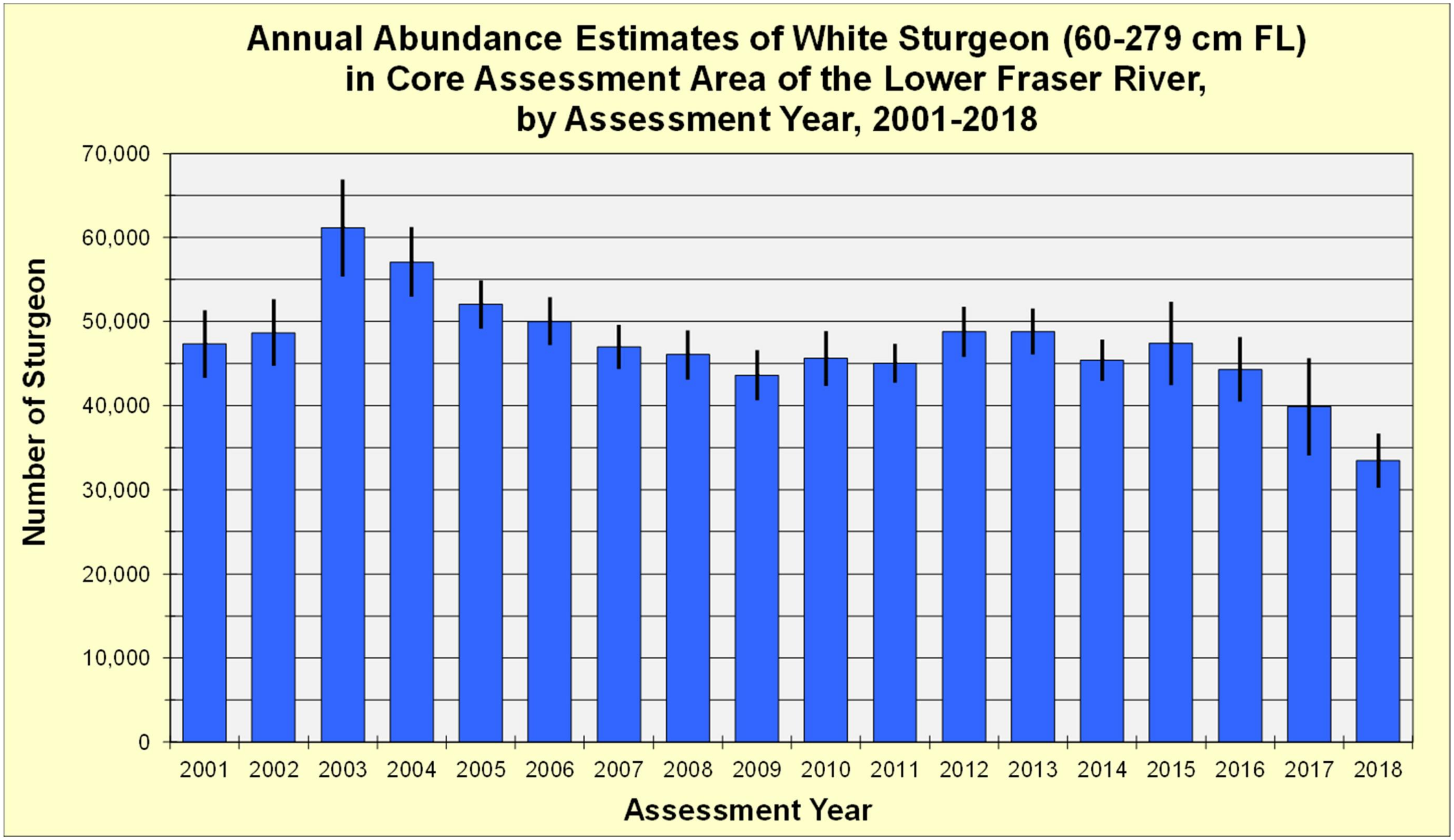

Figure 8. **Annual BMR24 abundance estimates of White Sturgeon (60-279 cm FL) in the core assessment area of the lower Fraser River, by assessment year, 2001-2018. See Table 5. Confidence ranges show the 95% Highest Probability Density. All sampling regions are combined for this analysis. The 2018 abundance estimate is the lowest estimate generated since the inception of the program; the 2018 estimate is 16.0% lower than the respective 2017 estimate and 45.3% lower than the peak abundance estimate generated for 2003.**

2005, between 2005 and 2008, and again between 2008 and 2018 (Table 5; Figure 8). The total annual abundance in 2018 was significantly lower than all other annual estimates except 2017 (Table 5; Figure 8).

In 2018, the BMR24 estimated abundance of 60-99 cm FL juvenile White Sturgeon was 6,556 fish (Table 6), which represented a 25.3% decline from the respective estimate in 2017 (8,776 fish; Figure 9). The estimated abundance of both 100-159 cm FL and 160-279 cm FL sturgeon in 2018 also declined from respective 2017 estimates (15.9% and 10.6%, respectively). Since 2004 there have been significant declines in the estimated abundance of 60-99 and 100-159 cm FL juvenile and sub-adult sturgeon (74.0% and 43.3%, respectively). Concurrently, there has been a significant increase (75.9%) in the abundance of 160-279 cm FL adult fish; however, estimated abundance for adult fish peaked in 2015 and has been steadily declining through 2018 (Figure 9). It should be noted that lower sampling rates (fewer fish examined) in sampling region A (see Table 2 and Figure 2) resulted in relatively large CVs for all size groups in this region (Table 6).

BMR24 abundances for 2018 by 20-cm (FL) size group are presented in Table 7 and Figure 10. Figure 11 displays the temporal trends for each 20-cm size bin from 2004-2018.

Table 6. BMR24 abundance estimates for three size groups of White Sturgeon within each of the four sampling regions that make up the core assessment area of the lower Fraser River, 2018. Within each sampling region, MLE values were scaled so that they summed to the mean regional estimate (Table 4).

Size Group (cm)	Sampling Region	Scaled MLE[1]	HPD[2] Low	HPD[2] High	CV(%)[3]
60-99	A	1,258	226	3,115	66.0
	B	2,230	1,292	3,340	24.7
	C	2,880	2,394	3,395	8.8
	D	188	155	225	9.5
	Total	6,556	4,540	8,572	15.7
100-159	A	1,326	486	2,527	46.9
	B	5,524	4,079	7,128	14.2
	C	6,593	5,974	7,228	4.8
	D	432	359	512	9.0
	Total	13,876	11,815	15,936	7.6
160-279	A	1,127	396	2,214	46.0
	B	3,967	2,268	5,993	25.4
	C	6,717	6,229	7,222	3.8
	D	1,218	1,025	1,420	8.2
	Total	13,029	10,748	15,310	8.9

[1] MLE - Maximum Likelihood Estimate

[2] HPD - Highest Probability Density

[3] CV - Coefficienct of Variation

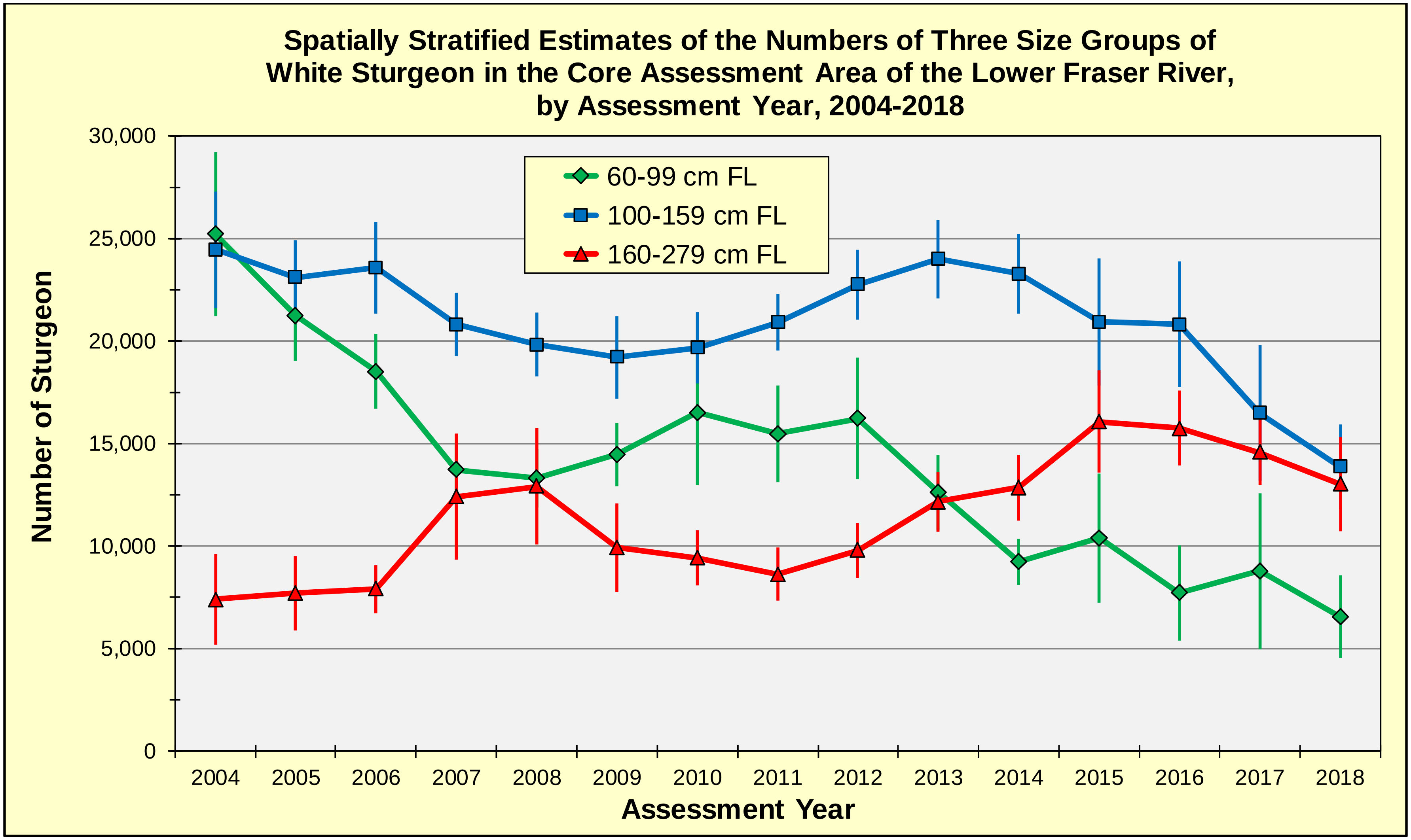

Figure 9. **BMR24 abundance estimates for three size groups (60-99 cm FL, 100-159 cm FL, and 160-279 cm FL) in the core assessment area of the lower Fraser River, by assessment year, 2004-2018. The error bars indicate the 95% CLs for each estimate. Within each sampling region in each year, the relative abundances have been scaled such that the size-specific estimates summed to the total estimated abundance of 60-279 cm FL sturgeon in that sampling region for that year.**

Table 7. BMR24 abundance estimates for 60-279 cm FL White Sturgeon in the core assessment area of the lower Fraser River, by 20-cm (FL) size group, 2018. Scaled MLE values were calculated by estimating MLE for each size bin, and then scaling the results so that they sum to the mean total estimate (Table 4). An illustration of these estimates and their associated HPD values is presented in Figure 10.

Size	Scaled		95% HPD[2]		
Group (cm)	MLE[1]	Percent	Low	High	CV[3] (%)
60-79	3,242	9.7	2,709	3,937	9.5
80-99	2,668	8.0	2,237	3,234	9.4
100-119	4,565	13.6	3,871	5,446	8.7
120-139	4,976	14.9	4,337	5,761	7.2
140-159	4,740	14.2	4,183	5,417	6.5
160-179	3,793	11.3	3,365	4,318	6.3
180-199	3,037	9.1	2,675	3,480	6.7
200-219	3,006	9.0	2,598	3,500	7.5
220-239	1,893	5.7	1,575	2,338	9.9
240-259	1,234	3.7	937	1,686	15.1
260-279	305	0.9	207	491	22.7
Total	33,461	100.0			4.9

[1] MLE - Maximum Likelihood Estimate
[2] HPD - Highest Probability Density
[3] CV - Coefficient of Variation

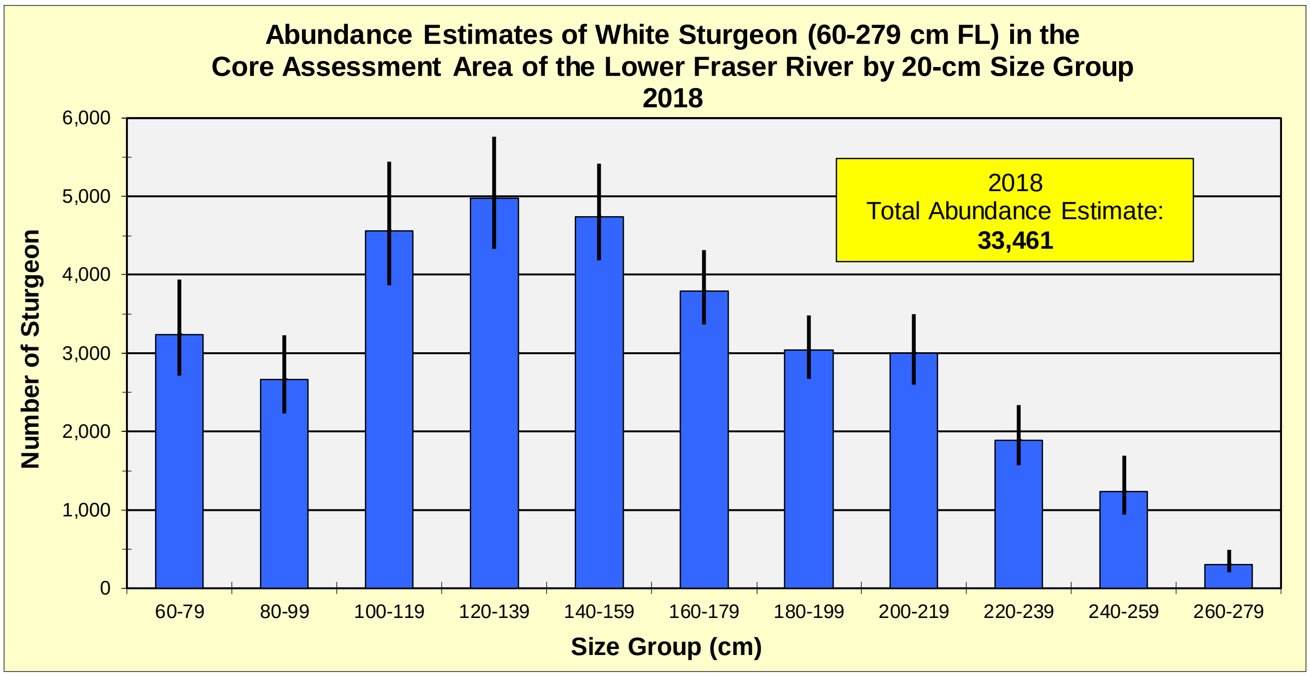

Figure 10. BMR24 abundance estimates of White Sturgeon (60-279 cm FL) in the core assessment area of the lower Fraser River, by 20-cm (FL) size group, 2018. Error bars show the 95% Highest Probability Density; see Table 7.

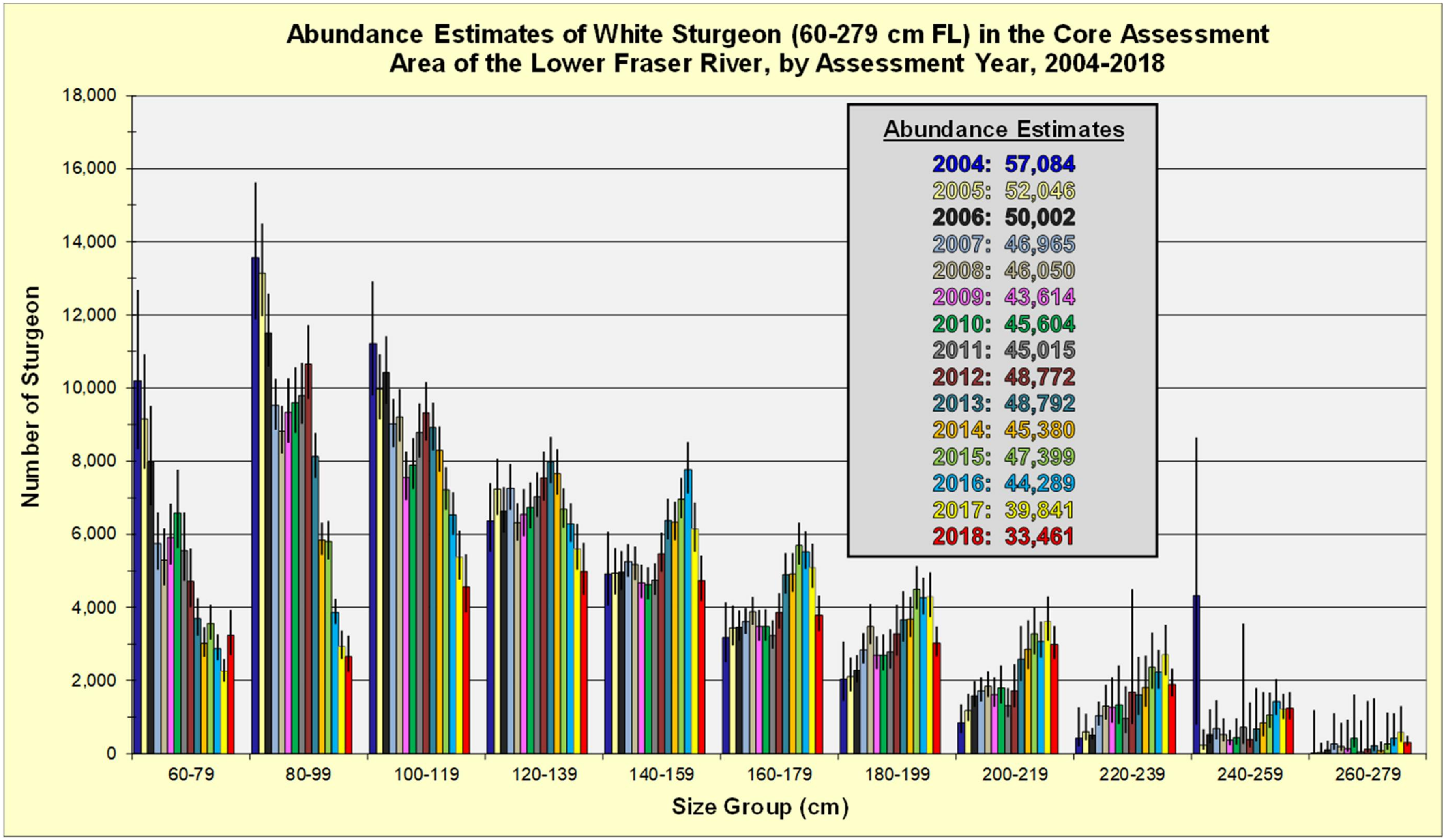

Figure 11. BMR24 abundance estimates of White Sturgeon (60-279 cm FL) in the core assessment area of the lower Fraser River, by 20-cm (FL) size group, for assessment years 2004 through 2018. Error bars show the 95% Highest Probability Density. Within each year, the relative abundances were scaled such that the size-specific estimates summed to the total estimated abundance of 60-279 cm sturgeon in the core assessment area for that year.

Integrated Spatial and Age Mark Recapture (ISAMR) Modeling

See Challenger et al. (2019) for a complete presentation of ISAMR results for 2018. Comparisons of results from BMR24 and ISAMR model outputs are presented in the DISCUSSION section of this report.

Growth Analyses

A comparison of average annual growth rates of White Sturgeon from 60-179 cm FL sampled from 2001-2018, by 20-cm FL size groups, suggested that annual growth rates for most size groups were greater before versus after 2005 (Figure 12). The average growth rate for all size groups in 2018 (3.5 cm/year) represented the second lowest annual growth rate observed since the beginning of the program; the program's lowest growth estimates were from 2017 (3.0 cm/year; Nelson et al. 2017). Both the 2017 and 2018 growth rates were well below the highest average annual growth rate of 5.7 cm/year observed in 2002 (Figure 12); the 2018 average growth rate for all size groups of White Sturgeon is 39.8% lower than the respective rate in 2002 (Figure 12).

Figure 13 provides average annual growth increments of White Sturgeon in the lower Fraser River by 20-cm FL size group during five time periods: 2001-04, 2005-09, 2010-12, 2013-15, and 2016-18. Average annual growth from 2005-2009 for all size groups (3.8 cm/year) represented a 30.3% decrease from respective previous growth rates from 2001-2004 (5.4 cm/year; Figure 13). Average annual growth for all size groups increased during 2010-2012 (4.9 cm/year) before declining to an average of 4.3 cm/year from 2013-2015, and decreasing again to 3.4 cm/year during 2016-18 (Figure 13).

Mortalities

Each year, observations of dead sturgeon are reported by program volunteers, enforcement officers, recreational anglers, First Nations fishers, and the general public. The number of reported and confirmed sturgeon mortalities in the lower Fraser River in 2018 (46) was the highest since the beginning of the program. The majority (n = 31) of reported sturgeon mortalities were sampled (scanned for the presence of a PIT tag and measured) by program volunteers. For sampled mortalities, 54% had been tagged, and some of these had been previously sampled by program volunteers from 1-7 times prior to the mortality event. All sturgeon mortality sampling events in 2018 occurred in either July, August, September, or November, and the likely cause of death could not be determined for 64% of the fish sampled.

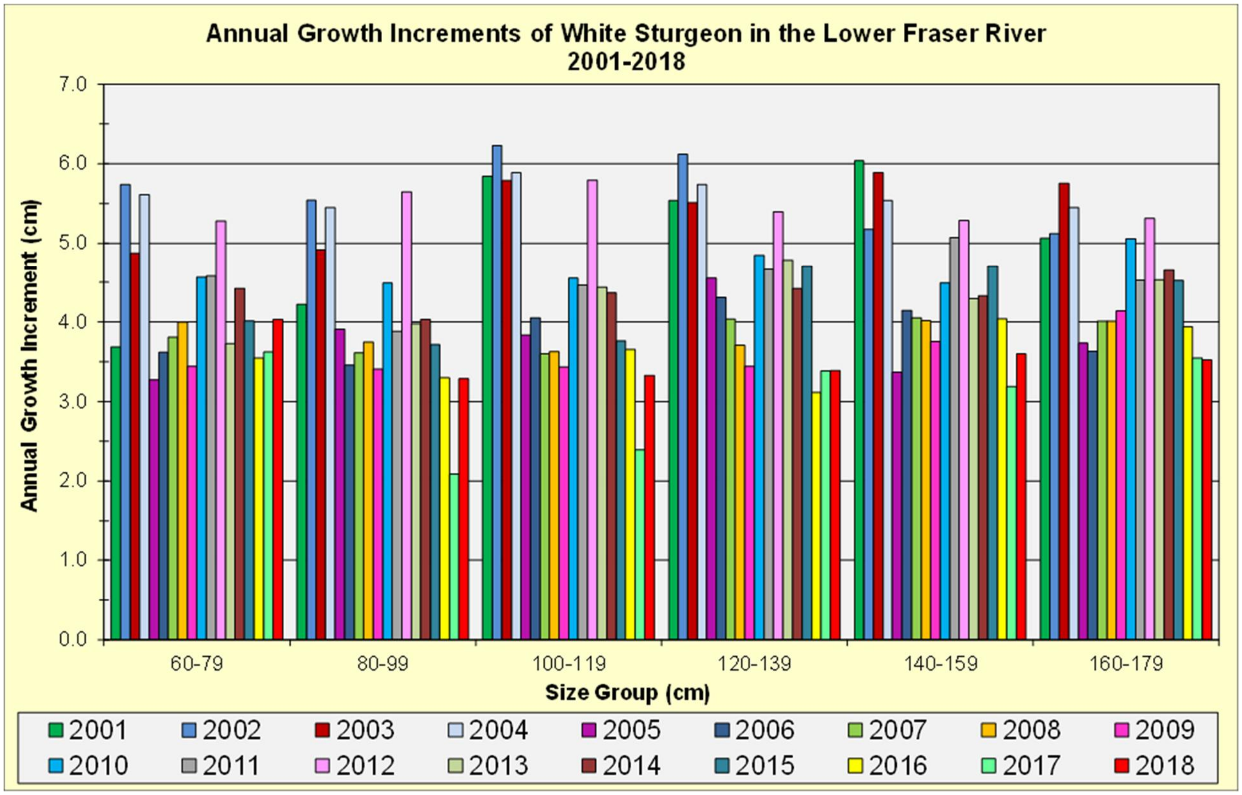

Figure 12. Average annual growth increments (cm) of White Sturgeon in the lower Fraser River, by 20-cm (FL) size group, 2001-2018. Annual growth was determined from measurements obtained from individual tagged sturgeon that were subsequently recaptured.

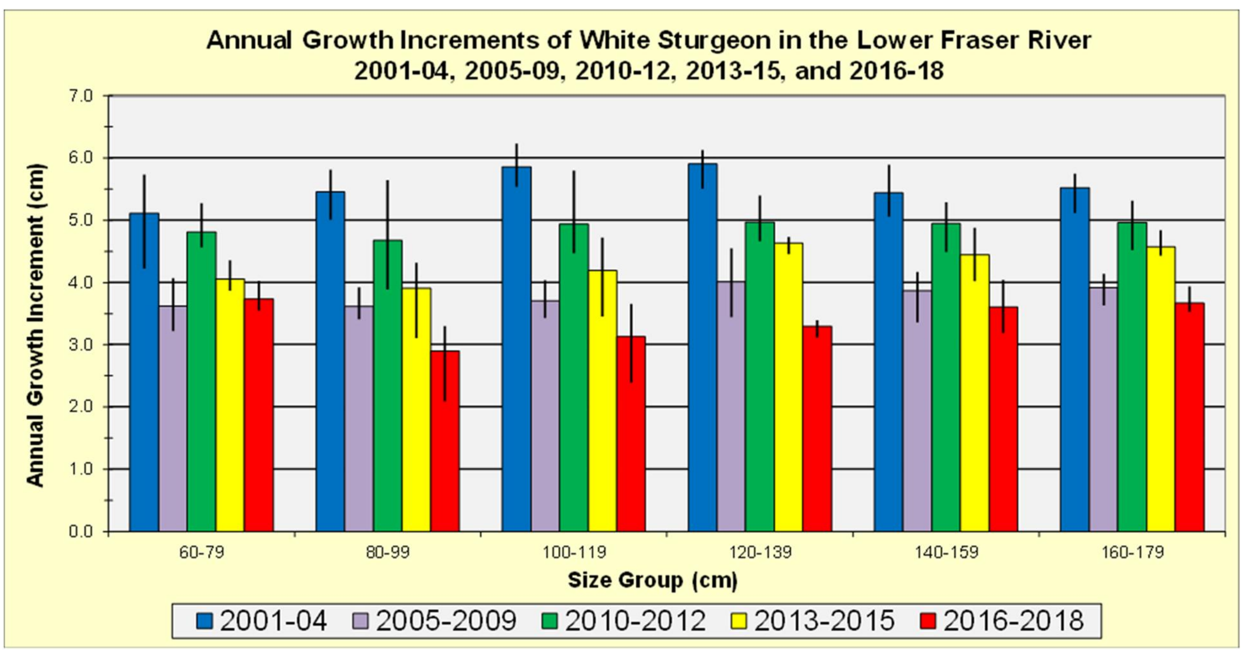

Figure 13. Average annual growth increments (cm) of White Sturgeon in the lower Fraser River, by 20-cm (FL) size group, during five time periods: 2001-04, 2005-09, 2010-12, 2013-15, and 2016-18. The error bars show the range of mean annual growth estimated for the years within each time period.

DISCUSSION

Sampling Sources

Three sources provided 98.6% of all scanned samples from the core assessment area over the term of the program through 2018: angling (91.3%), Albion Test Fishery (3.7%), and First Nations gill nets (3.2%; Figure 14). An additional 0.7% of the total sample was provided through dedicated sampling efforts using tangle nets associated with both the FLNRORD Lower Fraser Juvenile White Sturgeon Habitat Indexing Program, and the FRSCS Lower Fraser River Juvenile White Sturgeon Habitat Program (Glova et al. 2008). Additionally, approximately 1.1% of samples were provided by other sources including PSC Test Fishery, unsourced mortalities, juvenile angling gear, set line, fishwheel, ghost net, river guardian, and enforcement (Figure 14).

Recapture Rates

Recaptures of tagged sturgeon during this study confirmed that movements and migrations occur throughout the entire lower Fraser general study area. Recapture locations of any given individual varied, and were sometimes several kilometers apart, even when the fish was at large for a relatively short time period. Many individual tagged sturgeon have been recaptured and sampled numerous times. For example, by December 2018, 5,836 individual fish had been sampled five times, 536 fish had been sampled 10 times, and 21 fish had been sampled 20 times; the highest number of capture events for an individual sturgeon was 27 (Table 8).

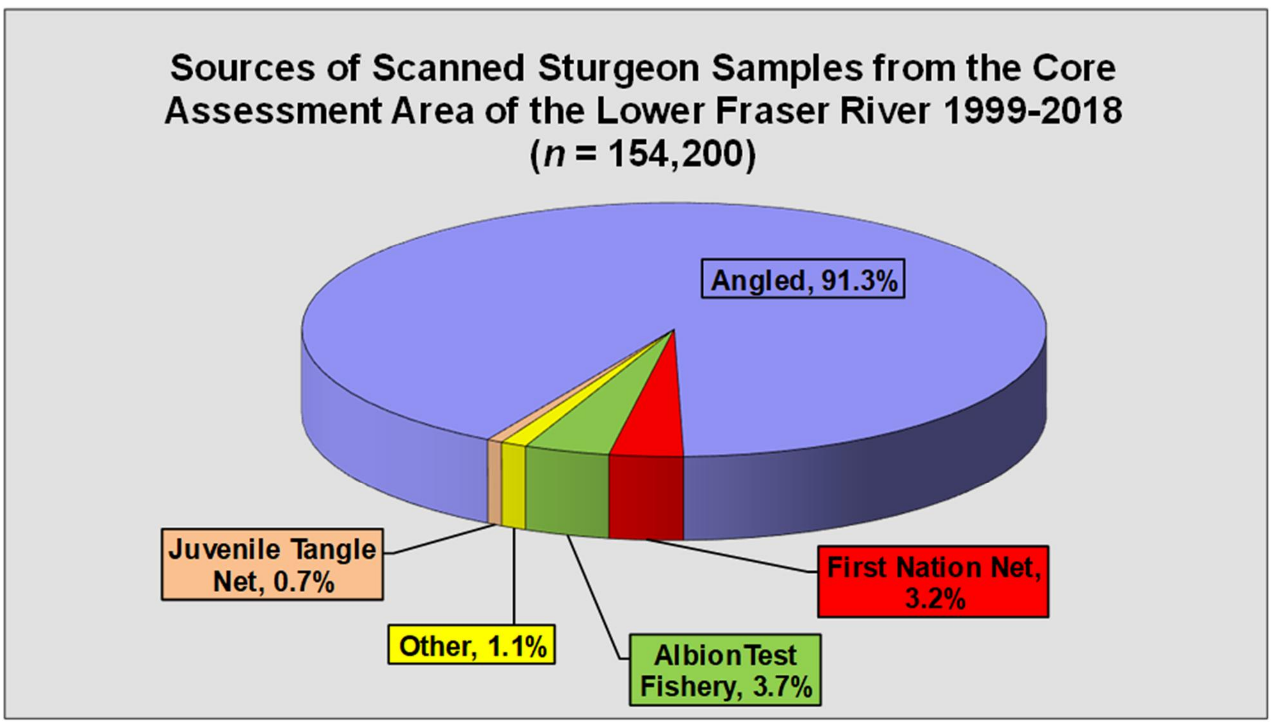

Figure 14. Summary of sources of sturgeon samples (all sizes) scanned for the presence of a PIT tag that were captured within the core assessment area of the Lower Fraser River White Sturgeon Monitoring and Assessment Program 1999-2018. *Other sources include: PSC Test Fishery, unsourced mortalities, commercial net, juvenile angling gear, set line, fishwheel, ghost net, river guardian, and enforcement.

Table 8. Summary of multiple sampling events for individual White Sturgeon sampled within the core assessment area of the lower Fraser River, identified by PIT tag number, from 1999-2018.

Number of Times Sampled	Number of Individual Sturgeon
2	34,542
3	18,390
4	10,153
5	5,836
6	2,445
7	2,158
8	1,317
9	827
10	536
11	374
12	272
13	191
14	132
15	95
16	68
17	50
18	35
19	28
20	21
21	20
22	16
23	11
24	6
25	4
26	2
27	1

Several individual tagged sturgeon have been sampled multiple times during the same year (up to seven times in 2018) and over consecutive years (up to 18 times over a five-year period; Table 9)t should be noted that the number of times each individual sturgeon is captured is likely higher than the number for which we have records. Program volunteers include only a fraction of the total number of active sturgeon anglers (anglers not participating do not scan fish or report their catch to the program), and annual numbers of capture events from gill net fisheries are not known (and could be significant in some years, especially when in-river salmon fishery openings are allowed).

Table 9. Numbers of unique (individual) tagged sturgeon sampled, presented by the number of times encountered (sampling events), within the general study area of the lower Fraser River, over five time periods from 2014-2018.

Number of Sampling Events	Numbers of Individual Sturgeon Sampled				
	2018	2017-18	2016-18	2015-18	2014-18
1	4,903	8,854	12,549	16,980	19,651
2	444	1,282	2,316	3,959	5,122
3	54	263	606	1,102	1,611
4	13	77	203	413	591
5		16	62	148	260
6		4	18	65	124
7	1	2	14	37	47
8			5	17	35
9			2	5	16
10			2	4	9
11				4	7
12					3
13					2
14				3	2
15				1	
16					2
17					
18					1
Totals	6,012	12,633	20,405	31,567	40,196

Immigration, Emigration, and Movements

Since there will always be a portion of 60-279 cm FL lower Fraser River origin White Sturgeon located in marine and freshwater areas outside the core assessment area; the abundance estimates presented in this report do not represent the entire population (Nelson et al. 2016). Freshwater areas accessible to Lower Fraser River White Sturgeon that are outside the core assessment area include: the entire North Arm and adjacent Middle Arm (north of Lulu Island (~23 km), the lower Pitt River upstream of the Highway 7 Bridge (~17 km), Pitt Lake (~27 km), Harrison Lake (~55 km), and the section of the upper Fraser Canyon between Lady Franklin Rock and Hell's Gate (25 km; Figure 1). All marine waters westward of the entrance points of the Fraser River at Garry Point and Canoe Pass (Figure 1) are also outside the core assessment area.

Numbers of White Sturgeon have been observed and captured in the bays and mouths of rivers in northern Puget Sound, with additional sightings and captures in the Southern Strait of Georgia and inlets/estuarine habitats on southern and western Vancouver Island (Nelson et al. 2013a). Although the origin (natal river) of White Sturgeon observed in marine waters adjacent to the Fraser River estuary is currently unknown, their proximity to the Fraser River suggests that at least some are of Fraser origin. Acoustic telemetry data have shown that a portion of lower Fraser White Sturgeon may briefly migrate to marine areas beyond the Fraser estuary, particularly during summer months (Robichaud et al. 2017).

The distinct pattern for monthly catch of White Sturgeon from the Albion Test Fishery since 2000 (Figure 15) suggests that sturgeon are moving past this point in the river (Figure 1) during April and May, and again during September through November. The spring movement (downstream) of White Sturgeon past the Albion Test Fishery site is likely explained by in-river foraging migrations from upstream overwintering locations into foraging areas in the lower river and estuary (in particular, areas that support spawning Pacific Eulachon, *Thaleichthys pacificus*), and perhaps upstream movements to late-spring and early- summer spawning locations. Late-summer and fall movements of White Sturgeon past the Albion Test Fishery site are likely both upstream and downstream migrations of sturgeon seeking out returning salmon stocks, and sturgeon returning to overwintering locations from summer/fall foraging areas.

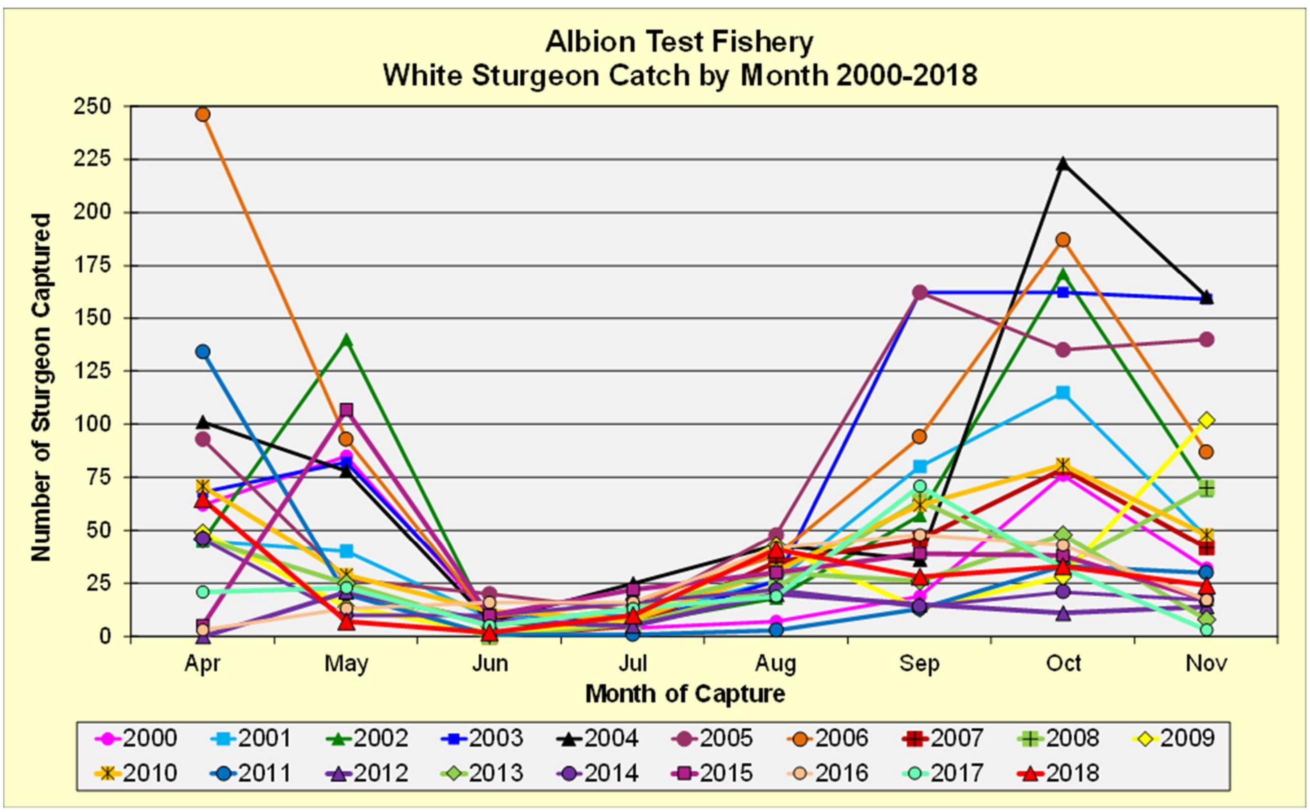

Figure 15. The number of White Sturgeon (all sizes) captured in the Albion Test Fishery during assessment net sets, by month of capture, 2000-2018. Data from Fisheries and Oceans Canada.

Movements past Hells Gate

Several tagged White Sturgeon have been documented passing both upstream and downstream of Hells Gate on the mainstem Fraser River (Appendix B). Hells Gate is located at rkm 212 in Provincial management Region 3, approximately 17 km upstream from the Region 2 boundary at Spuzzum (rkm 195). The confirmation of sturgeon passing both upstream and downstream from this location is important in that Hells Gate is considered to be a Designated Unit (DU) boundary that separates discrete populations of White Sturgeon (COSEWIC 2012). White Sturgeon downstream of Hells Gate have been assigned to the "Lower Fraser" DU, whereas the White Sturgeon upstream of Hells Gate (including all tributaries to the Fraser River, including the Nechako River) have been assigned to the "Upper Fraser" DU.

Although there has been sparse sampling effort upstream of the DU boundary, there are nevertheless three tagged White Sturgeon that are known to have moved upstream past Hells Gate (Appendix B). These include tagged sturgeon observed in Region 2 (from locations including the tidal section of the river below Mission and the lower Fraser Valley) that were subsequently recaptured in Region 3 (near Lillooet, over 120 kms upstream of Hells Gate). Also, 12 tagged White Sturgeon are known to have moved downstream past Hells Gate. These include: one sturgeon tagged and released near Williams Lake River (Region 5) that moved downstream to the upper Fraser Valley near Hope (Region 2); and five sturgeon tagged and released near Lillooet (Region 3) that moved downstream to various locations in Region 2 (including the Fraser Canyon, the lower Fraser Valley, and the tidal section of the river below Mission; Appendix B).

Growth

The variability and periodicity of growth rates (depicted in Figure 12) are likely associated with the availability of food (prey). For example, the relatively large returns of Pink and Chum salmon in 2001, 2003, and 2011 likely provided a substantial increase in the amount of food available to Lower Fraser River White Sturgeon, either directly through the consumption of eggs and carcasses, or indirectly as a result of consuming organisms that benefited from the increased nutrient inputs brought into the rivers via salmon returns during those years. Conversely, after 2012, the low abundance of returning Pacific Eulachon and most species of salmonids may have resulted in a nutrient deficit in the lower Fraser River ecosystem, which may have translated to declining and lower-than-average growth rates for resident White Sturgeon over the same time period.

Other impact factors that can result in reduced growth are physical and physiological stress. High capture rates in nets and by angling can result in immediate and latent physical trauma that can result in reduced feeding success, and/or ability to migrate to optimal feeding locations. Physiological stress induced by warm water temperatures and low oxygen levels, especially in combination with physical stress induced by capture events (McLean et al. 2016), could result in a reduction in feeding success.

The low annual rates observed in 2018 are similar to the low growth rates observed in 2017. The average growth rate for all sizes of White Sturgeon assessed in 2018 was 46.3% lower than the respective average growth rate observed in 2002. In the 1960s, the reported average growth rate for Lower Fraser River White Sturgeon up to age 25 was approximately 5.1 cm/year (Semakula and Larkin 1968), which is 31.4% higher than the average growth rate (3.5 cm/year) for the comparable size groups of sturgeon sampled in 2018 (Figure 12). Growth is a quantitative indicator of the general health and condition of a sturgeon population; based on 2018 growth rates, the current condition of White Sturgeon in the lower Fraser River is poorer than that estimated for earlier study years.

Mark Rate Variation

The differences in observed annual mark rates among seasons suggest a potential population segregation between winter (low mark rates) and summer-fall (high mark rates). Preferred overwintering habitats may attract sturgeon from a wide area where sturgeon migrate and forage during the balance of the year, including locations outside the core assessment area. It is probable that sampling effort (i.e., tag applications) is not occurring, or occurring at a lower rate, at some of those other foraging and rearing areas, and thus fish from those areas have a lower probability of possessing a tag. When sturgeon from all areas concentrate in known overwintering locations within the core assessment area, the result could be a lower mark rate during the winter season. In addition, there is less applied angling effort during winter months, and some program volunteers avoid angling in known overwintering locations.

Abundance Estimates

The BMR24 abundance estimates reported here do not represent the entirety of the population. This is based on our knowledge regarding the known presence of sturgeon outside of the core assessment area, and the omission of both small (under 60 cm FL) and large (over 279 cm FL) sturgeon from our estimates. However, our abundance estimates can be considered representative “indices of abundance” (as they have been generated consistently, using the same area and the same size groups of fish each year), which can be compared between and among assessment years to detect abundance trends within the total population.

The BMR24 abundances presented in this report are estimates of the mean number of White Sturgeon in the 60-279 cm FL size range that resided in the core assessment area over each two-year assessment period. The large number of sturgeon tagged and examined for tags each year has resulted in relatively precise estimates (Table 5). The precision and accuracy of these estimates depended upon the input of point estimates for growth, movement, mortality, and undetected marks.

<u>Comparison of BMR24 and ISAMR Model Results</u>

Recent abundance estimates generated by both the BMR24 and ISAMR models indicate that the abundance of White Sturgeon in the core assessment area of the lower Fraser River is well below historic levels and has been declining since 2003. The 2018 BMR24 abundance estimate for 60-279 cm FL White Sturgeon was 33,461 (95% CLs ± 9.5% of the estimate); this estimate is 45.3% lower than the program’s highest annual abundance estimate in 2003, and 16.0% lower than the 2017 estimate. Comparatively, the 2018 ISAMR abundance estimate for 60-279 cm FL (age 7-55) White Sturgeon was 44,430 (95% CIs ± 4.5% of the estimate). The 2018 ISAMR abundance estimate was 24.7% lower than the model’s highest respective annual abundance estimate in 2004 and 3.6% lower than the 2017 estimate. The ISAMR model indicates that at current (2018) juvenile recruitment rates this downward trend in abundance will continue at an average rate of 1.2% per year from 2018 through 2060 (Challenger et al. 2019).

Both the BMR24 and ISAMR models suggest that the observed decline in the total abundance of White Sturgeon in the core assessment area of the lower Fraser River since 2003 has been driven mostly by declines in juvenile recruitment into the population. Both models agree that in the past 15 years (2003-2018) significant declines in abundance have occurred for 60-99 cm FL juvenile sturgeon (BMR24, 78.2% decline; ISAMR, 75.7% decline; Figure 16). Both models also agree that the abundance of sub-adult White Sturgeon (100-159 cm FL) has declined significantly in the past 5 years (2013 to 2018; BMR24, 57.8% decline; ISAMR, 65.0% decline; Figure 16). In addition, both models indicate that the abundance of adult sturgeon (160-279 cm FL) within the core assessment area trended upward from 2000 to 2015, as surviving sub-adult sturgeon (100-159 cm FL) grew into

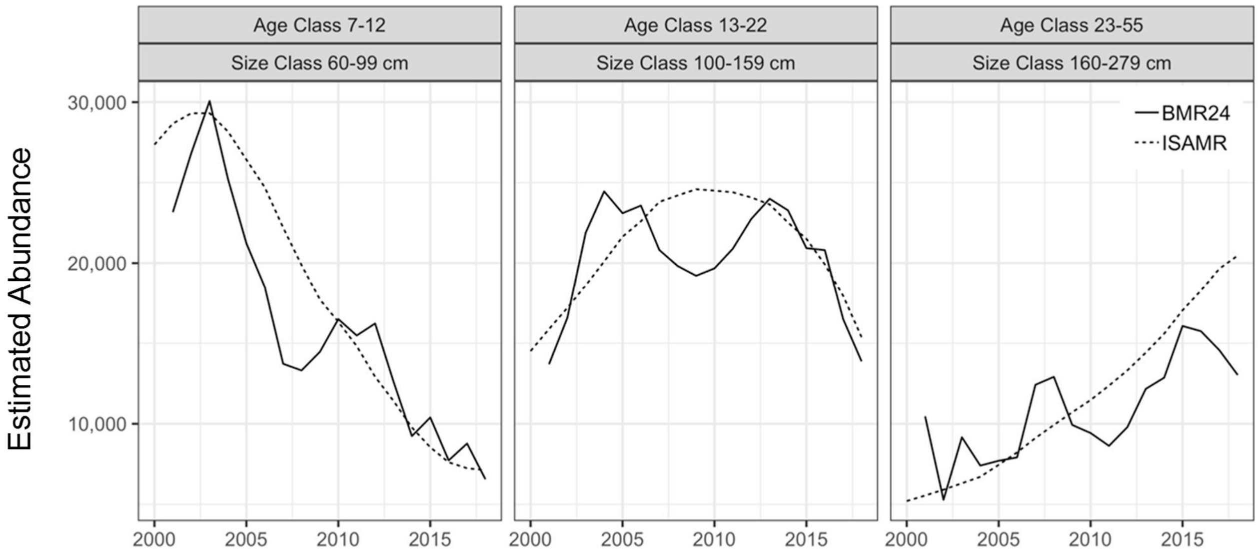

Figure 16. **Comparison of the ISAMR (adjusted) and BMR24 model estimates of abundance for three size/age categories of Lower Fraser River Sturgeon. From Challenger et al. (2019).**

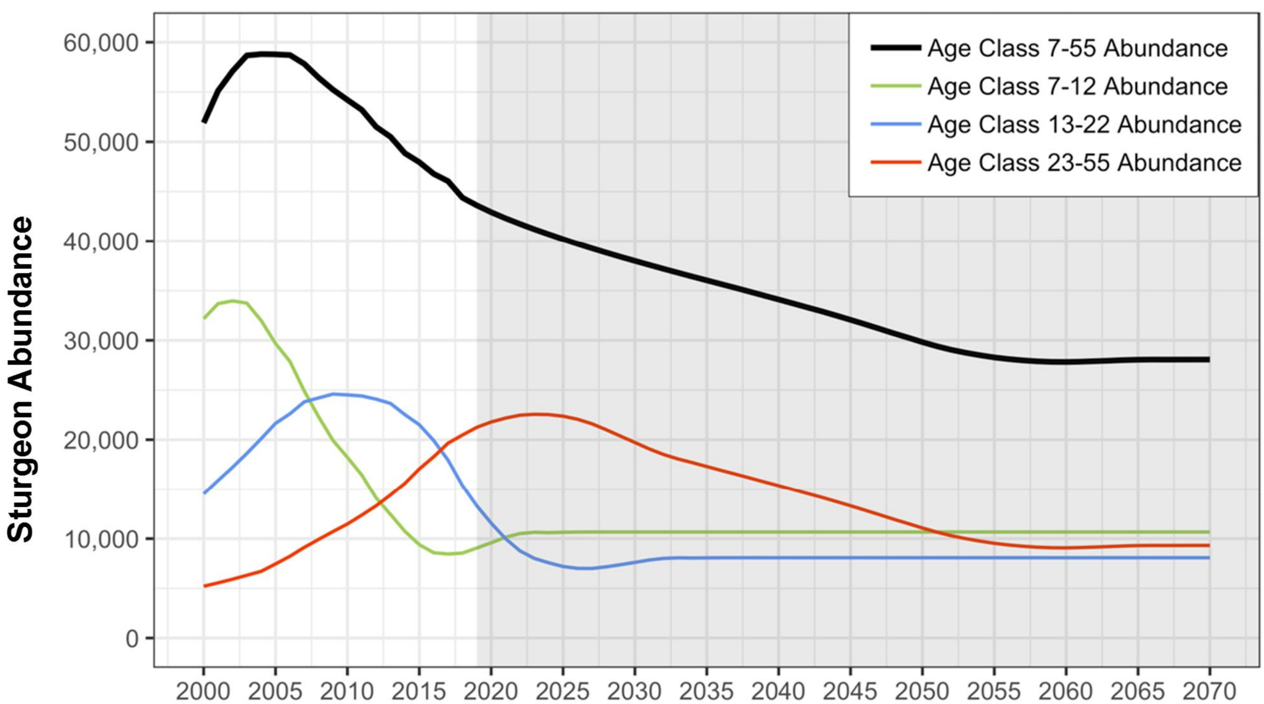

Figure 17. **Abundance projections for Lower Fraser River White Sturgeon for 2018-2070 assuming that annual age-1 recruitment remains the same as recent estimates (i.e., 2012-2017 recruitment). Grey shading indicates projected years. From Challenger et al. (2019).**

the adult size group over this time period. However, the two models differ on the recent (2015-2018) trend of adult sturgeon (>160 cm FL); while the BMR24 model indicates that the abundance of adult sturgeon commenced its predicted decline in 2015, the ISAMR model suggests that the abundance of adult sturgeon has continued to increase during this time period (Figure 16). The ISAMR model predicts that adult sturgeon abundance will continue to increase (by approximately 2,100 adult sturgeon) until 2023, followed by continual significant declines into the foreseeable future (the predicted adult decline from 2023 to 2060 will average 2.4% per year and equate to 13,485 adult sturgeon from 2023 to 2060 (Figure 17).

One important difference between the two models is the BMR24 model uses every sampling event within a two-year (24-month) sampling period. By contrast, the ISAMR model only uses a single recapture event for each tagged fish in a given year to confirm that a tagged fish was alive up to that year. Therefore, the same individual marked sturgeon can only contribute once to the ISAMR model analysis in a given year, whereas individual marked sturgeon can contribute multiple times to the mark rates used in the BMR24 model (in the event that an individual marked sturgeon is recaptured multiple times within the 24-month analysis interval). With the most-active angling guides returning to the same sampling locations multiple times in a given month, it is likely that the mark rate for their samples would be higher than those for less-active anglers (assuming that marked sturgeon remain in close proximity to their release locations for several days or weeks following release). This scenario was confirmed to have been occurring, starting in 2014, and becoming significant in 2017 and 2018 (Figure 18).

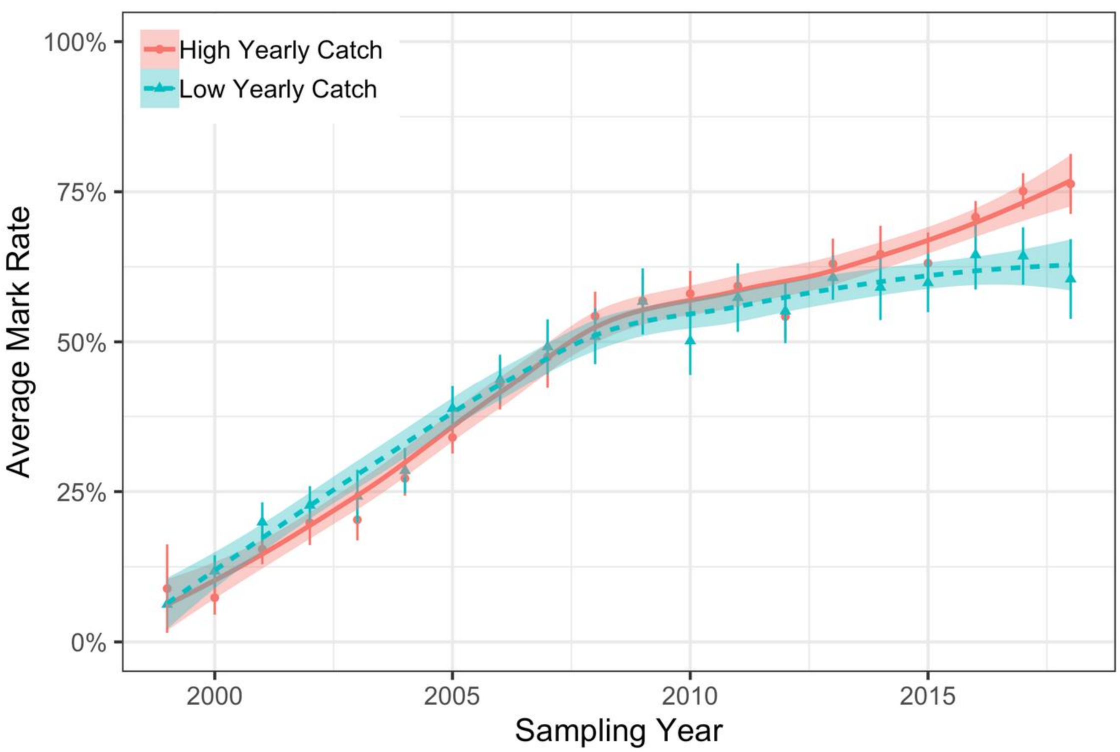

Figure 18. Average angling mark rates for guides/fishers designated as having either high (≥ 100 fish per year) or low (< 100 fish per year) yearly catch. Error bars indicate confidence intervals for average yearly mark rates, shading indicates confidence region for the local polynomial regression fit. In terms of mark rates, there appears to be some evidence of diverging mark rates in recent years for guides with high yearly catches of sturgeon.

Potential for Heterogeneous Capture Probabilities

One of the key assumptions for most mark-recapture models is that marked and unmarked fish in the population have equal probabilities of capture. The information presented in Figure 18 indicates that the average annual mark rates for the guides/fishers that have a high yearly catch (≥ 100 sturgeon sampled) have been notably higher in recent years than the average annual mark rate for guides/fishers with a low yearly catch (< 100 sturgeon sampled). Thus, because the most-active guides/fishers represent a higher portion of the annual sample, since 2015 tagged sturgeon have been more likely to be sampled than untagged sturgeon, and the resultant bias is having an effect on respective abundance estimates generated by the BMR24 model.

As indicated in the FIELD AND ANALYTICAL METHODS section, one way to adjust the BMR24 analysis to reduce the likely bias associated with this issue is to increase the model's minimum time-at-large (minTAL) such that marked fish must be "at-large" (and allowed time to mix within the population) for several weeks before they are included in the mark-rate sample. Under this model restriction, tagged releases are also not included in the number of tagged fish available for recapture until after the minTAL interval. Historically, the minTAL interval has been set at 1 day, which does

Table 10. Comparison of BMR24 abundance estimates of 60-279 cm FL White Sturgeon in the core assessment area of the Lower Fraser River, generated from 1-day TAL and 30-day TAL modeling, by assessment year, 2001-2018. See Figure 19 for an illustration of this comparison.

Assessment Year	1-Day TAL Estimate	30-Day TAL Estimate	Difference (No.)	Difference (%)
2001	44,341	47,320	2,979	6.3%
2002	46,139	48,690	2,551	5.2%
2003	56,384	61,135	4,751	7.8%
2004	53,969	57,084	3,115	5.5%
2005	48,730	52,046	3,316	6.4%
2006	47,118	50,002	2,884	5.8%
2007	44,769	46,965	2,196	4.7%
2008	43,638	46,050	2,412	5.2%
2009	41,938	43,614	1,676	3.8%
2010	44,093	45,604	1,511	3.3%
2011	43,630	45,015	1,385	3.1%
2012	47,354	48,772	1,418	2.9%
2013	47,925	48,792	867	1.8%
2014	44,004	45,380	1,376	3.0%
2015	45,038	47,399	2,361	5.0%
2016	42,133	44,289	2,156	4.9%
2017	36,545	39,841	3,296	8.3%
2018	29,552	33,461	3,909	11.7%

not give a tagged sturgeon much time to move from its initial capture location and mix with other sturgeon (both marked and unmarked). We experimented with both 30-d and 60-d minTAL intervals to assess the effect on respective abundance estimates, by size/age category. Our findings indicated that the 30-d minTAL model restriction provided a reasonable, more-conservative estimate than the 1-d minTAL used to produce abundance estimates for previous years (see Nelson et al. 2018). Table 10 presents a comparison of abundance estimates of 60-279 cm FL White Sturgeon in the core assessment area of the Lower Fraser River, generated from 1-day minTAL and 30-day minTAL modeling, by assessment year, from 2001-2018 (Figure 19 provides an illustration of these comparisons). Note that the percent difference between estimates was generally trending downward from 2000 through 2013, but that by 2015 the trend was increasing, and in 2017 and 2018 the difference increased markedly (from 4.9% in 2016 to 11.7% in 2018; Table 10 and Figure 19).

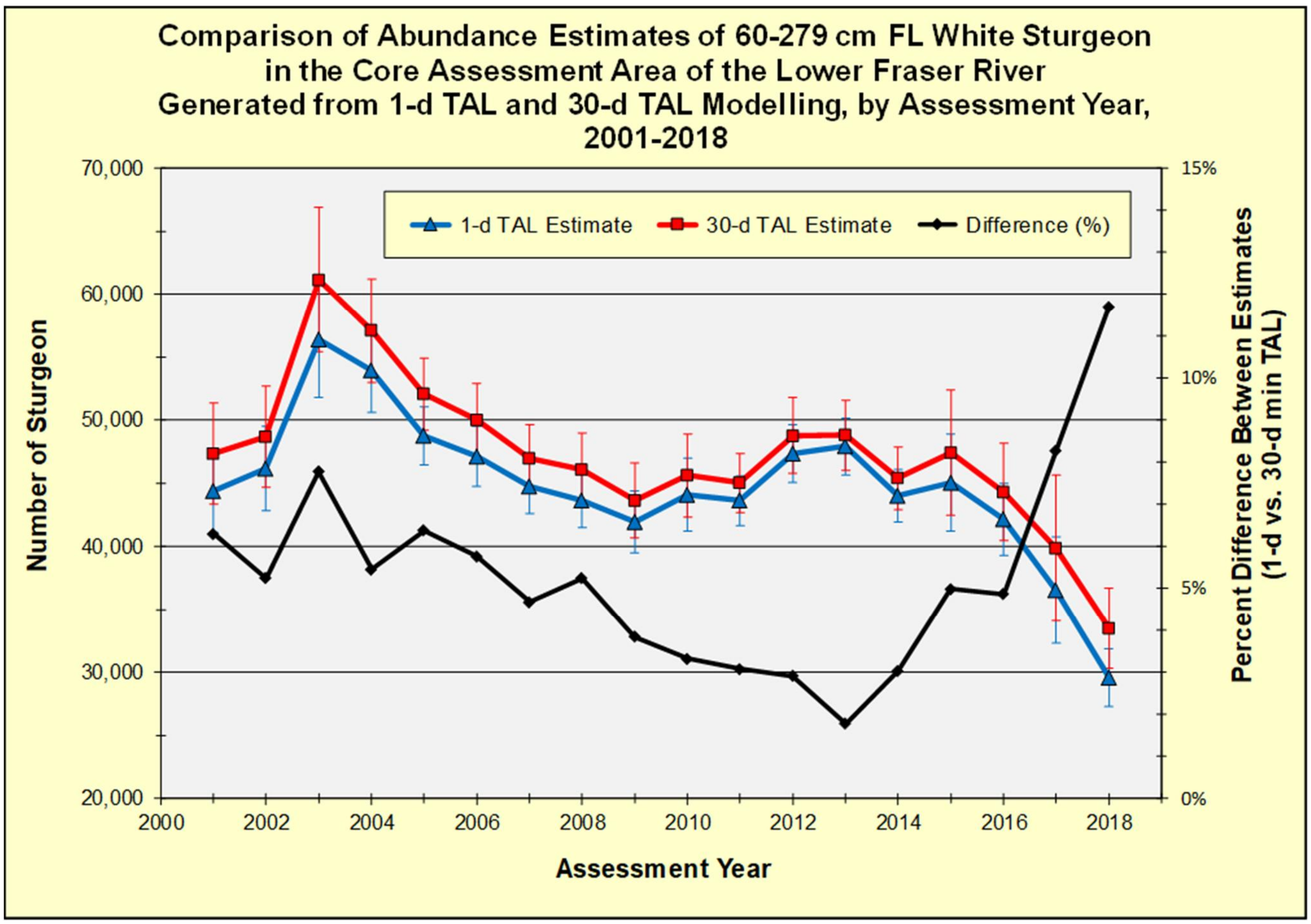

Figure 19. Comparison of BMR24 abundance estimates of 60-279 cm FL White Sturgeon in the core assessment area of the Lower Fraser River, generated from 1-day TAL and 30-day TAL modeling, by assessment year, 2001-2018.

Abundance Trends

Our estimates of the abundance of White Sturgeon in the lower Fraser River indicate that population abundance declined from 2003 to 2009, was variable from 2004 to 2015, and further declined from 2016 to 2018 (Table 5, Figure 8). This general and specific state of population decline has been reflected in several reports and publications (COSEWIC 2012, Nelson et al. 2013a, Hildebrand et al. 2016).

A comparison of size-specific annual abundances from 2004-2018 reflects that there was a significant decline in the abundance of juvenile 60-99 cm FL sturgeon in the lower Fraser River between 2004 and 2008 (Figures 9 and 11). A subsequent decline in the abundance estimates for the 60-99 cm FL size group started in 2013 and has continued through 2018. The declines in estimated abundance of 60-99 cm FL sturgeon within the core assessment area are most likely due to reduced levels of recruitment of young juveniles into the population. Note that 60-99 cm FL White Sturgeon in the lower Fraser River are likely between 6-16 years old; the average age for this size group is 10.7 years (age-length data from the 1995-99 provincial White Sturgeon study; RL&L 2000). There could be a number of factors limiting juvenile recruitment into the population, including:

- <u>Reductions in spawning activity or spawning success</u>. Reduced spawning activity could result from increased physiological stress, such as that caused by capture or handling (especially at high water temperatures, see McLean et al. 2016). Sturgeon captures by recreational angling have a low incidence of direct mortality (Robichaud et al. 2006); however the non-lethal impacts of angling is not known. Sturgeon captured in gill nets (that target migrating salmon) can die or be seriously injured (Robichaud et al. 2006); unfortunately, reliable estimates of gill net interceptions, including the number of sturgeon killed/retained during commercial and First Nation salmon fisheries in the lower Fraser River, and the number of sturgeon released from those fisheries, are not available. Spawning success could be limited by reduced food supply, which could result in sub adequate physiological condition for mature female (and perhaps male) sturgeon reproductive development. Reduced spawning success could also be the result of decreases in available spawning habitat, or by reductions in spawning habitat quality, such as gravel structure or size.
- <u>Increased mortality during early life stages (larval and post larval/fry)</u>. Early life mortality could result from sub-optimal environmental conditions (water temperature, water chemistry, etc.), high levels of predation, limited availability of food, or by reductions in suitable feeding or rearing habitat. Cannibalization may also be a factor as rearing sturgeon may feed upon sturgeon larvae and fry, and larger sturgeon may feed upon smaller sturgeon, especially in areas where sturgeon are concentrated (such as overwintering area) and there are limited levels of other prey items.
- <u>Increased mortality of age-0 to age-4+ fish</u>. Sturgeon of this size require specific rearing habitats that support suitable prey items, both of which are limited in the lower Fraser River. Juvenile sturgeon in this size group (up to approximately 35 cm FL) are also vulnerable to elevated salinity levels present in the lower Fraser River estuary (exposure to salinities over 16 ppt can result in high levels of mortality for small sturgeon; Amari et al. 2009).

The declines in the estimated abundance of 60-99 cm FL sturgeon in recent years could also be partly due to a combination of the following: smaller fish being less vulnerable to our primary sampling gear (angling); program volunteers changing their angling behaviour (e.g., fishing methods and locations that target large fish); and increased proportions of small fish residing outside of the core assessment area (or in less well-sampled portions of the core assessment area).

In addition to decreases in the smallest size classes, there were also significant decreases in abundance estimates for sturgeon in the 80-99 cm FL and 100-119 cm FL size groups (Figure 11). The abundance estimates for adult White Sturgeon over 160 cm FL had been generally trending upward from 2011 to 2015 (Figure 9); this was likely due to harvest restrictions enacted in the early 1990s on recreational, commercial and First Nations fisheries, and the subsequent recruitment of those fish into larger size groups (with growth) over time. However, the abundance of adult sturgeon has been steadily declining since 2015 (Figure 9). While a stable or generally declining number of adult spawning sturgeon provides potential short-term security for population rebuilding, this can only be realized if effective spawning and subsequent juvenile recruitment is occurring at a level sufficient to maintain and grow the population over time.

The proportion of small (< 100 cm FL) White Sturgeon sampled by angling has decreased continually and significantly since the beginning of the program (Figure 20). In 2000, over half of all sturgeon captured by angling (53%) were less than 100 cm FL; by 2008 this proportion dropped to 35%; and by 2018 this proportion further declined to 22% (which is a 59.3% decrease from 2000). The apparent decline in the proportion of angled sturgeon under 100 cm FL may be in part a result of a changes in angler behaviour, particularly of guides, who may have become more successful in targeting the largest fish possible, using new technologies (including high-resolution electronic sonar viewing systems), fishing tackle and terminal gear that increases the likelihood of hooking and

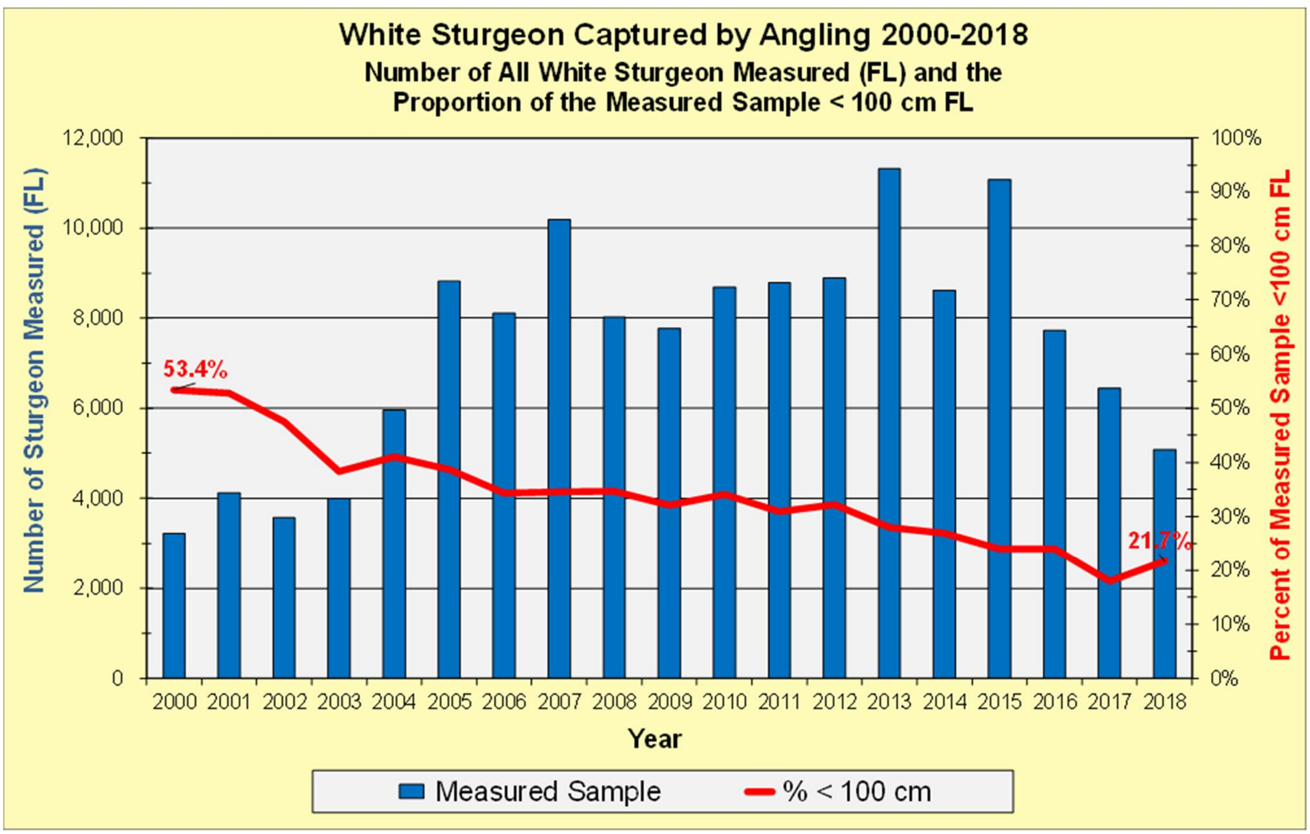

Figure 20. The annual proportions of White Sturgeon less than 100 cm FL from all measured samples captured by standard angling gear, 2000-2018. Declines reflected in this figure may be associated with declining numbers of small (< 100 cm FL) sturgeon and to changes in angler behavior.

capturing large sturgeon, and newly available information regarding large fish locations and behaviour quickly shared via electronic media. Targeted sampling of adult (large) sturgeon occurs within in volunteer angling behaviour, especially during summer and fall sampling periods and with volunteers that are guides for the recreational angling fishery. Conversely, there are several new research projects have been using angling guides to target small sturgeon in the lower Fraser River; thus we expect the decreasing trend to reverse or abate to some extent. However, such a reversal would be the result of shifting angler behaviour, and any changes in the proportion of juvenile sturgeon observed in the annual angling sample should not be considered to be a direct reflection of the numbers of juvenile sturgeon present in the Lower Fraser River population.

In contrast to the angling data described above, the Albion Test Fishery (a gillnet test fishery conducted at rkm 58 in the lower Fraser River, see Figure 1) is conducted in a relatively rigorous and consistent manner among years, and changes in the proportion of juvenile sturgeon observed in the gill net sample could certainly be a direct reflect ion of the numbers of juvenile sturgeon present in the Lower Fraser River population. And indeed, the Albion Test Fishery data provide evidence that over the course of the monitoring and assessment program there has been a declining proportion of juvenile sturgeon less than 100 cm FL within the population. In 2000, 54% of all sturgeon captured in the Albion Test Fishery were less than 100 cm FL; by 2008 this proportion dropped to 50%, and in 2018 it further declined to 21% (which is a 60.1% decrease from 2000; Figure 21). While there have been minor methodological changes for this test fishery over the years

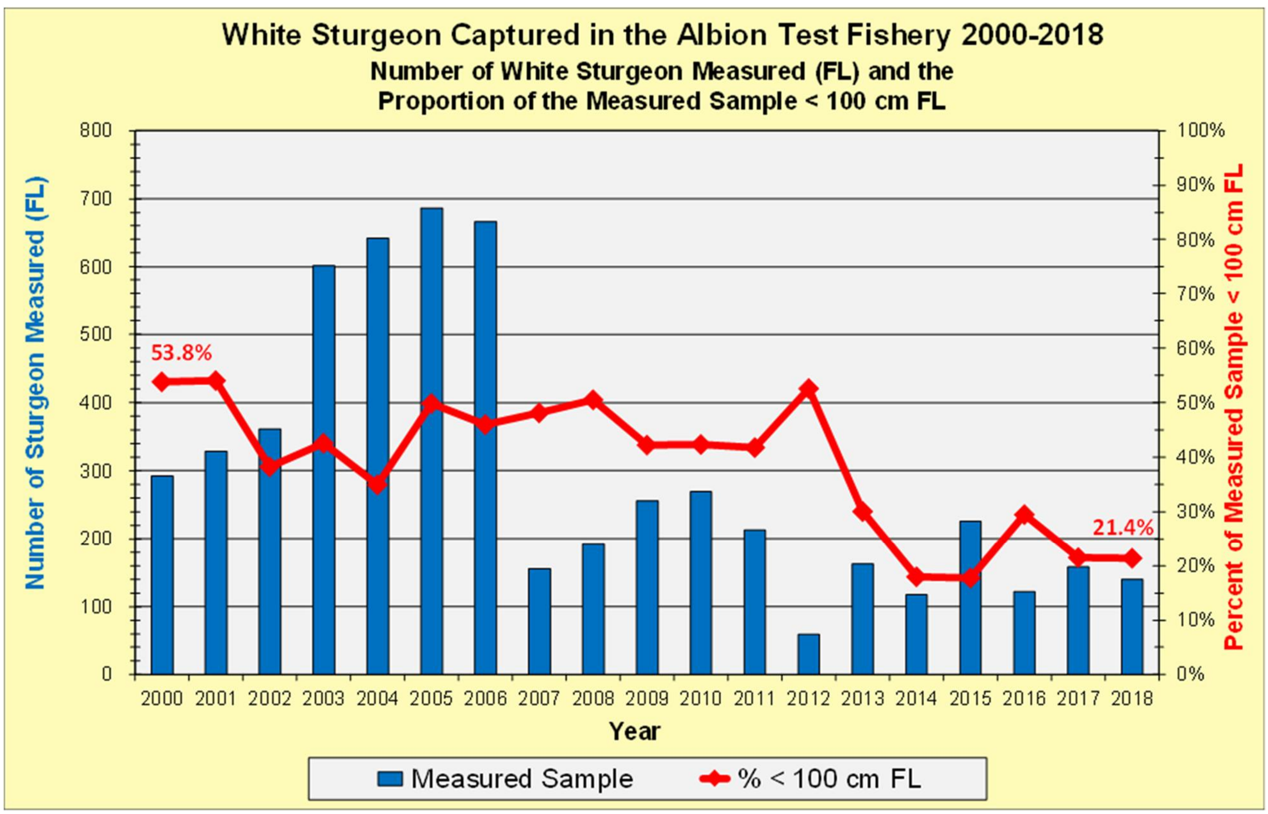

Figure 21. The annual proportions of White Sturgeon less than 100 cm FL from all measured samples captured in the Albion Test Fishery, 2000-2018. Since 2000, there has been a 60.1% decrease in the abundance of juvenile White Sturgeon present in total measured samples of sturgeon from the Albion Test Fishery. Methodological changes to the test fishery over the years do not explain the declines in small sturgeon proportions, especially since 2012.

(especially between 2006 and 2007), including variation in net size, effort, and deployment schedules, and habitat changes have resulted from dredging activities in the test fishery area, these cannot explain the observed declines in the proportion of small sturgeon sampled (especially since 2012; Figure 21). We believe that these data supply independent evidence of declining numbers of juvenile sturgeon present in the Lower Fraser River population of White Sturgeon.

Model Comparisons

There was a strong agreement between estimates of population abundances, trends in abundance, and spatial distribution of abundances, when the two modeling frameworks (BMR24 and ISAMR) were compared across the three size groupings. Nevertheless, there were also noticeable deviations, especially when combining size groupings. The BMR24 analysis model followed the same overall trends produced by the ISAMR analysis but tended to show more year-to-year variation in abundances (the ISAMR abundance estimates also produced relatively smoother trajectories). These differences in abundance estimates likely relate to underlying differences in the populations of interest and model structuring. The BMR24 analysis model uses a 24-month analysis window, and as such the biological population of inference are sturgeon that have used the lower Fraser River within that 24-month period. In contrast, the ISAMR model considers captures from all years, with a population of inference being sturgeon that have used the lower Fraser River throughout the entire 2000-2018 period. Individuals that temporarily emigrate will still be considered part of the population of interest, and as such ISAMR-derived abundance estimates should show more stability. This is especially true if a large proportion of temporary emigration events last longer than 24 months.

There is less year-to-year variability in abundance in the ISAMR model outputs than in the BMR24 model outputs. The estimates produced by the ISAMR model are for all sturgeon in the selected size range that were tagged in the core assessment area and believed to be alive in a given year, regardless of whether they were in the core assessment area or elsewhere in a given year. Because the ISAMR model employs an age-structured population matrix where individual recruitment cohorts are tracked over time, the structuring can result in more inertia in the annual abundance estimates. Furthermore, the ISAMR model uses a shared mortality-at-age curve across modeled years which represents the average age-specific mortality. Year-to-year variation in age-specific mortality rates are not considered by the ISAMR, and as such the abundance estimates will not reflect short term changes in mortality rate. If age-specific mortality rates change over time, the estimated mortality curve will change in response to available data, resulting in model inertia. If mortality rates for larger individuals declined in recent years, this might also be responsible for the recent discrepancy in sturgeon of size 100 cm FL and larger (Challenger et al. 2019). Future implementations of the ISAMR may wish to consider fitting additional mortality curves to test for changes to the rate of mortality-at-age over time.

Abundance Forecasts

Abundance forecasts from the ISAMR model indicate that immediate action should be implemented to improve age-1 recruitment, which is currently at a level approximately one third that of levels 15-20 years prior (Challenger et al. 2019). Increasing recruitment immediately by 1.6 times the current level, and sustaining this increased level of recruitment over time, would result in a continuation of total abundance decrease for approximately six years, followed by a gradual increase in abundance that would stabilize back to 2018 levels by approximately 2034 (Challenger et al. 2019). Even with improved recruitment the 100-159 cm FL (i.e., age 13-22) group is projected to decline until the mid to late 2020's resulting in an abundance level that is one third of the 2010 abundance. Larger sturgeon (i.e., 160-279 cm FL) abundances would be predicted to peak in the mid 2020's, then decline until approximately 2055, which could further reduce already low age-1 recruitment levels.

Medium- and long-term targets for rebuilding the Lower Fraser River White Sturgeon population should be based on recent abundance levels. The abundance of 60-279 cm FL sturgeon has approached 60,000 fish as recently as 2005, making 60,000 a reasonable interim population recovery goal for this size group. Similarly, the spawning component (160-279 cm FL) is projected to reach an abundance of approximately 20,000 fish by the early 2020's, before the projected decline. Given the current low recruitment levels, we recommend that 20,000 is identified as another recovery goal for spawning-age sturgeon. Indications that progress has been made to achieve these interim goals would be a significant increasing trend in abundance of 60-99 cm FL sturgeon by 2025.

Importance of Annual Data Review, Analysis, and Reporting

In-season data review and annual analyses are essential components of the ongoing Lower Fraser River White Sturgeon Monitoring and Assessment Program and are two of the key reasons why the program is considered to be both credible and world-class. Thousands of data records are submitted by program volunteers each year, during all months, from throughout the large study area. A thorough review of these data is critical to ensure that data forms submitted by volunteers are complete and accurate. Despite the best efforts of volunteers, our data review procedures do indeed identify erroneous or missing data, which we attempt to correct by promptly following up with the volunteers in question. These follow-ups are only effective when they occur in a timely manner, underpinning the need for constant and regular data review. Moreover, data inconsistencies and data entry errors have been identified while running the abundance models, highlighting the need for timely analyses as a critical part of our quality control and quality assessment procedures.

Running the abundance models annually is important, and not just as a quality assessment procedure. Results from the mark-recapture models provide relatively current estimates of abundance and growth rates for the Lower Fraser River White Sturgeon population; timely information regarding population change, status, and trends are of extremely high value for government personnel tasked with the conservation and recovery of White Sturgeon and their habitat. In addition, it is highly important to communicate updated results to program volunteers, program sponsors, local First Nations, sturgeon recovery teams, government personnel, and members and directors of the Fraser River Sturgeon Conservation Society. Results from annual analyses have been reported in a variety of forms, including: peer-reviewed journal articles, detailed technical reports, summary reports, press releases, PowerPoint presentations, and HCTF project reports. The production of reporting products on an annual basis is critically important for maintaining essential stewardship contributions to the program. Moreover, ongoing feedback that is encouraged and received following reporting events helps identify where the program and deliverables can be improved, and how we can be more effective at achieving our goals related to conservation and ultimate recovery of the population.

RECOMMENDATIONS

The population of White Sturgeon in the lower Fraser River continues to be in a critical state of decline and instability. The 2018 BMR24 abundance estimates are the lowest since the inception of the monitoring and assessment program in 2000 (the total 2018 abundance estimate has declined by 45.3% in 15 years and by 16.0% over the past year). At current recruitment rates, the ISAMR model indicates that abundance will continue to decline at an average rate of 1.2% per year into the foreseeable future. Juvenile recruitment rates are currently below the level of population sustainability. Therefore, it is critical that strategic actions are immediately applied in an effort to recover and rebuild the sturgeon population. Concurrently, population monitoring and assessment activities should be maintained and ideally improved.

As in previous reports, we emphasize the importance of taking immediate actions to improve both recruitment of age-1 fish and survival rates for age 1-6 fish. Actions should include: the protection of sturgeon spawning and juvenile rearing habitat; the removal of all fishing gear, and restrictions of boating activity, from known sturgeon spawning areas during the spawning period; and the protection of the spawning and rearing areas of sturgeon prey species (e.g., salmon species and Pacific Eulachon). Recent efforts to improve sturgeon handling techniques by sturgeon anglers (and for net fishers that intercept sturgeon as bycatch while targeting other species) are expected to positively impact both survival and spawning rates for adult sturgeon and should continue to be supported.

The Lower Fraser River White Sturgeon Monitoring and Assessment Program has been operating continuously for over 19 years. Based on this experience, we have identified recommendations to improve and deliver key program deliverables and conservation objectives. This section provides two sets of recommendations: 1) maintaining and improving population monitoring and assessment activities; and 2) actions to facilitate the recovery and rebuilding of the Lower Fraser River White Sturgeon population.

Recommendations related to maintaining and improving population monitoring and assessment activities include:

- The design and implementation of a program to monitor trends in sturgeon recruitment (i.e. the abundance of age 1-6 sturgeon in the Lower Fraser River (note that in 2019 a juvenile White Sturgeon monitoring program was initiated).
- Continue to work with volunteers to sample sturgeon caught in recreational, First Nations, and test fisheries, and apply tags to untagged sturgeon in the core assessment area.
- The annual sampling target should be at least 6,000 sturgeon distributed across the four regions in the Lower Fraser River.
- All healthy unmarked sturgeon caught by trained volunteer guides, anglers, First Nations and test fishery operators should be marked using PIT tags prior to release, up to a maximum of 2,000 PIT tags per year.
- All field (sampling) data collected each year must be checked as it is received such that data inconsistencies and/or errors are detected and corrected.
- Data analyses must include running both the BMR24 and ISAMR models on an annual basis to assess changes in abundance by size and age category and changes in mortality rates and abundance projections.

The results from these analyses must be communicated to government agencies, First Nations, anglers, angling guides, program supporters, and other interested parties on an annual basis. The FRSCS recommends the following actions to facilitate the recovery and rebuilding of the Lower Fraser River White Sturgeon population:

- Immediately implement strategic actions to increase juvenile recruitment and survival.
- Identify, conserve, and protect critical and important habitats, including: spawning habitat, juvenile rearing habitat, sub-adult and adult feeding habitat, and overwintering habitat.
- Identify, conserve, and protect critical and important habitats of key prey species of White Sturgeon.
- Work with Lower Fraser First Nations to reduce the impact of in-river gill net fisheries and protect important sturgeon habitats.
- Increase efforts to educate recreational anglers and angling guides about the guidelines for capture, handling, and release of sturgeon caught in Fraser River recreational fisheries.

- Work with First Nations, angling guides, and recreational fishers to keep boats and fishing effort away from known spawning and larval rearing areas for one month before and throughout the known sturgeon spawning period (i.e., 1 May to 31 July).
- Work with recreational angling guides and anglers to identify the best strategy and methods for managing and limiting the growth of the recreational fishery for sturgeon in the Lower Fraser River, and to reduce the annual levels of sturgeon captured by angling.
- Increase the cost of the White Sturgeon Conservation Surcharge Licence to reduce angler effort.
- Enact the requirement of the White Sturgeon Conservation Surcharge Licence for all angling of sturgeon in the tidal section of the lower Fraser River.
- Require the registration and permitting of commercial angling guides that guide for sturgeon in the tidal section of the lower Fraser River.
- Work with the provincial and federal governments to address the significant threat of cultured White Sturgeon (from the Nechako River sturgeon hatchery) that have migrated out of the Nechako River and have been observed mixing with the wild White Sturgeon population in the Fraser River mainstem.

The population of White Sturgeon in the lower Fraser River is currently in a critical state of decline and instability. The FRSCS is calling on all governments (First Nation, federal, provincial, and municipal) for immediate action focused on the goal of White Sturgeon population recovery in the lower Fraser River. Recovery actions are required to address all impacts and threats that contribute to population suppression; if actions are to be successful, implementation must commence immediately.

Critical and important habitats for both White Sturgeon and their key prey species must be protected against further erosion and alteration. All sources of physical and physiological stress currently endured by the population must be identified and removed or significantly reduced to the best ability of regulatory agencies and resource managers.

ACKNOWLEDGEMENTS

The novel and reliable information that has been produced by this program is a direct result of the energy, commitment, and dedication of program volunteers and sponsors. The level of in-kind contributions to the program from program volunteers, however measured (in hours, equipment, dollars, or numbers of individuals), is second-to-none for recent BC-based fisheries research programs. Program volunteers are true stewards of Fraser River White Sturgeon. The level of program involvement by volunteers and the significant support and interest shown by program sponsors, provincial and federal resource authorities, and the public at large, is a testimony to the broad community commitment toward population recovery of wild Lower Fraser River White Sturgeon. The core financial support for the program has in recent years been provided through surcharges from the provincial White Sturgeon Conservation Licence that recreational anglers are required to purchase prior to angling for sturgeon in non-tidal waters. All (100%) of the funding collected from this surcharge is managed by the Habitat Conservation Trust Foundation through a dedicated account.

Much of the success of this program has been the result of scientific oversight provided by the Science and Technical Committee of the FRSCS which is composed mostly of fishery science professionals; the committee provides key input regarding program design and direction and conducts critical reviews of program results. Individuals from the FRSCS Science and Technical

Committee also serve on the Lower and Middle Fraser River White Sturgeon Technical Working Group and the National Recovery Team for White Sturgeon in Canada.

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Ladd Foundation
LGL Limited environmental research associates
Lower Fraser River First Nations
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APPENDICES

Appendix A. Sturgeon biosampling, tagging, and recapture data entry form

FRASER RIVER STURGEON CONSERVATION SOCIETY FAX to Tyler Thibault : 604-200-5430 (phone: 604-613-6231)

WHITE STURGEON BIOSAMPLING, TAGGING, AND MARK- RECAPTURE RECORDS tyler.thibault18@gmail.com Page:______of

Name of Person that Recorded Data:________________________________ Phone number: ____________

Date (dd/mmm/yy______________Sampling Area:____________________ Weather:________________________ No. Passengers: ____________

Vessel Information: Vessel Name____________ Launch Location________________Launch Time:______________ Return Time:____________

Angling/Sampling Effort		Start Time	End Time	Total Minutes	Start Time	End Time	Total Minutes	Start Time	End Time	Total Minutes	Grand Total (Minutes)
Rod/Gear 1 (Name)											
Rod/Gear 2 (Name)											
Rod/Gear 3 (Name)											
Rod/Gear 4 (Name)											

COMPLETE FOR ALL STURGEON CAPTURED						TAGS APPLIED	RECAPTURES	OTHER	
Fish No.	**River Km (Captured)**	**Was the Sturgeon Scanned? (Yes/No)**	**Fork Length (cm)**	**Girth (cm)**	**Deformity / Wound Code[1]**	**Verified (Scanned at release) Tag Number**	**Tag Number**	**Condition code for sturgeon at release[2]**	**Comments**

Comments:

[1]Deformity/wound/scar codes: DEF = physical deformity; BLED = bleeding; BITE = seal bite; CUT = slice or tear; NET = net scar; OTHER = other (note in comments)

[2]Condition codes: 1 = vigorous, no bleeding; 2 = vigorous, bleeding; 3 = lethargic, no bleeding; 4 = lethargic, bleeding; 5 = dead

Appendix B. Summary of White Sturgeon (all sizes) sampled in the general study area of the lower Fraser River, from all sources and sampling gear types, 1999-2018

Appendix B. Summary of White Sturgeon (all sizes) sampled in the general study area of the lower Fraser River (see Figure 2), from all sources and sampling gear types, 1999-2018. A subset of these sampling records were used to generate annual abundance estimates (see Appendix C). Included is a summary of sturgeon sampled (under this program) outside the Fraser River watershed. See notes at bottom of sheet (page 2) for additional information.

Assessment Year	No. Scanned for PIT Tag (All) (A)	No. Tagged and Released with PIT Tag (Head) (B)	No. Recaptured with PIT Tag (Head) (C)	No. Scanned, Not Tagged, Not Recaptured (D)	No. Sampled, Not Scanned (E)	No. Recaptured With Dorsal Tag (First Recapture Only) (F)	No. Mortalities Sampled (G)	No. Moved Upstream Past Hells Gate (H)	No. Moved Downstream Past Hells Gate (I)	No. Tagged in Fraser, Recovered Outside Fraser Watershed (J)	No. Recaptures from WA or OR (First Recapture Only) (K)	No. Green Sturgeon Observed (L)	No. Scanned Outside of Fraser Watershed (M)	No. Tagged Outside of Fraser Watershed (N)
1999	459	413		11	1	36								
2000	4,387	3,966	219	134	73	58	18							
2001	5,508	4,552	752	147	39	52	24							2
2002	5,043	2,744	913	1,283	32	32	75			1	1		3	
2003	5,444	3,632	1,004	685	16	27	102							
2004	7,240	4,797	1,822	561	112	16	45				1			
2005	10,188	5,260	3,542	1,272	63	20	88					1		
2006	9,030	5,071	3,816	104	32	17	21							
2007	10,637	5,205	5,329	71	32	20	8	1	1		1	1	8	7
2008	8,566	3,873	4,585	51	41	16	15						15	11
2009	8,261	3,359	4,786	68	70	20	22		1		1	2	17	3
2010	9,097	3,746	5,264	56	71	5	7		1					
2011	9,135	3,602	5,433	67	78	11	5				2			
2012	9,195	3,861	5,250	32	189	9	9			1	1			
2013	12,155	4,437	7,590	60	48	13	11		1			2		
2014	9,186	2,637	6,018	473	96	5	13					1		
2015	11,417	3,558	7,644	153	112	7	21		1		1			
2016	7,918	2,174	5,637	70	73	13	14		1			1		
2017	6,765	1,698	4,985	39	64	14	25	2	3			1		
2018	6,175	1,954	4,140	28	46	3	31		3	1			1	
Totals	155,806	70,539	78,729	5,365	1,288	394	554	3	12	3	8	9	44	23

Appendix B - Column Notes

(A) Numbers of White Sturgeon scanned for the presence of a PIT tag; includes scanned samples that were not tagged or recaptured, and scanned mortalities

(B) Numbers of White Sturgeon tagged and released with a PIT tag applied by this program in the head location; includes head tagging of dorsal-tag recaptures

(C) Numbers of White Sturgeon recaptured that had a head PIT tag (applied by this program) upon recovery

(D) Numbers of White Sturgeon scanned, but no tag applied, and not a recapture

continued

Appendix B - Column Notes

(E) Number sampled but not scanned for a PIT tag (typically cases where scanner was lot functioning due to power issue)

(F) Numbers of White Sturgeon recaptures that possessed a "dorsal" PIT tag and/or external tag (tag applied in the dorsal area of the sturgeon during the 1995-99 provincial sturgeon study); first observation only (most of these sturgeon received "head" PIT tags under this program and are thus considered a head recapture following the initial head tag release)

(G) Numbers of dead White Sturgeon (mortalities) sampled; includes mortalities that were not scanned, but were sampled/observed (does not included reported mortalities that were not sampled). Does not include all mortalities from ghost net and provincial tangle net projects. The majority of mortalities observed from 2000-2005 were captured in set gill nets (First Nation fisheries)

(H) Number of recaptured White Sturgeon that moved upstream past rkm 212 (Hells Gate). Includes movements from Region 2 (lower Fraser Valley above and below Mission) to Region 3 near Lillooet.

(I) Number of recaptured White Sturgeon that moved downstream past rkm 212 (Hells Gate). Includes movements from Region 5 (near Williams Lake River) to Region 2 (near Hope) and movements from Region 3 (near Lillooet) to Region 2 (lower Fraser Valley above and below Mission).

(J) Number of White Sturgeon tagged in the lower Fraser River and recovered outside the Fraser watershed (two sturgeon were recovered as mortalities in Boundary Bay and Mud Bay south of the Fraser River, and a third sturgeon was recaptured and released in the Columbia River near Astoria on 12 July 2012)

(K) Numbers of White Sturgeon tagged (PIT or external tag) in the Columbia River (Oregon or Washington) and recovered in the lower Fraser River (first observation only)

(L) Numbers of Green Sturgeon observed by this program in the lower Fraser River (confirmed observations only)

(M) Numbers of White Sturgeon scanned (under this program) outside the Fraser watershed; includes live and dead samples from commercial seine vessel (Strait of Georgia), Skagit River Tribe (WA), and Puget Sound (WA; WDFG)

(N) Numbers of White Sturgeon PIT tagged and released (under this program) outside the Fraser watershed; includes samples from commercial seine vessel (Strait of Georgia), Skagit River Tribe (WA), and Puget Sound (WA; WDFG)

Appendix C. Summary of White Sturgeon sampled in the core assessment area of the lower Fraser River that were 60-279 cm FL when sampled, by month and year, 1999-2018

Appendix C. Summary of White Sturgeon sampled in the core assessment area of the lower Fraser River that were 60-279 cm FL when sampled, by month and year, 1999-2018. See additional notes at bottom of appendix.

Month and Year	No. Scanned (All)	No. Released With Tag (Head)	No. Scanned, Not Tagged, Not Recaptured	No. Recaptured (Head Tag)	Mark Rate (%)	Year	No. Scanned (All)	No. Released With Tag (Head)	No. Scanned, Not Tagged, Not Recaptured	No. Recaptured (Head Tag)	Mark Rate (%)
Oct-99	87	81	6	0	0.0%						
Nov-99	183	161	22	0	0.0%						
Dec-99	143	132	11	0	0.0%	**1999**	413	374	39	0	**0.0%**
Jan-00	36	36	0	0	0.0%						
Feb-00	122	110	5	7	5.7%						
Mar-00	173	164	2	7	4.0%						
Apr-00	272	254	10	8	2.9%						
May-00	357	331	15	11	3.1%						
Jun-00	249	234	9	6	2.4%						
Jul-00	585	540	19	26	4.4%						
Aug-00	351	314	15	22	6.3%						
Sep-00	430	399	6	25	5.8%						
Oct-00	645	573	29	43	6.7%						
Nov-00	512	464	9	39	7.6%						
Dec-00	53	41	6	6	11.3%	**2000**	3,785	3,460	125	200	**5.3%**
Jan-01	154	143	0	11	7.1%						
Feb-01	135	119	0	16	11.9%						
Mar-01	273	226	3	44	16.1%						
Apr-01	390	317	27	46	11.8%						
May-01	364	315	6	43	11.8%						
Jun-01	400	325	6	69	17.3%						
Jul-01	337	272	11	54	16.0%						
Aug-01	666	556	13	97	14.6%						
Sep-01	531	439	6	86	16.2%						
Oct-01	795	659	26	110	13.8%						
Nov-01	482	391	6	85	17.6%						
Dec-01	284	181	64	39	13.7%	**2001**	4,811	3,943	168	700	**14.5%**
Jan-02	105	53	41	11	10.5%						
Feb-02	140	42	79	19	13.6%						
Mar-02	124	59	45	20	16.1%						
Apr-02	216	96	88	32	14.8%						
May-02	327	171	104	52	15.9%						
Jun-02	206	118	35	53	25.7%						
Jul-02	532	361	71	100	18.8%						
Aug-02	736	517	65	154	20.9%						
Sep-02	352	134	131	87	24.7%						
Oct-02	1,019	544	294	181	17.8%						
Nov-02	492	173	211	108	22.0%						
Dec-02	151	93	30	28	18.5%	**2002**	4,400	2,361	1,194	845	**19.2%**
Jan-03	69	52	11	6	8.7%						
Feb-03	34	19	10	5	14.7%						
Mar-03	123	81	28	14	11.4%						
Apr-03	440	280	77	83	18.9%						
May-03	529	371	75	83	15.7%						
Jun-03	287	159	72	56	19.5%						
Jul-03	415	260	88	67	16.1%						
Aug-03	592	403	81	108	18.2%						
Sep-03	1,096	737	126	233	21.3%						
Oct-03	815	580	56	179	22.0%						
Nov-03	620	388	101	131	21.1%						
Dec-03	109	93	1	15	13.8%	**2003**	5,129	3,423	726	980	**19.1%**
Jan-04	142	120	0	22	15.5%						
Feb-04	303	259	5	39	12.9%						
Mar-04	137	107	3	27	19.7%						
Apr-04	723	565	5	153	21.2%						
May-04	574	430	7	137	23.9%						
Jun-04	415	300	8	107	25.8%						
Jul-04	445	323	1	121	27.2%						
Aug-04	610	393	41	176	28.9%						
Sep-04	825	570	15	240	29.1%						
Oct-04	1,609	882	263	464	28.8%						
Nov-04	1,016	595	143	278	27.4%						
Dec-04	93	60	6	27	29.0%	**2004**	6,892	4,604	497	1,791	**26.0%**

continued

Appendix C. Summary of White Sturgeon sampled in the core assessment area of the lower Fraser River that were 60-279 cm FL when sampled, by month and year, 1999-2018. See additional notes at bottom of appendix.

Month and Year	No. Scanned (All)	No. Released With Tag (Head)	No. Scanned, Not Tagged, Not Recaptured	No. Recaptured (Head Tag)	Mark Rate (%)	Year	No. Scanned (All)	No. Released With Tag (Head)	No. Scanned, Not Tagged, Not Recaptured	No. Recaptured (Head Tag)	Mark Rate (%)
Jan-05	26	20	0	5	19.2%						
Feb-05	208	165	0	43	20.7%						
Mar-05	272	208	1	63	23.2%						
Apr-05	824	565	20	239	29.0%						
May-05	446	267	23	156	35.0%						
Jun-05	710	417	16	277	39.0%						
Jul-05	701	432	19	250	35.7%						
Aug-05	1,451	714	141	596	41.1%						
Sep-05	1,784	732	414	638	35.8%						
Oct-05	2,050	928	321	801	39.1%						
Nov-05	1,054	410	313	331	31.4%						
Dec-05	272	127	90	55	20.2%	**2005**	9,798	4,985	1,358	3,454	**35.3%**
Jan-06	80	65	0	15	18.8%						
Feb-06	2	2	0	0	0.0%						
Mar-06	106	67	3	36	34.0%						
Apr-06	871	570	7	294	33.8%						
May-06	425	243	9	173	40.7%						
Jun-06	259	146	6	107	41.3%						
Jul-06	485	267	13	205	42.3%						
Aug-06	768	414	30	324	42.2%						
Sep-06	1,270	650	12	608	47.9%						
Oct-06	2,520	1,302	19	1,199	47.6%						
Nov-06	1,834	1,035	38	761	41.5%						
Dec-06	167	112	0	55	32.9%	**2006**	8,787	4,873	137	3,777	**43.0%**
Jan-07	54	40	0	14	25.9%						
Feb-07	113	74	0	39	34.5%						
Mar-07	540	343	2	195	36.1%						
Apr-07	593	356	7	230	38.8%						
May-07	314	144	3	167	53.2%						
Jun-07	450	214	1	235	52.2%						
Jul-07	807	356	4	447	55.4%						
Aug-07	1,421	582	10	829	58.3%						
Sep-07	2,523	1,125	28	1,370	54.3%						
Oct-07	2,232	1,051	14	1,167	52.3%						
Nov-07	1,184	588	11	585	49.4%						
Dec-07	42	27	0	15	35.7%	**2007**	10,273	4,900	80	5,293	**51.5%**
Jan-08	55	37	0	18	32.7%						
Feb-08	24	17	0	7	29.2%						
Mar-08	103	53	5	45	43.7%						
Apr-08	458	224	8	226	49.3%						
May-08	490	193	7	290	59.2%						
Jun-08	417	172	3	242	58.0%						
Jul-08	579	237	0	337	58.2%						
Aug-08	818	327	13	478	58.4%						
Sep-08	1,375	550	17	808	58.8%						
Oct-08	1,963	828	0	1,122	57.2%						
Nov-08	1,744	840	14	890	51.0%						
Dec-08	81	49	0	32	39.5%	**2008**	8,107	3,527	67	4,495	**55.4%**
Jan-09	21	12	0	9	42.9%						
Feb-09	88	60	0	28	31.8%						
Mar-09	141	77	0	64	45.4%						
Apr-09	517	246	7	264	51.1%						
May-09	312	95	1	216	69.2%						
Jun-09	312	98	5	209	67.0%						
Jul-09	407	161	4	242	59.5%						
Aug-09	1,018	349	15	654	64.2%						
Sep-09	1,748	620	17	1,111	63.6%						
Oct-09	2,039	813	26	1,200	58.9%						
Nov-09	1,234	565	18	651	52.8%						
Dec-09	139	57	15	67	48.2%	**2009**	7,976	3,153	108	4,715	**59.1%**

continued

Appendix C. Summary of White Sturgeon sampled in the core assessment area of the lower Fraser River that were 60-279 cm FL when sampled, by month and year, 1999-2018. See additional notes at bottom of appendix.

Month and Year	No. Scanned (All)	No. Released With Tag (Head)	No. Scanned, Not Tagged, Not Recaptured	No. Recaptured (Head Tag)	Mark Rate (%)	Year	No. Scanned (All)	No. Released With Tag (Head)	No. Scanned, Not Tagged, Not Recaptured	No. Recaptured (Head Tag)	Mark Rate (%)
Jan-10	259	150	0	109	42.1%						
Feb-10	169	95	0	74	43.8%						
Mar-10	220	90	4	126	57.3%						
Apr-10	606	271	6	329	54.3%						
May-10	383	141	3	239	62.4%						
Jun-10	387	127	3	257	66.4%						
Jul-10	467	213	4	250	53.5%						
Aug-10	728	212	2	514	70.6%						
Sep-10	1,360	423	17	920	67.6%						
Oct-10	2,743	1,089	23	1,631	59.5%						
Nov-10	1,159	526	12	621	53.6%						
Dec-10	307	181	3	123	40.1%	**2010**	8,788	3,518	77	5,193	**59.1%**
Jan-11	131	76	0	55	42.0%						
Feb-11	39	20	0	19	48.7%						
Mar-11	120	58	0	62	51.7%						
Apr-11	740	327	6	407	55.0%						
May-11	331	143	3	185	55.9%						
Jun-11	170	44	0	126	74.1%						
Jul-11	568	220	4	344	60.6%						
Aug-11	1,054	303	5	746	70.8%						
Sep-11	2,237	742	12	1,483	66.3%						
Oct-11	2,300	973	37	1,290	56.1%						
Nov-11	1,064	466	24	574	53.9%						
Dec-11	114	49	2	63	55.3%	**2011**	8,868	3,421	93	5,354	**60.4%**
Jan-12	60	28	0	32	53.3%						
Feb-12	48	21	0	27	56.3%						
Mar-12	171	74	0	97	56.7%						
Apr-12	447	181	4	262	58.6%						
May-12	354	156	1	197	55.6%						
Jun-12	229	76	1	152	66.4%						
Jul-12	713	302	5	406	56.9%						
Aug-12	1,003	345	10	648	64.6%						
Sep-12	1,646	662	11	973	59.1%						
Oct-12	2,703	1,123	31	1,549	57.3%						
Nov-12	1,002	369	9	624	62.3%						
Dec-12	304	139	1	164	53.9%	**2012**	8,680	3,476	73	5,131	**59.1%**
Jan-13	167	63	1	103	61.7%						
Feb-13	252	110	0	142	56.3%						
Mar-13	473	222	2	249	52.6%						
Apr-13	908	375	15	518	57.0%						
May-13	654	209	4	441	67.4%						
Jun-13	428	138	4	286	66.8%						
Jul-13	694	227	2	465	67.0%						
Aug-13	1,098	341	12	745	67.9%						
Sep-13	2,325	587	26	1,712	73.6%						
Oct-13	2,660	945	32	1,683	63.3%						
Nov-13	1,523	525	12	986	64.7%						
Dec-13	101	36	0	65	64.4%	**2013**	11,283	3,778	110	7,395	**65.5%**
Jan-14	122	46	1	75	61.5%						
Feb-14	80	36	0	44	55.0%						
Mar-14	454	175	0	279	61.5%						
Apr-14	846	327	6	513	60.6%						
May-14	473	125	5	343	72.5%						
Jun-14	438	112	5	321	73.3%						
Jul-14	768	227	8	533	69.4%						
Aug-14	1,049	165	108	776	74.0%						
Sep-14	1,118	98	137	883	79.0%						
Oct-14	1,974	519	127	1,328	67.3%						
Nov-14	913	258	52	603	66.0%						
Dec-14	206	65	23	118	57.3%	**2014**	8,441	2,153	472	5,816	**68.9%**

continued

Appendix C. Summary of White Sturgeon sampled in the core assessment area of the lower Fraser River that were 60-279 cm FL when sampled, by month and year, 1999-2018. See additional notes at bottom of appendix.

Month and Year	No. Scanned (All)	No. Released With Tag (Head)	No. Scanned, Not Tagged, Not Recaptured	No. Recaptured (Head Tag)	Mark Rate (%)	Year	No. Scanned (All)	No. Released With Tag (Head)	No. Scanned, Not Tagged, Not Recaptured	No. Recaptured (Head Tag)	Mark Rate (%)
Jan-15	388	110	40	238	61.3%						
Feb-15	269	125	11	133	49.4%						
Mar-15	330	93	7	230	69.7%						
Apr-15	731	245	11	475	65.0%						
May-15	541	170	4	367	67.8%						
Jun-15	363	93	5	265	73.0%						
Jul-15	808	226	6	576	71.3%						
Aug-15	1,236	288	11	937	75.8%						
Sep-15	2,286	587	39	1,660	72.6%						
Oct-15	2,558	814	50	1,694	66.2%						
Nov-15	1,000	262	16	722	72.2%						
Dec-15	273	100	2	171	62.6%	**2015**	10,783	3,113	202	7,468	**69.3%**
Jan-16	259	98	0	161	62.2%						
Feb-16	315	76	7	232	73.7%						
Mar-16	654	179	7	468	71.6%						
Apr-16	865	263	9	593	68.6%						
May-16	305	75	4	226	74.1%						
Jun-16	527	114	7	406	77.0%						
Jul-16	851	158	16	677	79.6%						
Aug-16	726	138	11	577	79.5%						
Sep-16	920	247	8	665	72.3%						
Oct-16	1,452	368	14	1,070	73.7%						
Nov-16	490	108	4	378	77.1%						
Dec-16	4	1	1	2	50.0%	**2016**	7,368	1,825	88	5,455	**74.0%**
Jan-17	75	23	0	52	69.3%						
Feb-17	121	14	0	107	88.4%						
Mar-17	170	38	0	132	77.6%						
Apr-17	344	120	1	223	64.8%						
May-17	174	29	4	141	81.0%						
Jun-17	252	48	1	203	80.6%						
Jul-17	422	89	1	332	78.7%						
Aug-17	833	167	19	647	77.7%						
Sep-17	1,663	335	23	1,305	78.5%						
Oct-17	1,596	343	10	1,243	77.9%						
Nov-17	444	83	3	358	80.6%						
Dec-17	109	43	0	66	60.6%	**2017**	6,203	1,332	62	4,809	**77.5%**
Jan-18	42	12	2	28	66.7% *						
Feb-18	50	21	0	29	58.0% *						
Mar-18	254	65	4	185	72.8% *						
Apr-18	542	153	4	385	71.0%						
May-18	171	30	1	140	81.9%						
Jun-18	265	60	6	199	75.1%						
Jul-18	541	110	7	424	78.4%						
Aug-18	836	139	10	687	82.2%						
Sep-18	751	183	9	559	74.4% *						
Oct-18	1,063	235	10	818	77.0%						
Nov-18	333	69	3	261	78.4%						
Dec-18	92	16	0	76	82.6%	**2018**	4,940	1,093	56	3,791	**76.7%**
					Totals All Years	**1999-2018**	**145,725**	**63,312**	**5,732**	**76,662**	**52.6%**

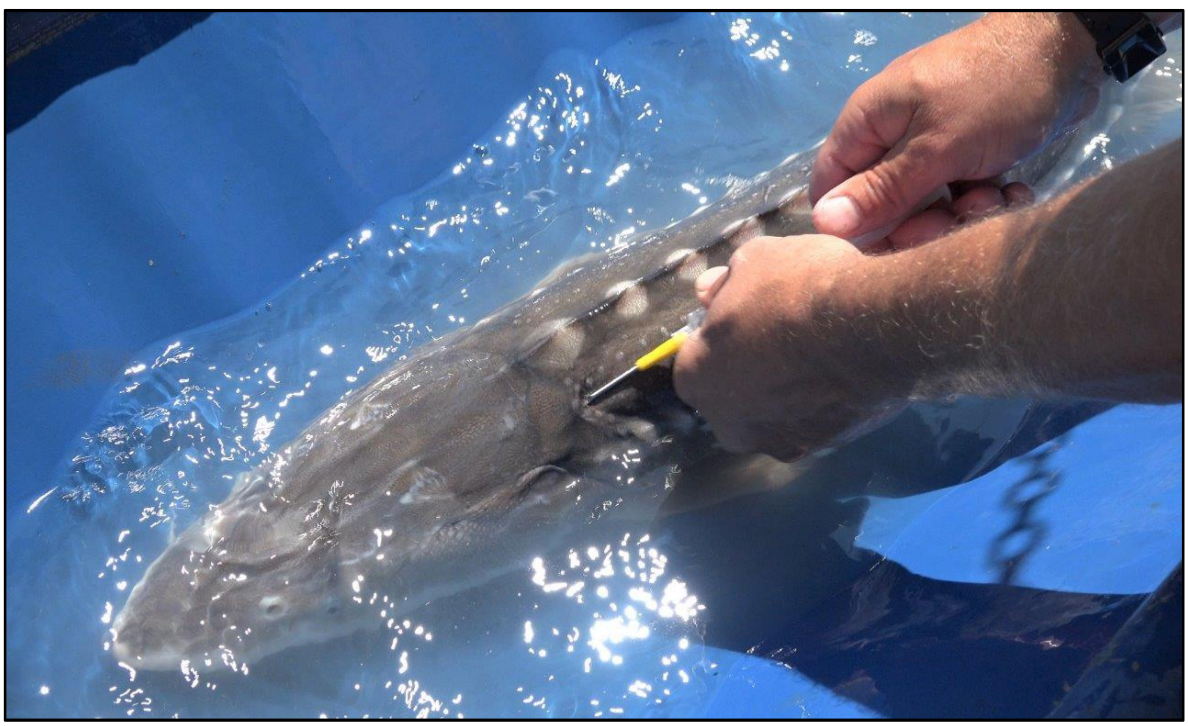
Notes – Appendix C: This appendix presents the bulk of the samples used in the BMR24 models. These records do not account for fish that grew into or out of the 60-279 cm FL range during respective assessment periods, whereas the BM24 modelling does account for growth. Also, some of the observations presented in this table were excluded from the BM24 analyses, based either on their time at large or the gear type used in capture.

PHOTOGRAPHS

"White Sturgeon in wetted sling – ready for sampling" *photo by Tony Nootebos, Volunteer - Lower Fraser River White Sturgeon Monitoring and Assessment Program.*

"Scanned for the presence of a PIT tag" *photo by Rob Dieleman, Volunteer - Lower Fraser River White Sturgeon Monitoring and Assessment Program.*

"PIT tag and tag applicator" *photo by Rick Hansen, Volunteer - Lower Fraser River White Sturgeon Monitoring and Assessment Program.*



"Applying a PIT tag in the head location" *photo by Rick Hansen, Volunteer - Lower Fraser River White Sturgeon Monitoring and Assessment Program.*

"Taking girth measurement" *photo by Rob Dieleman, Volunteer - Lower Fraser River White Sturgeon Monitoring and Assessment Program.*

"Taking fork length measurement" *photo by Rob Dieleman, Volunteer - Lower Fraser River White Sturgeon Monitoring and Assessment Program.*

"Lower Fraser River First Nations - White Sturgeon Monitoring and Assessment" *photo by Jim Rissling, Volunteer - Lower Fraser River White Sturgeon Monitoring and Assessment Program.*

"Sampled and released in good condition" *photo by Rick Hansen, Volunteer - Lower Fraser River White Sturgeon Monitoring and Assessment Program.*