LOWER FRASER RIVER WHITE STURGEON

MONITORING AND ASSESSMENT PROGRAM

SUMMARY REPORT

STATUS OF WHITE STURGEON IN THE LOWER FRASER RIVER IN 2017

WITH ABUNDANCE ESTIMATES DERIVED FROM 24-MONTH BAYESIAN ANALYSES AND INTEGRATED SPATIAL AND AGE MARK RECAPTURE (ISAMR) MODELING

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VANCOUVER, BC

AUGUST 2018

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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 summary report provides abundance and status assessments (as of January 2017) derived from the FRSCS' Lower Fraser River White Sturgeon Monitoring and Assessment Program.

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 2018, volunteers had conducted 149,257 sampling events (6,673 in 2017), tagged and released 68,375 sturgeon (1,648 in 2017), and documented 74,583 recapture events of tags applied by FRSCS volunteers within the core assessment area in the lower Fraser River (4,938 in 2017).

Abundance estimates presented in this report were derived from two models: 1) a Bayesian mark-recapture model, which has been used since 2000; and 2) an Integrated Spatial and Age Mark Recapture (ISAMR) model. For the Bayesian mark-recapture model, inputs were limited to sturgeon of 60-279 cm fork length (FL), a rolling temporal period of 24 months, and four spatial sampling regions (the combination of which comprised the core assessment area in the lower Fraser River). The model incorporates information of tag distribution, seasonal mixing, growth, and estimates of mortality, emigration, and observer error. The Bayesian model produces our best estimates of the abundance of 60-279 cm FL White Sturgeon in the core assessment area of the lower Fraser River during each 24-month period. The ISAMR inputs were limited to angled sturgeon of up to age 58 (283 cm FL), used all available captures within the assessment period, and adjusted for age-specific differences in gear selectivity. Age-structured modeling allowed for abundance projections.

The core assessment area 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. Although White Sturgeon are captured and sampled by FRSCS volunteers throughout the general study area, over 99.2% of all samples collected since 2000 have been taken within the core assessment area. By consistently imposing this spatial limitation from 2000 to the present, abundance estimates can be compared among assessment years.

Abundance Estimates, Trends, and Forecasts

Current abundance estimates for White Sturgeon in the lower Fraser River, derived from two independent models, suggest that abundance is well below historic levels, and has been declining since 2005. The mean 2017 abundance estimate for 60-279 cm FL White Sturgeon in the core assessment area was 34,860 (95% CLs ± 10.3% of the estimate). The total abundance estimate for 2017 was 38.2% lower than the program's highest annual abundance estimate in 2003, and 17.3% lower than the 2016 estimate.

The observed decline in the total abundance of White Sturgeon in the lower Fraser River since 2003 was likely driven mostly by declines in juvenile recruitment into the population. During this same time period, we estimate that abundances of larger-sized sturgeon (>160 cm FL) have increased. While an increasing number of larger-sized sturgeon provides potential security for population rebuilding and recovery, this can only be realized if juvenile recruitment occurs at a level sufficient to maintain and grow the population over time. Yet, the models indicate that significant recruitment reductions have occurred since 2004, with especially large declines in the smallest size groups (60-

79 cm FL and 80-99 cm FL). The monitoring and assessment program has documented three lines of evidence to suggest that juvenile recruitment is currently a primary concern for the long-term sustainability of the lower Fraser River population of White Sturgeon:

- Results of the mark-recapture modeling indicated that since 2004 there has been a 69.1% decline in the estimated abundance of 60-99 cm FL juvenile sturgeon in the core assessment area of the lower Fraser River.
- The proportion of juvenile White Sturgeon less than 100 cm FL in the total measured sample captured by angling decreased 66.3% between 2000 and 2017.
- The proportion of juvenile White Sturgeon less than 100 cm FL in the total measured sample captured by the Albion Test Fishery decreased 67.1% between 2000 and 2017.

Abundance forecasts predict that at current recruitment and morality rates, the population will continue to decline into the foreseeable future, with a possible leveling in approximately 40 years (i.e., late 2050's). Specifically, the 100-159 cm FL size group is expected to continue to decline until 2030. Larger sturgeon (160-279 cm FL) are predicted to start declining in the early 2020's and are expected to continue declining until approximately 2060.

Forecast modeling indicates that an immediate 60% increase in juvenile recruitment into the population, with sustained levels of annual recruitment at that level (1.6 times current levels), would result in a continuation of total abundance decrease for approximately seven years, followed by a gradual increase in abundance that would stabilize back to 2017 levels by approximately 2035. Under this scenario, larger sturgeon (i.e., 160-279 cm FL) abundances are still expected to peak in the early 2020's, then decline until approximately 2055.

These population abundance forecasts suggest immediate action should be implemented to improve age-1 recruitment, with medium- and long-term goals of increasing the abundances of 60-279 cm FL (i.e., age 7-55) and 160-279 cm FL (i.e., age 23-55) sturgeon. We recommend an interim population recovery goal for 60-279 cm FL sturgeon should be set at an abundance of 60,000 fish within the core assessment area; we believe this goal to be realistic in that this level of abundance was observed as recently as 2005. An interim long-term goal for the spawning component of the population (160-279 cm FL sturgeon) should be set at 20,000 fish within the core assessment area. Indications that progress has been made to achieve these interim goals would include a significant increasing trend in the abundance of 60-99 cm FL (age 7-12) sturgeon by 2025 (Challenger et al. 2017).

Growth

Average annual growth rates for most size groups of 60-179 cm FL White Sturgeon were greater before versus after 2005. The average growth rate for all size groups in 2017 (3.0 cm/year) was the lowest annual growth rate observed since the beginning of the program and is 46.3% lower than the average annual growth rate of 5.7 cm/year estimated for 2002.

Mortalities

The number of reported sturgeon mortalities (31) in 2017 in the lower Fraser River was high compared to previous years. For sampled mortalities (21), 81% were recaptured (tagged), and 57% were mature adults over 160 cm FL (38% were over 200 cm FL). All dead sturgeon sampling events in 2017 occurred in either August, September, or October, and the likely cause of death could not be determined (unknown) for 76% of the fish sampled.

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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 2018. 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, 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 2017 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 is the Fraser River watershed downstream of Hell’s Gate, which is located at river kilometer (rkm) 212 on the mainstem Fraser River (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, over 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.

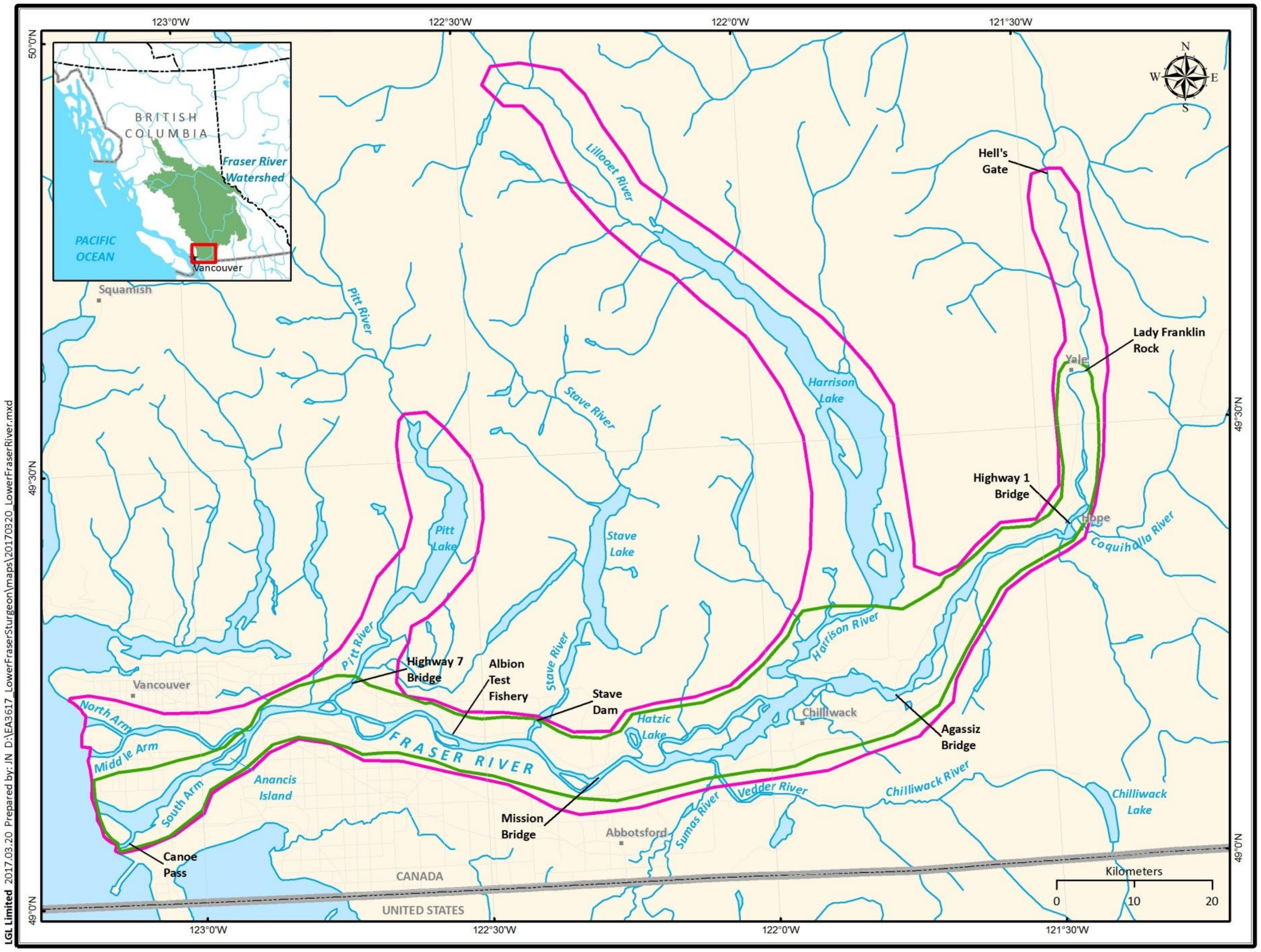

Figure 1. **General study area (area within red line), and the core assessment area (area within green line; used for the production of White Sturgeon abundance estimates presented in this report). The general study area as illustrated presents the extent of known/observed White Sturgeon distribution 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 fishery managers. 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 “PIT” (passive integrated transponder) tag, record all tag recapture data (from any PIT tag or external tag), apply new PIT tags (if one is not already present), take fork length (FL) and girth measurements, 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).

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.

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

Table 1. Sampling zones used for abundance estimation of White Sturgeon, 2016-2017.

Zone	River Km	From	To
S*	0-25	Georgia Strait	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 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)

Table 2. Sampling regions (A, B, C and D) used for abundance estimation of White Sturgeon, 2016-2017. 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	Georgia Strait to Eastern Annacis Island (South Arm of Fraser)
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 the Harrison River
D	14	Hwy 1 Bridge (Hope) to Lady Franklin Rock (Yale)

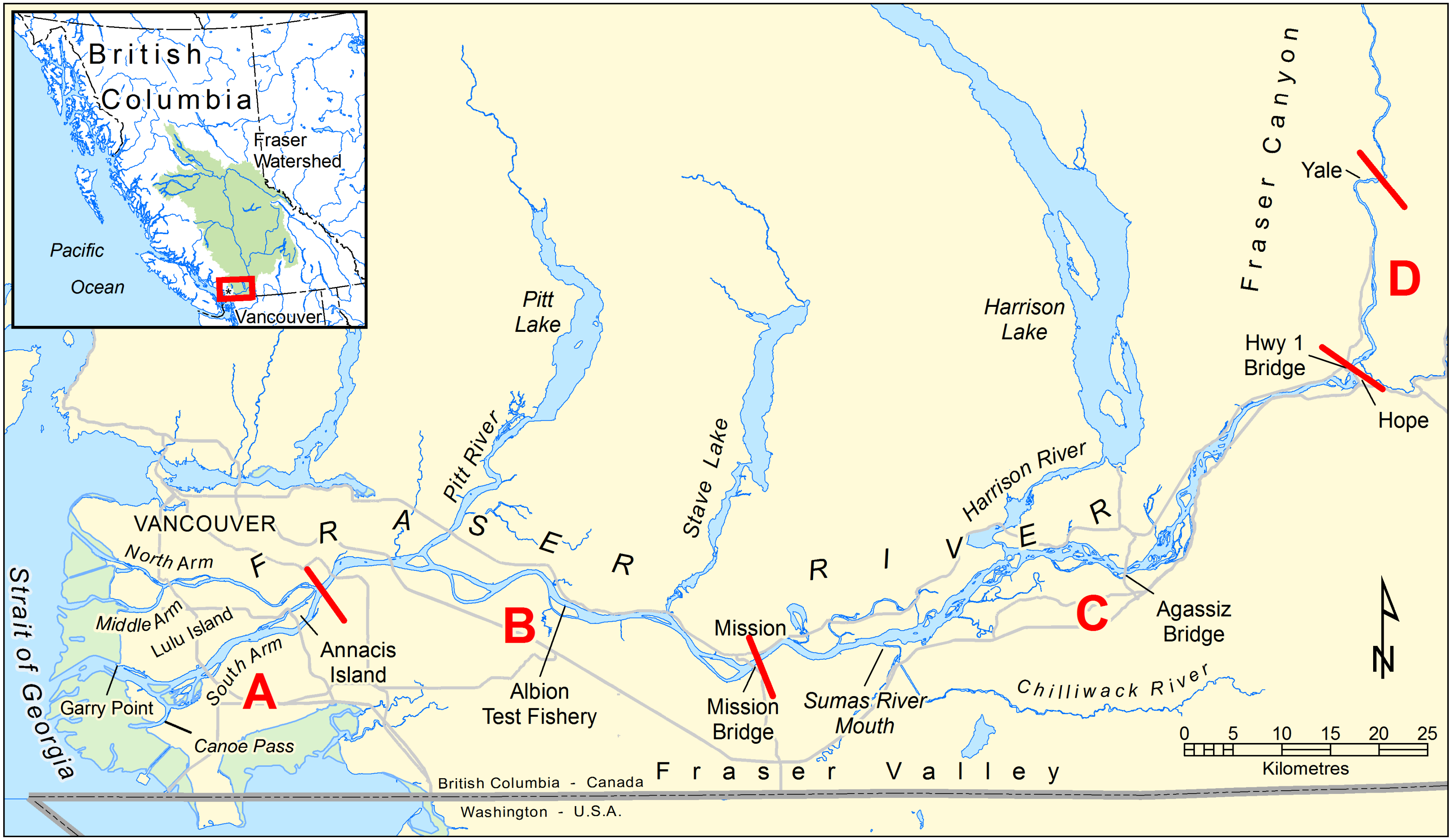

Figure 2. **Boundaries of the four sampling regions (A, B, C, and D) that comprise the core assessment area used to generate abundance estimates of White Sturgeon presented in this report. Each sampling region is made up of individual sampling zones used in the analytical model to stratify tag release 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.**

beneath the skin of sturgeon with a specialized hand-held syringe and hypodermic needle. PIT tag models used in this study were TX1400L and BIO12.A.02 (both 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.

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, has been used by sturgeon researchers in both Oregon and Washington, and measured tag retention has been close to 100% (Tom 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 the hand-held models MPR (125 kHz) and GPR Plus (dual-frequency 125 kHz and 134.2 kHz) distributed by Biomark Inc., and the AVID Power Tracker (125 kHz) from AVID Canada, distributed by PETIDCO, Calgary, Alberta. 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.

Tag Recoveries

An essential element of the abundance model used in this program was the positive identification and documentation of both tagged and non-tagged sturgeon in the sample. 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, and elsewhere have applied both PIT and various types of external tags to 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 outside this program were entered into the core program database, and in many cases original release data were obtained from respective research programs.

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 pectoral fins at a point just posterior to their insertion point.

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 of body cavity (the latter enables the carcass to more easily sink). PIT tag numbers of recaptured mortalities recovered were excluded from subsequent abundance analyses.

Data Management

Volunteers were trained to secure data sheets at the end of each sampling day. The original data 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 adapted a Bayesian mark-recapture model for closed populations (Gazey and Staley 1986) to accommodate growth, movement, mortality of marked sturgeon, non-detection of marks, and sparse recaptures on any given day or area. Detailed data assembly procedures and mathematical description of the 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 bounded by 60-279 cm FL, a rolling data window of two years (e.g., the 2017 estimate consists of data extracted from January 2016 to December 2017), and four spatial sampling regions (Table 2, Figure 2). 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.

Table 3. Parameter estimates for linear and non-linear sturgeon growth models from 2008-2009.

Parameter	Estimate	Std Error	R^2
Linear			
Daily Increment	8.212E-03	4.100E-04	0.158
Non-Linear von-Bertalanffy			
L_∞	532.6	15.8	
g	2.076E-05	1.003E-06	

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 the von Bertalanffy curve (see Fabens 1965; Table 3). Growth parameters were estimated from the mark-recapture data (length-at-release, length-at-recapture, and time-at-large). The estimated growth parameters 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.

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 the 2016 assessment year, the size range used in the abundance model was 40-279 cm FL. In 2016, this size range was changed to 60-279 cm FL as a result of a review of confidence levels associated with estimates of fish smaller than 60 cm FL (Nelson et al. 2017). For comparative purposes, we have recalculated (and document herein) abundance estimates for assessment years prior to 2016 using the new (60-279 cm FL) size range.

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 (2017 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 for total abundance estimates 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.

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 or four groupings would be used.

Integrated Spatial and Age Mark Recapture (ISAMR) Modeling

A summary of ISAMR modeling methodology is provided in Appendix C.

RESULTS

Sampling Effort for Mark-Recapture Abundance Estimates

From October 1999 through December 2017, program volunteers working in the core study area of the Lower Fraser River White Sturgeon Monitoring and Assessment Program (Figure 1) performed a total of 142,257 unique sturgeon sampling events that included the inspection of sturgeon for the presence of a PIT tag (Appendix B). Of this total sample, 68,375 sturgeon were tagged with a PIT tag (in the head location) and released. The total sample also includes 74,583 recapture events, 45.3% of which were repeat recapture events (recaptures of tagged sturgeon that had been previously recaptured). In addition, the total sample includes 6,276 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, 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).

The annual number of White Sturgeon sampled was fairly consistent from 2000-2017 (average of 8,267 sturgeon examined per year, with a range from 4,389 to 12,118 (Appendix B). The relative monthly contribution to respective annual total samples has remained relatively consistent throughout all years (2000-2017; Figure 3). The variability of sample size between months is the result of variability in three main factors: fishing effort applied, catch-per-effort, and sturgeon catchability. Sampling effort declined in 2016 (7,879 samples) and again in 2017 (6,673 samples) within the core assessment area; in 2017, this decrease was primarily the result of a reduction in the number volunteers that contribute to the program.

Three sources provided over 98% of samples over the term of the program through 2017: angling (91.7%), Albion Test Fishery (3.7%), and First Nations gill nets (3.3%). An additional 0.6% of the total sample was provided through dedicated sampling efforts using tangle nets associated with both

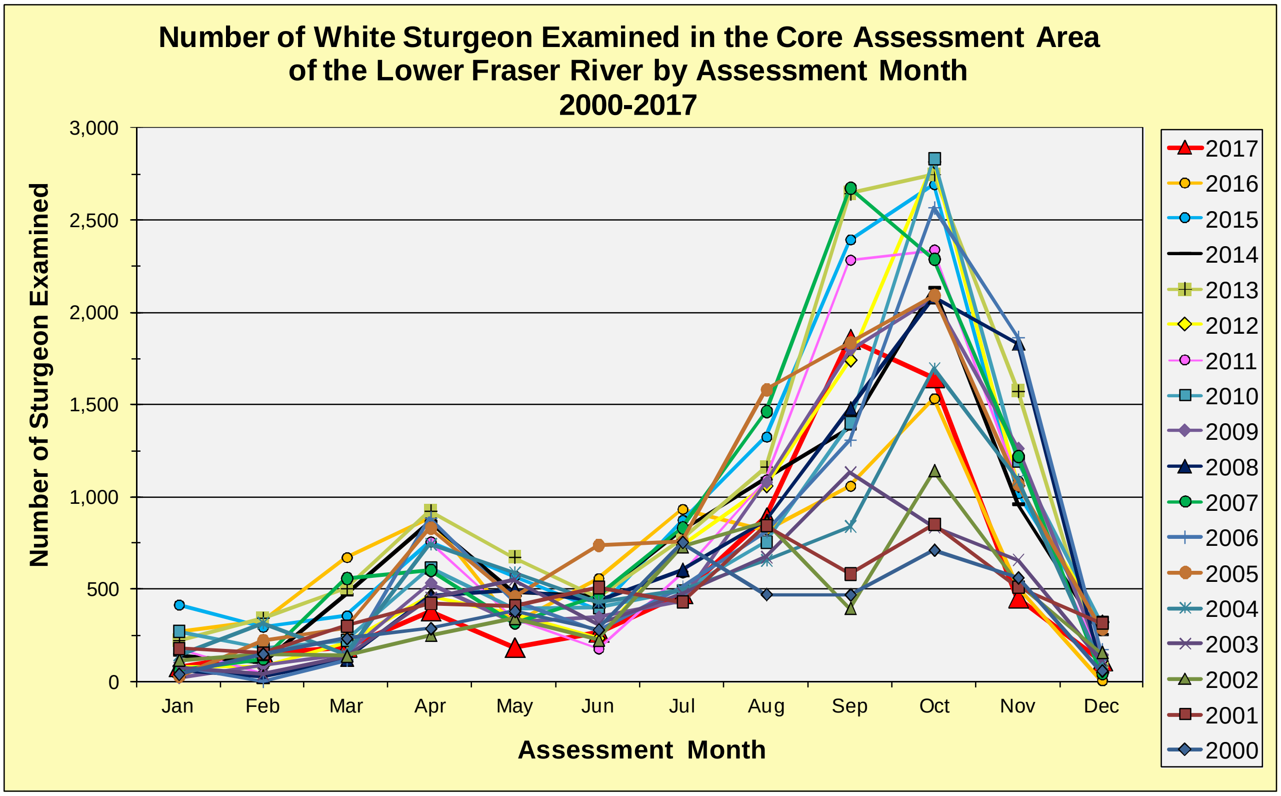

Figure 3. Number of White Sturgeon examined for the presence of a PIT tag in the core assessment area of the lower Fraser River, by assessment month, 2000-2017.

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). Approximately 0.7% of samples were provided by a mix of commercial net fisheries, enforcement (illegal retention/poaching) incidents, and both sourced and unsourced mortalities.

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. Movements in relation to size group and time of year (season) were explored and incorporated in the analytical processes of the program, as were the spatial distribution of samples over time. 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. Many individual tagged sturgeon have been recaptured and sampled numerous times (see Discussion section).

Mark Rates

An illustration of the annual numbers of tags applied, and reported number of tag recaptures, 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 18 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

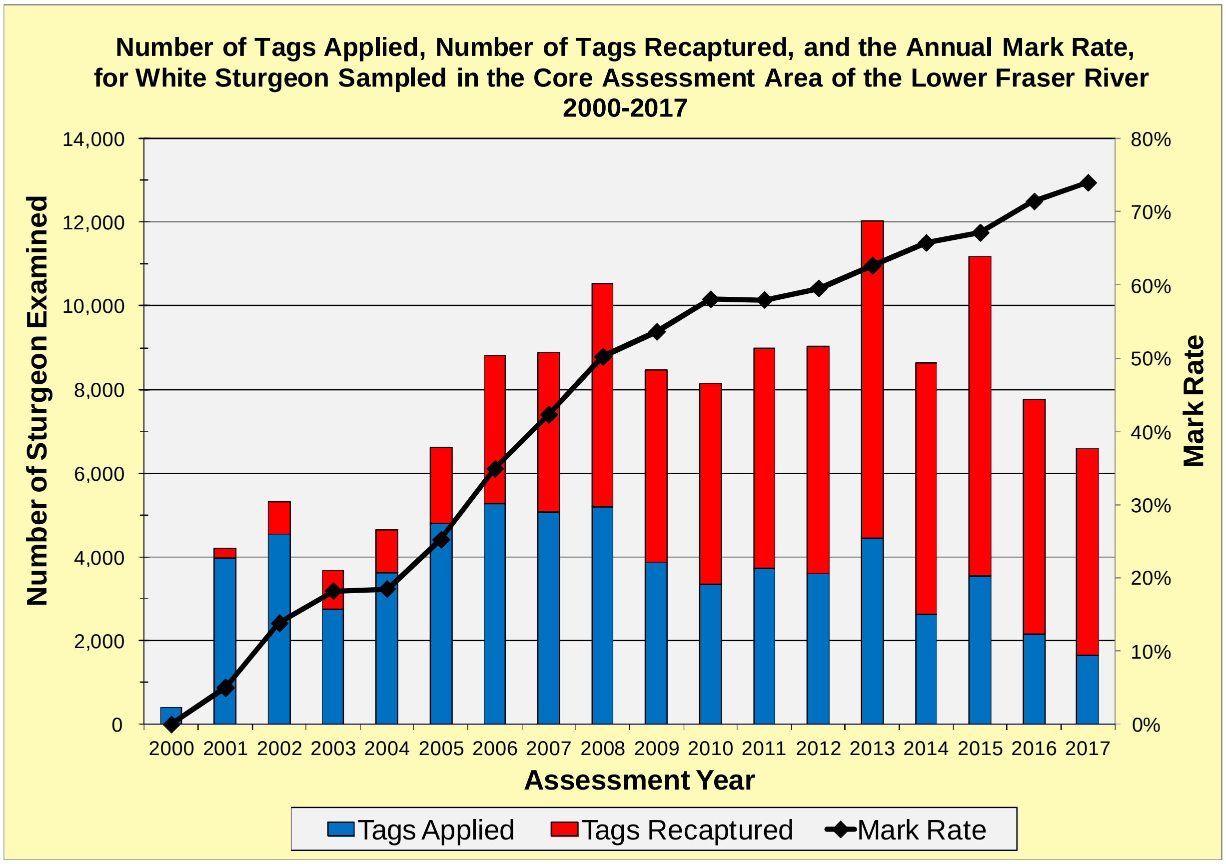

Figure 4. **Number of tags applied, reported number of tags recaptured, and the annual mark rate, for White Sturgeon sampled in the core assessment area of the lower Fraser River, by assessment year, 2000-2017.**

samples included in the 2001 abundance model calculations (samples from 2000 and 2001) were new tags applied, whereas only 26% of the samples used to produce the 2017 abundance estimates (samples from 2016 and 2017; Figure 4) were new tags applied.

In 2017, FRSCS volunteers applied 1,648 PIT tags and recaptured 4,938 tagged sturgeon in the core assessment area (Appendix B, Figure 4). The overall mark rate for the core assessment area in 2017 was 74.0% (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 2017 was 90.0% (Figure 5).

Monthly variation in White Sturgeon mark rates within the core assessment area was evident for each of the assessment years (Figure 6), and patterns have emerged that suggest an influence of season on mark rates. The most striking of these are the lower mark rates observed during winter months. For example, winter mark rates (December-February) after 2009 have in some years been 10-20% lower than summer mark rates (July-September; Figure 6). The mark rate for the core assessment area in 2017 varied from a low of 46.4% in December[1] to a high of 79.7% in November (Appendix B, Figure 6). This seasonal variation could be linked to varying use of habitats (especially overwintering habitat) combined with seasonal changes in angling effort behaviour by program volunteers.

[1] The mark rate for December 2017 (46.4%) is based on a low sample size (n=110).

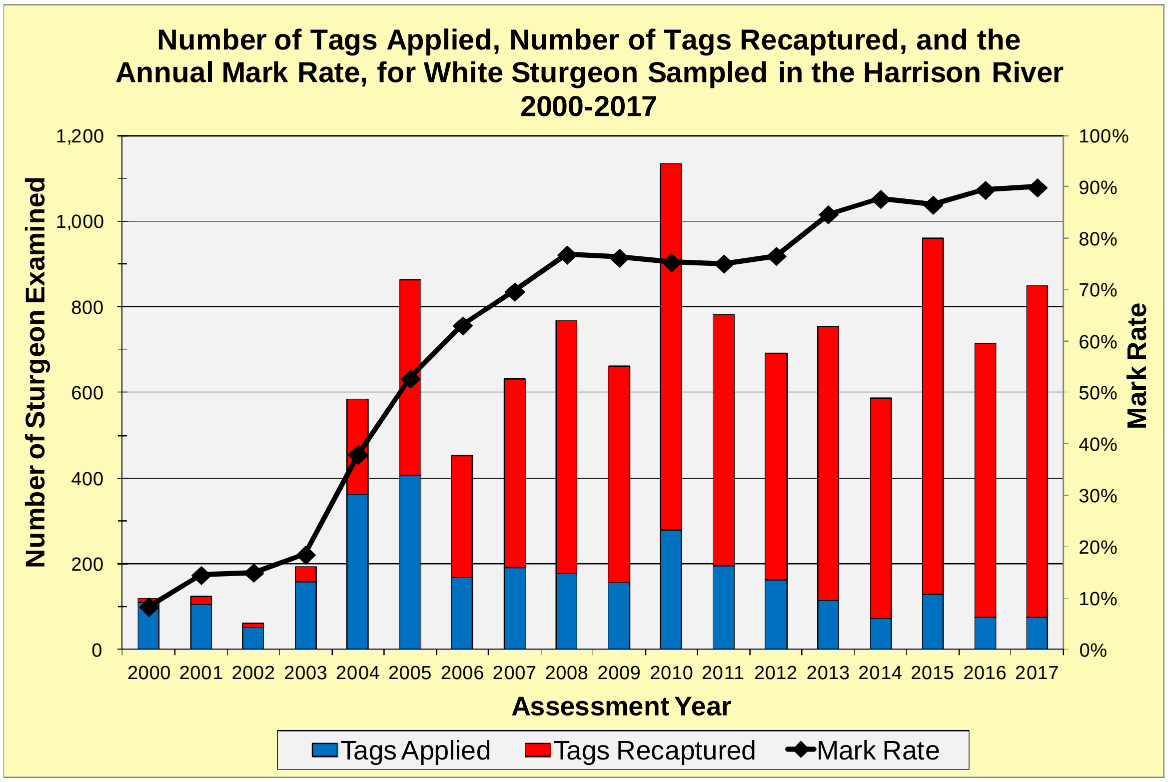

Figure 5. Number of tags applied, reported number of tags recaptured, and the annual mark rate, for White Sturgeon sampled in the Harrison River, by assessment year, 2000-2017.

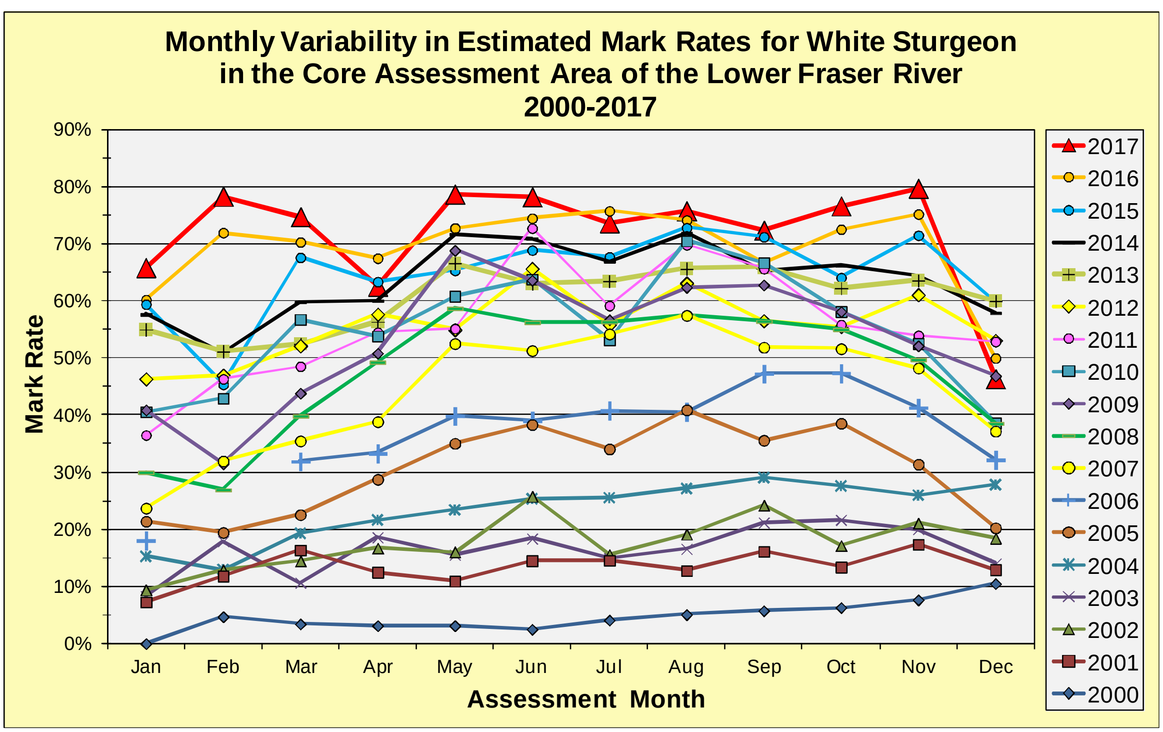

Figure 6. Monthly variability in estimated mark rates for White Sturgeon in the core assessment area of the lower Fraser River, 2000-2017.

Abundance Estimates

The Bayesian mark-recapture model produced a total abundance estimate of 34,860 White Sturgeon from 60-279 cm FL (95% CLs ± 10.3% of the estimate; Table 4) as of January 2017 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 15,368 fish (44.1% 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 19,492 fish (55.9% of the total abundance estimate; Table 4, Figure 7).

The 2017 total abundance estimate is 17.3% lower than the respective 2016 estimate, and 38.2% 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 (close to 45,000 fish), and were followed in 2003 by an increase to 56,384 fish (Figure 8). Since 2003, total annual abundance estimates indicate a general population decrease, with significant decreases in 2005 and 2009, and again in 2017 (Table 5; Figure 8).

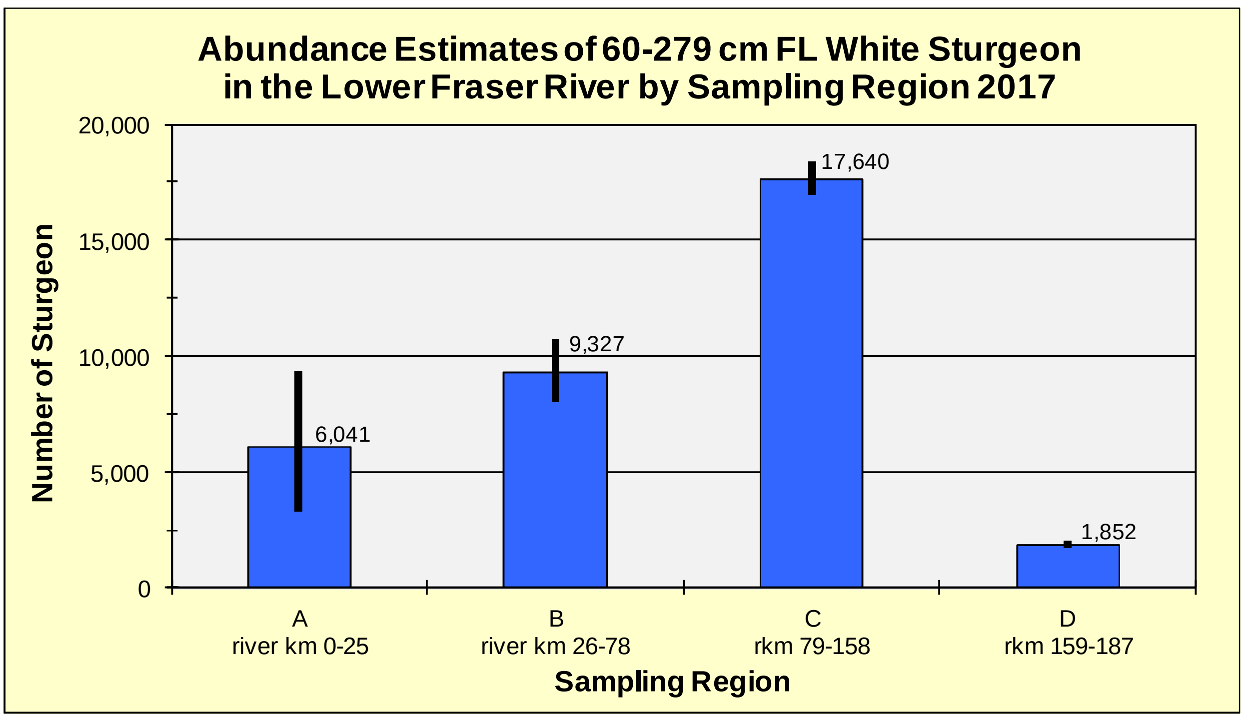

Figure 7. Abundance estimates of White Sturgeon (60-279 cm FL) in the lower Fraser River, by sampling region (A, B, C, and D; see Table 4 and Figure 2), 2017. Error bars show the 95% Highest Probability Density. Sturgeon movement and migration within the core assessment area results in a proportional redistribution of these mean abundance estimates, by season.

Table 4. Abundance estimates of 60-279 cm FL White Sturgeon in the lower Fraser River, by sampling region, 2017.

	Sampling Region		Zone			95% HPD[2]		
	From	To	Codes[1]	Mean	Mode	Low	High	Std. Dev
A	Georgia Strait	East Annacis Island	S	6,041	5,272	3,327	9,333	1,646
B	East Annacis Island	Mission CPR Bridge	3, 5, 6, 7	9,327	9,222	8,004	10,710	693
C	Mission CPR Bridge	Hwy 1 Bridge (Hope)	8, 10, 12, 13	17,640	17,624	16,922	18,368	367
D	Hwy 1 Bridge (Hope)	Yale	14	1,852	1,845	1,715	1,993	71
			Total	34,860		31,283	38,437	1,825

[1] See Table 1

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

Table 5. Abundance estimates of 60-279 cm FL White Sturgeon in the core assessment area of the lower Fraser River, 2001-2017. See Figure 8.

Sampling Period	Assessment Year	Abundance Estimate	95% HPD[1]		Bounds as % of Abundance Estimate	CV (%)[2]	Annual % Change
			Low	High			
2000-2001	2001	44,341	41,127	47,555	7.2%	3.70%	
2001-2002	2002	46,139	42,809	49,469	7.2%	3.68%	4.1%
2002-2003	2003	56,384	51,778	60,990	8.2%	4.17%	22.2%
2003-2004	2004	53,969	50,597	57,341	6.2%	3.19%	-4.3%
2004-2005	2005	48,730	46,450	51,010	4.7%	2.39%	-9.7%
2005-2006	2006	47,118	44,783	49,453	5.0%	2.53%	-3.3%
2006-2007	2007	44,769	42,631	46,907	4.8%	2.44%	-5.0%
2007-2008	2008	43,638	41,456	45,820	5.0%	2.55%	-2.5%
2008-2009	2009	41,938	39,508	44,368	5.8%	2.96%	-3.9%
2009-2010	2010	44,093	41,193	46,993	6.6%	3.36%	5.1%
2010-2011	2011	43,630	41,672	45,588	4.5%	2.29%	-1.1%
2011-2012	2012	47,354	45,036	49,672	4.9%	2.50%	8.5%
2012-2013	2013	47,925	45,662	50,188	4.7%	2.41%	1.2%
2013-2014	2014	44,004	41,956	46,052	4.7%	2.37%	-8.2%
2014-2015	2015	45,038	41,181	48,895	8.6%	4.37%	-6.0%
2015-2016	2016	42,133	39,275	44,991	6.8%	3.46%	-4.3%
2016-2017	2017	34,860	31,283	38,437	10.3%	5.23%	-22.6%

[1] HPD - Highest Probability Density

[2] CV - Coefficient of Variation

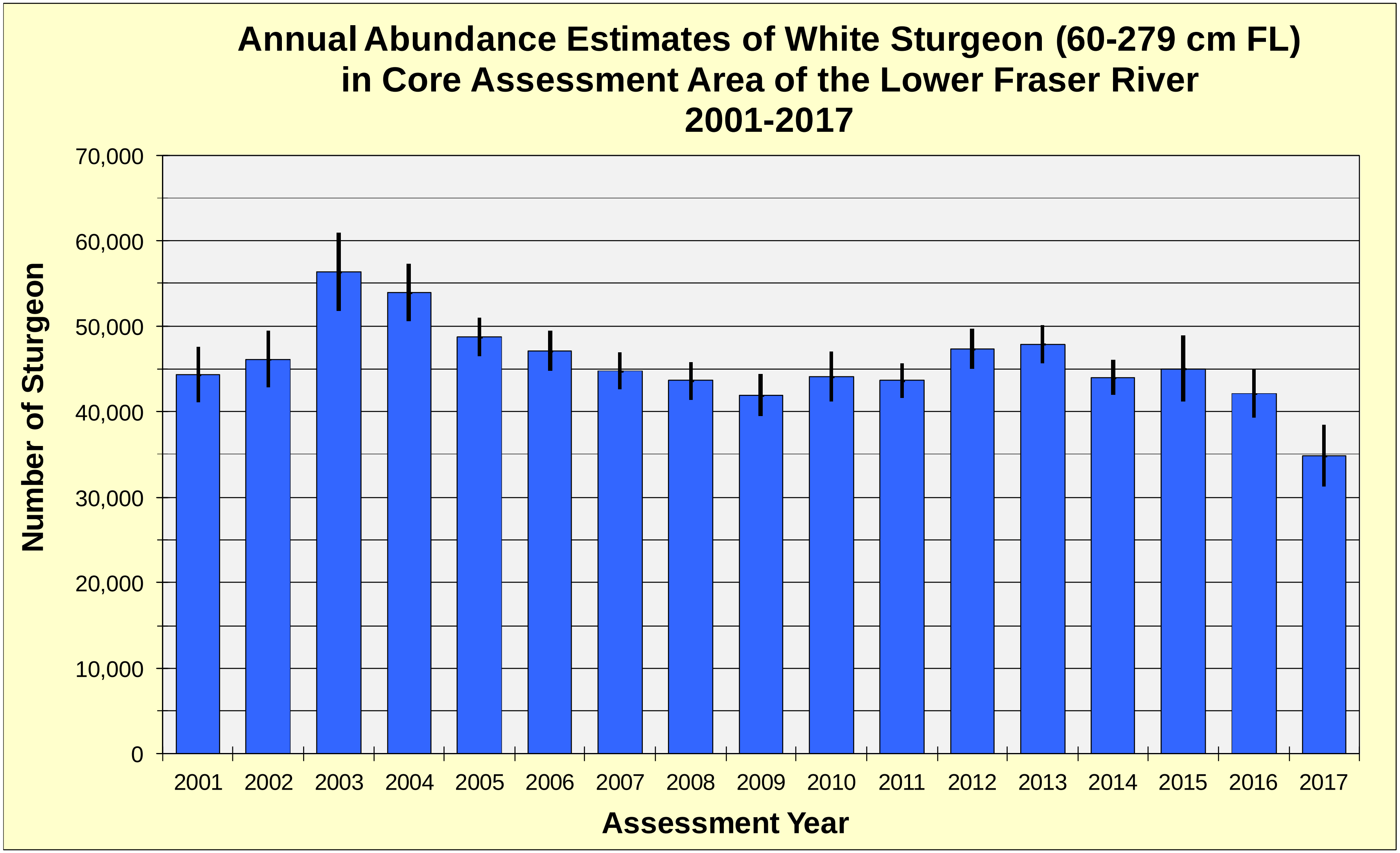

Figure 8. **Annual abundance estimates of White Sturgeon (60-279 cm FL) in the core assessment area of the lower Fraser River, 2001-2017. Error bars show the 95% Highest Probability Density. The value shown for each year is the sum of abundance estimates for the four sampling regions. The 2017 abundance estimate is 17.3% lower than the respective 2016 estimate, and 38.2% lower than the peak abundance estimate generated for 2003.**

In 2017 the estimated abundance of 60-99 cm FL juvenile White Sturgeon was 7,283 fish (Table 6), which represented a 0.80% decline from the respective estimate in 2016 (7,225 fish; Figure 9; Nelson et al. 2017). Since 2004 there has been a significant decline (69.1%) in the abundance of 60-99 cm FL White Sturgeon, concurrent with a significant increase in the abundance of larger-sized fish (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). In 2017, we estimated abundances of 14,339 fish in the 100-159 cm FL range, and 13,238 fish in the 160-279 cm FL range (Table 6). The significant decline in the abundance of 100-159 cm FL fish in 2017 (28.6% decline from the respective 2016 estimate; Table 6 and Figure 9) is further explored in the Discussion section of this report.

Abundances for 2017 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 2004-2017.

Table 6. Abundance estimates for three White Sturgeon size groups in four sampling regions in the core assessment area of the lower Fraser River, 2017. Within each 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	2,917	668	5,196	46.9
	B	1,901	1,343	2,525	16.2
	C	2,234	2,015	2,463	5.1
	D	230	204	257	5.8
	Total	7,283	4,523	10,043	19.3
100-159	A	2,529	1,023	4,589	40.9
	B	4,419	3,586	5,301	10.0
	C	7,003	6,579	7,439	3.1
	D	388	347	432	5.7
	Total	14,339	12,095	16,583	8.0
160-279	A	595	231	1,113	44.0
	B	3,007	2,093	4,020	16.7
	C	8,403	7,853	8,968	3.4
	D	1,234	1,046	1,431	8.0
	Total	13,238	11,982	14,495	4.8

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

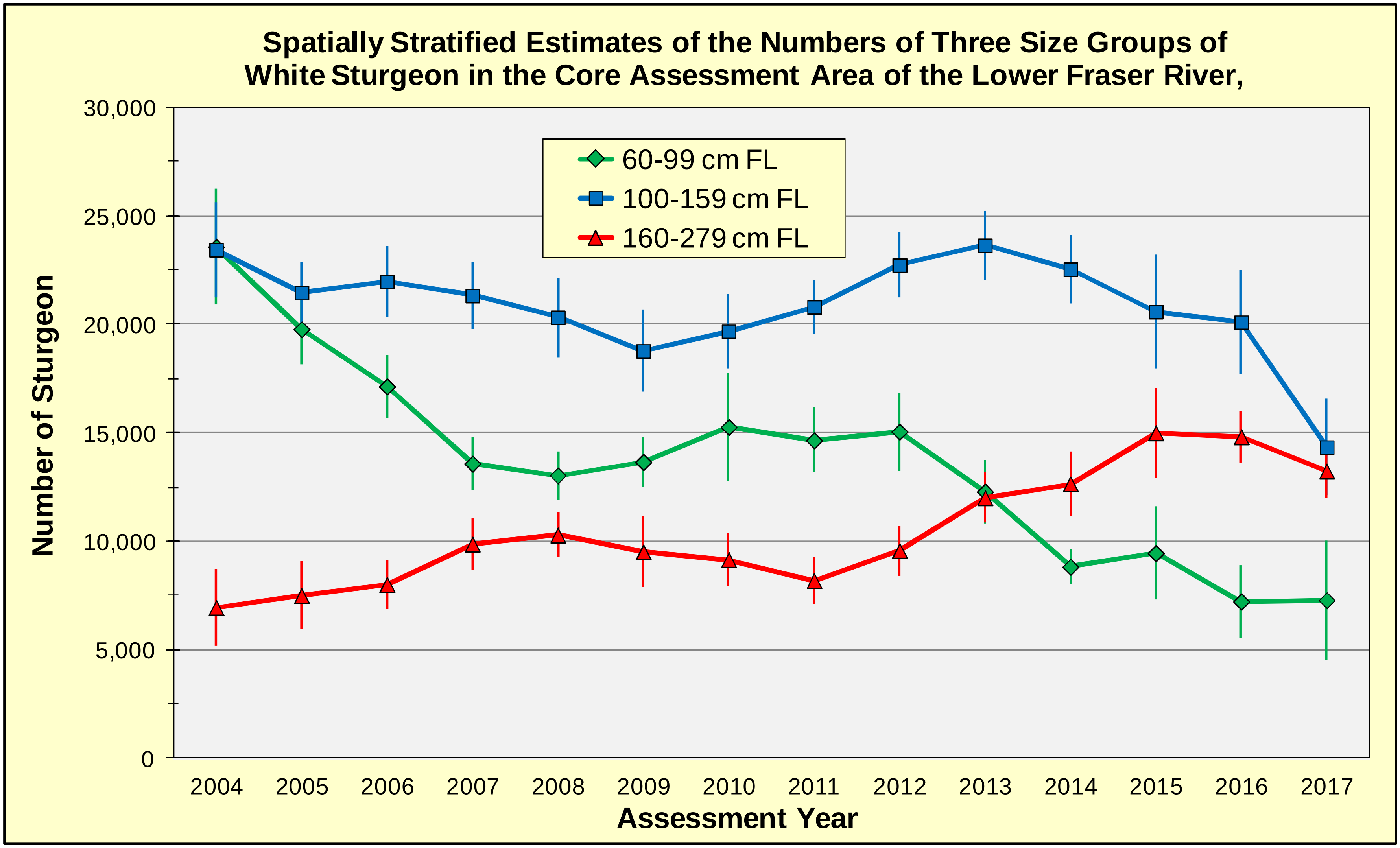

Figure 9. **Estimated White Sturgeon abundances for three size groups (60-99 cm FL, 100-159 cm FL, and 160-279 cm FL) in the core assessment area of the lower Fraser River, 2004-2017. The error bars indicate the 95% CLs for each estimate. Within each sampling region in each year, the relative abundances have been scaled such that the size-specific estimates summed to the total estimated abundance of 60-279 cm sturgeon in that sampling region for that year. See Figure 15 for additional information regarding the 100-159 cm FL size group.**

Table 7. 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, 2017. Scaled MLE values were calculated by estimating MLE for each size bin, and then scaling the results so that they summed 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	1,929	5.5	1,728	2,172	5.8
80-99	2,529	7.3	2,278	2,829	5.5
100-119	4,471	12.8	4,057	4,953	5.1
120-139	4,855	13.9	4,437	5,337	4.7
140-159	5,227	15.0	4,783	5,737	4.6
160-179	4,422	12.7	4,015	4,896	5.0
180-199	3,826	11.0	3,408	4,320	6.0
200-219	3,403	9.8	2,950	3,967	7.5
220-239	2,470	7.1	2,018	3,098	11.0
240-259	1,162	3.3	921	1,510	12.6
260-279	565	1.6	332	1,128	32.9
Total	34,860	100.0			5.2

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

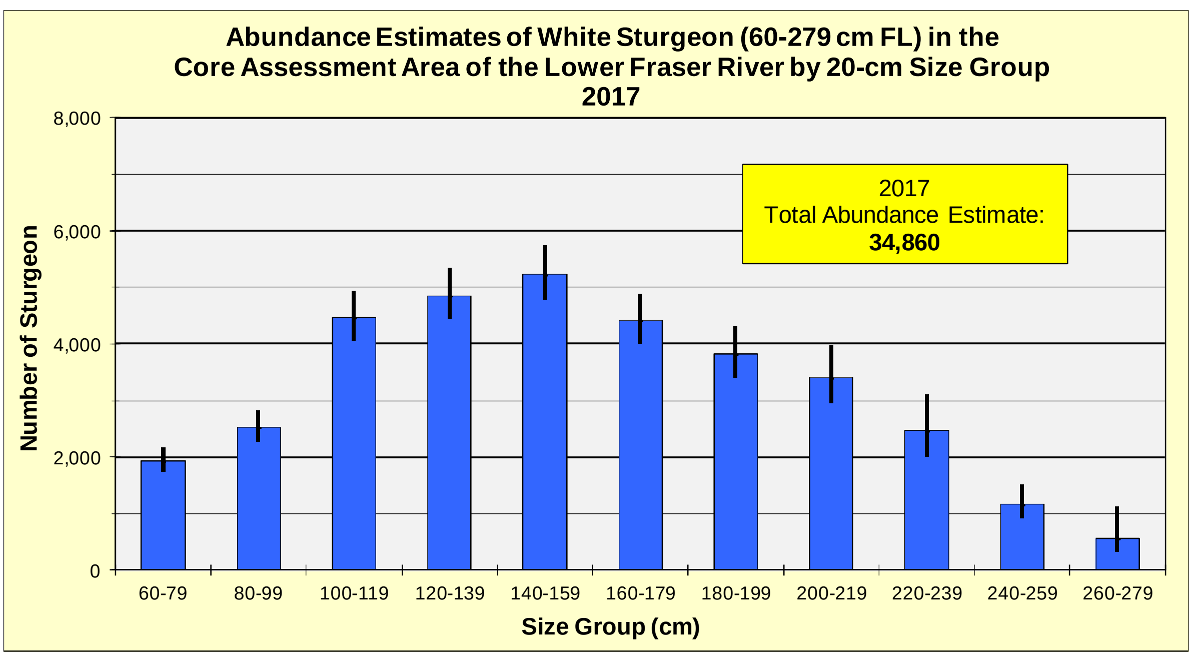

Figure 10. Abundance estimates of White Sturgeon (60-279 cm FL) in the core assessment area of the lower Fraser River, by 20-cm (FL) size group, 2017. Error bars show the 95% Highest Probability Density. See Table 7.

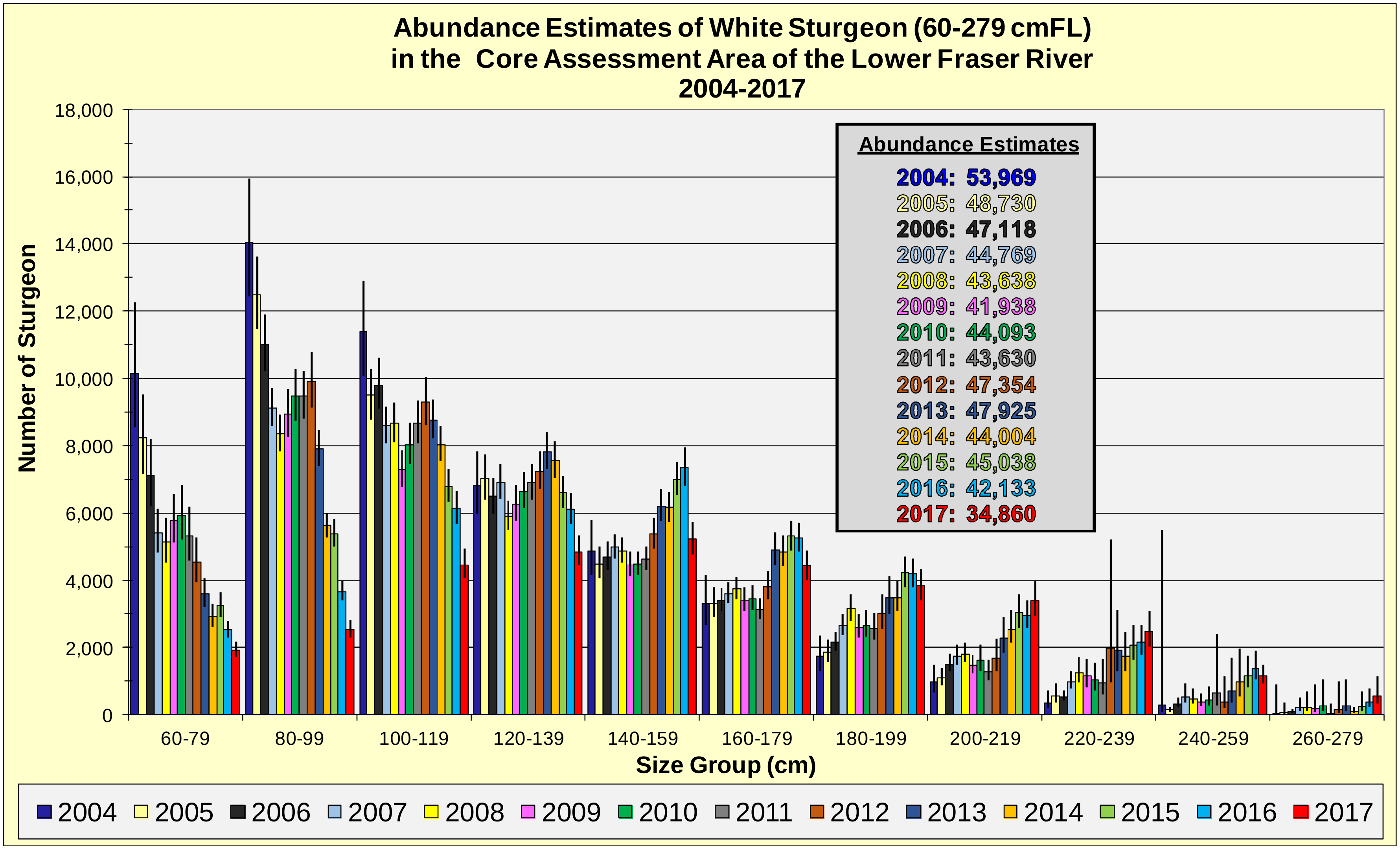

Figure 11. Abundance estimates of White Sturgeon (60-279 cm FL) in the core assessment area of the lower Fraser River, by 20-cm (FL) size group, for assessment years 2004 through 2017. Error bars show the 95% Highest Probability Density. Within each year, the relative abundances were scaled such that the size-specific estimates summed to the total estimated abundance of 60-279 cm sturgeon in the core assessment area for that year.

Growth Analyses

A comparison of average annual growth rates of White Sturgeon from 60-179 cm FL sampled from 2001-2017, 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 2017 (3.0 cm/year) represented the lowest annual growth rate observed since the beginning of the program; the respective 2016 growth rate (3.6 cm/year) was the program's previous low estimate (Nelson et al. 2017). Both the 2016 and 2017 growth rates are well below the highest average annual growth rate of 5.7 cm/year observed in 2002 (Figure 12); the 2017 average growth rate for all size groups of White Sturgeon is 46.3% lower than the respective rate in 2002.

Figure 13 provides 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, and 2013-15, and 2016-17. Average annual growth from 2005-2009 for all size groups (3.8 cm/year) represented a 32% decrease from respective previous growth rates from 2001-2004 (5.6 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 3.3 cm/year from 2016-17 (Figure 13).

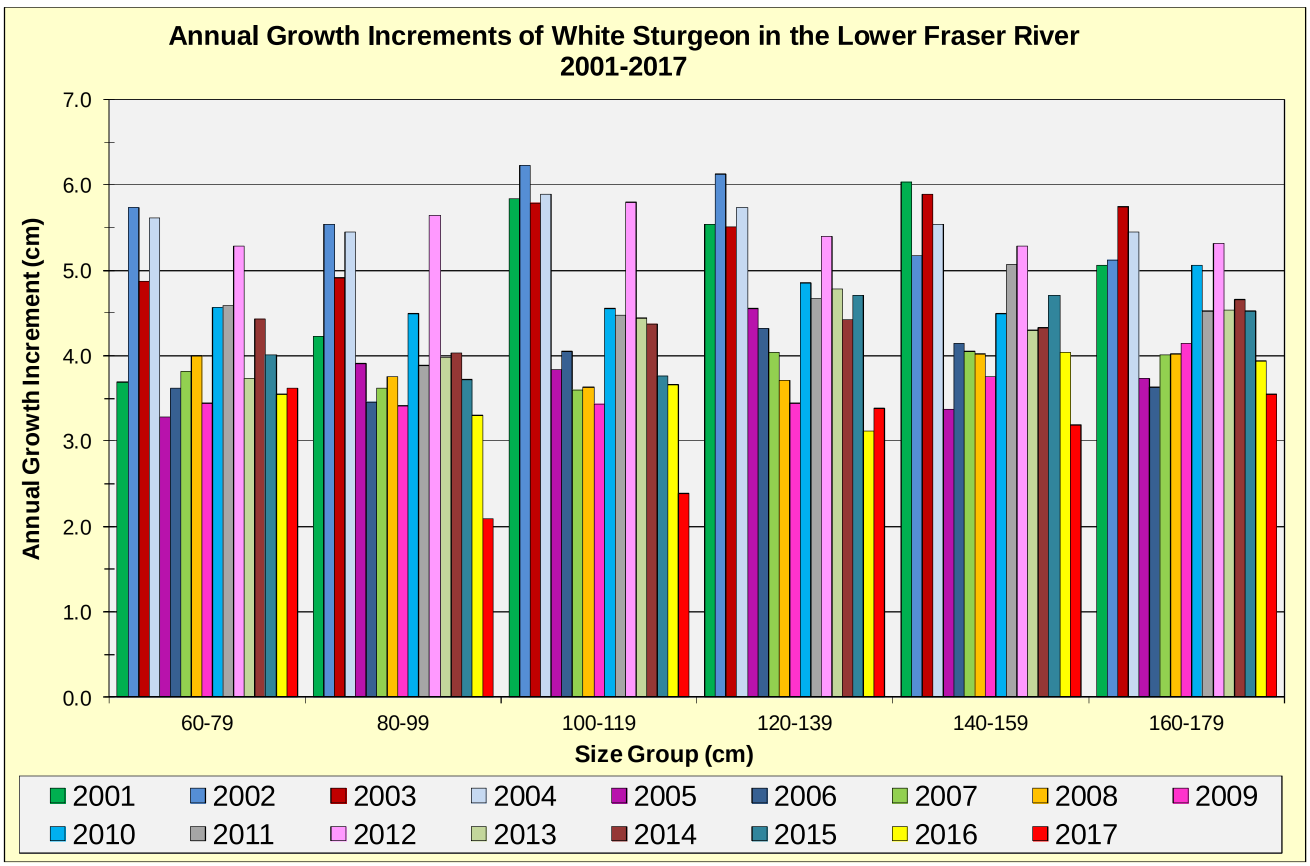

Figure 12. Average annual growth increments (cm) of White Sturgeon in the lower Fraser River, by 20-cm (FL) size group, 2001-2017. Annual growth was determined from measurements obtained from individual tagged sturgeon that were subsequently recaptured.

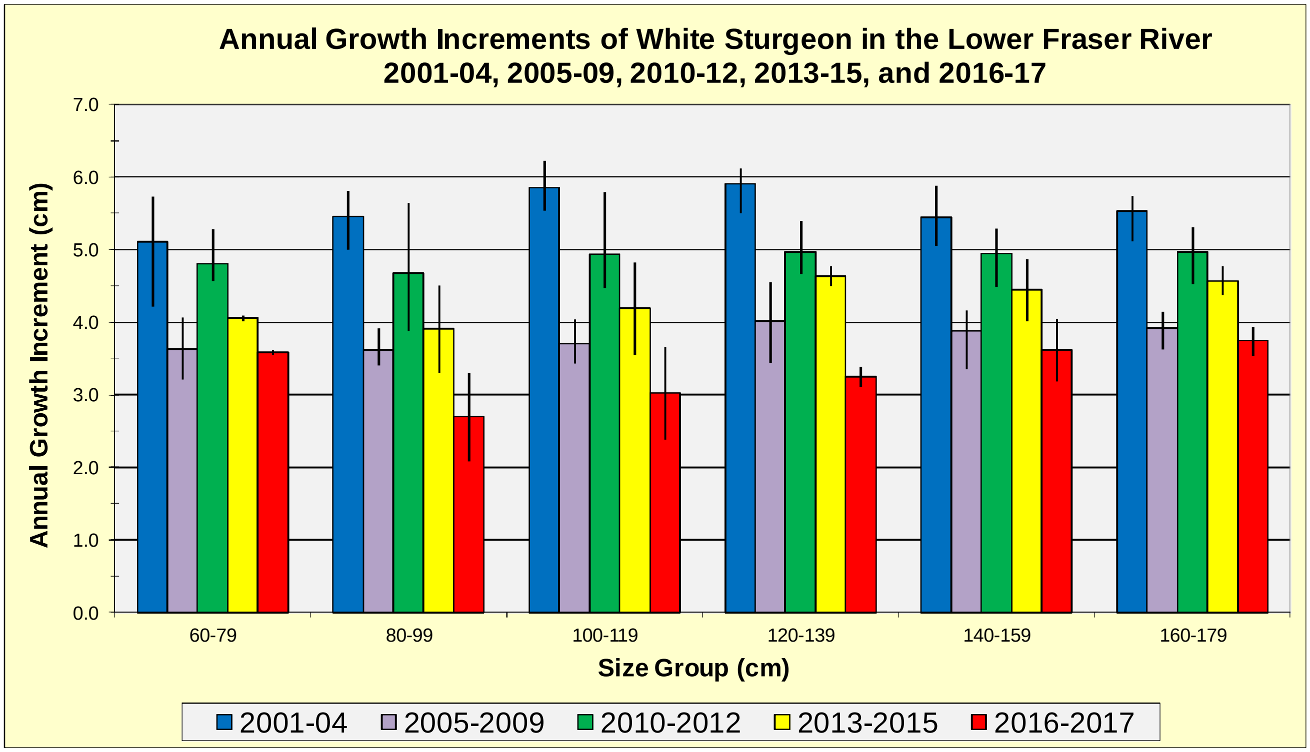

Figure 13. Average annual growth increments (cm) of White Sturgeon in the lower Fraser River, by 20-cm (FL) size group, during five time periods: 2001-04, 2005-09, 2010-12, 2013-15, and 2016-17. The error bars show the range of mean annual growth estimated for the years within each time period. The average growth rates for all size groups in 2016 (3.6 cm/year) and 2017 (3.0 cm/year) represent the lowest annual growth rates observed since the beginning of the program (average 2016-17 growth rate for 2016-17 was 3.3 cm/year).

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 Eulachon (*Thaleichthys pacificus*) and most species of salmonids may have resulted in a nutrient deficit in the lower Fraser River ecosystem, which has 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.

Mortalities

Each year, observations of dead sturgeon are reported by both program volunteers and the public in general. The number of reported sturgeon mortalities (31) in the lower Fraser River was high in 2017 compared to previous years (pers. comm., Erin Stoddard, FLNRORD). The majority (68%) of reported sturgeon mortalities were sampled (scanned for the presence of a PIT tag and measured) by program volunteers. For sampled mortalities (*n*=21), 81% were recaptured (tagged) with individuals previously sampled from 2-14 times prior to the mortality event. Of the sampled component, 57% were mature adults over 160 cm FL (38% were over 200 cm FL). All dead sturgeon sampling events in 2017 occurred in either August, September, or October, and the likely cause of death could not be determined (unknown) for 76% of the sample. Likely causes of death were determined for five mortalities (24% of the total sample); these included gill net (four sturgeon) and boat/propeller strike (one sturgeon).

Integrated Spatial and Age Mark Recapture (ISAMR) Modeling

Details results from the ISAMR modeling are provided in Appendix C.

DISCUSSION

Abundance Estimates

In 2015 we commenced using the term “abundance” rather than “population” for these estimates. The change is based on our understanding that the estimates do not represent the entirety of the population, based on our knowledge regarding the known presence of sturgeon outside of the core assessment area used in the analyses, and the omission of both small (under 60 cm FL) and large (over 279 cm FL) sturgeon in those estimates. Abundance estimates produced from data collected only from the core assessment area (Figure 1) can be considered representative “indices of abundance” (generated from the same area and for the same size groups of fish) that can be compared between and among assessment years to detect abundance trends within the total population.

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 (95% confidence intervals ± 4.5-10.3 percent of the mean; Table 5). The precision and accuracy of these estimates depended upon the input of point estimates for growth, movement, mortality, and undetected marks.

The 2016 assessment year was the first year that the analytical model used the size range of 60-279 cm FL to produce abundance estimates; prior to 2016, the size range used in the analytical model was 40-279 cm FL (Nelson et al. 2016). The exclusion of the 40-59 cm size group from the 2016 assessment was the result of a review of the levels of confidence associated with this size group, and the program objective to produce abundance estimates with high levels of confidence, and thus utility, for conservation assessment and management purposes. Abundance estimates for assessment years prior to 2016 were regenerated from the analytical model and are presented in this report as both total annual estimates (from 2001-2017) and broken-out by size group (from 2004-2017). The ISAMR estimates presented in this report integrate all mark-recapture data for all years and incorporate size selectivity curves, and thus derived the abundance estimates for all sturgeon in the population between 60 and 279 cm (7-55 age sturgeon).

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.

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 relatively short time periods. Many individual tagged sturgeon have been recaptured and sampled numerous times. For example, by December 2017, 5,396 individual fish had been sampled five times, 474 fish had been sampled 10 times, and 14 fish had been sampled 20 times; the highest number of capture events for a single sturgeon is 26. Several individual tagged sturgeon have been sampled multiple times (up to five times) during the same assessment year.

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.

Substantial 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 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 14) 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 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), and perhaps upstream movements to late-spring and early-summer spawning locations. Late-summer and fall movements 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.

Growth

The low annual rates observed in 2017 are striking (46.3% lower than in 2002) and are the lowest growth rates observed since the inception of the program. Reduced growth is likely the result of reduced food supply, and/or high levels of physical or physiological stress resulting from poor environmental conditions and excessive levels of capture events. In the 1960s, the reported

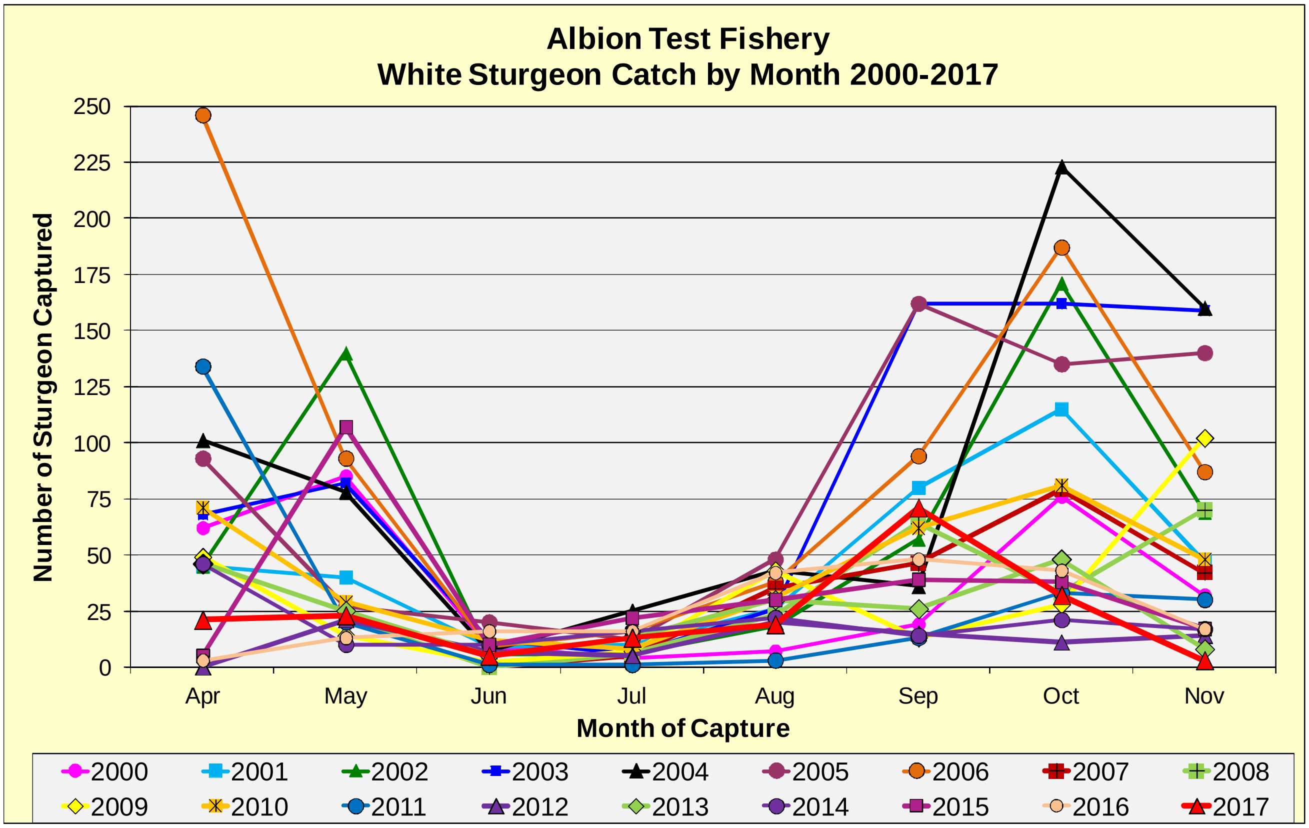

Figure 14. The number of White Sturgeon (all sizes) captured in the Albion Test Fishery during assessment net sets, by month, 2000-2017. Data from Fisheries and Oceans Canada.

average growth rate for Lower Fraser River White Sturgeon up to age 25 was approximately 5.1 cm/year (Semaluka and Larkin 1968), which is 43.7% higher than the average growth rate (2.9 cm/year) for the comparable size groups of sturgeon sampled in 2017 (Figure 12). Growth is a quantitative indicator of the general health and condition of a sturgeon population; based on 2017 growth rates, the current condition of White Sturgeon in the lower Fraser River is poorer than that estimated for earlier study years.

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 2016, and further declined in 2017 (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 2004-2017 reflects that there was a significant decline in the abundance of 60-99 cm FL sturgeon in the lower Fraser River between 2004 and 2006 (Figures 9 and 11). A subsequent decline in the abundance estimates for the 60-99 cm size group started in 2013 and has continued through 2017. 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 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:

- Reductions in spawning activity or spawning success. 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 in gill nets (that target migrating salmon) can result in both death and serious injury (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, is not available. Spawning success could be limited by limited 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.
- Increased mortality during early life stages (larval and post larval/fry). 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.
- Increased mortality of age-0 to age-4+ fish. 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 and 100-119 cm size groups (Figure 11). Conversely, the abundance estimates for White Sturgeon over 160 cm FL had been generally trending upward since 2010 (Figure 11); this is 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. While an increasing number of adult spawning sturgeon provides potential 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.

In 2017, the abundance of sturgeon from 100-159 cm FL declined sharply (Figure 11). We looked closely at the input data and estimator functions that produced this result, and have determined that the data and result are indeed valid. A closer look at this size group, parsed into 20-cm size groups, is presented in Figure 15. It appears that the steepest decline in the 100-159 cm FL category occurred in the 140-159 cm size group; this could be at least partially explained by the departure of the fish from that size group category via growth into the next size category (160-179 cm FL; Figure 11).

The proportion of small (< 100 cm FL) White Sturgeon sampled by angling has decreased continually and significantly since the beginning of the program (Figure 16). 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 2017 this proportion further declined to 18% (which is a 66.3% 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

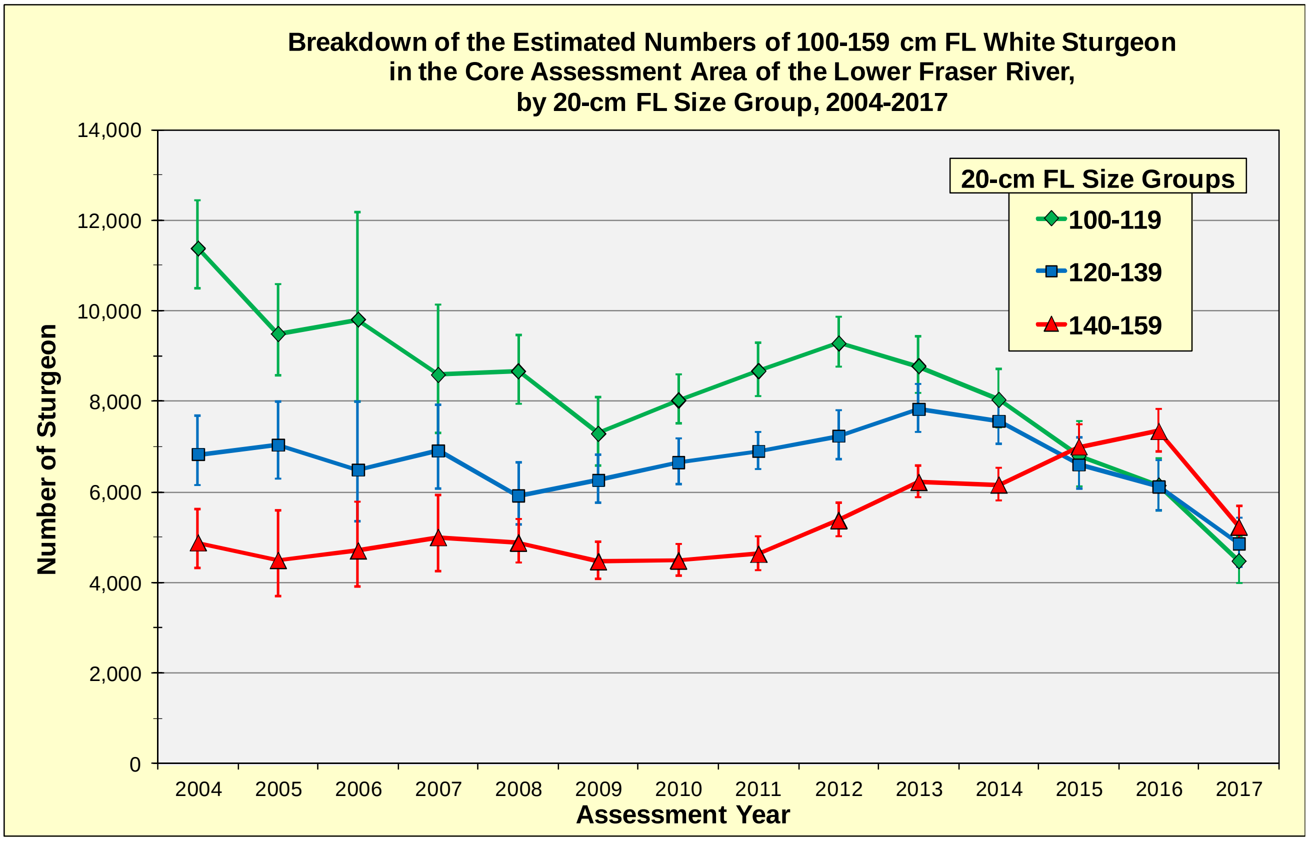

Figure 15. Breakdown of the numbers of 100-159 cm FL White Sturgeon in the core assessment area of the lower Fraser River, by 20 cm size group, 2014-2017. The abundance of these combined size groups is also presented in Figure 9.

viewing systems), fishing tackle and terminal gear that increases the likelihood of hooking and 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. In any case, the continuing decline in the proportion of juvenile sturgeon observed in the annual angling sample may be a direct reflection of the declining numbers of juvenile sturgeon present in the Lower Fraser River population.

The Albion Test Fishery, a gillnet test fishery conducted at rkm 58 in the lower Fraser River (see “Albion Test Fishery,” Figure 1), provides additional 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, 67.8% of all sturgeon captured in the Albion Test Fishery were less than 100 cm FL; by 2008 this proportion dropped to 50%; and in 2017 it further declined to 22.3% (which is a 67% decrease from 2000; Figure 17). While there have been methodological changes for this test fishery over the years (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 (< 100 cm) sturgeon sampled (especially since 2012; Figure 17). We believe that these data supply independent evidence of declining numbers of juvenile sturgeon present in the Lower Fraser River population of White Sturgeon.

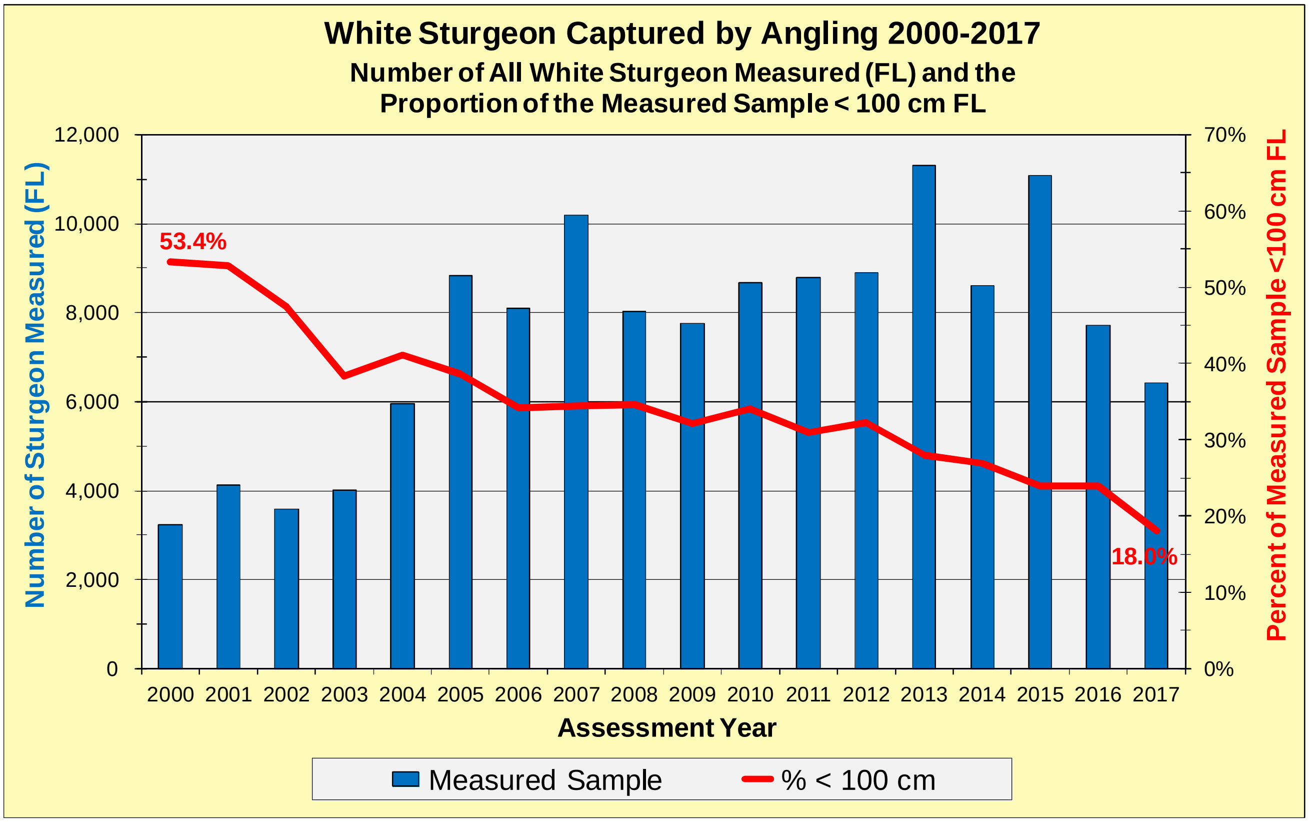

Figure 16. The annual proportions of White Sturgeon less than 100 cm FL from all measured samples captured by angling, 2000-2017. Declines reflected in this figure may be associated with declining numbers of small (< 100 cm FL) sturgeon and to changes in angler behaviour.

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 (24-month Bayesian and ISAMR) were compared across the three size groupings (Appendix C). Nevertheless, there were also noticeable deviations, especially when combining size groupings. The 24-month Bayesian 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 Bayesian analysis model uses a 24-month window analysis window, and as such the biological population of inference are sturgeon that have used the lower Fraser River within that 24-month window. In contrast, the ISAMR model considers captures from all assessment years, with a population of inference being sturgeon that have used the lower Fraser River through the assessment period (i.e., 2000-2017). 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 24-month model outputs. 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

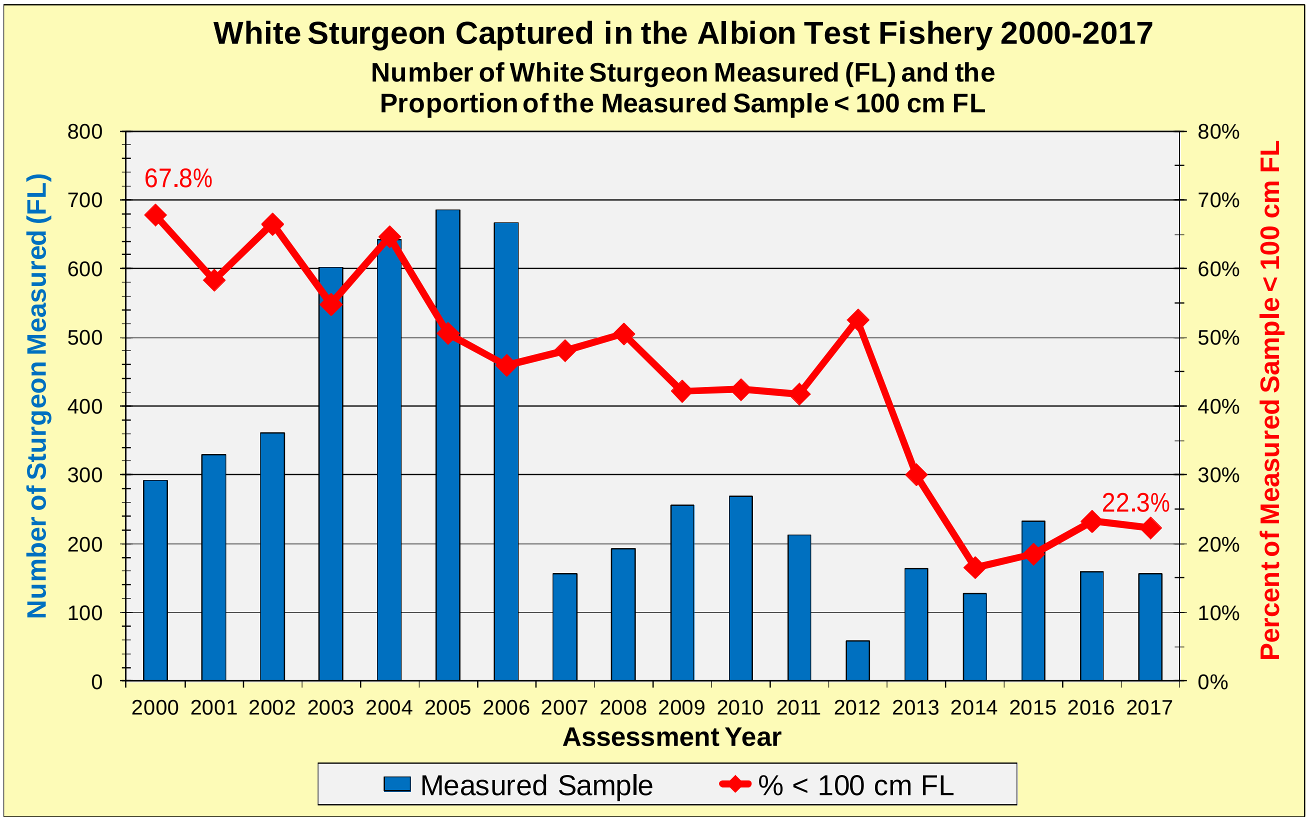

Figure 17. The annual proportions of White Sturgeon less than 100 cm FL from all measured samples captured in the Albion Test Fishery, 2000-2017. Since 2000, there has been a 67% decrease in the abundance of juvenile White Sturgeon present in total measured samples of sturgeon from the Albion Test Fishery. Methodological changes to the test fishery over the years do not explain the declines in small sturgeon proportions, especially since 2012.

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 (see Appendix C). 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. At the current rate of recruitment, the 60-279 cm FL size group (i.e., age 7-55) is projected to continue to decline over the next 40 years, which will result in an abundance level that is approximately half of the respective level in 2005. Increasing recruitment by 1.6 times the current level is projected to stabilize the 60-279 cm FL size group to the current abundance level (i.e., 2017 abundances) by 2035. 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

2010 abundance. The spawning component of the population (i.e., 160-279 cm FL; age 23-55) is currently increasing, but is projected to begin declining by early to mid 2020's, 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 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 is in a critical state of decline and instability. The 2017 abundance estimates are the lowest since the inception of the monitoring and assessment program in 2000 (the total 2017 abundance estimate has decreased by 38.2%, and is 17.3% lower than the 2016 estimate). 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.

The Lower Fraser River White Sturgeon Monitoring and Assessment Program has been operating continuously for over 18 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:

- Designing and implementing a program to monitor trends in sturgeon recruitment (i.e. the abundance of age 1-6 sturgeon in the Lower Fraser River.
- Continue to work with volunteers to sample sturgeon caught in recreational, First Nations, and test fisheries, and apply tags to untagged sturgeon in the Lower Fraser River study 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.
- The data collected each year must be checked as it is received and analyzed so data inconsistencies and/or errors are detected and corrected.
- These data analyses must include running both the 24-month Bayesian 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, 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:

- Initiate actions to increase juvenile recruitment; this should be done immediately and aggressively.
- Conserve and protect critical and important habitats, including: spawning habitat, juvenile rearing habitat, sub-adult and adult feeding habitat, and overwintering habitat.
- 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 on 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 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.
- 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 angling guides that guide for sturgeon in the tidal section of the lower Fraser River.

The FRSCS is calling on all governments (First Nation, federal, provincial, and municipal) for immediate and aggressive 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 commenced 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 the true stewards of the resource that is 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. All lower Fraser sturgeon anglers also support this work as 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.

Program support and sponsorship has been provided through partnership arrangements with provincial, federal, and non-government foundations and organizations, plus private donations. The authors would especially like to thank:

Albion Test Fishery Staff and Crew
British Columbia Institute of Technology
Canadian National Sportsmans Shows
Fisheries and Oceans Canada
Fraser Valley Angling Guides Association
Daryl Waddell
David Elliot
Habitat Conservation Trust Foundation (White Sturgeon Surcharge Fund)
Ladd Foundation

LGL Limited environmental research associates
Lower Fraser River First Nations
Mainland Sand and Gravel
Ministry of Environment
Ministry of Forest, Lands and Natural Resource Operations
North Growth Foundation
Pacific Salmon Commission Test Fishery and Crew
Pacific Salmon Foundation
Rick Hansen Foundation
Sara Ghilarducci Memorial Fund
University of British Columbia
Willow Grove Foundation

REFERENCES

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

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

COSEWIC. 2012. COSEWIC assessment and status report on the White Sturgeon *Acipenser transmontanus* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, Ontario.

Fabens, A. J. 1965. Properties and fitting of the von Bertalanffy growth curve. Growth 29:265-289.

Gazey, W. J. and M. J. Staley. 1986. Population estimation from mark-recapture experiments using a sequential Bayes algorithm. Ecology 67:941-951.

Glova, G., T. Nelson, K. English, and T. Mochizuki. 2008. A preliminary report on juvenile White Sturgeon habitat use in the lower Fraser River, 2007-2008. Report for the Fraser River Sturgeon Conservation Society, Vancouver, BC. http://www.frasersturgeon.com/media/juvenile-habitat-2008.pdf

Hildebrand, L. R., A. D. Schreier, L. Lepla, S. O. McAdam, J. McLellan, M. J. Parsley, V. L. Paragamian, and S. P. Young. 2016. Status of White Sturgeon (*Acipenser transmontanus* Richardson, 1863) throughout the species range, threats to survival, and prognosis for the future. Journal of Applied Ichthyology 32 (Suppl. 1): 261-312.

McLean, M. F., K. C. Hanson, S. J. Cooke, S. G. Hinch, D. A. Patterson, T. L. Nettles, and G. T. Crossin. 2016. Physiological stress response, reflex impairment, and delayed mortality of White Sturgeon Acipenser transmontanus exposed to simulated fisheries stressors. Conservation Physiology 4(1): cow031;doi:10.1093/conphys/cow031.

Nelson, T. C., W. J. Gazey, M. L. Rosenau, and K. K. English. 2004. Status of White Sturgeon in the lower Fraser River: Report on the findings of the lower Fraser River White Sturgeon monitoring and assessment program 1999-2004. Report for the Fraser River Sturgeon Conservation Society, Vancouver, BC. http://www.frasersturgeon.com/media/LFRWS-manuscript-2004.pdf

Nelson, T. C., W. J. Gazey, and K. K. English. 2008. Status of White Sturgeon in the lower Fraser River: Report on the findings of the lower Fraser River White Sturgeon monitoring and assessment program 2007. Report prepared for the Fraser River Sturgeon Conservation Society, Vancouver, BC. http://www.frasersturgeon.com/media/LFRWS-manuscript-2007.pdf

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

Nelson T. C., P. Doukakis, S. T. Lindley, A. D. Schreier, J. E. Hightower, L. R. Hildebrand, R. E. Whitlock, and M. A. H. Webb. 2013b. Research tools to investigate movements, migrations, and life history of sturgeons (Acipenseridae), with an emphasis on marine-oriented populations. PLoS ONE 8(8): e71552 doi:10.1371/journal.pone.0071552.

Nelson, T. C., D. Robichaud, T. Mochizuki, J. Rissling, K. K. English, and W. J. Gazey. 2016. Status of White Sturgeon in the lower Fraser River: Report on the findings of the Lower Fraser River White Sturgeon Monitoring and Assessment Program 2015. Report prepared for the Fraser River Sturgeon Conservation Society, Vancouver, BC.

Nelson, T. C., D. Robichaud, T. Mochizuki, J. Rissling, K. K. English, and W. J. Gazey. 2017. Status of White Sturgeon in the lower Fraser River: Report on the findings of the Lower Fraser River White Sturgeon Monitoring and Assessment Program 2016. Report prepared for the Fraser River Sturgeon Conservation Society, Vancouver, BC.

Rien T. A., R. C. P. Beamesderfer, and C. A. Foster. 1994. Retention, recognition, and effects on survival of several tags and marks for white sturgeon. California Fish and Game 80: 161-170.

RL&L. 2000. Fraser River white sturgeon monitoring program: Comprehensive report (1995-1999). Report by RL&L Environmental Services Ltd. for BC Fisheries, Victoria, BC.

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

Robichaud, D., K.K. English, and T.C. Nelson. 2017. Annual movements of acoustic-tagged White Sturgeon in the lower reaches of the Fraser River and its tributaries. Transactions of the American Fisheries Society 146:611-625. DOI: 10.1080/002847.2017.1204542.

Semakula, S. N. and P. A. Larkin. 1968. Age, growth, food and yield of the white sturgeon (*Acipenser transmontanus*) of the Fraser River, British Columbia. Journal of the Fisheries Research Board of Canada 25(12):2589-2602.

APPENDICES

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

FRASER RIVER STUGEON CONSERVATION SOCIETY FAX to Jim Rissling: 604-792-2630 (phone: 604-792-4368)

WHITE STURGEON BIOSAMPLING, TAGGING, AND MARK- RECAPTURE RECORDS Page:______ of ________

Name/Phone Number of Person that Recorded Data: ____________

Phone No: ____________

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	tn2OTHER	
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 - Lower Fraser River sturgeon sampling, tagging, and recapture summary, by month and year, 1999-2017

Appendix B. Summary of White Sturgeon sampled in the core assessment area (see Table 2) of the lower Fraser River, 1999-2017.

Month	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	96	89	7	0	0.0%						
Nov-99	206	182	24	0	0.0%						
Dec-99	157	143	14	0	0.0%	**1999**	459	414	45	0	**0.0%**
Jan-00	38	37	1	0	0.0%						
Feb-00	148	135	6	7	4.7%						
Mar-00	232	191	33	8	3.4%						
Apr-00	286	265	12	9	3.1%						
May-00	382	351	17	14	3.7%						
Jun-00	281	259	15	7	2.5%						
Jul-00	753	695	27	31	4.1%						
Aug-00	471	424	23	24	5.1%						
Sep-00	469	437	5	27	5.8%						
Oct-00	711	629	37	45	6.3%						
Nov-00	561	506	12	43	7.7%						
Dec-00	57	45	6	6	10.5%	**2000**	4389	3974	194	221	**5.0%**
Jan-01	178	165	0	13	7.3%						
Feb-01	152	134	0	18	11.8%						
Mar-01	299	250	0	49	16.4%						
Apr-01	423	340	30	53	12.5%						
May-01	410	360	5	45	11.0%						
Jun-01	509	427	8	74	14.5%						
Jul-01	432	355	14	63	14.6%						
Aug-01	844	717	19	108	12.8%						
Sep-01	582	484	4	94	16.2%						
Oct-01	851	711	26	114	13.4%						
Nov-01	512	417	6	89	17.4%						
Dec-01	316	197	78	41	13.0%	**2001**	5508	4557	190	761	**13.8%**
Jan-02	117	60	46	11	9.4%						
Feb-02	147	45	83	19	12.9%						
Mar-02	138	65	53	20	14.5%						
Apr-02	251	107	102	42	16.7%						
May-02	342	173	114	55	16.1%						
Jun-02	225	131	36	58	25.8%						
Jul-02	730	529	87	114	15.6%						
Aug-02	866	622	78	166	19.2%						
Sep-02	396	149	151	96	24.2%						
Oct-02	1142	582	364	196	17.2%						
Nov-02	531	187	232	112	21.1%						
Dec-02	157	97	31	29	18.5%	**2002**	5042	2747	1377	918	**18.2%**
Jan-03	72	55	11	6	8.3%						
Feb-03	39	20	12	7	17.9%						
Mar-03	131	89	28	14	10.7%						
Apr-03	451	290	77	84	18.6%						
May-03	553	383	84	86	15.6%						
Jun-03	310	180	73	57	18.4%						
Jul-03	474	311	92	71	15.0%						
Aug-03	674	473	89	112	16.6%						
Sep-03	1132	758	134	240	21.2%						
Oct-03	835	585	69	181	21.7%						
Nov-03	659	395	132	132	20.0%						
Dec-03	114	97	1	16	14.0%	**2003**	5444	3636	802	1006	**18.5%**
Jan-04	144	122	0	22	15.3%						
Feb-04	316	271	4	41	13.0%						
Mar-04	145	114	3	28	19.3%						
Apr-04	743	574	7	162	21.8%						
May-04	589	446	5	138	23.4%						
Jun-04	430	313	8	109	25.3%						
Jul-04	493	362	5	126	25.6%						
Aug-04	656	434	44	178	27.1%						
Sep-04	840	582	14	244	29.0%						
Oct-04	1695	916	311	468	27.6%						
Nov-04	1092	603	205	284	26.0%						
Dec-04	97	64	6	27	27.8%	**2004**	7240	4801	612	1827	**25.2%**
Jan-05	28	22	0	6	21.4%						
Feb-05	221	178	0	43	19.5%						
Mar-05	288	222	1	65	22.6%						
Apr-05	836	575	20	241	28.8%						
May-05	459	279	19	161	35.1%						
Jun-05	738	438	17	283	38.3%						
Jul-05	757	479	20	258	34.1%						
Aug-05	1581	785	149	647	40.9%						
Sep-05	1835	767	415	653	35.6%						
Oct-05	2092	965	320	807	38.6%						
Nov-05	1067	420	312	335	31.4%						
Dec-05	286	136	92	58	20.3%	**2005**	10188	5266	1365	3557	**34.9%**

continued

Appendix B. Summary of White Sturgeon sampled in the core assessment area (see Table 2) of the lower Fraser River, 1999-2017.

Month	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-06	83	68	0	15	18.1%						
Feb-06	2	2	0	0	0.0%						
Mar-06	116	76	3	37	31.9%						
Apr-06	885	582	8	295	33.3%						
May-06	439	254	10	175	39.9%						
Jun-06	274	161	6	107	39.1%						
Jul-06	510	289	13	208	40.8%						
Aug-06	808	450	30	328	40.6%						
Sep-06	1301	676	10	615	47.3%						
Oct-06	2566	1337	14	1215	47.3%						
Nov-06	1863	1054	38	770	41.3%						
Dec-06	171	116	0	55	32.2%	**2006**	9018	5065	132	3820	**42.4%**
Jan-07	59	45	0	14	23.7%						
Feb-07	122	83	0	39	32.0%						
Mar-07	558	359	1	198	35.5%						
Apr-07	602	363	5	234	38.9%						
May-07	318	148	3	167	52.5%						
Jun-07	460	222	2	236	51.3%						
Jul-07	832	378	3	451	54.2%						
Aug-07	1457	614	6	837	57.4%						
Sep-07	2661	1244	36	1381	51.9%						
Oct-07	2288	1091	16	1181	51.6%						
Nov-07	1219	614	17	588	48.2%						
Dec-07	43	27	0	16	37.2%	**2007**	10619	5188	89	5342	**50.3%**
Jan-08	60	42	0	18	30.0%						
Feb-08	26	18	1	7	26.9%						
Mar-08	118	66	5	47	39.8%						
Apr-08	465	231	5	229	49.2%						
May-08	499	200	6	293	58.7%						
Jun-08	434	185	5	244	56.2%						
Jul-08	600	253	0	338	56.3%						
Aug-08	864	353	14	497	57.5%						
Sep-08	1466	618	21	827	56.4%						
Oct-08	2079	922	0	1144	55.0%						
Nov-08	1832	906	15	911	49.7%						
Dec-08	83	51	0	32	38.6%	**2008**	8526	3845	72	4587	**53.8%**
Jan-09	22	13	0	9	40.9%						
Feb-09	89	61	0	28	31.5%						
Mar-09	146	82	0	64	43.8%						
Apr-09	533	254	8	271	50.8%						
May-09	321	100	0	221	68.8%						
Jun-09	348	124	3	221	63.5%						
Jul-09	434	183	5	246	56.7%						
Aug-09	1074	389	15	670	62.4%						
Sep-09	1798	654	16	1128	62.7%						
Oct-09	2079	847	24	1208	58.1%						
Nov-09	1262	588	16	658	52.1%						
Dec-09	143	61	15	67	46.9%	**2009**	8249	3356	102	4791	**58.1%**
Jan-10	271	161	0	110	40.6%						
Feb-10	178	102	0	76	42.7%						
Mar-10	223	92	4	127	57.0%						
Apr-10	614	277	6	331	53.9%						
May-10	393	146	2	245	62.3%						
Jun-10	402	140	4	258	64.2%						
Jul-10	488	225	4	259	53.1%						
Aug-10	753	219	6	528	70.1%						
Sep-10	1391	448	16	927	66.6%						
Oct-10	2832	1156	26	1650	58.3%						
Nov-10	1195	556	12	627	52.5%						
Dec-10	321	194	3	124	38.6%	**2010**	9061	3716	83	5262	**58.1%**
Jan-11	178	113	0	65	36.5%						
Feb-11	41	22	0	19	46.3%						
Mar-11	138	71	0	67	48.6%						
Apr-11	756	336	8	412	54.5%						
May-11	339	148	4	187	55.2%						
Jun-11	176	48	0	128	72.7%						
Jul-11	588	236	4	348	59.2%						
Aug-11	1090	325	4	761	69.8%						
Sep-11	2278	771	12	1495	65.6%						
Oct-11	2333	995	35	1303	55.9%						
Nov-11	1084	475	24	585	54.0%						
Dec-11	121	55	2	64	52.9%	**2011**	9122	3595	93	5434	**59.6%**

continued

Appendix B. Summary of White Sturgeon sampled in the core assessment area (see Table 2) of the lower Fraser River, 1999-2017.

Month	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-12	82	44	0	38	46.3%						
Feb-12	83	44	0	39	47.0%						
Mar-12	211	101	0	110	52.1%						
Apr-12	463	192	4	267	57.7%						
May-12	364	163	1	200	54.9%						
Jun-12	233	79	1	153	65.7%						
Jul-12	738	322	4	412	55.8%						
Aug-12	1060	379	12	669	63.1%						
Sep-12	1741	744	13	984	56.5%						
Oct-12	2816	1225	28	1563	55.5%						
Nov-12	1061	404	9	648	61.1%						
Dec-12	322	149	2	171	53.1%	**2012**	9174	3846	74	5254	**57.3%**
Jan-13	220	97	0	123	55.9%						
Feb-13	342	166	1	175	51.2%						
Mar-13	503	237	2	264	52.5%						
Apr-13	923	387	16	520	56.3%						
May-13	673	221	4	448	66.6%						
Jun-13	455	164	4	287	63.1%						
Jul-13	769	279	2	488	63.5%						
Aug-13	1161	384	15	762	65.6%						
Sep-13	2644	871	30	1743	65.9%						
Oct-13	2746	1002	36	1708	62.2%						
Nov-13	1572	558	14	1000	63.6%						
Dec-13	110	44	0	66	60.0%	**2013**	12118	4410	124	7584	**62.6%**
Jan-14	144	60	1	83	57.6%						
Feb-14	102	50	0	52	51.0%						
Mar-14	470	188	1	281	59.8%						
Apr-14	866	339	7	520	60.0%						
May-14	484	133	4	347	71.7%						
Jun-14	460	129	5	326	70.9%						
Jul-14	819	261	10	548	66.9%						
Aug-14	1099	192	118	789	71.8%						
Sep-14	1371	316	160	895	65.3%						
Oct-14	2133	587	135	1411	66.2%						
Nov-14	961	286	56	619	64.4%						
Dec-14	254	81	26	147	57.9%	**2014**	9163	2622	523	6018	**65.7%**
Jan-15	414	126	42	246	59.4%						
Feb-15	293	149	11	133	45.4%						
Mar-15	355	108	7	240	67.6%						
Apr-15	756	265	12	479	63.4%						
May-15	571	194	4	373	65.3%						
Jun-15	392	117	5	270	68.9%						
Jul-15	873	276	6	591	67.7%						
Aug-15	1324	349	11	964	72.8%						
Sep-15	2393	645	44	1704	71.2%						
Oct-15	2692	915	52	1725	64.1%						
Nov-15	1018	274	16	728	71.5%						
Dec-15	304	120	2	182	59.9%	**2015**	11385	3538	212	7635	**67.1%**
Jan-16	269	107	0	162	60.2%						
Feb-16	328	84	8	236	72.0%						
Mar-16	671	193	7	471	70.2%						
Apr-16	886	278	11	597	67.4%						
May-16	314	81	4	229	72.9%						
Jun-16	557	136	7	414	74.3%						
Jul-16	932	209	17	706	75.8%						
Aug-16	821	196	16	609	74.2%						
Sep-16	1058	342	10	706	66.7%						
Oct-16	1532	402	15	1115	72.8%						
Nov-16	507	122	4	381	75.1%						
Dec-16	4	1	1	2	50.0%	**2016**	7879	2151	100	5628	**71.4%**
Jan-17	79	26	1	52	65.8%						
Feb-17	152	32	1	119	78.3%						
Mar-17	186	47	0	139	74.7%						
Apr-17	382	142	1	239	62.6%						
May-17	183	36	3	144	78.7%						
Jun-17	266	57	1	208	78.2%						
Jul-17	475	123	2	350	73.7%						
Aug-17	887	195	20	672	75.8%						
Sep-17	1854	474	38	1342	72.4%						
Oct-17	1646	369	16	1261	76.6%						
Nov-17	453	89	3	361	79.7%						
Dec-17	110	58	1	51	46.4%	**2017**	6673	1648	87	4938	**74.0%**
					Totals All Years	**1999-2017**	**149,257**	**68,375**	**6,276**	**74,583**	**50.0%**

Appendix C - Results of the Integrated Spatial and Age Mark Recapture (ISAMR) model for Lower Fraser River White Sturgeon

Results of the Integrated Spatial and Age Mark Recapture (ISAMR) model for Lower Fraser River White Sturgeon

The Integrated Spatial and Age Mark Recapture (ISAMR) was applied to lower Fraser River White Sturgeon angling data from 2000 through 2017. The model is a class of age-structured mark-recapture model (Coggins et al. 2006) that tracks abundances for 58 age classes over four spatial areas on a yearly time step. Detailed data assembly procedures and mathematical description of the mark-recapture model and model assumptions are provided in Challenger et al. (2017); in the text that follows we present a brief overview of the methodology.

Angling captures were included if they occurred in one of the four lower Fraser River sampling regions (i.e., A, B, C, and D; Figure 2). Because age of captured sturgeon is a requirement, captures were aged based on length via a von Bertalanffy growth model developed for lower Fraser River (i.e., $L_a = 370.1 \times (1 - \exp(-0.025a))$; Whitlock and McAllister 2012; English and Bychkov 2012). For recaptures of previously marked individuals the aging was determined based on the age determined at first capture and elapsed time between captures. The ISAMR model also considers untagged and tagged captures separately and as such both untagged captures released either with a tag and untagged captures without a tag were included.

In total there were 144,736 available angling captures in four lower Fraser River sampling regions. Of these capture events, 72,569 were untagged captures and 72,167 were recaptures of previously tagged individuals; these include 67,560 unique tags released and 5009 sturgeon released without a tag. Of these total captures, 14,275 were found to be incompatible with the analysis parameters (e.g., outside assessment years and modeled age classes) leaving 130,461 captures retained in the analysis. Of the original 72,569 untagged captures, 642 were removed (136 had ages greater than the oldest age class, and 506 were outside the assessment period). Of the original 72,167 recaptures, 13,633 did not meet analysis parameters and were removed: 10,755 were removed for occurring within same calendar year (the ISAMR uses a yearly time step); 936 were associated with a release before the start of the assessment period (i.e., before 2000); and 1,942 were outside the analysis parameters (i.e., either too old at time of capture or caught after the assessment period).

The 130,461 captures that were retained where then analysed using the same model setup described in previous analyses (Challenger et al. 2017). A single S-shaped selectivity-at-age curve was estimated and shared across all assessment years. The curve represents how catchability of sturgeon falls to zero as we move from older individuals, which are targeted by anglers, to younger, smaller individuals, which are not targeted in the same manner. The ISAMR does support multiple selectivity curves, which can be used to model changes in fisher behaviour, however it was currently not found to be necessary. Instantaneous sampling rates for each region were modelled as a linear function of the number of angling boat trips to each region in each year (see Table C1), with separate coefficients estimated for each region. This formulation was the same as Challenger et al. (2017), except with updated boat trip data.

Markov Chain Monte Carlo (MCMC) was used to sample from the posterior distribution using the Metropolis-Hastings algorithm to generate and accept parameter proposals. Trace plots were used to assess convergence of MCMC chain. A total of 1.8 million posterior samples were taken after a burn-in of 20,000. The complexity of the model necessitated thinning the MCMC chain to every 900^{th} proposal to remove autocorrelation in the derived abundance metric, which resulted in 2,000 retained posterior samples.

Point estimates of select ISAMR output include mortality, recruitment (historical and assessment period), yearly regional sampling rates, selectivity-at-age and movement probabilities, and derived

Table C1. Angling boat trips to each study region by year.

Year	A	B	C	D	Total
2000	65	220	555	19	859
2001	101	261	597	33	992
2002	79	174	479	30	762
2003	67	264	659	17	1,007
2004	61	330	996	48	1,435
2005	99	344	1,390	34	1,867
2006	55	353	1,309	66	1,783
2007	53	294	1,599	37	1,983
2008	34	448	1,206	66	1,754
2009	50	483	884	74	1,491
2010	44	474	888	113	1,519
2011	42	471	896	68	1,477
2012	41	597	1,027	88	1,753
2013	46	565	1,243	141	1,995
2014	51	446	1,208	116	1,821
2015	33	477	1,416	183	2,109
2016	32	379	1,145	218	1,774
2017	36	257	987	129	1,409

abundances for sturgeon age 5 and older (Figure C1). Results are broadly similar to previous analyses by Challenger et al. (2017) with low mortality rates for older age classes, close to complete gear selectivity for sturgeon of age 12 and older, and substantial declines in recruitment within the assessment period. As indicated prior analyses, sturgeon also showed a tendency to remain within a given sampling region, with higher fidelity for sampling regions further away from the river mouth.

Abundance estimates were broken down into recruitment into the first age-1 (Figure C2), as well as for abundance estimates for subsequent age classes (Figure C3). Recruitment estimates showed the most uncertainty relative to abundance estimates for other demographic breakdowns, which is expected given that there is a lag in time between the recruitment event and when sturgeon are exposed to sampling (i.e., non-zero gear selectivity; Figure C1e). Historical recruitment (i.e., before the assessment period) showed the highest levels peaking at approximately 30,000 in 1995, followed by a steady decline through the assessment period until around 2005, where after it has stabilized at a level lower levels with a small increase to approximately 10,000 in recent years. Recruitment estimates from 2012 to 2017 shared the same parameter (i.e., were constrained to be equal), because there is not sufficient information to estimate recruitment in these years due to few captures of sturgeon age five and younger that results from the low gear selectivity associated with these ages (Figure C1e).

In general, recruitment estimates are informed by age-specific catch in the assessment period after accounting for movements, sampling rates, age-specific gear selectivity, and age-specific mortality rates. The large number of age classes tracked in the model also provide the ability to make inferences about a large number of recruitment cohorts, including those that preceded the start of the assessment period, with estimates reflecting the most likely number of recruits required to

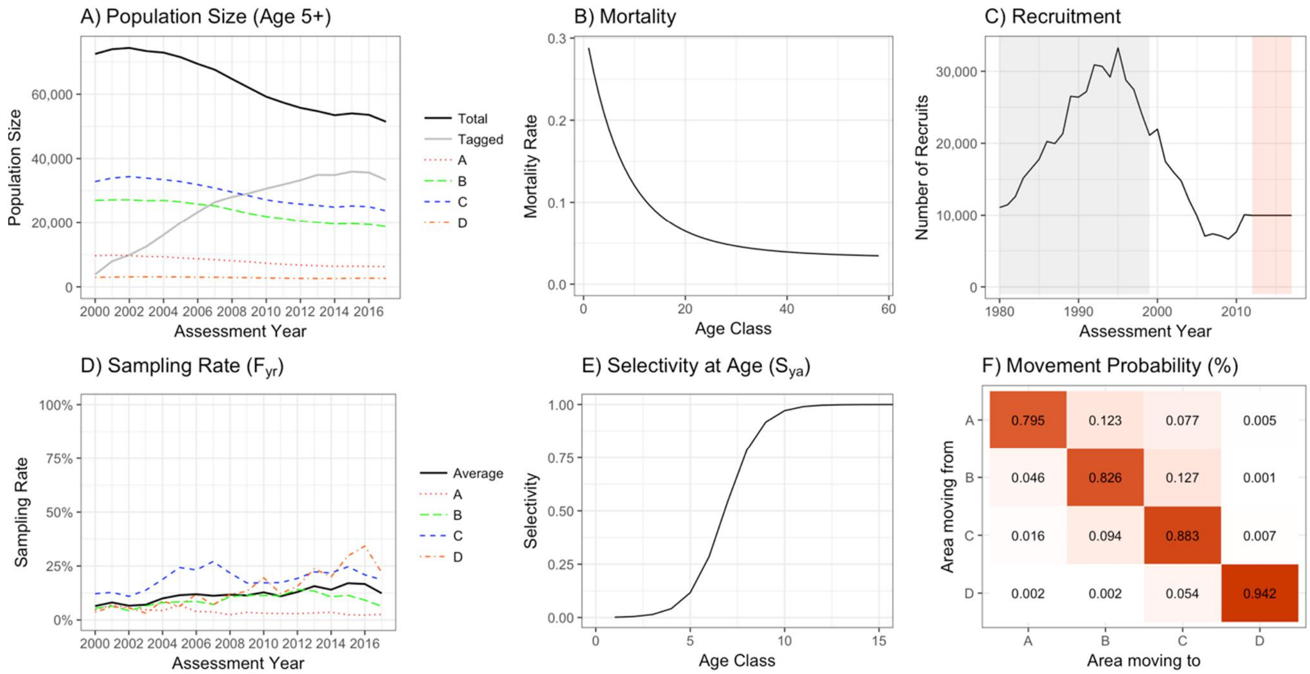

Figure C1. Select ISAMR model output including: A) population abundances for age-5 and above by sampling region; B) estimated mortality rate; C) historical and current recruitment (grey shading indicates historical recruitment; orange shading indicates terminal years that are constrained to be equal); D) regional sampling rates; E) selectivity-at-age; and F) regional movement probabilities.

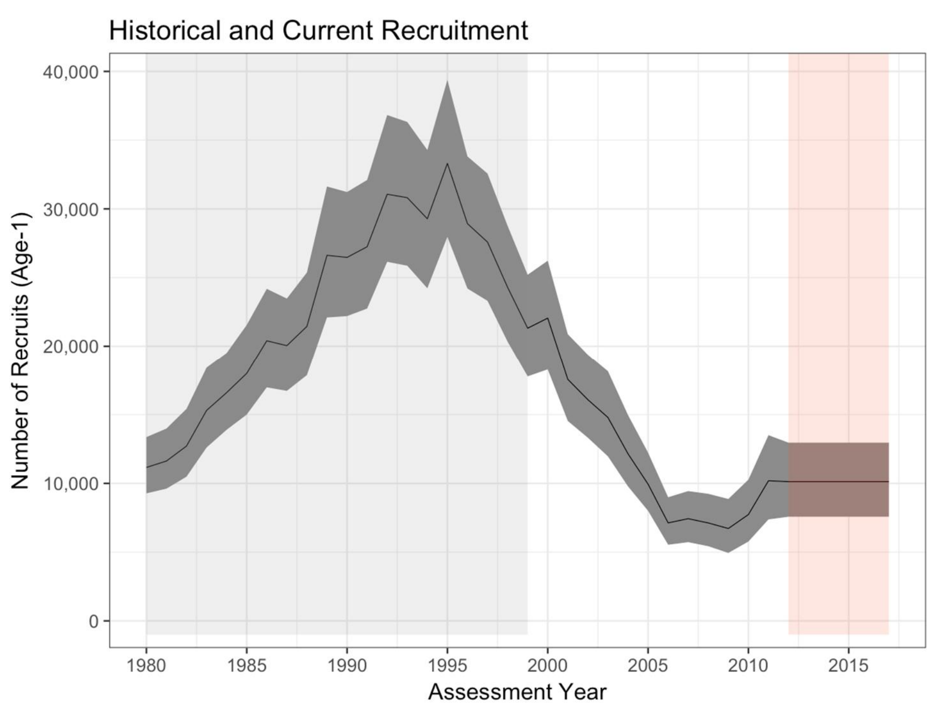

Figure C2. Estimated recruitment into age-1 prior to and during the assessment period, with 95% credible intervals (dark grey shading). Light grey shaded region indicates historical estimates and light orange shading indicates years constrained to have equal recruitment.

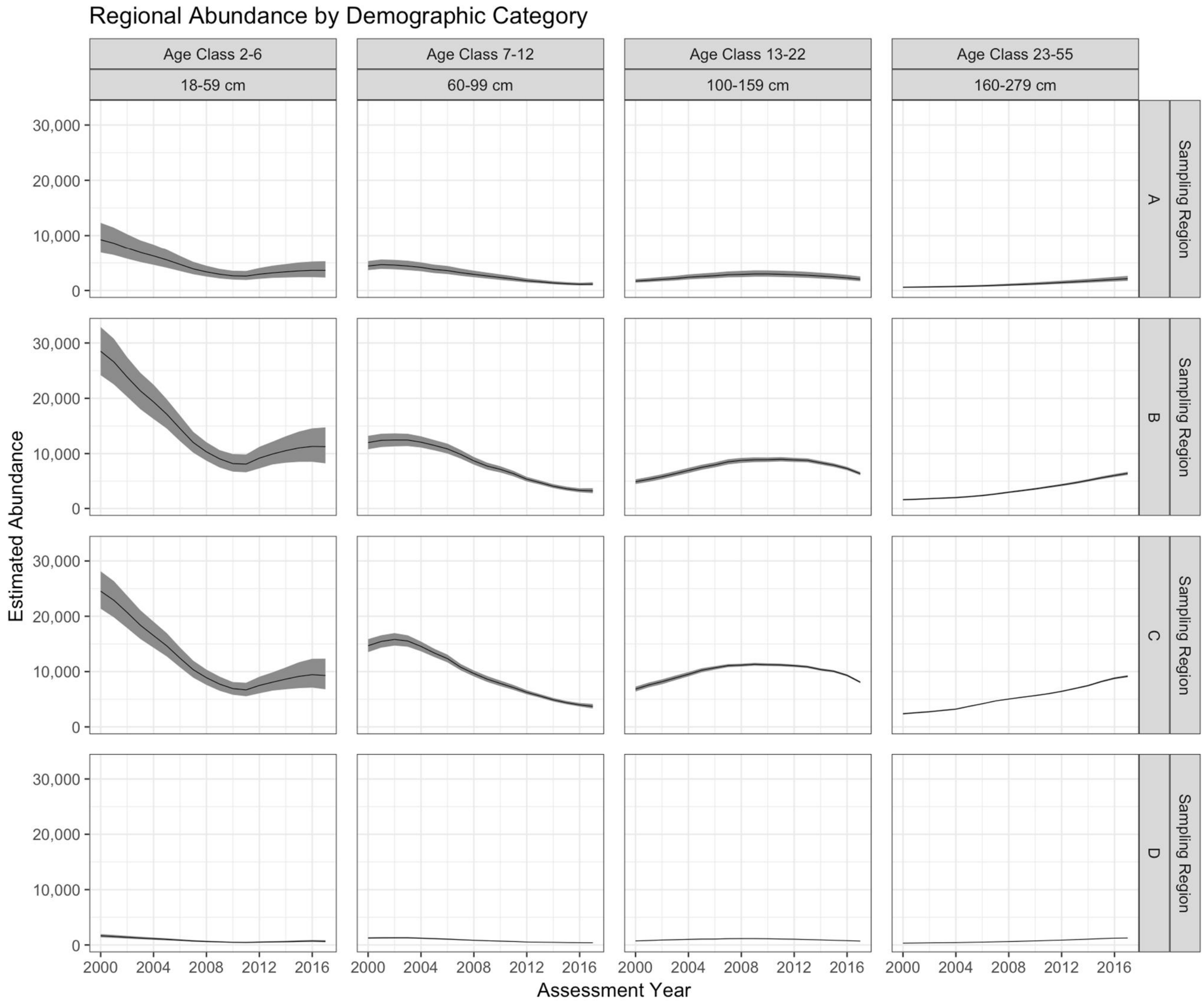

Figure C3. Estimates of region-specific abundances (sampling regions A, B, C, and D), broken down by age class for ages that are fully recruited into the fishery. Panel rows indicate sampling regions, while panel columns indicate size/age groups. Size groups are based predicted length-at-age growth model (RL&L 2000). Shaded region indicates 95% credible intervals.

support the observed catch-at-age within the assessment period. The complex model provides age structuring, with the associated ability to track recruitment cohorts throughout the assessment period. The results provide a wealth of information regarding historical and current recruitment events. Estimates rely on the mortality curve to correctly predict mortality rates in age classes where there are few observations. As such, recruitment, and age-class abundances for ages with low gear selectivity (e.g., the two left-most panel columns in Figure C3), were derived by combining the estimates for older-age sturgeon with average age-specific morality rates.

While recruitment estimates should not be viewed as an exact reconstruction, estimates will still reflect general trends in age-specific abundances. For example, the increasing trend for age 23-55 sturgeon over the past 10 years indicates that recruitment and/or survival for young sturgeon (< age 6) must have been substantially higher in the 1990’s than the estimates derived for 2005-2010. The estimated peak in recruitment in the 1990s is also consistent with an increase in abundance of age 13-22 sturgeon from 2000-09 and the subsequent decline of these respective age classes in recent years (Figure C3).

Abundance estimates also showed a high level of precision, which is in part a result of the high percentage of the population that is estimated to have been marked (Figure C4). Older age classes (i.e., age-13 and older) show the highest level of marking, with marking rates much lower for younger age groups. This is not unexpected as these older and larger individuals are targeted by fishers and have been exposed to both sampling and tagging since the beginning of the study. Interestingly, the group with intermediate selectivity (i.e., ages 7-12) showed a decline in the percent marked in the last two years of the assessment period, while older groups showed a general increase with some signs of leveling-off. This may be due to the recent decline in sampling effort where fewer of these new recruiting fish are tagged each year. Finally, the youngest age class group (age 2-6) shows a very low mark-rate that is consistent with the very low catchability of age 2-6 sturgeon.

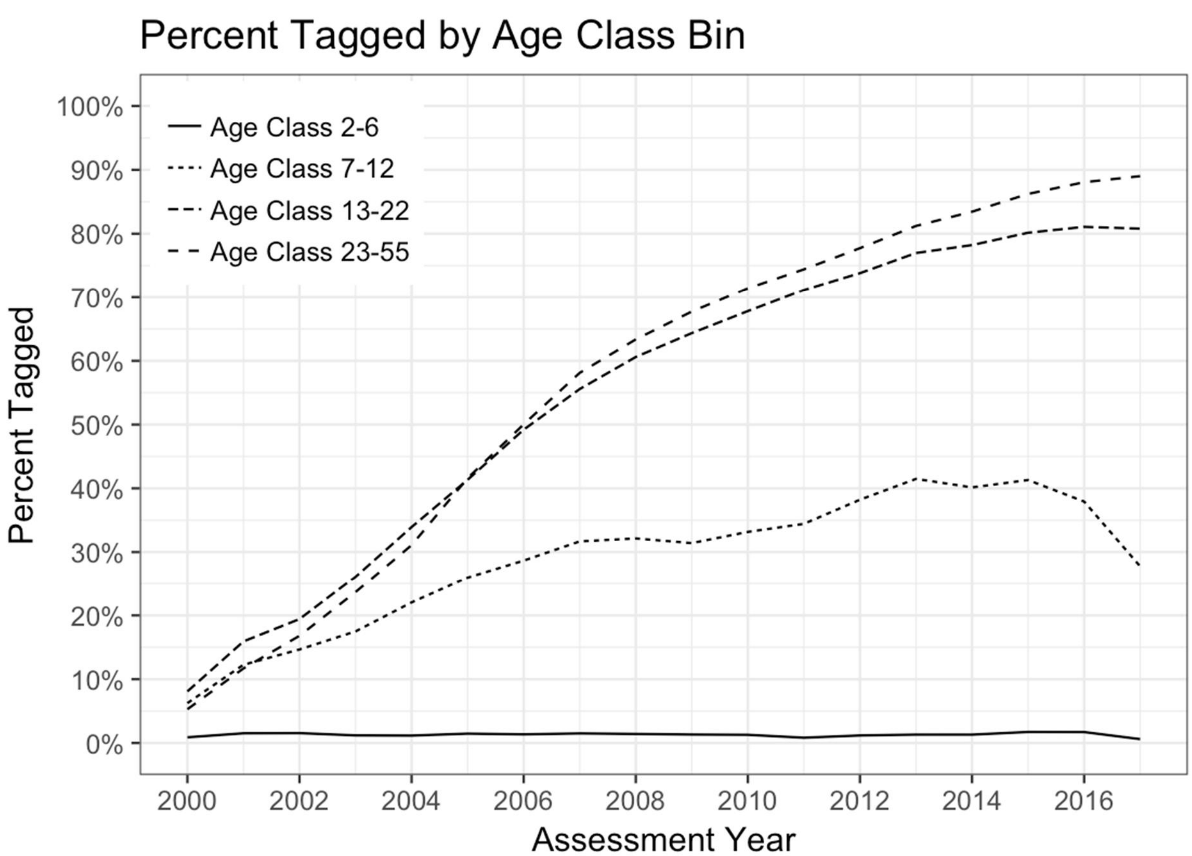

Figure C4. Estimated percent of the population tagged, by age class bin and assessment year.

Model age structuring makes forward abundance projections possible by combining age-specific abundance estimates with estimated age-specific mortality rates and future recruitment (i.e., age-1 recruitment) scenarios. Population abundances were forecasted from 2018 through to 2060 under a scenario where the average age-1 recruitment levels (i.e., 2012-2017) are: 1) maintained; or 2) increased 1.6 times current recruitment (Figure C5). Under the maintained (e.g., “1x recent recruitment”) scenario the total abundance of juveniles and adults (i.e., age-7 and older) are expected to continue to decline through the end of the projection period (i.e., late 2050’s), followed by a period of stabilization at an abundance level that is approximately half of the abundance level observed at the start of the assessment period (i.e., early 2000’s; Figure C5a). Within the forecasted period, the 100-159 cm FL size group (age 13-22) is expected to continue to decline until the late 2020’s, and then stabilize at an abundance level that is approximately one third of the peak abundance for this age group observed in 2010. Abundances of the spawning component of the population (i.e., 160-279 cm FL; age 23-55) are predicted to peak by the early 2020’s, followed by a continued decline through to around 2060, after which it is expected to stabilize. The rate of decline for this older age group is slower than other groups due to the higher number of age classes included in the grouping.

By contrast, under the scenario wherein age-1 recruitment is increased by 1.6 times the recent recruitment rate, abundance will continue to decline for several years, but is predicted to stabilize by the mid-2030’s at levels observed in 2017, which is approximately 75% of the peak abundance observed in the early 2000’s (Figure C5b). Assuming consistent recruitment after 2017 (at 1.6 times the current recruitment rate) and fixed average annual age-specific survival, estimated abundances for each age/size group will be 1.6 times those predicted under the assumption of constant recruitment at the current level.

ISAMR abundance estimates were compared with estimates from the Bayesian mark-recapture model (i.e., Gazey and Staley 1986) which uses a 24-month rolling window (herein referred to as BMR24; Figure C6). Both models employ Bayesian estimation, but the ISAMR uses age-class structuring while the BMR24 employs size groups. ISAMR age classes were therefore matched to the corresponding size groupings based on the size-at-age growth equation (English and Bychkov 2012). The two models also differ in how differences in gear selectivity are handled, with a selectivity-at-age relationship included within the ISAMR model, while the BMR24 does not explicitly model gear selectivity, but rather restricts the analysis to size groups that are believed to be mostly or completely recruited into the fishery. As such, the ISAMR abundance estimates were presented in two forms: 1) the “adjusted” estimate back-adjusts abundance for gear selectivity in order to better match BMR24 assumptions (Figure C6a; see Challenger et al. 2017 for full description); and 2) the “unadjusted” estimates (does not include adjustments; Figure C6b). As such, unadjusted ISAMR abundances are expected to be higher for age and size groups where catch is affected by gear selectivity.

In general, both models showed similar abundance estimates and similar trends in abundance across the different size/age groups (Figure C6). A notable exception was the unadjusted ISAMR estimates for the smallest age class (i.e., 60-99 cm FL; ages 7-12), which showed the same general trend, but higher abundance estimates (left most panel, Figure C6b). This result is consistent with gear selectivity that affects the abundance estimates for this size group. When ISAMR-adjusted abundances are compared for the same age group, there is a much closer match to the BMR24 estimates (left most panel, Figure C6a). The comparison of the BMR24 and adjusted ISAMR estimates across the four sampling regions shows good agreement between the two models (Figure C7). Although combining the older age groups (i.e., 100-279 cm FL) does highlight years where the two model estimates have been substantially different, most notably in 2017 (Figure C8).

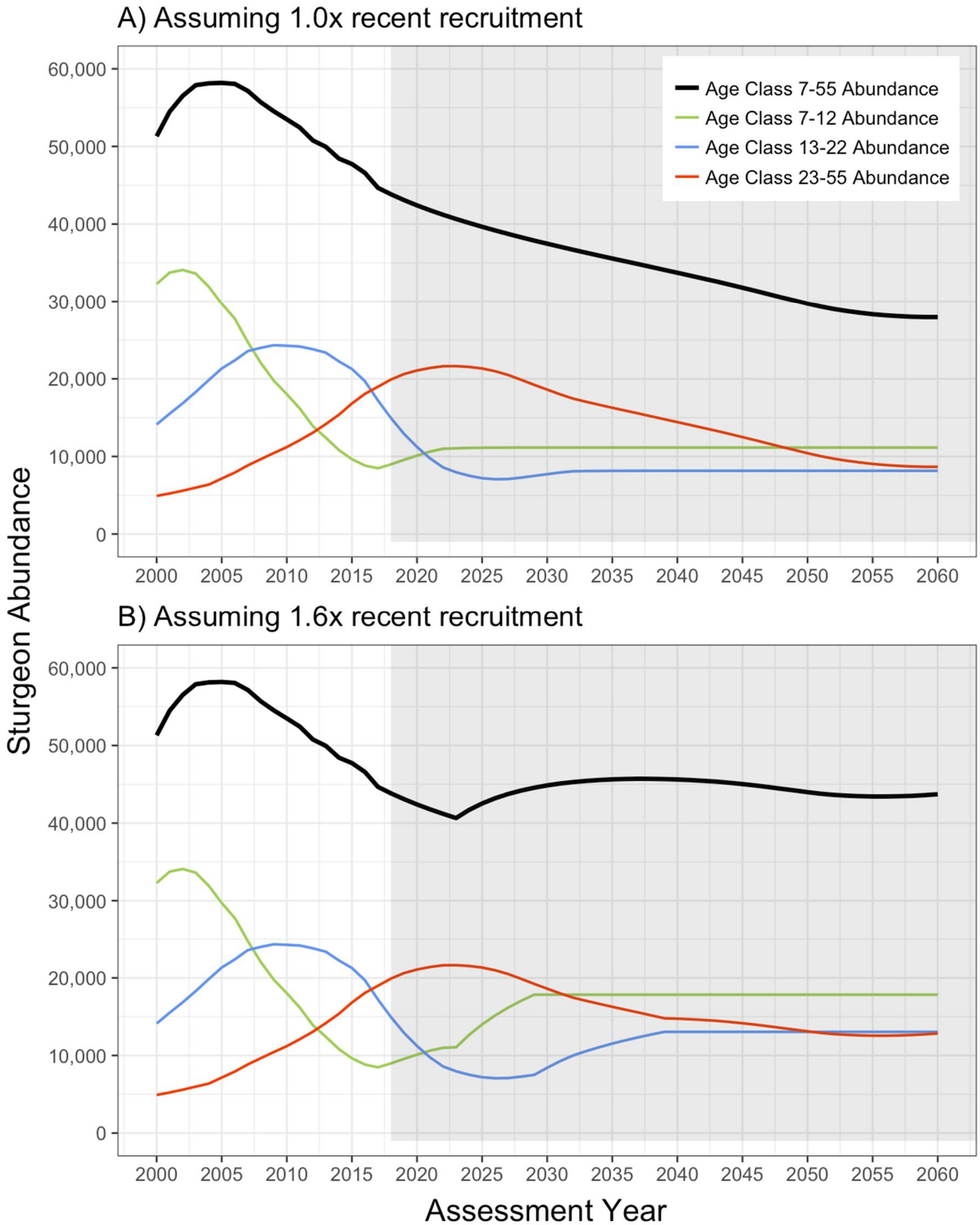

Figure C5. Abundance projections for Lower Fraser River White Sturgeon for 2018-2060 assuming A) that annual age-1 recruitment remains the same as recent estimates (i.e., 2012-2017 recruitment), and B) recruitment that is 1.6 times recent recruitment. Grey shading indicates projected years.

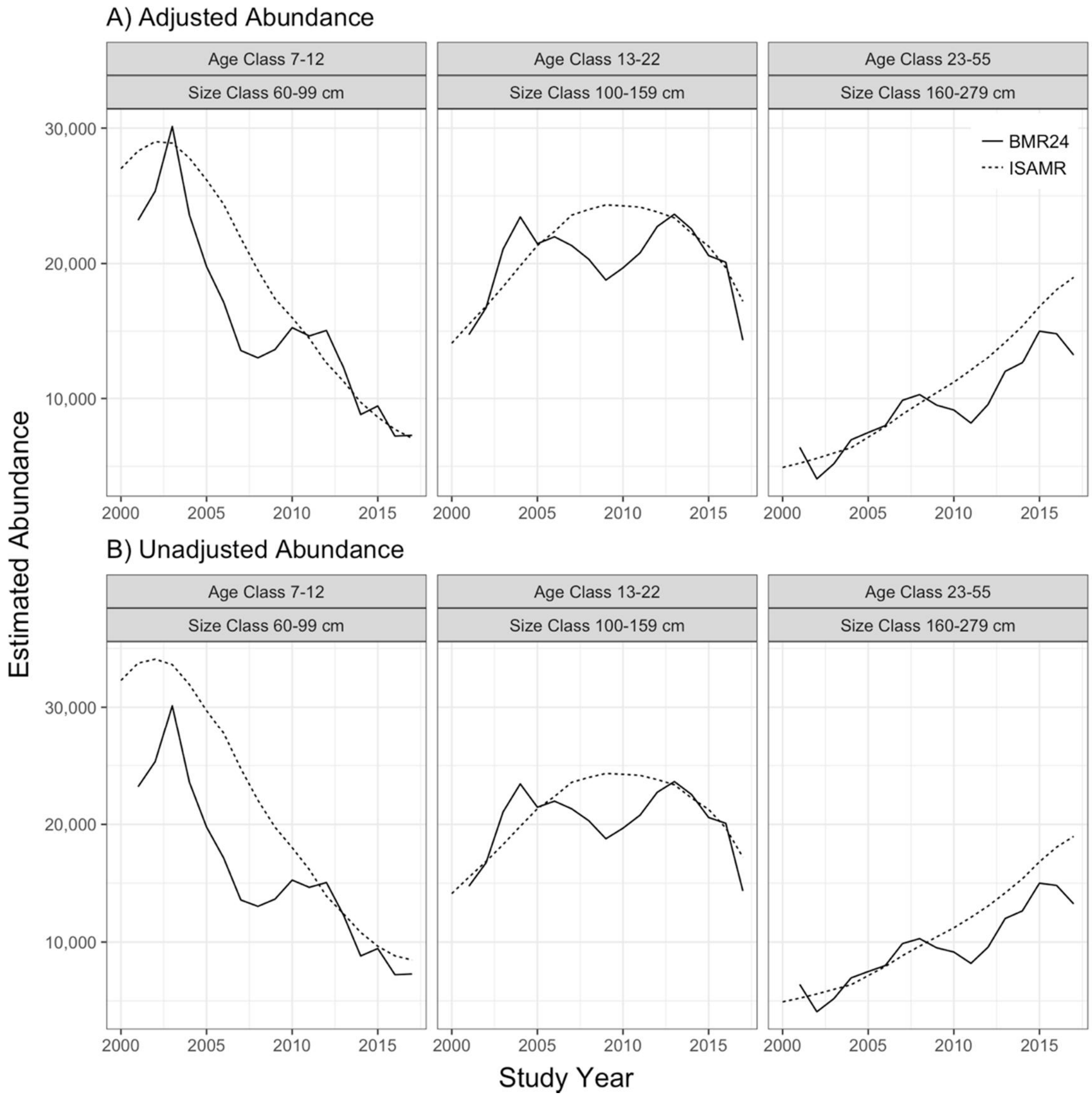

Figure C6. Comparison of assessment area BMR24 and ISAMR abundances for size groups with gear selectivity differences for A) adjusted ISAMR abundances and B) unadjusted ISAMR abundances. Size groups (see Nelson et al. 2007) affected by gear selectivity differences are located in the left-side panels, while groups largely unaffected by gear selectivity differences are located in the middle and right-side panels. Adjusted ISAMR abundance modeling removes the effect of age-specific selectivity for comparison with the BMR24 estimates. Unadjusted ISAMR abundance modeling includes gear selectivity differences, and thus results are larger than the adjusted ISAMR estimates for age 7-12 sturgeon which are not fully recruited into the fishery.

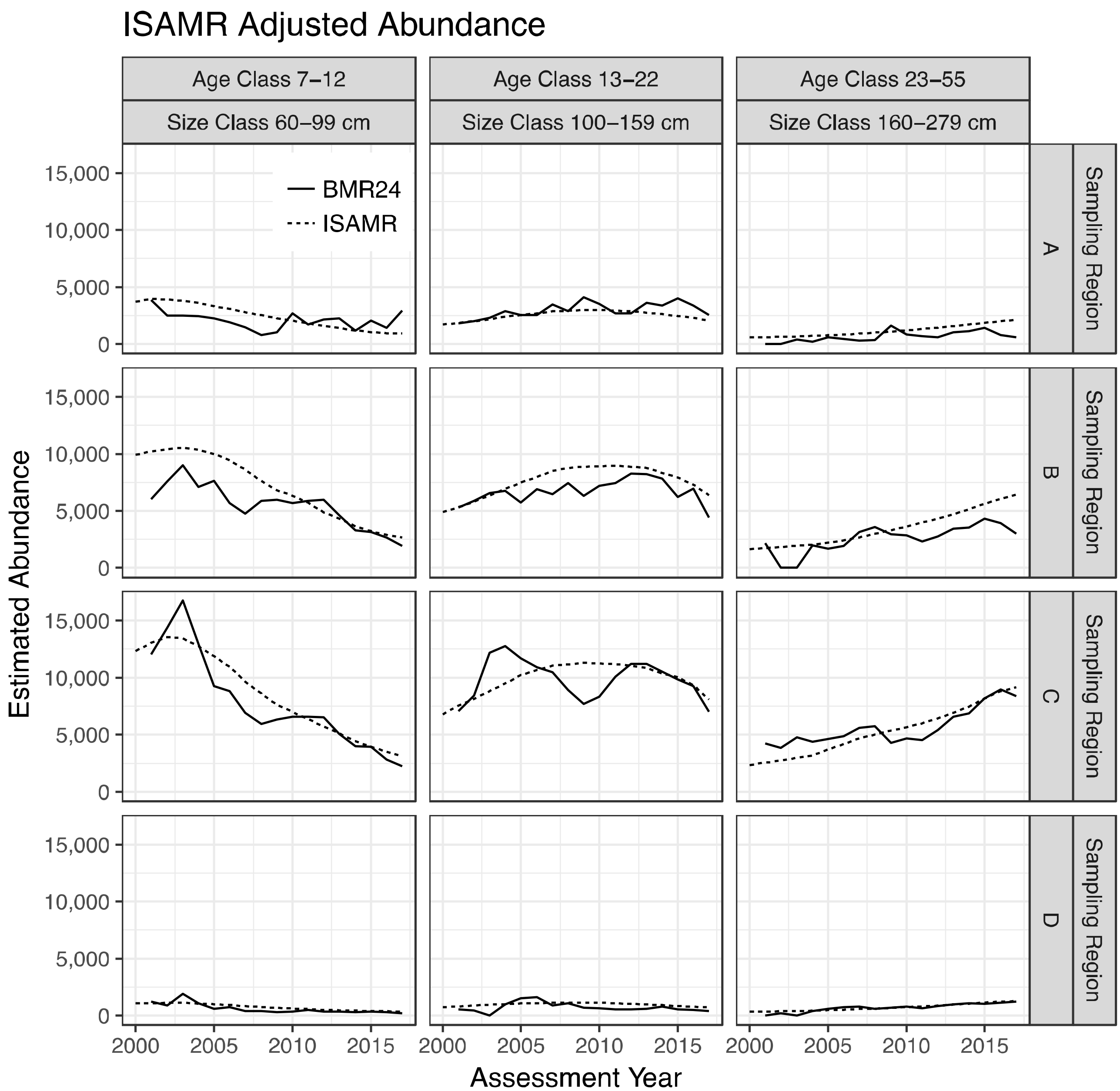

Figure C7. Comparison of assessment area BMR24 and adjusted ISAMR abundances across the four sampling regions. Size groups (see Nelson et al. 2007) were matched to age classes based on the length-at-age equation (see English and Bychkov 2002). Adjusted ISAMR abundance modeling removes the effect of age-specific selectivity for comparison with the BMR24 estimates.

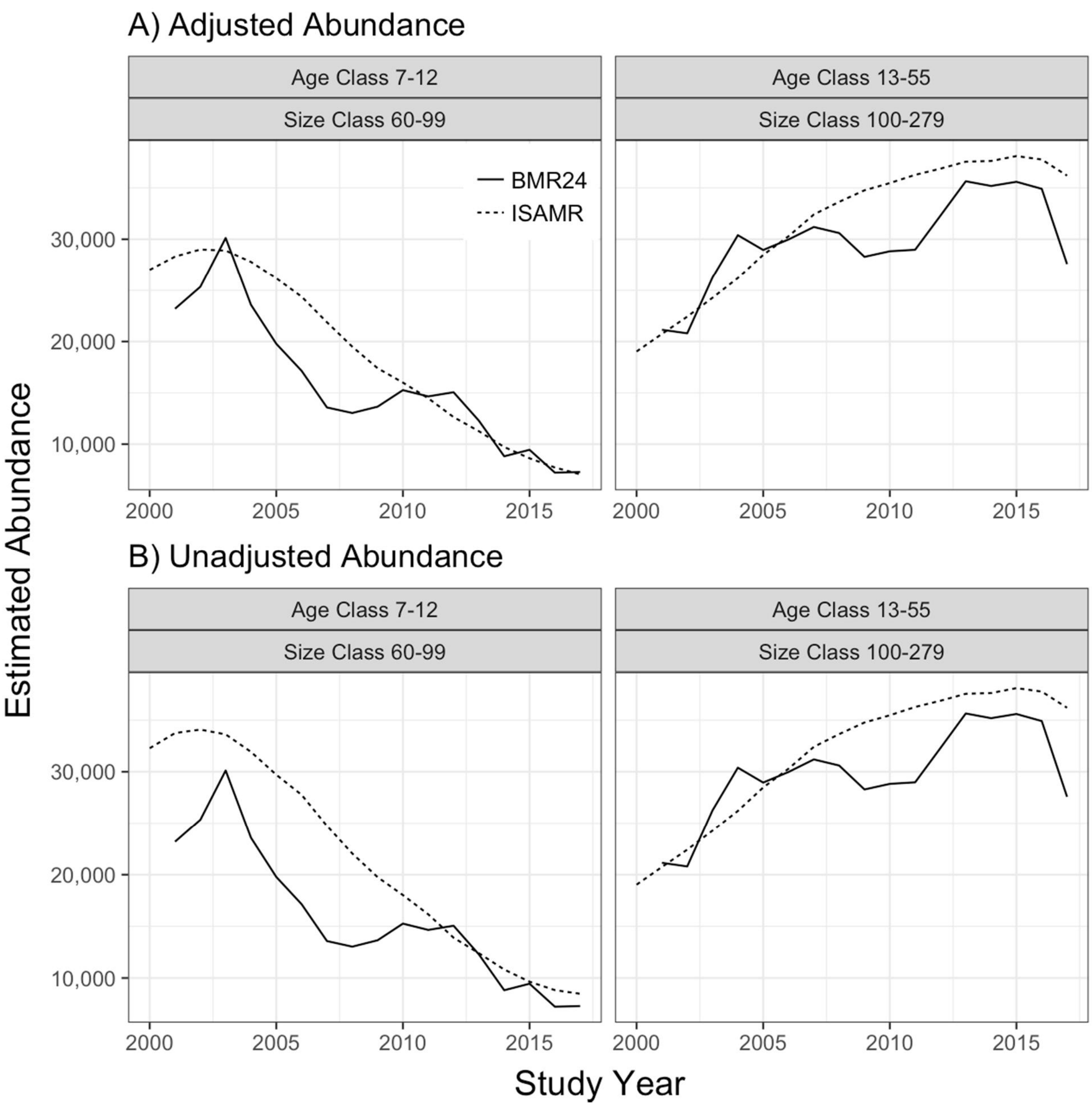

Figure C8. Comparison of assessment area BMR24 and ISAMR abundances for size groups with gear selectivity differences for A) adjusted ISAMR abundances and B) unadjusted ISAMR abundances. Size groups (see Nelson et al. 2007) affected by gear selectivity differences are located in the left-side panels, while groups largely unaffected by gear selectivity differences are located in the right-side panels. Adjusted ISAMR abundance modeling removes the effect of age-specific selectivity for comparison with the BMR24 estimates. Unadjusted ISAMR abundance modeling includes gear selectivity differences, and thus results are larger than the adjusted ISAMR estimates for age 7-12 sturgeon which are not fully recruited into the fishery.

Most differences between the two model estimates appear to occur in sampling regions A and B, which are the two sampling regions in the closest proximity to the river mouth (Figure C7). Because the BMR24 model fits data from a 24-month sampling window, estimates may also be more sensitive to temporary emigration than the ISAMR model that considers all assessment years. In this case, each model has a different biological population of interest; the BMR24 model considers sturgeon that have used the lower Fraser River in the last 24 months, while the ISAMR model considers sturgeon that have used the lower Fraser River at some point during the entire assessment period. As such, the ISAMR model is expected to include more potential individuals in its population of interest, which should result in higher abundance estimates and more stable estimates. This would be especially true if temporary emigration events lasted longer than 24 months.

REFERENCES

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

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

Coggins, L. G., Jr., W. E. Pine III, C. J. Walters, and S. J. D. Martell, 2006. Age-structured mark–recapture analysis: a virtual-population-analysis-based model for analyzing age-structured capture–recapture data. North American Journal of Fisheries Management 26: 201–205. doi:10.1577/M05-133.1.

English K. K. and Y. Bychkov. 2012. Stock reduction analysis for Lower Fraser White Sturgeon - Progress report for 1st study year. Report prepared for Habitat Conservation Trust Foundation. 29 p.

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