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Status of White Sturgeon in the Lower Fraser River in 2020

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KEY POINTS AND FINDINGS

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

The Lower Fraser White Sturgeon Monitoring and Assessment Program, including a PIT tag mark-recapture study, has been delivered by the Fraser River Sturgeon Conservation Society continuously since April 2000.

White Sturgeon sampling data are collected by trained volunteers within a core assessment area that covers over 200 linear river kilometers of the lower Fraser River and its tributaries downstream of Hells Gate; since 2000, approximately 99% of samples collected were from the core assessment area.

In 2020, the overall sample mark rate for 60-279 cm fork length (FL) White Sturgeon sampled in the core assessment area of the lower Fraser was 68.3%. The sample mark rate varied by size group: 60-99 cm FL juveniles (32.8%); 100-159 cm FL subadults (71.1%); and 160-279 cm adults (84.2%).

ISAMR model produces current and historical abundance estimates, and forecasts future trends

The ISAMR model indicated that the abundance of 60-279 cm FL (age 7-55) White Sturgeon in the lower Fraser River has been in a continual state of decline since 2006.

The 2020 ISAMR abundance estimate for 60-279 cm FL (age 7-55) Lower Fraser White Sturgeon was 44,930 (95% CIs ± 4.5% of the estimate), which is 25.5% lower than the program's highest annual abundance estimate in 2006 and 3.7% lower than the 2019 ISAMR estimate.

The estimated decline in the total abundance of 60-279 cm FL (age 7-55) Lower Fraser White Sturgeon that has been occurring since 2006 has been driven primarily by the sustained decline in age-7 recruitment since 2001, which led to substantial declines in the abundances of 60-99 cm FL (age 7-12) juvenile sturgeon (70.8% decline since 2002) and subsequent declines in 100-159 cm (age 13-22) subadult sturgeon (51.3% decline since 2009).

If low levels of age-7 recruitment persist, ISAMR abundance forecasts suggest the total abundance will continue to decline, with a possible leveling in approximately 40 years (i.e., early 2060s) at approximately 26,000 sturgeon (60-279 cm FL). Population abundances could be stabilized to levels comparable to current estimated abundances by the mid 2040's if there is sustained increase in age-7 recruitment that is 1.6 times higher than current levels. While the population would be stabilized, abundances would be lower than candidate recovery thresholds identified in the recent Recovery Potential Assessment (i.e., 60,000 individuals in the 60-279 cm size class (age 7-55)).

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

Albion Test Fishery sturgeon catch per unit effort has shown a significant decline since 2000, with sturgeon under 100 cm FL exhibiting a much steeper decline relative to larger fish. The percentage of annual Albion Test Fishery sturgeon catch under 100 cm FL has been declining at approximately 2.1 percentage points per year since 2000, indicating a general sustained reduction in the availability of juveniles for capture. Both trends are consistent with the general demographic results of the ISAMR abundance model. Estimated annual growth rates have also exhibited significant declines in long-term (20-year) trends for several of the core size categories, although shorter-term (five-year) trends may be stable or increasing.

EXECUTIVE SUMMARY

An Integrated Spatial and Age-structured Mark-Recapture (ISAMR) model was developed from 2015-17 for the analysis of mark-recapture data generated by the Lower Fraser River White Sturgeon Monitoring and Assessment Program. Challenger et al. (2017) provided a detailed description of Version 2.0 of the ISAMR model and showed that the results were comparable to those from the Bayesian 24-month mark-recapture (BMR24) model, which has been historically used within the monitoring and assessment program (Nelson et al. 2017). While results from the two models are comparable, the ISAMR model is more robust (Nelson et al. 2019) based on its handling of heterogeneity in capture probabilities, because it uses the whole dataset instead of just the two most recent years, and because of its ability to generate forecasts of estimated abundance by size/age.

The ISAMR model uses Bayesian estimation to provide point estimates, with credible intervals, of abundance by age. It considers all captures within the assessment period in a single analysis framework and uses a demographic model to transition fish through the available age classes over the course of the assessment period. ISAMR explicitly models the process of births and deaths; it incorporates a selectivity-at-age relationship (that is estimated from the data) to accommodate for size selectivity in the recreational angling fishery, and it incorporates a sampling effort relationship based on the total number of angling trips within a defined sampling region. Abundance estimates generated by the ISAMR model are limited to White Sturgeon within the core assessment area, and aged 7-55 (60-279 cm FL), due to limited sampling outside of this area, and limited samples generated outside of this age/size range, especially during the early years of the program.

The 2020 core assessment area abundance estimate for 60-279 cm FL (age 7-55) Lower Fraser White Sturgeon, as derived from the ISAMR model, was 44,930 (95% CIs ± 4.5% of the estimate). This estimate does not include fish smaller than 60 cm FL (younger that age 7) or longer than 279 cm FL (older than age 55), or fish that permanently reside outside of the core assessment area. The 2020 abundance estimate was 25.5% lower than the program's highest annual abundance estimate in 2006 and 3.7% lower than the 2019 estimate.

Declines in 60-279 cm FL (age 7-55) White Sturgeon abundance in the lower Fraser River that have occurred consistently since the 2006 peak are driven primarily by the sustained decline in estimated age-7 recruitment that has occurred since 2001. This low level of recruitment affected the abundance of 60-99 cm FL (age 7-12) juvenile sturgeon (which have declined 70.8% since 2002 peak) and subsequently reduced the abundance of 100-159 cm FL (age 13-22) subadult sturgeon (51.3% decline since 2009 peak). Recent moderate improvements in age-7 recruitment into the sampled population have begun to stabilize the 60-99 cm FL (age 7-12) juvenile sturgeon abundances (albeit at levels approximately 71% below peak levels estimated for 2002); however, 100-159 cm (age 13-22) subadult sturgeon continue to decline. Currently, estimates of 160-279 cm FL (age 23-55) mature sturgeon continue their long-term increasing trend, but are anticipated to show a decline in the next 4-5 years as insufficient sustained replenishment begins to impact older demographic groups.

If the current age-7 recruitment rates persist into the future, the overall abundance of 60-279 cm FL (age 7-55) sturgeon is forecasted to continue to decline, possibly leveling off after approximately 40 years (i.e., early 2060s). Specifically, the 100-159 cm FL size group (age 13-22) of subadult sturgeon is expected to continue to decline until the 2030s, with adult sturgeon (age 23-55; 160-279 cm FL)

predicted to begin declining in the mid 2020s and continue to decline until approximately 2060. Forecast modelling indicated that an immediate and sustained 60% increase in age-7 recruitment into the sampled population (i.e., 1.6 times current levels) would stabilize the abundance of 60-279 cm FL (age 7-55) sturgeon at abundance levels similar to 2020. An immediate and sustained increase in age-7 recruitment of 140% (i.e., 2.4 times current levels) would be required to achieve an abundance of 60-279 cm FL (age 7-55) sturgeon similar to levels estimated for 2004-06.

Aside from abundance model results, there are other demographic indicators that also present concerns regarding the status of Lower Fraser River White Sturgeon. Over the past 20 years the Albion Test Fishery has shown a steady decline in sturgeon catch per unit effort, with sturgeon smaller than 100 cm FL exhibiting a much steeper decline relative to larger sturgeon. The percentage of White Sturgeon captured in the Albion Test Fishery that were less than 100 cm FL has shown a steady decline of approximately 2.1 percentage points per year from 2000 to 2020. Both trends are consistent with the general demographic results estimated by the ISAMR abundance model. Annual growth rates of sturgeon sampled by the monitoring and assessment program have also exhibited significant declines in long-term (i.e., 20-year) trends for several of the core size categories, although shorter-term (five-year) trends may be stable or increasing.

Given the estimated declining trend in abundance, setting management objectives (e.g., abundance, mortality, or exploitation-based targets) will be important for managing Lower Fraser White Sturgeon. For example, English et al. (in press) suggested a candidate recovery threshold of 60,000 fish in the 60-279 cm FL (age 7-55) size/age range, based on levels of abundance estimated to have occurred in the mid-2000s. Similarly, 20,000 adult sturgeon (160-279 cm FL; age 22-55) is another candidate recovery threshold suggested by English et al. (in press), as it is the abundance level projected to occur within the decade (neither of these thresholds have been formally ratified by managers, but are presented here as part of an exploratory exercise). Only one abundance forecast scenario, which had age-7 recruitment at a level that was more than double that of recent recruitment rates, was able to attain and sustain either of these abundance thresholds. This suggests that substantial increases in recruitment will be required to meet either of these potential abundance thresholds. Given the long-lived nature of White Sturgeon, it will take a considerable amount of time (i.e., a minimum of 50 years) to achieve these candidate thresholds.

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INTRODUCTION

Given conservation concerns for White Sturgeon (*Acipenser transmontanus*) in the lower Fraser River (e.g., COSEWIC 2012, English et al. in press) there is a need to track abundances against recovery targets, to monitor natural variations over time, and to evaluate population responses to management actions. This translates into 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 2021. 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 Lower Fraser River White Sturgeon, by age/size class and by location; and 3) increase public awareness regarding the conservation and preservation of White Sturgeon in British Columbia. The program uses a volunteer-based “stewardship” approach, initially developed in 1999 (Nelson et al. 2000), to address objectives and generate field data. Since 2000, program field data have been produced by 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, provincial staff from the BC Ministry of Forests, Land, Natural Resource Operations, and Rural Development (FLNRORD), and from Fisheries and Oceans Canada. Over the years, the program has been funded by HCTF, the Province of BC, and by private donations.

To estimate abundances, the Integrated Spatial and Age Mark Recapture (ISAMR) model was developed (Challenger et al. 2017). The ISAMR model uses the PIT tag mark-recapture data that have been collected by the FRSCS volunteers since 2000. It is a spatially explicit and age-structured mark-recapture Bayesian model (e.g., see Coggins et al. 2006) that tracks cohort abundances for 58 age classes over four spatial areas (“sampling regions”) on a yearly time step, by explicitly modelling birth and death. New recruits into the population are modelled as entering the first age class (i.e., age 1), with mortality based on an extrapolation of the mortality-at-age curve estimated for captured age classes. The ISAMR model considers all data from the assessment period at one time (a subset of abundances are reported on, for example, age 7-55, due to the reduced catch rates of fish < age 7 as a result of size selectivity by recreational anglers, and due to the paucity of recaptures of fish > age 55). Translation between age classes and size classes are based on a documented growth curve for Lower Fraser River White Sturgeon (RL&L 2000, English and Bychkov 2012, Whitlock and McAllister 2012). Since the sampling methods (e.g., recreational angling) are expected to produce size selectivity (differences in catch due to recreational anglers targeting larger-sized sturgeon), the ISAMR model estimates a selectivity-at-age relationship from the data. The ISAMR model directly models the effect of yearly sampling effort (i.e., boat days) on catch rates and therefore the predicted yearly catch in each age category.

Challenger et al. (2017) provided a detailed description of the ISAMR model (Version 2.0), including mathematical formulation and data assembly procedures. The objective of this report is to update the Challenger et al. (2017) results with additional years of sampling effort (i.e., to the end of 2020).

FIELD AND ANALYTICAL METHODS

Study Area

The general study area for the Lower Fraser River White Sturgeon Monitoring and Assessment Program includes the Fraser River watershed downstream of Hells Gate (located at river kilometer (rkm) 212 on the mainstem Fraser River), the Harrison River and Harrison Lake, and the Pitt River and Pitt Lake (Figure 1). The general study area is essentially the extent of known and observed White Sturgeon distribution in both the mainstem Fraser River and all tributaries and lakes connected to the lower Fraser River, downstream of Hells 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 Hells Gate. Although White Sturgeon are captured and sampled by FRSCS

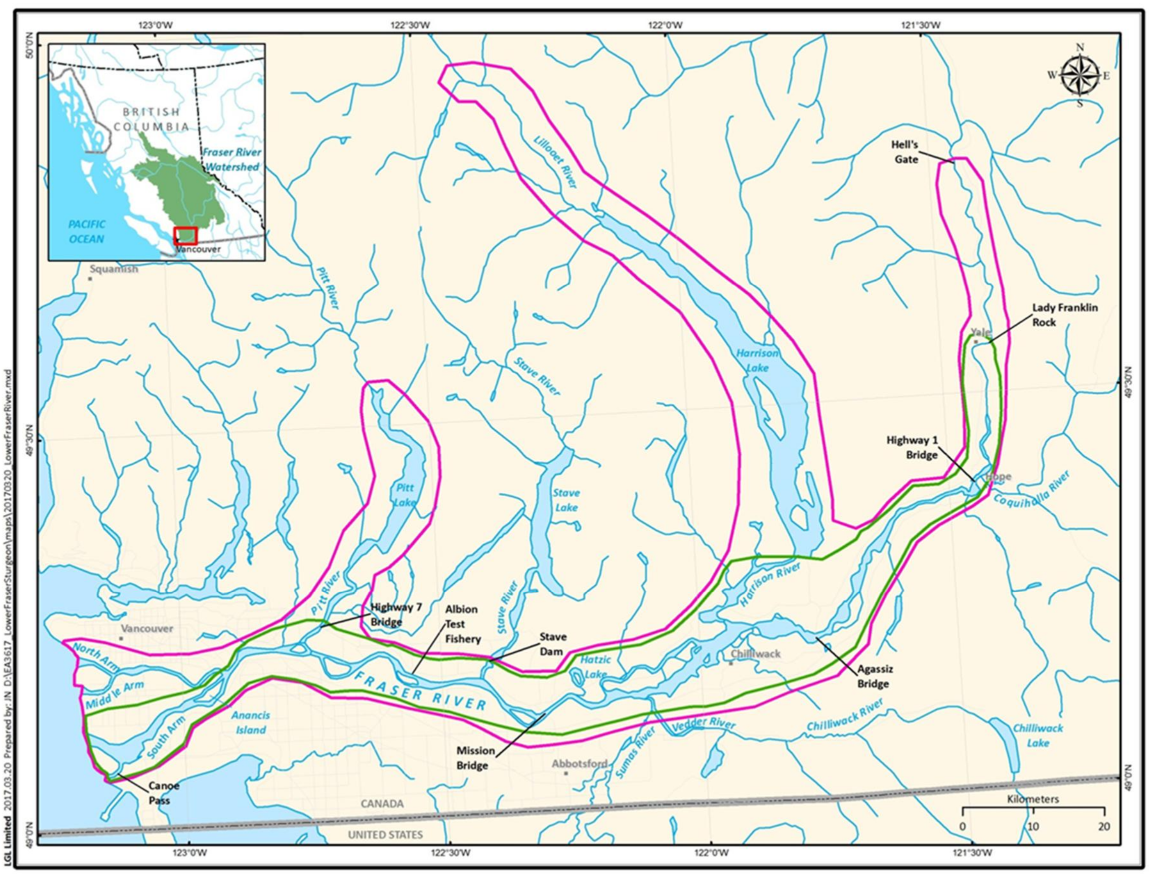

Figure 1. General study area (area within red line), and the core assessment area (area within green line; used for the production of White Sturgeon abundance estimates presented in this report). The general study area as illustrated presents the extent of known/observed White Sturgeon distribution in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

volunteers throughout the general study area, approximately 99% 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 modelling have been limited to those samples collected within the boundaries of the core assessment area, thus allowing direct comparison of annual abundance estimates among years.

Sturgeon Capture and Handling Procedures

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

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

Green Sturgeon (*Acipenser medirostris*) are present in the lower Fraser River (nine confirmed in this program since 2000; Appendix B), and volunteers have information to assist with species identification.

Documentation of Capture Location

A simple mapping system was established to facilitate the documentation of capture locations to the nearest 0.5 km. Waterproof maps, delineated with rkm markings, were provided to all volunteers as part of the tagging equipment kit. Documentation of sturgeon capture location at this scale 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 was assigned to a specific

Table 1. Definition of sampling regions located within the core assessment area and used for abundance estimation of White Sturgeon, 2000-2020. Sampling regions are comprised of unique sampling zones that include the Harrison River and portions of the lower Pitt and lower Stave rivers (Figure 2).

Sampling Region	Sampling Zone River km	From	To	Description
A	0 - 25	Garry Point	East Annacis Island	Main (South) Arm of the Fraser River including Canoe Pass
B	26 - 56.5	East Annacis Island	McMillan Island (Glover Road)	E. Annacis Island to Mission Railway Bridge; lower 4 km of Pitt River (below Hwy 7 bridge); lower Stave River (below Ruskin Dam)
	57 - 78	McMillan Island (Glover Road)	Mission Railway Bridge	
	P0 - P4	Mouth of Pitt River	Pitt River rkm 4	
	ST0 - ST2	Mouth of Stave River	Ruskin Dam	
C	79 - 93 [1]	Mission Railway Bridge	Mouth of Sumas River	Mission Railway Bridge to Hope including Hatzic Slough and the Harrison River
	H0 - H21	Confluence Fraser River	Outlet of Harrison Lake	
	94 - 122	Mouth of Sumas River	Agassiz Bridge	
	123 - 158	Agassiz Bridge	Hwy 1 Bridge (Hope)	
D	159 - 187	Hwy 1 Bridge (Hope)	Lady Franklin Rock (Yale)	Hwy 1 Bridge (Hope) to Lady Franklin Rock (Yale)

[1] Zone includes Hatzic Slough downstream of the water control weir located approximately 1.5 km from the Fraser confluence

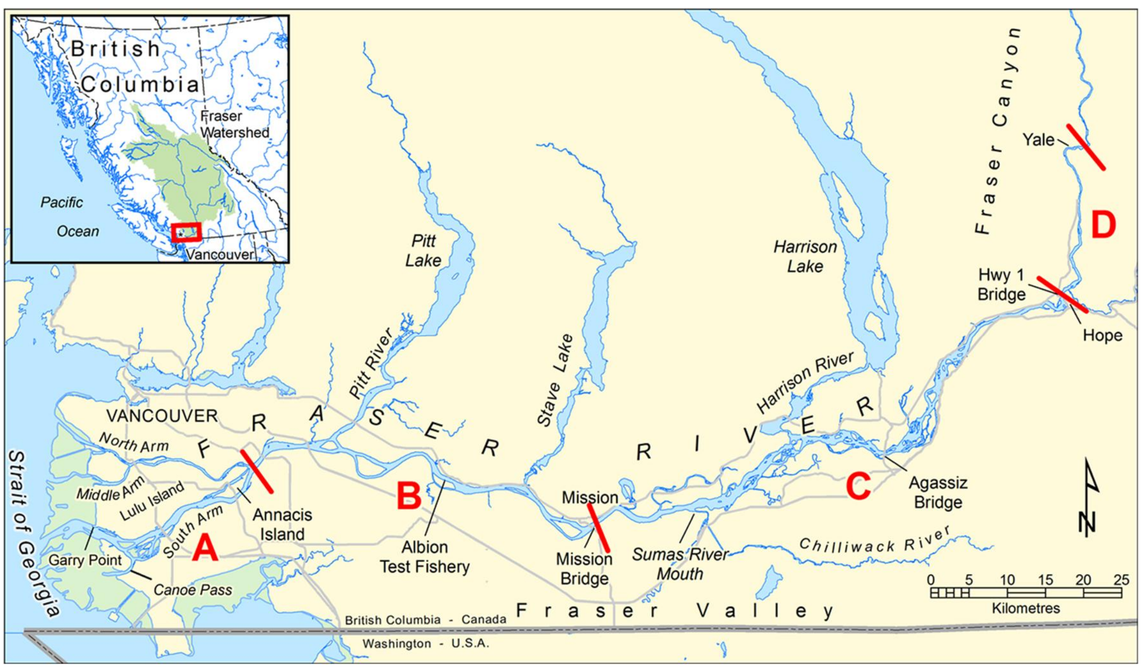

Figure 2. Boundaries of the four sampling regions (A, B, C, and D) that comprise the core assessment area used to generate abundance estimates of White Sturgeon presented in this report. Sampling regions are used in the analytical model to stratify tag release and recapture data. See Table 1 for descriptions of individual sampling region and sampling zone locations and boundaries. See Figure 1 for an illustration of the core assessment area.

sampling region (A, B, C, and D; Table 1, 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. 2013). PIT tags used in the study (distributed by Biomark Inc., Boise, Idaho) were injected beneath the skin of sturgeon with a specialized hand-held syringe and hypodermic needle. PIT tag models used in this study were TX1400L, BIO12.A.02, and BIO12.A.03V1 (12 mm long), and TX1405L (14 mm long); all tag types were 2 mm in diameter. When scanned with a tag reader, these glass-bodied tags emit a unique 10-digit alphanumeric code at a frequency of 125 kHz. PIT tags were kept in small glass or plastic jars that contained ethyl alcohol for disinfection purposes. Hypodermic needles (2.4 mm in diameter), 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 nearly 100% (T. Rien, Oregon Dept. of Fish and Game, pers. comm.). Not all West Coast sturgeon tagging studies have applied PIT tags to the head location; other tag locations include the body cavity and the dorsolateral area near the dorsal fin. Volunteers were trained to scan all alternative areas, and sturgeon recaptured during this study that had a PIT tag in a non-standard location received a new tag in the head location. Tag-recapture data for all tags, regardless of tag type or body location, were recorded and entered in the recapture database.

The tag readers (scanners) used for the program were hand-held units that were capable of detecting both 125 kHz and 134.2 kHz PIT tags. Tag readers included two models from Biomark (models GPR Plus and HPR.LITE) and one from AVID Canada (model Power Tracker V). All 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. Tag readers were also used to scan PIT tags prior to tag application (so that the tag number could be recorded on the data sheet) and, once inserted into the sturgeon, to confirm the active status and number of the applied tag (prior to the release of the sturgeon).

Tag Recoveries

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

Biosampling

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

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

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 new tag being applied.

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

Data Management

Volunteers were trained to secure data sheets at the end of each sampling day. Data sheets were transferred to the field program coordinator for review; copies of data sheets were retained by the respective volunteer for filing. All volunteers retained a copy of the data that they provided, not only as a data security measure but also for future reference. The 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, and database updates were transferred to the program manager 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.

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. For each 20-cm size category, growth was plotted against sampling year, and Gaussian linear regression was used to estimate trends (slopes).

Abundance Estimation

The FRSCS PIT tag mark-recapture dataset was filtered to produce a subset of data for analysis that only included samples from 2000-2020 which met the compatibility criteria for the model. Recreational angling captures and incidental captures from the Albion Test Fishery were included if the fish fell within the modelled age range (age 7 to 55), and if they occurred in one of the four lower Fraser River sampling regions that make up the core assessment area of this study (Figure 1, Table 1) with known sampling effort for each year (Table 2). Because age of captured sturgeon is a requirement for the model, fish ages were estimated via a von Bertalanffy growth model (i.e., $L_a = 370.1 \times (1- \exp(-0.025a))$) developed for lower Fraser River White Sturgeon (RL&L 2000, English and Bychkov 2012, Whitlock and McAllister

Table 2. Sampling effort (number of trips) by FRSCS volunteers in the core assessment area, by sampling region and year.

Year	Region A	Region B	Region C	Region D	Total
2000	65	220	555	19	859
2001	101	261	597	33	992
2002	79	166	479	30	754
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	32	448	1,206	66	1,752
2009	50	483	884	74	1,491
2010	44	474	888	112	1,518
2011	42	471	896	68	1,477
2012	41	597	1,027	87	1,752
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	37	256	993	129	1,415
2018	45	237	901	156	1,339
2019	65	389	1,100	212	1,766
2020	30	310	667	80	1,087

2012). For recaptures of previously marked individuals, aging was determined based on the age determined at first capture and the elapsed time between captures. Multiple recaptures of the same fish in a given year were considered redundant for the ISAMR model and were ignored. The ISAMR model considers untagged and tagged captures separately, thus the model includes both untagged captures released with a tag, and untagged captures released without a tag.

The capture data were analyzed using the same model formulation described in Challenger et al. (2017). A single S-shaped selectivity-at-age curve was estimated and shared across all assessment years. The curve represented 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 by the fishing gear to the same degree. The ISAMR model, at this time, does support multiple selectivity curves (multiple curves could be used to model changes in angler behaviour over time), as this application was not found to be necessary when it was originally formulated (see Challenger et al. 2017). Instantaneous sampling rates for each region were modelled as a linear function of the number of angling trips to each region in each year (see Table 2), with separate coefficients estimated for each sampling region.

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 10 million posterior samples were taken after a burn-in of 50,000. The complexity of the model necessitated thinning the MCMC chain to every 900th proposal to remove autocorrelation in the derived abundance metrics, which resulted in 10,000 retained posterior samples.

Abundance Forecasts

The inclusion of age structuring in the ISMAR model makes forward abundance projections possible by combining age-specific abundance estimates with estimated age-specific mortality rates and future recruitment (i.e., age-7 recruitment) scenarios. Population abundances were forecast from 2021 through to 2070 under a scenario where the average age-7 recruitment levels from the last 10 years (i.e., 2011-2020) were maintained. This scenario was then compared to scenarios where recruitment was increased by 1.6 times and 2.4 times that of current recruitment, in order to determine the level of improvement in recruitment required to stabilize the population (i.e., "1.6x Recruitment") or to return the population to abundances achieved in the recent past (i.e., "2.4x Recruitment"). Importantly, no evaluations were made under the scenarios of further recruitment decline.

Forecasts were generated based on the posterior distribution of age-specific abundances and mortality rates, along with the recruitment scenario under consideration. Each posterior sample contained a unique set of age-specific abundances and age-specific mortalities, which were projected forward based on a sample-specific average recruitment value with a year-to-year variation drawn from a normal distribution. The unique average recruitment value assigned to each posterior sample was drawn from the posterior distribution of age-7 recruitment over the last 10 years. Year-to-year variation in the forecasted recruitment was based on the year-to-year variability in the posterior average of age-7 recruitment over the last 10 years. For all scenarios a period of 10 years was used to transition recruitment from current levels (i.e., the sample specific average recruitment value) to the recruitment scenario level (e.g., "1.6x Recruitment"). This procedure created a posterior predictive distribution of age-specific abundances up to the year 2070 for each recruitment scenario.

RESULTS

Sampling Sources

Three sources provided 96.5% of all scanned samples from the core assessment area over the term of the program from 1999 through 2020: angling (89.4%), Albion Test Fishery (3.5%), and First Nations net fishery (2.9%; Table 3). An additional 0.7% of the total sample was provided through dedicated sampling efforts using tangle nets and bottom trawls associated with the FRSCS Lower Fraser River Juvenile White Sturgeon Habitat Program (Glova et al. 2008, 2009, 2010) and from tangle net captures from the provincial Lower Fraser Juvenile White Sturgeon Habitat Indexing Program (Stoddard and Rochetta 2014). Additionally, approximately 3.5% of samples were provided by other sources including PSC Test Fishery, unsourced mortalities, juvenile angling gear, set line, fishwheel, ghost net, river guardian, and enforcement (Table 3).

From October 1999 through December 2020, a total of 172,060 White Sturgeon sampling events occurred in general study area of the lower Fraser River (Appendix B, Table 3). The total number of sampling events were generated from variety of gear types and sources, but the high majority (over 90%) of sturgeon samples were provided by FRSCS volunteers that were using regular angling gear. Since 2000, the number of samples collected varied from a low of 4,387 (in 2000) to a high of 12,155 (in 2013) and has averaged 8,171 samples per year over the 21-year span (Appendix B). The numbers of samples collected from 2016 to 2018 (range from 6,214 to 7,919) were lower than in the previous 12 years. Though sampling increased in 2019 (9,808 samples), the number of sturgeon samples collected in 2020 (6,154) returned to a level similar to that observed in 2018 (Appendix B). Note that there were notable effort reductions in 2020 that resulted from COVID-19 restrictions.

Of the total samples collected from the general study area between 1999 and 2020, 76,376 sturgeon were tagged with a PIT tag (in the head location) and released (Appendix B). The total sample includes 88,770 recapture events. In addition, the total sample includes 5,657 sturgeon that were sampled (examined for the presence of a PIT tag and measured) but not tagged (Appendix B), because of a shortage of available PIT tags, safety concerns, or because the fish was considered to be in poor physical condition (bleeding, wound, or other significant physical injury) when it was sampled.

Population abundance estimates and trends were generated using the ISAMR population model, which was developed for this population (Challenger et al. 2017), using an assessment period from 2000 until

Table 3. Summary of sources of sturgeon samples (all sizes) scanned for the presence of a PIT tag that were captured within the general study area of the Lower Fraser River White Sturgeon Monitoring and Assessment Program 1999-2020.

Source	Samples	Percentage	Comment
Angling	153,787	89.38%	
Albion Test Fishery	5,936	3.45%	
First Nation Net Fishery	4,955	2.88%	
Juvenile Tangle Netting	1,290	0.75%	
Other	6,091	3.54%	Includes: PSC Test Fishery, unsourced mortalities, commercial net, juvenile angling gear, set line, fishwheel, ghost net, river guardian, and enforcement
Total	172,060		

the end of 2020. Only samples collected by regular angling gear or by the Albion Test Fishery met the compatibility criteria for the model. In addition, there were 29,546 captures from volunteer recreational anglers and the Albion Test Fishery that were found to be incompatible with the ISAMR population model (e.g., no scan performed, outside assessment years, outside core assessment area, ages outside the modelled ages, no length or age data available, and repeat captures of the same individual within a year). This left 142,514 individual capture events that were compatible with the ISAMR model, of which 73,569 were untagged captures, and 68,945 were recapture events. Within the assessment period, 96% of the compatible capture events came from 31,976 recreational angling trips (sturgeon angling for the purposes of mark-recapture data collection; Table 2), which was used as a metric of effort in the population model (Challenger et al. 2017).

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. Recaptures of tagged sturgeon during this study confirmed that movements and migrations occur throughout the entire lower Fraser River general study area. Recapture locations of any given individual varied, and were sometimes several kilometers apart, even when the fish was at large for relatively short time periods. In addition, several tagged White Sturgeon have been observed to move across the supposed boundary between sturgeon populations (Upper and Lower Fraser River populations) at Hells Gate (rkm 212), either being tagged upstream of Hells Gate and recaptured downstream, or the reverse (see Appendix B).

Many individual tagged sturgeon have been recaptured and sampled numerous times. For example, by December 2020, 2,598 individual fish had been sampled five times, 202 fish had been sampled 10 times; three individual sturgeon have been sampled 27 times, and one fish has been sampled 29 times (Appendix E). Several individual tagged sturgeon have been sampled multiple times during the same year (up to 10 times in 2019, Appendix D). The number of times each individual sturgeon is captured is likely higher than the number for which we have sampling records; angled sturgeon captures by program volunteers represent only a fraction (likely less than 20%; English et al. in press) of the total number of sturgeon captured by the full recreational sturgeon fishery, and annual numbers of capture events from gill net fisheries are not known.

Sample Mark Rates and Percentages Tagged

The annual numbers of tags applied and the reported number of tag recaptures have varied over time. The proportion of recaptures recorded in a given 12-month sampling period (i.e., the annual mark rate) steadily increased each year until 2017. Concomitantly, the proportion of newly released tags has declined over the same period, as the pool of marked fish available for recapture increased.

In 2020 within the general study area (Figure 1), 2,120 PIT tags were applied, and 3,958 tagged sturgeon were recaptured (Appendix B). In the core assessment area (Figure 2), the sample mark rate for angling and the Albion Test Fishery in 2020 was 68.3% (Appendix C, Figure 3). The sample mark rate is the proportion of all scan events for which the scanned fish already possessed a mark; the sample mark rate treats each scan event as an independent data point, regardless of whether the individual fish has been repeatedly recaptured within the year. Sample mark rates in 2020 varied by the size group of sampled sturgeon; the adult (age 23-55; 160-279 cm FL) group had the highest sample mark rate (84.2% of scan

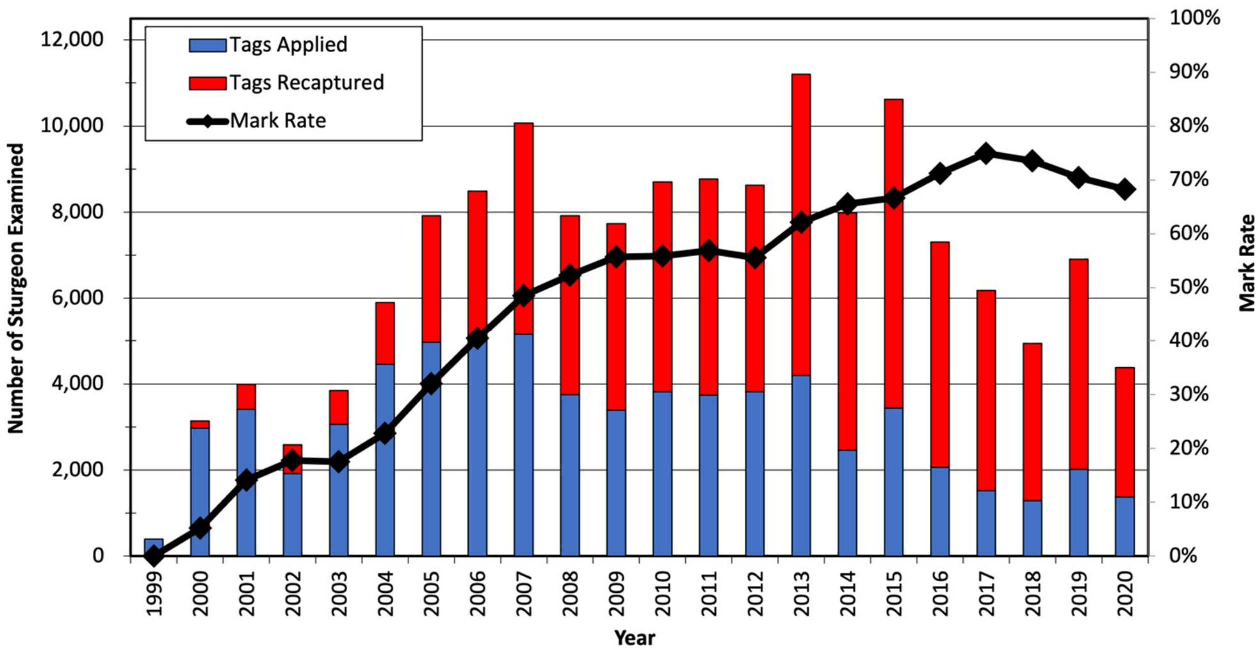

Figure 3. Number of tags applied, reported number of tags recaptured, and the annual mark rate for 60-279 cm FL White Sturgeon sampled by angling and the Albion Tet Fishery in the core assessment area of the lower Fraser River, by year, 1999-2020.

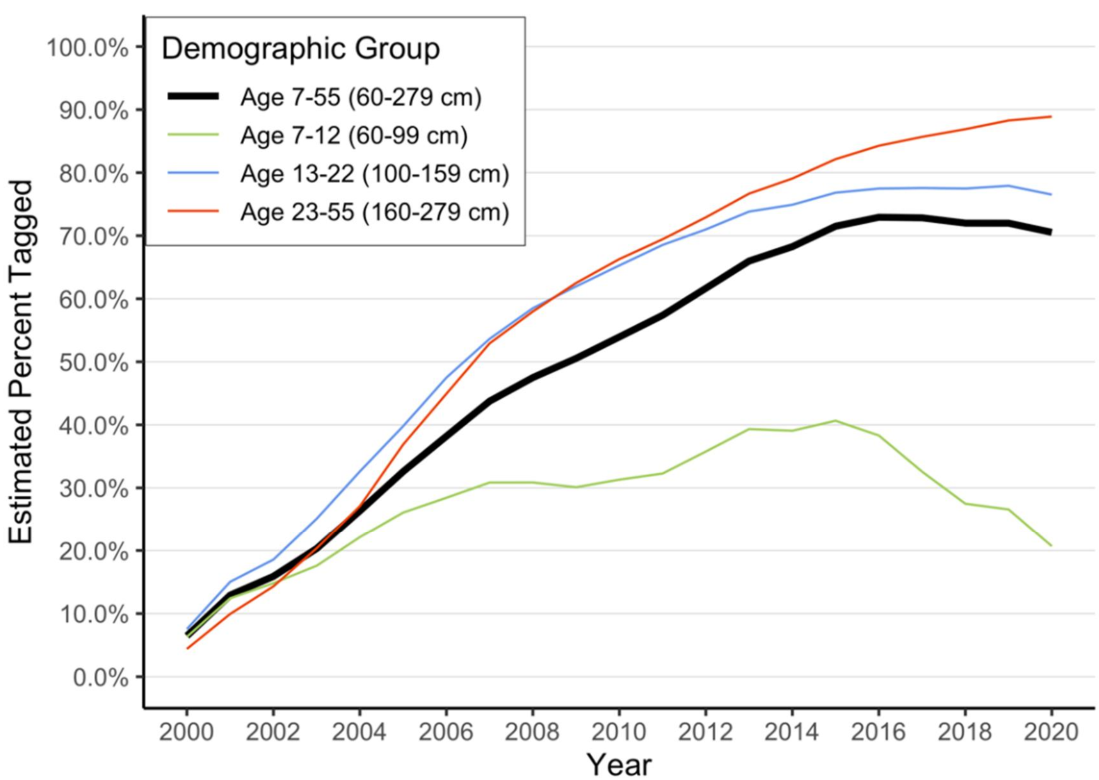

Figure 4. Estimated percent of the population tagged, by demographic group and year for age 7-55 (60-279 cm FL) sturgeon. Estimates were generated from the ISAMR model.

events were of a fish that possessed a PIT tag applied under this program), followed by the subadult (age 13-22; 100-159 cm FL) group (71.1% of scans were recapture events) and the juvenile (age 7-12; 60-99 cm FL) group (32.8% of scans were of fish that possessed a tag).

In contrast to the sample mark rate, the 'percent tagged' is an estimate of the proportion of individuals in the population that are in possession of a tag at some point within the calendar year (repeat recaptures of a single marked individual will inflate the sample mark rate, but will not impact the percent tagged). As expected, estimates of the percent tagged (Figure 4) for age 7-55 (i.e., 60-279 cm FL) were very similar to the sample mark rate for 60-279 cm FL sturgeon. Within the population, the percent tagged was highest for the older age classes (i.e., age 13 and older), with percentages dropping progressively for younger age groups. This is not unexpected, as larger individuals are typically targeted by recreational anglers; furthermore, older individuals have also been exposed to the marking program for a longer period of time than younger individuals. Juvenile fish aged 7-12 showed a decline in the percent tagged in the last two years of the assessment period, while older groups showed a general increase with some signs of leveling-off. Additional sampling effort has been focused on juvenile sturgeon in recent years to provide the data needed to produce abundance estimates for sturgeon under age 7 (English and Robichaud 2020).

Mortalities

Each year, observations of dead sturgeon are reported by program volunteers, enforcement officers, recreational anglers, First Nations fishers, and the general public. FRSCS program volunteers are trained to sample and mark sturgeon mortalities that are encountered, and attempts are made to sample mortalities reported by the public. In 2020, 42 dead sturgeon were reported and observed; this is the highest number of sturgeon mortalities observed in the lower Fraser River since 2005. The high numbers of observed mortalities in 2020 were the result of a small number of cases where abandoned gill nets that contained sturgeon were reported; the confirmed cause of death for 90% of sturgeon mortalities in 2020 was gill net. One abandoned gill net contained 22 White Sturgeon, 20 of which were dead and two that were released alive but in poor condition; a second abandoned gill net contained 13 sturgeon, all of which were dead. FRSCS volunteers were able to scan (for the presence of a PIT tag) 45% of observed sturgeon mortalities in 2020, and 68% of scanned mortalities had a PIT tag (i.e., a recapture). Tag numbers from mortalities that possessed a PIT tag were flagged in the FRSCS core database as not being available for subsequent recapture.

Growth Analyses

A comparison of average annual growth rates of White Sturgeon from 60-179 cm FL sampled from 2001-2020, by 20-cm FL size groups, revealed variation among years, and for several size groups showed declining long-term trends (Figure 5). However, the 2020 growth rates were greater than or approximately equal to those from 2019 for all size groups, and all are showing stable or positive short term (< 5 year) trends.

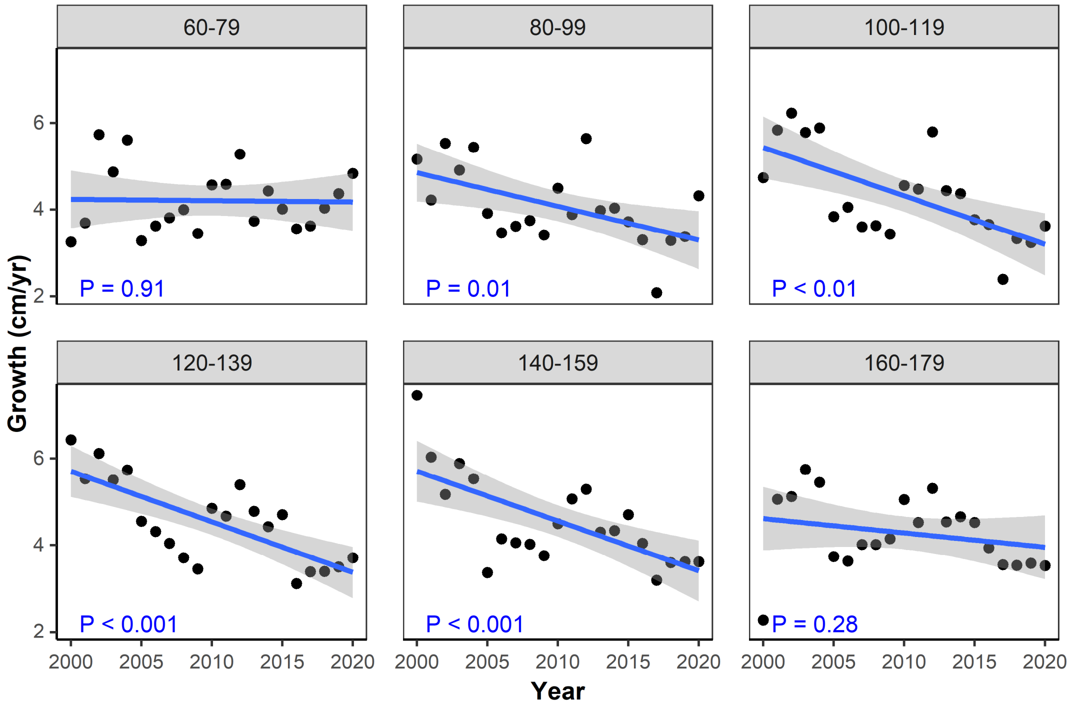

Figure 5. Average annual growth of 60-179 cm FL White Sturgeon in the lower Fraser River, by year and by 20-cm FL size group. The 95% confidence bounds around the linear trendlines are shown in grey shading, and the regression P values are shown in the bottom left corner of each panel.

Abundance Estimates

Estimates of select ISAMR output include mortality, recruitment (historical and assessment period), yearly regional sampling rates, selectivity-at-age, and movement probabilities (Figure 6). Results from the current analyses are broadly similar to those previously published (Challenger et al. 2017, 2020), including: 1) mortality rates were lowest for the older age classes; 2) there was close-to-complete gear selectivity for sturgeon of age 12 and older; and 3) there were substantial declines in recruitment to the sampled population within the assessment period. As indicated in prior analyses, results for 2020 also suggested that sturgeon showed a tendency to remain within a given sampling region, with higher fidelity for sampling regions upstream from the lower estuary (sampling region A; Figure 6d).

Abundance estimates for the population exposed to sampling (i.e., the population of fish 60-279 cm FL in the core assessment area) were broken down into size/age categories, including the recruitment into age 7 (Figure 7), and three subsequent demographic age groupings (Figure 8). Age-7 was used as an indicator for juvenile recruitment due to this age class being roughly 50% selected into the recreational fishery (Figure 6a), and thus estimates are well supported by observed catch data. Historical age-7 recruitment showed a steady increase from 1980 up to an estimated peak of 8,493 individuals (95% CI: 7,360, 9,717) that occurred at the start of the assessment period in 2001 (Figure 7). After the 2001 peak, age-7 abundances began a steady and precipitous decline until leveling-off at an estimated abundance of under 2,000 individuals from 2012-2016, the lowest level of estimated age-7 abundances within the study period. There have been some modest signs of improvement (i.e., 2017-2020), with a mean abundance estimate for 2020 of 2,479 (95% CI: 1,758, 3,389), although uncertainty is currently higher than earlier in the time series.

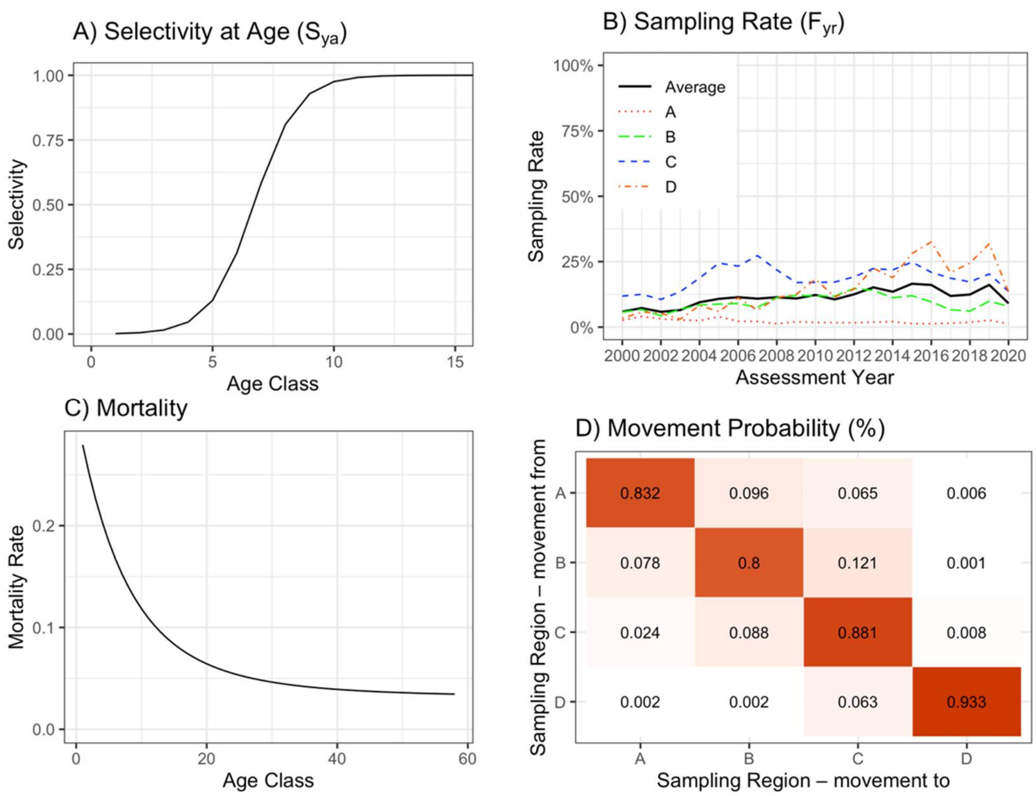

Figure 6. Select ISAMR model output including: A) selectivity-at-age; B) regional sampling rates; C) estimated mortality rate; and D) regional movement probabilities.

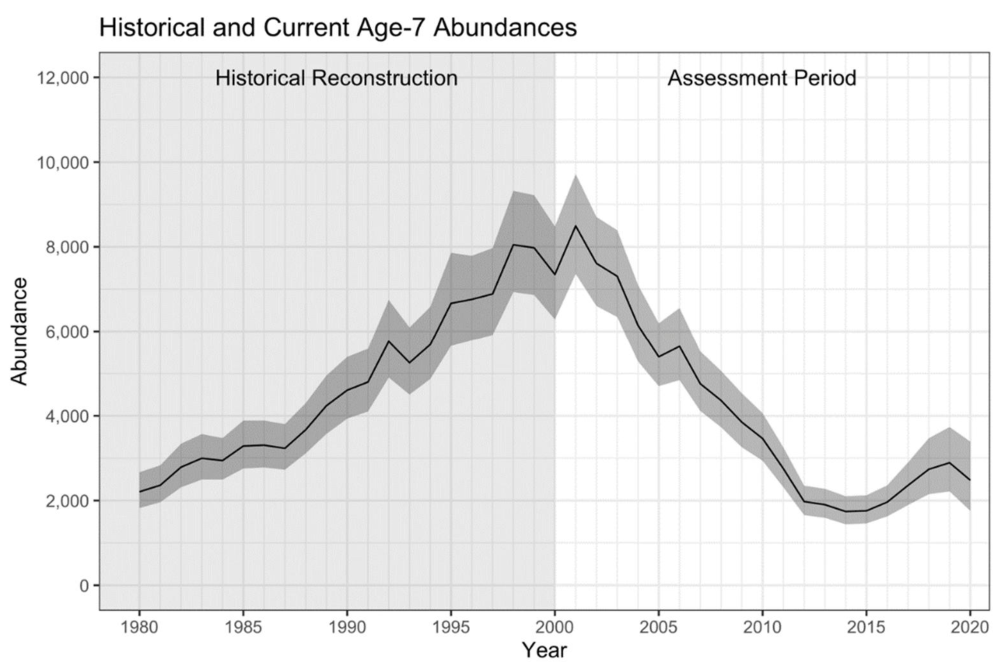

Figure 7. Estimated abundances of age-7 Lower Fraser River White Sturgeon prior to 2000 (light grey shaded region) and during the 2000-2020 assessment period, with 95% credible intervals (dark grey shading).

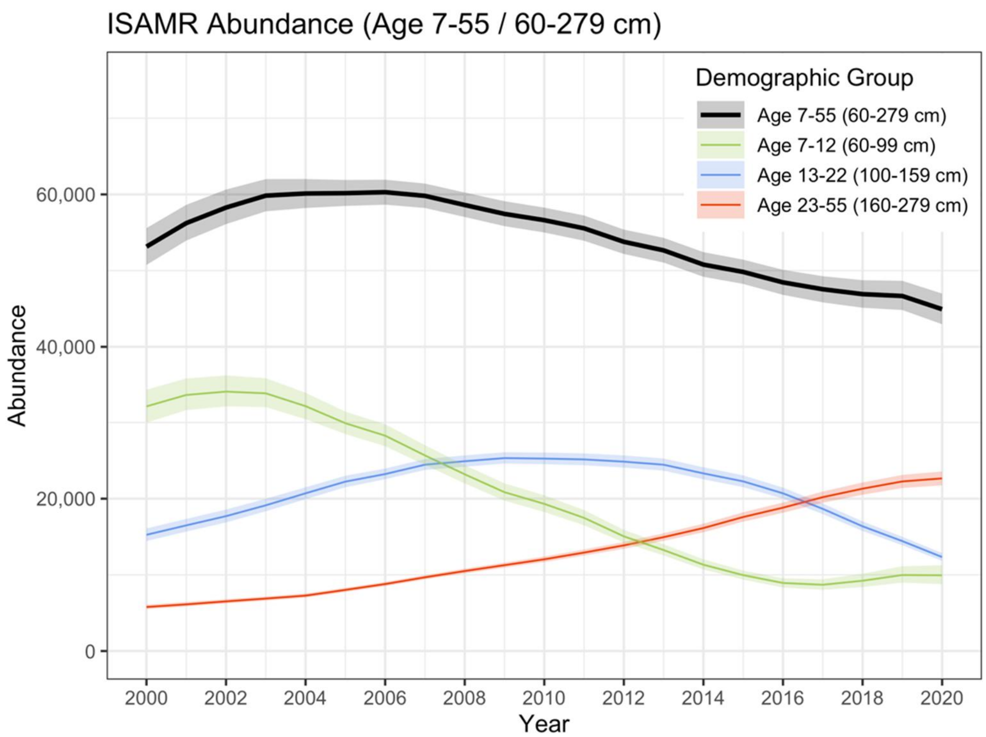

Figure 8. Abundance estimates of age 7-55 (60-279 cm FL) Lower Fraser River White Sturgeon from 2000 to 2020. Shading indicates 95% credible intervals.

For the adult (age 23-55) population, abundance estimates showed a high level of precision (Figure 8), which is due in part to the large sample size, and to the high percentage (88.9%) of the adult population that is estimated to have already been marked (Figure 4). Estimates of older age classes are possible, but are of limited usefulness due to sample size limitations (encounters with very large/old fish are rare and infrequent). Similarly, estimates of younger age classes are possible, but less observed catch occurs in these younger age categories, requiring a stronger reliance on the mortality curve extrapolation (Figure 6c), a parametric curve estimated based on catch and mark-recapture histories from older age classes (i.e., age 7-55) where the majority of catch occurs (i.e., higher selectivity; Figure 6a). As such, only age-7 and older abundances were reported, as this was the first age class to be at least 50% selected into the fishery (Figure 6a). Thus, age 7 represents an evidence-based measure of effective juvenile recruitment, that may, or may not, be a reliable indicator of the temporal pattern of recruitment into younger age classes. The reduction in estimated recruitment levels could be the result of reductions of any component from spawning and egg production through to hatching and emergence as well as survival of free-swimming larvae through to exogenous feeding and subsequent survival into older age classes prior to age 7. As such, care should be taken when interpreting temporal patterns in age-7 abundance as a direct indicator of temporal patterns in egg production or abundance levels in younger age categories.

While these estimates are not exact reconstructions, they should reflect general trends in age-specific abundances. Estimates of abundance for age 7-55 (60-279 cm FL) were presented for 2000-2020 (Table 4), with an illustration of these estimates included in Figure 8. These are estimates of all sturgeon age 7-

Table 4. Abundance estimates of age 7-55 (60-279 cm FL) Lower Fraser River White Sturgeon from 2000 to 2020.

Year	Abundance Estimate	95% CI[1] Low	95% CI[1] High	Bounds as % of Abundance Estimate	CV (%)[2]	Annual % Change
2000	53,145	50,742	55,575	4.5%	2.3%	
2001	56,230	53,939	58,630	4.2%	2.1%	5.8%
2002	58,274	56,100	60,637	3.9%	2.0%	3.6%
2003	59,839	57,779	62,008	3.5%	1.8%	2.7%
2004	60,120	58,216	62,018	3.2%	1.6%	0.5%
2005	60,164	58,484	61,895	2.8%	1.4%	0.1%
2006	60,291	58,653	61,930	2.7%	1.4%	0.2%
2007	59,809	58,219	61,422	2.7%	1.4%	-0.8%
2008	58,609	57,037	60,247	2.7%	1.4%	-2.0%
2009	57,441	55,835	59,107	2.8%	1.5%	-2.0%
2010	56,617	55,002	58,265	2.9%	1.5%	-1.4%
2011	55,548	53,918	57,233	3.0%	1.5%	-1.9%
2012	53,778	52,184	55,383	3.0%	1.6%	-3.2%
2013	52,655	51,051	54,297	3.1%	1.6%	-2.1%
2014	50,786	49,187	52,422	3.2%	1.6%	-3.6%
2015	49,822	48,252	51,437	3.2%	1.7%	-1.9%
2016	48,451	46,818	50,101	3.4%	1.8%	-2.8%
2017	47,552	45,829	49,262	3.6%	1.9%	-1.9%
2018	46,911	45,127	48,740	3.9%	2.0%	-1.3%
2019	46,665	44,827	48,656	4.1%	2.1%	-0.5%
2020	44,930	42,960	46,985	4.5%	2.3%	-3.7%

[1] CI – Credible Interval
[2] CV – Coefficient of Variation

55 (60-279 cm FL) that used the core assessment area during the study period. That said, within a given year, individual sturgeon may have temporarily been outside the core assessment area due to emigration which is typically short lived (Robichaud et al. 2017). As such, abundance estimates represent the population of sturgeon using the lower Fraser River at some point during the recreational angling season, which occurs during the entirety of the calendar year.

Overall, abundance trends include:

- a steady decline in age 7-12 juveniles (60-99 cm FL) from 2002 to 2017 (Figure 8; including a 70.8% decline over the 18 years since 2002).
- a decrease in subadults (age 13-22, 100-159 cm FL) since 2009 (including a 51.3% decline over the 11 years since 2009); and
- an increase in adult abundances (age 22-55, 160-279 cm FL) since 2000.

These three patterns are indicative of a historical recruitment pulse (e.g., the peak in age-7 abundance; Figure 7), followed by a reduction of recruitment into the juvenile age category. This reduced replenishment of juvenile sturgeon resulted in the estimated decline of age 7-12 (60-99 cm FL) juvenile sturgeon starting in 2002, which subsequently resulted in a decline of age 13-22 (100-159 cm FL) subadult sturgeon that commenced after 2009 (Figure 8). Both demographic groups (age 7-12 juveniles and age 13-22 subadults) showed the same general temporal pattern as age-7 recruitment but were right-shifted and slightly more spread-out (Figure 8).

Recently, estimated age-7 recruitment has shown signs of stabilizing with possible improvements since 2012 although uncertainty is higher in the later portion of the time series. The most-recent (2020) estimate of age-7 recruitment was lower than the prior year (2019; Figure 7). Depending on the duration of any potential stabilization or improvement in age-7 recruitment, future assessments would first see a stabilization of estimated abundances in the age 7-12 demographic, followed in subsequent years by stabilizations in the subadult age 13-22 demographic (i.e., age 13-22; 100-159 cm FL). Currently, the juvenile category is showing signs of stabilization (albeit at low levels), while the subadult category appears to be in a state of decline as the abundance in this demographic are from the 2005-2014 age-7 cohorts that have exhibited a steady year-over-year decline since 2001 (Figure 7). The mature adult size class (i.e., age 22-55; 160-279 cm FL) has increased in abundance over the last two decades due to a steady increase in age-7 recruitment estimated to have occurred until around 2001. However, the increasing adult abundance trend is expected to reverse within a few years as younger cohorts with lower estimated abundances grow into and begin to dominate this category, and individuals currently in this category either age out (i.e., older than age 55) or die. Adult peak abundance is expected to occur soon, as most cohorts from the earlier age-7 recruitment pulse (Figure 7) should enter this category in the coming years. We explore the implications of this further in the Abundance Forecasts section below.

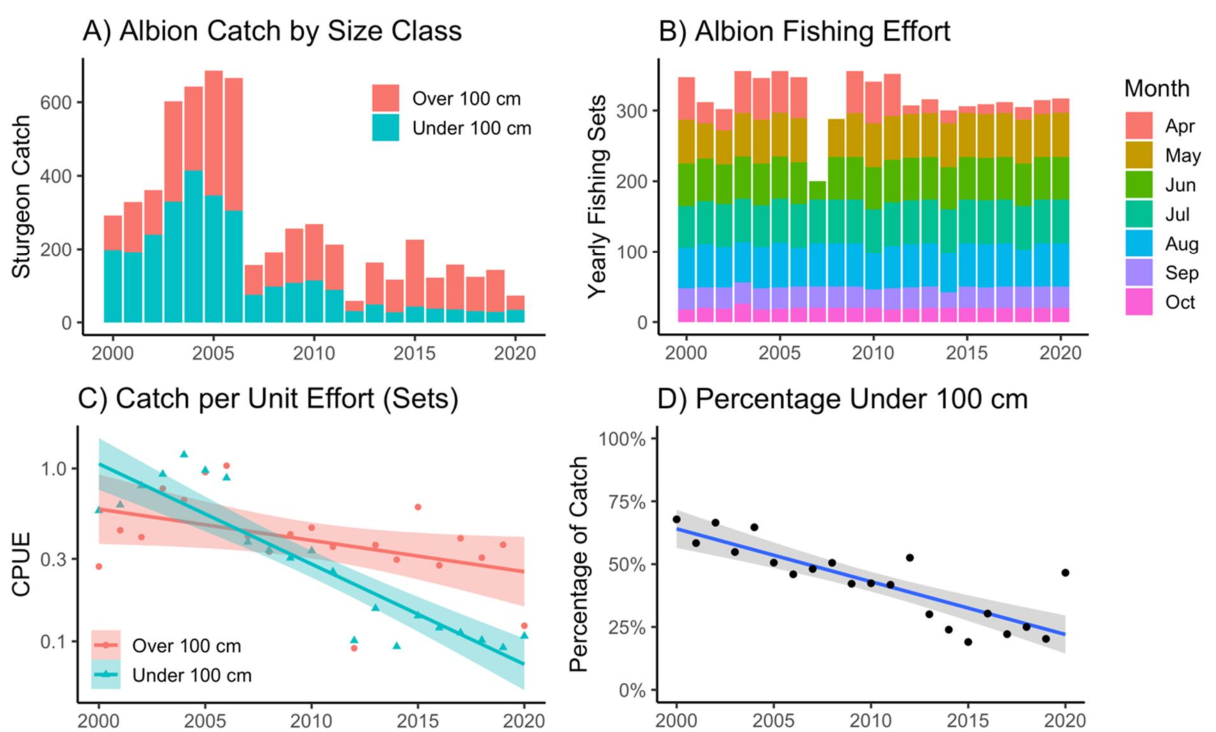

Figure 9. Summary of Albion Test Fishery sturgeon (A) total catch by size category, (B) yearly fishing sets, (C) catch per unit effort for sturgeon under and over 100 cm FL and (D) percentage of catch under 100 cm FL during the assessment period. Lines represent simple linear regression fit, with shading indicting the 95% confidence region for the regression line.

Albion Test Fishery

Sturgeon catch in the Albion Test Fishery provides more perspective on recent demographic changes within the population. Sturgeon catch from the Albion Test Fishery varied over the 21-year assessment period (Figure 9a), whereby the highest catch rates occurred during the first six years of the assessment period (this corresponds with the highest ISAMR age 7-55 abundance estimates; see Figure 8). Albion Test Fishery sturgeon catches then dropped precipitously in 2007 (Figure 9a), which corresponded with a period of reduced effort (Figure 9b), but remained low thereafter even though Albion Test Fishery effort rebounded in the latter half of the assessment period.

While sturgeon of different sizes cannot be expected to be captured at the same rate (due to gear-selectivity issues; e.g., Figure 6a), trends in catch rate *within a size category* would not be biased by selectivity. By selecting 100 cm FL as a cut-off between size categories, the Albion trends can be directly compared to those estimated by the ISAMR model. Standardizing for effort (i.e., number of sets performed in a year) the Albion Test Fishery catch per unit effort (CPUE) showed different trends for the two size categories (Figure 9c). Both showed a significant decline (P value = 0.02), but the juvenile (< 100 cm FL) CPUE showed a significantly steeper decline (juveniles were decreasing at a faster rate than subadult/adult fish; $P < 0.001$), which is consistent with the general ISAMR results that found an overall abundance decline in age 7-55 sturgeon, and a steeper decline in age 7-12 sturgeon. The proportion of the Albion sturgeon catch that was made up of juveniles declined over time, decreasing by, on average, 2.1 percentage points per year (95% CI: 1.5% to 2.8% decrease), a trend that was statistically significant ($P < 0.001$). The percentage of the Albion sturgeon catch that was smaller than 100 cm FL was much greater in 2020 relative to the trend line, although the total catch in the Albion Test Fishery was one of the lowest to date (Figure 9a).

Abundance Forecasts

Abundance forecasts were generated based on average age-7 recruitment over the last 10 years (mean: 8,399, sd: 2,086), and the year-to-year recruitment variability over the same period (i.e., an estimate of process error; sd: 1,835). Various recruitment scenarios (i.e., “1.0x Recruitment”, “1.6x Recruitment”, and “2.4x Recruitment”) were explored.

Under the maintained scenario (i.e., “1.0x Recruitment”; Figure 10), total abundance for age 7-55 (60-279 cm FL) sturgeon is expected to continue to decline over the next 40 years (i.e., until the 2060s), before leveling off at less than half the estimated abundance level (i.e., approximately 26,000 [95% CI: 16,300, 39,500]) at the start of the assessment period (i.e., early 2000s; Figure 10). This forecast represents a further 42% decline below the current population levels. Within the forecasted period, juvenile sturgeon (age 7-12; 60-99 cm FL) would continue to remain stable at the current levels of approximately 9,900 individuals (95% CI: 5,700, 15,300) per year. This would result in a continued decline of subadults (age 13-22; 100-159 cm FL) until the late 2020s, followed by a stabilization at approximately one third of the 2010 abundance (i.e., approximately 7,600 [95% CI: 4,500, 11,700]). Abundances of adult sturgeon (age 23-55; 160-279 cm FL) would peak by the early to mid 2020s (i.e., approximately 23,500 [95% CI: 22,400, 24,600]), followed by a gradual decline through 2060, after which it would be expected to stabilize at less than half of the anticipated peak (i.e., approximately 8,600 [95% CI: 5,400, 12,900]). The rate of decline for the adult group is slower than other groups due to the higher number of age classes (33 ages) included in this grouping (as compared to six ages for juveniles and 10 ages for subadults).

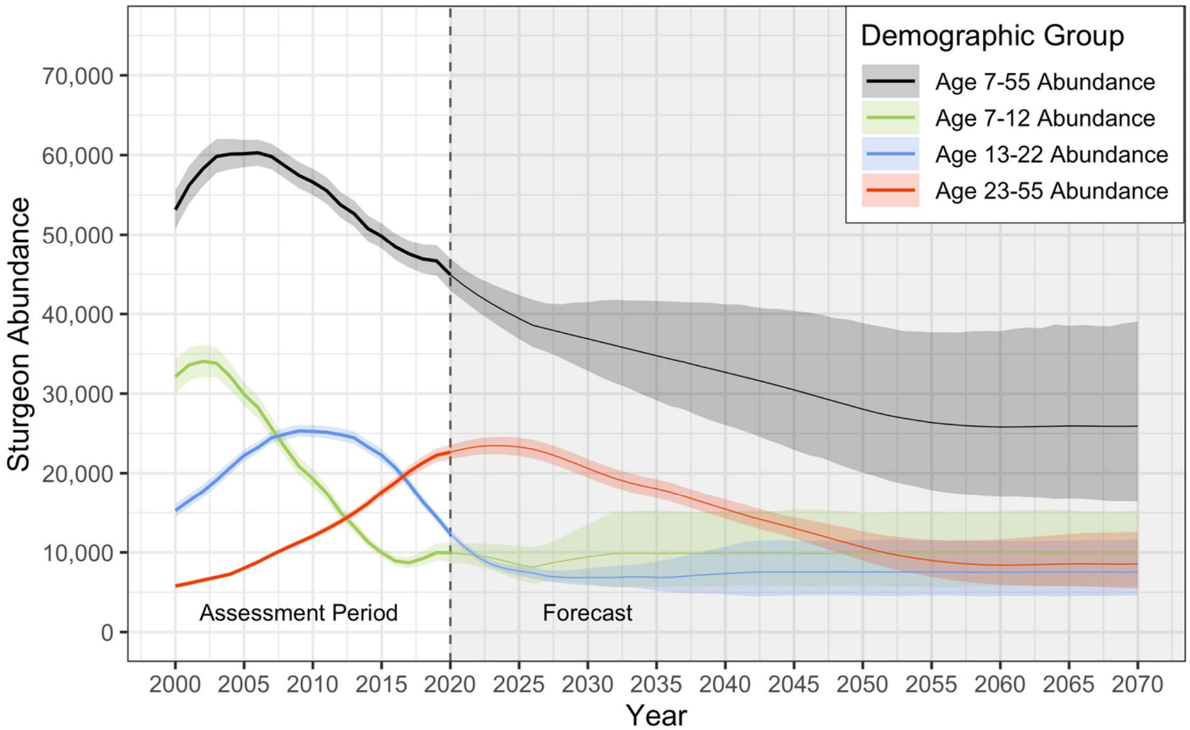

Figure 10. Abundance estimates for Lower Fraser River White Sturgeon for 2000-2020, and abundance projections for 2021-2070 (assuming that annual age-7 recruitment remains the same as recent estimates, e.g., 2011-2020recruitment). Shading around lines indicates uncertainty associated with the annual estimates and forecasts. Background grey shading (after 2020) indicates projected years.

Under the "1.6x Recruitment" scenario (Figure 11, middle panel), total abundance of age 7-55 (60-279 cm FL) would decline for several years and stabilize by the 2030s at an abundance close to current population levels (i.e., approximately 40,000 [95% CI: 29,900, 55,200]), which is approximately a 33% decline relative to the peak abundance estimated in the early 2000s. Under this scenario, juvenile sturgeon (age 7-12; 60-99 cm FL) would, by definition, stabilize at abundance levels 1.6 times higher than current levels (approximately 15,800 [95% CI: 9,000, 24,500]). Age 13-22 (100-159 cm FL) sturgeon were also forecasted to decline until around 2030, but with abundances stabilizing twenty years later (i.e., late 2040s) at approximately 1.6 times higher than under the "1.0x Recruitment" scenario (i.e., approximately 12,100 [95% CI: 7,100, 18,700]). Similar to the "1.0x Recruitment" scenario, adult sturgeon (age 23-55; 160-279 cm FL) would achieve peak abundance by mid 2020s, followed by a decline, but abundances would stabilize a little later, by the mid-to-late 2060s, at approximately 1.6 times the current estimated abundance for adult sturgeon.

Under the "2.4x Recruitment" scenario (Figure 11, bottom panel), total abundance of age 7-55 (60-279 cm FL) sturgeon would continue to decline for several years, until the mid to late 2020s, before the cohorts from the improved recruitment years reach age 7, and the age 7-55 population began to increase. Under this recruitment scenario the age 7-55 population is forecasted to continue to increase through to 2070, when abundances are predicted to reach the 2003 abundance peak (i.e., approximately 60,500 [95% CI: 38,400, 92,800]). Juvenile sturgeon (age 7-12; 60-99 cm FL), and subadult sturgeon (age 13-22; 100-159 cm FL) would be expected to stabilize by the early 2040s and

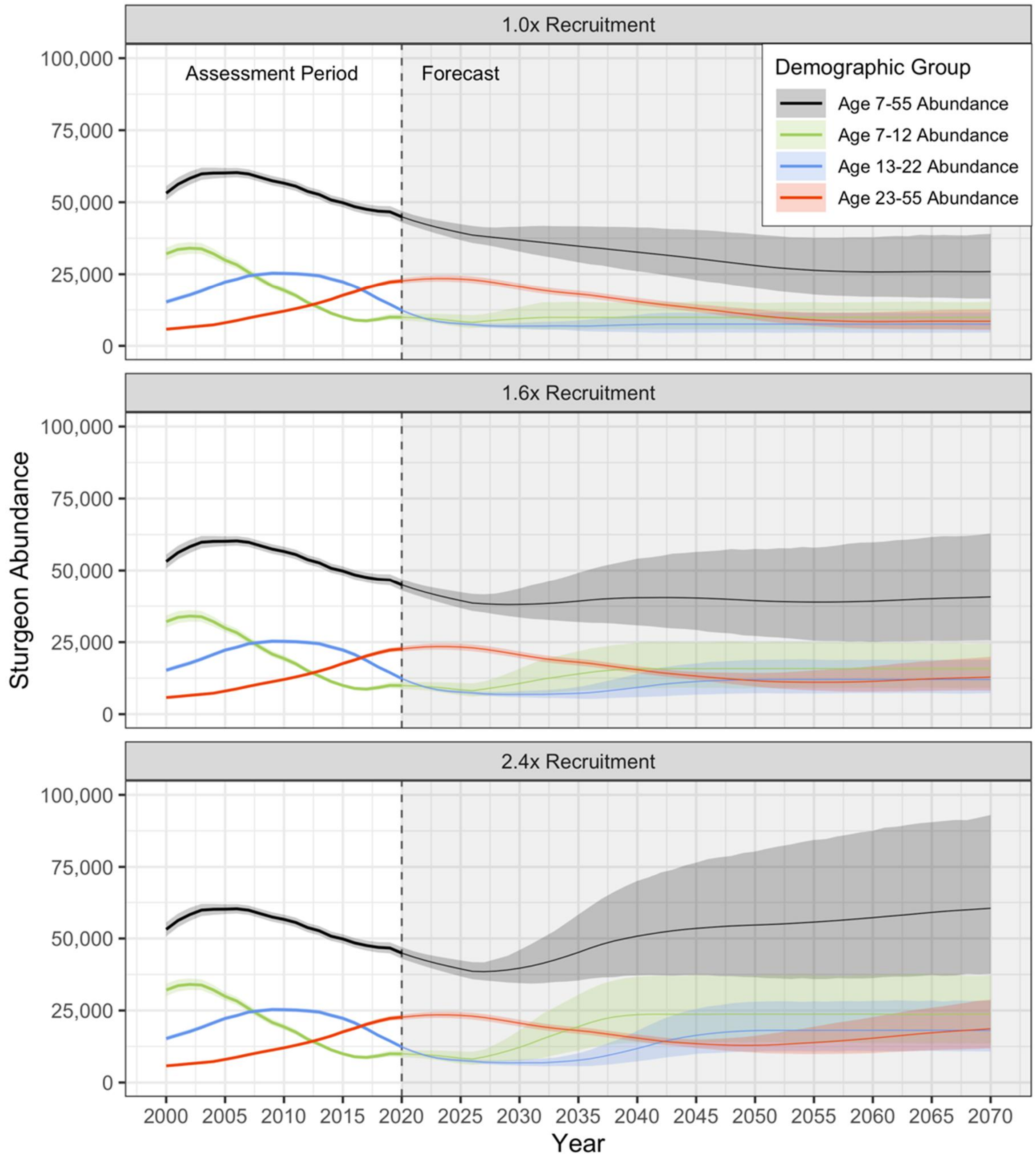

Figure 11. Abundance projections for Lower Fraser River White Sturgeon for 2021-2070 assuming annual age-7 recruitment under three recruitment scenarios. The "1.0x Recruitment" scenario (top panel) assumes a recruitment state the same as recent (i.e., 2011-2020) recruitment estimates [the top panel is the same as Figure 10, but with Y axis scaled to match the other two panels]. The "1.6x Recruitment" (middle panel) and "2.4x Recruitment" (bottom panel) scenarios assume future age-7 recruitment will be 1.6 times and 2.4 times as high as recent recruitment, respectively. Shading around lines indicates uncertainty associated with the annual estimates and forecasts. Background grey shading (after 2020) indicates projected years.

2050s, respectively, at abundance levels approximately 2.4 times those under the "1.0x Recruitment" scenario. Adult sturgeon (age 23-55; 160-279 cm FL) would still be expected to peak by the mid 2020s, decline, then start to increase by the mid 2040s, and continue to increase through 2070 to an abundance level approximately 80% of the predicted mid-to-late 2020s peak.

DISCUSSION

Sampling Sources

The majority of samples used to monitor and assess the status of the population of White Sturgeon in the lower Fraser River continues to be derived from volunteer anglers and the Albion Test Fishery. The FRSCS volunteer program, a community-science endeavour, has been operating continuously for over two decades and provides one of the richest mark-recapture data sets available for any modern fishery. Older size classes tend to be preferentially targeted by this fishery, as the angling gear deployed tends to select for larger body sizes. In addition, with the advent of advanced, sonar-based fish finders, anglers (especially fishing guides) are able to detect the presence and location of large sturgeon and target those individuals while angling. While gear selectivity corrections were included in the main analysis, the lack of sampling of smaller body sizes means that less direct information is available for younger fish with smaller body sizes. The age structuring in the ISAMR model allows inferences about smaller sturgeon for a given point in time, based on observations of larger sturgeon at a later point in the assessment period. To limit the degree of extrapolation, the youngest age category reported on was age 7, which was approximately 50% selected into the angling fishery and therefore supported by observed catch data. Inferences on younger age classes are possible, but not reported here due to an over reliance on extrapolation.

Additional sampling programs that target smaller body sizes (e.g., "juvenile sturgeon sampling programs") are currently in progress. Once results from these programs has been reviewed and verified, additional work will need to be conducted to include these data into the ISAMR model. Fishing gear used by juvenile sampling programs (e.g., small hooks and baits) will differentially select for smaller body sizes relative to the regular angling gear (e.g., large hooks) that is typically used by program volunteers. As such, the ISAMR model will need to be extended to model observations from these programs separately, and employ different effort and selectivity relationships that better match the respective programs (e.g., a dome-shaped selectivity curve that accommodates for larger sizes selected out of the fishery; see Thompson 1994).

Growth Rates

Annual growth rate estimates have shown a long-term declining trend for most size classes of sturgeon over the assessment period (i.e., 1999 to present). The only exceptions were the smallest (i.e., 60-99 cm) and largest (160-179 cm) groups considered, which did not appear to exhibit significant temporal trends.

The strong temporal declining trend in growth is concerning, given that the potential impacts of reduced growth (smaller body sizes) on female fecundity (both annual and lifetime fecundity) are currently unknown. This is especially concerning given the general decline in juvenile recruitment that has also been observed. Currently, we do not have a mechanistic explanation for the trend, but it likely represents the cumulative effect of several factors that have also changed within the assessment period, these may include: increased captures and handling from the recreational fishery, decreases in food supply, off-channel habitat availability, temperature-related metabolic costs, and other environmental changes that have occurred since the start of the assessment period. Ideally, future investigations should strive to disentangle some of these factors.

Repeated Recaptures

Many individual tagged sturgeon have been recaptured and sampled numerous times. For example, by December 2020, 2,598 individual fish had been sampled five times, 202 fish had been sampled 10 times, three fish had been sampled 27 times, and one fish had been sampled 29 times (Appendix E). Several individual tagged sturgeon have been sampled multiple times during the same year (one fish was sampled 10 times in 2019; Appendix D). The number of times each individual sturgeon is captured is likely higher than the number of sampled captures. Program volunteers represent only a fraction of the total number of anglers that participate in the recreational fishery (anglers not participating do not scan sturgeon for the presence of a PIT tag or report their catch to the program). In addition, annual numbers of capture events from gill net fisheries are not known (and could be significant in some years, especially when in-river salmon fishery openings are allowed).

Given the number of interactions sturgeon have with fishery operations, there is still a lack of information on whether these interactions have long-term effects on physiology, reproduction, or survival. Handling and air exposure cause a stress response, reflex impairment, and reduced post-release activity in Lower Fraser White Sturgeon (McLean et al. 2016, 2019, 2020). Whether these stresses and impairments translate into long-term effects is unclear. Survivorship for this population, especially for adults, is considered to be generally high, so it is unclear whether handling-related survivorship effects should be expected. The growth analyses conducted did not find evidence for population-level growth effects relative to overall fishing effort, but individual effects were not explored. Further analyses, looking for the impact of repeat captures on individual growth and survival (e.g., comparing survival in low-handling and high-handling groups) could refine and build on the results presented here. Ideally, these investigations should be done in collaboration with BC Government scientists, given that management of the population is the responsibility of the BC Government.

Abundance Estimates and Trends

Abundance estimates from the ISAMR model show a continued decline in the abundance of 7-55 age fish (60-279 cm FL) through the latter half of the assessment period to present (i.e., after the 2006 peak). This has been largely driven by a steady decline in juvenile recruitment that has been occurring throughout most of the assessment period. The low levels of recruitment into the younger demographics means that there are not sufficient individuals to replenish natural mortalities in older demographics, which is why these demographics have either undergone declines (e.g., subadults) or are projected to undergo declines in the near future (e.g., adults). Given the long-lived nature of sturgeon, these issues can take several years to manifest (especially for adults) and may require extended time horizons to correct.

The general decline in juvenile recruitment and therefore juvenile abundance was also observed within the Albion Test Fishery data, with the percentage of catch comprised of fish smaller than 100 cm FL declining approximately 2.1 percentage points per year since 2000. Catch per unit effort of fish smaller than 100 cm FL also showed a prominent decline since 2000, relative to catch of larger sturgeon. This is generally consistent with the prominent juvenile decline (i.e., 60-99 cm FL) estimated in the ISAMR abundance model, which considered trends over a larger area than would be reflected in the Albion Test Fishery samples.

Recently, ISAMR juvenile (i.e., age-7 fish) recruitment estimates have shown signs of stabilizing, and even some small improvements; however, the 2020 estimates of age-7 fish were not consistent with a continued improvement. That said, there is also a larger uncertainty in estimates at the end of time series, so a stabilization or a modest increase is also within the realm of possibilities. Further time is required to see whether subsequent years exhibit continued improvements in recruitment, or whether juvenile recruitment will stabilize or experience further declines. Either way, population projections indicate that juvenile recruitment is currently too low to maintain the adult population over time, and if it continues at its current pace into the future, adult (160-279 cm FL) abundances are expected to start declining by 2025 and then continue to decline over the next 50 years.

Juvenile fish (i.e., ages 7-12) showed a decline in the percent marked in the last two years of the assessment period (Figure 4). This may be partly the result of recent moderate increases in age-7 recruitment (Figure 7), but may also be indicative of a shift in size classes targeted by anglers (in recent years, additional sampling programs have targeted smaller sturgeon using modified angling techniques; e.g., English and Robichaud 2020). Incorporation of juvenile sampling into the monitoring and assessment program would allow for the ability to reliably estimate recruitment into age classes prior to age 7, which could provide a quicker turn-around for assessing changes in recruitment that may result from natural or management measures. Such programs could be included in the ISAMR model, extending it such that it fits a separate selectivity curve and effort relationship for this differing catch methodology. Thus, the ISAMR model could provide estimates for younger-age sturgeon and thus provide an earlier indication of any changes in the trends for juvenile abundance. Currently, there is a seven-year lag between changes in age-0 recruitment and when they can be reliably estimated in the monitoring and assessment program. This lag time, combined with long maturation times, could significantly impact the management of the population, making the inclusion of sampling programs that target smaller sturgeon a priority.

Importantly, the assessment program does not currently produce estimates of the abundance of sturgeon greater than 279 cm FL. The numbers of tags applied and recaptured for sturgeon greater than 279 cm FL is very small and currently not sufficient to produce reliable estimates of abundance for this size group. While there certainly is some number of very large adult sturgeon (greater than 279 cm FL) present in the lower Fraser River population, neither the current abundance nor the abundance trend for these fish are known at this time.

Abundance Forecasts

The age-structuring components of the ISMAR model made it possible to construct forward abundance projections under scenarios of future recruitment, as currently we do not possess a predictive model for recruitment. The current abundance of 7-55 age fish has also been in a state of steady decline for well over a decade, so forecasts were generated under differing recruitment scenarios to determine the likely trajectory of the population as well as the changes required to either stabilize the population or to return abundances to levels observed (estimated) within recent years (i.e., early 2000s). We did not consider scenarios in which mean recruitment levels were lower than current levels (see English et al. in press).

If no effective interventions or management actions are applied, forecasts that assume future recruitment levels will be similar to recent (i.e., the last 10 years) levels represent our best understanding of where the population is likely to trend in the near future (i.e., status quo). Current recruitment levels of age-7 fish have stabilized in recent years, but are roughly a third of the recruitment estimated at the start of the assessment period. If recent recruitment levels are maintained into the near future (i.e., the next 50 years) the population is expected to continue to decline a further 42% before potentially stabilizing in the 2060s, with an age 7-55 (60-279 cm FL) abundance well below 30,000 fish, and less than 10,000 age 23-55 (160-279 cm FL) adult fish.

English et al. (in press) suggested an adult safety threshold of 10,000 age 23-55 (160-279 cm FL) fish which is the abundance threshold suggested for medium- to long-term persistence of the population. Under the status quo scenario the adult population is expected to fall below this threshold at some point in the 2050s. Given the long-lived nature of the species and the generally slow rate of reproduction, if the population is allowed to decline to this level, it may take and an extended period to subsequently recover the population to a safer abundance threshold; this could expose the population to an elevated risk of local extinction, especially if climate conditions worsen in the latter half of the century (English et al. in press). Droughts could reduce access to off-channel habitat, and higher water temperatures would increase their metabolic rate and thus food requirements, as well as exacerbate the impacts of angling, net encounters, and handling (e.g., McLean et al. 2016). That said, droughts are not yet known to have been a significant factor for the lower Fraser River ecosystem due to the size of the watershed. While water temperatures have been increasing in recent years, they are rarely in the range where they could be a significant factor in White Sturgeon survival (i.e., >25 °C, Secor and Gunderson, 1998).

Our ‘improved recruitment” scenarios investigated the size of change required to stabilize the population (i.e., “1.6x Recruitment” scenario) or to recover the population to abundance levels similar to the early 2000s (i.e., “2.4x Recruitment” scenario). The “1.6x Recruitment” scenario stabilizes the population decline and may ensure the adult safety threshold is attained, but projected population abundances were below the suggested candidate recovery thresholds proposed by English et al. (in press) for the age 7-55 population (60-279cm FL; 60,000 individuals) and adults (160-279cm FL; 20,000 individuals). Only under the “2.4x Recruitment” scenario was either of these candidate recovery thresholds achieved and sustained. While the candidate adult recovery threshold was briefly surpassed in the “1.6x Recruitment” scenario (due to the earlier recruitment pulse fully entering this demographic category), it was not sustained because of the continued poor recruitment from younger age classes.

These forecasts highlight the fact that substantial increases in juvenile recruitment are required to ensure the adult safety threshold is maintained, as well as to achieve any of the candidate recovery thresholds. Given the long-lived and infrequent spawning nature of White Sturgeon, it will take a considerable amount of time to achieve these targets. These forecasts only considered general improvements in recruitment; they did not explicitly consider the relative effectiveness of potential mechanisms, such as improving early survival (e.g., decreased bycatch), or improving reproductive success (e.g., spawning habitat restoration, increased fecundity). The potential effectiveness of some available strategies has been considered elsewhere (English et al. in press). Rather, the purpose for these forecasts was to show the magnitude of improvement in recruitment required to reach a proposed target.

Forecasts also should not be interpreted as direct predictions of future population states, but as an informative exercise exploring where the population may go in the near future given the current state of the population and plausible future events. The period of time required to stabilize most demographic groupings was quite protracted, which necessitated long projection windows (i.e., 50 years). This was especially true for the adult demographic grouping which featured the oldest fish and largest number of age categories, resulting in a long lag period between when changes in juvenile recruitment occurred and the subsequent change adult abundances. All projections assumed some form of constancy in future recruitment to facilitate stabilizing demographic groupings so that the effectiveness of the magnitude of change in recruitment could be assessed. Constant environmental conditions are not expected in the near future, which is why these forecasts should not be viewed as direct predictions of future abundances. Projections included allowances for year-to-year variation in recruitment; however, variations applied were derived from the year-to-year variance from the last decade and may not reflect future yearly variations.

As in previous reports, we emphasize the importance of taking immediate actions to improve both recruitment and survival rates of juvenile fish. Forecasts assumed a lag of only 10 years before recruitment improvements would be observed in the monitored component of the population. Delays to action will push recovery timelines out even farther than was modelled in the forecasts. Moving forward, it is recommended that the ISAMR model should continue to be used to evaluate efficacy of various strategies toward achieving approved goals and should also continue to be used within the monitoring and assessment program.

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, the data review procedures do indeed identify erroneous or missing data, triggering a follow up with the volunteers to make corrections. 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 high value for government personnel tasked with the conservation and recovery of White Sturgeon and their habitat. In addition, it is very 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.

Sources of Uncertainty

The proposed candidate recovery thresholds presented in this report are based on limited information about key factors affecting juvenile recruitment, population viability, and extinction risk; revised target recovery thresholds may be established in the future as new and updated information is available.

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

- the identification of important rearing habitats for juvenile White Sturgeon in the lower Fraser River;
- key drivers that affect juvenile White Sturgeon recruitment in the lower Fraser River;
- reliable estimates of White Sturgeon bycatch in lower Fraser River gillnet fisheries;
- reliable estimates of White Sturgeon caught and released by lower Fraser River anglers;
- limited information about illegal harvest of White Sturgeon in the lower Fraser River;
- limited knowledge around cumulative sub-lethal effects of capture events on survival and recruitment; and
- limited knowledge on the effects of other threats and limiting factors on the population (e.g., pollution, predation, temperature, prey availability/choice).

RECOMMENDATIONS

Recommendations have not been included in this report. However, the authors continue to support recommendations provided in previous reports (Nelson et al. 2018, 2019). Potentially important future work, as identified during the Recovery Potential Assessment process for Lower Fraser River White Sturgeon (English et al. in press) includes:

- explore the relationship between key prey species (e.g., salmon species, eulachon) and juvenile sturgeon recruitment;
- conduct sensitivity analysis on the effect of alternative growth curves on the ISAMR model;
- collect additional data and conduct analyses to relate age and length under more recent growth conditions;
- investigate the impact of repeat captures on individual growth and survival;
- incorporate ongoing juvenile monitoring program information into future analyses; and
- maintain a monitoring and assessment program that will provide sufficient information needed to assess White Sturgeon abundance status and trends for the Lower Fraser River White Sturgeon DU.

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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 any 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. Supporting the vision of the FRSCS Board of Directors, 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. We thank members of the FRSCS Science and Technical Committee for their independent reviews of this report while in draft form. In addition, the authors are particularly thankful to Colin Schwindt, Sr. Aquatic Biologist, FLNRORD (Region 2), who provided a review of the draft report that included useful and constructive recommendations.

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REFERENCES

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

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

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.

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.

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

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

English, K.K., W. Challenger, D. Robichaud, and J. Korman. *in press*. Recovery Potential Assessment for Lower Fraser River White Sturgeon *(Acipenser transmontanus*). DFO Canadian Science Advisory Secretariat Research Document.

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

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.

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

Glova, G., T.C. Nelson, K.K. English, and T. Mochizuki. 2010. Investigations of juvenile White Sturgeon abundance and habitat preferences in the lower gravel reach of the lower Fraser River, 2009-10. Report for the Fraser River Sturgeon Conservation Society, Vancouver, BC.

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.

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

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

Nelson, T.C., K.K. English, and M.L. Rosenau. 2000. Design of a stewardship project to supplement information required to assess the status of white sturgeon in the lower Fraser River. Report for the Fraser River Sturgeon Conservation Society, Richmond, BC, and BC Ministry of Fisheries, Conservation Section, Victoria, BC.

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 for the Fraser River Sturgeon Conservation Society, Vancouver, BC.

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. 2013. Research tools to investigate movements, migrations, and life history of sturgeons (*Acipenseridae*), with an emphasis on marine-oriented populations. PLoS ONE 8(8): e71552.

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 for the Fraser River Sturgeon Conservation Society, Vancouver, BC.

Nelson, T.C., D. Robichaud, W. Challenger, T. Mochizuki, J. Rissling, K.K. English, and W.J. Gazey. 2018. 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. Report for the Fraser River Sturgeon Conservation Society, Vancouver, BC.

Nelson, T.C., D. Robichaud, W. Challenger, K.K. English, T. Mochizuki, T. Thibault, J. Rissling, and W.J. Gazey. 2019. Lower Fraser River White Sturgeon Monitoring and Assessment Program: Status of White Sturgeon in the lower Fraser River in 2018 with abundance estimates derived from 24-month Bayesian mark recapture modeling. Report for the Fraser River Sturgeon Conservation Society, Vancouver, BC.

RL&L (RL&L Environmental Services Limited) 2000. Fraser River white sturgeon monitoring program-comprehensive report (1995– 1999). Final report to British Columbia Fisheries, Victoria.

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.

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

Stoddard, M., and M. Rochetta. 2014. Lower Fraser River White Sturgeon (*Acipenser transmontanus*) juvenile indexing surveys - 2012 summary report. Report for the BC Ministry of Forests, Lands and Natural Resources Operations.

Thompson, G.G. 1994. Confounding of gear selectivity and the natural mortality rate in cases where the former is a nonmonotone function of age. Canadian Journal of Fisheries and Aquatic Science 51: 2654–2664.

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.

APPENDICES

Appendix A: Sturgeon biosampling, tagging, and recapture data entry form, 2020

FRASER RIVER STURGEON CONSERVATION SOCIETY FAX to Tyler Thibault: 604-200-5430 (phone: 604-613-6231)
WHITE STURGEON BIOSAMPLING, TAGGING, AND MARK- RECAPTURE RECORDS tyler.thibault18@gmail.com Page:_____ of _____

Name of Person that Recorded Data: __________ Phone number: __________

Date (dd/mmm/yy __________ Sampling Area: __________ Weather: __________ No. Passengers: __________

Vessel Information: Vessel Name __________ Launch Location __________ Launch Time: __________ Return Time: __________

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

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

Comments:

[1]Deformity/wound/scar codes: DEF = physical deformity; BLED = bleeding; BITE = seal bite; CUT = slice or tear; NET = net scar; OTHER = other (note in comments)
[2]Condition codes: 1 = vigorous, no bleeding; 2 = vigorous, bleeding; 3 = lethargic, no bleeding; 4 = lethargic, bleeding; 5 = dead

Appendix B: Summary of sampling in the general study area

Summary of White Sturgeon (all sizes) sampled in the general study area (see Figure 1), from all available sources* and sampling gear types, 1999-2020. A subset of these sampling records was used to generate annual abundance estimates (see text). Included is a summary of sturgeon sampled (under this program) outside the Fraser River watershed. See notes at bottom of sheet (and on next page) for additional information.

Assessment Year	No. Scanned for PIT Tag (All)	No. Tagged and Released with PIT Tag (Head)	No. Recaptured with PIT Tag (Head)	No. Scanned, Not Tagged, Not Recaptured	No. Sampled, Not Scanned	No. Recaptured With Dorsal Tag (First Recapture Only)	No. Mortalities Sampled	No. Moved Upstream Past Hells Gate	No. Moved Downstream Past Hells Gate	No. Tagged in Fraser, Recovered Outside Fraser Watershed	No. Recaptures from WA or OR (First Recapture Only)	No. Green Sturgeon Observed	No. Scanned Outside of Fraser Watershed	No. Tagged Outside of Fraser Watershed
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)	(N)
1999	459	413		11	1	36								
2000	4,387	3,966	219	134	73	58	18							
2001	5,508	4,552	752	147	39	52	24							2
2002	5,043	2,744	913	1,283	32	32	75			1	1		3	
2003	5,444	3,632	1,004	685	16	27	103							
2004	7,240	4,797	1,822	561	102	16	45				1			
2005	10,188	5,260	3,542	1,272	63	20	80					1		
2006	9,030	5,071	3,816	104	32	17	19							
2007	10,752	5,205	5,329	186	51	20	9	1	1		1	1	8	7
2008	8,654	3,886	4,585	126	46	16	16						15	11
2009	8,295	3,382	4,787	76	64	20	8		1		1	2	17	3
2010	9,097	3,746	5,264	56	71	5	7		1					
2011	9,135	3,602	5,433	67	78	11	5				2			
2012	9,195	3,861	5,250	32	92	9	9			1	1			
2013	12,155	4,437	7,590	60	48	13	11		1			2		
2014	9,186	2,637	6,018	473	96	5	13		1			1		
2015	11,416	3,557	7,645	153	113	7	20		1		1			
2016	7,919	2,174	5,637	71	72	13	14		1			1		
2017	6,781	1,706	4,993	39	63	14	25	1	2			1		
2018	6,214	1,959	4,176	28	48	3	29		3	1			1	
2019	9,808	3,669	6,037	49	98	0	7	1	12					
2020	6,154	2,120	3,958	44	77	4	42	1	3					
Totals	172,060	76,376	88,770	5,657	1,375	398	579	4	27	3	8	9	44	23

* Data presented in this summary are from all known White Sturgeon projects conducted in the lower Fraser River since 1999, with the exception of a single project in 2020 conducted by the Fraser Valley Angling Guides Association (a project that targeted juvenile White Sturgeon in 2020-21); data generated from that project were requested but not provided at the time of this reporting.

Appendix B - Column Notes

(A) Numbers of White Sturgeon sampled by lower Fraser River sturgeon projects* scanned for the presence of a PIT tag; includes samples that were not tagged or recaptured, and scanned mortalities

(B) Numbers of White Sturgeon sampled by lower Fraser River sturgeon projects and tagged with a PIT tag in the head location and released; includes head tagging of dorsal-tag recaptures

continued

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(C) Numbers of White Sturgeon sampled by lower Fraser River sturgeon projects that were recaptured and possessed a PIT tag located in the head location upon recovery

(D) Numbers of White Sturgeon scanned, but no tag applied, and not a recapture (tag not applied due shortage of available PIT tags, safety concerns, or because the fish was considered to be in poor physical condition when sampled

(E) Number of White Sturgeon sampled but not scanned for a PIT tag (typically, these cases where the result of tag reader malfunction due to power issue)

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

(G) Numbers of dead White Sturgeon (mortalities) sampled; includes mortalities that were not scanned, but were sampled/observed (does not included reported mortalities that were not sampled); does not include all mortalities from ghost net and provincial tangle net projects; the majority of mortalities observed from 2000-2005 were captured in set gill nets (First Nation fisheries). In 2020, 38 (90%) of the 42 total reported mortalities were dead sturgeon removed from five abandoned gill nets by Fisheries Officers and FRSCS volunteers.

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

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

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

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

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

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

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

Appendix C: Summary of sampling in the core assessment area

Summary of White Sturgeon sampled by regular angling gear and the Albion Test Fishery in the core assessment area (see Figure 2) that were 60-279 cm FL when sampled, by year from 1999 to 2020. A subset of these samples were used to generate annual abundance estimates (see text). 'Mark rate' refers to the proportion of scanned fish that were marked (tagged) and includes repeat captures of the same individual fish in the same calendar year. This differs from percentage tagged estimates (i.e., the proportion of marked individuals in a population) that estimates the proportion of individuals in possession of a mark at some point within the calendar year.

Year	No. Scanned for PIT Tag	No. PIT Tags Applied (Head)	No. Scanned, Not Tagged, Not Recaptured	No. Recaptured with PIT Tag (Head Tag)	Mark Rate (%)
1999	406	398	8	0	0.0%
2000	3,210	2,970	72	168	5.2%
2001	4,112	3,414	118	580	14.1%
2002	3,707	1,922	1,125	660	17.8%
2003	4,469	3,063	622	784	17.5%
2004	6,346	4,455	444	1,447	22.8%
2005	9,188	4,974	1,269	2,945	32.1%
2006	8,599	5,009	109	3,481	40.5%
2007	10,123	5,158	59	4,906	48.5%
2008	7,975	3,751	56	4,168	52.3%
2009	7,804	3,387	70	4,347	55.7%
2010	8,764	3,813	58	4,893	55.8%
2011	8,836	3,739	70	5,027	56.9%
2012	8,665	3,813	38	4,814	55.6%
2013	11,270	4,198	72	7,000	62.1%
2014	8,427	2,462	440	5,525	65.6%
2015	10,784	3,436	166	7,182	66.6%
2016	7,366	2,060	63	5,243	71.2%
2017	6,216	1,520	38	4,658	74.9%
2018	4,975	1,286	32	3,657	73.5%
2019	6,946	2,019	37	4,890	70.4%
2020	4,407	1,372	26	3,009	68.3%
Totals	152,595	68,219	4,992	79,384	52.0%

Appendix D: Frequency of sampling events for individual tagged sturgeon

Numbers of unique (individual) tagged sturgeon sampled by volunteer anglers with standard angling gear, presented by the number of sampling events (encounters, identified by PIT tag number), within the general study area of the lower Fraser River, by year from 2000-2020. Numbers presented include sampling events where tags were applied to untagged sturgeon and sampling events where sturgeon were determined to possess a tag when sampled (recaptures). In 2020, 265 individual sturgeon were sampled two times and three individual sturgeon were sampled four times. The number of sampling events for individual sturgeon are not cumulative; for example, the three sturgeon sampled four times in 2020 are not included in the count of sturgeon sampled three times (n = 34) in 2020.

INDIVIDUAL STURGEON Number of Sampling Events	Numbers of Individual Sturgeon Sampled by Year																				
	2020	2019	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000
1	3,837	5,760	4,118	5,228	6,097	8,626	6,670	9,197	7,529	7,367	7,152	6,453	6,572	7,898	6,490	5,918	4,897	3,201	2,261	3,531	2,886
2	265	517	407	463	572	873	662	983	612	601	619	538	597	872	619	630	317	128	109	201	137
3	34	76	50	75	89	134	84	107	55	60	78	45	69	108	81	78	19	2	6	15	6
4	3	14	11	8	27	23	13	15	5	5	11	7	11	29	5	17	1			1	
5		5	1	2	5	10	4	5	2	3	3	2	3	5		3					
6		1		1	1	6		1					1								
7		1			1			1													
8			1			1															
9					1																
10		1																			
Number of Individual Sturgeon Sampled	4,139	6,375	4,588	5,777	6,793	9,673	7,433	10,309	8,203	8,036	7,863	7,045	7,253	8,912	7,195	6,646	5,234	3,331	2,376	3,748	3,029
Number of Sampling Events	4,481	7,126	5,139	6,427	7,663	10,960	8,318	11,582	8,948	8,784	8,683	7,702	8,038	10,107	7,991	7,495	5,592	3,463	2,497	3,982	3,178
Percent Sampled Once Only	92.7%	90.4%	89.8%	90.5%	89.8%	89.2%	89.7%	89.2%	91.8%	91.7%	91.0%	91.6%	90.6%	88.6%	90.2%	89.0%	93.6%	96.1%	95.2%	94.2%	95.3%

Appendix E: Cumulative individual recapture frequencies over the study period

Numbers of unique (individual) tagged sturgeon sampled for the presence of a PIT tag, presented by the number of times encountered (number of sampling events), within the general study area of the lower Fraser River, over 22 time periods from 1999-2020. In 2020, 61 individual sturgeon were sampled three times, and six sturgeon were sampled four times. From 1999-2020, 2,598 individual sturgeon were sampled five times, and three sturgeon were sampled 27 times. One Individual sturgeon has been sampled 29 times between 2003 and 2020.

INDIVIDUAL STURGEON Number of Sampling Events	Numbers of Individual Sturgeon Sampled for the Presence of a PIT tag																						
	No. Years	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*
	Time Period	2020	2019-2020	2018-2020	2017-2020	2016-2020	2015-2020	2014-2020	2013-2020	2012-2020	2011-2020	2010-2020	2009-2020	2008-2020	2007-2020	2006-2020	2005-2020	2004-2020	2003-2020	2002-2020	2001-2020	2000-2020	1999-2020
1		5,385	11,368	13,842	16,395	19,015	22,382	24,484	27,131	28,835	30,140	31,278	32,136	33,063	34,039	34,950	36,062	37,285	38,382	39,319	40,614	41,605	41,702
2		449	1,674	2,654	3,580	4,626	6,262	7,363	8,934	10,072	11,041	11,872	12,616	13,273	14,153	14,795	15,422	15,899	16,211	16,471	16,903	17,201	17,230
3		61	305	616	975	1,380	1,920	2,419	3,175	3,713	4,429	4,979	5,520	6,013	6,570	6,971	7,495	7,798	7,988	8,186	8,403	8,545	8,565
4		6	89	203	338	523	776	1,012	1,348	1,717	2,003	2,303	2,587	2,884	3,221	3,564	3,812	4,020	4,198	4,319	4,513	4,624	4,632
5		4	25	57	131	225	359	467	637	770	944	1,175	1,336	1,529	1,761	1,923	2,088	2,243	2,345	2,399	2,461	2,593	2,598
6			6	31	53	103	185	261	347	446	514	617	731	846	1,013	1,178	1,243	1,314	1,357	1,389	1,452	1,481	1,494
7			5	10	21	40	73	126	186	203	273	335	387	461	587	684	786	839	867	885	908	947	953
8			3	1	14	22	47	64	98	119	149	191	246	295	335	393	461	497	514	542	575	604	604
9			0	2	5	14	30	39	57	77	98	124	141	174	235	246	288	313	329	336	355	364	362
10			1	4	3	6	3	18	31	31	40	54	71	82	97	150	158	173	179	187	193	203	202
11					3	7	15	10	19	30	34	47	57	61	74	89	118	116	125	127	139	140	143
12				1		3	6	13	17	19	18	24	38	45	54	52	72	83	89	89	90	97	98
13					1	1	3	8	7	14	19	17	17	27	41	54	58	63	66	72	75	71	70
14							2	4	5	3	5	17	15	23	24	26	31	36	39	40	45	46	46
15							2	2	8	9	9	8	17	22	26	30	29	30	29	31	36	41	41
16						1	1	3		4	3	7	6	6	15	23	26	26	26	25	23	24	25
17							1	3	4	4	5	6	5	10	8	9	14	19	20	20	19	21	21
18				1	1	1	2	1	4	1	5	3	5	6	4	3	8	11	15	16	20	18	17
19									1	3	3	3	3	3	5	5	4	6	6	7	6	8	9
20											1	2	4	4	5	4	6	5	4	4	6	6	6
21								1		2			1	1	3	2	2	1	2	1		1	1
22									1	2	3	2		1	2	3	2	3	3	3	4	3	3
23											1	3	2	2	2	2	3	4	3	4	3	3	3
24												1	2	1	2	2	2	2	3	3	4	4	4
25													2	3		2	2	3	3	3	3	4	4
26									1	1	1	1	1	3	6	5	3	3	3	3	3	3	3
27																1	3	3	3	3	3	3	3
28																	1	1					
29																			1	1	1	1	1