EA3932/EA3947

Status of White Sturgeon in the Lower Fraser River in 2018 Derived Using an Integrated Spatial and Age Mark Recapture (ISAMR) Model

Prepared for:

Fraser River Sturgeon Conservation Society

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August 2019

KEY POINTS AND FINDINGS

1. The Lower Fraser White Sturgeon Monitoring and Assessment Program uses two separate models to generate abundance estimates: 1) an Integrated Spatial and Age-structured Mark-Recapture (ISAMR) model (described herein); and 2) a Bayesian mark-recapture model (BMR24), reported separately (Nelson et al. 2019).

2. Both the BMR24 and ISAMR models indicate that the abundance of 60-279 cm fork length (FL) (age 7-55) White Sturgeon in the lower Fraser River has been in a continual state of decline since 2004.

3. The ISAMR and BMR24 models were found to produce similar abundance estimates and trends for both 60-99 cm FL (age 7-12 "juvenile") and 100-159 cm FL (age 13-22 "sub-adult") sturgeon, but were found to diverged significantly in the last two years for 160-279 cm FL (age 23-55 "adult") sturgeon. The ISAMR model showed an increasing abundance trend for 160-279 cm FL sturgeon (with a 2018 abundance estimate of 20,470), whereas the BMR24 estimate for this size group shows a decline (from 16,000 in 2015 to 13,000 in 2018). This divergence accounted for 70% of the difference between the total abundance estimates from the two models (see Nelson et al. 2019).

4. A data review by Nelson et al. (2019) determined that the BMR24 model was more sensitive to recent changes in the distribution of tagging and sampling effort than the ISAMR model and concluded that the best estimates of abundance for 60-279 cm Lower Fraser White Sturgeon are those derived using the ISAMR model.

5. The 2018 ISAMR abundance estimate for 60-279 cm FL (age 7-55) Lower Fraser White Sturgeon was 44,430 (95% CIs ± 4.5% of the estimate), which is 24.7% lower than the program's highest annual abundance estimate in 2004 and 3.6% lower than the 2017 ISAMR estimates.

6. The decline in the total abundance 60-279 cm FL (age 7-55) Lower Fraser White Sturgeon from 2004 to 2011 was driven by the substantial decline in the abundance of 60-99 cm FL (age 7-12) "juvenile" sturgeon, with declines since 2011 being largely the result of declines in 100-159 cm (age 13-22) sub-adult sturgeon which were expected given the earlier declines in younger-age sturgeon.

7. Given a continuation of low recruitment levels into the population, ISAMR abundance forecasts suggest the population will continue to decline, with a possible leveling in approximately 40 years (i.e., late 2050s) at approximately 28,000 sturgeon 60-279 cm FL (age 7-55). An increase in future recruitment (i.e., 1.6 times current levels) will stabilize abundances at 2018 levels by approximately 2034, but will not achieve the population recovery goal of 60,000 individuals in the 60-279 cm size class (age 7-55) suggested by Challenger et al. (2017) a reasonable interim goals.

8. Immediate actions should be implemented to improve age 1 recruitment and survival rates for age 1-6 sturgeon. These measures should include: protection of sturgeon spawning and juvenile rearing habitat, the removal of all fishing activity from known sturgeon spawning areas during the spawning period, a reduction of the incidence of net interceptions from all net fisheries during all times of the year, a reduction in the annual capture rates in the recreational fishery, and the protection of spawning and rearing areas for areas of the prey species upon which juvenile and adult sturgeon depend (e.g., salmon and eulachon).

9. Management agencies, recreational anglers, angling guides, and First Nations should continue to support measures to improve survival rates and spawning success for adult sturgeon.

EXECUTIVE SUMMARY

An Integrated Spatial and Age-structured Mark-Recapture (ISAMR) model was developed from 2015-17 for analysis of PIT tag mark-recapture data available for Lower Fraser River White Sturgeon. Challenger et al. (2017) provides a detailed description of Version 2.0 of the ISAMR model and compares the abundance estimates derived from this model with those derived from the Bayesian 24-month mark-recapture (BMR24) model (Nelson et al. 2017).

Both the ISAMR and BMR24 models use Bayesian estimation to provide point estimates and credible intervals, however the two models have very different population modelling structures. The ISAMR model uses age classes, while the BMR24 model employs size groups. The ISAMR model reconstructs and transitions fish through the available age classes over the course of the assessment period, explicitly modeling births and deaths. The BMR24 model assigns individual fish to a size-class for each 24-month analysis period and assumes demographic closure during each 24-month assessment period. The two models also differ in how selectivity in the sampling methods are handled. The ISAMR model applies a selectivity-at-age relationship that is estimated from the data, while the BMR24 model does not include differential selectivity by age and thus assumes that size groups of interest are fully recruited into the sampling methods. The ISAMR model also includes information on sampling effort and considers all captures within the assessment period in a single analysis, while the BMR24 model does not include sampling effort and uses a 24-month rolling data window. Despite these differences, annual abundance estimates for each of the three main size/age classes showed good agreement between the two models for 2000-2016 (see Challenger et al. 2017).

Subsequent analysis incorporating the 2017 and 2018 mark-recapture data into both the ISAMR and BMR24 models produced similar abundance estimates and trends for both 60-99 cm FL (age 7-12 “juvenile”) and 100-159 cm FL (age 13-22 “sub-adult”) sturgeon. However, estimates and trends for 160-279 cm FL (age 23-55 “adult”) sturgeon have diverged significantly in the last two years. The ISAMR model results show a continuing increasing abundance trend for 160-279 cm FL sturgeon (with a 2018 abundance estimate of 20,470), whereas the BMR24 estimate for this size group shows a decline (from 16,000 in 2015 to 13,000 in 2018). This divergence in the abundance estimates for 160-279 cm FL sturgeon accounts for 70% of the difference between the total abundance estimates from the two models and thus prompted additional data reviews and analysis of the 2000-2018 data. It was determined that the BMR24 model was more sensitive to recent changes in the distribution of tagging and sampling effort than the ISAMR model (Nelson et al 2019) and concluded that the best estimates of abundance for 60-279 cm Lower Fraser White Sturgeon are those derived using the ISAMR model.

The 2018 abundance estimate for 60-279 cm FL (age 7-55) Lower Fraser White Sturgeon derived from the ISAMR model was 44,430 (95% CIs ± 4.5% of the estimate). This abundance estimate was 24.7% lower than the program’s highest annual abundance estimate in 2004 and 3.6% lower than the 2017 estimate derived using the ISAMR model.

The observed decline in the total abundance of White Sturgeon in the lower Fraser River from 2004 to 2011 was driven by the substantial decline in the abundance of 60-99 cm FL (age 7-12) “juvenile” sturgeon. Abundance declines since 2011 have been largely the result of declines in 100-159 cm (age 13-22) sub-adult sturgeon and these declines were expected given the earlier

declines in younger-age sturgeon. The increasing trend for 160-279 cm FL (age 23-55) "adult" sturgeon has helped slow the overall rate of decline for the Lower Fraser River White Sturgeon population but the abundance of these larger fish is destined to decline in the future because of the trends we have seen with the younger age groups. The monitoring and assessment program has documented two independent lines of evidence to suggest that juvenile recruitment into the sampled population is currently a primary concern for the long-term sustainability of the lower Fraser River population of White Sturgeon (Nelson et al. 2019).

The ISAMR abundance forecasts considered recruitment into age 1 current rates resulting in a continued decline into the foreseeable future with a leveling off in age 7-55 abundance in approximately 40 years (i.e., early 2060s). Specifically, the 100-159 cm FL size group (age 13-22) of sub-adult sturgeon is expected to continue to decline until 2030, with adult sturgeon (age 23-55; 160-279 cm FL) predicted to begin declining in the mid 2020's, with a continued decline until approximately 2060. Forecast modeling also indicates that an immediate and sustained 60% increase in age 1 recruitment into the sampled population (i.e., 1.6 times current levels), would result in a continuation of total abundance decrease for approximately six years, followed by a gradual increase in abundance that would stabilize back to 2018 levels by approximately 2034. Under this scenario, abundance estimates for 160-279 cm FL adult sturgeon are expected to peak in the mid 2020's, then decline and stabilizing by approximately 2055.

Given the observed declining trend in abundance, it is important to set some interim recovery goals for Lower Fraser White Sturgeon and implement actions that should increase the abundance of juvenile sturgeon. As indicated in Challenger et al. (2017), a reasonable interim population recovery goal of 60,000 60-279 cm FL (age 7-55) Lower Fraser River White Sturgeon. Similarly, an interim goal for adult sturgeon (160-279 cm; age 22-55) of 20,000 fish would be a reasonable target (Challenger et al. 2017; Nelson et al. 2018). Neither projection scenario reached these interim recovery goals, suggesting substantial increases in the recruitment will be required to meet these proposed targets. Given the long-lived nature of White Sturgeon, it will take a considerable amount of time to achieve these goals.

As in previous reports, we emphasize the importance of taking immediate actions to improve both recruitment of age 1 fish and survival rates for age 1-6 fish. The ISAMR model should also be used to evaluate efficacy of various strategies towards achieving these goals and the mark-recovery program. Actions should include: 1) the protection of sturgeon spawning and juvenile rearing habitat; 2) the removal of all fishing gear from known sturgeon spawning areas during the spawning period; and 3) the protection of the spawning and rearing areas of sturgeon prey species (e.g., salmon and eulachon). Recent efforts to improve sturgeon handling techniques by sturgeon anglers (and for net fishers that intercept sturgeon as bycatch while targeting other species) should continue to be supported as they positively impact both survival and spawning rates for adult sturgeon.

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INTRODUCTION

The Integrated Spatial and Age Mark Recapture (ISAMR) was developed for the PIT tag mark-recapture data available for Lower Fraser River White Sturgeon (Challenger et al. 2017). The model is a class of age-structured mark-recapture model (e.g., see Coggins et al. 2006) that tracks abundances for 58 age classes over four spatial areas on a yearly time step. Challenger et al. (2017) provided a detailed description of ISAMR model (Version 2.0), including mathematical formulation and data assembly procedures, as well as comparisons of abundance estimates those derived from the Bayesian 24 month mark-recapture (referred to as BMR24) model (i.e., Gazey and Staley 1986), which uses a 24-month rolling window and has been in the past been the primary abundance model for this sturgeon population (e.g., Nelson et al. 2017).

Both the ISAMR and BMR24 models are spatial mark-recapture models employing Bayesian estimation to provide abundance estimates of Lower Fraser River White Sturgeon across four sampling regions, but differ in their specifications. The BMR24 model employs three primary size groups, but does not have a mechanism for modelling transitions between group sizes. As a result the model assumes demographic closure (i.e., no births or deaths) during a series of 24 month assessment periods used to reconstruct the full abundance time series. In contrast, the ISAMR model is an open demographic model which employs 58 age classes (i.e., age 1 to 58) and transitions fish though available age classes on each yearly time step by explicitly modeling the birth and death. New recruitment is modelled as entering the first age class (i.e., age 1), with mortality based on extrapolating the mortality at age curve estimated for captured age classes. The ISAMR model therefore considers all data from the assessment period at one time, rather than parceling the data into smaller contiguous periods. Comparisons between the two models are made by mapping the ISAMR age classes to the corresponding BMR24 size classes, based on documented growth curve for Lower Fraser River White Sturgeon.

Sampling methods (e.g., angling) are also expected to produce size selectivity differences in catch due to inability of currently deployed fishing gear to target and retain smaller sized sturgeon. The ISAMR model directly models this issue by estimating a selectivity-at-age relationship from the data, while the BMR24 model restricts size groups to sizes that are assumed to be fully recruited by the employed fishing gear by ignoring catch below 60 cm in size. Due to the difference approaches in potential gear selectivity some comparisons between the ISAMR and BMR24 models use “adjusted” ISAMR abundances, where the effects of selectivity-at-age corrections on abundance estimates are removed.

Finally, the two models also differ in how yearly sampling effort is handled. The ISAMR model directly models the effect yearly sampling effort (i.e., boat days) on catch rates and therefore the predicted yearly catch in each age category. The BMR24 model, because of the rolling 24 month window, does not include sampling effort, but instead assumes a constant sampling effort occurred in each 24-month rolling data window.

The objective of the current report is to update the Challenger et al. (2017) results with two additional years of sampling effort and compare the results to updated estimates from the BMR24 model (Nelson et al. 2019).

METHODS OVERVIEW

Angling captures were included if they occurred in one of the four lower Fraser River sampling regions (see Figure 2 in Nelson et al. 2019). Because age of captured sturgeon is a requirement, captures were aged based on length via a von Bertalanffy growth model developed for lower Fraser River (i.e., $L_a = 370.1 \times (1 - \exp(-0.025a))$; Whitlock and McAllister 2012; English and Bychkov 2012). For recaptures of previously marked individuals the aging was determined based on the age determined at first capture and elapsed time between captures. The ISAMR model also considers untagged and tagged captures separately and as such both untagged captures released either with a tag and untagged captures without a tag were included.

In total there were 153,062 capture events available from angling captures and the Albion Test Fishery in Region 2 from 1999-2018. Of these capture events, 76,341 were untagged captures and 76,721 were recaptures of previously tagged individuals. The dataset was filtered to produce a subset of data for analysis that only included samples from 2000-2018 which met the compatibility criteria for the model. Of the 153,062 total captures, 16,700 were found to be incompatible with the analysis (e.g., outside assessment years [2000-2018], modeled age classes, and repeat captures within a year) leaving 136,362 captures retained in the analysis. Of the original 76,341 untagged captures, 1,723 were removed (485 occurred outside the assessment period, 336 could not be aged, 132 had ages greater than the oldest age class, and 770 were captured outside the assessment area). Of the original 76,721 recaptures, 14,977 did not meet analysis parameters and were removed (628 occurred outside the assessment period and 419 were outside the assessment area, 74 could not be aged, 68 had ages greater than the oldest age class, 13,390 were removed for occurring within same calendar year [the ISAMR uses a yearly time step], and 398 recaptures were orphaned due to the previous filtering steps and treated as untagged captures for the purpose of the analysis).

The 136,362 captures that were retained where then analyzed using the same model setup described in previous analyses (Challenger et al. 2017). A single S-shaped selectivity-at-age curve was estimated and shared across all assessment years. The curve represents how catchability of sturgeon falls to zero as we move from older individuals, which are targeted by anglers, to younger, smaller individuals, which are not targeted in the same manner. The ISAMR does support multiple selectivity curves, which can be used to model changes in fisher behaviour, however it was currently not found to be necessary. Instantaneous sampling rates for each region were modeled as a linear function of the number of angling boat trips to each region in each year (see Table 1), with separate coefficients estimated for each region. This formulation was the same as Challenger et al. (2017), except with updated boat trip data.

Markov Chain Monte Carlo (MCMC) was used to sample from the posterior distribution using the Metropolis-Hastings algorithm to generate and accept parameter proposals. Trace plots were used to assess convergence of MCMC chain. A total of 5 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 5,500 retained posterior samples.

Table 1. Angling boat trips to each study region by year.

Year	A	B	C	D	Total
2000	65	220	555	19	859
2001	101	261	597	33	992
2002	79	174	479	30	762
2003	67	264	659	17	1,007
2004	61	330	996	48	1,435
2005	99	344	1,390	34	1,867
2006	55	353	1,309	66	1,783
2007	53	294	1,599	37	1,983
2008	34	448	1,206	66	1,754
2009	50	483	884	74	1,491
2010	44	474	888	113	1,519
2011	42	471	896	68	1,477
2012	41	597	1,027	88	1,753
2013	46	565	1,243	141	1,995
2014	51	446	1,208	116	1,821
2015	33	477	1,416	183	2,109
2016	32	379	1,145	218	1,774
2017	36	257	987	129	1,409
2018	42	222	851	156	1,271

RESULTS AND DISCUSSION

Point estimates of select ISAMR output include mortality, recruitment (historical and assessment period), yearly regional sampling rates, selectivity-at-age, and movement probabilities, and abundances for sturgeon age 5 and older (Figure 1). Results are broadly similar to previous analyses by Challenger et al. (2017) with low mortality rates for older age classes, close to complete gear selectivity for sturgeon of age 12 and older, and substantial declines in recruitment to the sampled population within the assessment period. As indicated in prior analyses, sturgeon also showed a tendency to remain within a given sampling region, with higher fidelity for sampling regions further away from the river mouth (Figure 1f).

Abundance estimates were broken down into recruitment into age 1 (Figure 2), as well as for abundance estimates for subsequent age classes (Figure A1). Age 1 recruitment estimates showed the most uncertainty relative to abundance estimates for other demographic breakdowns, which is expected given that there is a lag in time between the recruitment event and when sturgeon are exposed to sampling (i.e., non-zero gear selectivity; Figure 1e). Historical age 1 recruitment (i.e., backcasted estimates occurring prior to the assessment period) showed the highest levels peaking at approximately 30,000 in 1995, followed by a steady decline through the assessment period until around 2005, after which it stabilized at lower levels with a small increase to approximately 10,000 in recent years. Recruitment estimates from 2013 to 2018 shared the same parameter (i.e., were constrained to be equal), because there is not sufficient information to estimate recruitment in these years due to few captures of sturgeon age five and younger (a result of low gear selectivity associated with these ages; Figure 1e).

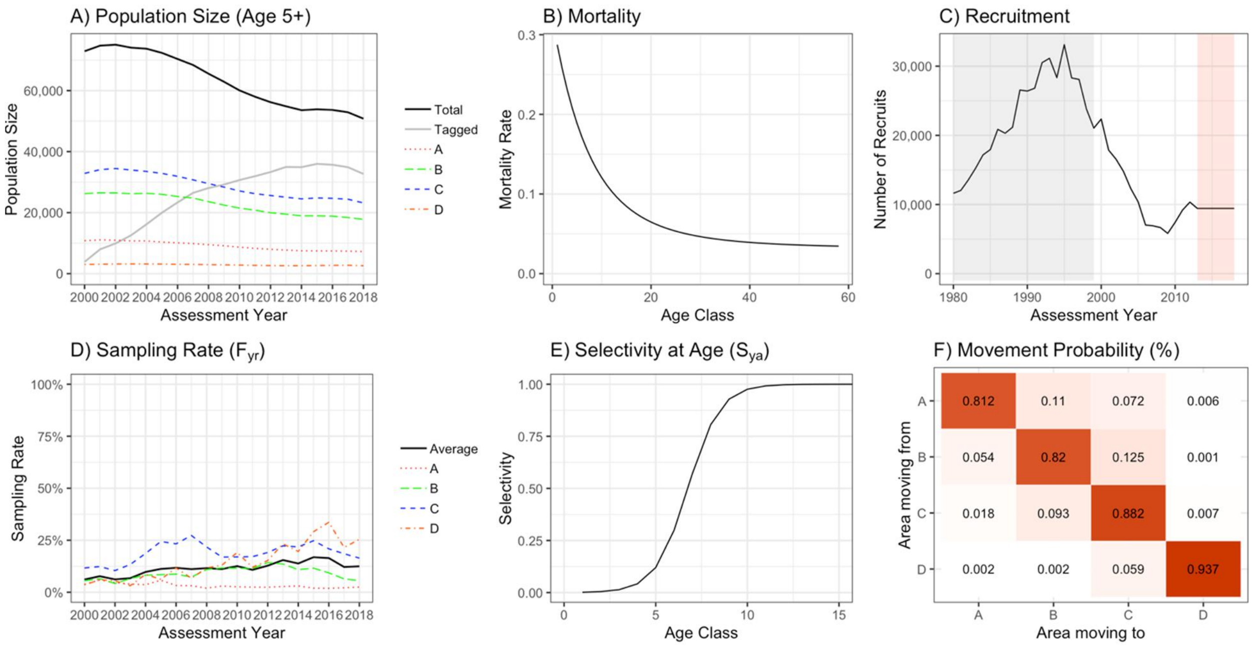

Figure 1. Select ISAMR model output including: A) population abundances for age 5 and above by sampling region; B) estimated mortality rate; C) historical and current recruitment (grey shading indicates historical recruitment; orange shading indicates terminal years that are constrained to be equal); D) regional sampling rates; E) selectivity-at-age; and F) regional movement probabilities.

In general, recruitment estimates are informed by age-specific catch in the assessment period after accounting for movements, sampling rates, and age-specific gear selectivity, and age-specific mortality rates. The large number of age classes tracked in the model also provide the ability to make inferences about a large number of recruitment cohorts, including those that preceded the start of the assessment period, with estimates reflecting the most likely number of recruits required to support the observed catch-at-age within the assessment period. The model provides age structuring, with the associated ability to track recruitment cohorts throughout the assessment period. The results provide a wealth of information regarding historical and current recruitment events. Estimates rely on the mortality curve to predict mortality rates in age classes where there are few observations.

While recruitment estimates should not be viewed as an exact reconstruction, estimates will still reflect general trends in age-specific abundances. For example, one predominant trend has been the increase in older age classes due to the high levels of recruitment during the pre-assessment period, while the decline of recruitment through the assessment period has resulted in a decline for younger age classes (i.e., ages 2-6 and 7-12 - often termed “juveniles”) due to the lack of replenishment. The pre-assessment period recruitment peak can also be seen in the intermediate age classes (i.e., age 13-22) as an increase followed by a decrease in abundances in recent years, as the pre-assessment period peak makes its way through to the intermediate age class and into the oldest age class (age 23-55; Figure 3).

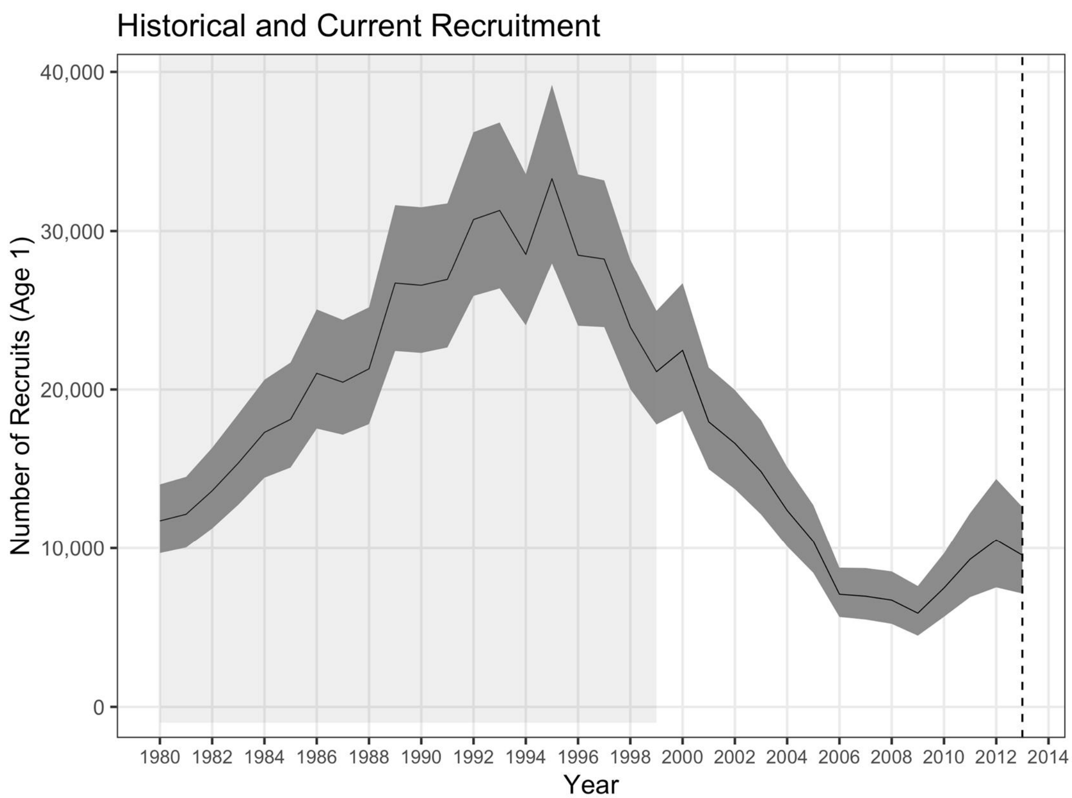

Figure 2. Estimated recruitment into age 1 prior to and during the assessment period, with 95% credible intervals (dark grey shading). Light grey shaded region indicates historical estimates and vertical line indicates cut-off for estimated recruitment due to lack of available catch data in smaller age categories.

Estimates of abundance for all White Sturgeon from age 7-55 (60-279 cm FL) were produced by the ISAMR model for 2000-2018 (Table 2); an illustration of these estimates is presented in Figure 3. The estimates represent an estimate of all sturgeon aged 7-55 that used the core study area during the study period. On a given year individual sturgeon may, or may not, have been present in the study area due to temporary emigration.

Abundance estimates also showed a high level of precision, which is in large part the result of the high percentage of the population that is estimated to have been marked (Figure 4). Older age classes (i.e., age 13 and older) show the highest level of marking, with marking rates dropping for younger age groups. This is not unexpected as these individuals are targeted by fishers and have been exposed to the marking program for the longest period of time. Interestingly, the group with intermediate selectivity (i.e., ages 7-12) showed a decline in the percent marked in the last two years of the assessment period, while older groups showed a general increase with some signs of leveling-off. This may indicate a shift in size classes targeted by fishers and implies that future analyses may need to fit a separate selectivity-at-age curve for more recent assessment years. In that case, selectivity-at-age curves can be expected to drop off quicker in the 7-12 age range. Finally, the youngest age class group (age 2-6) shows a constant low level associated with the low catch rates.

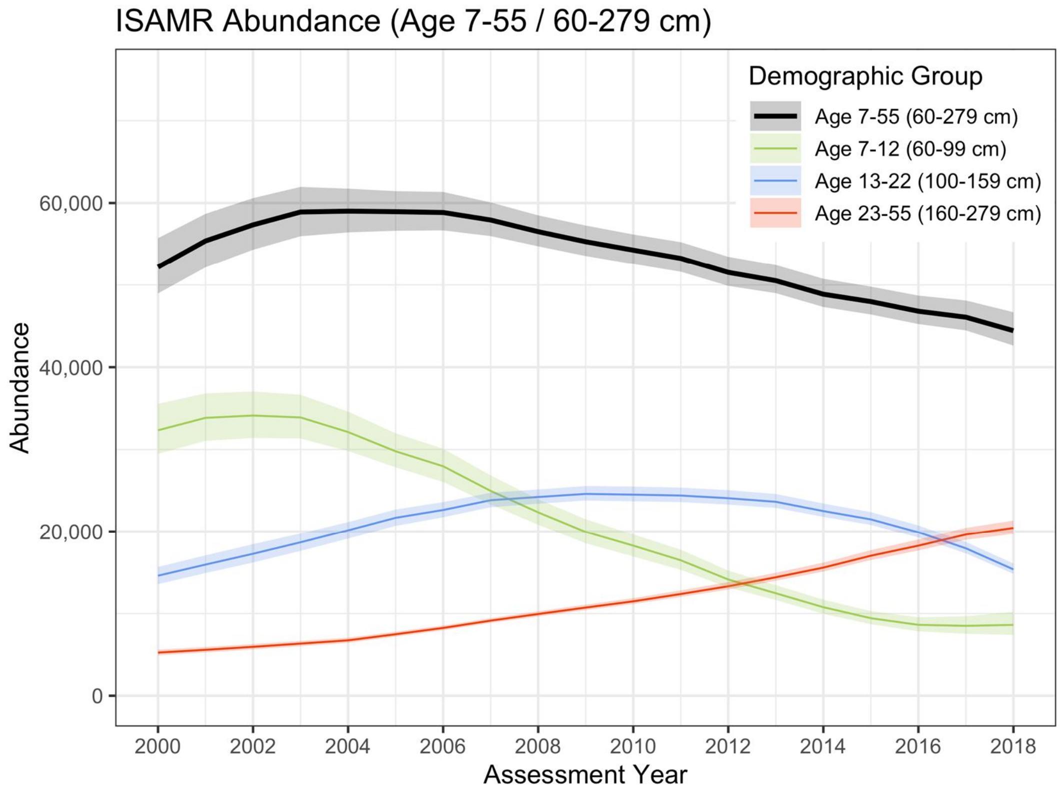

Figure 3. Abundance estimates of age 7-55 (60-279 cm FL) Lower Fraser River White Sturgeon from 2000 to 2018. Shading indicates 95% credible intervals.

Table 2. Abundance estimates of age 7-55 (60-279 cm FL) Lower Fraser River White Sturgeon from 2000 to 2018.

Year	Abundance Estimate	95% CI[1] Low	95% CI[1] High	Bounds as % of Abundance Estimate	CV (%)[2]	Annual % Change
2000	52,162	48,862	55,989	6.8%	3.49%	
2001	55,342	52,041	58,684	6.0%	3.06%	6.1%
2002	57,313	54,014	60,718	5.8%	2.98%	3.6%
2003	58,872	55,887	61,901	5.1%	2.61%	2.7%
2004	58,986	56,280	61,734	4.6%	2.36%	0.2%
2005	58,931	56,423	61,363	4.2%	2.14%	-0.1%
2006	58,824	56,639	61,234	3.9%	1.99%	-0.2%
2007	57,919	55,937	59,982	3.5%	1.78%	-1.5%
2008	56,511	54,717	58,447	3.3%	1.68%	-2.4%
2009	55,285	53,507	57,279	3.4%	1.74%	-2.2%
2010	54,265	52,570	56,230	3.4%	1.72%	-1.8%
2011	53,259	51,630	55,225	3.4%	1.72%	-1.9%
2012	51,535	49,983	53,396	3.3%	1.69%	-3.2%
2013	50,521	49,044	52,374	3.3%	1.68%	-2.0%
2014	48,866	47,480	50,731	3.3%	1.70%	-3.3%
2015	47,962	46,569	49,783	3.4%	1.71%	-1.8%
2016	46,798	45,431	48,699	3.5%	1.78%	-2.4%
2017	46,068	44,512	48,085	3.9%	1.98%	-1.6%
2018	44,430	42,611	46,621	4.5%	2.30%	-3.6%

[1] CI - Credible Intervals

[2] CV - Coefficient of Variation

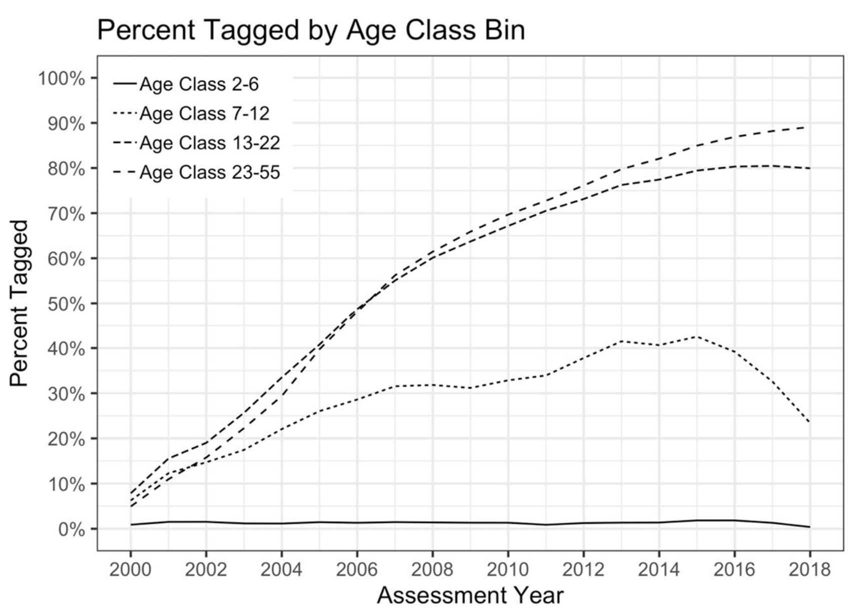

Figure 4. Estimated percent of the population tagged, by age class bin and assessment year.

Model age structuring makes forward abundance projections possible by combining age-specific abundance estimates with estimated age-specific mortality rates and future recruitment (i.e., age-1 recruitment) scenarios. Population abundances were forecasted from 2019 through to 2070 under a scenario where the average age 1 recruitment levels (i.e., 2013-2018) are: 1) maintained; or 2) increased 1.6 times current recruitment (Figure 5). No evaluations were made under the scenario where recruitment declines further.

Under the maintained scenario (e.g., "1x recent recruitment") the total abundance of juveniles and adults (i.e., 60-279 cm FL; age 7-55) are expected to continue to decline over the next 40 years (i.e., late 2050's), before leveling off at approximately half the abundance level (i.e., approximately 28,000) observed at the start of the assessment period (i.e., early 2000's; Figure 5a). Within the forecasted period, the 100-159 cm FL size group (age 13-22) is expected to continue to decline until the late 2020's, followed by a stabilization by the early 2030's at approximately one third of the 2010 abundance (i.e., approximately 8,000). Abundances of the spawning component of the population (i.e., 160-279 cm FL; age 23-55) are predicted to peak by the early 2020's (i.e., approximately 22,000), followed by a continued decline through to around 2060, after which it is expected to stabilize at a much lower level (i.e., approximately 9,200). The rate of decline for this group is slower than other groups due to the increased number of age classes included in this grouping. The time window required for stabilization is long due to the long-lived nature of sturgeon, but is likely an underestimate as future recruitment is unlikely to remain completely constant over time.

By contrast, under the scenario where age 1 recruitment is increased by 1.6 times the recent recruitment rate, abundance of 60-279 cm FL (age 7-55) will continue to decline for several years, but is predicted to stabilize by the mid-2030's at current population levels (i.e., approximately 45,000), which is approximately 75% of the peak abundance observed in the early 2000's (Figure 5b). The 100-159 cm FL size group (age 13-22) is also forecasted to decline until the late 2020's, but abundances would be expected to stabilize a little later (i.e., 2040) at an abundance level approximately 1.6 times that forecasted under current recruitment levels. The spawning population (i.e., 160-279 cm FL; age 23-55) would achieve peak abundance by mid 2020's, followed by a decline that will eventually stabilize in the mid-to-late 2050's at an abundance level approximately 1.6 times that forecast under the current recruitment scenario.

Challenger et al. (2017) suggested that reasonable interim population recovery goal would be 60,000 individuals in the 60-279 cm size class (age 7-55), with 20,000 adult sturgeon (age 22-55) being an interim goal (Challenger et al. 2017; Nelson et al. 2018). Even the 1.6 times recruitment scenario, which stabilizes the age 7-55 population, does not meet either objective suggesting that substantial increases in the recruitment of juveniles into the sampled population would be required to meet these proposed targets. Even if there were substantial improvements in recruitment it will take a considerable amount of time to achieve these goals given the long-lived nature of White Sturgeon.

As in previous reports, we emphasize the importance of taking immediate actions to improve both recruitment of age 1 fish and survival rates for age 1-6 fish. Moving forward the ISAMR model should be used to evaluate efficacy of various strategies towards achieving these goals and the mark-recovery program. Actions should include: 1) the protection of sturgeon spawning and juvenile rearing habitat; 2) the removal of all fishing gear from known sturgeon spawning areas during the spawning period; and 3) the protection of the spawning and rearing areas of sturgeon prey species (e.g., salmon and eulachon). Recent efforts to improve sturgeon handling techniques by sturgeon anglers (and for net fishers that intercept sturgeon as bycatch while targeting other species) should continue to be supported as they positively impact both survival and spawning rates for adult sturgeon.

Figure 5. **Abundance projections for Lower Fraser River White Sturgeon for 2018-2060 assuming A) that annual age 1 recruitment remains the same as recent estimates (i.e., 2012-2017 recruitment), and B) recruitment that is 1.6 times recent recruitment. Grey shading indicates projected years.**

ISAMR abundance estimates were compared with estimates from the BMR24 model which has been traditionally used to generate abundance estimates for the population. All abundance estimates will be sensitive to capture probability estimates, which can be affected by gear selectivity. For example, smaller fish are often relatively more difficult to capture relative to larger fish. If allowances are not made, this can bias abundance estimates. While the BMR24 does not explicitly model gear selectivity, it does restricts the analysis to size groups that are believed to be mostly or completely recruited into the fishery, which should control to a large degree gear selectivity differences. That said, the ISAMR model does directly estimate gear selectivity, which could result differing abundance estimates for smaller fish that may still be affected to some degree by gear selectivity. As such, the ISAMR abundance estimates were presented in two forms: 1) the “adjusted” estimate back-adjusts abundance for gear selectivity in order to better match BMR24 assumptions (Figure 6a; see Challenger et al. 2017 for full description); and 2) the “unadjusted” estimates (does not include adjustments; Figure 6b). As such, unadjusted ISAMR abundance are expected to be higher for age and size groups where catch is affected by gear selectivity.

In general, both models showed similar abundance estimates and similar trends in abundance across the different size/age groups (Figure 6) and across the four sampling regions (Figure 7; note only adjusted ISAMR abundances are presented). A notable exception was the unadjusted ISAMR estimates for the smallest age class (i.e., 60-99 cm FL; age 7-12), which showed the same general trend, but higher abundance estimates (left most panel, Figure 6b); this result is consistent with gear selectivity that may affect abundance estimates for this size group. When ISAMR- adjusted abundances are compared for the same age group, there is a much closer match to the BMR24 estimates; this suggests that gear selectivity affects the scaling of BMR24 estimates for the smallest size grouping (left most panel, Figure 6a). Although combining the older age groups (i.e., 100-279 cm FL) does highlight a more recent divergence (Figure 8).

Abundance estimates for the middle size group (i.e., 100-159 cm FL; age 13-22) showed the strongest association between the two models with little to no difference between the adjusted and unadjusted ISAMR abundance estimates (middle panels, Figure 6). This is not surprising as the majority of catch occurs in this size grouping. Both models show a sharp decline in abundance in recent years (i.e., 2012-2018), which corresponds to recruitment cohorts from 1990 to 2005, a set of recruitment years defined by peak recruitment in about 1995 followed by a steady decline (Figure 2). Because this decline in recruitment continued until 2006, the recent decline in the 100-159 cm FL group is expected to continue until stabilization sometime around 2030 (Figure 5a). By this point in time the 100-159 cm FL the group will consist primarily of more-recent recruitment cohorts, where recruitment levels have begun to stabilize (Figure 2). If, however, the recent stabilization of recruitment does not hold, and recruitment declines further, then the predicted stabilization in the 100-159 cm FL group abundance should not be expected (i.e., this size group would continue to decline in abundance).

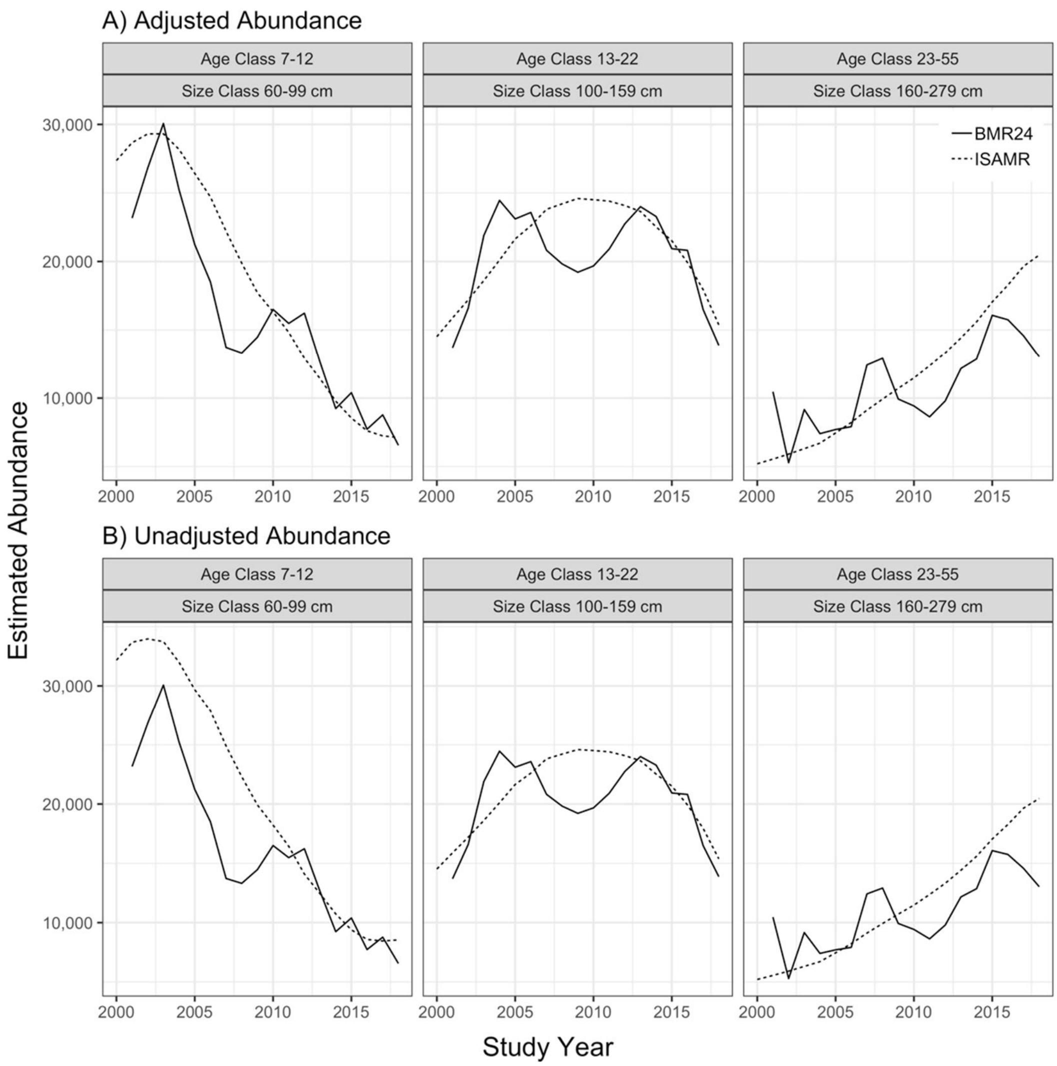

Figure 6. **Comparison of assessment area BMR24 and ISAMR abundances for size groups with gear selectivity differences for A) adjusted ISAMR abundances and B) unadjusted ISAMR abundances. Size groups (see Nelson et al. 2007) affected by gear selectivity differences are located in the left-side panels, while groups largely unaffected by gear selectivity differences are located in the middle and right-side panels. Adjusted ISAMR abundance modeling removes the effect of age-specific selectivity for comparison with the BMR24 estimates. Unadjusted ISAMR abundance modeling includes gear selectivity differences, and thus results are larger than the adjusted ISAMR estimates for age 7-12 sturgeon which are not fully recruited into the fishery.**

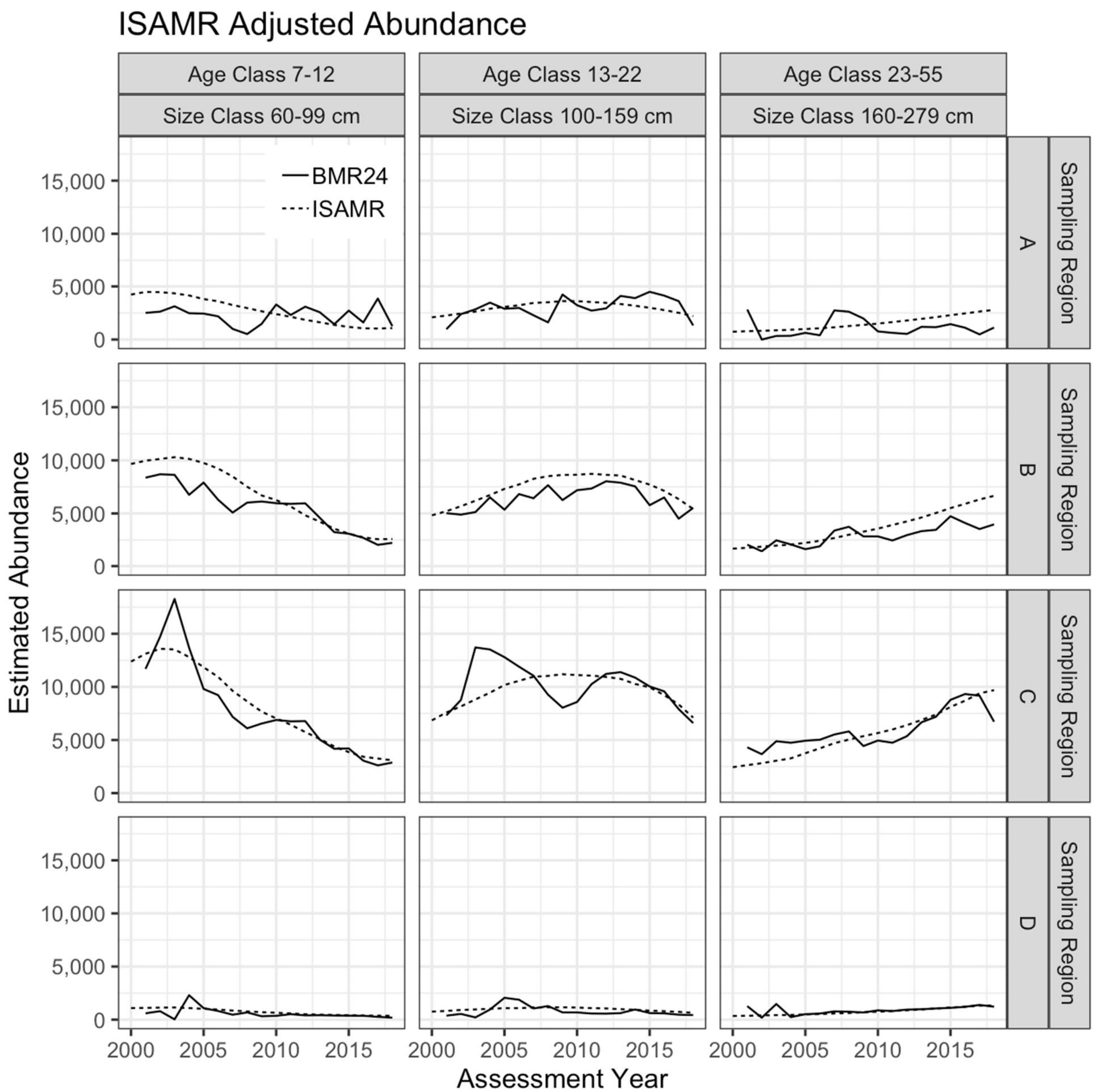

Figure 7. Comparison of assessment area BMR24 and adjusted ISAMR abundances across the four sampling regions. Size groups (see Nelson et al. 2007) were matched to age classes based on the length-at-age equation (see English and Bychkov 2002). Adjusted ISAMR abundance modeling removes the effect of age-specific selectivity for comparison with the BMR24 estimates.

The largest size group (i.e., 160-279 cm FL; age 23-55) showed a similar association between the two models, with little to no difference between adjusted and unadjusted ISAMR abundance estimates, indicating that this size class was fully recruited into the fishery. While there was general agreement in most years, recent years have featured a prominent deviation with the BMR24 abundances indicating a decline, while ISAMR abundances suggest an increase (rightmost panels, Figure 6). This divergence is prominent enough that it accounts for approximately 70% of the total difference in the 60-279 cm FL (age 7-55) abundances between the two model. While this group is predicted by the ISAMR model to decrease in the near future (i.e., by the mid to late 2020's, see Figure 5a), this potential decline would be occurring much earlier than predicted, and if real would suggest a different mechanism (e.g., differential mortality) than natural changes in the population age structure.

While this prominent deviation accounts for most of the difference between the two models, the BMR24 abundance estimates showed higher year-to-year variability in this size groups, than the ISAMR abundance estimates so this divergence could also be an artifact of estimate uncertainty with estimates coming back into agreement at a later point-in-time (e.g., 2007-2013 showed a similar deviation, middle panels, Figure 6). This large year-to-year variability is demographically unlikely, as it would require large number of mortality events and large number of immigration events of mature sturgeon into the population. The ISAMR model likely presents more stable estimates due to the age structuring constraint inherent in the model.

When broken down by region most of difference between the two model estimates appears to occur in sampling regions A and B, which are the two sampling regions in the closest proximity to the river mouth (Figure 7). Because the BMR24 model fits data from a 24-month sampling window, estimates may also be more sensitive to temporary emigration than the ISAMR model that considers all assessment years. If this was the case, each model has a different biological population of interest; the BMR24 model considers sturgeon that have used the lower Fraser River in the last 24 months, while the ISAMR model considers sturgeon that have used the lower Fraser River at some point during the entire assessment period.

Either way the difference abundance estimates between the two models prompted additional data reviews and analysis of the 2000-2018 data by Nelson et al (2019) where it was determined that the BMR24 model was more sensitive to recent changes in the distribution of tagging and sampling effort than the ISAMR model and concluded that the best estimates of abundance for 60-279 cm Lower Fraser White Sturgeon are those derived using the ISAMR model. Given the general agreement between the models in regard to most abundance categories, and abundance trajectories, it is also possible that these sampling deviation will be resolve in future analyses as additional years of data are collected.

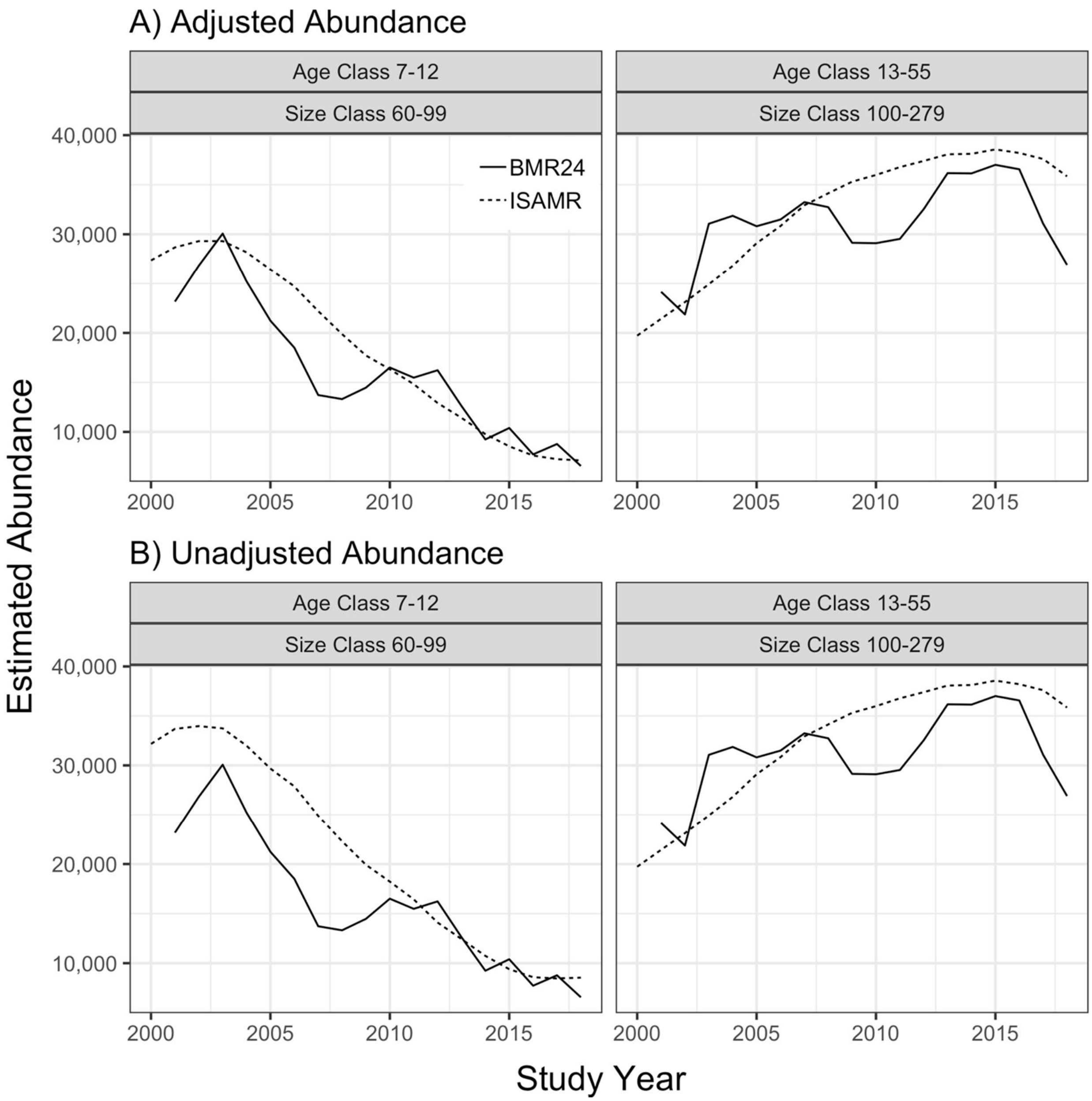

Figure 8. Comparison of assessment area BMR24 and ISAMR abundances for size groups with gear selectivity differences for A) adjusted ISAMR abundances and B) unadjusted ISAMR abundances. Size groups (see Nelson et al. 2007) affected by gear selectivity differences are located in the left-side panels, while groups largely unaffected by gear selectivity differences are located in the right-side panels. Adjusted ISAMR abundance modeling removes the effect of age-specific selectivity for comparison with the BMR24 estimates. Unadjusted ISAMR abundance modeling includes gear selectivity differences, and thus results are larger than the adjusted ISAMR estimates for age 7-12 sturgeon which are not fully recruited into the fishery.

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APPENDIX A

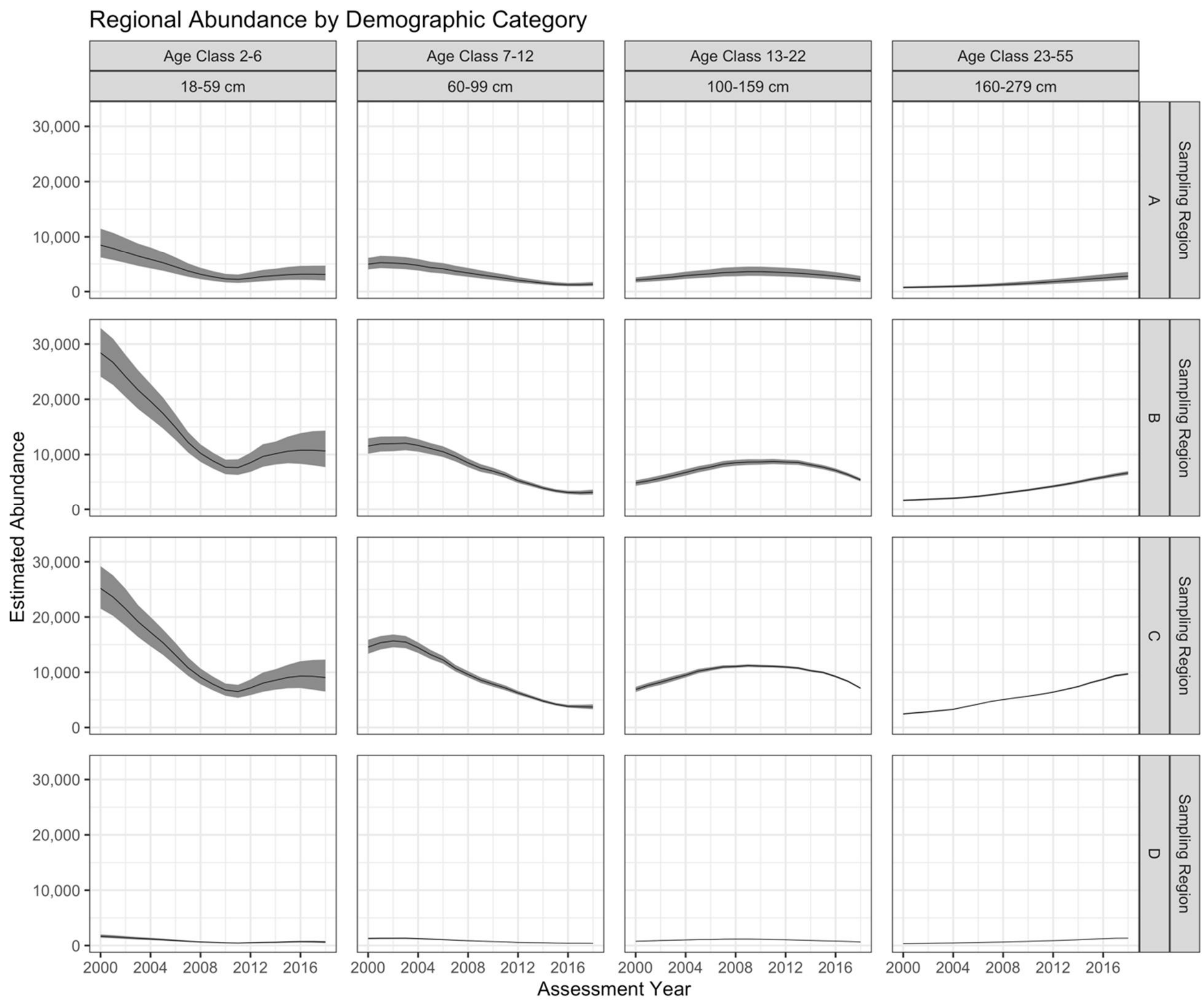

Figure A1. Estimates of region-specific abundances (sampling regions A, B, C, and D), broken down by age class for ages that are fully recruited into the fishery. Panel rows indicate sampling regions, while panel columns indicate size/age groups. Size groups are based predicted length-at-age growth model (RL&L 2000). Shaded region indicates 95% credible intervals.