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ASSESSMENT OF THE STATUS OF THE SPAWNING POPULATION OF SAINT JOHN RIVER ATLANTIC STURGEON (*ACIPENSER OXYRINCHUS*)

*Atlantic sturgeon (*Acipenser oxyrinchus*)*
D. Peddle

Figure 1. Map showing the Maritime provinces and the location of the Saint John River.

Context:

*Atlantic Sturgeon (*Acipenser oxyrinchus*) is a demersal, anadromous species distributed along the Atlantic coast of North America from the southern United States to Labrador. Two spawning populations of Atlantic Sturgeon are known to exist in Canadian waters: one in the Saint John River, New Brunswick, and another in the St. Lawrence River, Québec.*

Atlantic Sturgeon was assessed as threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in May 2011 and is under consideration for listing under the Species at Risk Act. Fisheries Management is seeking Science advice on the status of the spawning population of the Saint John River to improve the management of the Atlantic Sturgeon fishery. The advice will be used to guide Fisheries Management decisions in the management of food, social, and ceremonial allocations, commercial quota allocations, and access for recreational fishers. The fishery is managed through limited entry, a total allowable harvest, minimum gillnet mesh size, minimum total fish length and closed fishing season during June.

The information provided in this advisory process will also be used to support decisions related to the current terminal licence policy in the commercial fishery.

*This Science Advisory Report is from the March 23-25, 2021, regional advisory meeting on the Assessment of the Status of the Spawning Population of Saint John River Atlantic Sturgeon (*Acipenser oxyrinchus*). Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule](#) as they become available.*

September 2024

SUMMARY

- Previous assessments of the Saint John population of Atlantic Sturgeon to support a Non-Detriment Finding under CITES and a Recovery Potential Assessment were based primarily on an evaluation of the size/age structure of the population. These concluded that the population had a healthy age structure with at least 20 age classes, and that the current harvest was sustainable over the short-term.
- Understanding of stock structure (e.g., broad size structure) has not changed from the last assessment. However, in order to answer current and future fisheries management questions, efforts were made to develop and apply a population model.
- Two measures used to manage the modern commercial sturgeon fishery, which are assessed here, are a total allowable annual catch (TAC) of 350 fish (175 males and 175 females) and a closed season in June.
- A two-sex age-structured model was developed using Stock Synthesis 3 (SS3) software and commercial landings, catch data, and biological sampling from the Saint John River (SJR) and Bay of Fundy (BOF). Model outputs were compared to those from a Brownie tag-recovery model.
- In the reference SS3 model, growth, natural mortality (M), and maturity parameters were fixed. Steepness was set at 0.6 because of the late maturity and spawning periodicity of sturgeon. The sensitivity of the model was tested using alternative fishing mortalities (F), percent SJR fish in BOF catch, sex ratio of catch, fishery selectivity, and steepness profiles.
- While this modelling approach allows for stock status to be evaluated by estimating F and Spawning Stock Biomass (SSB) relative to reference points, lack of information on some of the model parameters and lack of confidence in the scaling of the model led to the conclusion that it may be premature to set and evaluate biological reference points from this model for management purposes at this time. However, it was agreed that assessment of fishing mortality relative to fishing mortality reference points (F_{ref}) would be appropriate.
- Potential fishing mortality and biomass reference points were discussed. A range of spawner per recruit (SPR) values from X = 20, 30, 40, 50, and 60% was calculated, where a higher SPR threshold reflects higher precaution in terms of conservation. SSB at MSY (SSB_{MSY}) was used as a biomass reference point.
- The mean fishing mortality rate during 2018–2020 was used as the $F_{benchmark}$ for stock status (relative to F reference points), while the SSB in 2020 was used as the biomass benchmark. All scenarios showed that both $F_{benchmark}$/F50% and $F_{benchmark}$/F0.1 were less than one. SSB/SSB_{MSY} was greater than one in 2020 in all scenarios except when steepness equals 0.45. $F_{benchmark}$ is lower than M estimated from growth parameters.
- Almost all models showed that the stock is in the healthy zone (above SSB_{MSY} in 2020). Projecting the model until 2030 indicated that the population is expected to remain in the healthy zone with the current TAC of 175 males and 175 females. Only in low steepness scenarios (0.45 and lower values) would the stock size fall below SSB_{MSY}.
- The June 1-June 30 closure provides sturgeon the opportunity to travel through Long Reach to their spawning location unimpeded and is effective in protecting some females while they enter the river and ripen prior to spawning.

- Various sources of uncertainty were identified that influenced how far this stock assessment model could be developed including catch composition and selectivity of the early historical fishery. Limited information is available to inform population resilience (i.e., steepness), which is needed to inform the development of reference points.
- Impacts of climate change have been observed, for example, two flood years were followed by low river flow in 2018-2020s. Sturgeon has been identified as highly vulnerable to warming water temperatures associated with climate change in the US, and it is recommended that environmental data be included in future assessment development.

BACKGROUND

A commercial Atlantic Sturgeon fishery has existed in the Saint John River (SJR) since the late 1800s, but the first evaluation of the sustainability of sturgeon removals occurred in 2009. After review of the total commercial fishery removals and other sources of mortality, the Department of Fisheries and Oceans (DFO) set a maximum total allowable harvest of 350 animals (175 female and 175 males) annually; a value based on commercial fisheries landings data and opportunistically collected biological data (DFO 2009).

Atlantic Sturgeon is under consideration for listing under the *Species at Risk Act*, following designation of the Maritimes Region Designatable Unit (including the SJR population) as Threatened by the Committee on the Status of Endangered Wildlife (COSEWIC 2013). DFO Maritimes Region has asked for Science advice on the status of the SJR spawning population to improve and guide Fisheries Management decisions. The three objectives of this assessment are to:

- provide an estimate of the current spawning stock biomass as well as advice on appropriate reference points;
- provide advice as to whether the current 350 fish commercial quota (175 males and 175 females) is appropriate relative to the estimate of spawning stock biomass; and
- provide advice as to the usefulness and appropriateness of the current annual closure (month of June) to protect spawning adults, i.e., does the closure provide benefits and is it of the appropriate duration and at the appropriate time of year.

Previous assessments of the Saint John population of Atlantic Sturgeon to support a Non-Detriment Finding under CITES and a Recovery Potential Assessment (RPA) were based primarily on an evaluation of the size/age structure of the population. The RPA ((DFO 2013) concluded that there were at least 20 age classes and that the current harvest was sustainable over the short-term (5 years). A recent population assessment, using annual tag-returns and fish-length data from the commercial SJR fishery concluded that the population abundance is now near virgin levels, and that the fishery is sustainable at current harvest levels (Dadswell et al. 2017).

Understanding of stock structure (e.g., broad size structure) has not changed from the last assessment. However, in order to answer current and future fisheries management questions, efforts were made to develop and apply a population model. A two-sex age-structured model was developed using Stock Synthesis 3 (SS3, version 3.30.15) software, catch data, and biological sampling from the Saint John River and Bay of Fundy. Model outputs were compared to a Brownie tag-recovery model.

Species Biology

Atlantic Sturgeon, *Acipenser oxyrinchus*, occurs in major rivers and coastal environments from the east coast of Labrador, Canada to Florida, USA. The Saint John River, New Brunswick, (SJR) is one of two locations of known spawning populations of Atlantic Sturgeon in Canadian waters.

Atlantic Sturgeon are anadromous, with pre-spawning adults migrating into the SJR from mid-May to August. Neither the historical (i.e., prior to construction of the Mactaquac Dam in 1968) nor current spawning locations have been documented for SJR Atlantic Sturgeon. Based on the capture of yolk sac larvae and exogenous feeding larvae in late July 2011, there may be a spawning location near Burton, NB (River Kilometre 106) with spawning occurring between mid-June and mid-July (Taylor and Litvak 2017).

Migration is a characteristic of Atlantic Sturgeon, from the larval through juvenile and adult life stages. Young of the year sturgeon likely spend their first winter in freshwater and then move downstream into more saline water in the following spring. Juveniles migrate seasonally within the estuarine portion of the rivers, moving to deep, wintering areas in winter and upstream in spring. They leave their natal estuary generally between 2 to 6 years of age and at lengths of 80-120 cm to initiate a coastal foraging migration. They also enter the estuarine areas of non-natal rivers and forage for the summer and fall, with some remaining all winter.

In summer, aggregations of adult and juvenile sturgeon are common in the Lower SJR, Cumberland and Minas basins as well as elsewhere in the Bay of Fundy (e.g. St Mary’s Bay, NS), and the Atlantic coastal areas of Nova Scotia, Newfoundland and the Gulf of St Lawrence (DFO 2013). Adult sturgeon aggregate in deeper portions of the Bay of Fundy in winter (Taylor et al. 2016, Beardsall et al. 2016).

Age at maturity in Atlantic Sturgeon varies with northern populations maturing at an older age than southern populations and males maturing at a younger age than females. Sturgeon from the SJR probably have similar ages of maturity to the Saint Lawrence River population, with males maturing around at 16-24 years and females around 17-28 years (DFO 2013, Bradford et al. 2016). Among the SJR population, both females and males return to the river at intervals of 1-6 years (Dadswell et al. 2017, Tsitrin et al. 2021).

The Fishery

Commercial fishing for sturgeon in the Saint John River began in 1880 with removals of 712 t over seven years. Average reported landings since the fishery resumed in 1897 have been below 9 mt except for a brief period in the 1980s when landings peaked at 41 mt. Two measures used to manage the modern commercial sturgeon fishery, which are assessed here, are a total allowable annual catch (TAC) of 350 fish (175 males and 175 females) and a closed season in June. Other management measures are a minimum size limit of 130 cm TL and minimum gillnet mesh size of 33 cm. Due to implementation of a terminal license policy in the mid-1980s, the number of licenses authorized to fish in the Saint John River has declined to two, fishing a maximum of 11 fixed gillnets (610 m).

Sturgeon landings from outside the SJR in the Bay of Fundy (BOF) were < 1 mt for most years from 1880 to 1956. Landings from 1957 to 2000 averaged 5 mt with a peak at 18 mt in 1985. Retention of sturgeon by other fisheries has been prohibited since 2000.

ASSESSMENT

Estimation of Current Spawning Stock Biomass and Reference Points

Historical commercial sturgeon landings were taken from Bradford et al. (2016) (Figure 2). Composition data from the SJR fishery were taken from Dadswell et al. (2016)). Age and size structure data from Dadswell et al. (2016) were used to estimate selectivity of the BOF catches.

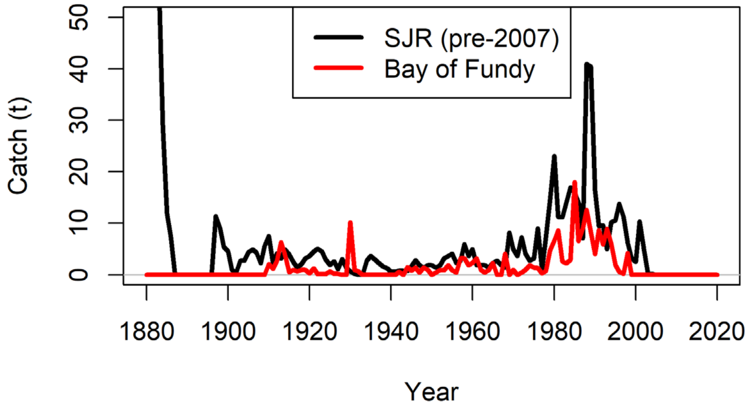

Figure 2. Historical sturgeon landings (pre-2007, in tonnes) for the assessment. All landings prior to 1890 were greater than 50 t. Values are reported in Table 4 of Bradford et al. (2016).

An index of abundance was derived from 2009-2020 fishery catch data ((catch per unit effort in numbers of fish caught per day per net) and standardized by year, month and river flow (measured by water discharge from Mactaquac Generating Station)) as covariates.

The observed CPUE series, calculated as annual geometric means, showed a notable decline from 2009 to 2012 (Figure 3). During the middle of the series (2011 – 2018), observed values were relatively stable, if not slightly increasing, followed by a slight decrease since 2018.

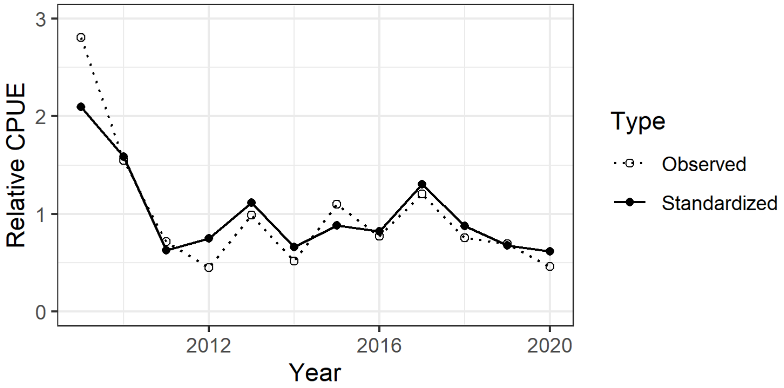

Figure 3. Comparison of the observed CPUE and standardized by month, day and river flow. Each series was calculated as annual geometric means, and then rescaled to have a mean of one.

Growth, natural mortality and maturity parameters were fixed in the SS3 model, using values taken from recent studies in Minas Basin (Table 1). The coefficient of variation in length-at-age was fixed to 0.1. Natural mortality (M) was estimated using growth parameters. Although estimates of M using maximum age is the preferred method, these were high (M=0.13 and 0.16

for females and males, respectively), relative to those from the older estimators and previous estimates of M for the SJR stock (Dadswell et al. 2017), and considered less plausible when considering the life history of the stock.

Table 1. Biological parameters for Saint John River Atlantic Sturgeon. Length parameters are in terms of total length (cm) and weight parameters are in terms of round weight (kg).

Parameter	Female	Male	Source
Von Bertalanffy Linf (cm)	264	230	Stewart et al. (2015)
Von Bertalanffy K (yr^{-1})	0.04	0.06	Stewart et al. (2015)
Von Bertalanffy t_0 (yr)	-0.94	-0.60	Stewart et al. (2015)
Length-weight a (coefficient)	2e-5	2e-5	Dadswell et al. (2017)
Length-weight b (exponent)	2.72	2.72	Dadswell et al. (2017)
Length of 50% maturity (cm)	175	160	Visual comparison of length composition
Length of 5% maturity (cm)	160	140	Stewart et al. (2015)
Natural mortality (yr^{-1})	0.06	0.09	Then et al. (2015) using growth parameters

Steepness is a parameter (with a range of 0.2 - 1.0) of the Beverton-Holt stock recruit relationship describing the resilience of the population and the rate of recovery when the stock is at very low levels. A value of 0.6 was chosen in consideration of the late maturity and periodicity in spawning of Atlantic Sturgeon. Annual recruitment (age 0) was calculated using the stock-recruit relationship internal to the model. No recruitment deviates were estimated in the assessment. The sex ratio of recruits was set at 50% female.

Model structure

Separate fishing fleets for the SJR and BOF catches were modeled in SS3. To accommodate the historical catches in weight pre-2007 and the modern catches (in numbers) post-2007, the SJR fishery was further split into two fleets with selectivity parameters shared between them. Sex-specific length composition of the removals in the SJR fishery were used, as well as unsexed length and age composition reported in Dadswell et al. (2016) for the BOF fishery, resulting in a sex-specific selectivity for the SJR fleet and a unisex selectivity for the BOF fleet. The SJR fishery selectivity was modeled as a logistic curve while the BOF fishery was modelled as a dome-shaped curve.

The SJR fishery CPUE was specified to be an index of female spawning stock numbers. Fishing mortality (F) was estimated in SS3 using the hybrid method option, which calculates F such that the predicted catches match the observed values. A constraint was placed on F such that it could not exceed 3, corresponding to a maximum annual harvest rate of approximately 0.94. The model was run using the full time series of catches to 1880, when the stock was assumed to be in an unfished state. The stock likely experienced high F with the rapid depletion in the initial years of the SJR fishery, likely fishing out the exploitable portion of the stock (Bradford et al. 2016, Dadswell et al. 2017). Thus, sensitivity runs were conducted with alternative values of max. F of 1 and 6, corresponding to harvest rates of 0.62 and 0.99, respectively, to evaluate the importance of this constraint.

The SS3 model consists of two major components, with the first component being the estimation component (using maximum likelihood) for the historical reconstruction of the stock, and the second component being the forecast component intended to generate short-term projections of the stock from a schedule of catches or fishing mortality for the near future. A separate configuration of SS3 was generated to explicitly allow testing of the 175-175 TAC. An additional sensitivity run modeled dome selectivity for the SJR gillnet fishery. In addition to assuming 60% of the historical BOF catches originated from the SJR stock, sensitivity analyses also explored scenarios with 30% and 90% BOF catches of SJR origin.

To evaluate uncertainty with respect to steepness values, a likelihood profile was generated comparing biomass and F from values of 0.45 to 0.85. Several other diagnostics were utilized, including a likelihood profile for the unfished recruitment parameter and a retrospective analysis to evaluate the consistency of model estimates as recent data were removed.

Reference Points

Stock status was evaluated by estimating F and SSB relative to reference points. The summary F was defined as the F calculated at the apical value for the SJR fishery in the model. For models with SJR logistic selectivity, this corresponded to the maximum age of 60 years and for the model run with SJR dome selectivity, to a maximum age of 40 years.

With no information on steepness, reference points that use the stock-recruit relationship, such as MSY (maximum sustainable yield), may not be appropriate. Alternate proxies for fishing mortality, $F_{0.1}$, the mortality at which the change in yield-per-recruit is 10% of that at F = 0, and $F_{X\%}$, the mortality that reduces spawning potential ratio (SPR, mature biomass produced per recruit) to X% of the spawning biomass per recruit produced when fishing mortality = were reported as potential reference points for fishing mortality. A range of SPR values from X = 20, 30, 40, 50, and 60% was calculated, where a higher SPR threshold reflects higher precaution in terms of conservation. These reference points are relative to the summary F.

The spawning biomass at MSY (SSB_{MSY}), or potentially some scalar thereof, is provisionally presented as a biomass reference point. Values of SSB_{MSY} vary among models depending on the value of unfished recruitment and steepness, but the ratio SSB/SSB_{MSY} in 2020 could be used as a status determinator and can be robust across models. Reference points were calculated internally in SS3 during the forecast phase. The mean fishing mortality rate during 2018-2020 was used as the $F_{benchmark}$ for stock status (relative to F reference points), while the SSB in 2020 was used as the biomass benchmark.

Model Fit and diagnostics

The reference model estimated that the unfished female spawning biomass (SSB_0) was 347 t in 1879 (Figure 4). Rapid depletion of the stock occurred with early catches in the 1880s, with the fishing mortality for the SJR fishery reaching the maximum of 3 in 1883 and the fishery closed soon afterwards. The stock was not fished into extinction because the fishery selectivity was restricted to a subset of the spawning component. The juvenile and young spawner components of the stock that were invulnerable or only partially vulnerable to the fishery remained and contributed to the stock recovery. The stock recovery continued into the 1910s, but stabilized in the 1920s, as the SJR fishery continued and catches from the BOF began. From the 1920s until 1980, the stock continued to increase, but at slower rate than in the late 19th and early 20th century. Another period of higher F occurred in the 1980s, coinciding with notable removals in the BOF. Since 2007, at the start of the modern fishery, the stock size has been decreasing, although at a slower rate than estimated in the past. The stock has remained above SSB_{MSY} since the late 19th century (Figure 4).

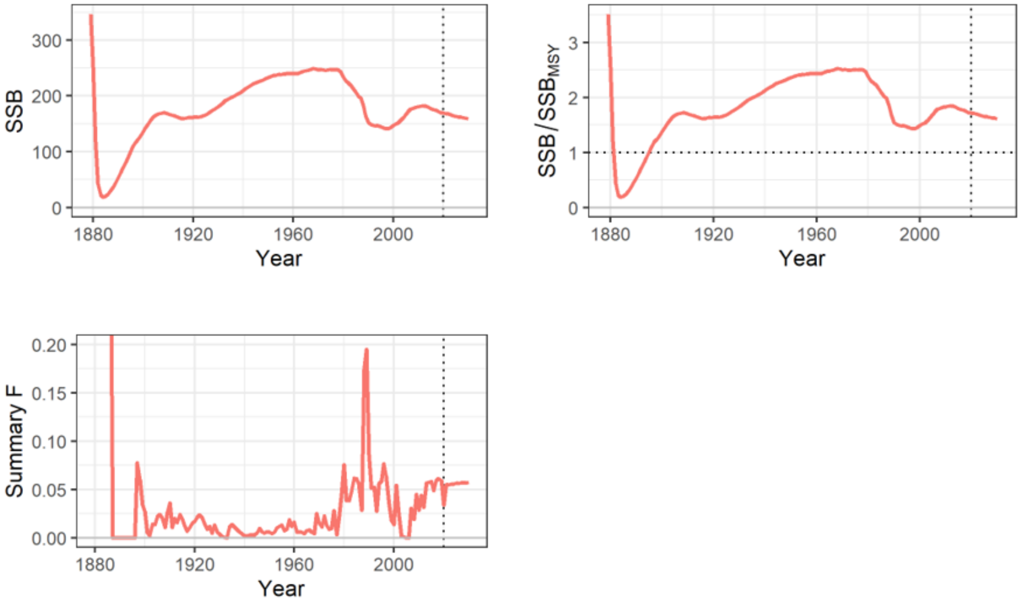

Figure 4. Estimates of Spawning Stock Biomass (SSB) (top left), SSB/SSB$_{MSY}$ (top right), and Fishing Mortality (F) (bottom left) from the reference model. All fishing mortality (F) rates in years prior to 1886 exceed 0.20. Dotted vertical line indicates year 2020. Values after 2020 are forecasted values from implementing the current Total Allowable Catch (TAC).

Full selectivity of the SJR fishery was estimated to be 200 cm and 180 cm for females and males, respectively corresponding to approximately 35 and 25 years, respectively, using mean length-at-age (Figure 5). The selectivity curve was larger than the maturity-at-length. The BOF fishery caught smaller, immature fish with the dome selectivity peak at 150 cm (18 years).

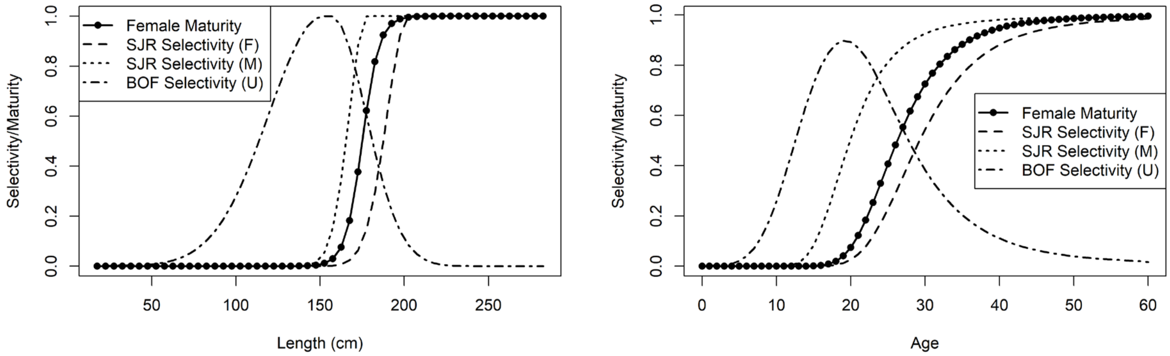

Figure 5. Selectivity estimates from the reference model (shown alongside female maturity for comparison). Selectivity was modeled primarily as a function of length (left) with the corresponding age-based schedule (right)

When dome selectivity was estimated for the SJR fishery, the estimated SSB and SSB/SSBMSY was higher compared to the reference model for much of the time series (Figure 6).

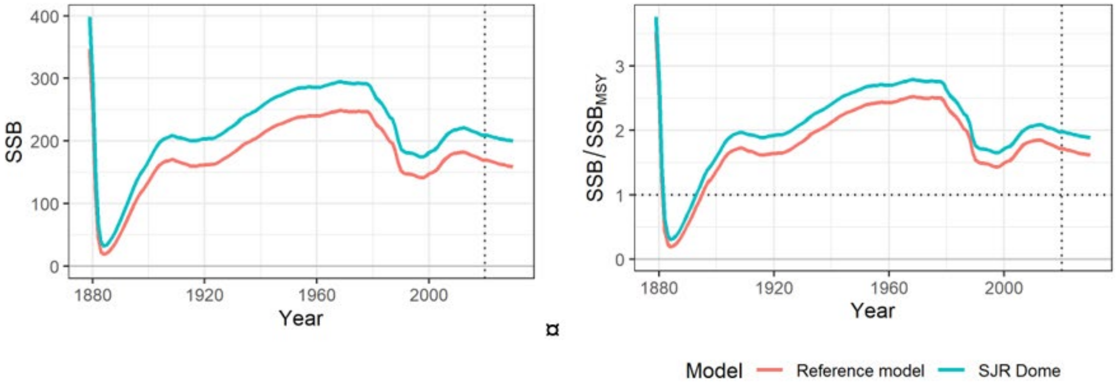

Figure 6. Estimates of Spawning Stock Biomass (SSB) and SSB/SSB$_{MSY}$ between the reference model (logistic selectivity in the Saint John River (SJR) fishery)(left panel) and the model with dome selectivity in the SJR fishery (right panel).

The profile likelihood for steepness (h) indicated that lower values were preferred, with the minimum at h = 0.30; however, such low values imply that there is little to no density dependence in the population and there is no fishing mortality can be sustainable. In other words, SSB$_{MSY}$ approaches SSB$_0$ as steepness approach 0.2. Such a value also implies that the recent SSB is similar to that in the 1880s, despite markedly lower catches. For comparison with the reference model and other sensitivity fits, a range of more plausible values between 0.45 – 0.85 was used. As steepness value used in the model increased, the current biomass became more optimistic. The unfished biomass remained unchanged, since it is dependent on the max. F value, although the biomass at MSY decreases with increased steepness (Figure 7).

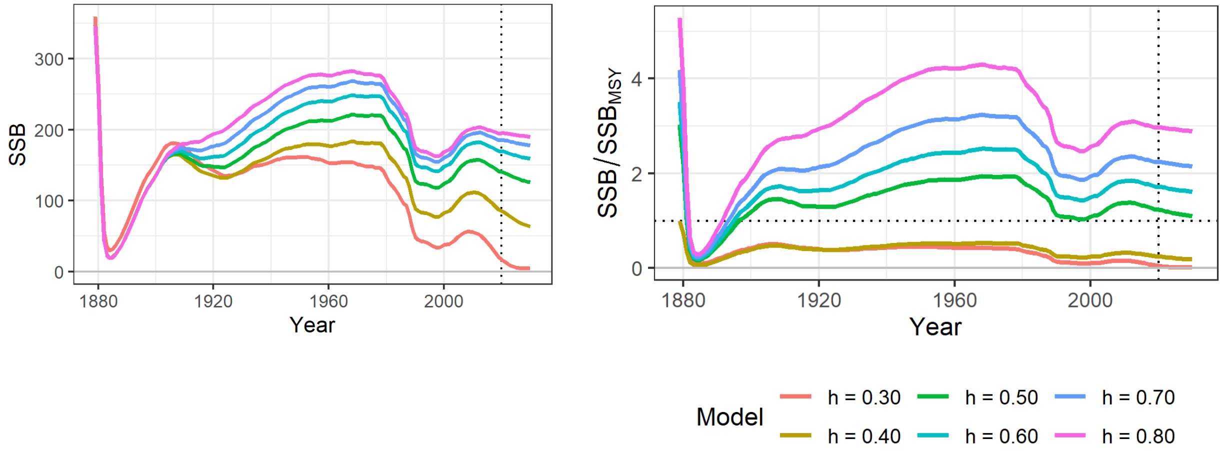

Figure 7. Estimates of Spawning Stock Biomass (SSB) (left) and SSB/SSB$_{MSY}$ (right) across the steepness profile. The reference model is the h = 0.6 model.

The reference model generally generated good fits to the SJR female length composition, although the model predicts higher abundance of large animals that are only occasionally seen in the data (e.g., 2015 and 2016, (Figure 8). The fit to the SJR male composition, on the other hand, was poorer. The mode of the predicted distribution often matched the observed, although the mode of the observed frequently changed over time (Figure 9). Due to the larger sample size of the BOF length composition relative to the age data, the model fitted the lengths much better (Figure 10).

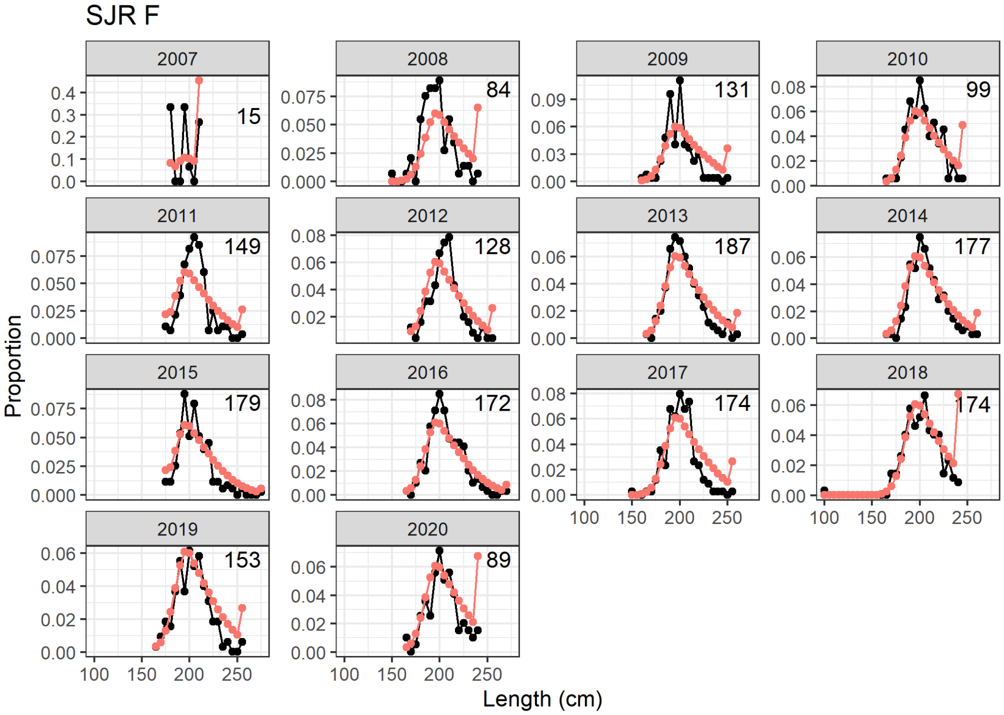

Figure 8. Observed (black) and predicted (orange) length composition of harvested females in the Saint John River (SJR) fishery in the reference model. Numbers in top right of each panel indicate the sample size.

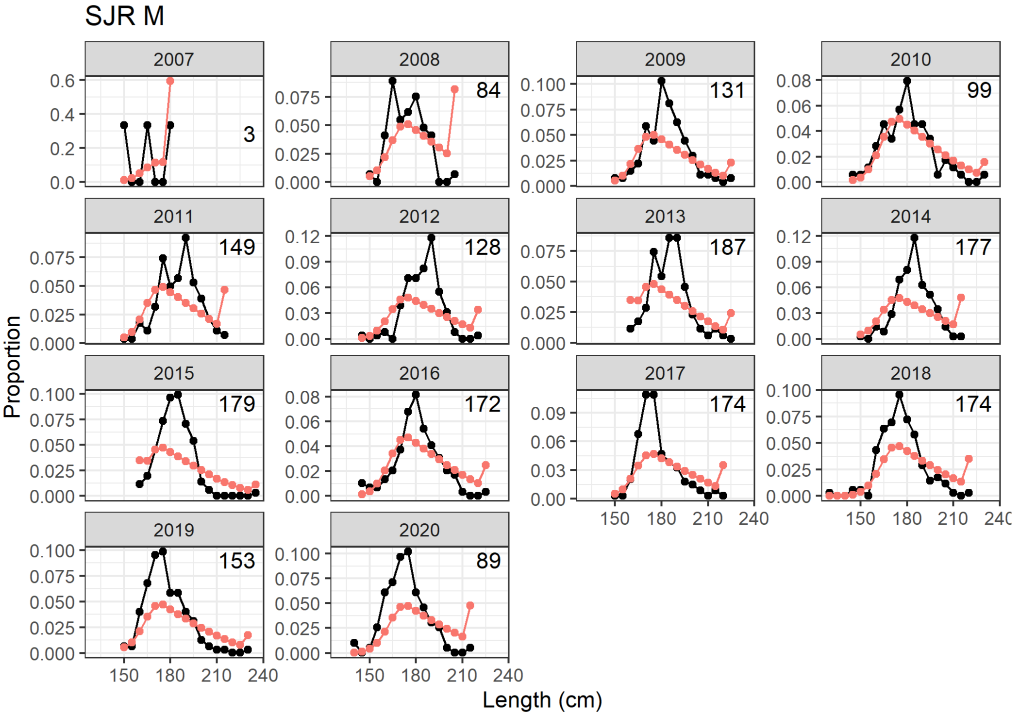

Figure 9. Observed (black) and predicted (orange) length composition of harvested females in the SJR fishery in the reference model. Numbers in top right of each panel indicate the sample size.

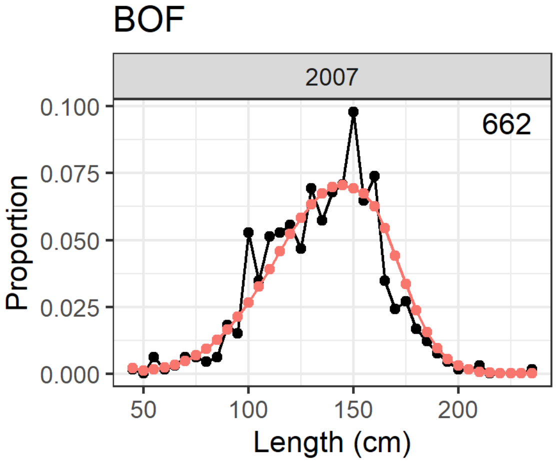

Figure 10. Observed (black) and predicted (orange) length composition of the Bay of Fundy (BOF) fishery. The number in top right of the panel indicates the sample size.

The CPUE index predicted by the model was flat relative to the standardized series (Figure 11). The change in the estimated spawning stock numbers over 2009-2020 time period was smaller relative to the standardized CPUE (Figures 3,11). In particular, the decreasing trend of the standardized values during 2009-2011 was not captured in the predicted index.

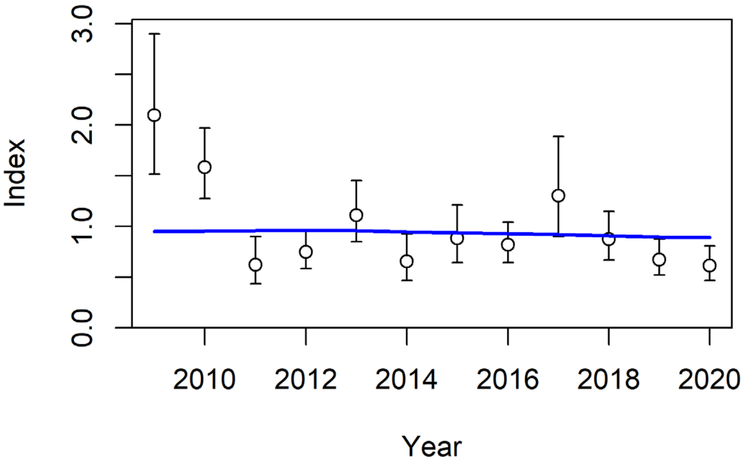

Figure 11. The predicted index (blue) compared to the standardized Catch Per Unit Effort (CPUE) (white points with error bars) in the reference model.

A retrospective analysis did not reveal major pathological problems. As data were removed (from 2014-2019), historical SSB and F do not substantially change (Figure 12). The Mohn's rho for the estimated SSB was less than 0.01.

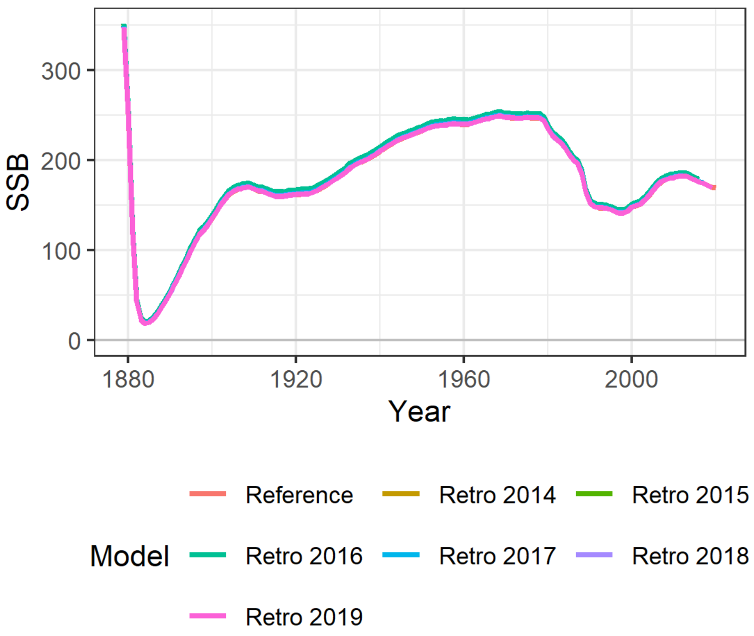

Figure 12. Retrospective analysis of the reference model when additional years of data are removed.

A summary of the sensitivity scenarios and their effects on model output relative to the reference model is provided in Table 2. Almost all models explored here showed that the stock was above SSB_{MSY} in 2020 and would remain above SSB_{MSY} with the current TAC. Only in low steepness scenarios (h = 0.45 and lower values) would the stock be below SSB_{MSY}. In essence, the stock is above SSB_{MSY} since current catches are lower compared to the early years of the fishery.

Table 2. Description of the various model configurations evaluated and their effects on the historical reconstruction and SSB_{MSY} relative to the reference model.

Name	**Description**	**Effect relative to reference model**
Reference model	Maximum F = 3, steepness = 0.6, 60% of Bay of Fundy (BOF) catches are SJR origin, identical apical F between sexes	-
Max. F = x	Set maximum F to either 1 or 6	Unfished stock size, SSB_{MSY}, and current stock size decrease as maximum F increases
SSF (Separate -sex fleet)	Set historical sex ratio of catch (pre-2007) to be 60% female, apical F is independent by sex	Unfished stock size, SSB_{MSY}, and current stock size increase
SJR Dome	Estimate dome selectivity for the SJR fishery	Unfished stock size, SSB_{MSY}, and current stock size increase
X% BOF	Assume X% of BOF catches are SJR origin	Unfished stock size and SSB_{MSY} unchanged, but current stock size decreases as X% increases
Profile h = x	Use alternative values of steepness, where h = 0.45, 0.50, …, 0.85 (increments of 0.05)	Unfished stock size unchanged, but SSB_{MSY} decreases and current stock size increases as steepness increases

Provisional fishing mortality reference points are presented in Table 3. Spawning potential ratio (SPR) does not vary among models that have very similar selectivity estimates. All models used the same female biological parameter values and the calculations are not dependent on steepness.

Table 3. Values of fishing mortality biological reference points.

Reference point	Value
$F_{0.1}$ (SSF)	0.13
$F_{0.1}$ (dome)	0.15
$F_{0.1}$ (otherwise)	0.10
$F_{20\%}$ (dome)	0.23
$F_{30\%}$ (dome)	0.12
$F_{40\%}$ (dome)	0.08
$F_{50\%}$ (dome)	0.05
$F_{60\%}$ (dome)	0.03
$F_{20\%}$ (otherwise)	0.27
$F_{30\%}$ (otherwise)	0.15
$F_{40\%}$ (otherwise)	0.09
$F_{50\%}$ (otherwise)	0.06
$F_{60\%}$ (otherwise)	0.04

Potential stock status for removal rate is presented as the estimated F in 2020 relative to $F_{0.1}$ and $F_{50\%}$ (Table 4). The provisional biomass reference point SSB_{MSY} increased as the unfished stock size increased and decreases when the steepness value used in the model increased. All scenarios showed that the $F_{benchmark}/F_{50\%} < 1$ and $F_{benchmark}/F_{0.1} < 1$. Similarly, $SSB/SSB_{MSY} > 1$ in 2020 in all scenarios except when steepness = 0.45.

Table 4. Spawning biomass and fishing mortality estimates in 2020, along with forecasted values in 2030 using the current Total Allowable Catch (TAC), from the suite of Stock Synthesis models.

Model	SSB_0	SSB_{MSY}	SSB_{2020}	SSB_{2020} / SSB_{MSY}	F_{2020}	F_{2020} / $F_{50\%}$	F_{2020} / $F_{0.1}$	SSB_{2030}	SSB_{2030} / SSB_{MSY}	F_{2030}	F_{2030} / $F_{50\%}$	F_{2030} / $F_{0.1}$
Reference model	347	99	169	1.72	0.03	0.57	0.34	159	1.61	0.06	0.95	0.57
Max. F = 1	415	118	242	2.05	0.02	0.38	0.23	233	1.97	0.04	0.65	0.39
Max. F = 6	327	93	148	1.58	0.04	0.65	0.39	137	1.47	0.07	1.10	0.66
SSF	430	132	276	2.10	0.02	0.28	0.17	263	1.99	0.03	0.57	0.34
SJR Dome	398	106	209	2.09	0.04	0.80	0.27	200	1.89	0.07	1.40	0.47
30% BOF	349	99	186	1.88	0.03	0.52	0.31	174	1.75	0.05	0.87	0.52
90% BOF	347	99	154	1.56	0.04	0.62	0.37	146	1.48	0.06	1.03	0.62
Profile h = 0.45	347	122	117	0.96	0.05	0.83	0.5	99	0.81	0.09	1.50	0.90
Profile h = 0.5	347	114	140	1.23	0.04	0.68	0.41	126	1.10	0.07	1.20	0.72
Profile h = 0.55	347	106	157	1.48	0.04	0.62	0.37	145	1.36	0.06	1.03	0.62
Profile h = 0.6	347	99	169	1.72	0.03	0.57	0.34	159	1.61	0.06	0.95	0.57
Profile h = 0.65	347	91	178	1.96	0.03	0.53	0.32	170	1.87	0.05	0.90	0.54

Model	SSB_0	SSB_{MSY}	SSB_{2020}	SSB_{2020} / SSB_{MSY}	F_{2020}	F_{2020} / $F_{50\%}$	F_{2020} / $F_{0.1}$	SSB_{2030}	SSB_{2030} / SSB_{MSY}	F_{2030}	F_{2030} / $F_{50\%}$	F_{2030} / $F_{0.1}$
Profile h = 0.7	347	83	185	2.23	0.03	0.52	0.31	178	2.15	0.05	0.85	0.51
Profile h = 0.75	347	75	191	2.55	0.03	0.50	0.3	185	2.47	0.05	0.82	0.49
Profile h = 0.8	347	66	195	2.97	0.03	0.48	0.29	190	2.89	0.05	0.80	0.48
Profile h = 0.85	347	56	198	3.53	0.03	0.48	0.29	194	3.47	0.05	0.78	0.47

Comparisons of the F benchmark relative to alternative reference points are shown in Table 5. The projection component implemented an approximation of the current 175-175 TAC for 2021-2030. Compared to 2020, the fishing mortality and spawning biomass increases and decreases, respectively, in all models with the ratio of the change larger as the unfished stock size is smaller and steepness is lower. In 2030, the forecasted $F/F_{0.1} < 1$ in 2030 in all cases, but $F/F_{50\%} > 1$ in the low steepness ($h < 0.6$) and Max. F = 6 scenarios. For biomass, SSB/SSB_{MSY} remains greater than one except in the low steepness ($h = 0.45$ and presumably lower values) scenario.

Table 5. Benchmark fishing mortality estimates relative to three spawning potential ratio reference points.

Model	$F_{benchmark}$	$F_{benchmark}$ / $F_{40\%}$	$F_{benchmark}$ / $F_{50\%}$	$F_{benchmark}$ / $F_{60\%}$
Reference model	0.051	0.53	0.86	1.25
Max. F = 1	0.036	0.37	0.59	0.87
Max. F = 6	0.059	0.61	0.98	1.44
SSF	0.027	0.27	0.44	0.65
SJR Dome	0.037	0.38	0.61	0.89
30% BOF	0.047	0.48	0.78	1.14
90% BOF	0.057	0.58	0.94	1.38
Profile h = 0.45	0.075	0.77	1.24	1.82
Profile h = 0.5	0.062	0.64	1.03	1.51
Profile h = 0.55	0.056	0.57	0.93	1.36
Profile h = 0.6	0.051	0.53	0.86	1.25
Profile h = 0.65	0.049	0.50	0.81	1.19
Profile h = 0.7	0.047	0.48	0.78	1.15
Profile h = 0.75	0.046	0.47	0.76	1.11
Profile h = 0.8	0.044	0.46	0.74	1.08
Profile h = 0.85	0.043	0.45	0.73	1.07

COSEWIC Considerations

Historical changes in the abundance of SJR sturgeon were estimated from the SS3 output, based on a mean generation time of 43 years. The change in abundance over three generations was calculated as the ratio of spawning stock numbers (SSN) in 2020 relative to that in 1891. The stock in 1891 was near its lowest, following the high catches in the 1880s. The stock is more abundant today, resulting in depletion ratios > 1 (Table 6). The ratio increases when either the steepness, the max. F, or the percent SJR origin of BOF catch increases.

Table 6. Estimates of historical (in 1891) and current (in 2020) spawning stock numbers (female, male, and both) from the suite of Stock Synthesis models.

Model	Female SSN_{2020}	Female SSN_{1891}	Female Ratio	Male SSN_{2020}	Male SSN_{1891}	Male Ratio	Total SSN_{2020}	Total SSN_{1891}	Total Ratio
Reference model	4113	1815	2.27	2506	1385	1.81	6619	3200	2.07
Max. F = 1	5751	3370	1.71	3487	2353	1.48	9238	5724	1.61
Max. F = 6	3622	1395	2.60	2205	1116	1.98	5827	2511	2.32
SSF	6472	4434	1.46	3579	1785	2.01	10051	6219	1.62
SJR Dome	4997	2450	2.04	3205	1876	1.71	8202	4326	1.90
30% BOF	5751	3370	1.71	3487	2353	1.48	9238	5724	1.61
90% BOF	3622	1395	2.60	2205	1116	1.98	5827	2511	2.32
Profile h = 0.45	2889	1824	1.58	1678	1387	1.21	4567	3211	1.42
Profile h = 0.5	3433	1819	1.89	2043	1385	1.48	5476	3204	1.71
Profile h = 0.55	3826	1816	2.11	2309	1385	1.67	6135	3201	1.92
Profile h = 0.65	4327	1815	2.38	2655	1386	1.92	6982	3201	2.18
Profile h = 0.7	4490	1815	2.47	2771	1386	2.00	7262	3201	2.27
Profile h = 0.75	4618	1815	2.54	2864	1387	2.06	7482	3202	2.34
Profile h = 0.8	4721	1815	2.60	2940	1388	2.12	7661	3203	2.39
Profile h = 0.85	4804	1815	2.65	3004	1389	2.16	7808	3204	2.44

Brownie Model

Tagging data collected during the commercial fishery provided an opportunity for a complementary assessment of the stock and subsequent comparison of models that used different data. The Brownie model (as cited in Hoenig et al. 1998) is an approach for estimating annual survival in a population from multiple years of tagged releases of animals and subsequent recaptures over time. The model’s flexible framework allows for modifications to relax and account for strict assumptions, such as immediate, complete mixing of the tags into the population and complete tag retention. The SJR Atlantic Sturgeon tagging dataset was processed into a set of releases and recaptures for analysis.

With M=0.06, the Brownie model estimated fishing mortality rates between 0.04–0.09 during 2009–2020. The trend in F increased steadily over time (Figure 13) from F = 0.04 to 0.07 between 2009 and 2019. In 2020, the F was lower due to the decreased number of recaptures relative to previous years. In 2016, the F peaked at 0.09, arising from a high number of recaptures of the 2016 tag cohort. The model fit was predominated by the within-year recaptures and the estimated latent effect for the within-year recaptures indicated much higher (6.41x) probability of capture. Between 1–3 years after release, the relative catchability is lower (< 1) and gradually increases. With fixed M=0.06, the estimated tag retention rate was 0.81. The joint likelihood profile of M and tag retention indicated very high correlation between the two parameters indicating that both parameters cannot be simultaneously estimated.

Compared to the SS3 model, the Brownie model does not need additional assumptions regarding historical depletion. Both models agree on the trend and magnitude in F, which gradually increased from 2009–2019 followed by a drop in 2020 due to lower catches in SS3 and fewer recaptures in the tag data. While there are notable uncertainties in the SS3 model, results from different models can provide insight on the plausibility of trends and magnitude of fishing mortality.

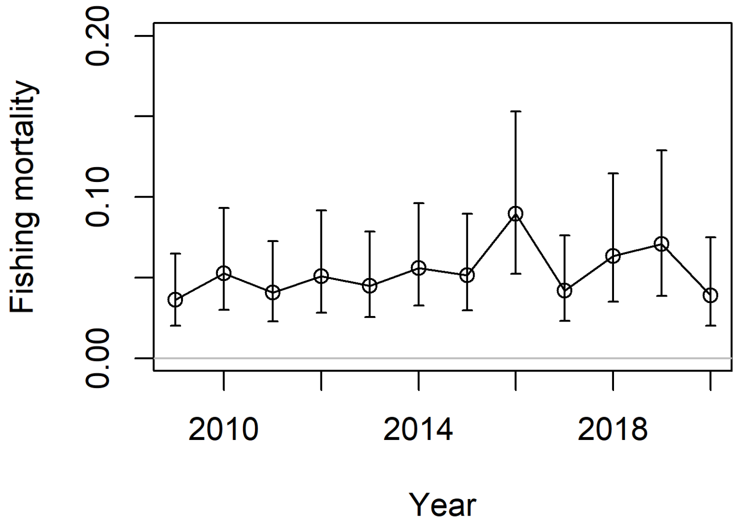

Figure 13. Time series of F estimates from the Brownie model, with error bars defining the 95% confidence interval of estimates.

Usefulness and Appropriateness of the Current June Closure to Protect Spawning Adults

Several information sources were examined to estimate the degree of overlap between the June closure and Atlantic Sturgeon spawning activity in the river, including information on body length, sex and gonad maturation of individual fish caught during commercial fishing, experimental fishing during June 2016 using the same gear and methods as utilized by the commercial fishery, commercial logbook data, and acoustic detections of 33 sturgeon tagged in the SJR and tracked from 2013-2020 (Tsitrin et al. 2021).

Annual observations of spent females in the commercial catches indicates that spawning was underway in the first week of July in all years. Residence time in the river for females was variable; some spawned and returned downstream relatively soon post-spawning but others were in the river for several weeks before or after spawning. Ripe females were present in Long Reach until mid-August. Using catch data from 2016 as a general model of the annual sturgeon run, males are initially more abundant in Long Reach until the beginning of June. Abundance was highest in mid-June as the number of females increased (Figure 14).

The June closure provides some early spawning sturgeon the opportunity to travel through Long Reach to their spawning location without interacting with the fishery and is effective in protecting some females while they enter the river and ripen prior to spawning. Female sturgeon are still ripening in July, and frequenting the area where the fishery occurs.

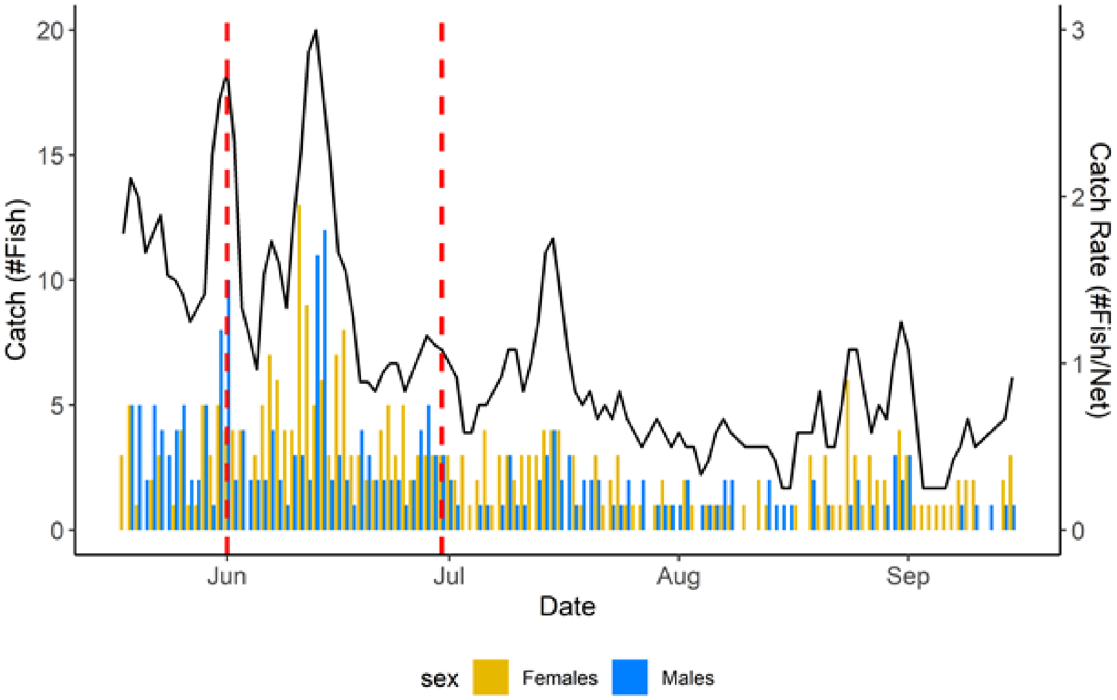

Figure 14. Three-day smoothed average of daily catch rates and numbers of males and females caught by gillnets in 2016 in Long Reach, Saint John River. Vertical red dashed lines indicate the start and end of the June closure.

Sources of Uncertainty

Various sources of uncertainty were identified that influenced how far this stock assessment model could be developed. For example, while the early historical fishery had a huge impact on this population, catch composition and selectivity information was not recorded at that time and so cannot be used to inform the model.

The most impactful changes to the model results arose from alternative assumptions of the catch history (over those for the index, composition, and tagging data It is also possible that the selectivity of the early fishery, before gillnet size restrictions were implemented, was different compared to the modern fishery. No data were available for this assessment to inform early selectivity.

Limited information is available to inform population resilience (i.e., steepness), which is needed to inform the development of reference points for this population. The stock-recruit parameters are influential in calculating biomass reference points as well as current depletion. While the unfished recruitment parameter is typically estimated, steepness is typically difficult to estimate in an age-structured model, and no prior information was available to inform this assessment. A value of 0.6 was initially chosen in the reference model using a relatively low value that reflects the late maturity and potentially lower resilience of Atlantic Sturgeon relative to taxa with early-maturity and higher resilience.

The stock-recruit relationship is invariant to spawning frequency and movement so long as these processes are time invariant.

The SS3 model did not fit the CPUE index (the in-river component of the stock) well, which could be due to a number of factors, including the fact that the model attempts to represent the full population (i.e., not just the in-river component). Estimates of abundance and biomass are of the closed population, which includes the residents and active spawners in the SJR, as well as migrating individuals and inactive spawners outside the river. Abundance estimates of active spawners in the SJR would require assumptions regarding movement or spawning frequency.

Future improvements could be made both to the model (and how it handles the CPUE index), and to the CPUE index itself, independent of the model, including addition of other environmental variables (e.g., better metrics of water flow conditions). Improvements to the CPUE index could be helpful for use of the CPUE index to inform the assessment, either as a stand-alone index or within the model. Development of a fishery independent index would helpful for the assessment and from a model development perspective (e.g., to inform logistic versus domed selectivity).

Impacts of climate change have been observed in recent years, for example, lower catch rates and earlier spawning in 2020 were attributed to two years of spring flooding followed by a year of low water flow in 2018-2020. Atlantic Sturgeon has been assessed as highly vulnerable to climate change in the US (Hare et al. 2016). It is recommended that environmental data, for example, water flow and temperature data from the nearby hydrometric station at Oak Point maintained by Environment Canada and Climate Change be included in future assessment development.

CONCLUSION

Almost all models explored here showed that the stock was in the healthy zone (above SSB_{MSY}) in 2020 and would remain above SSB_{MSY} with the current TAC. Only in low steepness scenarios (h=0.45 and lower values) would the stock be below SSB_{MSY}. The alternative historical catch scenarios did not alter the current stock status relative to SSB_{MSY}. In essence, the stock is above SSB_{MSY} since current catches are lower compared to the early years of the fishery.

Projecting the model until 2030 indicates that the population is expected to remain in the healthy zone with the current TAC of 175 males and 175 females. Only in low steepness scenarios (h = 0.45 and lower values) would the stock be below SSB_{MSY}.

The June 1–June 30 closure provides sturgeon the opportunity to travel through Long Reach to their spawning location unimpeded and is effective in protecting some females while they enter the river and ripen prior to spawning.

LIST OF MEETING PARTICIPANTS

Name	Affiliation
Rod Bradford	DFO Maritimes Science
Cornel Ceapa	Atlantic Sturgeon & Caviar
Matthew Cieri	Dept of Marine Resources, State of Maine (Reviewer)
Michael Dadswell	Acadia University
Sarah Deller	DFO Maritimes Aquatic Ecosystems Management
Guy Verreault	Bureau d'écologie appliquée (COSEWIC writer)

Name	Affiliation
Luke Finley	Atlantic Sturgeon Fishery
William Ford	Atlantic Sturgeon Fishery
Quang Huynh	Blue Science Matters
Aruna Jayawardane	Maliseet Nation Conservation Council
Tamara Joseph	Mi'gmawe'l Tplu'taqnn Incorporated
Tara McIntyre	DFO Maritimes Science
Koren Spence	DFO Maritimes Resource Management
Greg Stevens	DFO Maritimes Resource Management
Brady Stevenson	DFO Maritimes Resource Management
Michael Stokesbury	Acadia University
Andrew Taylor	DFO Maritimes Science (Reviewer)
Daphne Themelis	DFO Maritimes Science
Liza Tsitrin	DFO Maritimes Science
Tana Worcester	DFO Maritimes Science

SOURCES OF INFORMATION

This Science Advisory Report is from the March 23-24, 2021, regional advisory meeting on the Assessment of the Status of the Spawning Population of Saint John River Atlantic Sturgeon (*Acipenser oxyrinchus*). Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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Center for Science Advice (CSA)
Maritimes Region
Fisheries and Oceans Canada
Bedford Institute of Oceanography
1 Challenger Drive, PO Box 1006
Dartmouth, Nova Scotia, B2Y 4A2

E-Mail: DFO.MARCSA-CASMAR.MPO@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

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