Survival and Seasonal Movements of Adult Saint John River Atlantic Sturgeon Exposed to Commercial Fishing

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2021

Canadian Technical Report of Fisheries and Aquatic Sciences 3418

Fisheries and Oceans Canada   Pêches et Océans Canada

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Canadian Technical Report of Fisheries and Aquatic Sciences

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Cat. No. Fs-97-6/3418E- PDF ISBN 978-0-660-37342-3 ISSN 1488-5379

Correct citation for this publication:

Tsitrin, E., Crawford, K., Clark, C.M., Themelis, D., and Bradford, R.G. 2021. Survival and seasonal movements of adult Saint John River Atlantic Sturgeon exposed to commercial fishing. Can. Tech. Rep. Fish. Aquat. Sci. 3418: iv + 55 p.

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ABSTRACT

Tsitrin, E., Crawford, K., Clark, C.M., Themelis, D., and Bradford, R.G. 2021. Survival and seasonal movements of adult Saint John River Atlantic Sturgeon exposed to commercial fishing. Can. Tech. Rep. Fish. Aquat. Sci. 3418: iv + 55 p.

The Maritimes population of Atlantic Sturgeon has a single known spawning site in the lower Saint John River, New Brunswick. We used acoustic tracking data from 33 tagged individuals between 2013 and 2020 to estimate spawning periodicity, survival, and potential exposure of sturgeon to the commercial fishery during their breeding season. Spawning periodicity varied from one to four years for males, and one to six years for females, on the assumption that all acoustically-tagged adult fish re-entered the Saint John River for no other purpose than to spawn. A higher proportion of tagged males were detected, despite near-equal sample sizes (16 tagged females, 17 tagged males) and a higher catchability of females in the commercial fishery. We tested Cormack-Jolly-Sever (CJS) and Burnham live-dead models to estimate survival, the latter of which includes observations of known mortalities. The CJS model estimated a 94% apparent survival, while survival in the Burnham model was time-dependent. Further expansion of telemetry methods in the Saint John River are required to address the lack of quantitative data on population size and responses to exploitation.

RÉSUMÉ

Tsitrin, E., Crawford, K., Clark, C.M., Themelis, D., and Bradford, R.G. 2021. Survival and seasonal movements of adult Saint John River Atlantic Sturgeon exposed to commercial fishing. Can. Tech. Rep. Fish. Aquat. Sci. 3418: iv + 55 p.

La population d’esturgeon noir des Maritimes n’a qu’une seule frayère connue dans le fleuve Saint-Jean, au Nouveau-Brunswick. Nous avons utilisé les données d’un suivi acoustique recueillies entre 2013 et 2020 à l’égard de 33 individus marqués afin d’estimer la périodicité du frai, le taux de survie, et l’exposition potentielle des esturgeons à la pêche commerciale pendant leur période de reproduction. Les esturgeons noirs mâles avaient une périodicité de frai de deux à trois ans, alors que celle des femelles était de deux à quatre ans, à condition que tous les retours dans le fleuve étaient pour seule raison de frayer. Une plus grande proportion de mâles a été détectée malgré l’utilisation d’échantillons de taille égale (16 femelles marquées, 17 mâles marqués) et une plus grande capturabilité des femelles dans la pêche commerciale. Nous avons testé les modèles de Cormack-Jolly-Seber (CJS) et de Burnham pour estimer le taux de survie, le dernier modèle comportant des observations de mortalités connues. Le modèle CJS nous a permis d’estimer un taux de survie de 94%, alors que la survie variait selon le temps dans le modèle de Burnham. L'amélioration des suivis télémétriques dans le fleuve Saint-Jean permettra de remédier au manque de données quantitatives à l’égard de la taille de la population et des réactions de celle-ci face à l’exploitation.

1. INTRODUCTION

The Atlantic sturgeon, *Acipenser oxyrinchus oxyrinchus*, is a demersal, anadromous fish found along the Atlantic coast of North America, from the southern United States to Labrador (Scott and Scott, 1988). Two genetically distinct spawning populations occur in Canada in two watersheds: the Saint Lawrence River, QC, and the Saint John River, NB (COSEWIC 2011; DFO 2013). The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2011 defined these populations as the Maritimes Population Designatable Unit (DU) and Saint Lawrence River (Saint Lawrence River DU) respectively (COSEWIC 2011). The Maritimes Population DU, the focus of this study, was designated as Threatened (COSEWIC 2011) on the basis of its small breeding population (estimated to be in the low thousands), an restricted spawning location (a relatively small area within the lower Saint John River), and because of uncertainty about the impact of the commercial sturgeon fishery on the health of the population.

The commercial fishery is authorized to harvest sturgeon over 130 cm total length, and is therefore effectively a fishery on adult sturgeon migrating up the river to spawn. It began as an intense and mainly unregulated gillnet-based fishery in 1880 that collapsed seven years later (Bradford et al. 2016). Since re-opening in 1897, landings have remained low, averaging 9 metric tons from 1965-2009, with a peak at 41 t in 1988 and 1989 (DFO 2013, Bradford et al. 2016). A limited entry fishery with non-transferrable licenses, the total number of license holders had declined to two from ten by the mid 1980s (Bradford et al. 2016). The fishery is managed by daily reporting of fishing activities and outcomes (Dockside Monitoring Companies), mandatory logbook reporting, a closure during June to coincide with the peak in the upriver spawning migration, a Total Allowable Catch (TAC) of 350 sturgeon, and a 50:50 sex ratio for the landed catch. Fishing ceases once 175 males or 175 females have been landed.

Following the designation by COSEWIC and consequent consideration for listing under the Species at Risk Act, fishery managers required information to evaluate the conservation risks of maintaining the commercial fishery. Evaluating fishery impacts is challenged by the species life history and associated variation in susceptibility to capture. Atlantic Sturgeon are long-lived and may spawn multiple times in their lifetime, but not every year, and the spawning periodicity of the SJR population, and whether spawning periodicity differs between males and females, are not well-understood (Smith 1985, Taylor and Litvak 2017). The fishery selects fish to maximize meat and caviar production within the TAC, therefore, a portion of the fish caught are considered unsuitable for harvest and released (Cornel Ceapa, Acadia Sturgeon and Caviar, Carters Point, N.B.; pers. comm.). These fish are assumed to survive, but post-release impacts on their behaviour, including reproductive behaviour, are unknown.

This study was initiated to better understand the nature of the interaction between adult Atlantic Sturgeon and commercial gill nets designed specifically to catch sturgeon, and the fate of fish returned to the wild following capture. Ultrasonic transmitters with a longevity of six to seven years were deployed in 33 adult sturgeon, with an approximate 50:50 sex ratio, captured during the commercial fishery in 2013 (n=17), 2014 (n=15) and 2016 (n=1). Sturgeon were tracked using hydrophone receivers dedicated to each of the commercial fixed gillnets, and through opportunistic detections at hydrophones deployed both within the Saint John River and the Bay of Fundy-Gulf of Maine by other investigators. The study accordingly allows for estimation of the frequency of spawning and annual survival of individual male and female sturgeon.

2. METHODS

2.1 Study Location

This study was conducted on the Saint John River in New Brunswick, the only location where Atlantic Sturgeon are presently fished for commercial purposes in the Canadian Maritime Provinces. The Saint John River's headwaters are in Quebec and northern Maine, and the river extends 700 km to its mouth at Saint John Harbour. Ascent of Atlantic sturgeon is presently limited to River Kilometer (RK) 140 owing to the presence of the impassable Mactaquac Dam that was constructed in 1968 a short distance upstream of the limit of tidal influence (Kidd et al. 2011). The study site, referred to as Long Reach, is a 31-km section of the Saint John River that stretches roughly from Grand Bay-Westfield (RK18) to Evandale (RK49) (Figure 1). Long Reach varies between 430 m to 2800 m in width, and has a mean depth of 10.2 m and a maximum depth of 42.1 m (Carter & Dadswell 1983). While Long Reach is within the bounds of the spawning area described in DFO (2013), from the Mactaquac Dam to Reversing Falls, bottom salinities that are higher than the optimal (0 parts per thousand (ASMFC 2012)) for egg incubation prevail in this section of the river. Long Reach is accordingly considered to be an avenue for Atlantic Sturgeon migration to and from freshwater spawning areas.

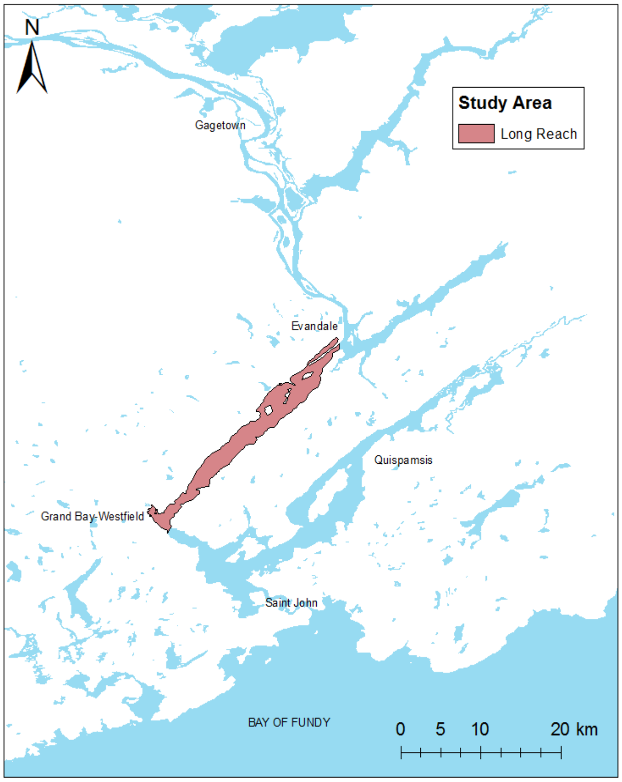

Figure 1. Map of the Saint John River, with the study area (Long Reach) highlighted in red.

2.2 Acoustic Tagging

Thirty-three Atlantic Sturgeon were collected from the commercial gillnet fishery (330 mm minimum stretch mesh size) deployed at seven locations in Long Reach (Figure 2) during 2013 (n =15, 8 female, 7 male) and 2014 (n =17, 8 female, 9 male) (Fig. 3).

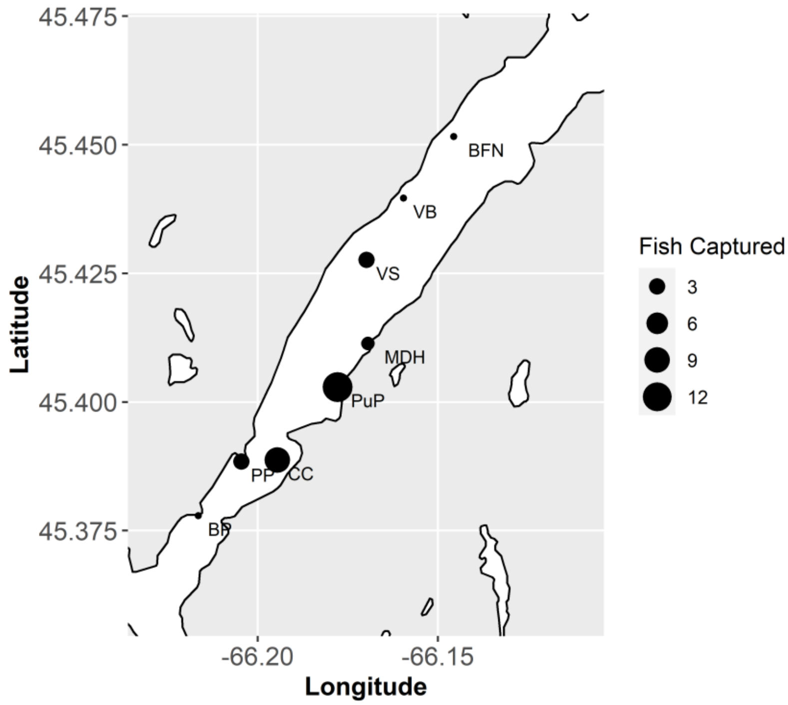

Figure 2. Map of locations at which Atlantic Sturgeon were captured prior to tagging. Point size proportional to the number of sturgeon captured at each location.

First, animals were transported to a holding facility by boat, out of water but covered with a heavy, continuously wetted absorbent cloth, as is the practice for the transport of all commercially caught fish retained either to supply a commercial hatchery or for processing. Each fish was measured to total length (TL), sexed, and surgically implanted with individually coded V16-6L transmitters (69 kHz, Vemco Ltd., Nova Scotia) with an manufacturer defined battery life of 2516 days. The transmitters measured 16 mm by 95 mm, weighed 14.9 g in water, and had a power output of 158 dB/1uPa at 1m, with a random nominal delay of 50-13 sec. Following surgeries, sturgeon were held overnight and then released from Carter's Cove (CC in Figure 2).

Two tags were repurposed from fish tagged in 2013 that were captured as mortalities in the commercial fishery in 2014. An additional tag from a recaptured sturgeon, initially tagged in 2014, was redeployed in 2016 (Fig. 3). The distribution of tagging days is evident from Figure 6.

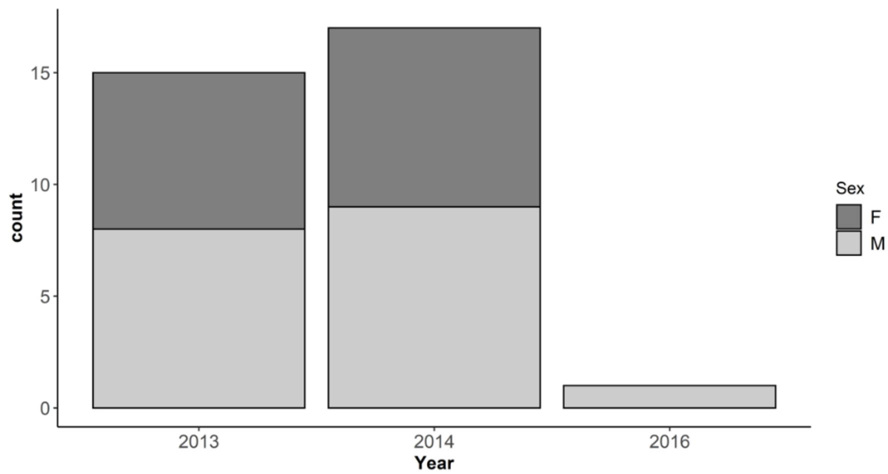

Figure 3. Proportion of male and female Atlantic Sturgeon tagged by year. A total of 18 males and 15 females were caught and tagged during the study.

The length distribution of the tagged sturgeon was generally representative of the commercial catch (Fig. 4) but tagged female sturgeon were all ≤ 2 m TL, compared to the maximum size of 2.5 m recorded in the fishery (Fig. 4). Males were generally smaller than females, with the exception of one male sturgeon measuring nearly 2 m.

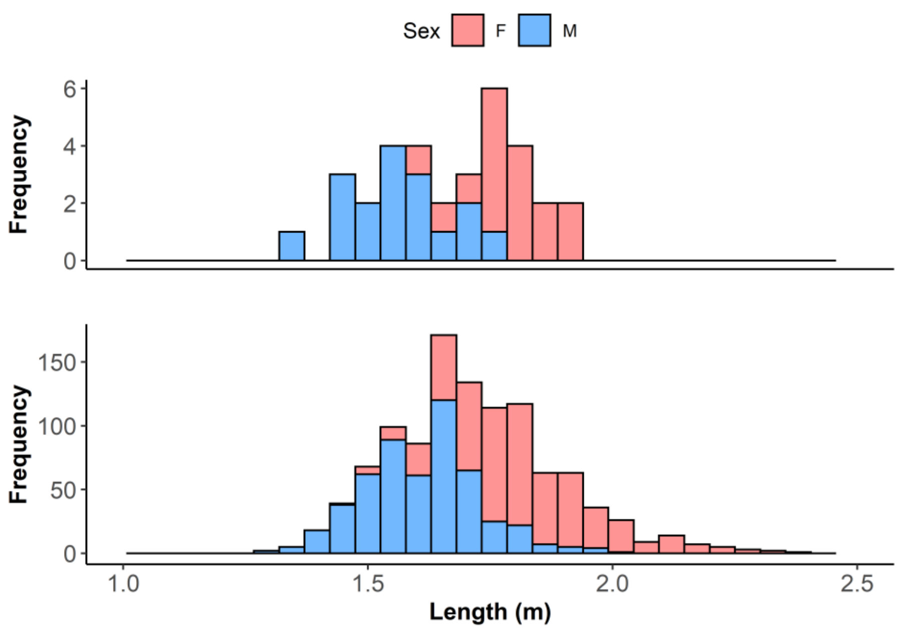

Figure 4. Length distributions of male and female Atlantic Sturgeon tagged in the study (top) compared to the 2013-2014 commercial fishery catches (bottom).

2.3 Receiver Deployments

Innovasea VR2W receivers (Innovasea, Nova Scotia, Canada) were moored next to fishing nets during the fishing seasons from 2013 to 2020 (Table 1; Fig. 5). These were deployed at or before the onset of commercial fishing each year, and were recovered at the end of the fishing season, between mid-August and mid-September. Additional receivers were deployed within the Saint John River, including Long Reach, by researchers from Mount Allison University (MtA) in New Brunswick (Dadswell et al. 2010) and in Saint John Harbour during the months of May to September by DFO (Hardie 2017). Duration of receiver deployment periods varied between years (Table 2).

Table 1. Receiver sites in Long Reach. Distance in river kilometre (RK) is given upriver from Reversing Falls. Y indicates hydrophone present at a given location in a given year; N indicates no hydrophone was present. DFO receiver metadata was incomplete for 2015, and some receivers locations could not be resolved(N/A).Owners: Fisheries and Oceans Canada (DFO); Mount Allison University (MtA).

Owner	RK	Site Name	2013	2014	2015	2016	2017	2018	2019	2020
DFO	0	SJR Harbour	N	N	N	N	Y	Y	N	N
DFO	20	PP	Y	Y	Y	N	Y	Y	Y	Y
DFO	21	CC	Y	Y	N/A	N	N	N	N	Y
DFO	22	Unnamed	N	N	N/A	Y	N	N	N	N
DFO	22	CH	N	N	N/A	N	N	Y	Y	Y
DFO	23	PuP2	N	N	N/A	Y	N	Y	Y	N
DFO	23	PuP	Y	Y	N/A	N	N	N	N	N
DFO	24	MDH	Y	Y	Y	Y	Y	Y	Y	Y
DFO	25	VS	Y	Y	N/A	Y	Y	Y	Y	Y
DFO	27	VB	Y	Y	Y	N	Y	Y	Y	N
DFO	29	BFN	Y	Y	Y	N	N	N	N	N
MtA	15	J28	Y	Y	Y	N	N	N	N	-
MtA	15	J29	N	N	N	Y	Y	Y	Y	-
MtA	18	J40	Y	Y	N	N	N	N	N	-
MtA	21	J41	N	N	Y	Y	N	N	N	-
MtA	29	J42	N	Y	Y	Y	Y	Y	Y	-
MtA	34	J47	Y	N	N	Y	N	N	N	-
MtA	36	J54	N	Y	Y	Y	Y	N	Y	-
MtA	40	J66	Y	Y	N	Y	Y	Y	Y	-

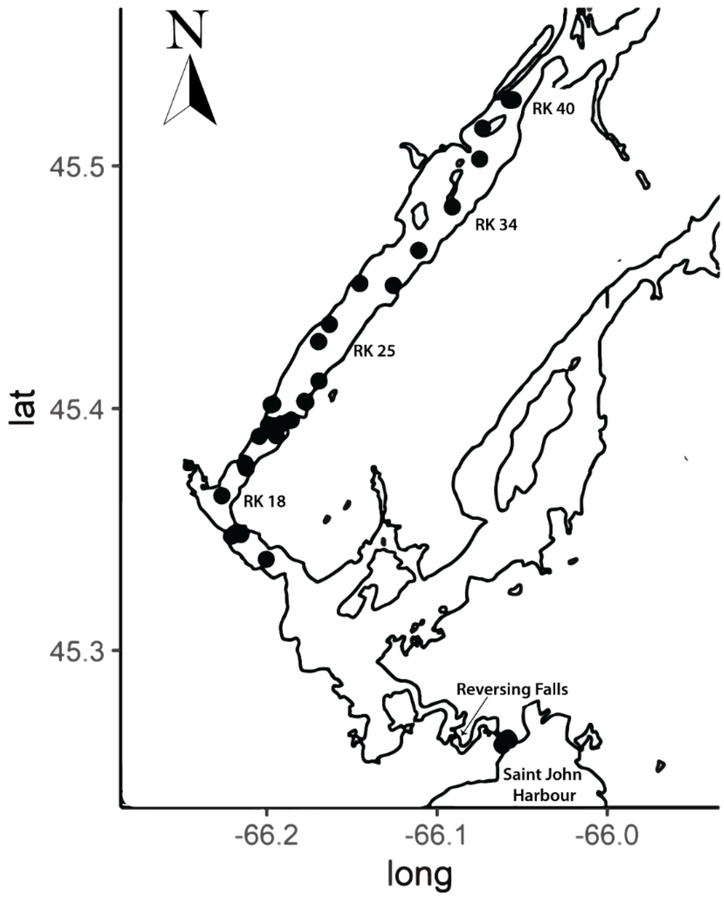

Figure 5. Locations of DFO and Mount Allison University receiver stations in Long Reach. Distance in river kilometre (RK) is given upriver from Reversing Falls.

Table 2. Deployment and recovery dates of hydrophones belonging to Fisheries and Oceans Canada (DFO) and Mount Allison University (MtA) compared to duration of commercial fishing from 2013 to 2020.

Year	DFO Deployment	DFO Recovery	MtA Deployment	MtA Recovery	Fishery Start	Fishery End
2013	05/16*	09/01	05/19 - 08/20	11/11	05/13	08/07
2014	05/27	09/15	07/01	10/05	05/22	08/15
2015	07/02	08/31	05/20 - 07/29	NA	05/26	08/08
2016	05/27	09/22	04/21 - 05/27	11/10	05/18	09/15
2017	06/01	09/03	-	-	05/23	08/03
2018	05/25	08/30	06/17 - 07/05	**	05/23	08/16
2019	05/28	08/31	**	11/22	05/22	08/23
2020	05/24	09/10	-	-	05/18	09/12

* based on earliest detection

** receivers were downloaded but remained deployed at their stations into 2019

2.4 Data Acquisition and Analysis

Telemetry data were organized into three file types: transmitter and receiver deployment metadata, and receiver download files (downloaded using Vue software, Innovasea, Nova Scotia, Canada). The receiver download files for all years were merged into a single database in 'R' to facilitate the creation of a chronological detection history for each of the tagged Atlantic Sturgeon, and to summarize detection results from various receivers.

Additional detection data of the 33 fish in this study were sourced from datasets uploaded to the Ocean Tracking Network (OTN) website. These included data sourced from receivers deployed year-round at locations within the Saint John River by Mount Allison University, the University of New Brunswick, and DFO (Currie et al. 2010, Taylor and Litvak 2017, Hardie 2017), receivers deployed year-round within the Minas Basin by Acadia University and the Marine Institute of Natural and Academic Science (MINAS) (Stokesbury et al. 2009; Dadswell et al. 2010; Dadswell and Porter 2017), receivers deployed from late March to November on the inter-annual fixed location array OTN Minas Passage Line by Acadia University (Stokesbury et al. 2009), receivers deployed by the Fundy Ocean Research Centre for Energy (Scotney et al. 2017), as well as receivers deployed in Passamaquoddy Bay (Trudel et al. 2018), Musquash Harbour (Bradford & LeBlanc 2012), coastal Nova scotia (Reid 2017; Bowlby, Canadian Atlantic Shark Research Laboratory, Fisheries and Oceans; pers. comm.), Cape Cod (Buchan; pers. comm), Casco Bay (Hawkes, NOAA; pers. comm), and Massachusetts Bay (Hawkes, NOAA; pers. comm) for other projects.

All statistical analyses were conducted in the program R (version 4.0.2; R Foundation for Statistical Computing Platform 2020). Preliminary screening of the data was conducted using the GLATOS package (Great Lakes Acoustic Telemetry Observation System; Binder et al., 2018); data were filtered to eliminate false detections based on the minimal tag delay. The filtered DFO and external detections were combined into one dataset that was used for further analysis. Data from the commercial fishery were obtained in the form of fishery logs for each year of the study.

2.4.1 Processing of Acoustic Data

The presence of Atlantic Sturgeon in Long Reach was examined for each year of the study based on arrival times, mean residence time (in days), as well as proportion of detections by month, sex, and distance in river kilometres (RK) upriver from Reversing Falls. In order to eliminate bias caused by some animals spending prolonged periods of time within detection range of a single receiver (thereby resulting in a large number of detections at one location), raw detections were distilled into detection days, either by individual or by location, depending on the type of analysis being performed. A detection day by an individual was defined as a day when a given sturgeon was detected at least once; a detection day by station was defined as a day when at least one sturgeon was detected at that location (Redden et al. 2014, Sanderson et al. 2017).

Mean annual detection days were normally distributed (Shapiro-Wilks test: W= 0.908, p=0.11). An Independent Samples T-Test was applied to assess whether detection frequency differed between sexes, given that the commercial catch data (landed and released fish) indicates that the catchability of sturgeon in the commercial fishery differs between female and male spawners (DFO 2013).

Capture probability p_i in a given year was calculated as:

$$p_i = \frac{m_i}{M_i}$$

where *i* is a given sampling year, *m* is the number of acoustically tagged Atlantic Sturgeon that were captured by the commercial fishery in year *i*, and *M* is the total number of acoustically tagged sturgeon that were detected within the study area during the fishing season. We did not consider fish that were marked and recaptured in the same year as recaptures. Fish that were recaptured multiple times in one year were only counted as a single capture.

2.4.2 Survival Analysis

The Cormack-Jolly-Seber (CJS) model (Cormack 1964; Jolly 1965; Seber 1965) was applied to estimate the apparent survival of tagged sturgeon in years following release. The CJS model only incorporates data obtained from discrete mark–recapture (acoustic detection) events, and provides estimates of two parameters: the apparent survival (Φ) from year i to $i + 1$, and the probability (*p*) of being detected in year i conditional on surviving. Detection probability for any given year is given as:

$$\widehat{p_i} = \frac{r_i}{r_i + z_i}$$

where r_i is the number of fish detected in years following year *i* that were also detected in year i, and z_i is the number of fish that were not detected in year i but were detected in following years. Annual survival (from year i to $i + 1$) is given as:

$$\hat{S}_{i-1} = \frac{\widehat{M}_i}{\widehat{M}_{i-1}}$$

where $\widehat{M}_i$ estimates the number of fish alive in year i based on the number detected divided by the detection probability. The apparent survival probability is thus the estimated number of fish alive in year i divided by the estimated number of fish alive in the previous year, $i - 1$. Fork length and sex were included as covariates to test their effects on survival. Models also allowed detection probability and survival to vary temporally. Candidate models were compared using the Akaike Information Criterion (AICc) and AICc weights. Models were constructed using the program MARK (White and Burnham 1999) within the RMark package (Laake 2013).

Apparent survival estimates from CJS models fit only to the Long-Reach data were compared with estimates derived from models that included all known detections (including far-field detections). Both datasets were used to estimate survival from the Burnham model (Burnham 1993), which provides consideration of known mortalities, in this case recovered transmitters from the commercial fishery, by estimating four parameters: survival (*S*), live re-encounter (*p*), dead encounter (*r*) and fidelity (*F*). The definitions of probabilities *S* and *p* are equivalent to Φ and *p* from the standard CJS model. The dead encounter probability *r* is defined as the probability that an animal that died between occasions i and $i+1$ is both found and reported. The parameter *F* is defined as the probability than an animal available at time i will still be available at time $i+1$. We allowed *p* to vary temporally due to variable tracking effort, and fixed *F* to1 because, despite variability in spawning, we expect sturgeon from this population to eventually return to the Saint John River. Model structures for *S* included a null effect (intercept only), temporal variation, length and sex, considered individually and in additive combinations.

2.4.3 Behaviour Analysis

Commercial logbook data were consulted in order to identify recaptures of individual acoustic-tagged fish. The receiver data associated with the nets where recaptures occurred were then used to estimate post-release residency of these fish in the proximities of the nets. Detections that occurred within one hour of each other were grouped into detection events, with the number of detections and distance traveled averaged for each event to estimate the relative activity levels of sturgeon post-release.

3. RESULTS

3.1 Long Reach Detections

Detection histories were generally consistent with the *a priori* expectation that spawning adults would be present from about mid-to-late May until late-August to early-September (Table 3). Detections in the upper portion of the river, where spawning is assumed to take place, generally occurred from mid-June to late-August. Males generally appeared in the lower reaches of the Saint John River and Long Reach earlier than females, however females were detected upstream of Long Reach earlier than males (Table 4). The difference between the number of detection days for males and females is further examined in section 3.2. 2018 had the earliest recorded first detection of tagged Atlantic Sturgeon over the study period (25 April), however the earliest detection in Long Reach was May 4 in 2016. This was also the year with the earliest known receiver deployments. Figure 6 shows the proportion of individual Atlantic Sturgeon detected each year based on their first detection in Long Reach; animals were excluded from the year that they were tagged, as their arrival dates are not known.

Table 3. Annual dates of first and last detection, mean residence time (days), number of Atlantic Sturgeon detected, total number of detection days, and earliest known receiver deployment date by relative location in the Saint John River (SJR). Locations: Lower SJR (RK < 15), Long Reach (RK 15-40), and Upper SJR (RK > 40). Receiver deployment metadata are incomplete for some stations, therefore discrepancies between deployment and first detection are possible. Tagging events are excluded.

Year	Relative location	First detection	Last detection	Mean residence (days)	No. Individuals	No. Days	First known deployment
2013	Lower SJR	-	26 Sep	0	13	15	*
2013	Long Reach	-	1 Sep	48	14	108	*
2013	Upper SJR	30 May	25 Aug	29	4	25	*
2014	Lower SJR	29 May	25 Sep	9	17	31	*
2014	Long Reach	3 Jun	24 Sep	53	19	101	May 27
2014	Upper SJR	11 Jun	21 Sep	36	14	97	*
2015	Lower SJR	7 May	23 Dec	59	8	29	*
2015	Long Reach	20 May	14 Aug	59	4	66	May20
2015	Upper SJR	10 Jun	13 Aug	53	3	65	*
2016	Lower SJR	10 Apr	23 Aug	44	11	69	*
2016	Long Reach	4 May	22 Aug	54	8	109	April 21
2016	Upper SJR	15 May	21 Aug	50	7	92	*
2017	Lower SJR	15 May	27 Nov	65	11	56	May 4
2017	Long Reach	22 May	11 Nov	56	10	79	June 1
2017	Upper SJR	1 Jun	21 Aug	49	9	82	*
2018	Lower SJR	25 Apr	17 Aug	53	8	64	May 10
2018	Long Reach	26 May	7 Aug	47	7	60	May 25
2018	Upper SJR	30 May	3 Aug	33	7	66	*
2019	Lower SJR	9 May	30 Aug	24	7	15	**
2019	Long Reach	21 May	29 Aug	52	7	57	**
2019	Upper SJR	23 May	25 Aug	51	6	81	**
2020	Lower SJR	-	-	-	-	-	-
2020	Long Reach	25 May	11 Aug	50	5	14	May 24
2020	Upper SJR	-	-	-	-	-	-

** deployment data missing*

*** receivers present all year*

Table 4. Average timing of first and last detections and mean residence time in days of male (M) and female (F) Atlantic Sturgeon across all study years (tagging events excluded), based on relative location (as defined in Table 3) in the Saint John River (SJR).

	Lower SJR		**Long Reach**		**Upper SJR**	
	M	F	M	F	M	F
Average first detection	May 20	June 4	June 1	June 6	June 10	June 8
Average last detection	July 13	July 17	July 24	July 25	July 27	July 21
Average residence (d)	7	7	13	21	36	31

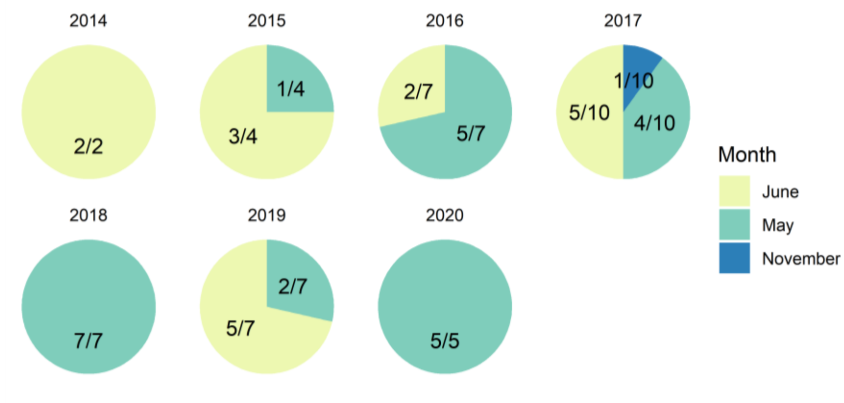

Figure 6. Proportion of first detections by month for tagged Atlantic Sturgeon returning to Long Reach.

Where data were available from receivers deployed in the SJR harbour by other research projects (Hardie 2017), it was evident that Atlantic Sturgeon spent 1-12 days in the harbour during the months of May and June before moving further upstream, compared to only one day in the months of July and August, presumably during their seaward migration (Table 5). The number of sturgeon present in the harbour increased through late-May to early-June, and subsequently declined after mid-June as sturgeon swam further upstream (Fig. 7).

Table 5. Average annual number of Atlantic Sturgeon detection days and number of individuals detected by month in the Saint John River harbour from 2017 to 2019.

Year	Month	Detection Days	Individuals	Males	Females
2017	May	2	8	3	5
2017	June	3	3	2	1
2017	July	1	3	1	2
2018	May	8	7	3	4
2018	June	3	5	2	3
2019	May	3	5	2	3
2019	June	2	3	2	1
2019	July	1	1	1	0
2019	August	1	3	2	1

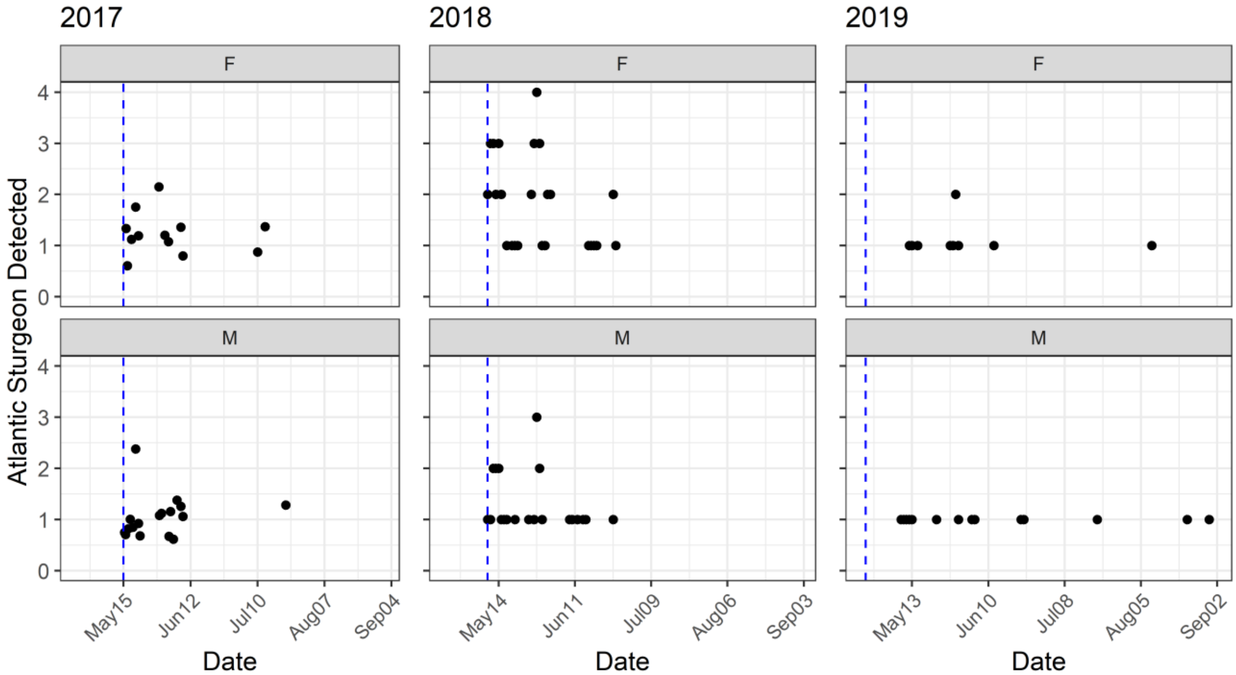

Figure 7. Presence of Atlantic Sturgeon in the Saint John River harbour between 2017 and 2019. Blue lines indicate receiver deployments.

Individual detection histories (Fig. 8) indicated that, with the exception of one male sturgeon (Unique ID 7), all animals were detected at least once in the Long Reach study area following release, with most being detected in years subsequent to tagging. Of the 15 sturgeon tagged in 2013, two were detected again in Long Reach the following year, and four in 2015. Fish tagged in 2014 were not detected in 2015, but five were detected in 2016. One female (Unique ID 14) tagged in 2013 was not detected again until 2019, and three females returned to Long Reach two years after being tagged (Fig. 9). In general, tagged males returned to the Saint John River more frequently than females; most males were detected in Long Reach within two or three years of their initial capture, while females were most often detected after two to four years (Fig. 10).

Figure 8. Abacus plot illustrating location (river kilometre (RK)) of individual sturgeon detected in Long Reach throughout the study period. Black squares indicate when each fish was initially tagged and released. Red stars indicate known mortalities in the commercial fishery.

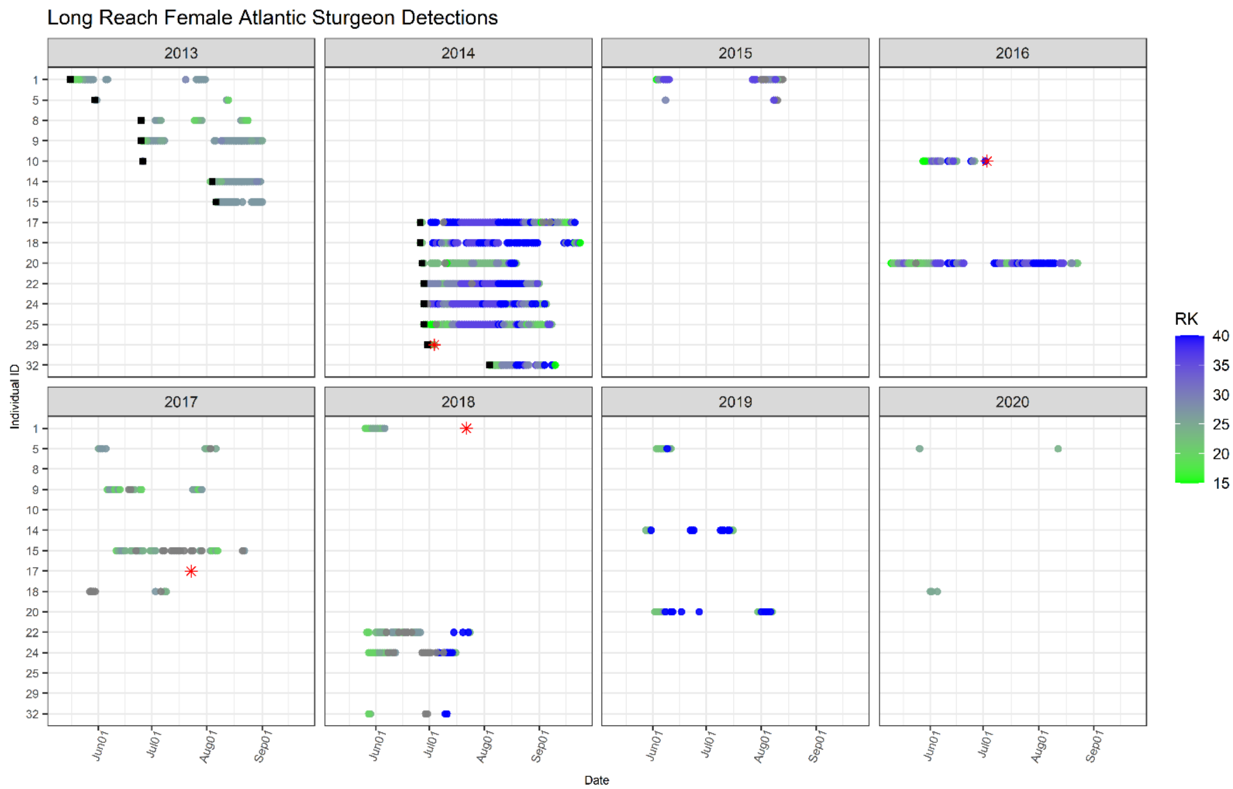

Figure 9. Abacus plot illustrating location (river kilometre (RK)) of individual female Atlantic Sturgeon detected in Long Reach throughout the study period. Black squares indicate when each fish was initially tagged and released. Red stars indicate known mortalities in the commercial fishery.

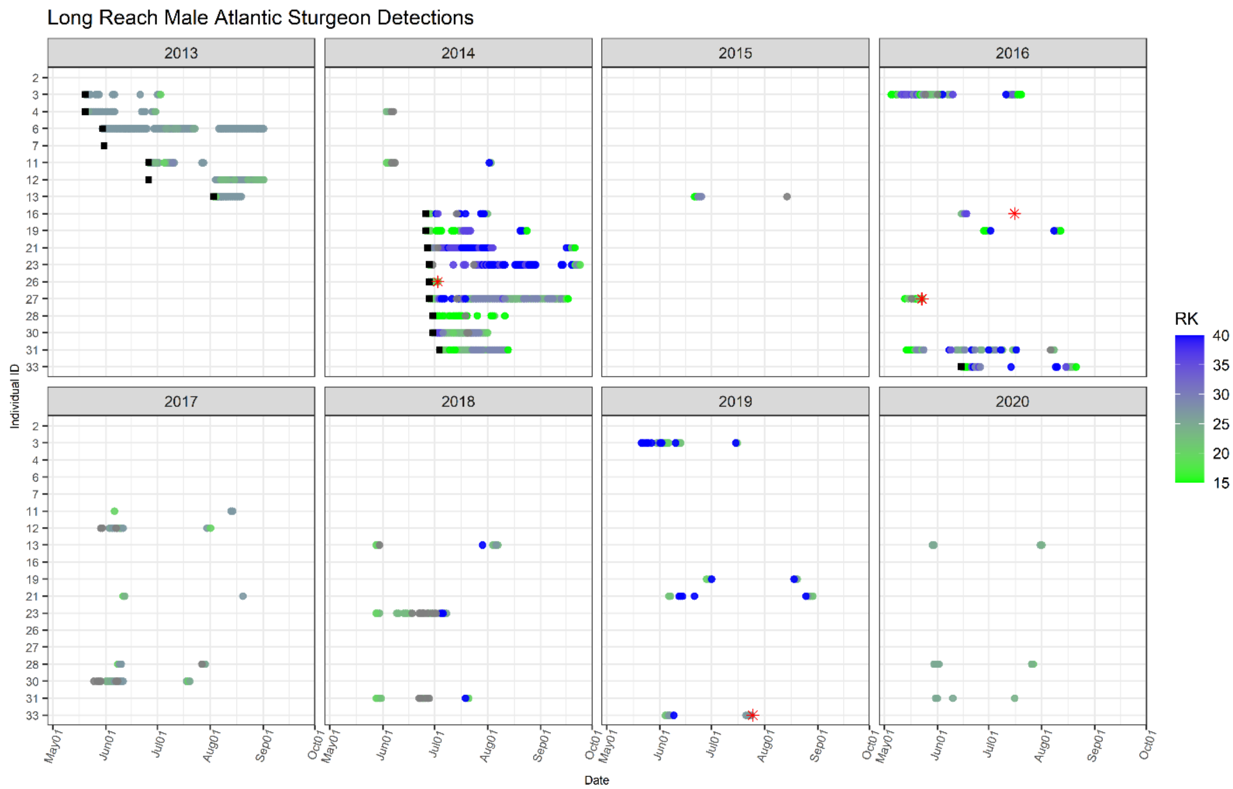

Figure 10. Abacus plot illustrating location (river kilometre (RK)) of individual male Atlantic Sturgeon detected in Long Reach throughout the study period. Black squares indicate when each fish was initially tagged and released. Red stars indicate known mortalities in the commercial fishery.

The distribution of detection days was generally uniform across receiver stations in each year of the study (Fig. 11). The exception was 2015, when a higher proportion of detection days was recorded on one of the central receivers, however, this may have been a consequence of the uneven distribution of sampling effort in that year, as some receivers were deployed late in the season. The movements of sturgeon between receiver stations as they related to the annual commercial fisheries are further examined in section 3.5.

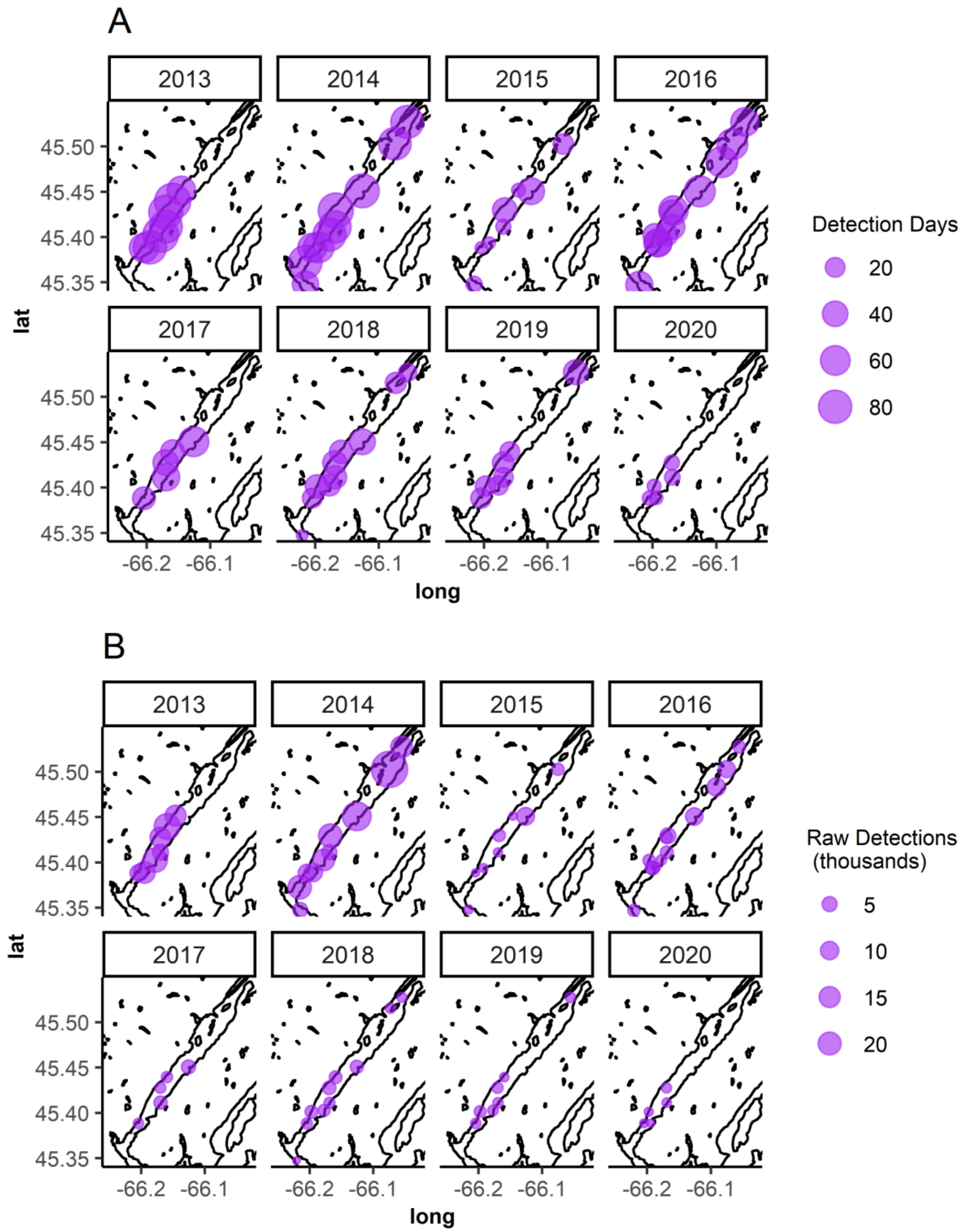

Figure 11. Distribution of detection days (A) and raw detections (B) in Long Reach by year. The point size is proportional to the number of Atlantic Sturgeon detections that were made at each location.

3.2 Availability to the Commercial Fishery

Reappearance of male Atlantic Sturgeon in Long Reach varied from one to four years, with reappearance most prevalent after two or three years. Females reappeared from one to six years, with prevalence tending towards three to four years (Fig. 12). This difference had no statistical significance whether return to Long Reach was considered as an independent event (Kruskal-Wallis Rank Sums test; $x^2 = 1.63$, p= 0.202) or whether observations were weighted by individual variability ($x^2 = 3.01$, p= 0.08).

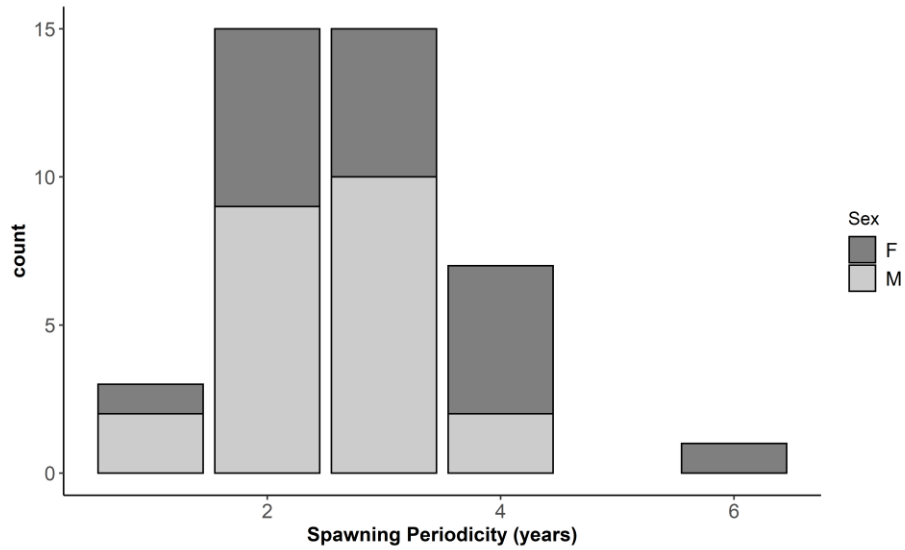

Figure 12. Period (years) between detections of adult male and female Atlantic Sturgeon in Long Reach.

The June 1st to June 31st close time has been in effect for the Saint John River commercial Atlantic Sturgeon fishery since at least 1965 (Bradford et al. 2016) as a conservation measured presumed to protect spawning adults[1] (DFO 2013). The proportion of time that Atlantic Sturgeon were available to be captured by the commercial fishery was estimated from the average number of days individual sturgeon spent in Long Reach, excluding the month of June (Table 6). The total possible exposure period was calculated as the difference in days between the first and last detection of each individual; this assumed that tagged sturgeon remained within Long Reach and were exposed to the fishery for the entire period between their first and last known detections, but were not detected on each day.

Estimates of exposure to the fishery based on the number of days fish were detected in the study area were generally low (14±12 days), with the exception of 2014, when tagged sturgeon detections strongly overlapped with the fishing season. If all potential sturgeon presence days are accounted for, their exposure to the fishery could be 68±19% of the total residence time in Long Reach. A detailed account of each individual's residence time is provided in Appendix A.

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[1] A May 31 to July 15 close time had been in effect since 1891, prior to the change in 1965 (Bradford et al. 2016).

Table 6. Average number of days and possible days (based on first and last detection) that individual Atlantic Sturgeon were detected in Long Reach, excluding the month of June, and mean length of time they were exposed to the commercial fishery.

Year	Average days detected	Average possible days	Length of fishery (days)	Time available for capture (%)
2013	22	49	57	39 – 86
2014	39	50	55	71 – 91
2015	10	18	44	23 – 41
2016	23	57	91	25 – 63
2017	8	31	43	19 – 72
2018	8	47	55	15 – 85
2019	7	29	62	11 – 47
2020	3	50	67	4 – 75

June frequently had a high presence of tagged sturgeon, with at least one detection made almost every single day in all years except 2020 (Table 7). Presence in the other months varied by year, but was generally high in July and August. May and September had the lowest presence of Atlantic Sturgeon, but were also the months with the least monitoring effort. In 2016, when monitoring effort in May was high, sturgeon were present on 27 days.

Table 7. Proportion of days by month when Atlantic Sturgeon were detected by receivers in Long Reach. The total number of detection days over days by month is given in brackets. Detections for June are shaded in grey to indicate when the commercial fishery was closed.

Year	May	June	July	August	September	November
2013	0.52 (16/31)	1.00 (30/30)	0.97 (30/31)	1.00 (31/31)	0.03 (1/30)	-
2014	0.00 (0/31)	0.50 (15/30)	1.00 (31/31)	1.00 (31/31)	0.8 (24/30)	-
2015	0.39 (12/31)	0.97 (29/30)	0.35 (11/31)	0.45 (14/31)	-	-
2016	0.87 (27/31)	1.00 (30/30)	1.00 (31/31)	0.68 (21/31)	0.00 (0/30)	-
2017	0.32(10/31)	0.87 (26/30)	0.81 (25/31)	0.35 (11/31)	0.00 (0/30)	0.23(7/30)
2018	0.19 (6/31)	0.97 (29/30)	0.68 (21/31)	0.13 (4/31)	0.00 (0/30)	-
2019	0.26 (8/31)	0.73 (22/30)	0.45 (14/31)	0.42 (13/31)	0.00 (0/30)	-
2020	0.16 (5/31)	0.10 (3/30)	0.16 (5/31)	0.03 (1/31)	0.00 (0/30)	-

The frequency that sturgeon were detected in Long Reach varied among sites. A higher proportion of detections within a given year occurred between RK21 to RK25 (Table 8, Fig. 13) with the exception of 2015, when a higher proportion of detections occurred between RK26 and RK30. As previously stated, this may be attributed to the distribution of monitoring effort in that year; in most years, the majority of receivers were located from RK18 to RK30, but in 2015 these stations were deployed late in the season. Further, over 50% of detections in 2015 could not be identified to locations due to missing deployment metadata.

Table 8. Proportion of detection days at each river kilometre (RK) by year. A dash indicates that no receiver was deployed at that location in a given year; 0 indicates that a receiver was deployed, but made no detections. Detections made by receivers that could not be identified to location in 2015 are excluded (n=5%).

RK	2013	2014	2015	2016	2017	2018	2019	2020
15-20	0.07	0.16	0.02	0.11	0.08	0.07	0.11	0.10
21-25	0.80	0.25	0.19	0.33	0.54	0.67	0.77	0.89
26-30	0.14	0.18	0.60	0.16	0.38	0.17	-	-
31-35	-	-	-	0.19	-	-	-	-
36-40	-	0.40	0.13	0.19	-	0.09	0.13	-

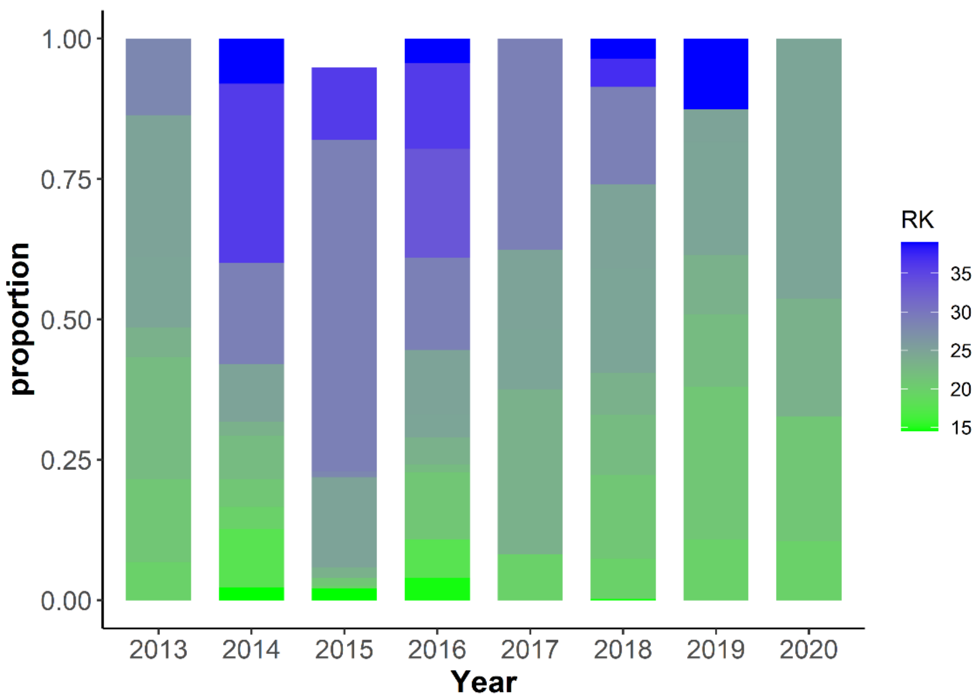

Figure 13. Yearly proportion of detections separated by number of kilometres (RK) upstream from Reversing Falls. Detections made by receivers that could not be identified to location in 2015 are excluded.

3.3 Catchability of Tagged Atlantic Sturgeon

Since the beginning of the study in 2013, 17 tagged Atlantic Sturgeon have been recaptured by the fishery in later years (Table 9). Of these, seven individuals were processed, with three of the tags re-deployed in new fish in 2014 and 2016. All remaining fish were released from the nets alive and subsequently detected within the study area (Fig. 14). Seven of the recaptured fish were female, of which four were processed; the other ten were male, of which three were processed. Most recaptures were made at RKs 19, 27 and 47 (Fig. 15). The fork lengths of the recaptured sturgeon ranged from 163-185 cm for females and 147-175 cm for males.

Table 9. Capture details of tagged Atlantic Sturgeon recaptured in the commercial fishery following their initial release. The net locations are in number of river kilometres (RK). Capture number indicates the number of times that this individuals was previously captured (including the initial tagging event). Individuals processed following recapture are highlighted in bold. Grey cells indicate events in which tags from harvested sturgeon were re-deployed in new fish.

ID	Date	Number of Events	Days Since Last Capture	Location (RK)	Sex	FL (cm)	Outcome
2	**2018-07-22**	**1**	**1893**	**47**	**F**	**193**	**Processed**
5	2017-08-01	1	1524	24	F	170	Released
6	2013-08-06	1	68	20	M	170	Released
10	**2016-07-02**	**1**	**1102**	**47**	**F**	**185**	**Processed**
12	2013-08-04	1	39	27	M	155	Released
15	2013-08-06	1	2	19	F	175	Released
16	**2016-07-15**	**1**	**750**	**47**	**M**	**175**	**Processed**
17	2014-06-27	1	1	20	F	165	Released
20	2014-08-13	1	47	23	F	178	Released
20	2016-05-19	2	645	24	F	178	Released
20	2016-07-10	3	52	47	F	178	Released
20	2016-07-11	4	1	26	F	178	Released
20	2016-07-14	5	3	18	F	178	Released
23	2014-06-30	1	2	27	M	152	Released
26	2014-06-30	1	2	27	M	147	Released
26	**2014-07-03**	**2**	**3**	**19**	**M**	**147**	**Processed**
27	**2016-05-22**	**1**	**694**	**23**	**M**	**173**	**Processed**
28	2014-07-08	1	8	18	M	155	Released
29	**2014-07-04**	**1**	**4**	**20**	**F**	**176**	**Processed**
30	2014-07-09	1	9	26	M	163	Released
31	2014-06-30	0	-	27	M	147	Released
31	2014-07-04	1	4	23	M	147	Released
32	2014-08-04	0	-	29	F	163	Released
33	2016-06-14	0	-	18	M	152	Released
33	**2019-07-25**	**1**	**1136**	**29**	**M**	**152**	**Processed**

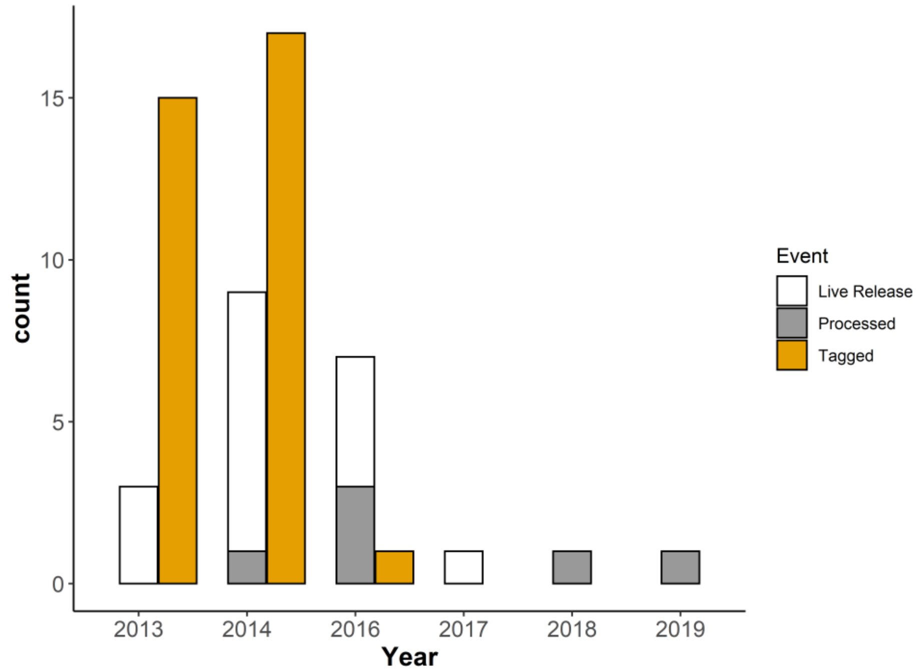

Figure 14. Number of Atlantic Sturgeon tagged and recaptured by the commercial fishery by year.

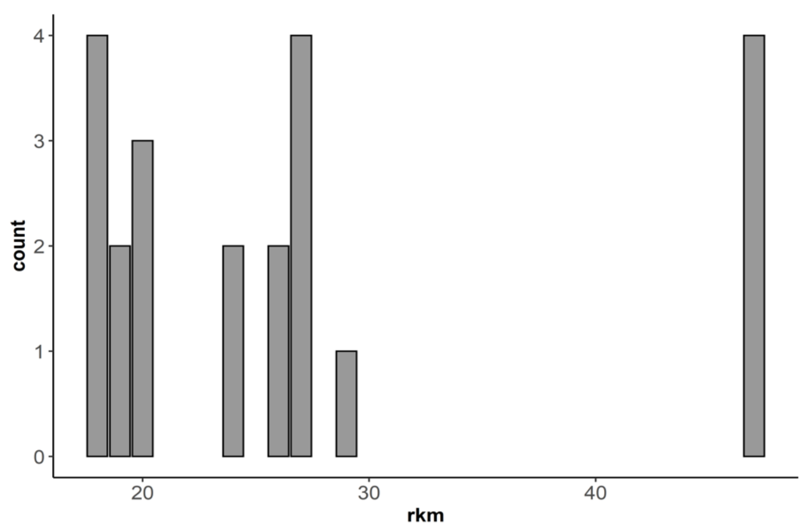

Figure 15. Capture locations in river kilometers (rkm) of the tagged Atlantic Sturgeon that were recaptured in gill nets by the commercial fishery following their initial release.

Two fish were recaptured more than once: AS26 (male) and AS20 (female). AS26 was captured twice in 2014; first at RK27 on June 30th, and second time at RK19, thereafter the fish was harvested by the fishery. AS20 was tagged in 2014, recaptured on August 13 at RK 23, and was not detected again by any of the receivers in Long Reach until 2016. During 2016 this female was captured four times: on May 19th at

RK23, on July 10th at RK4747, on July 11th at RK26, and finally on July 14th at RK18. This fish survived to be detected in Minas Basin in 2018, and in again in Long Reach in 2019.

On average, the commercial fishery intercepts 450 sturgeon each year, of which 71% are harvested. Comparisons of the total number of tagged sturgeon captured in the commercial fishery each year to the number detected in Long Reach in that year (sexes combined) indicates that vulnerability to capture is variable among years, ranging from 0.00 to 0.50 (Table 10), with a mean of 0.18 ± 0.19 Standard Deviations (SD), a geometric mean of 0.04, and median and modal values of 0.14. The high catchability in 2016 is due to experimental scientific fishing conducted for Atlantic Sturgeon in Long Reach that year. With 2016 excluded, the average proportion of tagged sturgeon recaptured annually was 0.13 ± 0.14.

Table 10. Proportion of acoustically tagged Atlantic Sturgeon captured by the commercial fishery compared to total number detected that year. Total annual catches (includes every Atlantic Sturgeon that was intercepted by the nets) and landings of the commercial fishery are provided for reference.

Year	Total catch (landings)	No. Tagged fish caught	No. Tagged fish detected	Proportion
2014	514 (344)	7	19	0.37
2015	471 (347)	0	4	0.00
2016	394 (286)	4	8	0.50
2017	449 (339)	1	10	0.10
2018	454 (351)	1	7	0.14
2019	460 (330)	1	7	0.14
2020	298 (197)	0	5	0.00

The commercial fishery consistently captured more female than male sturgeon during the eight years of the study, however, the numbers of tagged male sturgeon detected each year was generally higher than the number of females detected (Table 11). There was no significant difference in the number of detection days between males and females (two sample t-test; $t_{14} = -0.18$, $p=0.9$). This between-sex difference may be a consequence of higher catchability for females than males; tagged females were significantly larger than males (two sample t-test; $t_{31} = -5.06$, $p < 0.01$), which could make them less likely to escape the nets upon capture. However sex-specific behaviour may also be a factor.

Table 11. Total number of males (M) and females (F) detected in Long Reach, number of recaptures, and total catches by the commercial fishery; this includes all recorded captures, including Atlantic sturgeon that were released. Individuals captured multiple times within a year are only listed once.

Year	M	F	Tagged M captured	Tagged M detected	Tagged F captured	Tagged F detected
2013	288	261	2	6	1	8
2014	241	261	4	11	6	8
2015	203	260	0	1	0	3
2016	158	211	2	6	2	2
2017	210	232	0	5	1	5
2018	203	245	0	3	1	4
2019	209	227	1	4	0	3
2020	115	153	0	3	0	2

3.4 Survival

In addition to the seven known mortalities in the commercial fishery, one acoustic tag (assigned to AS17) was discovered lying on a beach in Saint John Harbour next to a dead sturgeon in July 2017 by a member of the general public. The beach is located about three km downstream of Reversing Falls. This is considered a mortality with an unknown cause, thereby raising the total number of known mortalities to 8 (24%) for the duration of the study.

With the assumption that all acoustic detections represented live fish, estimates of apparent survival were generated from the CJS model with consideration of body length and sex as covariates. None of these models achieved a weight above 50% (Table 12); the top model yielded an estimate of apparent survival of 94% (±3%), and detection probability of 43% (± 5%) (Table 13). The varying detection probability model (Table 14) also indicated that the tagged Atlantic Sturgeon had a 94% (±3%) chance of surviving year-to-year, regardless of sex or length, yielding a cumulative survival estimate of 65% (±14%) for up to end of 2019 (Fig. 16). Including the 24% known mortalities, the remaining 11% (~ 4 fish) of the fish that were tagged represent either unknown mortalities or emigrants from the study area. Detection probability varied among years in model 2, but was generally comparable to the fixed effects model.

Table 12. Ranking of CJS models fit using all available detections. Terms in parentheses indicate factors across which survival (Φ) or detection probability (p) varied.

Model	Parameters	AICc	∆AICc	Weight	Deviance
Φ (~1) *p* (~1)	2	267	0.00	0.31	141
Φ (~1) *p* (~time)	8	268	0.69	0.22	128
Φ (~length) *p* (~1)	3	268	1.57	0.14	263
Φ (~sex) *p* (~1)	3	269	2.07	0.12	141
Φ (~length) *p* (~time)	9	270	2.47	0.11	250
Φ (~sex) *p* (~time)	9	270	3.05	0.07	128
Φ (~time) *p*(~1)	8	271	3.86	0.05	131
Φ (~time + sex + length) *p* (~1)	10	275	8.20	0.00	253
Φ (~time) *p* (~time)	14	282	14.50	0.00	127
Φ (~time + sex + length) *p* (~time)	16	286	18.74	0.00	248

Table 13. Summary of fixed effects CJS model (CI – confidence interval).

Variable	Estimate	Standard error	Lower CI	Upper CI
Φ-intercept	2.71	0.46	1.81	3.61
p-intercept	-0.28	0.19	-0.66	0.09
Φ	0.94	0.03	0.86	0.97
p	0.43	0.05	0.34	0.52

Table 14. Summary of temporally varying detection probability CJS model (SE – standard error).

Segment	Φ ± SE	Cumulative Φ ± SE	*p* ± SE
2013-2014	0.94 ± 0.03	0.94 ± 0.03	0.50 ± 0.14
2014-2015	0.94 ± 0.03	0.88 ± 0.06	0.41 ± 0.09
2015-2016	0.94 ± 0.03	0.83 ± 0.08	0.44 ± 0.10
2016-2017	0.94 ± 0.03	0.78 ± 0.10	0.46 ± 0.10
2017-2018	0.94 ± 0.03	0.73 ± 0.12	0.36 ± 0.10
2018-2019	0.94 ± 0.03	0.69 ± 0.13	0.69 ± 0.12
2019-2020	0.94 ± 0.03	0.65 ± 0.14	0.18 ± 0.09

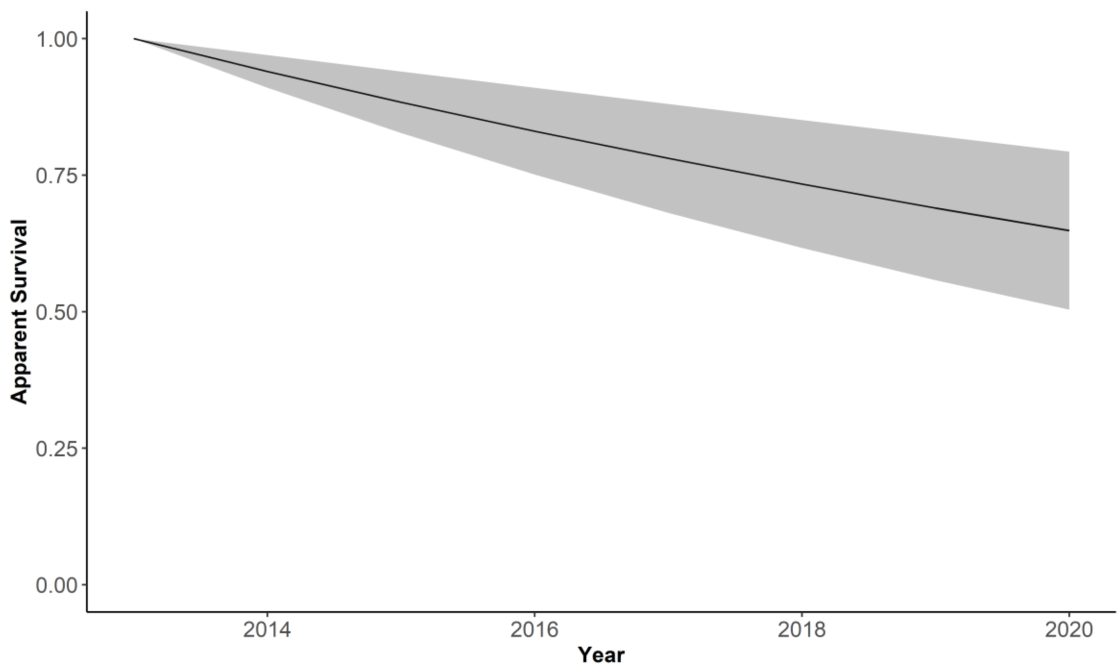

Figure 16. Cumulative survival (grey area indicates standard error) estimated by the temporally varying detection probability CJS model fit to all detections data.

When only Long Reach detections were used, the highest ranking CJS model (weight = 0.59) estimated 100% apparent survival, with a 0.19 yearly detection probability (Tables 15 and 16). This estimate did not differ by sex or length, and survival estimates did not vary even in the lower ranking models. A manual survival estimate was tabulated to compare with model outputs (Appendix C).

Table 15. Ranking of CJS models fit using Long Reach detections. Terms in parentheses indicate factors across which survival (Φ) or detection probability (p) varied.

Model	Parameters	AICc	ΔAICc	Weight	Deviance
Φ (~1) *p* (~1)	2	209	0.00	0.59	93
Φ (~length) *p* (~1)	3	211	2.19	0.20	205
Φ (~sex) *p* (~1)	3	211	2.19	0.20	93
Φ (~1) *p* (~time)	8	219	10.07	0.00	89
Φ (~length) *p* (~time)	9	222	12.72	0.00	201
Φ (~sex) *p* (~time)	9	222	12.72	0.00	89
Φ (~time) *p*(~1)	8	222	12.92	0.00	92
Φ (~time + sex + length) *p* (~1)	10	223	13.50	0.00	199
Φ (~time) *p* (~time)	14	237	27.45	0.00	89
Φ (~time + sex + length) *p* (~time)	16	238	29.31	0.00	196

Table 16. Summary of highest ranking CJS model fit using Long Reach detections (CI – confidence interval.

Variable	Estimate	Standard error	Lower CI	Upper CI
Φ-intercept	22.98	0.00	22.98	22.98
p-intercept	-1.45	0.18	-1.80	-1.11
Φ	1.00	0.00	1.00	1.00
p	0.19	0.03	0.14	0.25

Burnham models were fit with the same parameters as the CJS models. The highest weighted model had time-varying survival estimates and detection probabilities, and fixed recovery and fidelity (Table 17). Survival estimates were high (> 80%) from 2013 to 2018, but decreased rapidly in 2019 and 2020 (Table 18). Thus, the model predicted 54% survival by 2018, a decline to 19% by 2019, and 100% mortality by the end of sampling in 2020. A similar trend was observed in Burnham models fit from Long Reach detections (Table 19); the top ranking model (weight = 0.48) estimated 31% survival from 2013-2018 and 100% mortality in 2020 (Table 20). For the purpose of validating survival assessment, both CJS and Burnham models were fit to randomly generated detection data (Appendix C).

Table 17. Ranking of Burnham models fit using all available detections. Terms in parentheses indicate factors across which survival (S) or detection probability (p) varied.

Model	Parameters	AICc	ΔAICc	Weight	Deviance
S(~time)p(~time)	17	305	0.00	0.51	150
S(~time)p(~1)	11	305	0.55	0.39	168
S(~time + Sex + Length)p(~1)	13	309	4.41	0.06	279
S(~time + Sex + Length)p(~time)	19	309	4.70	0.05	262
S(~1)p(~time)	10	339	34.7	0.00	204
S(~Length)p(~time)	11	342	37.1	0.00	317
S(~Sex)p(~time)	11	342	37.2	0.00	204
S(~1)p(~1)	4	342	37.7	0.00	221
S(~Length)p(~1)	5	345	39.8	0.00	334
S(~Sex)p(~1)	5	345	39.9	0.00	221

* r(~1)F(~1) for all

Table 18. Summary of highest ranking Burnham model fit using all detections (S – survival; p – detection probability; SE – standard error).

Year	S ± SE	Cumulative S ± SE	p ± SE
2013	0.87 ± 0.09	0.87 ± 0.09	
2014	0.93 ± 0.05	0.81 ± 0.13	0.54 ± 0.14
2015	0.92 ± 0.05	0.74 ± 0.16	0.46 ± 0.10
2016	0.88 ± 0.06	0.66 ± 0.18	0.37 ± 0.10
2017	0.95 ± 0.04	0.62 ± 0.20	0.55 ± 0.11
2018	0.86 ± 0.08	0.54 ± 0.22	0.38 ± 0.11
2019	0.22 ± 0.10	0.12 ± 0.10	0.83 ± 0.09
2020	0.00 ± 0.00	0.00 ± 0.00	1.00 ± 0.00

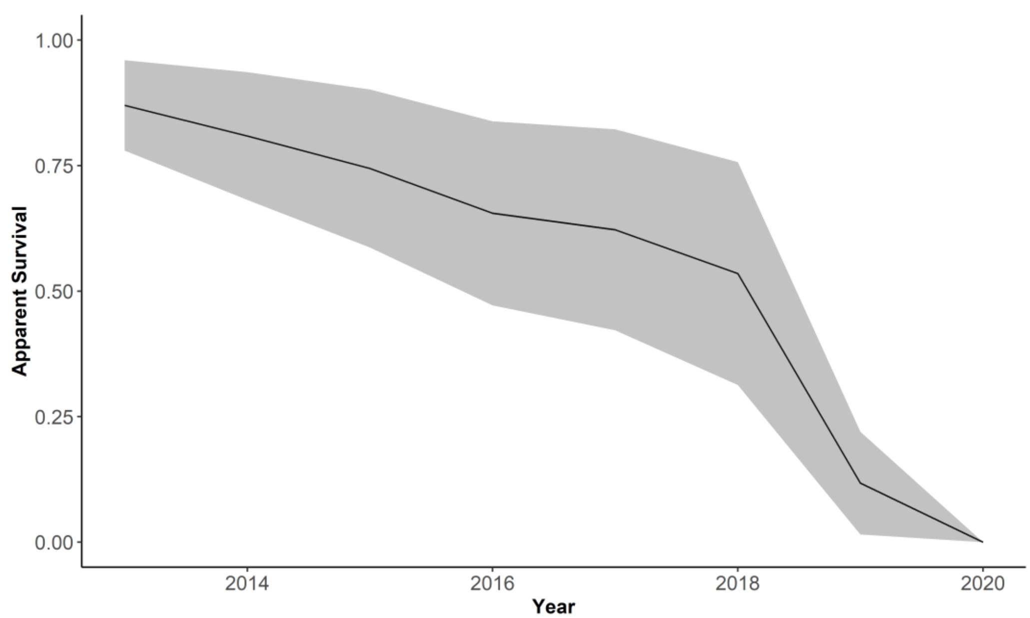

Figure 17. Cumulative survival (grey area indicates standard error) estimated by the highest ranking Burnham model fit using all detections.

Table 19. Ranking of Burnham models fit using Long Reach detections. Terms in parentheses indicate factors across which survival (S) or detection probability (p) varied.

Model	Parameters	AICc	ΔAICc	Weight	Deviance
S(~time)p(~1)	11	283	0.00	0.48	149
S(~time)p(~time)	17	283	0.20	0.43	130
S(~time + Sex + Length)p(~1)	13	287	4.26	0.06	254
S(~time + Sex + Length)p(~time)	19	289	6.11	0.02	234
S(~1)p(~time)	10	292	8.88	0.01	161
S(~Length)p(~time)	11	294	11.61	0.00	161
S(~Sex)p(~time)	11	295	11.76	0.00	268
S(~1)p(~1)	4	296	13.20	0.00	181
S(~Sex)p(~1)	5	298	15.39	0.00	181
S(~Length)p(~1)	5	298	15.53	0.00	287

* r(~1)F(~1) for all

Table 20. Summary of highest ranking Burnham model fit using Long Reach detections S – survival; p – detection probability; SE – standard error).

Year	S ± SE	Cumulative S ± SE	p ± SE
2013	0.80 ± 0.10	0.80 ± 0.10	
2014	0.88 ± 0.06	0.70 ± 0.14	0.32 ± 0.44
2015	0.96 ± 0.04	0.68 ± 0.16	0.32 ± 0.44
2016	0.88 ± 0.06	0.59 ± 0.18	0.32 ± 0.44
2017	0.76 ± 0.09	0.45 ± 0.19	0.32 ± 0.44
2018	0.69 ± 0.12	0.31 ± 0.19	0.32 ± 0.44
2019	0.36 ± 0.14	0.11 ± 0.11	0.32 ± 0.44
2020	0.00 ± 0.00	0.00 ± 0.00	0.32 ± 0.44

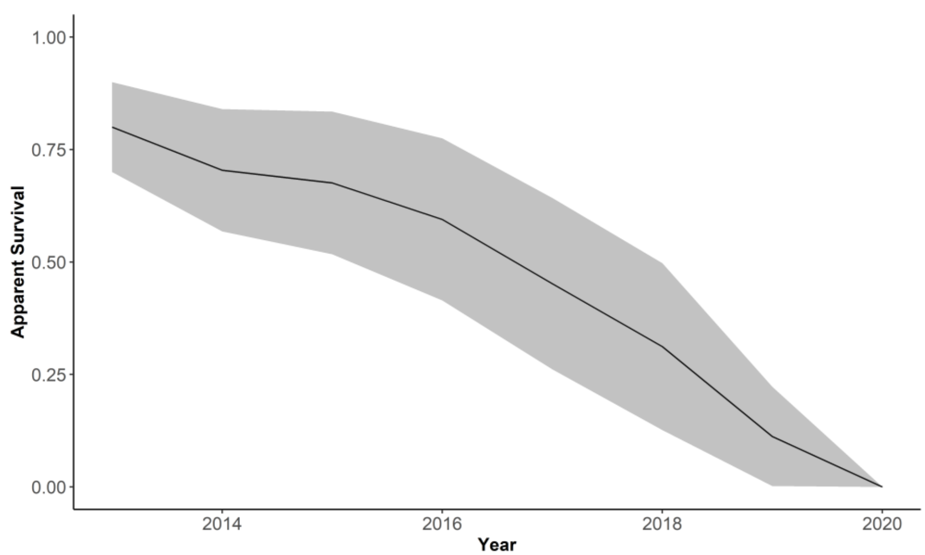

Figure 18. Cumulative survival (grey area indicates standard error) estimated by the highest ranking Burnham model fit using Long Reach detections.

3.5 Post-capture behaviour

Detection logs of two recaptured Atlantic Sturgeon were examined for evidence of behavioural changes as a result of capture in commercial gill nets. The other recaptured fish were omitted from this observation, either because there was no receiver present at the net that they were caught in, or because > 24 h had passed between release and first detection, making it impossible to determine behaviour immediately after release. The first Atlantic Sturgeon whose behaviour was examined was AS20. This female was recaptured on August 13, 2014 at RK23, and four times in 2016: on May 19th at RK23, on July 10th at RK47, on July 11th at RK26, and finally on July 14th at RK18. Detections were available from three of those days (Table 21).

Table 21. Detection history of Atlantic Sturgeon AS20 following recapture events (RK – river kilometre).

First detection	Last detection	Detections/hr	Detection interval (hr)	Average RK
2014-08-13 04:50	2014-08-13 17:52	16	13	23.5
2014-08-14 02:59	2014-08-14 03:17	17	0.3	23.5
2016-07-11 04:33	2016-07-12 21:35	28	41	23.5
2016-07-14 18:20	2016-07-14 22:29	16	4	23.5

On August 13, 2014, AS20 was repeatedly detected by receivers at RK 23 and 24 (Fig. 19). There was a ~9 hr interval before she was detected again, which is presumed to be the time when the sturgeon was taken out of the net and released; when releasing sturgeon, fishermen would motor the boat ~ 100 m away from the nets into the main channel. After release she was only present for a short interval at RK24 before moving further upstream. Her last detection day in Long Reach that year was August 19. This sturgeon was not detected in Minas Basin in 2015, but returned to the Saint John River in 2016.

In 2016, AS20 was recaptured by the commercial fishery on May 19. No receiver was present at her capture location, but after release the sturgeon was seen to remain in the lower portion of Long Reach for a few days before migrating upstream (Fig. 19). She remained around and above RK40 through mid to late-June. On July 10 AS20 was detected post-release consecutively over a period of 41 hours during which time she moved downstream and was captured at two more nets on July 11 and 14. After the final capture, AS20 returned further upstream and remained in Long Reach until late-August. She was detected in future years in the Minas Basin and the Saint John River, therefore, it can be concluded that this individual survived four interactions with gill nets in on year, and returned to the river to spawn in subsequent years. The average length of detection events following captures was 19 hr, compared to 7 hr when no captures were made (Fig. 20). Post-capture detections were also more frequent (average 20 detections per hr in post-capture events vs.15 per hr in normal events), suggesting that the sturgeon moved less after release. It is important to note, however, that there was a large variability across all events. In particular, one event lasted 47 hr from May 30 to June 1, 2016, during which this sturgeon was continuously detected between RK21 and 26, with long periods of immobility and an average of 43 detections per hr, even though no capture was reported on this day. Given the small number of recaptures, differences between post-capture and regular events could not be compared statistically.

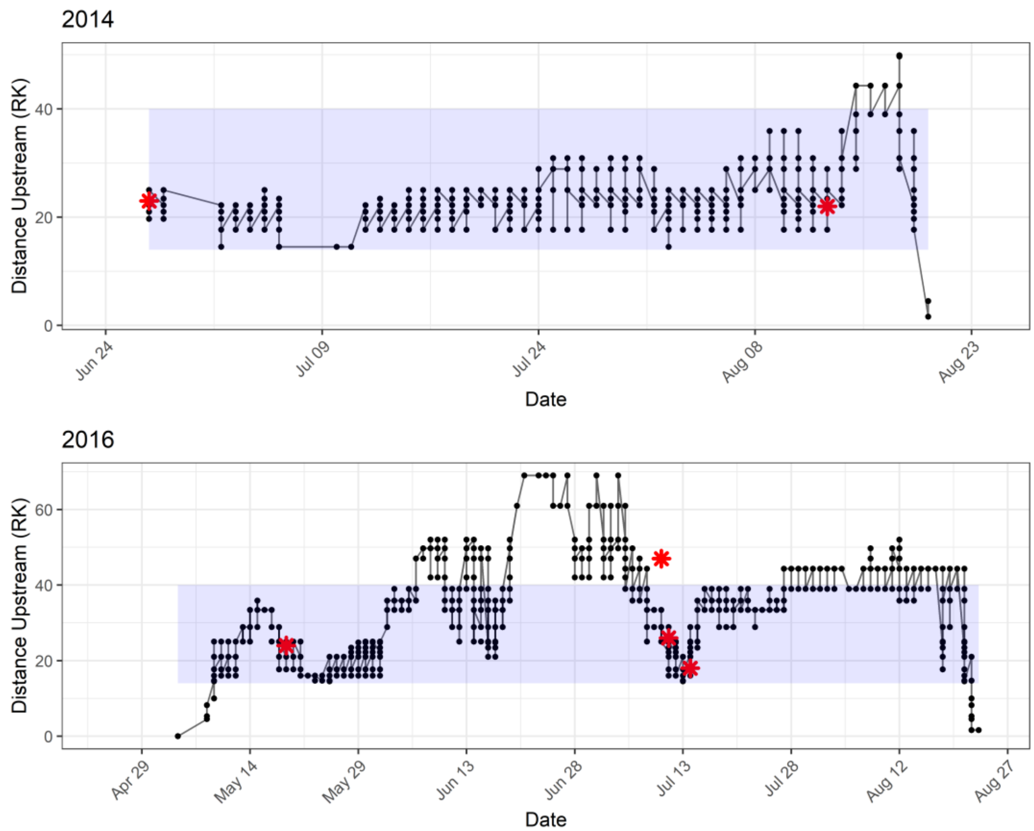

Figure 19. Daily detections of sturgeon AS20 in the Saint John River in 2014 and 2016. Capture events are identified with red stars. Distances given in river kilometers (RK), with Long Reach highlighted in blue.

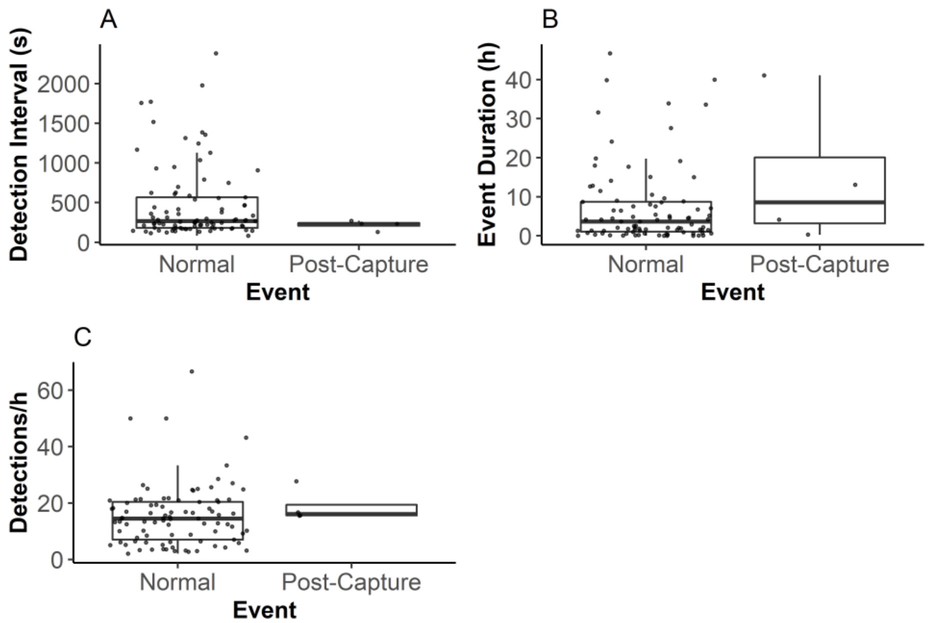

Figure 20. Comparison of post-capture and regular detection events for AS20 based on A) interval (in seconds) between individual detections in each detection event, B) event duration, and C) number of detections averaged by event duration (h -hours).

The other Atlantic Sturgeon whose behaviour after release was examined was male AS26. He was tagged on June 28, 2014 at RK24, and recaptured on June 30th at RK27. Detections first occurred at RK23 on the afternoon of June 30th, presumably after the sturgeon was released from the gillnet. After release, AS26 traveled downstream for the next eight hours, logging a total of 420 detections (Table 22). He remained around RK20 for the next two days, where he was subsequently recaptured and processed (Fig. 21). As with the previous fish, there are differences in the number of detections made per detection event when the fish is presumed to be in the gillnet, or immediately after release (Fig. 22). However, whether the movements of this sturgeon after first release are evidence of active swimming, or if the fish was drifting with the current until being captured again is not known.

Table 22. Detection histories of AS26 following recapture events (RK – river kilometre).

First detection	Last detection	Detections/hr	Detection interval (hr)	Average RK
2014-06-30 15:03	2014-06-30 23:12	16	8	21
2014-07-01 00:36	2014-07-01 01:57	13	1.4	19.5
2014-07-02 18:50	2014-07-03 12:45	26	18	19.5

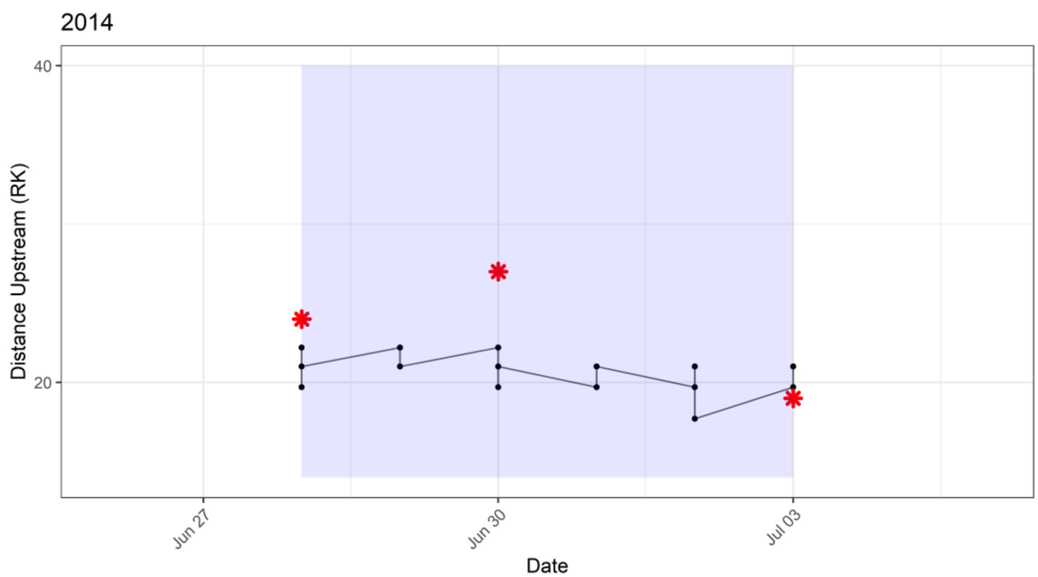

Figure 21. Daily detections of sturgeon AS20 in the Saint John River in 2014 and 2016. Capture events are identified with red stars. Distances given in river kilometers (RK). Long Reach is highlighted in blue.

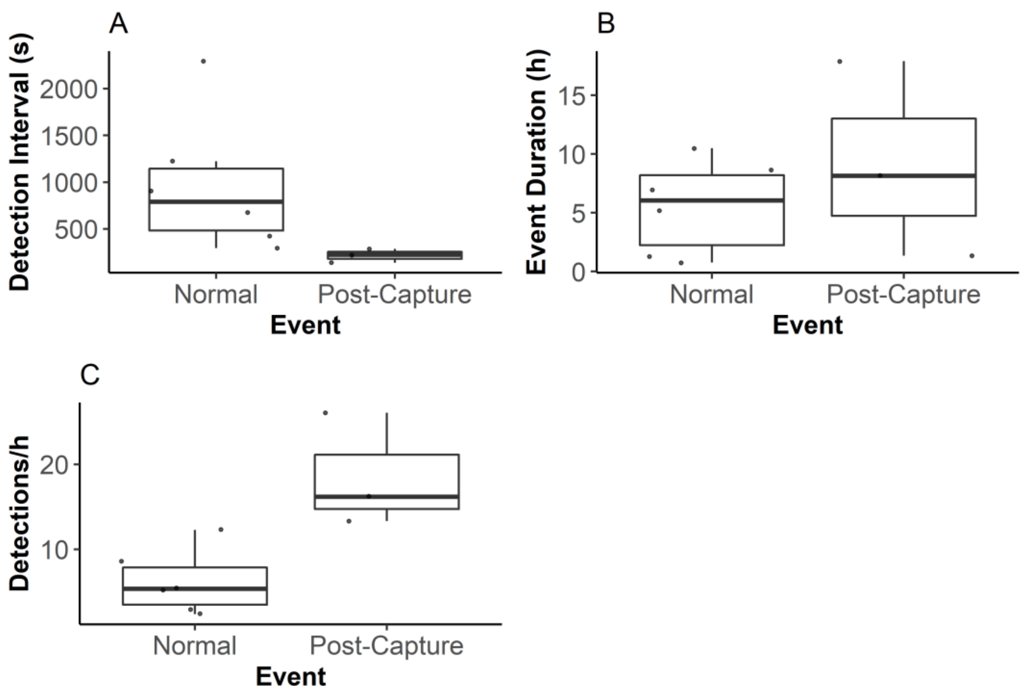

Figure 22. Comparison of post-capture and regular detection events for AS26 based on A) interval (in seconds) between individual detections in each detection event, B) event duration, and C) number of detections averaged by event duration (h-hours).

3.6 Far-field Detections

Not much is known about where Atlantic Sturgeon go after they have returned to sea post-spawning. By utilizing the data housed by the Ocean Tracking Network, detections of some of these tagged Atlantic Sturgeon on receivers owned by other researchers were obtained (Fig. 23). The data housed by OTN are continuously updated as new detections are submitted by various researchers to the program. More detections from the monitoring period may become available from other projects as these data are uploaded. From the data available thus far, it is apparent that some adult Saint John River Atlantic Sturgeon 1) travel between the Saint John River and the Minas Basin during their year of spawning, and 2) visit Minas Basin in years when they did not enter their natal river to spawn (Fig. 24). Detections from other regions of the Bay of Fundy included Passamaquoddy Bay, Musquash Harbour, and Clarks Ledge. Detections in coastal Nova Scotia occurred off Seal Island, Port Mouton, Port Medway, and St. Margaret's Bay. Detections in the USA included Cape Cod, Casco Bay, and Massachusetts Bay.

In 2013, one sturgeon (AS8) was detected in the Gulf of Main during the month of October, following detections in the Saint John River in September of that year. Two individuals were similarly detected in the Gulf of Main during late fall of 2015; one of these (AS17) had been detected in Minas Basin in mid-May but did not eventer the Saint John River at that time, however, following the Gulf of Main detection, this sturgeon returned North and was detected in the Saint John harbour in the month of November. The other sturgeon (AS22) had been detected in Minas Basin in May of

2015, but did not make any appearance in the river before nor following the Gulf of Main detection. In 2019, AS20 was detected in the Musquash Estuary in the Bay of Fundy in mid-May, followed by a migration to the Saint John River, then to the Gulf of Main. The last in-river detection and the first detection in the Gulf of Maine occurred five days apart, suggesting that sturgeon are able to cover a large distance rapidly.

In addition to the Gulf of Main, sturgeon were occasionally detected in other regions of the Bay of Fundy, such as Passamaquoddy Bay and Musquash Estuary. From the data available so far, we have seen four events of sturgeon being detected in these regions in years outside of their spawning run (AS20 in 2015 and 2018, AS23 in 2017, and AS6 in 2019), and three events of sturgeon being detected in those regions following or preceding migration in the Saint John River (AS20 in 2016 and 2019, and AS33 in 2019). In addition, one sturgeon (AS12) was detected in deep waters on the Scotian Shelf two months after migrating through the Saint John River in 2017. Three sturgeon were detected in coastal waters of Nova Scotia near Lunenburg County: AS6 was detected in 2018 and 2019, outside of the spawning run, and AS24 was detected in 2018 following migration in the Saint John River.

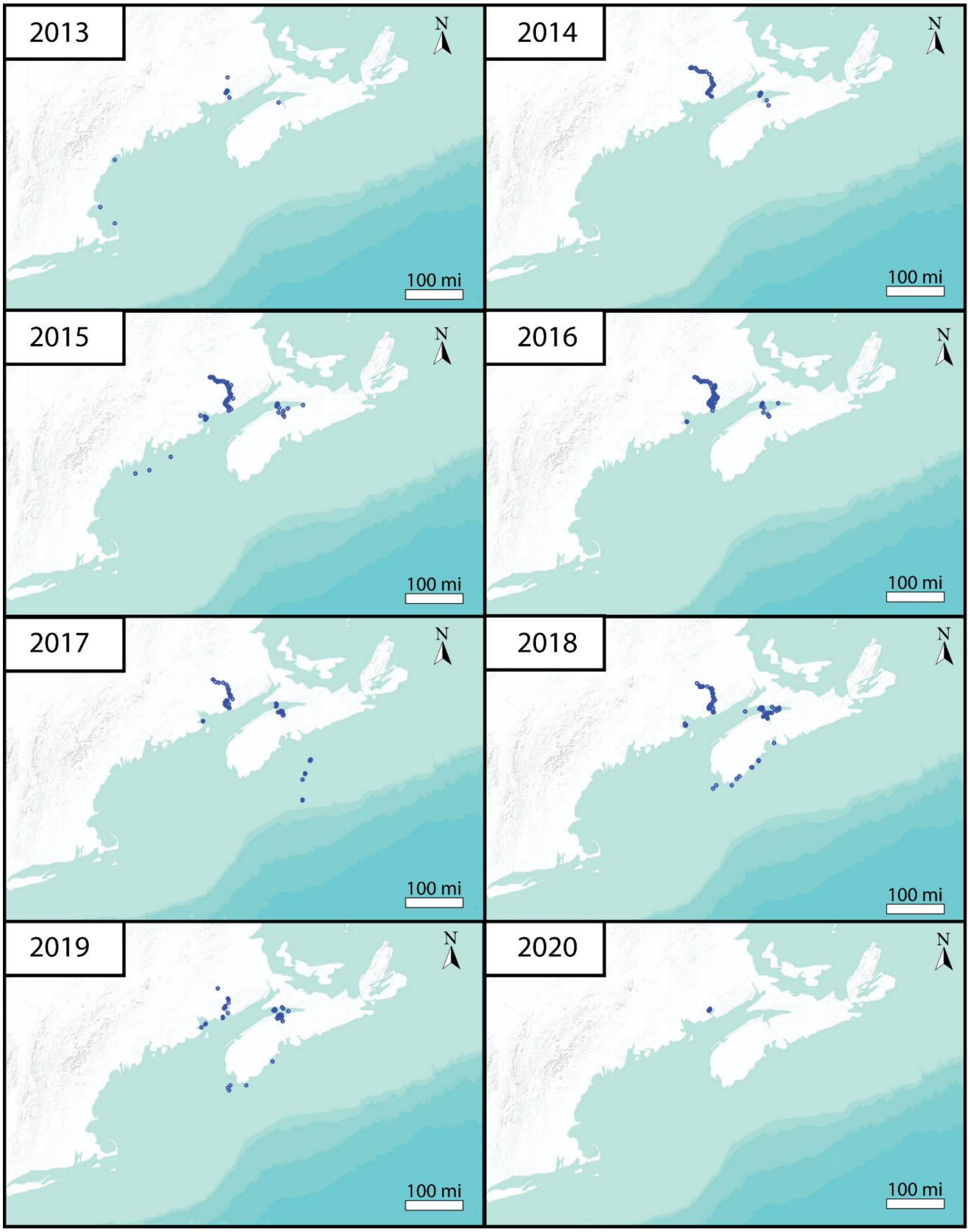

Figure 23. Locations of receivers that detected tagged Atlantic Sturgeon between 2013 and 2020. Data obtained from the Ocean Tracking Network (OTN). Map created using Leaflet (©OpenStreetMap Contributors, CC-BY-SA, source: USGS, Esri, TANA, DeLorme, NPS).

Figure 24. Abacus plot of all Atlantic Sturgeon detections from Long Reach, the rest of the St John River, Minas Basin, as well as opportunistic detections from coastal Nova Scotia and the United States. Black squares indicate when each fish was initially tagged and released. Red stars indicate known mortalities in the commercial fishery.

4. DISCUSSION

4.1. General Detection trends

Atlantic Sturgeon exhibited a high affinity for Long Reach, with most animals being detected again in the area in years following initial tagging.Tagged males returned to the Saint John River more frequently: from one to four, compared to one to six years for females. This frequency of the detections coincides with previous literature stating that males return to their spawning river every 1-5 years, in comparison to females returning every 2-6 years (DFO 2009; Dadswell et al. 2017). Although the difference was not statistically significant in this analysis, that may be the result of small sample sizes. Some of the tagged sturgeon were detected by receiver arrays in Minas Basin in years when they were not present in the Saint John River. The Basin is known to be a feeding location for this species (Redden et al. 2014; Dadswell et al. 2016).

4.2. Interactions with the Commercial Fishery

It has been suggested that closing the commercial fishery in June would allow for some protections for Atlantic Sturgeon during their spawning period (DFO 2013). Atlantic Sturgeon were detected in Long Reach throughout the entire month of June in most years of the study, indicating a high presence of sturgeon in the area during this time. Early June was also the recorded time of arrival of Atlantic Sturgeon to Long Reach for half of the tagged animals. However, it must be noted that this observation is biased by the lack of monitoring effort in the month of May for most of the study years. July and August were the most heavily monitored months, as they coincide with the commercial fishing season, and thus the deployment of hydrophones at the fishing nets. Detections outside of the fishing season rely primary on data provided through OTN by other researchers from stationary receivers in the lower and upper reaches of Long Reach, and thus may be under sampling the presence of sturgeon in the area.

The commercial fishery consistently captures more females than males, but the number of detections days did not differ between the sexes in tagged sturgeon, and a higher proportion of tagged males was detected in most years of the study. However, the sample of tagged sturgeon was not representative of the fished population, as we did not sample the full range of body sizes taken in the commercial fishery, particularly for the females. It is possible that female Atlantic Sturgeon are more exposed to the commercial fishing gear due to their larger size, which makes them less likely to escape the nets if captured. If tagged female sturgeon were smaller than the females generally caught by the fishery, we might not expect them to experience a similar recapture rate.

4.3. Survival

Atlantic Sturgeon survival was examined using the CJS and Burnham models based on live recapture (acoustic detection) events. Contrary to expectations, the CJS models estimated a higher survival that the Burnham models, which accounted for known mortalities in the commercial fishery. Both models were fit separately using detections from Long Reach only as well as in combination with far field detections to confirm survival in years that animals did not return to the river. The CJS model estimated a 94% annual survival (65 (±14 SD)% total survival at the end of 2019); a 21% fishing mortality is known from recaptures, and an additional dead sturgeon was discovered by members of the public, which leaves about 11% as either unknown mortalities or emigration. These findings are comparable to the 90.9% mean annual survival estimated from previous mark-recapture work on this population (Dadswell et al. 2017). In contrast, survival estimated from the Burnham model was only 54% by 2018, followed by 100% mortality over the next two seasons.

There is no known reason to believe that 2019 would have been a year of higher-than-average mortality for Atlantic Sturgeon in Long Reach; rather, the low return rate in these years can be attributed to the lifespan of the acoustic tags, which was expected to be around 6.8 years. Therefore, sturgeon tagged in 2013 would stop being detected in 2019, and sturgeon tagged in 2014 would no longer be detected in 2020. Combined with the spawning periodicity of both males and females, and the low monitoring effort in 2020, the low numbers of detected sturgeon in these years are not surprising. Therefore, survival estimates provided in this assessment should only be considered until 2018.

Survival probability was not affected by sex in any of the models tested, and size was not an important factor in any but the Long Reach-only CJS model, which is expected to have inflated survival estimates. However, it is important to note that these parameters are not known for the population at large; the process of acoustic tagging itself could have unknown effects on survival compared to untagged fish.

The differences between the various survival analyses demonstrate the importance of incorporating all available data into survival estimates, including detections outside of the monitoring area that may confirm survival of fish that would otherwise go undetected. Given the short time span of the acoustic tags employed in this study, and the small sample of tagged sturgeon, further tracking efforts in this population are recommended in order to provide more accurate estimates of yearly survival and fisheries mortality.

4.4. Behaviour after Release

The two fish whose behaviour following release from commercial fishing gear was examined were travelling downriver when they were intercepted by the gill nets. AS20 showed a lot of movement between receiver stations, and was recaptured by the fishery five times. In 2014 she was captured once, and remained in Long Reach for over a month after being released. In 2016 she was captured four times, three of which happened on consecutive days, yet the sturgeon remained in Long Reach for a month following the final capture, and was detected again in Minas Basin the following year, and in Long Reach the year after.

Although AS20 appeared to be initially affected by captures, the evidence of upstream movement following release, and detections in subsequent years suggest that she recovered from this experience, and is presumed to have behaved normally in subsequent detections. In contrast, AS26 showed only downstream movement after first capture, which might be attributed to transport by current rather than active swimming. He was detected for a prolonged period in one area, where he was then captured again and processed, which suggests that this animals was severely impacted by the first recapture. Fishing log records did not clarify whether this sturgeon was already dead when retrieved from a gillnet, or if it was captured alive and later processed. However, it is likely that damage caused by the first recapture event contributed to this sturgeon being captured a second time. It is also possible that the animal was initially impacted by the tagging procedure, which took place only two days before the first recapture. No data are available from the tagging event to discern whether this sturgeon behaved differently from the others, and he was not detected on any of the upstream receivers, but there was some evidence for upstream movement between the time of tagging and first recapture, which suggests that he was at least swimming actively at that time.

With post-release data lacking for most of the recaptured fish, it is difficult to assess the effects of capture in the commercial fishery on sturgeon health and behaviour. Detection logs from the two animals examined suggest that there may be temporary impacts on swimming activity, but that survival and spawning periodicity may not be affected in the long term. Only one of the six recaptured fish that were subsequently released has not been detected since. However, more data are necessary to make any conclusive remarks about the behaviour of these fish after they have been released from a gill net.

4.5 At-Sea Movements During Migration

We were able to observe evidence of migratory movement patterns in some Atlantic Sturgeon tracked in this study. In addition to movements to and from the Minas Basin, we also observed movements through other regions of the Bay of Fundy, Gulf of Maine, as well as in coastal Nova Scotia and on the Scotia Shelf. Some of these far-far field detections were made in years outside of the presumed spawning season, when sturgeon were not detected in the Saint John River. However, an equal proportion of far-field detections were made following or preceding the spawning migration of the individual in question. This suggests that Atlantic Sturgeon may frequently move over large distances, regardless of whether they are traveling to spawn or not. Furthermore, there is evidence that sturgeon can travel relatively quickly over large distances, as seen by one animal migrating between the Saint John River and the Gulf of Maine in the span of 5 days.

Currently, the Minas Basin is the most heavily monitored region in the Bay of Fundy, while monitoring efforts in other areas and off the coast of Nova Scotia are more opportunistic, with fewer receivers deployed over larger areas. This creates a bias wherein the Minas Basin appears as the dominant habitat for Atlantic Sturgeon outside of the Saint John River. However, given the observed movement patterns both during and outside of spawning migrations, Atlantic Sturgeon may use a larger area than is currently known. There is a need to continue acoustic tracking efforts in these regions in order to gain a better understanding of sturgeon habitat use and migratory behaviour outside of the Saint John River.

4.6. Sources of Uncertainty

The impact of the acoustic telemetry tags on sturgeon survival and behaviour are unknown. Acoustic tagging is an invasive process that is known to have sub-lethal effects on stress, physiology and behaviour in many fishes (Barton et al. 1986; Caputo et al. 2009; McLean et al. 2016). Therefore, the survival estimates and behaviours examined in this study may be uncharacteristic of unhandled Atlantic Sturgeon, and care must be taken when applying them to the Saint John River population in whole. It is also important to remember that the duration of the monitoring period and receiver locations were directly related to fishing efforts, and likely do not offer a comprehensive view of the use of the Saint John River by Atlantic Sturgeon. Finally, although the presence of sturgeon in river is attributed to spawning migrations, spawning behaviour cannot be directly inferred from acoustic data.

In addition to the data gaps already noted in previous sections, the accounts of recaptures in the commercial fishery are also incomplete, as fishing logs often do not report the acoustic identifier of tagged recaptured fish that can be compared with detection logs. As a result, we do not have a complete account of the acoustically tagged sturgeon that may have been recaptured by the commercial fishery over the course of this study. More detailed data will be necessary to apply acoustic tagging to mark-recapture models that would allow estimation of the size of the Atlantic Sturgeon population of the Saint John River.

5. CONCLUSIONS

The status of the returning Atlantic sturgeon spawners to Long Reach appears to be stable over the past seven years. This finding is consistent with the suggestions by COSEWIC (2011) and DFO (2013) that total removals within average historical harvest levels would be sustainable for maintaining the population in the short term. It was observed that some Atlantic sturgeon appear to be more susceptible to being captured in the commercial fishing gear than others, however, most recaptured fish that were released alive were detected in subsequent years in coastal environments near and within the Saint John River, confirming their survival. Acoustic tracking confirms high sturgeon presence in June, supporting the proposed June closure of the commercial fishery as a means of reducing effects on the population. It is recommended that passive acoustic telemetry studies are continued in this region to confirm trends observed within this study, and to provide more robust estimates of catchability and survival that can be extrapolated to the population level. Current data are insufficient to assess population-level effects of the commercial fishery, but acoustic tracking has proved a successful method for monitoring sturgeon presence and behaviour in this region, and will allow for future research questions to be addressed.

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APPENDIX A

Table A1. Tagging metadata of Atlantic Sturgeon tagged in this study.

Unique ID	Tag ID	Length	Sex	Release Location	Release Date
1	A69-9001-27184	1.823	F	PuP	2013-05-16
2	A69-9001-27186	1.905	F	PuP	2013-05-16
3	A69-9001-27188	1.6	M	CC	2013-05-20
4	A69-9001-27190	1.549	M	PuP	2013-05-20
5	A69-9001-27192	1.702	F	PuP	2013-05-30
6	A69-9001-27194	1.702	M	PuP	2013-05-30
7	A69-9001-27185	1.626	M	VS	2013-05-31
8	A69-9001-27187	1.778	F	PuP	2013-06-25
9	A69-9001-27189	1.905	F	PuP	2013-06-25
10	A69-9001-27191	1.854	F	CC	2013-06-26
11	A69-9001-27193	1.575	M	PuP	2013-06-26
12	A69-9001-27195	1.549	M	VB	2013-06-26
13	A69-9001-27196	1.651	M	CC	2013-08-03
14	A69-9001-27197	1.778	F	CC	2013-08-04
15	A69-9001-27198	1.753	F	PP	2013-08-06
16	A69-9001-24609	1.75	M	PuP	2014-06-26
17	A69-9001-24610	1.651	F	CC	2014-06-26
18	A69-9001-24611	1.88	F	PuP	2014-06-26
19	A69-9001-24612	1.473	M	CC	2014-06-26
20	A69-9001-24613	1.778	F	PuP	2014-06-27
21	A69-9001-24614	1.321	M	CC	2014-06-27
22	A69-9001-24615	1.803	F	PP	2014-06-28
23	A69-9001-24616	1.524	M	CC	2014-06-28
24	A69-9001-24617	1.829	F	CC	2014-06-28
25	A69-9001-24618	1.829	F	MDH	2014-06-28
26	A69-9001-24619	1.4732	M	MDH	2014-06-28
27	A69-9001-24620	1.727	M	VS	2014-06-28
28	A69-9001-24621	1.549	M	PP	2014-06-30
29	A69-9001-24622	1.7626	F	PP	2014-06-30
30	A69-9001-24623	1.626	M	PuP	2014-06-30
31	A69-9001-24619	1.473	M	PuP	2014-07-04
32	A69-9001-24622	1.626	F	BFN	2014-08-04
33	A69-9001-24620	1.524	M	PuP	2016-06-14

Table A2. Arrival and departure dates for the Atlantic sturgeon detected in Long Reach by year. Years of tagging for each individual are highlighted in grey. Detection days in June were subtracted from total days to get the number of days sturgeon were present during the commercial fishing season. Number of possible days of exposure are based on first and last detections.

Year	Unique ID	First Detection	Last Detection	Possible Exposure Days	Detections Days in Season
2013	1	2013-05-16	2013-07-31	77	23
2013	10	2013-06-26	2013-06-26	1	1
2013	11	2013-06-26	2013-07-28	33	16
2013	12	2013-08-04	2013-09-01	29	29
2013	13	2013-08-03	2013-08-19	17	17
2013	14	2013-08-03	2013-08-31	29	29
2013	15	2013-08-06	2013-09-01	27	21
2013	2	2013-05-16	2013-08-11	88	42
2013	3	2013-05-20	2013-07-03	45	13
2013	4	2013-05-20	2013-06-30	42	22
2013	5	2013-05-30	2013-08-13	76	4
2013	6	2013-05-30	2013-09-01	95	79
2013	8	2013-06-25	2013-08-24	61	15
2013	9	2013-06-25	2013-09-01	69	40
2014	11	2014-06-03	2014-08-03	62	12
2014	16	2014-06-27	2014-08-01	36	15
2014	17	2014-06-26	2014-09-21	88	83
2014	18	2014-06-26	2014-09-24	91	63
2014	19	2014-06-26	2014-08-24	60	24
2014	20	2014-06-27	2014-08-19	54	48
2014	21	2014-06-27	2014-09-21	87	43
2014	22	2014-06-28	2014-09-01	66	66
2014	23	2014-06-28	2014-09-24	89	52
2014	24	2014-06-28	2014-09-05	70	70
2014	25	2014-06-28	2014-09-08	73	71
2014	26	2014-06-28	2014-07-03	6	6
2014	27	2014-06-28	2014-09-17	82	77
2014	28	2014-06-30	2014-08-11	43	22
2014	29	2014-06-30	2014-07-04	5	5
2014	30	2014-06-30	2014-08-01	33	33
2014	31	2014-07-04	2014-08-13	41	40
2014	32	2014-08-04	2014-09-10	38	32
2014	4	2014-06-03	2014-06-09	7	7
2015	1	2015-06-03	2015-08-13	72	26
2015	13	2015-06-21	2015-08-14	55	8
2015	2	2015-05-20	2015-07-05	47	46
2015	5	2015-06-08	2015-08-10	64	7
2016	10	2016-05-27	2016-07-01	36	21
2016	16	2016-06-14	2016-06-17	4	4
2016	19	2016-06-25	2016-08-11	48	11

Year	Unique ID	First Detection	Last Detection	Possible Exposure Days	Detections Days in Season
2016	20	2016-05-09	2016-08-22	106	86
2016	27	2016-05-12	2016-05-22	11	11
2016	3	2016-05-04	2016-07-19	77	41
2016	31	2016-05-13	2016-08-07	87	38
2016	33	2016-06-14	2016-08-20	68	23
2017	11	2017-06-05	2017-08-14	71	4
2017	12	2017-05-26	2017-08-01	68	17
2017	15	2017-06-11	2017-08-22	73	36
2017	18	2017-05-27	2017-07-09	44	8
2017	21	2017-06-11	2017-08-20	71	3
2017	25	2017-11-05	2017-11-11	7	7
2017	28	2017-06-07	2017-07-29	53	7
2017	30	2017-05-22	2017-07-20	60	24
2017	5	2017-05-31	2017-08-07	69	11
2017	9	2017-06-06	2017-07-30	55	19
2018	1	2018-05-26	2018-06-06	12	12
2018	13	2018-05-28	2018-08-07	72	8
2018	22	2018-05-27	2018-07-24	59	28
2018	23	2018-05-28	2018-07-08	42	25
2018	24	2018-05-28	2018-07-16	50	33
2018	31	2018-05-28	2018-07-21	55	14
2018	32	2018-05-28	2018-07-11	45	6
2019	14	2019-05-28	2019-07-16	50	13
2019	19	2019-06-28	2019-08-20	54	6
2019	20	2019-06-02	2019-08-07	67	18
2019	21	2019-06-06	2019-08-29	85	11
2019	3	2019-05-21	2019-07-16	57	19
2019	33	2019-06-04	2019-07-24	51	9
2019	5	2019-06-03	2019-06-11	9	9
2020	13	2020-05-28	2020-07-31	65	4
2020	18	2020-05-31	2020-06-04	5	3
2020	28	2020-05-29	2020-07-26	59	6
2020	31	2020-05-30	2020-07-15	47	4
2020	5	2020-05-25	2020-08-11	79	2

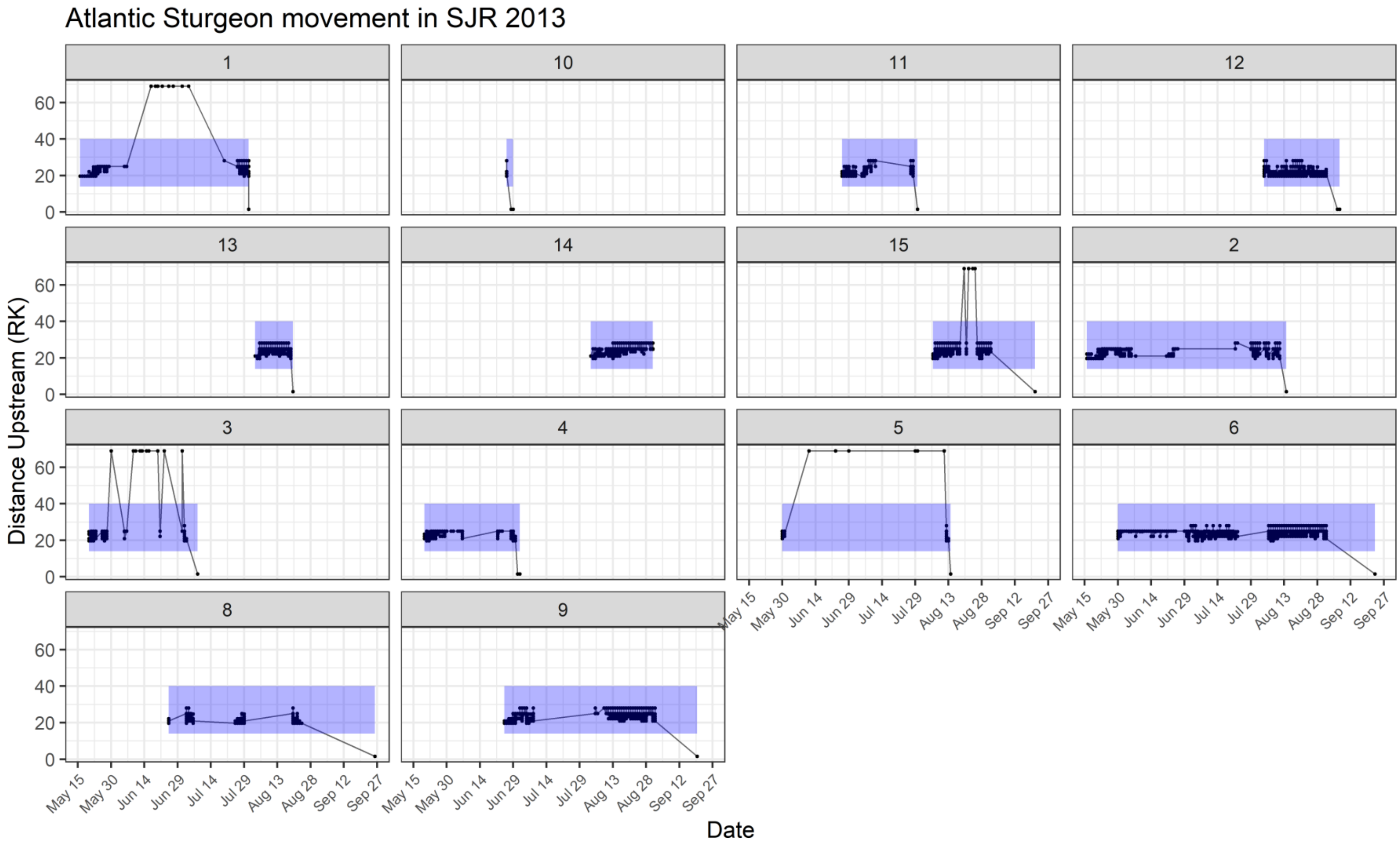

Figure A1. Individual movement histories of tagged Atlantic Sturgeon in the Saint John River in 2013. Distances are given in river kilometers (RK). Long Reach is highlighted in blue.

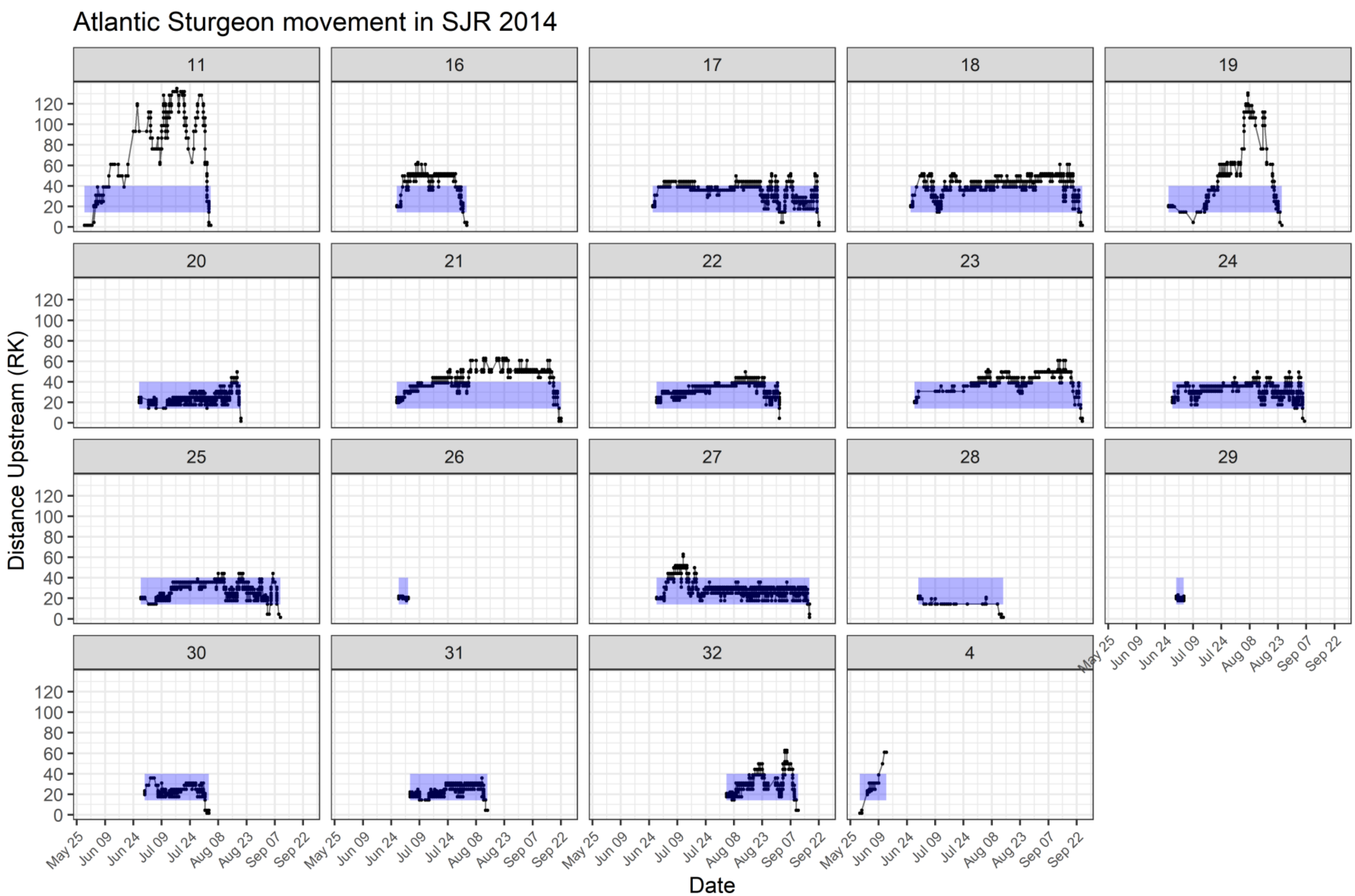

Figure A2. Individual movement histories of tagged Atlantic Sturgeon in the Saint John River in 2014. Distances given in river kilometers (RK). Long Reach is highlighted in blue.

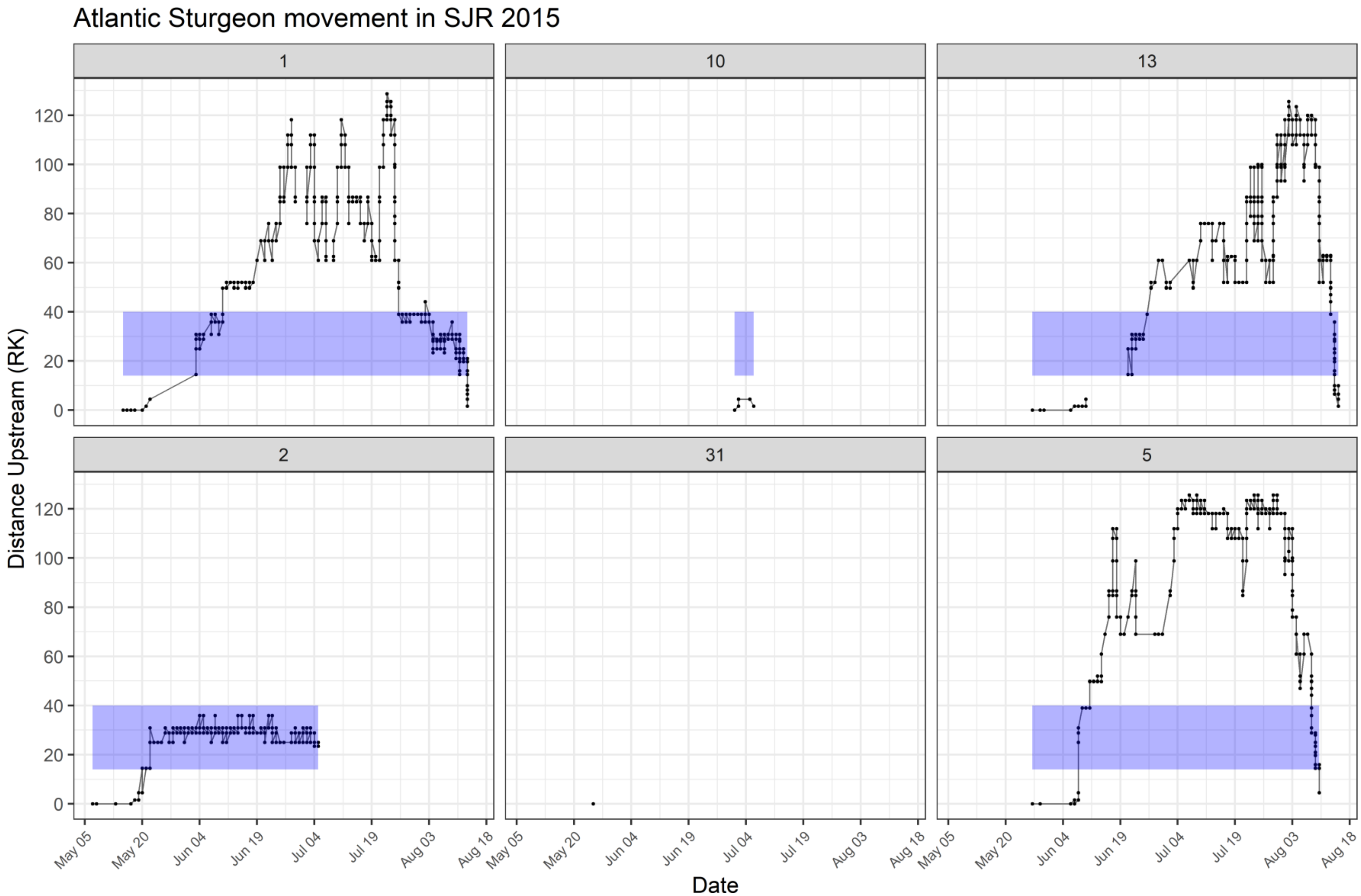

Figure A3. Individual movement histories of tagged Atlantic Sturgeon in the Saint John River in 2015. Distances given in river kilometers (RK). Long Reach is highlighted in blue.

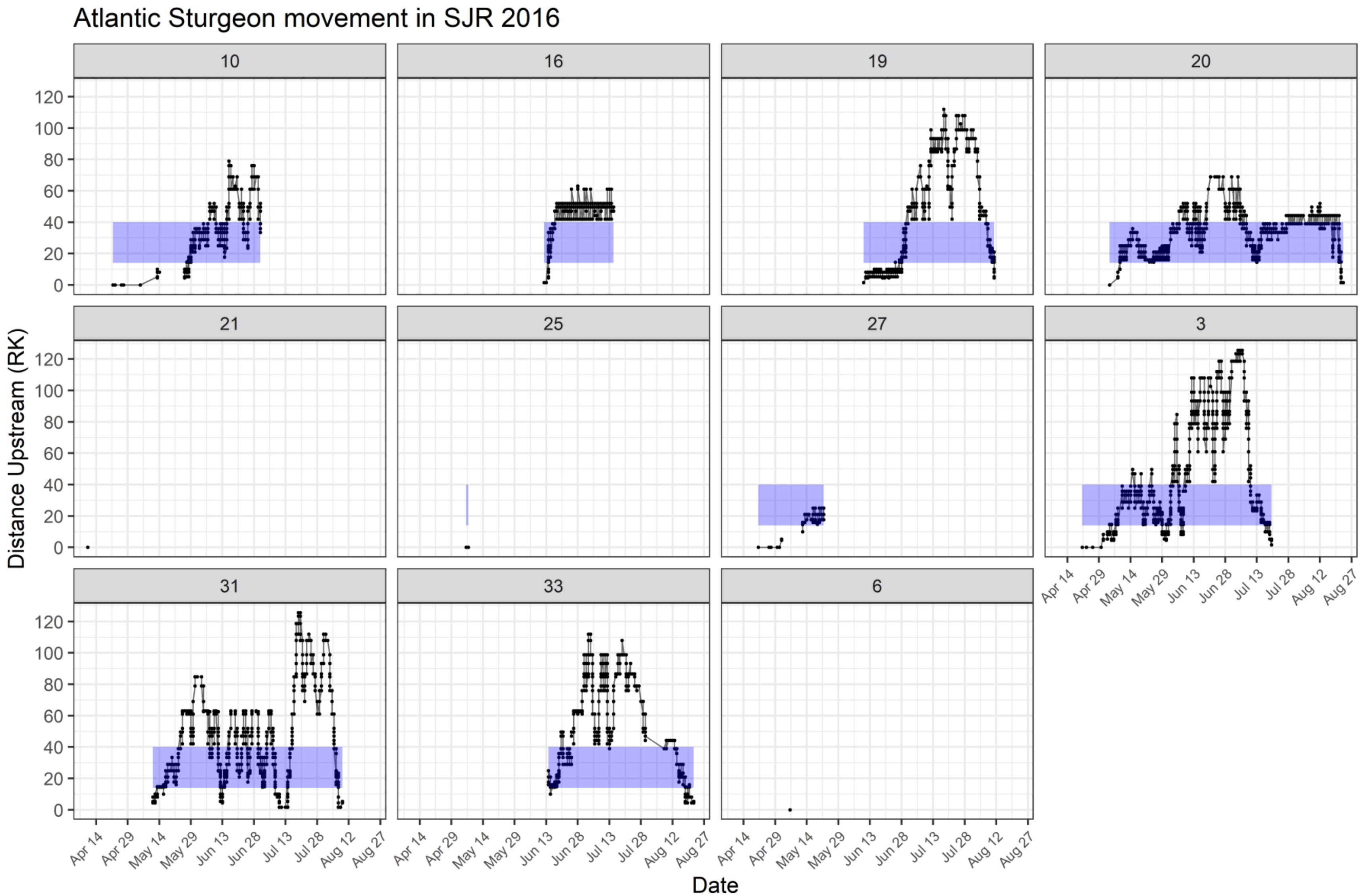

Figure A4. Individual movement histories of tagged Atlantic Sturgeon in the Saint John River in 2016. Distances given in river kilometers (RK). Long Reach is highlighted in blue.

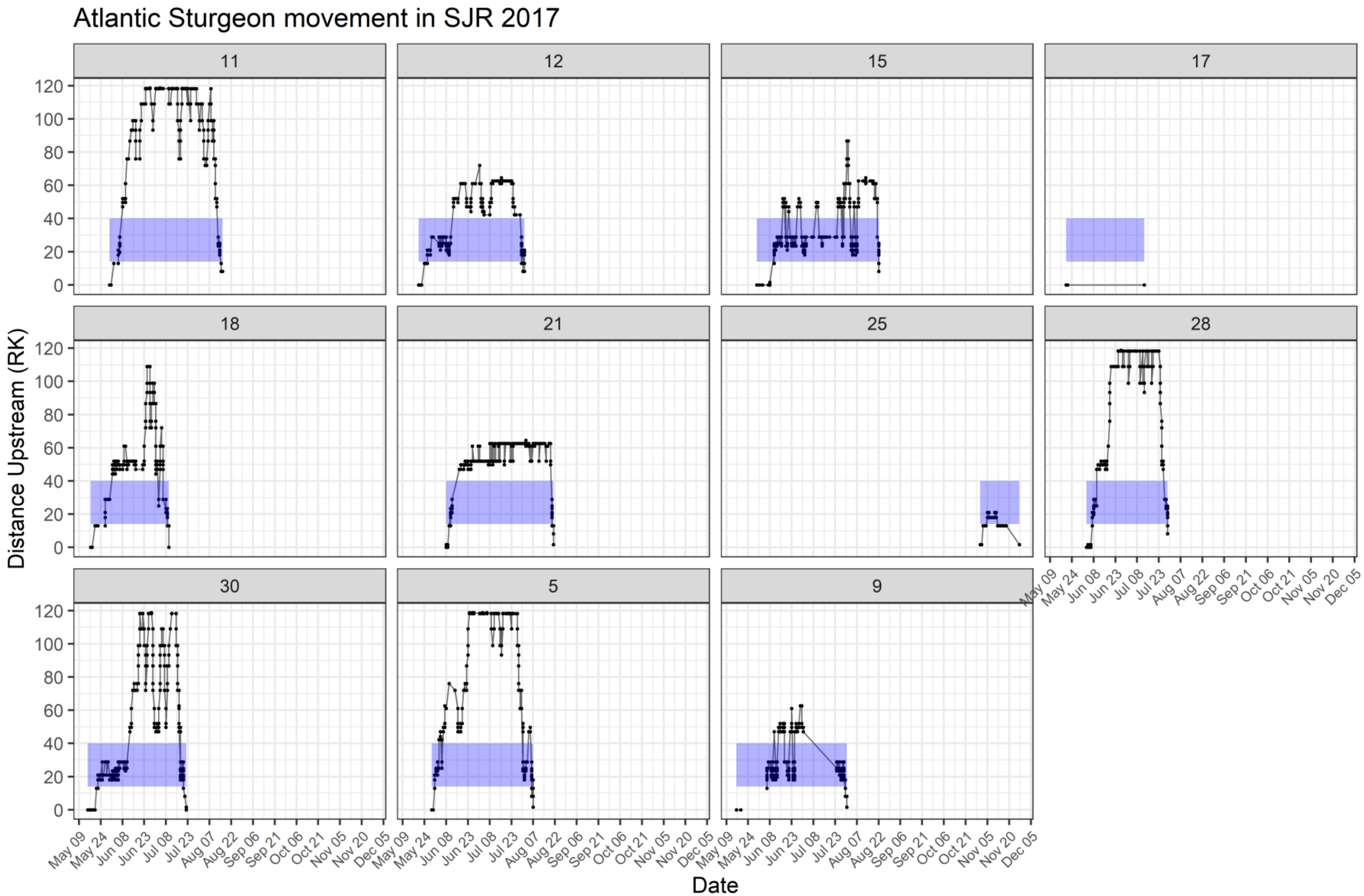

Figure A5. Individual movement histories of tagged Atlantic Sturgeon in the Saint John River in 2017. Distances given in river kilometers (RK). Long Reach is highlighted in blue.

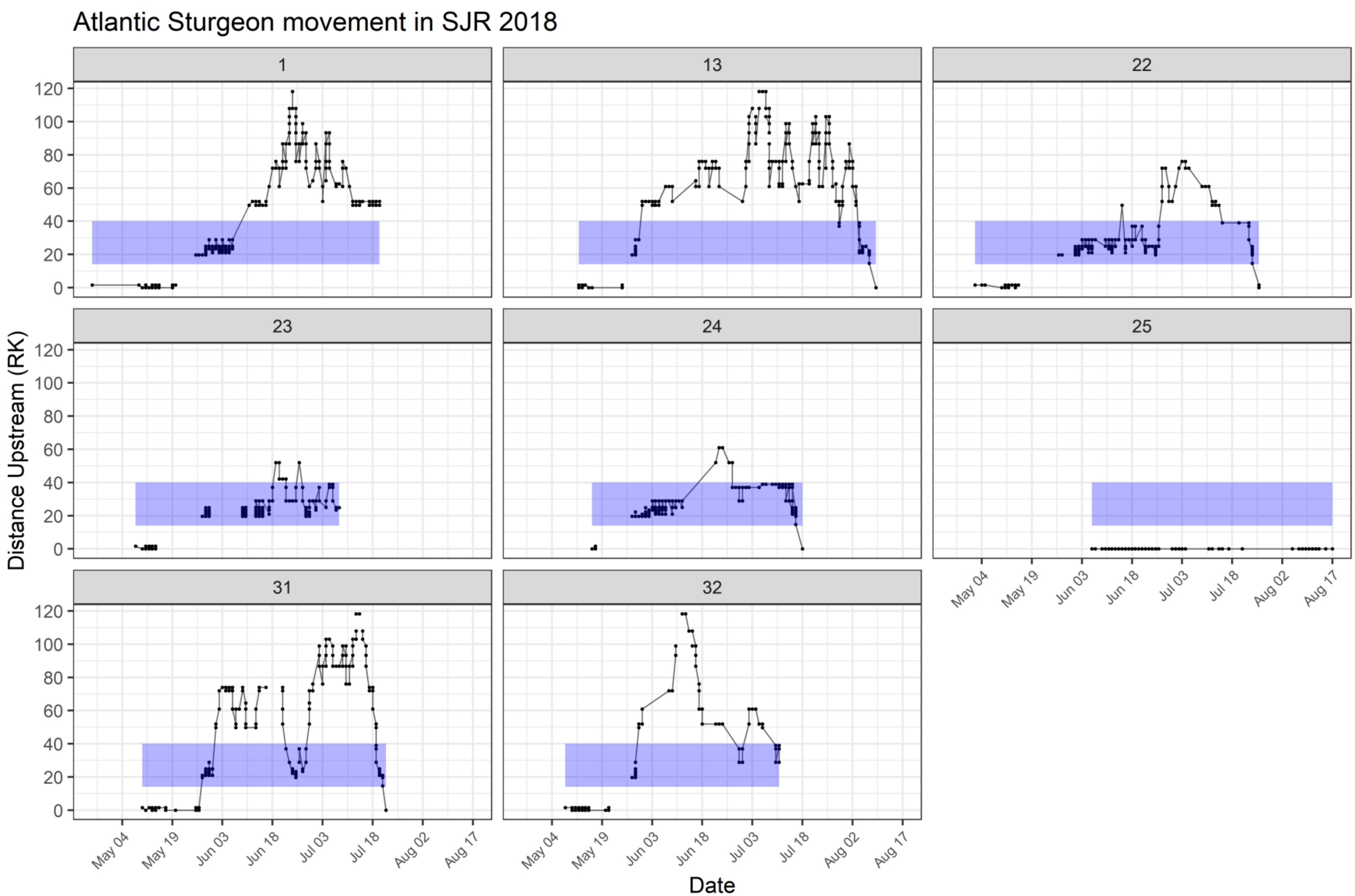

Figure A6. Individual movement histories of tagged Atlantic Sturgeon in the Saint John River in 2018. Distances given in river kilometers (RK). Long Reach is highlighted in blue.

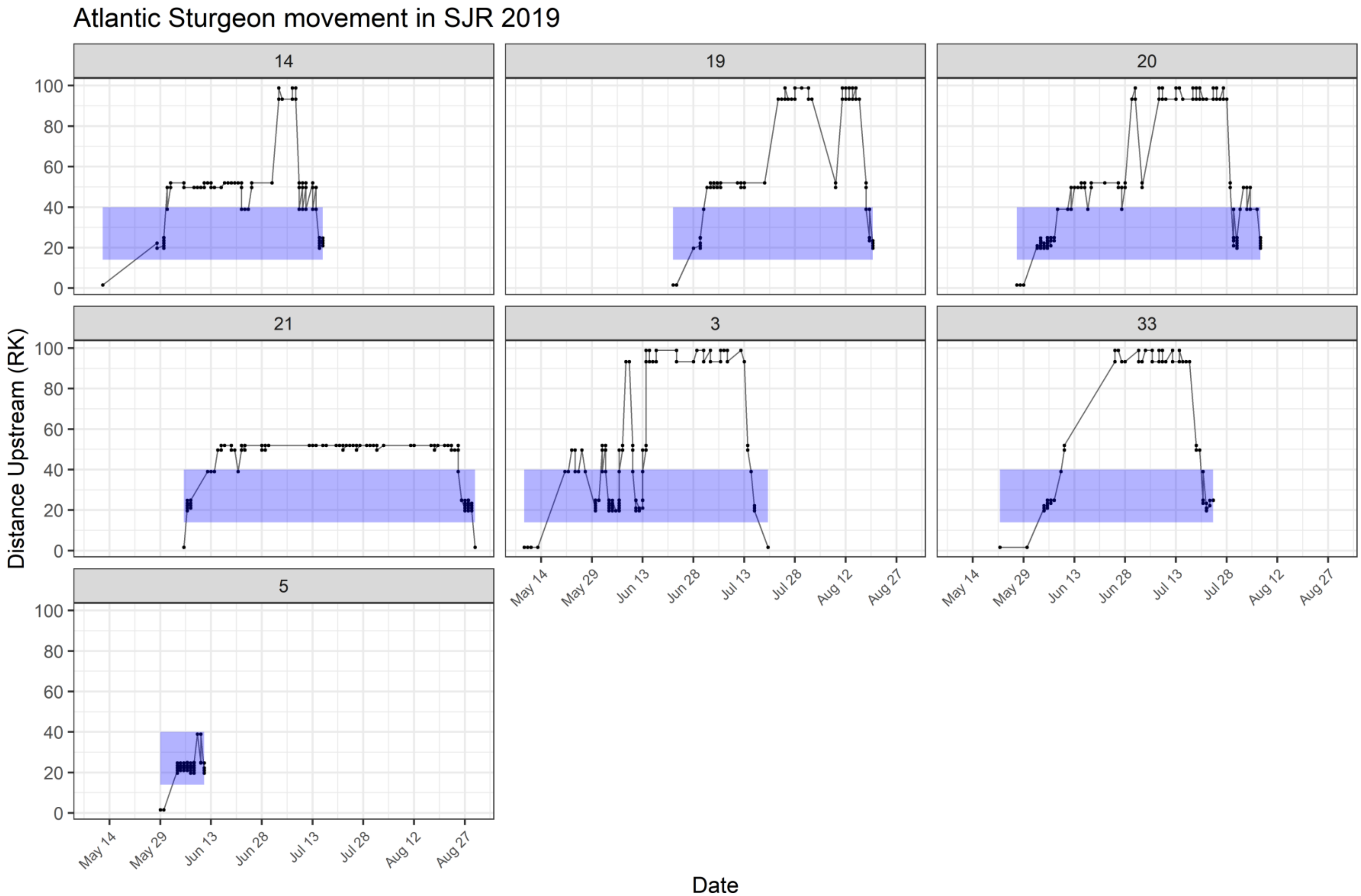

Figure A7. Individual movement histories of tagged Atlantic Sturgeon in the Saint John River in 2019. Distances given in river kilometers (RK). Long Reach is highlighted in blue.

APPENDIX B

Figure B1. Deployment histories of individual receivers across all study years. Deployment periods were obtained from receiver metadata provided by the receiver owners; where these data were missing, deployment period was based on first and last detections made by the receiver. Detections of Atlantic Sturgeon by each receiver are shown.

APPENDIX C

Table C1. Estimates of detection probability (p_i) and survival (Φ) of Atlantic Sturgeon tagged in 2013 based on the numbers of fish detected in each year (N_i) compared to the numbers detected in subsequent years ($N_{>i}$) and those detected both in the given year and following years ($N_{i+>i}$). The number of fish expected to be lost as a result of mortality or permanent emigration in each year is given (L_i).

Segment	N_i	$N_{>i}$	$N_{i+>i}$	p_i	se	N_{alive}	Φ	se	L_i
2013	13	13	13	1.00	0.00	15	1.00	0.00	0
2014	7	12	6	0.50	0.20	14	0.93	0.13	1
2015	7	11	6	0.55	0.20	13	0.92	0.13	2
2016	3	10	2	0.20	0.28	12	1.17	0.10	3
2017	7	9	6	0.67	0.19	11	0.88	0.12	5
2018	3	7	1	0.14	0.35	10	2.00	0.09	5
2019	7	1	1	1.00	0.00	7	0.70	0.00	8

Table C2. Estimates of detection probability (p_i) and survival (Φ) of Atlantic Sturgeon tagged in 2014 based on the numbers of fish detected in each year (N_i) compared to the numbers detected in subsequent years ($N_{>i}$) and those detected both in the given year and following years ($N_{i+>i}$). The number of fish expected to be lost as a result of mortality or permanent emigration in each year is given (L_i).

Segment	N_i	$N_{>i}$	$N_{i+>i}$	p_i	se	N_{alive}	Φ	se	L_i
2014	17	14	14	1.00	0	17	1.00	0.00	0
2015	5	13	4	0.31	0.23	16	0.96	0.11	1
2016	9	11	7	0.64	0.18	14	0.87	0.12	3
2017	5	11	5	0.45	0.22	11	0.77	0.12	6
2018	6	10	5	0.50	0.22	11	1.09	0.12	6
2019	8	3	1	0.33	0.47	11	2.00	0.11	6

Table C3. Estimates of the number of Atlantic Sturgeon expected to be alive and dead in each year of the study based on calculations from Tables C1 and C2, compared to the numbers detected and reported as mortalities in each year.

Segment	N_{alive}	N_{lost}	$N_{detected}$	$N_{reported}$
2013	15	0	15	0
2014	31	1	20	2
2015	29	2	4	0
2016	26	3	9	3
2017	22	4	9	1
2018	21	1	9	1
2019	18	3	8	1
TOTAL	**18**	**14**	**5**	**8**

Estimated survival = 56%
Known mortality = 25%
Unaccounted = 19%

Table C4. CJS models fit using randomly generated detection data. Terms in parentheses indicate factors across which survival (Φ) or detection probability (p) varied.

Model	**Parameters**	**AICc**	**ΔAICc**	**Weight**	**Deviance**
Φ (~1) *p* (~time)	20	488	0.00	0.61	242
Φ (~length) *p* (~time)	21	491	2.65	0.16	239
Φ (~sex) *p* (~time)	21	491	2.82	0.15	242
Φ (~1) *p*(~1)	2	493	5.26	0.04	292
Φ (~length) *p* (~1)	3	495	7.03	0.02	489
Φ (~sex) *p* (~1)	3	495	7.18	0.02	292
Φ (~time) *p*(~1)	20	532	44.23	0.00	286
Φ (~time + sex + length) *p* (~1)	22	537	49.32	0.00	482
Φ (~time) *p* (~time)	38	552	63.96	0.00	239
Φ (~time + sex + length) *p* (~time)	40	559	71.30	0.00	434

Table C5. Summary of highest ranking CJS model fit using randomly generated detection data (SE – standard error; p - probability).

Segment	**Φ ± SE**	***p* ± SE**
1	0.98 ± 0.01	0.17 ± 0.06
2	0.98 ± 0.01	0.15 ± 0.06
3	0.98 ± 0.01	0.37 ± 0.08
4	0.98 ± 0.01	0.15 ± 0.06
5	0.98 ± 0.01	0.25 ± 0.08
6	0.98 ± 0.01	0.00 ± 0.00
7	0.98 ± 0.01	0.27 ± 0.08
8	0.98 ± 0.01	0.07 ± 0.05
9	0.98 ± 0.01	0.07 ± 0.05
10	0.98 ± 0.01	0.18 ± 0.08
11	0.98 ± 0.01	0.00 ± 0.00
12	0.98 ± 0.01	0.19 ± 0.08
13	0.98 ± 0.01	0.08 ± 0.05
14	0.98 ± 0.01	0.04 ± 0.04
15	0.98 ± 0.01	0.04 ± 0.04
16	0.98 ± 0.01	0.33 ± 0.11
17	0.98 ± 0.01	0.21 ± 0.09
18	0.98 ± 0.01	0.18 ± 0.09
19	0.98 ± 0.01	0.13 ± 0.08

Table C6. Burnham models fit using randomly generated detection data. Terms in parentheses indicate factors across which survival (Φ) or detection probability (p) varied.

Model	**Parameters**	**AICc**	**ΔAICc**	**Weight**	**Deviance**
S (~time) *p* (~1)	23	695	0.00	0.72	428
S (~time + sex + length) *p* (~1)	25	697	2.05	0.26	635
S (~time) *p* (~time)	41	702	6.92	0.02	371
S (~time + sex + length) *p* (~time)	43	707	11.58	0.00	579
S (~1) *p* (~time)	22	709	13.96	0.00	445
S (~sex) *p* (~time)	23	712	16.68	0.00	445
S (~length) *p*(~time)	23	712	16.77	0.00	656
S (~1) *p* (~1)	4	721	25.63	0.00	501
S (~sex) *p* (~1)	5	723	27.59	0.00	501
S (~length) *p* (~1)	5	723	27.69	0.00	712

* r(~1) and F(~1) for all

Table C7. Summary of highest ranking Burnham model fit using randomly generated detection data.

Segment	**S ± SE**	***p* ± SE**
1	0.94 ± 0.04	0.23 ± 0.02
2	0.97 ± 0.03	0.23 ± 0.02
3	1.00 ± 0.00	0.23 ± 0.02
4	0.97 ± 0.03	0.23 ± 0.02
5	1.00 ± 0.00	0.23 ± 0.02
6	1.00 ± 0.00	0.23 ± 0.02
7	1.00 ± 0.00	0.23 ± 0.02
8	0.97 ± 0.03	0.23 ± 0.02
9	0.90 ± 0.05	0.23 ± 0.02
10	0.96 ± 0.04	0.23 ± 0.02
11	0.92 ± 0.05	0.23 ± 0.02
12	0.96 ± 0.04	0.23 ± 0.02
13	1.00 ± 0.00	0.23 ± 0.02
14	0.91 ± 0.06	0.23 ± 0.02
15	0.71 ± 0.10	0.23 ± 0.02
16	0.60 ± 0.13	0.23 ± 0.02
17	0.67 ± 0.16	0.23 ± 0.02
18	0.50 ± 0.20	0.23 ± 0.02
19	0.67 ± 0.27	0.23 ± 0.02
20	0.00 ± 0.00	0.23 ± 0.02