

Seasonal movements of striped bass *Morone saxatilis* in a large tidal and hydropower regulated river

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Abstract Following a failed spawning event in 1975 and the suspected absence of recent spawning by Striped Bass *Morone saxatilis* in the Saint John River, New Brunswick, the native Striped Bass population has been considered extirpated. Non-native migratory Striped Bass, however, still frequent the river, and a remnant, likely native, population may still exist. To characterize the movements and habitat use of adult Striped Bass still arriving to, and possibly residing within the Saint John River, Striped Bass ($n = 40$, size range, 40.5–90.9 cm FL) were captured throughout 2010–13 in the lower Saint John River, and surgically implanted with multi-year acoustic transmitters. Striped Bass were passively tracked using an array of 5–33 project specific receivers between 2010 and 14 and augmented by detections from the Ocean Tracking Network from 2011 to 13. Most tag detections recorded during the predicted spawning period occurred near locations suspected to have supported Striped Bass spawning historically. Only six tagged fish (15% of total) were detected outside of the river, five of which only left the river briefly during the spawning period and then returned. Tagged Striped Bass used four

overwintering sites within the Saint John River to which individuals demonstrated annual fidelity. Our findings suggest the presence of a local, possibly reproducing Striped Bass population that exhibits multi-annual residency within the river; however, successful spawning remains to be confirmed.

Keywords Striped bass · Acoustic tracking and tagging · Saint John River · Spawning · Migration · Overwintering

Introduction

Striped Bass *Morone saxatilis* (Walbaum) is an anadromous fish that ranges between many coastal rivers of Eastern North America from the St. Johns River in Florida, USA to the St. Lawrence River in Quebec, Canada (Scott and Crossman 1973; Scott and Scott 1988). Seasonal Striped Bass movements in many rivers, including the locations of spawning and overwintering grounds, are relatively well documented (e.g., Dudley et al. 1997: Savannah River; Carmichael et al. 1998: Roanoke River; Rulifson and Tull 1999: Shubenacadie River; Douglas et al. 2009: Miramichi River; Wingate et al. 2011: Chesapeake Bay). One notable exception, however, is the Saint John River (SJR), New Brunswick, Canada (Fig. 1) (see Andrews et al. (2017) for a complete review of *status quo* in SJR).

Striped Bass movements within the SJR have been increasingly limited by the construction of two main-stem hydro-electric facilities and their dams. Beechwood Dam, installed in 1957 (Ruggles and Watt

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1975), and Mactaquac Dam with the associated Mactaquac Generating Station (MGS) completed in 1968, effectively excluded Striped Bass from accessing ~200 km of habitat from the MGS upstream to a natural barrier at Grand Falls. River habitat and flow alterations caused by the MGS (Cunjak et al. 2011; Curry et al. 2015) are further suspected to have attenuated Striped Bass spawning downstream (Jessop 1995; COSEWIC 2012; DFO 2014; Bradford et al. 2015) (see review in Andrews et al. 2017 for list of all Saint John River spawning searches) and resulted in the suspected disappearance of the native Striped Bass population (COSEWIC 2012). Striped Bass occurring within the river are believed to be predominately seasonal migrants, though recent genetic data suggests that a distinct group of individuals occurs within the SJR and may be a remnant native population (Bentzen and Paterson 2008).

The MGS has recently come to a critical decision threshold regarding its future. An aggressive Alkali-Aggregate reaction (AAR; Hayman et al. 2010) has reduced the predicted 100-year life expectancy of the MGS and prompted an accelerated decision on whether to remove, rebuild or repair the concrete structure, a task requiring completion by 2030. In December 2016, a decision was made to refurbish the existing Mactaquac Dam and powerhouse, extending its service life to 2068. Thus, spawning requirements for Striped Bass (i.e., flow velocities and temperature regime) downstream of the MGS must be understood. To better describe the status, and the potential for population recovery of Striped Bass in the SJR, a long term acoustic tracking program was established in 2010.

Given the current understanding of Striped Bass in the SJR, we examine the *status quo* hypothesis that all Striped Bass frequenting the SJR are feeding migrants from external source populations and no native spawning population persists. If true, we predicted that: 1) no individuals would be detected continuously and exclusively within the SJR throughout the entire year or over multiple consecutive years; 2) Striped Bass would exit the river in the spring prior to the spawning period in order to spawn in their natal rivers, and no upstream movements would occur in the SJR at that time; and 3) Striped Bass would arrive in the SJR in the early summer after spawning, and leave in the fall or following spring if they have overwintered in the SJR. A failure of one or more of these predictions would lend support to an alternative hypothesis that the SJR Striped Bass

population includes individuals that are resident, and perhaps native, to the river.

Saint John River

The SJR, New Brunswick, Canada, drains an extensive watershed spanning 55,000 km² within the provinces of New Brunswick and Quebec and the State of Maine (Fig. 1). The SJR extends from its headwaters in the Little Saint John Lake on the Maine-Quebec border 673 km to the mouth in the city of Saint John where it empties into the Bay of Fundy. The river is tidally influenced to ~130 km upriver, (near the city of Fredericton; Cunjak et al. 2011), with saline water intrusion occurring to the village of Gagetown, ~70 km from the river mouth (Carter and Dadswell 1983; Fig. 2). The lower SJR encompasses numerous large lakes and bays that are readily accessible to Striped Bass (Fig. 2). The river has three main stem dams, with the furthest downstream and the largest, the MGS, completed in 1968 (Ruggles and Watt 1975). Fish passage at the MGS is arranged via a trap and truck operation where Atlantic salmon *Salmo salar* and Gaspereau (a combination of alewife *Alosa pseudoharengus* and blueback herring *Alosa aestivalis*) are actively passed upstream; other fish species, if captured at MGS, are returned downstream of the dam. The section of the SJR between the City of Fredericton and the MGS is relatively shallow (<7 m; Curry and Munkittrick 2005); water temperature and flow rates are influenced by cold-water releases from the MGS (R.A. Curry, unpublished data) as well as variable and rapidly changing discharges for power production.

Methods

Striped Bass ($n = 40$; FL mean 61.2 cm, range, 40.5–90.9 cm) were surgically implanted with Vemco acoustic tags (Table 1) and tracked for a four-year study period from 2010 to 05-15, when the first fish was tagged, to 2014–05-14 (which we defined as the end of the 2014 wintering period within the SJR). Tag weight (range 11–34 g) never exceeded 0.006% of fish weight (range 0.7–10.5 kg; Table 2) and is not considered to have effects on subsequent behavior (Jepsen et al. 2003). In 2010, Striped Bass were tagged in Swan Creek ($n = 19$) and in Otnabog Lake

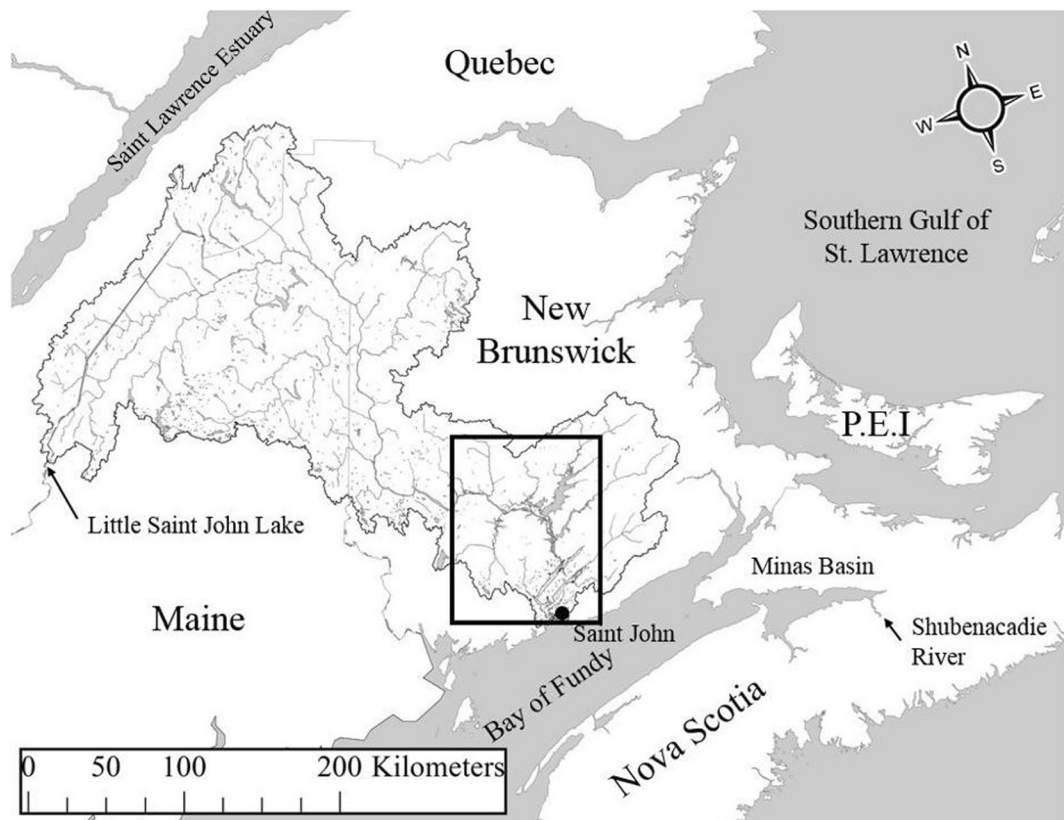


Fig. 1 The Saint John River watershed, New Brunswick, expanding 55,000km² into Quebec and Maine. The black

rectangle delineates the main study area; some detections however, were incurred in the Bay of Fundy and Minas Basin

($n=4$) after being captured in the commercial Gaspereau fishery (Fig. 3). In 2011, Striped Bass were tagged at Harts Lake (Fig. 3; $n=3$) from the commercial Gaspereau fishery and the fish lift of the MGS (Fig. 3; $n=1$). All fish tagged in 2012 were captured in the commercial Gaspereau fishery in White's Cove in Grand Lake (Fig. 3; $n=10$) and in 2013 all tagged fish were captured at the MGS fish lift (Fig. 3; $n=3$). Tagging followed standard surgical tagging procedures described in Wingate and Secor (2007) using 40 mg/L clove oil (nine-parts ETOH, one-part clove oil) as anesthetic and three monofilament sutures.

Tagged Striped Bass were tracked with a Vemco VR2W receiver array distributed along the SJR from the river mouth at Reversing Falls upstream to the MGS. The receivers were moored on the river bottom and were annually retrieved to download detection data. The VR2W array for the project included ($n=5$) units in 2010, ($n=30$) units in 2011, ($n=29$) units in 2012, ($n=33$) units in 2013, and ($n=10$) units in 2014 that

were successfully retrieved and downloaded (Fig. 3). Additional tracking data were received from the Ocean Tracking Network (OTN - <http://oceantrackingnetwork.org/>). OTN receivers detected tagged Striped Bass both within and outside the river in 2011 ($n=21$), 2012 ($n=23$), and 2013 ($n=3$). No OTN detection data was available for Striped Bass in 2010 or 2014 prior to the end of the study.

Receiver coverage in 2010 was spatially restricted, as the aim of the study at the time was to characterize Striped Bass occurrence and habitat use in selected watercourses of Canadian Forces Base (CFB) Gagetown in accordance with the requirement to manage species at risk that potentially frequent federally owned property. As such, receivers were placed in watercourses near CFB Gagetown, namely Swan Creek Lake and Otnabog Lake (Fig. 3). In 2011–2014, the tracking effort was expanded to include the remainder of the areas accessible to Striped Bass within the SJR and was supplemented with data received from the OTN both within and outside of the Saint John River.

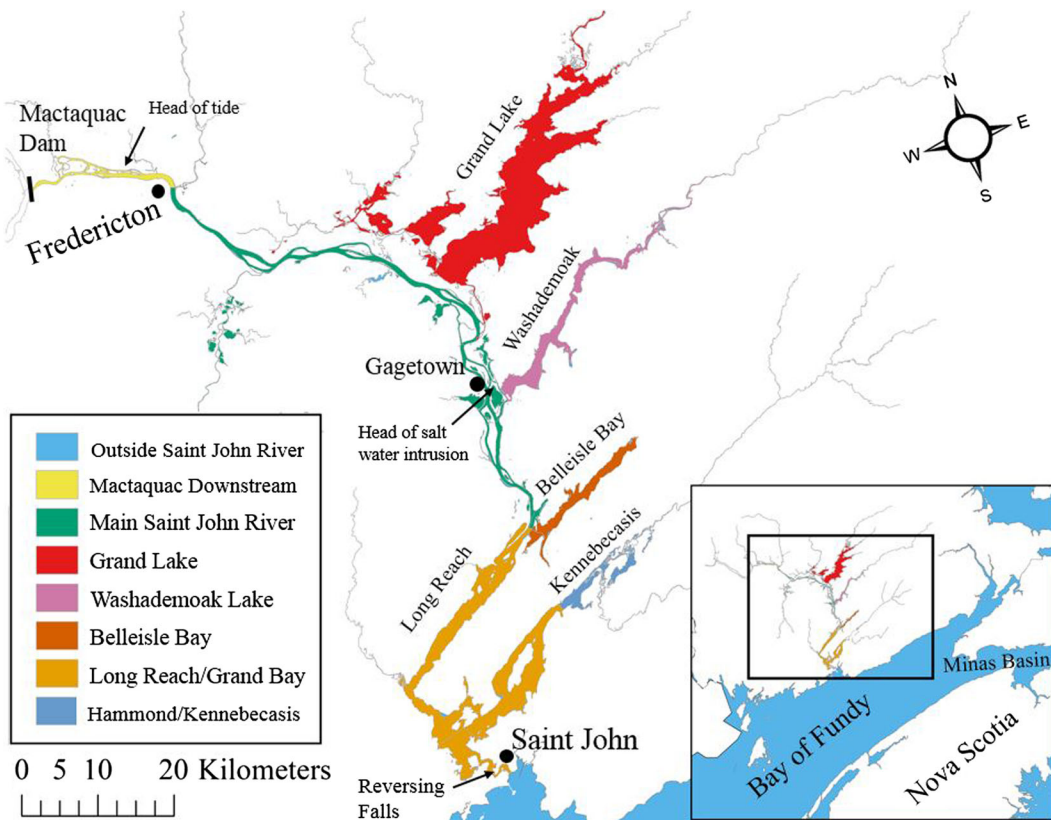


Fig. 2 Map of the Saint John River, Bay of Fundy and Minas Basin indicating the seven major areas into which the region was subdivided to analyze Striped Bass movements

Due to the variability in receiver placement and scale of the studied water body, receiver locations were subdivided into seven areas for analysis. These areas included the area downstream of Mactaquac Dam, the main SJR, Grand Bay/Long Reach, Grand Lake, Washademoak Lake, Belleisle Bay, Kennebecasis Bay and the area lying outside the SJR (i.e., Bay of Fundy and Minas Basin; Fig. 3). For the analysis, a tagged Striped Bass was assumed to have remained in the same area in which it was detected until it was

detected in another predefined area. The first week of detection data for each tagged fish was omitted to account for possible tagging related impacts on Striped Bass behavior.

Results

All but two of the 40 tagged Striped Bass were detected following release in this study.

Table 1 Description of vemco acoustic tags surgically implanted in Striped Bass between 2010 and 2013

Model	# Deployed	Tag life (days)	Transmission (db)	Detection range (m)	Ping rate (s)
V13-1H	7	191	153	406–700	30–90
V13-1H	7	366	153	406–700	60–180
V16-4 L	18	858	152	384–672	30–90
V13-1 L	4	1088	152	384–672	30–90
V16-6 L	4	2977	152	384–672	60–180

Table 2 Acoustic tags ($n = 22$) included in the analysis including tagging location, date, tag type and Striped Bass metrics

Tag ID	Tagging location	Year	FL (cm)	Weight (kg)	Tag type	Tag life (days)	Days at large	Detections
48328	Swan Creek Lake	2010	66.0	3.86	V16 - 4 L	859	810	31762
48329	Swan Creek Lake	2010	71.1	5.17	V16 - 4 L	859	767	227
48331	Swan Creek Lake	2010	50.2	1.59	V16 - 4 L	859	511	9313
48332	Swan Creek Lake	2010	49.6	1.36	V16 - 4 L	859	829	4055
48334	Swan Creek Lake	2010	65.3	3.86	V16 - 4 L	859	870	24553
48337	Swan Creek Lake	2010	53.1	1.95	V16 - 4 L	859	867	53146
48338	Swan Creek Lake	2010	46.8	1.36	V16 - 4 L	859	868	22748
48339	Swan Creek Lake	2010	52.1	3.63	V16 - 4 L	859	789	404
48340	Swan Creek Lake	2010	49.0	1.50	V16 - 4 L	859	783	1649
44167	Harts Lake	2011	79.5	6.40	V16 - 4 L	859	849	68794
44168	Harts Lake	2011	87.5	10.21	V16 - 4 L	859	26	987
44175	Mactaquac hatchery	2011	85.5	9.16	V16 - 4 L	859	746	30621
44169	Grand Lake	2012	56.4	2.95	V16 - 4 L	859	599	106050
62179	Grand Lake	2012	54.8	2.40	V13 - 1 L	1088	30	377
56720	Grand Lake	2012	72.3	5.90	V13 - 1H	191	217	4135
56721	Grand Lake	2012	56.9	2.54	V13 - 1H	191	185	4410
56722	Grand Lake	2012	57.2	3.18	V13 - 1H	191	101	1347
56727	Grand Lake	2012	65.5	4.63	V13 - 1H	366	381	5286
62172	Grand Lake	2012	79.1	6.71	V13 - 1 L	1088	572	14539
32645	Mactaquac hatchery	2013	83.6	9.30	V16 - 6 L	2977	63	2232
32647	Mactaquac hatchery	2013	76.5	10.52	V16 - 6 L	2977	37	1001
32648	Mactaquac hatchery	2013	90.9	9.66	V16 - 6 L	2977	88	2653

Tags not shown ($n = 18$) either incurred too few detections or were not detected in enough different location to make observations on movements

Of the 38 tagged Striped Bass detected within the SJR, 17 stopped producing detection records 3–13 months prior to the estimated end of tag battery life. It is unknown if these tags reached the end of their battery life prematurely or if those individuals were captured, died, lost their tag, or left the Saint John River without being detected on any of the receivers downstream of their last known whereabouts. The majority of Striped Bass that stopped producing detections prior to the estimated end of tag battery life ($n = 13$, 76%) were tagged in 2010, i.e., the period of the study during which receiver coverage was the lowest. The following analysis considers data derived from 22 tagged Striped Bass (some of which disappeared prior to expected battery expiry) that were detected with sufficient frequency and duration through the SJR to draw insight into individual movements (Table 2).

Striped Bass ($n = 8$) exhibited upstream movements towards suspected spawning areas during the spring spawning period (Tag ID: 48328, 48,337, 48,331,

48,338, 44,175, 44,167, 56,727, 44,169; Fig. 4), ranging from May 12 to June 21 for Canadian populations (Rulifson and Dadswell 1995). During this time, these individuals were detected between the City of Fredericton and the MGS (Fig. 2). Tagged Striped Bass arrived upstream as early as May 18 and departed by June 30 (2011: $n = 4$, June 8–29; 2012: $n = 5$, May 17 to June 30; 2013: $n = 3$, May 18 to June 20). Of the tagged fish migrating to the MGS in spring, four individuals (Tag ID: 48328, 48,338, 48,337, 44,175; Fig. 4) were observed in two consecutive years. All Striped Bass exhibiting this pattern of movement were of spawning size (range, 40.5–90.9 cm; estimated age $\geq 4+$). Striped Bass ($n = 5$) were detected on OTN receivers outside the SJR during the spawning period (2011: $n = 2$, May 14–June 19; 2012: $n = 2$, May 1 – June 10; 2013: $n = 1$, May 8 – June 10). One of these Striped Bass (Tag ID: 62172; Fig. 4) was detected in the Minas Basin, Nova Scotia and was likely headed for Shubenacadie River (a known spawning location for Nova Scotia origin Striped

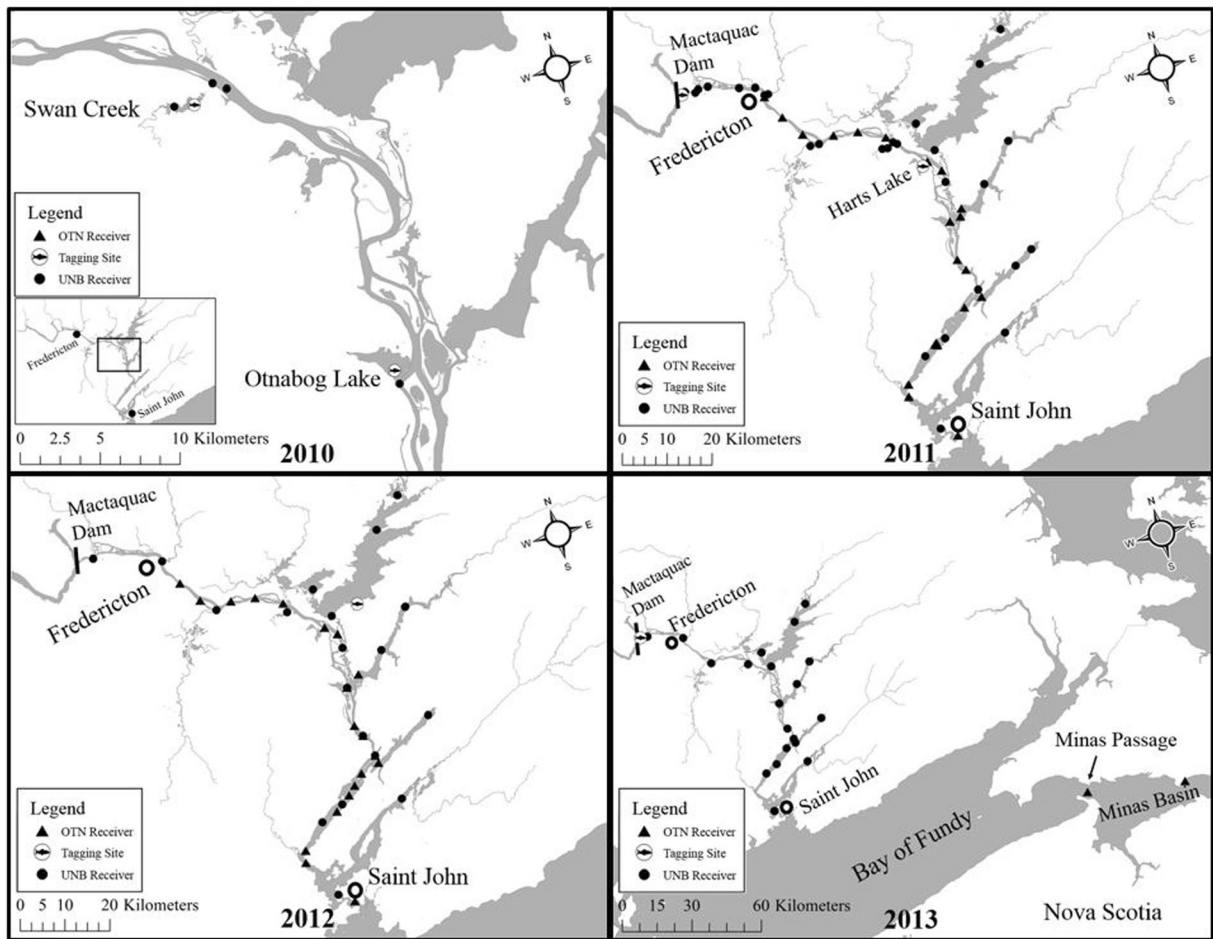


Fig. 3 Location of Striped Bass tagging (fish circles) as well as project specific receiver placement (black circles) and OTN receivers which detected tagged fish (black triangles) along the Saint John River from 2010 to 2013. Receiver coverage in the Saint

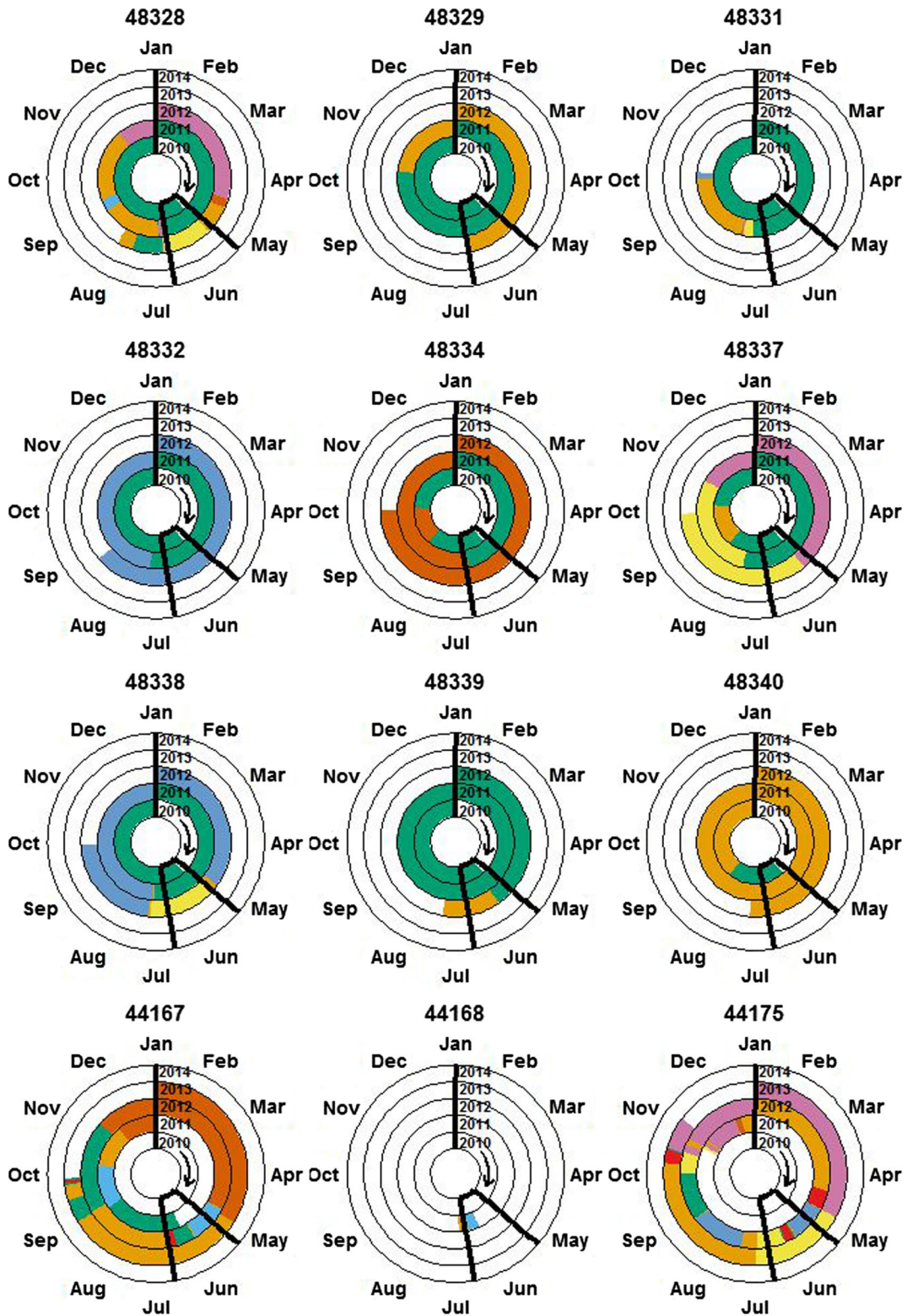
John River was minimal in 2010 as the aim of the study at the time was to characterize movement of Striped Bass surrounding the CFB Gagetown. Receiver placement for 2014 (2014-01-01 to 2014-05-14) was the same as in 2013

Bass) prior to returning to the SJR (June 14, 2014; after 37 days, outside of the SJR). Similarly to this individual, all other Striped Bass that left the SJR (Tag ID: 44167, 44,168, 62,179, 56,720; Fig. 4) during the spawning period were later detected returning to the river (13–41 days after departure).

Throughout summer and fall (June 16–Oct 31), tagged Striped Bass displayed three general patterns of movement (Fig. 4). In summer, some (23% $n=5$) spent time between Long Reach and Reversing Falls, while another group of Striped Bass (18% $n=4$) travelled to the Kennebecasis (Figs. 2 and 4). In the fall (Sept–Oct), Striped Bass ($n=3$) migrated up stream to the base of the MGS. These regions overlap with popular Striped Bass fishing grounds in the SJR and are thought to be key feeding grounds for the species.

During winter (Nov 1–May 14 across all study years; Fig. 4), 11 individuals (50%) used Washademoak Lake ($n=4$, 36%), Belleisle Bay ($n=5$, 46%), and Grand Lake ($n=2$, 18%). In addition, Striped Bass ($n=2$; Tag ID: 48332, 48,338) appeared to winter somewhere in the upper Kennebecasis Bay suggesting presence of a previously undocumented overwintering area. A single individual was detected consistently overwinter near Victoria Beach (Long Reach, ~km 27 upstream from

Fig. 4 Polar coordinate chart of individual Striped Bass ($n=22$; Tag IDs marked above) movements by area, day and year arranged from the centermost circle to the outermost in a clockwise fashion. Colors within the chart indicate the detection period and area of occupancy in correspondence to Fig. 2. The black section outlined at the bottom right of each plot indicates the Canadian range of spawning (May 12–June 21; Rulifson and Dadswell 1995). Plots are arranged in order of tagging



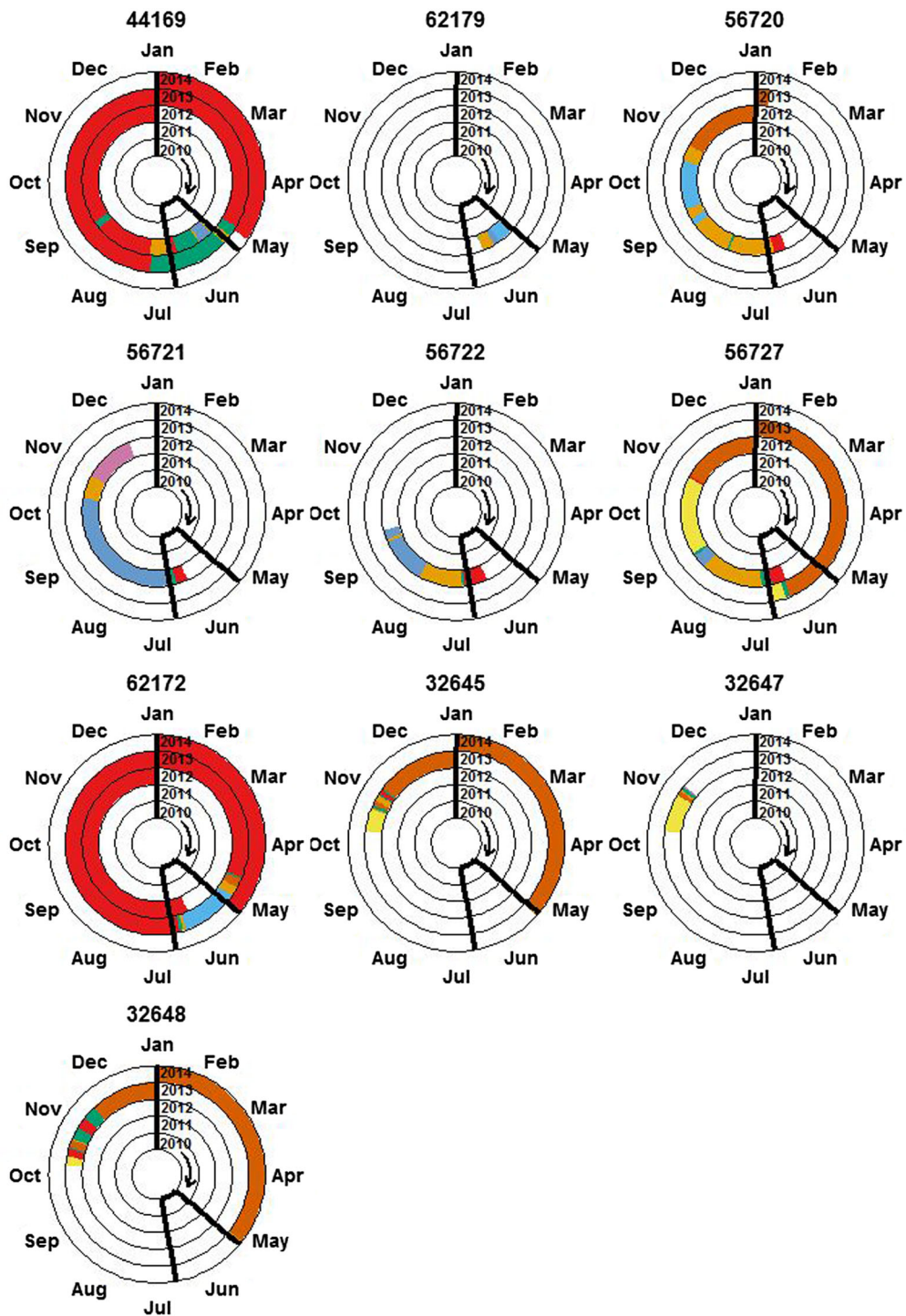


Fig. 4 (continued)

river mouth; Tag ID: 48340; Fig. 2). Striped Bass detected over multiple wintering periods ($n = 4$; Tag ID: 48334, 44,167, 44,169, 62,172; Fig. 4) were observed to

return to the same overwintering site in consecutive years. Interestingly, overwintering site fidelity to the SJR was also observed in Striped Bass ($n = 2$; Tag ID:

44167, 62,172) that left the SJR during the spawning period. Overwintering habitats were often deeper areas of the river, as suggested by Dadswell (1976) though it is unknown if the accessible deep water was in fact utilized. Due to inconsistency in receiver placement, true overwintering duration for Striped Bass could not be determined. However, Striped Bass appear to arrive on the wintering grounds in late October to early November as water temperature drops below 10 C and remain in these locations for a period of ~6 months until late April/ early May.

Discussion

Striped Bass exhibited migrations that support the prevailing hypothesis that the SJR hosts visitors from external non-native Striped Bass populations. However, most of the tracked Striped Bass supported an alternative hypothesis that a resident, and possibly native population persists in the SJR. During this study, only six tagged Striped Bass ventured out of the SJR, five of which did so only during the spawning period. One of these emigrants was detected in the Minas Basin, Nova Scotia, only six days after emigrating from the SJR and re-entered the SJR only six days after that. Shubenacadie River is a known spawning location for Nova Scotia origin Striped Bass (Rulifson and Dadswell 1995), and it is plausible that this individual was migrating to Shubenacadie to reproduce. All Striped Bass that exited the SJR promptly returned, indicating the SJR likely provides an important habitat even for those fish exhibiting anadromous characteristics. With further study, the SJR may need to be considered as important habitat for a contingent of SJR resident Shubenacadie origin Striped Bass.

Importantly, the majority of tagged Striped Bass [$n = 34$ (85% of tagged fish)] were never detected outside the SJR and were unlikely to be non-native migrants. Tagged Striped Bass [$n = 8$ (20% of tagged fish)] sought upstream habitat within the SJR during the spring spawning period [i.e., May 12–June 21; Rulifson and Dadswell 1995] and Striped Bass ($n = 4$) exhibit this behavior for at least two consecutive years. We do not know if Striped Bass attempt spawning downstream from the MGs or if such attempts are successful. What is clear is that the presence of tagged Striped Bass at a historical spawning location during the suspected spawning period requires further evaluation. The capture of eggs/larvae, will be necessary to confirm if spawning

activities continue. Alternatively, capture of ripe adult Striped Bass, but no eggs/larvae may further indicate that the fish migrate to the area with the intention of spawning. It is also possible that the Striped Bass migrating upstream to the MGS in the spring are following prey, such as Alewife or Blueback Herring (Andrews et al. 2018). The spawning migration timing of these Alosids, loosely coincides with the typical spawning migration of Striped Bass, peaking in late May or early June (Ingram 1980; Ingram 1985; Jessop 2003). Alosids form the most common prey item for Striped Bass when present in the downstream vicinity of the MGS (Andrews et al. 2017) and may in part motivate upstream migration.

Tagged Striped Bass often occupied areas between Long Reach and Reversing Falls in summer, likely key feeding areas. In the late summer and fall, a few Striped Bass were detected re-ascending the river to Mactaquac Dam. In this location, Striped Bass could be benefiting from the release of cooler, hypolimnetic, waters from the reservoir as a thermal refuge in late summer but their main motivation may also be to feed on juvenile Alewife or Blueback herring descending from the reservoir (Andrews et al. 2017, 2018). Striped Bass were detected occupying deeper parts of the river during winter; however, avoidance of tidal currents may be more important than water depth given the selection of tributary embayments. Lower flow environments may reduce energy expenditure and the chance of individuals being swept out to marine environments where sub-lethal temperatures may exist.

As we improve our understanding of the SJR Striped Bass, it is apparent that the SJR is far more complicated than current reports suggest (COSEWIC 2012; Bradford et al. 2015). These new findings demonstrate that 1) Striped Bass spawning migrations may persist within the SJR; 2) Shubenacadie River origin Striped Bass may reside year round in the SJR except for the spawning period; 3) Striped Bass appear to overwinter in four major locations; and 4) numerous Striped Bass that overwinter within the SJR appear to exhibit overwintering site fidelity. Future studies will be necessary to characterize contingents of Striped Bass inhabiting the SJR, identify and confirm spawning locations, characterize possible impacts of hydropower operations to spawning success, and thoroughly describe Striped Bass wintering areas and behavior. The SJR should be recognized not only as supporting its own resident population but also as an important habitat for Striped Bass originating from multiple populations within the Bay of Fundy designatable unit.

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References

- Andrews SN, Linnansaari T, Curry RA, Dadswell M (2017) The misunderstood striped bass of the Saint John River, New Brunswick: past, present, and future. *North Am J Fish Manage* 37:235–254
- Andrews SN, Zelman K, Ellis T, Linnansaari T, Curry RA (2018) Diet of striped bass and muskellunge downstream of a large hydroelectric dam: a preliminary investigation into suspected Atlantic Salmon smolt predation. *N Am J Fish Manag* 38(3): 734–746
- Bentzen P, Paterson IG (2008) Genetic analysis of striped bass collected by Kingsclear first nation in the Saint John River. New Brunswick. Report to the Department of Fisheries and Oceans, Dartmouth, Nova Scotia
- Bradford RG, Halfyard EA, Hayman T, LeBlanc, P (2015) Overview of 2013 Bay of Fundy Striped Bass biology and general status *Can Sci Ad Sec Res Doc* 2015/024
- Carmichael JT, Haeseker SL, Hightower JE (1998) Spawning migration of telemetered striped bass in the Roanoke River. *North Carolina Trans Am Fish Soc* 127:286–297
- Carter JCH, Dadswell MJ (1983) Seasonal and spatial distributions of planktonic Crustacea in the lower Saint John River, a multi-basin estuary in New Brunswick, Canada. *Estuaries* 6: 142–153
- COSEWIC (Committee on the Status of Endangered Wildlife in Canada) (2012) COSEWIC assessment and status report on the striped bass (*Morone saxatilis*) in Canada. COSEWIC, Canadian Wildlife Service Environment Canada, Ottawa
- Cunjak RA, Monk WA, Haralampides K, Baird DJ (2011) River habitats. Pages 57-75 in the Saint John River: a state of the environment report. Canadian rivers institute, Fredericton, NB, Canada
- Curry RA, Munkittrick KR (2005) Fish community responses to multiple stressors along the Saint John River, New Brunswick, Canada. *Am Fish Soc Symp* 45:505–521
- Curry RA, St-Hilaire A, Dugdale S, Monk WA (2015) Interim report on the predicted hydrological regime: future discharge at Fredericton (station 01AK003). Canadian rivers institute, University of new Brunswick, Mactaquac aquatic ecosystem study report series 2015-001, Fredericton, New Brunswick
- Dadswell MJ (1976) Notes on the biology and resource potential of striped bass in the Saint John estuary. In: Dadswell MJ (ed) Baseline survey and living resource potential study of the Saint John River estuary. Vol III. fish and invertebrates. Huntsman Marine laboratory, St Andrews, New Brunswick, pp 1–20
- DFO (Department of Fisheries and Oceans) (2014) Recovery potential assessment for the Bay of Fundy Striped Bass *Morone saxatilis* designatable unit *Can Sc Ad Sec Res Doc* 2014/053
- Douglas SG, Chaput G, Hayward J, Sheasgreen J (2009) Prespawning, spawning, and Postspawning behavior of striped bass in the Miramichi River. *Trans Am Fish Soc* 138(1):121–134. <https://doi.org/10.1577/T07-218.1>
- Dudley RG, Mullis AW, Terrell JW (1997) Movement of adult striped bass (*Morone saxatilis*) in the Savannah River Georgia. *Trans Am Fish Soc* 106(4)
- Hayman S, Thomas M, Beaman N, Gilks P (2010) Selection of an effective ASR-prevention strategy for use with reactive aggregate for the reconstruction of concrete structures at Mactaquac Generating Station. *Cem Concr Res* 40:605–610
- Ingram JH (1980) Capture and distribution of Atlantic salmon and other species at Mactaquac dam and hatchery, Saint John River, N.B., 1972-76. *Can data rep fish Aquat Sci* 181
- Ingram JH (1985) Capture and distribution of Atlantic Salmon in the Mactaquac area, Saint John River system, 1977-82. *Can Data Rep Fish Aquat Sci* 508
- Jepsen N, Schreck C, Clements S, Thorstad EB (2003) A Brief discussion of the 2% tag/bodymass rule of thumb. Aquatic telemetry: advances and applications. Proceedings of the Fifth Conference on Fish Telemetry held in Europe. Spedicato MT, Lembo G, Marmulla G, (eds) Ustica, Italy, 9–13 June 2003. Rome FOA/COISPA 2005. 295p
- Jessop BM, (1995) Update on striped bass status in scotia-Fundy region and proposals for stock management. Fisheries and Oceans Canada, Atl fish res doc 95/9, Halifax, Nova Scotia
- Jessop BM (2003) The effects of exploitation on alewife and blueback herring stock composition at the Mactaquac dam, Saint John River. *New Brunswick American Fisheries Society Symposium* 35:349–359
- Ruggles CP, Watt WD (1975) Ecological changes due to hydroelectric development on the Saint John River. *J Fish Res Board Can* 32:161–170
- Rulifson RA, Dadswell M (1995) Life history and population characteristics of striped bass in Atlantic Canada. *Tran Am Fish Soc* 124:477–507
- Rulifson RA, Tull KA (1999) Striped bass spawning in a tidal Bore River: the Shubenacadie estuary, Atlantic Canada. *Trans Am Fish Soc* 128:613–624
- Scott WB, Crossman EJ (1973) *Freshwater Fishes of Canada*. B Fish Res Board Can 184:693–698
- Scott WB, Scott MG (1988) *Atlantic fishes of Canada*. *Can Bull Fish Aquat Sci* 219:356–360
- Wingate RL, Secor DH (2007) Intercept telemetry of the Hudson River striped bass resident contingent: migration and homing patterns. *Trans Am Fish Soc* 136:95–104
- Wingate RL, Secor DH, Kraus RT (2011) Seasonal patterns of movement and residency by striped bass within a sub estuary of the Chesapeake Bay. *Trans Am Fish Soc* 140(6):1441–1450. <https://doi.org/10.1080/00028487.2011.630279>