RESTORATION POTENTIAL FOR REPRODUCTION BY STRIPED BASS (*Morone saxatilis*) IN THE SAINT JOHN RIVER, NEW BRUNSWICK

by

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Abstract

In 2012 the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) listed the Striped Bass (*Morone saxatilis*) of the Saint John River, New Brunswick, as endangered as part of the Bay of Fundy designatable unit. This listing was due to an apparent rapid collapse and subsequent absence of presumed native origin Striped Bass, juvenile recruitment, and spawning by the species following the completion of the large Mactaquac Dam in 1968. Expert reports hypothesized that alteration in the river flow and temperature regime imposed upon the Saint John River downstream from the Mactaquac Dam were responsible for the disappearance, however, no recovery efforts or exploratory studies were conducted, and the native Striped Bass population was deemed extinct. This dissertation explored the collapse of the Saint John River Striped Bass starting with a complete historic perspective of the species in the Saint John River and concluded with a possible means to recover the population that was once believed to be lost.

Within the chapters of this thesis I first summarize the history of Striped Bass in the Saint John River and explore why the current understanding of the species status needs to be updated. I locate and sample juvenile Striped Bass within the Saint John River for the first time since 1979, prove their native ancestry, and monitor their year class success. Native adult Striped Bass matching juvenile ancestry are tagged and tracked to determine the timing and location of their upstream spawning migration and the migrations of non-native adult Striped Bass within the Saint John River are also explored. I summarize information on Striped Bass winter ecology in Canada, then locate and describe four key winter habitats used by Striped Bass in the Saint John

River. Finally, I draw a possible connection between the regulated discharges at the Mactaquac Generating Station to the success of Striped Bass juvenile recruitment observed in the Saint John River over six consecutive years of sampling.

My general conclusion is that spawning by native Striped Bass in the Saint John River downstream of the Mactaquac Dam has been severely impacted, though not eliminated, by the regulated discharges resulting for power production. These discharge regimes have resulted in infrequently successful year classes, poor recruitment and possible spawning failures; however, spawning by surviving native origin Striped Bass may be recovered through the management of spring discharges. Managing for extended periods of moderate, sustained flow of sufficient volume and duration to keep Striped Bass eggs in suspension during the incubation period may restore successful Striped Bass spawning and juvenile recruitment in the Saint John River, New Brunswick.

Acknowledgements

Dr. Allen Curry and Dr. Tommi Linnansaari supervised my doctoral studies and together provided the perfect challenging yet supportive environment in which to complete this project. I want to sincerely thank Allen for providing thoughtful discussion and answers to my many questions, having enough faith in my work to allow me to develop my own research direction, methods, and explorations, and for carefully reading, commenting, and correcting all my chapters and articles. Allen has given me the confidence to take on large projects from start to finish and worked tirelessly to help me improve upon my writing. I also want to thank Tommi for always being interested in my progress and ideas and for always being available for discussions despite his chaotic schedule. Talking to Tommi has always meant learning something new, sharing a laugh, and has left me feeling the passion and motivation to keep on working. None of this project could have been accomplished without the kind and solid support of these two incredible supervisors. I also want to thank my committee, Rick Cunjak and Steve Peake, for their direction and helpful discussions concerning this ever-evolving project.

This doctoral work was conducted as part of the Mactaquac Aquatic Ecosystem Study (MAES) directed by Dr. Allen Curry to study the status of the Saint John River in anticipation of large changes being proposed for the Mactaquac Dam. This project was funded in part by New Brunswick Power and NSERC and I am very grateful to have had the unique opportunity to conduct such a large and important project within the Saint John River across the last 5 years. Throughout this project I also received support from the Canadian Rivers Institute (Create WATER) grant, the Wildlife Trust Fund (WTF), and the Atlantic Salmon Conservation Foundation (ASCF) without which this project would not have been nearly as successful.

As this project required a large field component, this work could not have been completed without the passionate and tireless work of all the CRI summer students and technicians. I would like to thank Mark Gautreau, Caitlin Tarr, and Ben Wallace for their help with vehicles and technical equipment and I would particularly like to thank our many students especially Chris Palmer, Lisa Rickard, Matt Miller, Eric Meng and Sarah Hirtle, and Post-doc Meaghan Bruce for spending long days in the field checking drift nets and retrieving receivers. Finally, I could not have completed this project without the help of the many hardworking graduate students on the MAES project including Daniel Arluison, Kaleb, Zelman, Antòin O'Sullivan, Bernhard Wegscheider and Amanda Babin who were always available to help with field work and research question no matter how large or complex. I also owe Dr. Wendy Monk and Bronwyn Fleet-Pardy a very sincere thank you for their patience in helping me with statistical and GIS questions, I learned so much and you both helped me streamline this project tremendously.

I want to extend a special thank you to Steve Delaney who took keen interest in my work from the first day on the river and provided a lifetime of Striped Bass angling knowledge and observations. Steve has proven time and again to be a living fisheries archive to which I returned for insight and information on countless occasions. Many adventures on the Saint John River were shared on his boat, often with fishing rod in hand. I also want to thank Danny Sears for first sparking my interest in Striped Bass so many years ago on the Stewiacke River and perhaps sincerely, or maybe in jest, suggesting that I study the species for my PhD. Regardless, I fell for the joke and he has kept in touch to provide support every step of the way.

I am also very grateful to have had the support of Dr. Mike Dadswell who wrote so many of the first and most influential papers documenting and describing Striped Bass on the Saint John River. His kindness and incredible knowledge were always freely given, and his history of work formed the foundation upon which this project was built. Without his original explorations, hard work, and thoughtful guidance this project would hardly have achieved any of what is presented within these covers.

I must also sincerely thank Scott Young and his late father Keith Young who graciously allowed me to accompany them at their family commercial fishing operation. Both were always kind and welcoming to me and any accompanying students, and openly shared their incredible depth of knowledge and love for the Saint John River. Keith fished with me until his very final season and his perspective, knowledge and love for the river will be irreplaceable.

Finally, I would like to sincerely thank my family for their continuous support throughout the last 5 years, I could not have completed this project without them.

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General Introduction and Background

1.1 Introduction

The Saint John River, New Brunswick, Canada, once hosted a world-renowned Striped Bass (*Morone saxatilis*) population supporting a trophy recreational and a moderate commercial fishery. The species ranged throughout the river, spawned amongst the islands near the City of Fredericton (Adams 1873) and attracted anglers to the famed Reversing Falls in the City of Saint John. Following the completion of the Mactaquac Dam and associated Mactaquac Generating Station in 1968, an observed spawning failure in 1975 (Dadswell 1975), a general lack of juvenile recruitment (DFO 2007), and the seeming absence of genetically distinct Striped Bass by the mid 90s (Wirgin et al. 1995), the Saint John River Striped Bass was largely regarded as having disappeared. Striped Bass occurring within the Saint John River have since been assumed to originate from either the United States or Nova Scotia (Wirgin et al. 1995) arriving seasonally during summer feeding migrations, occasionally overwintering, and then departing to spawn in natal rivers in spring.

More recently, Bentzen and Paterson (2008) revealed that Striped Bass with a unique genetic signature not matching any recognized Striped Bass population were present in the Saint John River. This discovery raised the question of whether native Striped Bass could persist, whether and where these individuals may be spawning, and what habitats within the Saint John River may be critical to their survival and recovery. However, simultaneous skepticism regarding possible alternative sources for these Striped Bass of unknown origin appeared to preclude interest and study. Despite findings by Bentzen and Paterson (2008), the continued absence of juveniles, spawning, and egg production in the Saint John River resulted in the native Striped Bass being listed as endangered by COSEWIC (2012) as a part of the Bay of Fundy Designatable Unit for Striped Bass management. This conservation status upgrade was the result of the Bay of Fundy, once having supported three unique reproducing Striped Bass populations (Shubenacadie River and Annapolis River, Nova Scotia, and Saint John River, New Brunswick), now being reduced to a single reproducing population in the Shubenacadie River.

In 2014, the Mactaquac Generating Station on the Saint John River (then only 46 years old) was prematurely reaching the end of its service life (predicted to last ~100 years) due to an aggressive alkali aggregate reaction affecting concrete structures (Hayman et al. 2010). The decision was thus announced that the New Brunswick Power utility would decide between three possible options: to remove, rebuild, or refurbish the existing structure. In response, the Mactaquac Aquatic Ecosystem Study (MAES) was initiated by the Canadian Rivers Institute at the University of New Brunswick to study the Saint John River and better inform decisions made by New Brunswick Power by establishing a river wide baseline under the current hydroregulation scenario.

The Mactaquac Dam and its effects on river temperature and flow regimes over historic Striped Bass spawning grounds have long been suspected (Bradford 2015; DFO 2014; COSEWIC 2012). As a result, the opportunity was seized to study Striped Bass in the Saint John River, locate possible spawning grounds (should they still exist) and determine how the species may be affected under the three proposed future scenarios for the Mactaquac Dam and Mactaquac Generating Station. This thesis dissertation entails all Striped Bass related work conducted as part of the first phase of MAES taking the reader through the entire history of Striped Bass on the Saint John River up to the present day.

Through this study, my co-authors and I determine the origin of Striped Bass inhabiting the Saint John River, describe their movements throughout the system, assess a historic spawning location subject to regulated flow, and provide a method for possible Striped Bass recovery. It is our hope that future researchers will build upon this work with the goal of one day recovering the Saint John River Striped Bass.

1.2 Objectives of and purpose for Dissertation

The objective of this dissertation is to determine the status of the native Saint John River Striped Bass population, and if it is indeed "endangered", then determine mitigation measures that may promote population recovery. To establish the status of the Striped Bass population, I (a) conducted a comprehensive historical review, (b) located juvenile Striped Bass within the Saint John River, (c) confirmed the existence of a remnant native Saint John River Striped Bass population with help from my co-authors using genetic methods, (d) used native juvenile age classes to determine years of successful recruitment, and (e) monitored the movements of the adult Striped Bass to confirm their residency in the river. To establish measures to mitigate population decline and promote Striped Bass recovery, I (a) monitored the spawning migration of native origin adult Striped Bass, (b) recorded juvenile recruitment strength over multiple years, (c) compared juvenile recruitment to discharge at the Mactaquac Dam during the spawning period, and (d) made recommendations for discharge regimes that may promote spawning.

The overarching goal of this dissertation is to improve management decision making with the goal of recovering the native Striped Bass population in the Saint John River, New Brunswick. Specific recommendations include (a) regulation of discharge at the Mactaquac Dam to provide temperature and discharge conditions throughout the Striped Bass spawning period that are conducive to spawning and subsequent egg and larval survival, and (b) designing regulations for protecting Striped Bass that may be frequently removed by fisheries harvest before reproducing successfully, particularly following the completion of the Mactaquac Dam in 1968. Finally, these recovery actions should include both egg and juvenile Striped Bass monitoring to gage reproductive success and juvenile recruitment under appropriately managed flow regimes.

1.3 Overview of Chapters

1.3.1 Chapter 1: The Misunderstood Striped Bass of the Saint John River, New Brunswick: Past, Present, and Future

This complete literature review summarises all available information pertaining to Striped Bass (*Morone saxatilis*) on the Saint John River, New Brunswick (published in NAJFM; S.N. Andrews, T. Linnansaari, R.A. Curry and M.J. Dadswell. (2017) The Misunderstood Striped Bass of the Saint John River, New Brunswick: Past, Present, and Future, North American Journal of Fisheries Management, 37:1, 235-254, DOI: 10.1080/02755947.2016.1238424). This review explores the history of Saint John River Striped Bass from the very first historic account until the 2012 COSEWIC report detailing what is known and why the population collapsed and offers a new interpretation of the Striped Bass population status. This chapter most importantly demonstrates why the conclusions reached during the 2012 COSEWIC assessment may have been incorrect and lays the framework for all subsequent Striped Bass research on the Saint John River.

S. N. Andrews located all historic articles, compiled the commercial fisheries data and wrote the article with guidance from M. J. Dadswell who conducted many of the influential studies on the Saint John River in the 1970s and 80s. T. Linnansaari and R. A. Curry were the primary editors and acquired funding for the project.

Erratum:

The Canadian record Striped Bass of 28.58 kg captured at Reversing Falls on August 15, 1979 was not confirmed to be of Saint John River origin. This Striped Bass was unlikely to be of Saint John River origin due to its size (Dadswell 1982) and most probably originated from the United States

1.3.2 Chapter 2: Interannual Variation in Spawning Success of Striped Bass (*Morone saxatilis*) in the Saint John River, New Brunswick

In this chapter I located, monitored juvenile and sub-adult Striped Bass (*Morone saxatilis*) within the Saint John River, New Brunswick, from 2014-2019. The observed Striped Bass ranged in age from 1-8 years, represented 6-year classes and were nearly all genetically distinct from both Shubenacadie-origin and US-origin populations representing a native genotype. Simultaneously, the upstream spawning migration of adult Striped Bass matching this confirmed native genotype were tracked to historic spawning locations near the City of Fredericton in spring. Using this monitored spawning migration (May 19 – June 9) as the period of observation, hourly discharge volumes measured at the Mactaquac Dam and river water temperatures were compared to year class strength. Successful Striped Bass year classes in the Saint John River coincided with periods of sustained steady discharge at the Mactaquac Dam. In contrast, years where river discharge was characterised by uninterrupted hydropeaking during the spawning period did not result in any juvenile recruitment. The results of this chapter are important as Striped Bass spawning in the Saint John River is infrequent, however, based on these findings the possibility may exist to increase spawning success through the regulation of spring discharge at the Mactaquac Dam.

S. N. Andrews located the juvenile Striped Bass, monitored year class strength from 2014-2019, and conducted all scale ageing and back calculations. S. N. Andrews also captured, tagged, and tracked the adult Striped Bass for this project, maintained the tracking receiver array and conducted all movement analysis. Finally, he also defined the spawning period and locations, drew the link between discharge at the Mactaquac Generating Station and year class success, and wrote the article apart from sections dealing specifically with genetic ancestry. N. M. Leblanc conducted ancestry analysis in the laboratory set up by S. Pavey using his analysis methods, N. M. Leblanc also made statistical comparisons for both juvenile and adult Striped Bass and wrote the respective article sections. R. A. Curry was the primary editor with help from T. Linnansaari and both were critical in planning the project.

1.3.3 Chapter 3: Left out in the cold: the understudied overwintering ecology of striped bass in Canada

Due to a scarcity of winter ecological data pertaining to Striped Bass (*Morone saxatilis*) I reviewed all information pertaining to Striped Bass overwintering habits and habitats in Canadian waters to form a baseline with which to compare those in the Saint John River (published in ENBF; S. N. Andrews., C. F. Buhariwalla, B. Fleet-Pardy, M. J. Dadswell, T. Linnansaari, and R. A. Curry. (2019) Left out in the cold: the understudied overwintering ecology of striped bass in Canada. Environmental Biology of Fishes. 102:499-518.) This review chapter explores all known winter habitat of Canadian Striped Bass and the physical habitat characteristics found therein. In this chapter I describe how winter habitat is critical to Striped Bass in Canada where the winter period can last up to 7 months. Due to the challenges associated with winter survival and the similarities between selected habitats throughout the Canadian range, I concluded that winter habitats are unlikely to be opportunistically chosen refugia but rather are specifically selected and interannually occupied. This hypothesis would be tested through the exploration of Striped Bass winter habitat in the Saint John River, New Brunswick in chapter 4.

S.N. Andrews compiled all articles pertaining to Striped Bass overwintering in Canadian waters, summarised the information and wrote the article with help from C.F. Buhariwalla and M.J. Dadswell who made contributions to sections pertaining to overwintering in Cape Breton. B. Fleet-Pardy created the maps and R.A. Curry and M.J. Dadswell were the primary editors with help from T. Linnansaari.

1.3.4 Chapter 4: Winter Ecology of Striped Bass (*Morone saxatilis*) near their Northern Limit of Distribution in the Saint John River, New Brunswick

In this chapter, adult Striped Bass (*Morone saxatilis*) were tagged and tracked to their winter habitat sites both within and exterior to the Saint John River. In total, four winter habitats were located within the Saint John River to which Striped Bass (both native and non-native) demonstrated interannual fidelity. Striped Bass departing from the Saint John River in late fall travelled to the Minas Basin, Minas Passage and most probably Shubenacadie Grand Lake. I observed an increasing gradient of non-native migrant Striped Bass in winter habitat moving closer to the river mouth, documented distinct departure dates to and from these winter habitats, and discussed winter aggregation size. This chapter further described a unique warm water habitat occurring in Belleisle Bay in winter attracting a large majority of the river's winter residents.

S.N. Andrews tagged all the Striped Bass, maintained the Saint John River acoustic receiver array, and conducted extensive active tracking over winter ice to locate all four described winter habitats. S.N. Andrews also conducted the tracking analysis, determined the arrival times to and departure times from winter habitats, mapped Striped Bass distribution therein, produced the figures, and wrote the article except for the section pertaining specifically to population ancestry. N.M. Leblanc determined the ancestry of sampled individuals in the laboratory set up by S. Pavey using his analysis methods, N.M. Leblanc also wrote sections on population ancestry. R.A. Curry was the primary editor with help from T. Linnansaari and both were critical in planning the project.

1.3.5 Chapter 5: Conclusion

The final chapter presents the main findings of the thesis as a report on the current status of Striped Bass in the Saint John River. Spawning success, the occurrence of juveniles and adult movements are discussed to update current Striped Bass knowledge and research questions and goals are outlined for the future.

1.4 Appendix chapters; Annotated bibliography

1.4.1 Chapter A1: Seasonal Movements of Striped Bass Morone Saxatilis in a large tidal and hydropower regulated river

This chapter forms a preliminary analysis of acoustic tracking data collected for Saint John River Striped Bass (*Morone saxatilis*) prior to the beginning of the Mactaquac Aquatic Ecosystem Study (published in ENBF; S.N. Andrews, B. Wallace, M. Gautreau, T. Linnansaari, and R. A. Curry (2018) Seasonal movements of striped bass *Morone saxatilis* in a large tidal and hydropower regulated river. Environmental Biology of Fishes. 101:1549-1558). This data set provides the first look at Striped Bass migration patterns within the SJR and sets a baseline on which to build more detailed and extensive tracking analyses.

B. Wallace and M. Gautreau tagged and tracked the Striped Bass and maintained the acoustic receiver array with funding obtained by R. A. Curry. S. N. Andrews analyzed the Striped Bass movements, produced the figures and wrote the article. R. A. Curry was the primary editor with help from T. Linnansaari.

1.4.2 Chapter A2: Looking for Striped Bass in Atlantic Canada: The Reconciliation of Local, Scientific, and Historical Knowledge

This chapter reviews Canadian regions and rivers where Striped Bass (*Morone saxatilis*) are documented to occur but have not been studied while acknowledging that much of Canadian Striped Bass research has focused solely on well described spawning rivers (published in NENA; S.N. Andrews., M.J. Dadswell., C.F. Buhariwalla., T. Linnansaari., and R.A. Curry (2019) Looking for Striped Bass in Atlantic Canada: The Reconciliation of Local, Scientific, and Historical Knowledge. Northeastern Naturalist. 26(1):1-30.) This review compiles historic reports, certified angling catches and anecdotal evidence to put unstudied Striped Bass populations on the map so that they can be assessed and managed in the future.

S.N. Andrews developed the idea of describing Striped Bass where they have not been studied. S. N. Andrews compiled the information, came up with the idea of the “Cape Breton and northeastern Nova Scotia designatable unit”, produced the maps and wrote the article except for the section on the Annapolis River, NS. M. J. Dadswell wrote the Annapolis river section and C. F. Buhariwalla made large contributions to the section pertaining to Cape Breton. M. J. Dadswell and R. A. Curry were the primary editors with help from T. Linnansaari.

1.4.3 Chapter A3: Diet of Striped Bass and Muskellunge Downstream of a large Hydroelectric Dam: A Preliminary Investigation into Suspected Atlantic Salmon Smolt Predation

Striped Bass (*Morone saxatilis*), a native predator in the SJR, and Muskellunge (*Esox musquinongy*), a naturalized predator, are often described as major threats to Atlantic Salmon smolts. This assumption, however, is poorly studied and has never been addressed in the Saint John River. This chapter assesses the diets of both predators directly downstream of the Mactaquac Dam, the largest and lowermost barrier on the Saint John River and the most likely ambush point at which to capture migratory prey. (published in NAJFM; S.N. Andrews, K. Zelman, T. Ellis, T. Linnansaari, and R.A. Curry (2018). Diet of Striped Bass and Muskellunge Downstream of a Large Hydroelectric Dam: A Preliminary Investigation into suspected Atlantic Salmon Smolt Predation. North American Journal of Fisheries Management. 38:734-746.). Collected prey data from gastric lavage was compared to telemetry tracking data from Muskellunge, Striped Bass and Atlantic Salmon Smolts.

S. N. Andrews applied for and received additional funding from the Atlantic Salmon Conservation Foundation, developed the gastric lavage method, produced the Striped Bass dietary figures and wrote the article. K. Zelman produced the Muskellunge dietary figures and made large contributions to Muskellunge related sections of the Article. T. Ellis conducted much of the diet sample collection and compiled data. R. A. Curry and T. Linnansaari were the primary editors.

1.4.4 Chapter A4: Evaluating consumption of Atlantic Salmon Smolt by Striped Bass: A review of predator prey encounters, interactions, and analysis. Report submitted to the Atlantic Salmon Conservation Foundation.

The resent and rapid recovery of the Miramichi Striped Bass (*Morone saxatilis*) population has prompted concern that they could cause the collapse of the already embattled Atlantic Salmon population of that river. This chapter explored all available information regarding the impacts of Striped Bass on Atlantic Salmon smolt within their native overlapping ranges. We concluded that while impacts are possible, no study has yet to provide evidence of a quantifiable adverse effect and therefore more carefully conducted studies will be required in the future.

S. N. Andrews applied for and received the writing contract from the Atlantic Salmon Conservation Foundation. S. N. Andrews and S. V. Hirtle shared the task of compiling information and writing the article. T. Linnansaari and R. A. Curry were the primary editors.

1.5 Additional contributing documents

1.5.1 Evid**ence of a Genetically Distinct Population of Striped Bass within the Saint John River, New Brunswick, Canada.**

Leblanc et al. (2018) examined the ancestry of the first juvenile Striped Bass collected in the Saint John River since 1979, these samples were assessed to determine their population of origin (see chapter 2, published in NAJFM; N.M. Leblanc, S.N. Andrews., T.S. Avery., G.N. Puncher., B.I. Gahagan., A.R. Whiteley., R.A. Curry, and S.A. Pavey (2018) Evidence of a Genetically Distinct Population of Striped Bass within the Saint John River, New Brunswick, Canada. North American Journal of Fisheries Management. 38:1139-1349). Striped Bass rarely departed from their natal river prior to age 2 and all 23 individuals sampled did not match any possible source population. These results conclude that the Saint John River continues to support a native reproducing Striped Bass population; however, the frequency of juvenile recruitment remains to be assessed.

N. M. Leblanc conducted the analysis of Striped Bass ancestry, coordinated the collections of reference samples and wrote much of the article pertaining to genetic methods, results, and data analysis and produced ancestry figures. The laboratory, sampling protocols, and funding were set up, developed and acquired by S. Pavey with help from G. Puncher. S. N. Andrews collected the Saint John River origin juveniles, produced the Saint John River map and assisted with section describing Striped Bass ecology and population history on the Saint John River. B. I. Gahagan and A. R. Whiteley provided samples from US populations and assisted with manuscript writing and editing. T. Avery provided samples of Shubenacadie River origin Striped Bass. S. Pavey and R. A. Curry were the primary editors.

1.5.2 Impact of Future Climate Change on Water temperature and thermal Habitat for Keystone Fishes in the Lower Saint John River, Canada.

Dugdale et al. 2018 examined the issue of climate change in the SJR (published in WRM; S.J. Dugdale., R.A. Curry., A. St-Hilaire., and S.N. Andrews (2018) Impact of Future Climate Change on Water Temperature and Thermal habitat for Keystone Fishes in the Lower Saint John River, Canada. Water Resources Management. 32:4853-4878). Warming climates have sparked interest in how various fish species would fare under future climate scenarios likely to affect riverine water temperatures. This article forms water temperature predictions using a CEQUEAU climate model and explores findings considering both a cold adapted river resident, the Atlantic Salmon (*Salmo salar*) near the southern extent of its range and a native warm water adapted species, the Striped Bass (*Morone saxatilis*) occurring near the northern extent of its range.

S. J. Dugdale produced the CEQUEAU Climate model with A. St-Hilaire and wrote the article and conducted the analysis with R. A. Curry and A. St-Hilaire who were also the primary authors and editors. S. N. Andrews provided ecological information on how Striped Bass in the Saint John River may be affected under the predicted future climate scenarios.

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Wirgin, I., B. Jessop, S. Courtenay, M. Pederson, S. Maceda, and J. R. Waldman. 1995. Mixed-stock analysis of Striped Bass in two rivers in the Bay of Fundy as revealed by mitochondrial DNA. Canadian Journal of Fisheries and Aquatic Sciences 52:961–970.

Chapter 1:

The Misunderstood Striped Bass of the Saint John River, New Brunswick: Past, Present, and Future

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1.1 Abstract

The Striped Bass *Morone saxatilis* of the Saint John River, New Brunswick, is an enigma, having now existed in a state of uncertain species status for more than four decades. Despite a well-established historical record of adult occurrence in large numbers, the available literature, historical accounts, and status reports contain no evidence for the persistence of a native, reproducing Striped Bass population. In 2012, the Committee on the Status of Endangered Wildlife in Canada listed the Saint John River Striped Bass as endangered as part of the Bay of Fundy designatable unit. This listing lacked current peer-reviewed literature and based its conclusions predominately on restatements of findings and opinions from the 1970s and 1980s. After the apparent failure of Striped Bass spawning in 1975, the decline of native Saint John River Striped Bass was accredited to many factors ranging from chemical pollutants to overfishing to the installation of a sizeable hydropower facility. Modest attempts to locate eggs and juveniles of the native species have been taken; however, the results have been inconclusive due to ineffective, infrequent, and poorly timed sampling. Here we reviewed all available information, literature, reports, and data to effectively describe the Saint John River Striped Bass population in an effort to help manage and recover (if required) this apparently missing population.

1.2 Introduction

Striped Bass *Morone saxatilis* is a large anadromous fish ranging naturally along the Atlantic seaboard of North America from the St. Johns River, Florida, in the south to the St. Lawrence River, Quebec, in the north (Scott and Crossman 1973; Scott and Scott 1988; Rulifson and Dadswell 1995). Striped Bass spawn in fresh or brackish water at or above the head of tide of rivers in the early spring (Setzler et al. 1980; Scott and Scott 1988; Melvin 1991) and often occupy coastal or estuarine environments where they serve as the apex predator of the inshore environment throughout much of their range (Setzler et al. 1980).

Striped Bass have been artificially introduced to numerous freshwater reservoirs in the continental United States and the Pacific coast (Setzler et al. 1980). Canadian-origin fish are still confined to their historic range and rivers (Scott and Scott 1988; Rulifson and Dadswell 1995). For management purposes, the species range within Atlantic Canada has been subdivided into three designatable units by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) comprising the St. Lawrence River, the Southern Gulf of St. Lawrence, and the Bay of Fundy (COSEWIC 2004, 2012).

Most recently, the Bay of Fundy designatable unit has come under scrutiny because the region, once supporting three self sustaining Striped Bass populations, i.e., the Shubenacadie and Annapolis rivers, Nova Scotia, and the Saint John River (SJR), New Brunswick (Jessop 1990; DFO 1999), may now be reduced to a sole reproducing population in the Shubenacadie River (COSEWIC 2012; DFO 2014; Bradford et al. 2015). This sobering conclusion has resulted in the recent designation of “endangered” for Bay of Fundy Striped Bass (COSEWIC 2012).

The Striped Bass of the SJR were at one time present as adults in great abundance supporting both commercial (Dadswell 1976, 1983; Dadswell et al. 1984; Jessop 1990, 1991; Rulifson and Dadswell 1995) and recreational fisheries (Wilson 1958; O’Donnell 1963; Dadswell 1976, 1983; Dadswell et al. 1984; R. L. Manderson, 1979 memorandum to Saint Andrews Biological Station). Striped Bass in the SJR had been prominently recognized throughout Atlantic Canada and along the New England coast for their size and numbers (O'Donnell 1963) and were harvested commercially throughout the SJR (DMF 1871–1918; DFSC 1918–1951; DFNB 1952–1962; SCNB 1963–1976; Reid 1978).

There are many accounts describing the spawning of Striped Bass in the SJR (e.g., Adams 1873; O'Donnell 1963; Scott and Crossman 1973; Williamson 1974; Dadswell 1975), suggesting that the abundant adults were a native, self-sustaining population during these earlier times. Declining abundance and the apparent lack of recruitment in the mid-1970s resulted in a closure of the commercial fishery in 1978 (Dadswell 1975; Jessop 1991; Rulifson and Dadswell 1995). It has been widely hypothesized that pollution and the construction of the Mactaquac Dam and associated Mactaquac Generating Station (MGS), the largest and lowermost hydroelectric power station on the SJR, may have adversely affected important spawning locations and egg viability (e.g., Meth 1972; Dadswell 1975; Jessop 1990, 1991, 1995; Wirgin et al. 1995; Robinson and Courtenay 1999; Douglas et al. 2003; COSEWIC 2004, 2012; Forsythe 2010; DFO 2011, 2014; Bradford et al. 2012, 2015).

Understanding the enigma surrounding the SJR Striped Bass should be the first step in designating and/or recovering this socioeconomically important population. It is particularly important that we quickly improve our understanding of the population given the pending decision to either rebuild or remove the Mactaquac Dam (Hayman et al. 2010; Stantec Consulting 2015), which has been described as one of the major threats for this species in the SJR (COSEWIC 2004, 2012). The lack of information and misinterpretations of historical records regarding this population in contemporary literature greatly impedes the decision making needed to protect or recover the species.

We reviewed the available information from peer-reviewed literature; academic, government, and nongovernment organization reports; historical fishery catches; landings data; angling; and historical accounts to better understand population trends, potential lack of recruitment, and the origin and movements of SJR Striped Bass. We discuss information voids that must be imminently addressed to understand the SJR Striped Bass and assess the potential impacts of the Mactaquac Dam's future (Hayman et al. 2010; Stantec Consulting 2015). This information will directly affect the conservation mandate of COSEWIC to assess species at risk and its ability to inform the Canadian Species at Risk Act in mandating conservation actions.

1.3 Saint John River

The SJR is the largest watershed between the St. Lawrence and Mississippi rivers spanning 55,000 km^2 within the provinces of New Brunswick and Quebec and the state of Maine (Metcalf et al. 1976; Cunjak et al. 2011; Figure 1.1). The SJR extends ~670 km from the Little Saint John Lake on the Maine–Quebec border to the city of Saint John, New Brunswick, where it empties through a relatively narrow opening (~100 m), known as Reversing Falls, into the Bay of Fundy (Cunjak et al. 2011; Figure 2.1). The head of tide is ~130 km upriver (at the city of Fredericton) and salt water penetrates ~70 km upriver (to the village of Gagetown) (Carter and Dadswell 1983; Figure 2.1). The large tidal range of the Bay of Fundy provides expansive saline, estuary habitat for fish throughout the year (Trites 1960; Dadswell 1983).

Due to the narrow river mouth and extreme tidal fluctuation of the Bay of Fundy, tidal filling of the river upstream and subsequent emptying can be delayed by many hours from the occurrence of high and low tide (Hachey 1935). This phenomenon has a large effect on water level and current direction and can determine the timing of migratory fish entering and exiting the river (Dadswell et al. 1984). The large tidal range of the Bay of Fundy combined with a heterogeneous mix of interspersed lentic and lotic habitats, various colonization routes, and a history of species introductions have resulted in a relatively diverse fish fauna with a community comprising 54 documented fish species (5 marine, 35 freshwater, and 14 diadromous species: Canadian Rivers Institute, unpublished data; Mark Gautreau, University of New Brunswick, Fredericton, personal communication).

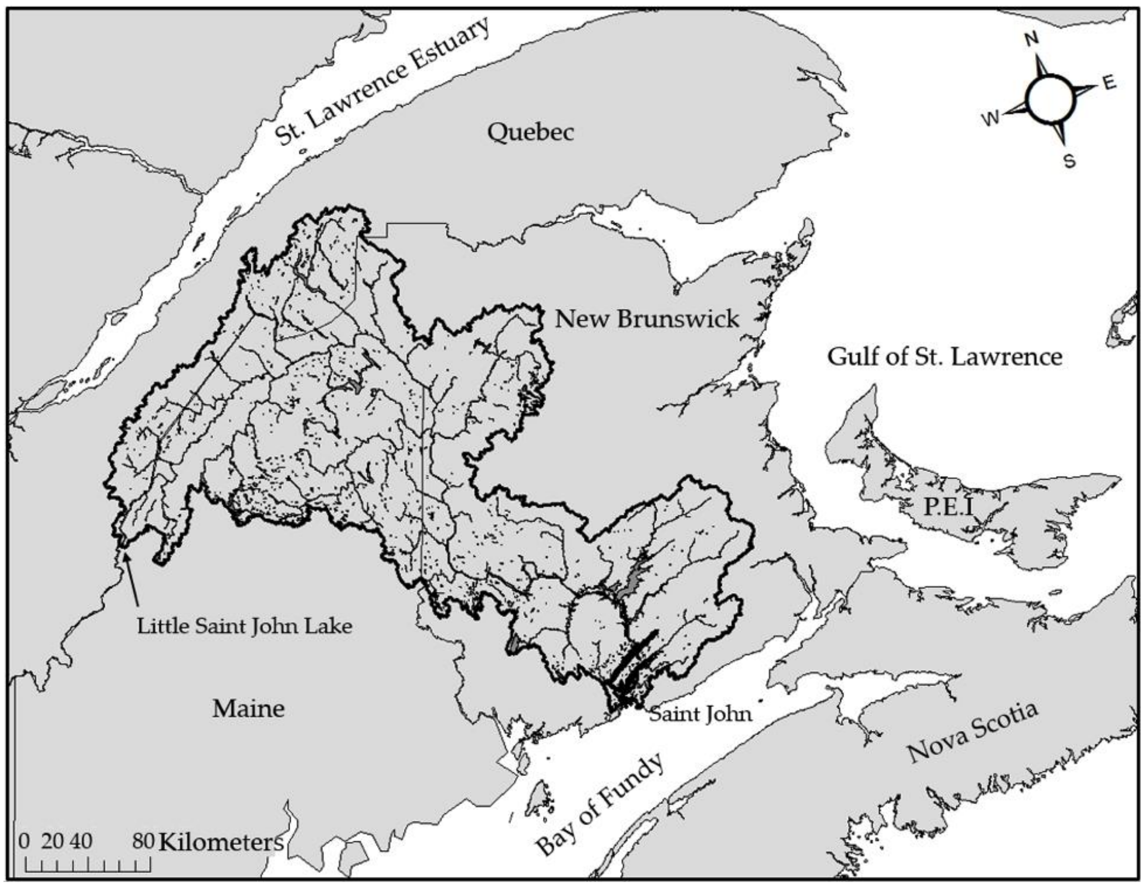

Figure 1.1: The Saint John River watershed, New Brunswick, expanding over 55,000 km^2 into Quebec and Maine. The major hydropower dam is indicated in Figure 1.2. The Saint John River extends from its headwaters in Little Saint John Lake on the Maine–

Quebec border 673 km to its mouth in the city of Saint John where it empties into the Bay of Fundy.

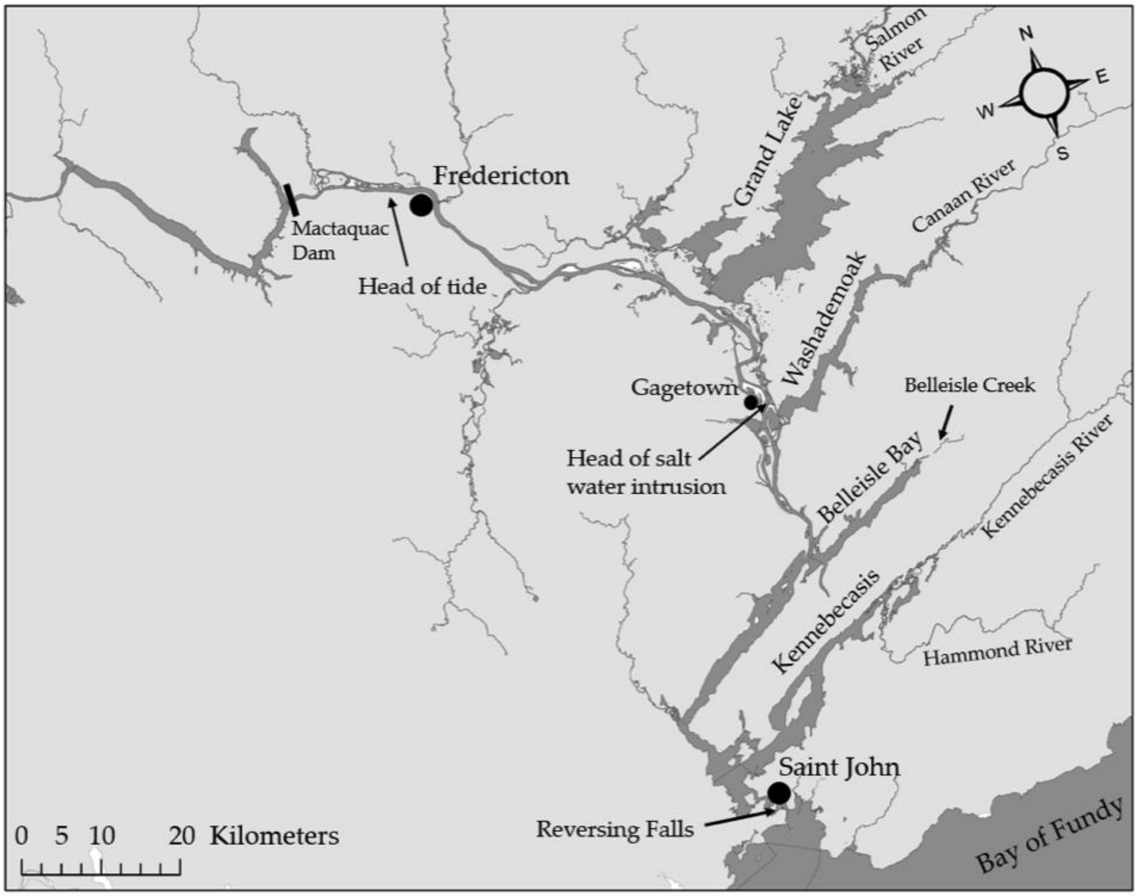

Figure 1.2: The lower Saint John River including its four major tributaries (Grand Lake, Washademoak, Belleisle Bay, and Kennebecasis) as well as the head of tide and head of saltwater intrusion. The cities of Fredericton and Saint John, Reversing Falls, and the location of the Mactaquac Dam are also marked along with a number of smaller tributaries that provide potentially important habitat for Striped Bass.

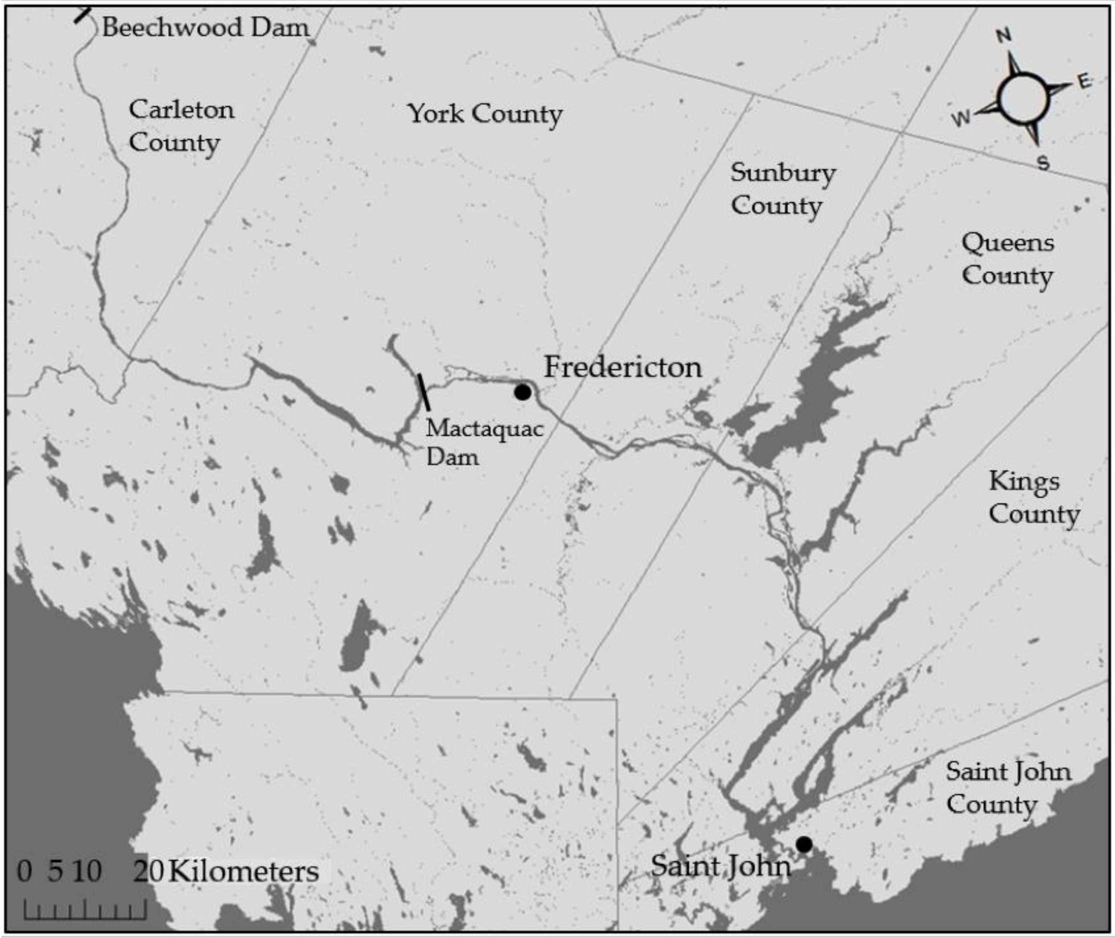

Figure 1.3: The New Brunswick counties for which Striped Bass commercial fishery records exist for the Saint John River. Locations of the Mactaquac Dam (~150 km from the river mouth) and Beechwood Dam (~285 km from the river mouth) are also indicated.

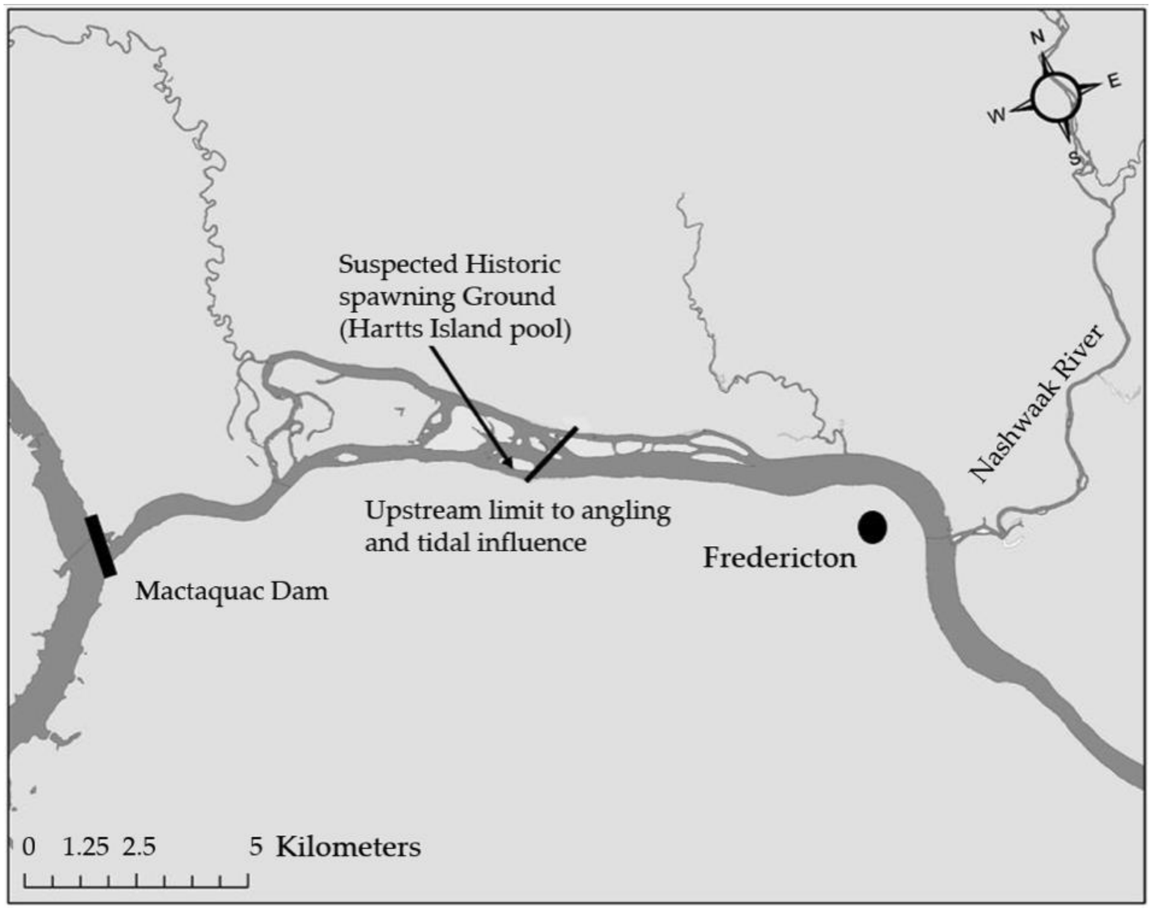

Figure 1.4: The Saint John River between the city of Fredericton and the Mactaquac Dam. Historically, Striped Bass were thought to have spawned in the vicinity of Hartts Island. Tidal influence in the Saint John River extends 130 km upstream to the downstream tip of Hartts Island. Currently recreational fishing is not permitted in the area between Hartts Island and the Mactaquac Dam for individuals other than members of First Nations.

The SJR has five major dams along its length: three on the main stem and one near the mouths of the Aroostook and Tobique Rivers (Ruggles and Watt 1975; Cunjak et al. 2011). The MGS is the largest, most recent (installed in 1968), and lowermost obstruction to migratory fish on the SJR and is located ~150 km from the river mouth (Figures 1.2–1.4). The operation of the MGS as a run-of-the-river facility and its Function as a critical energy producer for New Brunswick creates several physical effects (e.g., altered discharge and velocity regimes, river levels, and sediment fluxes) on the river downstream especially between the dam and the city of Fredericton (Figure 1.4; Cunjak et al. 2011; Curry et al. 2015). The next upstream obstruction to the SJR is the Beechwood Generating Station constructed in 1952 (Ruggles and Watt 1975); it lies ~285 km from the river mouth (Figure 1.3).

1.4 Meristics, Growth, and Sexual Maturation of Saint John River Striped Bass

Until recently the ability to identify a unique population of Striped Bass in the SJR was difficult with the tools available. Williamson (1974) and Melvin (1976) reported similar meristic data for Striped Bass sampled in the SJR (n = 411 and n = 57; respectively). Sampled fish had 17–22 caudal fin rays, 30–36 pectoral fin rays, 1 spine and 11–12 soft rays on the second dorsal fin, and fewer than 64 lateral line scales for most fish. These meristics are similar to those for Striped Bass populations in the Annapolis River, Chesapeake Bay, Albemarle Sound, and St. Johns River in Florida; thus, these methods were unable to distinguish a native SJR Striped Bass from other possible migrants to the SJR. Mixing with other river populations could, however, have masked possible differences (Williamson 1974). Lateral line scales for a small number of fish (n = 3) did offer some notable deviations (>64 lateral line scales; Williamson 1974) from known scale count ranges for Canadian Striped Bass populations typically expressing 58–64 scales (Scott and Crossman 1973).

Striped Bass in the SJR were found to reach sexual maturation at ages 3–7 years (Williamson 1974). Males can mature at age 3, and 84% are fully mature by age 5

(Williamson 1974). Females have been observed to reach maturity later, and most are ready to spawn by age 6 (82%) or 7 (100%); no females of age 3 were found to be mature (Williamson 1974). Female Striped Bass may only spawn every other year in the SJR (Williamson 1974); skipping spawning years is possible and has been observed, for example, in the Roanoke River (Lewis 1962).

Growth of Striped Bass in the SJR is comparable with that of more southern populations in the first few years (Dadswell 1976) but slows substantially after age 6 (Williamson 1974; Dadswell 1976). No comprehensive length–weight relationship exists in published literature across a representative range of fish lengths; however, Williamson (1974) described a length–weight relationship for Striped Bass ranging from 28.0 to 81.9 cm as $\log L = 0.608 + \log 0.0550W$, where L is length and W is weight. Dadswell (1976) calculated a b-value of 0.660 for the log 10 length–weight relationship. Striped Bass up to 19 years of age were captured by Melvin (1976), though Striped Bass in the SJR may live 30–40 years (Dadswell 1976). The largest Striped Bass captured from the SJR was caught on August 15, 1979; it weighed 28.58 kg, was measured at 133 cm in length, had a girth of 81 cm, and was determined to be 21 years of age (Manderson, memorandum). However, due to the fish's size, and the time and location of capture it was considered unlikely that it was of native SJR origin.

1.5 Striped Bass Population Trends Inferred from Fisheries Data

1.5.1 Population monitoring

The Striped Bass population of the SJR has never been fully assessed (Melvin 1976). There is currently no monitoring program that could produce an estimate of the number of the Striped Bass annually emigrating, immigrating, or residing within the SJR. The only current population data come from the Fisheries and Oceans Canada

(DFO) fish collection gallery (a channel like structure designed to attract and direct migrating fish into the fish lift for upstream passage) at the MGS, which has provided an annual record of Striped Bass captures since its completion in 1968 (Table 1.1; Ruggles and Watt 1975). This record, however, is solely an enumeration of Striped Bass taken as bycatch while Atlantic Salmon *Salmo salar* and gaspereau (also known as river herring; combination of Alewife *Alosa pseudoharengus* and Blueback Herring *A. aestivalis*) were monitored as they attempted to pass above the Mactaquac Dam. Operation of the fish lift is predominantly conducted for the passage of Atlantic Salmon (Williamson 1974) for which it was chiefly designed (Ruggles and Watt 1975).

Although the fish lift was originally intended to "protect various fish populations using the [river] system" as they were of "significant value" (Smith 1979), the remaining species arriving at the fish lift, including Striped Bass, are now considered to be "garbage fish" (Armstrong 2006). These other species are actively inhibited from passing and, in the case of the Striped Bass at least, from accessing upstream habitat occupied historically (Figure 1.5; Table 1.2; Warner1956; Scott and Crossman 1959; Meth 1974; Smith 1979; Ingram 1981; Jessop1990; Fishing lore 1991). Fish captures incurred at the Beechwood Dam display an abrupt attenuation of Striped Bass observations both during and following the construction of the Mactaquac Dam initiated in 1966 (Figure 1.5).

Sampling effort (i.e., the number of times the fish lift is raised and duration the hopper is left to fish) at the MGS is undocumented. The Striped Bass capture records at the MGS are further undermined as "attraction efficiency of the fish lift for Striped Bass can be manipulated through the alteration of flow, allowing, on occasion for the targeted capture of the species" (Rob Beaumaster, DFO, personal communication). These catches of Striped Bass taken as occasional bycatch and infrequent, targeted captures for research purposes are combined into yearly counts (Table 1.1). This practice has most probably resulted in artificial peaks in the number of Striped Bass captured at the fish lift, which was operated to selectively target the species for tagging, e.g., in 1999–2002 (Table 1.1; Douglas et al. 2003), and to gather genetic samples, e.g., in 1999–2006 (Bentzen and Paterson 2008).

These additional targeted captures and inferred population spike have in part been used to match the relative strength of adult returns at the MGS to juvenile recruitment peaks of previous years in U.S. rivers (e.g., Douglas et al. 2003). Depending on the fish lift at MGS as the sole counting facility also inherently assumes that every Striped Bass in the SJR, regardless of origin, migrates to this upstream point, an unlikely assumption that has never been addressed.

The unreliable selectivity of the fish lift is also visible in weekly Striped Bass captures. Douglas et al. (2003; for 1968–2000) and Williamson (1974; for 1968–1973) reported peak Striped Bass captures (and therefore occurrence at the MGS) occurred from August to September (standard week 31–35). This period coincides with a decreased focus on Atlantic Salmon after their peak migration (Smith 1979), and a decrease in food availability for Striped Bass near Mactaquac Dam (S. N. Andrews, unpublished data, Appendix 2) possibly resulting in increased activity close to the MGS collection gallery. Striped Bass captures at this time are unlikely to match true seasonal abundance.

Striped Bass arrive at the MGS in large numbers in early spring coinciding with the runs of gaspereau, or river herring, most likely for the purpose of feeding and spawning and later return in the fall (October) to feed (S. N. Andrews, unpublished data,

Appendix 2; Kings Clear First Nation anglers, personal communication). Also, “dense runs of gaspereau in the early spring can clog the entrance gallery of the fish lift and often prevent other species from entering at this time” (MGS fish lift operator, R. Beaumaster, DFO, personal communication), possibly inhibiting the capture of Striped Bass in spring, even when present.

Table 1.1: Captures of Striped Bass at the Mactaquac Dam fish lift since its construction in 1968 until 2002 as accounted by eight sources. Values in grey bands indicate years in which large discrepancies are present between records of the exact same counts. Differences in 1980–1981 among Ingram (1985), Hooper (1991), and Douglas et al. (2003) may be due to typographic errors by authors.

	Meth (1972)	Williamson (1974)	Smith (1979)	Ingram (1980)	Ingram (1985)	Jessop (1990)	Hooper (1991)	Douglas (2003)
1968	872	855	872+			800	872	873
1969	142	99	52+250				307	367
1970	127	133	127				127	130
1971	13	26	13				13	13
1972		67					5	5
1973		11					49	54
1974				5			0	0
1975				49			17	166
1976				0			0	0
1977				17	0		0	0
1978				0	54		54	74
1979					16	<25	16	19
1980					6	<25	6	187
1981					187		187	6
1982					141		141	146
1983							22	22
1984							12	14
1985						<25	32	32
1986							15	12
1987							80	79
1988							20	17
1989							29	30

1990	26	27
1991		253
1992		29
1993		108
1994		14
1995		49
1996		151
1997		450
1998		715
1999		217
2000		142
2001		44
2002		227

Sampling conducted from a single fish lift hopper at a single location far upstream during only part of the year, i.e., “May 1st – October 31 depending on conditions” (Leroy Anderson, DFO, personal communication) does not represent the complex multipopulation dynamics of Striped Bass within the accessible portion of the SJR, which stretches nearly 150 km from the sea. Numerous incongruous fish lift counts also undermine any conclusion regarding the SJR Striped Bass population (Meth 1972; Williamson 1974; Smith1979; Ingram1980, 1985; Jessop 1990; Hooper 1991; Douglas et al. 2003) as well as current stock status reporting by DFO (Table 1.1).

1.5.2 Commercial fishery

The SJR Striped Bass population has been subjected to heavy fishing pressure since at least the early 1800s (Rogers 1936; Dadswell 1983; Jessop 1991). Striped Bass were initially taken mainly for sustenance, and many accounts describe the fisheries conducted by the native peoples and early settlers of the area (Perley 1852; DMF1871–1918; Adams1873; Cox1893; Rogers 1936), with substantial exports to U.S. markets in later years (DMF 1871–1918). Striped Bass were captured by angling, set line, seine net, bag net, dip nets, bow net, and spear, both on the spring spawning grounds and in the winter through the ice (Adams 1873; Rogers 1936; DFO1992). Concern about Striped Bass abundance had already begun by the late 1800s (DMF 1871– 1918; Adams1873; Bayne 1930).

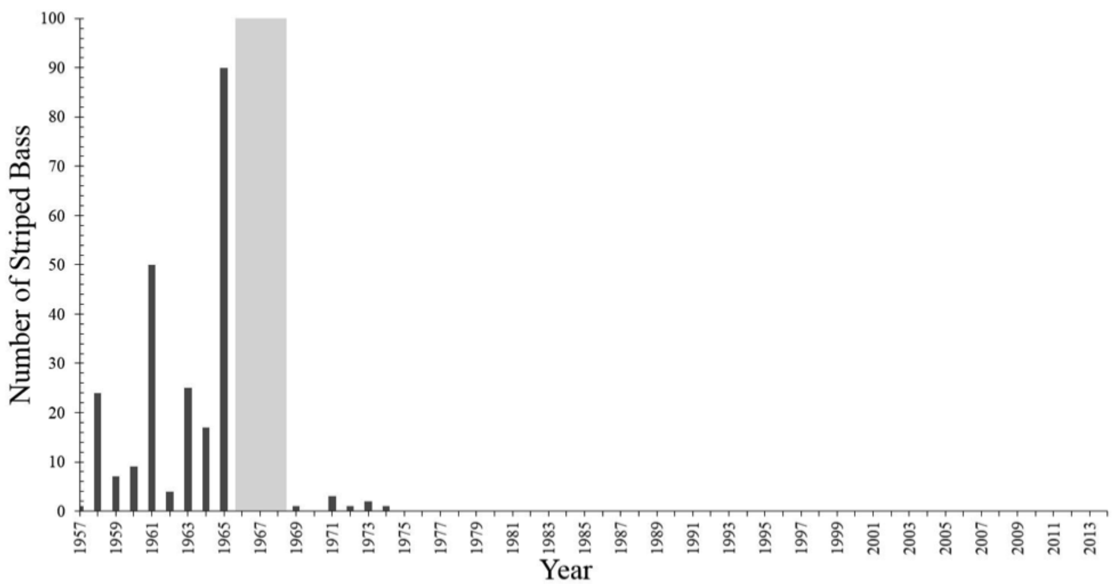

Figure 1.5: Captures of Striped Bass at the Beechwood Dam from 1957 to 2014 indicating the complete obstruction of Striped Bass upstream passage during the construction of the Mactaquac Dam from 1966 to 1968 (gray bar) (Smith 1979, data for 1957–1971). The few fish captured after the completion of the Mactaquac Dam could have been trapped upstream prior to construction or accidentally transferred over the Mactaquac Dam during spring fish passage operations (Smith 1979; data for 1972–1975 in Ingram 1981; data for 1977–1982 in Ingram 1987; data for 1983–2014 in DFO, unpublished fish lift records). Prior to the obstruction of the Saint John River by the Mactaquac Dam, records indicate that Striped Bass captures at the Beechwood Dam occurred predominantly in June and July (Smith 1979; Jessop 1990).

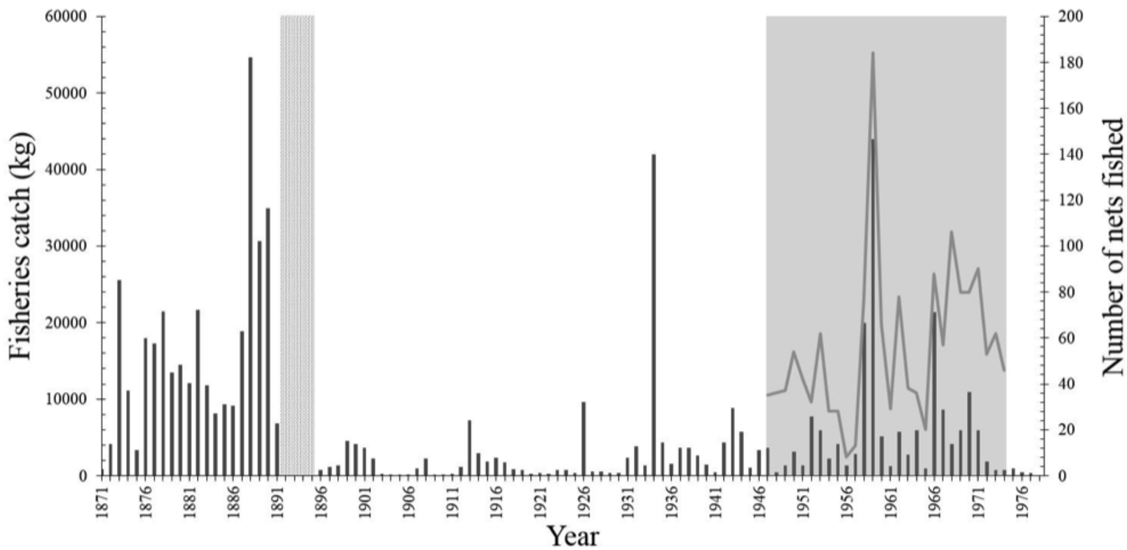

Figure 1.6: Yearly landings (kg) of Striped Bass captured in the Saint John River commercial fisheries both as marketable bycatch (pre-1930) and bycatch and targeted catch (post-1930) after the opening of the directed winter commercial fishery in Belleisle Bay (Kings County) until its closure in 1978. Striped Bass catches are tallied from Sunbury, York, Carleton, Kings, and Queens counties along the Saint John River and include catches from the Saint John Harbour in Saint John County (Figure 1.3) (yearly catch data by county are available in Table 1.2). The stippled band indicates the 3-year fishery closure from 1892 to 1895 before reopening in the winter of 1896. The gray band highlighting 1947–1974 indicates the number of nets fished during the Belleisle Bay winter commercial fishery where data are available. Note: the data presented by the gray bar for 1947–1974 include catches from Kings and Queens counties involving Striped Bass taken as both targeted catch and bycatch. Data sources: DMF 1871–1918; DFSC 1918–1951; DFNB 1952–1962; SCNB 1963–1976; Fisheries and Marine Service, Halifax (see Reid 1978).

Table 1.2: Annual landings (kg) by county of Striped Bass captured in the Saint John River commercial fisheries both as marketable bycatch (before 1930) and bycatch and targeted catch (after 1930) after the opening of the directed winter commercial fishery in Belleisle Bay (Kings County) until its closure in 1978. Catches incurred in Queens County (after 1930) would have been taken as bycatch; those reported for Kings County would have been predominately targeted captures (Belleisle Bay), though some bycatch may be included in catch data (Kennebecasis) (Figure 1.2, 1.3). After the fishery closure, Striped Bass were still harvested as bycatch in other fisheries until 1996; data on retained commercial bycatch (1978–1996) are unavailable.

<table>
<tr><th>Year</th><th>Carleton</th><th>York</th><th>Sunbury</th><th>Queens</th><th>Kings</th><th>Saint John</th><th>Total</th><th>Source</th></tr>
<tr><td>1871</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>816.47</td><td>816.47</td><td>DMF 1872</td></tr>
<tr><td>1872</td><td>544.31</td><td>2267.96</td><td colspan="3">362.87</td><td>979.77</td><td>4154.91</td><td>DMF 1873</td></tr>
<tr><td>1873</td><td>5170.95</td><td>226.80</td><td colspan="3">19504.46</td><td>680.39</td><td>25582.59</td><td>DMF 1874</td></tr>
<tr><td>1874</td><td>3567.05</td><td>3855.53</td><td colspan="3">2308.78</td><td>1360.79</td><td>11092.15</td><td>DMF 1875</td></tr>
<tr><td>1875</td><td>0</td><td>247.66</td><td colspan="3">1247.38</td><td>1814.38</td><td>3309.42</td><td>DMF 1876</td></tr>
<tr><td>1876</td><td>317.51</td><td>544.31</td><td colspan="2">1678.29</td><td>1814.37</td><td>13607.85</td><td>17962.33</td><td>DMF 1877</td></tr>
<tr><td>1877</td><td>0</td><td>0</td><td colspan="2">997.90</td><td>3628.74</td><td>12700.66</td><td>17327.30</td><td>DMF 1878</td></tr>
<tr><td>1878</td><td>0</td><td>0</td><td colspan="2">6486.37</td><td>1410.67</td><td>13607.85</td><td>21504.89</td><td>DMF 1879</td></tr>
<tr><td>1879</td><td>136.08</td><td>0</td><td colspan="2">3175.14</td><td>1093.16</td><td>9071.90</td><td>13476.28</td><td>DMF 1880</td></tr>
<tr><td>1880</td><td>0</td><td>204.12</td><td>9979.02</td><td>907.18</td><td>1161.20</td><td>2267.98</td><td>14519.49</td><td>DMF 1881</td></tr>
<tr><td>1881</td><td>0</td><td>0</td><td>4581.28</td><td>4173.05</td><td>635.03</td><td>2721.57</td><td>12110.92</td><td>DMF 1882</td></tr>
<tr><td>1882</td><td>0</td><td>0</td><td>18597.27</td><td>181.44</td><td>1564.89</td><td>1360.79</td><td>21704.39</td><td>DMF 1883</td></tr>
<tr><td>1883</td><td>0</td><td>2721.55</td><td>4490.56</td><td>272.16</td><td>3406.48</td><td>907.19</td><td>11797.93</td><td>DMF 1884</td></tr>
<tr><td>1884</td><td>0</td><td>907.18</td><td>3855.53</td><td>680.39</td><td>2267.96</td><td>453.60</td><td>8164.66</td><td>DMF 1885</td></tr>
<tr><td>1885</td><td>0</td><td>2267.96</td><td>3855.53</td><td>0</td><td>1338.10</td><td>1814.38</td><td>9275.97</td><td>DMF 1886</td></tr>
<tr><td>1886</td><td>0</td><td>2177.24</td><td>3855.53</td><td>136.08</td><td>1133.98</td><td>1814.38</td><td>9117.21</td><td>DMF 1887</td></tr>
<tr><td>1887</td><td>0</td><td>2326.93</td><td>12836.65</td><td>181.44</td><td>1241.03</td><td>2267.98</td><td>18854.02</td><td>DMF 1888</td></tr>
<tr><td>1888</td><td>0</td><td>453.59</td><td>6395.65</td><td>635.03</td><td>45359.20</td><td>1814.38</td><td>54657.85</td><td>DMF 1889</td></tr>
<tr><td>1889</td><td>0</td><td>907.18</td><td>4490.56</td><td>1043.26</td><td>22861.04</td><td>1360.79</td><td>30662.83</td><td>DMF 1890</td></tr>
<tr><td>1890</td><td>0</td><td>1814.37</td><td>272.16</td><td>1088.62</td><td>31751.44</td><td>0</td><td>34926.58</td><td>DMF 1891</td></tr>
<tr><td>1891</td><td>0</td><td>0</td><td>0</td><td>453.59</td><td>6390.66</td><td>0</td><td>6844.25</td><td>DMF 1892</td></tr>
<tr><td>1892</td><td colspan="7">Fishery Closed May 1st</td><td>DMF 1893 (No Data)</td></tr>
<tr><td>1893</td><td colspan="7">Fishery Closed</td><td>DMF 1894 (1892-1893)</td></tr>
<tr><td>1894</td><td colspan="7">Fishery Closed</td><td>DMF 1895</td></tr>
<tr><td>1895</td><td colspan="7">Fishery re-opened in winter 1895 - catches reported in 1896</td><td>DMF 1896</td></tr>
<tr><td>1896</td><td>0</td><td>0</td><td>0</td><td>0</td><td>755.23</td><td>0</td><td>755.23</td><td>DMF 1897</td></tr>
</table>

1897	0	0	0	0	1133.98	0	1133.98	DMF 1898
1898	0	0	0	0	1360.78	0	1360.78	DMF 1899
1899	0	0	0	0	4535.92	0	4535.92	DMF 1900
1900	0	0	0	0	4082.33	0	4082.33	DMF 1901
1901	0	0	0	0	3628.74	0	3628.74	DMF 1902
1902	0	0	0	0	2267.96	0	2267.96	DMF 1903
1903	0	0	0	0	226.80	0	226.80	DMF 1904
1904	0	0	0	0	113.40	0	113.40	DMF 1905
1905	0	0	0	0	113.40	0	113.40	DMF 1906
1906	0	0	0	0	90.72	0	90.72	DMF 1907
1907	0	0	0	0	907.18	0	907.18	DMF 1908
1908	0	0	0	0	2267.96	0	2267.96	DMF 1909
1909	0	0	0	0	45.36	0	45.36	DMF 1910
1910	0	136.08	0	0	0	0	136.08	DMF 1911
1911	0	181.44	0	90.72	0	0	272.16	DMF 1912
1912	0	181.44	0	45.36	907.18	0	1133.98	DMF 1913
1913	0	181.44	0	680.39	6350.29	0	7212.11	DMF 1914
1914	0	589.67	0	226.80	2086.52	0	2902.99	DMF 1915
1915	0	453.59	0	272.16	1133.98	0	1859.73	DMF 1916
1916	0	453.59	0	272.16	1587.57	0	2313.32	DMF 1917
1917	0	226.80	0	680.39	816.47	0	1723.65	DMF 1918
1918	0	226.80	0	362.87	226.80	0	816.47	DFSC 1918
1919	0	226.80	0	362.87	136.08	0	725.75	DFSC 1919
1920	0	0	0	226.80	0	0	226.80	DFSC 1920
1921	0	0	0	226.80	90.72	0	317.51	DFSC 1921
1922	0	0	0	181.44	90.72	0	272.16	DFSC 1922
1923	0	0	0	680.39	90.72	0	771.11	DFSC 1923
1924	0	0	0	544.31	226.80	0	771.11	DFSC 1924
1925	0	0	0	226.80	90.72	0	317.51	DFSC 1925
1926	0	0	0	0	9616.15	0	9616.15	DFSC 1926
1927	0	0	0	0	544.31	0	544.31	DFSC 1927
1928	0	0	0	90.72	408.23	0	498.95	DFSC 1928
1929	0	0	0	90.72	272.16	0	362.87	DFSC 1929
1930	0	0	0	90.72	226.80	0	317.51	DFSC 1930
1931	0	0	0	635.03	1678.29	0	2313.32	DFSC 1931
1932	0	0	0	1360.78	2494.76	0	3855.53	DFSC 1932
1933	0	0	0	816.47	498.95	0	1315.42	DFSC 1933
1934	0	0	0	1133.98	40823.28	0	41957.26	DFSC 1934
1935	0	0	0	680.39	3628.74	0	4309.12	DFSC 1935
1936	0	0	0	181.44	1360.78	0	1542.21	DFSC 1936
1937	0	0	0	907.18	2721.55	0	3628.74	DFSC 1937
1938	0	0	0	45.36	3583.38	0	3628.74	DFSC 1938
1939	0	0	0	226.80	2358.68	0	2585.47	DFSC 1939
1940	0	0	0	136.08	1315.42	0	1451.49	DFSC 1940
1941	0	0	0	90.72	317.51	0	408.23	DFSC 1941

1942	0	0	0	45.36	4309.12	0	4354.48	DFSC 1942
1943	0	0	0	136.08	8708.97	0	8845.04	DFSC 1943
1944	0	0	0	226.80	5533.82	0	5760.62	DFSC 1944
1945	0	0	0	0	1088.62	0	1088.62	DFSC 1945
1946	0	0	0	0	3356.58	0	3356.58	DFSC 1946
1947	0	0	0	453.59	3175.14	0	3628.74	DFSC 1947
1948	0	0	0	0	453.59	0	453.59	DFSC 1948
1949	0	0	0	453.59	907.18	0	1360.78	DFSC 1949
1950	0	0	0	0	3175.14	0	3175.14	DFSC 1950
1951	0	0	0	453.59	907.18	0	1360.78	DFSC 1951
1952	0	0	0	2267.96	5443.10	0	7711.06	DFNB 1952
1953	0	0	0	1360.78	4535.92	0	5896.70	DFNB 1953
1954	0	0	0	1360.78	907.18	0	2267.96	DFNB 1954
1955	0	0	0	1360.78	2721.55	0	4082.33	DFNB 1955
1956	0	0	0	453.59	907.18	0	1360.78	DFNB 1956
1957	0	0	0	129.27	2721.55	0	2850.83	DFNB 1957
1958	0	0	0	453.59	19504.46	0	19958.05	DFNB 1958
1959	0	0	0	453.59	43544.83	0	43998.42	DFNB 1959
1960	0	0	0	164.65	4989.51	0	5154.17	DFNB 1960
1961	0	0	0	362.87	907.18	0	1270.06	DFNB 1961
1962	0	0	0	236.32	5443.10	0	5679.43	DFNB 1962
1963	0	0	0	0	2721.55	0	2721.55	SCNB 1963
1964	0	0	0	453.59	5443.10	0	5896.70	SCNB 1964
1965	0	0	0	453.59	453.59	0	907.18	SCNB 1965
1966	0	0	0	453.59	20865.23	0	21318.82	SCNB 1966
1967	0	0	0	453.59	8164.66	0	8618.25	SCNB 1967
1968	0	0	0	453.59	3628.74	0	4082.33	SCNB 1968
1969	0	0	0	0	5896.70	0	5896.70	SCNB 1969
1970	0	0	0	0	10886.21	0	10886.21	SCNB 1970
1971	0	0	0	0	5896.70	0	5896.70	SCNB 1971
1972	0	0	0	0	1814.37	0	1814.37	SCNB 1972
1973	0	0	0	0	769.75	0	769.75	SCNB 1973
1974	0	0	0	0	730.74	0	730.74	SCNB 1974
1975	0	0	0	0	987.92	0	987.92	SCNB 1975
1976	0	0	0	0	453.59	0	453.59	SCNB 1976
1977	0	0	0	0	342.92	0	342.92	Reid (1978)
1978	Fishery Closed							NA

Initially, the SJR supported no directed commercial fishery for Striped Bass (Table 1.2; DMF1871–1918). However, substantial harvest still occurred from the Saint John Harbour to Carleton County (Figure 1.3; Table 1.2; DMF1871–1918; Jessop 1991).

These landings were predominantly taken as bycatch in other fisheries (Atlantic Salmon, gaspereau, American Shad *Alosa sapidissima*, Rainbow Smelt *Osmerus mordax*, Atlantic Sturgeon *Acipenser oxyrinchus*, and Shortnose Sturgeon *A. brevirostrum*; DMF1871–1918; Dadswell 1983). Striped Bass taken as bycatch were legally marketable at the time (Reid 1978; Bradford et al. 2015). Reid (1978) noted that not all bycatch was reported and thus the total bycatch is uncertain; therefore, true catches could be much higher than reported (Figure 1.6). In addition, poaching was most probably occurring according to a fisheries warden report (DMF 1876).

The major producer in the area was Kings County (Figure 1.3; Table 1.2) where “the principal bass fishery was in Belleisle Bay” (Figure 1.2; DMF 1889) where catches occurred primarily in winter. Catches were also taken in the Kennebecasis River (Kings County), and to a lesser extent Queens County (Jessop 1991), and in the Saint John Harbour, most notably from 1876 to 1879 (Figure 1.2; Table 1.2; DMF1871–1918).

Early commercial catches were large and peaked between 1888 and 1890 (Jessop 1991; Figure 1.6). Steep declines throughout the river forced a closure “prohibiting fishing for bass, in any manner whatever for the period of three years from May 1st, 1892” (Figure 1.6; DMF 1892; Jessop 1991). The retention closure remained from May 1, 1892, until it was reopened in the winter of 1895, and a catch record was available in 1896 (DMF 1896). After the closure, the fishery was primarily restricted to Belleisle Bay (Kings County), and only small quantities, possibly taken as bycatch, occasionally were registered from Queens and York counties (Figure 1.3; Table 1.2).

The fishery once again failed between 1903 and 1906 (Figure 1.6; DMF 1871–1918; Jessop 1991). Catches peaked in 1913 before dropping to relatively low levels for close to 10 years, and high catches were not seen again until 1926 when more than

11,000 kg were landed (Figure 1.6; Table 1.2; Dadswell 1976). Declines in the fishery were of concern to Bayne (1930) who described the destruction of young Striped Bass as bycatch in the Rainbow Smelt fishery; he feared the complete destruction of the Striped Bass stock after the forceful opposition by fishers to every attempt to regulate the fishery at the time.

In 1930, a directed winter Striped Bass fishery was officially opened in Belleisle Bay, Kings County (Figures 1.2, 1.3). Fishers were directed to use 13-cm-mesh gill nets (Reid 1978; Dadswell 1976, 1983), which may have removed immature Striped Bass ages 4–6 prior to their first spawn (Reid 1978). Nets were set under the ice at depths from 10 to 30 m using an ice jigger (Dadswell 1983). This directed commercial fishery was conducted between late December and early February (Meth 1971) or March (Meth 1972, 1973a); however, newspaper articles of the time and evidence of higher monthly catches reported by Smith (1969) and Reid (1978) suggested that the true season extended from December 1 to March 31. The highest catches were often seen early in the season (Meth 1973a), and large quantities were shipped to major cities such as Boston and New York in the United States (Kings County Historical Society, unpublished data). License data for commercial fishers are available for a small window (1947–1974; Figures 1.6, 1.7; M.J. Dadswell, unpublished data), where each license holder would have been permitted to fish with one net. The fishery in Belleisle Bay remained “reasonably good” until ~1970 even though recreational catches at the mouth of the SJR had declined to almost nothing (Meth 1972).

The general patterns of abundance according to the commercial fishery reports followed a 9–11-year cycle (Dadswell 1983; but see Jessop 1990 who proposed 7–14-year cycles) until steep declines occurred after 1970 (Figures 1.6, 1.7; Table 1.2;

Dadswell 1976; Jessop 1990). Managers at the time feared the disappearance of the native population following a steep drop in catches and apparent lack of recruitment since 1973 (Dadswell et al. 1984), including a spawning failure event observed in 1975 (Dadswell 1976). The directed commercial fishery was finally closed for a 10-year period in 1978 to allow for stock recovery (Dadswell 1983); it has not reopened (Figure 1.6; Table 1.2).

After the 1978 closure, Striped Bass were still taken as bycatch in other fisheries and could be retained and sold commercially (Ingraham and Burnley 1994; Bradford et al. 2012), most likely to local buyers (Morse and DeWolf 1979). No catch data exist from this time until present in published records. In 1996, the commercial bycatch fishery of Striped Bass was closed completely (Bradford et al. 2012). Since then, licensed commercial fishers along the SJR have only been allowed to retain one Striped Bass ≥68 cm TL per day for personal consumption (DFO 1999, 2014; Bradford et al. 2012).

1.5.3 Recreational Fishery

The Striped Bass was first described as a sport fish in the SJR by Adams (1873). The recreational fishery has mainly been focused in the area of the Reversing Falls in the city of Saint John (Figure 1.2; Jessop 1991). Anecdotal evidence from anglers suggest that the recreational fishery was poor in 1915 (Dadswell 1976) and increased in popularity (and most likely productivity) from 1950 to 1960 continuing to 1970 (O'Donnell 1963; Balance 1969; Mosher 1969; Moss1971, 1972; Jessop 1991). Following this short boom, "[t]he angling fishery at Reversing Falls declined to virtually nothing in 1971" (Meth 1972). This decline in recreational fishery catches, however, did not mirror catches in the Belleisle Bay winter commercial fishery that "while experiencing a decline from the previous year, was still reasonably good." (Figure 1.6; Meth 1972). This comparison seemed to suggest that the two fisheries may have been supported by separate populations or groups of Striped Bass in the river (Dadswell 1976), though the Belleisle Bay fishery declined steeply in the following year and crashed soon after (Figure 1.6; Table 1.2).

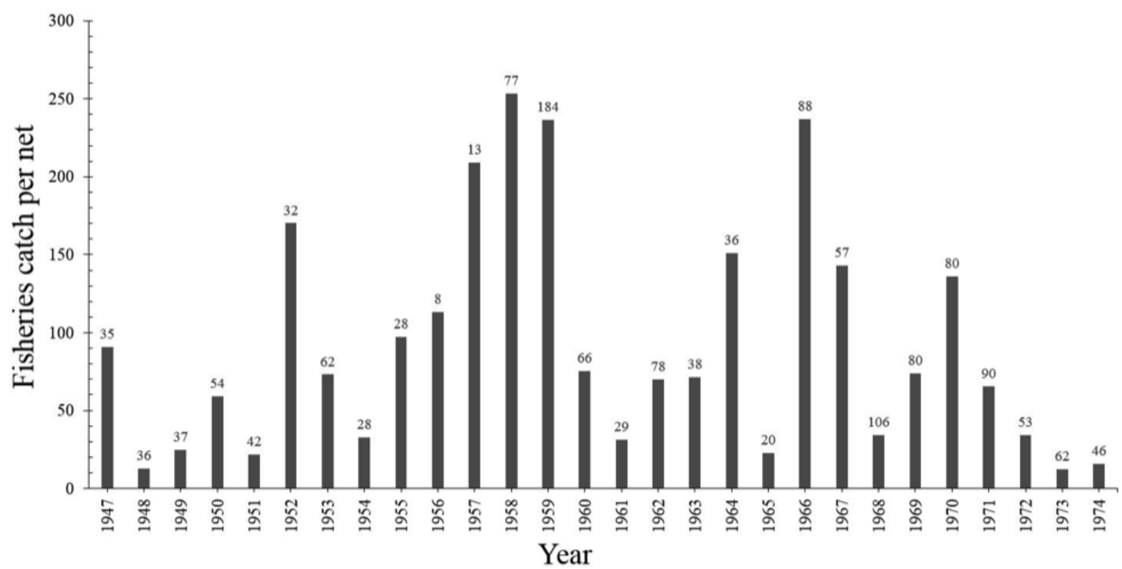

Figure 1.7: Catch of Striped Bass (kg) per net employed in Kings County in the Belleisle Bay winter commercial fishery from 1947 to 1974. The bars indicate annual catch (kg) while the numbers above bars represent the number of nets employed. A small portion of the documented catch may have been incurred as bycatch in the Kennebecasis (Figures 1.2), which also falls within Kings County (Figures 1.3), though was not subject to a directed commercial fishery.

Little to no regulations for Striped Bass angling or retention were present prior to 1990 (Jessop 1990). A management strategy implemented in 1994 limited angler retention to a single Striped Bass per person per day, with the season extending from May 1 to October 15 in inland waters. A minimum retention size of ≥38 cm TL was imposed in this first year (1994), with the minimum size transitioning to ≥68 cm TL by 1996 (Bradford et al. 2012). A Striped Bass of this size would be of age 6–8 years (Williamson 1974; Dadswell 1976) and would have had at least two opportunities to spawn if it were female and three or four spawning opportunities if it were male (Williamson 1974).

Initially, a season occurring from July 1 to October 30 had been proposed for the SJR in 1992, with catch-and-release angling of Striped Bass being implemented for the first 5 years (DFO 1992), but this proposal was never enacted. Retentions are currently open year-round in tidal areas, including almost all waters of the SJR from Reversing Falls upstream to the Hartts Island campground 5 km upstream from the city of Fredericton (Figures 1.2, 1.4; Bradford et al. 2012), and the minimum retention size is the same as for inland waters (=68 cm TL).

Overall, the recreational fishery for Striped Bass in the SJR is very poorly understood (Dominy 1972; Meth1972; Morse and DeWolf 1979; Duston and Rowlands 2009; Duston2010; Forsythe 2010). Fisheries warden estimates (1951–1967), as recounted by Bradford et al. (2012) describe peak recreational catches occurring in 1952–1953 with large numbers of Striped Bass (~2,000 fish) being taken annually from the Kennebecasis River in the early 1950s (Figure 1.2). Dominy (1972) accounted for an average catch of 2,375 Striped Bass taken by 7,374 rod-days of effort at Reversing Falls between 1959 and 1966, the suggested high point in the fishery. Bradford et al. (2012), however, report relatively low catches of Striped Bass in Saint John at this time. Morse and DeWolf (1979) listed an average of 440 Striped Bass being taken in the SJR estuary, most likely calculated from annual counts occurring in the early 1960s to 1970s.

In a 3-year creel survey conducted from 2007 to 2009, only one angler reported SJR Striped Bass catch data, severely limiting any possible conclusions on the fishery (Duston and Rowlands 2009; Duston 2010; Forsythe 2010). There is currently no management plan for the recreational fishery for Striped Bass beyond the season, retention limit and minimum size regulations. By definition, Striped Bass is not considered to be a game fish in New Brunswick or other Canadian maritime provinces (Recreational Fisheries Biologist, C. Connel, DERD, personal communication).

Sparse reports exist of Striped Bass being angled in the Mactaquac headpond (Fishing lore 1991). The continued presence of Striped Bass above the Mactaquac Dam is unknown and the occurrence of any measurable sport fishery is unlikely. The possibility of stocking Striped Bass in the Mactaquac headpond to form a landlocked population has been suggested (Gridley 1980) but never thoroughly explored.

1.6 Early Life History of Striped Bass in Saint John River

1.6.1 Spawning

Early documentation suggests that the SJR Striped Bass were spawning in the spring in freshwater portions of the river (Perley 1852; Cox1893; Bayne 1930; Rogers 1936) or at the head of the estuary (Meth 1973a). No reports provide specific coordinates, leaving a significant number of possible spawning locations suspect as suggested by Dadswell (1976). Some early accounts provide clues suggesting that areas around the islands near the city of Fredericton (Figure 1.4) were a “favorite resort” (Adams 1873) and “pools at the head of tide” (Meth 1972); specifically, the Hartt’s Island pool located 5 km upstream from the city of Fredericton (Figure 1.4; O’Donnell 1963; Hooper 1967; Williamson 1974) may have been a spawning location. Unfortunately, no eggs or larvae have ever been collected in the vicinity of these locations, and thus, successful spawning and reproduction at these locations has not occurred.

Literature regarding presumed spawning in the vicinity of Mactaquac Dam unanimously concludes that all spawning ceased in 1968, coincident with the completion of the MGS (Meth 1972; Jessop 1990, 1991, 1995; Wirgin et al.1995; Robinson and Courtenay 1999; Bradford et al. 2001, 2012, 2015; Douglas et al. 2003; COSEWIC2004, 2012; Forsythe 2010; DFO2011, 2014). Multiple hypotheses can be derived to try to explain possible effects of the dam, e.g., altered temperature and flows regimes, including potential effects induced by hydropeaking operation of the MGS (see examples in: Setzler et al. 1980; Rulifson and Manooch 1990), but no study has ever addressed the apparent loss of spawning in the SJR downstream of the MGS. While the evidence seems to point to the existence of
some cause–effect relationship between the construction of the MGS and the disappearance of spawning, it is important to note that spawning seems to have also ceased in other localities unaffected by dams within the SJR in a similar time frame (e.g., Dadswell 1975). Evidence therefore suggests some other, more widespread phenomenon may have also affected spawning success of Striped Bass in the SJR in the late 1960s and early 1970s.

Striped Bass probably used the reach downstream from the MGS for spawning, but the only evidence of gravid Striped Bass are incidental reports during spring electrofishing surveys (Dr. R. Allen. Curry, UNB, unpublished data), anecdotal evidence from local anglers, and the recent capture of 31 ripe males and 3 ripe females below the MGS (June 9–July 27, 2016: S. N. Andrews, unpublished data). Spawning may have, and could still be, occurring in many smaller tributaries of the SJR (Dadswell 1976), including those ofBelleisle Bay and Grand Lake (Figure 1.2) as suggested by local knowledge (Melvin 1978; Cunjak et al. 2011; Bradford et al. 2015; DFO 2014). Additionally, large gravid Striped Bass have been caught in Washademoak Lake, Belleisle Bay, and Kennebecasis River (Williamson 1974), as well as in Grand Lake where a large egg-bearing female was captured (May 28, 2015: S. N. Andrews, unpublished data; Figure 1.2). The first documented report of gravid Striped Bass in the SJR came from Belleisle Creek in May 1972 (Dadswell 1976), and 2 years later, 40 male and 40 female Striped Bass with running milt and eggs were captured in gill nets in May at the same location (Dadswell 1976; Table 1.3).

Table 1.3: Successful and unsuccessful surveys of Striped Bass eggs and spawning conducted within the Saint John River. Four successful surveys were conducted from 1972 to 1975, during which gravid adults or spawned Striped Bass eggs were collected. Three unsuccessful surveys were conducted from 1973 to 1994 throughout the Saint John River, during which no gravid Striped Bass or eggs were captured.

	Year	Sampling period	Findings	Sampling details and gear	Location(s)	Reference
Successful surveys	1972	May	Striped Bass spawning run successfully intercepted	Gill net	Belleisle Creek	Dadswell (1976)
	1974	May	Striped Bass spawning run successfully intercepted, 40 Striped Bass of both sexes captured that were ripe and ready to spawn	Gill net	Belleisle Creek	"
	1975	May	Striped Bass spawning run successfully intercepted	Gill net	Belleisle Creek	"
	1975	May 13-May 19	1800 Striped Bass eggs caught in plankton nets, spawning confirmed	Plankton nets set and checked daily	Belleisle Creek	"
Unsuccessful surveys	1992	Late June	No Striped Bass eggs were collected	Tows and sets of a 1 m diameter plankton net	Kennebecasis and Hammond tributaries	Jessop (1995)
	1973	Last 2 weeks of May	No evidence of spawning found	plankton nets set, unable to check them frequently enough	Belleisle Creek	(M. J. Dadswell)
	1994	June 6- June 25	No Striped Bass eggs were collected	Bi-daily, 15 minute tows of a 1 m diameter plankton net, mesh size 1mm at sampling locations. A plankton net was also set in Belleisle Creek and checked every 48 hours	Fredericton Area, Hammond, Kennebecasis, Belleisle Creek, lower section of the Canaan River	Ingraham and Burnley (date unknown), Jessop (1995)

1.6.2 Survey of Eggs and Larvae

In 1975, more than 1,800 Striped Bass eggs were collected from Belleisle Creek between May 12 and 19 (Figure 1.2; Table 1.3; Dadswell 1976). Spawning was initiated when water temperatures reached 11.5°C with peak egg production (661 eggs in 24 h) occurring at 14.5°C (May 15) (Dadswell 1976). This is the only documented confirmation of spawning of Striped Bass in the SJR, i.e., release of gametes that drifted freely. A reference to spawning in 1979, as alluded to in various reports (Bradford et al. 2001, 2012, 2015; Douglas et al. 2003; COSEWIC 2004, 2012; Cunjak et al. 2011; Wallace 2012), is incorrect. These reports reference a letter (M. J. Dadswell, 1982 memorandum to R. Wilson, Environmental Protection Service) that clearly states, "[t]here also appears to have been a first year-class in many years produced in the Saint John about this time. We captured 1-year-old bass there in 1979 for the first time since 1968" but the letter, as confirmed by the author, makes no reference to the collection of eggs or larvae, nor does it suggest Belleisle Bay as a possible location for such a collection. The reported juveniles cannot be confirmed as SJR origin as they could be migrants from other rivers (see also DFO 2014).

Since 1975, intermittent surveys for Striped Bass spawning, eggs, and larvae have been inconclusive (Table 1.3; Ingraham and Burnley 1994; Jessop 1995). Accordingly, such results have since prompted the status downgrade of the species to "threatened" in the Bay of Fundy designatable unit (COSEWIC 2004) and more recently to "endangered" (COSEWIC 2012). However, absence of evidence is not evidence of absence, and the seeming loss of a native SJR Striped Bass population may only stem from the lack of any effective search for the eggs (Ingraham and Burnley 1994; Jessop 1995) or larvae of the species since the late 1970s (Dadswell 1976, 1982; Jessop 1995). Recent efforts have conducted only sparse sampling over selected locations and have consistently missed critical spawning times; (Table 1.3; Ingraham and Burnley 1994; Jessop 1995; DFO 2014; Bradford et al. 2015).

1.6.3 Juvenile Survey

Only three accounts document the occurrence of juvenile Striped Bass in the SJR. Hooper (1967) documented a single, age-1 Striped Bass collected in a commercial Gaspereau net (location unknown). Dadswell (1982) mentioned the capture of some number of age-1 Striped Bass in 1979. DFO (2014) and Bradford et al. (2015) mentioned that age-1 and age-2 Striped Bass have been "detected," which appears to be a reference to COSEWIC (2012) where the capture of "14 juveniles, 1–2 years of age" was reported in 2008, possibly referring to an unpublished follow-up study to Bentzen and Paterson (2008); those juveniles were apparently determined to be of Shubenacadie River origin (Table 1.4). Dadswell (1976) indicated that commercial fishers recalled catching age-1–2 Striped Bass regularly within the SJR (location unknown) until 1969.

Numerous other studies have tried and failed to locate juvenile Striped Bass within the SJR (Table 1.4; Dadswell 1976; Ingraham and Burnley 1994; Jessop 1995; DFO 2007, 2009). All unsuccessful studies employed beach-seining methods in various locations and at various times (Table 1.4). A failure to capture juveniles in these haphazard sampling events is not scientific evidence that they were not present in the SJR. Most recently (2014–2016), commercial fishers operating within the SJR (i.e., Grand Lake and Kennebecasis) have noticed large numbers of juvenile Striped Bass (TL range, 12–30 cm) in their nets beginning in 2014 (Refer to data sets in Chapter 2).

Table 1.4: Successful and unsuccessful surveys of juvenile Striped Bass conducted within the Saint John River. Three successful surveys were conducted in 1967, 1979, and 2008 during which at least one juvenile was captured. Five unsuccessful beach-seine surveys were conducted from 1974 to 2001 throughout the Saint John River, during which no juveniles were captured.

	Year	Sampling period	Findings	Sampling details and gear	Location(s)	Reference
Successful surveys	1967	May-June	A single 1-year-old Striped Bass was captured	Commercial Gaspereau Nets	Lower Saint John River	Hooper (1967)
	1979	Unknown	(Unknown number) of 1-year-old Striped Bass captured	Unknown	Unknown	Dadswell (1982)
	2008	Unknown	14 juveniles age 1 and 2 determined to be of Shubenacadie River origin	Unknown	Lower Saint John River	Bentzen and Paterson (2008) COSEWIC (2012) DFO (2014; 2015)
Unsuccessful surveys	1974	August and September	No juvenile Striped Bass were collected	Beach seining survey (sein, 16m long, 1m deep, 1.3cm mesh), occasional electrofishing	Unknown	Williamson (1974)
	1992	Late August	No juvenile Striped Bass were collected	Beach seining survey	Upper Kennebecasis (5 sites) and known spawning sites in Belleisle Bay (6 sites)	Jessop (1995)
	1994	July 27- August 19	No Juvenile Striped Bass were captured	Weekly Beach seining survey, 50m beach sein, 1/4-inch mesh	Oak point, Grand Lake, Salmon River, Fredericton area, Hammond River, Kennebecasis River, Belleisle Creek, Lower region of Canaan River.	Ingram and Burnley (date unknown) Jessop (1995)
	2000	Summer	No juvenile Striped Bass were captured	Beach seining survey	Throughout the Saint John River	DFO (2007; 2009)
	2001	Summer	No juvenile Striped Bass were captured	Beach seining survey	Throughout the Saint John River	DFO (2007; 2009)

1.7 Adult Life History in Saint John River

1.7.1 Mark-Recapture Studies

While recruitment remains uncertain, adult Striped Bass are still relatively common in the SJR (Douglas et al. 2003). The presence of adult Striped Bass suggests that one or more alternative river stocks are migrating to the SJR (Dadswell 1976). Mark–recapture studies from 1964 to 1973 (Table 1.5) identified fish in the SJR traveling or returning to areas throughout the Atlantic seaboard ranging from the Blackstone River, Rhode Island, to Maryland, New Jersey, Delaware, and Massachusetts (O'Donnell 1963; Williamson 1974; Dadswell 1976; Scott and Scott 1988); the origin of these individuals, however, is unknown. The persistence of a SJR stock was suggested by Striped Bass being both tagged and recaptured within the SJR, predominantly in Belleisle Bay during the winter commercial fishery, indicating the existence of an overwintering and thus possible resident population (Moss 1971; Williamson 1974; Dadswell 1976).

Collectively these previous mark–recapture studies marked 952 Striped Bass within the river (Table 1.5). There have been 39 local in-river recaptures and 7 fish recaptured from various locations along the Atlantic seaboard of the United States (Table 1.5). One tagging study conducted by J. Boone (Maryland Department of Natural Resources, personal communication, cited in Rulifson and Dadswell 1995) marked 1,375 Striped Bass in the United States, one of which was said to have been tagged in the Nanticoke River in Maryland and recaptured at Reversing Falls at the mouth of the SJR in 1976 after 1,279 d at large. Review of Boone (unpublished data), however, suggests that this information may be incorrect and that the fish was both tagged and recaptured within the SJR in the same time frame.

Historical recapture data (pre-1976) suggests that two distinct migratory trends may exist: (1) a native population overwintering within the river, and (2) a transient contingent that leaves the river in the fall or sometimes overwinters (Dadswell 1976; Dadswell et al. 1984). Striped Bass tagged in the SJR in summer have been recaptured in Belleisle Bay during the winter in the commercial fishery (Table 1.5). Furthermore, Striped Bass tagged after capture in the winter commercial fishery have been recaptured near Reversing Falls in the SJR in the following summer. These results suggest the presence of a population that spends the warmer months of the year feeding in the estuary and retreating to overwinter in Belleisle Bay or other deep stretches of the river (Dadswell 1976). This tactic would be predicted for a native SJR population.

Recapture data also suggest the presence of Striped Bass within the river that originated from the United States (O'Donnell 1963; Moss 1971; Williamson 1974; Dadswell 1976; Dadswell et al. 1984; Rulifson and Dadswell 1995). Anecdotal evidence has suggested that Striped Bass of U.S. origin may migrate north arriving in the Reversing Falls area of the SJR in early spring as Striped Bass were first caught near the river mouth and then farther upstream prior to exiting the SJR in the fall (Dadswell 1976). This observed "arrival" of Striped Bass at Reversing Falls in the spring, however, may in fact be the departure of non-native Striped Bass that overwintered within the SJR, whereas those individuals found farther upstream may be native residents migrating from wintering grounds a few weeks later (S. N. Andrews, Chapter 4). The suggested fall "departure" could also be a re-entry of Striped Bass having spent their summer in the Bay of Fundy, or SJR residents moving down to the river mouth to feed before overwintering (S. N. Andrews, Chapter 4).

Rulifson et al. (2008) tagged nearly 2,000 Striped Bass in Cobequid Bay and Minas basins of the Inner Bay of Fundy, Nova Scotia, and none were recovered in the SJR. A small number of recently tagged fish in the SJR did travel to the Minas Basin (S. N. Andrews, Chapter 2,4), although they may have originated from the Shubenacadie River. Despite the compilation of recaptures, the marine migration patterns of the true SJR-origin Striped Bass remains uncertain, including if or under what circumstances such a migration occurs.

1.7.2 Tracking Studies

The most recent (still ongoing) and the only comprehensive tracking study to date also supports the native and non-native hypotheses (AMEC Earth and Environmental 2011, 2012; Wallace 2012; S. N. Andrews, Appendix 1). Acoustic tracking data of 40 Striped Bass (27 tagged by Wallace 2012, 13 tagged by S. N. Andrews, Appendix 1) indicated that a number of fish made upstream movements towards the MGS in the spring. Only two fish were confirmed to have left the river during the spawning period, and of these, one was detected in the vicinity of the Shubenacadie River in Nova Scotia before promptly returning to the SJR (S. N. Andrews, Chapter 1,4, Appendix 1).

An extensive Striped Bass acoustic tracking study is currently being undertaken within the SJR (see thesis chapter 2, 4); a small number of these tagged individuals reside within the river over the entire year except for the spawning period (late May–early June) when they quickly migrate to the Shubenacadie River and promptly return to the SJR, and they have repeated this migration over several years. The vast majority of acoustic-tagged fish appear to remain in the river year-round over multiple, consecutive years. These individuals never leave the river and move upstream to various areas during the spring spawning period. It remains unknown whether these multiyear residents are native in origin or whether they are fish that originated in the United States or Nova Scotia and have colonized the SJR and may now be spawning and/or hybridizing in the river.

1.7.3 Genetic Population Structuring

Two genetic studies have been conducted on Striped Bass within the SJR (Wirgin et al. 1995; Bentzen and Paterson 2008). Wirgin et al. (1995) examined the genetic structure of 132 Striped Bass caught in the SJR from 1992 to 1993. The majority (n = 97) were captured at MGS (n = 47 in 1992 and n = 50 in 1993), and the remaining samples came from Reversing Falls in 1993 (n = 35). It was concluded that 63% and 97% of the Striped Bass in 1992 and 1993, respectively, originated from the United States while the remainder were most probably from the Shubenacadie River in Nova Scotia; no fish suspected to be native to the SJR were identified (Wirgin et al. 1995).

Table 1.5: Summary of six mark–recapture studies totaling 952 tagged fish marked within the Saint John River and recaptures of those tagged fish both within and outside of the Saint John River. One tagging study conducted in the United States is also included as one of the marked fish was recaptured in the Saint John River in 1976. Note: tagging details for Williamson (1974) are found in Price (1975).

Tagging site	N	Release date	Recaptures	Recapture site	Recapture date	Days at large	Distance travelled	Reference
Tagged and Re-captured in the Saint John River								
Saint in John River (lower)	100	Summer 1968	8	Belleisle Bay	January-March 1969	< 1 year		Moss (1970)
Grand Bay Westfield	26	September 21, 1971	1	Belleisle Bay	January 31, 1972	133	20 miles	Williamson (1974)
"		September 29, 1971	1	Belleisle Bay	February 3, 1972	128	20 miles	"
"		September 30, 1971	1	Belleisle Bay	January 17, 1972	109	20 miles	"
"		September 17, 1972	1	Belleisle Bay	December 29, 1972	83	20 miles	"
"		October 3, 1972	1	Belleisle Bay	January 20, 1973	109	20 miles	"
Darlings Lake	70	Spring 1975	3	Hammond River area	Summer			Dadswell (1976), Melvin (1976)
Belleisle Bay		May 1, 1975	3	Reversing Falls	Summer			"
Reversing Falls		August 1975	6	Belleisle Bay	Winter			"
Mactaquac Dam	189	1999	2	Mactaquac Dam	1999			Douglas (2003)
Mactaquac Dam	137	2000	7[a]	Mactaquac Dam	2000			"
Mactaquac Dam	44	2001	3[a]	Mactaquac Dam	2001			"
Mactaquac Dam	225	2002	2[a]	Mactaquac Dam	2002			"
Swan Creek, Grand lake, Otanabog	51	2010-2011	None	NA	NA			Wallace (2012)
Tagged in the Saint John River and Re-captured in the United States								
Saint John River	110	1964	1	Massachusetts				O'Donnell (1967)
"		"	1	New Jersey				"
"		"	1	Delaware				"
"		"	1	Maryland				"

Darlings Lake		June 5, 1969	1	Montauk, NY	November 19, 1969	167	500 miles	Moss (1970)
Westfield		September 12, 1972	1	Blackstone River, RI	October 23, 1972	36	500 miles	Williamson (1974)
Reversing Falls		August 7, 1973	1	Southampton, NY	November 1973	90	600 miles	Dadswell (1976)
Tagged in the United States and Re-captured in the Saint John River								
Nanticoke River Maryland[b]	1,375	April 14, 1973	1	Reversing Falls	October 25, 1976	1,279		Boone (date unknown), (Rulifson and Dadswell 1975)

[a]Boone (unpublished), however, stated that this fish was tagged in the SJR and may not have migrated from the United States.

[b]Recaptures from previous year of tagging.

1.8 Effects of Pollution

Several reports have hypothesized that chemicals such as DDT, polychlorinated biphenyls, heavy metals, and other industrial/agricultural pollutants have adversely impacted the SJR Striped Bass (Smith 1969; Dadswell 1975, 1976; Jessop 1990). From 1952 to 1968, DDT was applied heavily across forests (0.27– 0.57 kg/ha over 0.08–2.1 million ha) in New Brunswick for spruce budworm control (Yule and Tomlin 1971; Miller andKettela 1975); peak application occurred during 1957–1961 (Miller and Kettela 1975). Striped Bass sampled from Belleisle Bay had average DDT concentrations of 0.44 and3.6 ppm in muscle and gonads, respectively, with one gonad sample containing 8.1 ppm DDT (Dadswell 1975), well above the 0.5 ppm safety level of the time (Meth 1973b). Methyl mercury concentrations averaged 2.13 ppm with a maximum of 3.16 ppm (Dadswell 1975). The use of DDT was suggested as being linked to spawning failures observed in 1975 when 95.4% of SJR Striped Bass eggs were observed to have ruptured chorionic membranes (Dadswell 1975, 1976). As a result of these chemical effects on spawning, it has been hypothesized that Striped Bass within the SJR could have faced “biochemical extinction” (Dadswell 1975). Higher DDT concentrations have been reported in Striped Bass (9.93 ppm in flesh and 9.72 ppm in ova) without causing reproductive failure (Hunt and Linn 1970). The true impact of DDT use on Striped Bass in New Brunswick remains unknown

1.9 Conclusion

1.9.1 Knowledge Gaps, Future Research, and Management Needs

Collectively, the reports to date (including both tagging and genetic studies) support a hypothesis that three populations of distinct origin make up the Striped Bass assemblage in the SJR. One group of Striped Bass migrate from the rivers of the

United States for feeding, concentrating in areas such as the Reversing Falls and below the MGS. These individuals, most likely arriving mid-summer, may leave in the fall to return to their natal rivers or overwinter within the SJR and then leave in the spring. A second group migrates to SJR from the Shubenacadie River. It is not clear from preliminary reports when these fish arrive or how long they remain in the SJR; however, current tracking data suggest that they may reside within the SJR year-round apart from the spawning period. A third native resident group once existed; however, their current persistence is now in question.

It is uncertain if Striped Bass are reproducing successfully in the SJR, although juveniles (age 1-3) were captured in 2014 to 2016 (n = 77; TL = 12–36 cm: S. N. Andrews, Chapter 2). Acoustically tagged juveniles (n = 40) have so far remained within the river during the first year of tracking, suggesting that areas within the SJR serve as nursery areas for Striped Bass. The origin of these juveniles has yet to be determined.

Despite a long, though inconsistent, record of studies, the Striped Bass of the SJR remain poorly understood. The increasing collection of studies starting in the 1970s began with directed observation that improved our understanding of this complex population, but recent studies and technical reports are principally recitations of old documents, often reporting exaggerated and inaccurate information. Curiously, this lack of understanding is not reflected in the COSEWIC reports that have, in actuality, been assessing the SJR Striped Bass population as it was described in the mid-1970–1980s due to a lack of recent original studies (see COSEWIC 2004, 2012). There are reasons to consider a special status for the population, e.g., poor understanding of the ecology, uncertain reproductive success, and no comprehensive studies in more than three decades, but no indication of this need is given anywhere in published COSEWIC reports, nor does this lack of information seem to be a concern at any point in these documents.

1.9.2 Future Steps

Ten key areas must be urgently addressed:

1. Population size and structure: The most pressing need is a determination of the population size, abundance, and structure, e.g., mixed versus uniform stock, size, age, and sex.

2. Juvenile ecology: There is no information on juvenile Striped Bass in the SJR, especially in their first 2 years (Melvin 1991). Where these juveniles occur, seasonality, feeding, nursery areas, abundance, origin, movements, overwintering areas, and survival all remain unknown.

3. Recreational fisheries: There is no information on the number of Striped Bass harvested by an unknown number of recreational anglers within the SJR or what sizes or age-classes of fish are most often taken. In addition, there are no records of commercial bycatch or catches by aboriginal fisheries or how a combination of these fisheries is currently affecting the population (which is of unknown size).

4. Reproductive success: The last confirmed spawning event (although unsuccessful) was reported in Belleisle Creek in 1975. Even though several studies subsequently attempted to confirm reproduction of Striped Bass within the SJR, these surveys occurred long after the Striped Bass spawning period and cannot be considered evidence of a lack or failure of spawning. Current spawning by Striped Bass must be carefully assessed.

5. Habitats: There is no information of critical habitat for any SJR Striped Bass life stage, even though impact to habitat is often invoked as the overarching issue facing

SJR Striped Bass. We have yet to determine whether all or some or what mixture of Striped Bass (both juvenile and adult) use various habitats. In particular, winter residence is documented historically, but habitats, including movements and overwintering locations, have not been studied. The continued existence of Striped Bass in any location above the Mactaquac Dam is completely unknown.

6. Marine movements: The occurrence, direction, timing, and magnitude of marine movements of SJR Striped Bass are largely unknown. Such information will help distinguish between native contingents and between varying life history strategies and will possibly reveal density dependent trends associated with migration patterns.

7. Genetic structure: The existing studies of the genetic structure of the SJR Striped Bass population remain highly equivocal (Wirgin et al. 1995; Bentzen and Paterson 2008). This is in part due to the restricted sampling of Striped Bass in these studies, and therefore broader and more conclusive sampling of age-class structure throughout the river at various locations and times of the year is required. Pre-migratory juveniles and larvae would provide the most credible genetic baseline; however, it remains possible that current spawners may include emigrants from elsewhere.

8. Feeding and species interaction: No information is available on the diet or seasonal feeding habits of Striped Bass within the SJR. Nothing is known about how Striped Bass may be impacting other fish species or how the SJR's various commercial fisheries (i.e., American Shad, gaspereau) may be affecting Striped Bass.

9. Other potential stressors: The effect of pollutants (DDT, heavy metals, polychlorinated biphenyls, mercury) on Striped Bass egg and larval survival, as well as information on bioaccumulation in adults, must be updated (Dadswell 1975; Jessop 1990).

10. Mactaquac Dam: Much speculation exists surrounding the impact that the construction of the Mactaquac Dam has had on Striped Bass spawning after its completion in 1968. It is unknown how these impacts would change or if they could be reversed if the Mactaquac Dam is reconstructed or removed. It is also unknown whether the Mactaquac headpond could support a landlocked population of Striped Bass should the Mactaquac Dam be left in place.

Until more rigorous studies establish the true population status, origins, movements, threats, and concrete recovery strategies for Striped Bass in the SJR, fisheries managers will continue blindly into the future making decisions about a species whose ecology and population dynamics, both past and present, are barely understood.

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Chapter 2:

Interannual Variation in Spawning Success of Striped Bass (*Morone saxatilis*) in the Saint John River, New Brunswick

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2.1 Abstract

Barriers such as dams have been cited as a serious threat to Striped Bass survival, especially when they affect or impede migration and access to spawning grounds. On the Saint John River, New Brunswick, the installation of the large Mactaquac Dam in the immediate vicinity of a historic Striped Bass spawning location was suspected to have caused the arrest of Striped Bass reproduction and the collapse of the native Striped Bass population. In 2014, juvenile Striped Bass of confirmed Saint John River origin were documented in the river for the first time since 1979. In the current study, we examined juveniles from six years of sampling to determine corresponding years of successful recruitment. We also tracked adult Striped Bass matching the ancestry of native Saint John River juveniles to determine the timing and location of spawning. Over 5 years, we observed an annual upstream migration by adult Striped Bass to historic spawning areas near Fredericton, identified a dominant year class of Saint John River origin juveniles reproduced in 2013, and linked the apparent successful production of year classes to definable discharge conditions, i.e., extended periods of sustained flow >36 h downstream from the Mactaquac Dam. The results of this study suggest important first management actions towards recovering and sustaining a once lost Striped Bass population in the Saint John River, New Brunswick.

2.2 Introduction

Throughout its range, Striped Bass (*Morone saxatilis*) spawn in rivers with (a) enough flow velocity to suspend the semi-buoyant eggs (Green et al. 2009), (b) adequate temperature for egg incubation (Talbot 1966), and (c) sufficient length (or enough tidal influence; Rulifson and Tull 1999) to maintain the eggs in fresh or low salinity water throughout the incubation process (Parley et al. 1994). The spawning process itself is suspected to be triggered by a minimum temperature threshold (Talbot 1966) or possibly growing degree days (Duston et al. 2018) and the occurrence of moderate sustained flows on the spawning grounds (Rulifson and Tull 1999). Subsequently, the maintenance of these conditions in the hours and days immediately after spawning is critical for juvenile survival and recruitment (Manooch and Rulifson 1989) and most likely transport to nursery habitats.

In locations where natural temperature regimes and flow conditions have been disrupted, such as downstream of dams or hydroelectric facilities, poor Striped Bass spawning and recruitment success has been observed (Fish and McCoy 1959, Rulifson and Manooch III 1990). On the Saint John River (SJR), New Brunswick, the completion of the large Mactaquac Dam in 1968 in the immediate vicinity of a historic Striped Bass spawning (see Andrews et al. 2017, Chapter 2) location was suspected to have caused the cessation of Striped Bass reproduction (COSEWIC 2012). Additionally, documented spawning failures within the SJR (1975; Dadswell 1975), and an apparent abundance of USA origin Striped Bass (Wirgin et al. 1995; Bentzen and Paterson 2008) have suggested a lost or highly depressed native SJR population (Andrews et al. 2017, Chapter 2). In combination, these factors contributed to the current designation of the SJR Striped Bass as “Endangered” by COSEWIC (2012) within the Bay of Fundy Designatable Unit (Fig. 2.1).

In 2014, age 1 Striped Bass were sampled from the SJR for the first time since 1979, suggesting that successful spawning by surviving native Striped Bass had occurred (Leblanc et al. 2018). This year class and others subsequently sampled have provided the first chance to examine discharge conditions at Mactaquac Dam that may promote Striped Bass spawning and could provide management options to recover a once lost population. To further explore these findings, this study details the results of six consecutive years of monitoring putative native SJR Striped Bass year classes aged 1-8 (juvenile to sub-adult). In addition, we tracked adult Striped Bass that matched the genetic profile of putative native juveniles to determine spawning periods and locations. Finally, we compared juvenile year class strength to temperature and discharge characteristics measured in the SJR at the Mactaquac Dam. We hypothesized that the highly regulated, river temperature and discharge regimes imposed by Mactaquac Dam operations impact spawning success at this upstream location through the disruptions of moderate sustained flow and temperature required for Striped Bass reproduction. We further predicted that the observed disjunct, juvenile production is linked to definable discharge and temperature conditions of the dam regulated waters. Collectively, we are seeking to define a managed flow regime that could promote future and consistent Striped Bass reproduction within the SJR.

2.3 Study Area

Saint John River (SJR) is a 55,000 km^2 catchment that extends ~670 km from the Bay of Fundy to northern Maine and southeastern Québec (Cunjak et al. 2011; Fig. 2.1). The head of tide lies ~130 km upstream from the river's mouth and salt water intrusion is measurable ~70 km upriver (village of Gagetown; Carter and Dadswell 1983). The river is fragmented by three large, main stem dams of which the Mactaquac Generating Station (MGS) is the largest and most downstream located facility (approx 150 km upstream from the river mouth). The MGS has no directed fish passage for Striped Bass (Andrews et al. 2017, Chapter 2, Appendix 1) making it a physical barrier to upstream migration and the upstream limit of our study area. Downstream from MGS, the river is fed by four large mainstem tributaries including Grand Lake, Washademoak Lake, Belleisle Bay, and Kennebecasis Bay that support habitat ranging from deep stratified basins (65 m depth) to warmer, shallow salt marshes (>25°C in summer, 1-3 m depth), all of which receive varying degrees of tidal and salt water influence (Fig. 2.1).

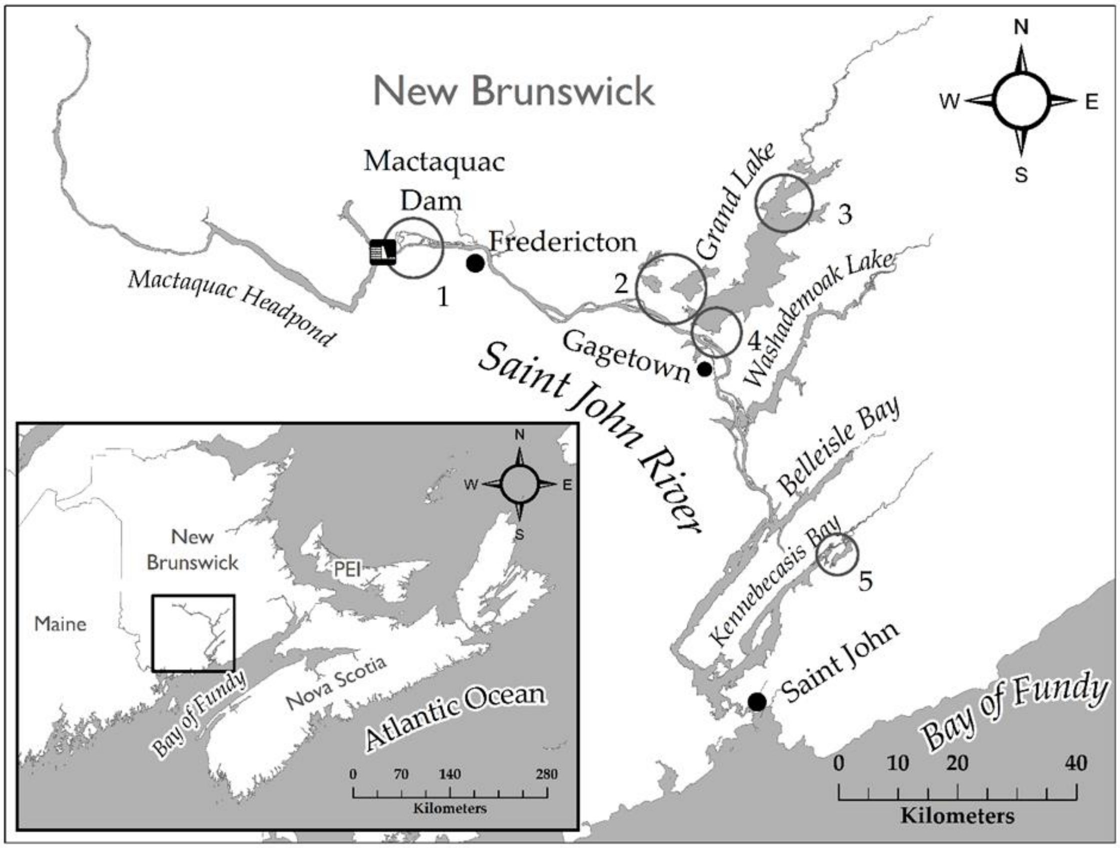

Figure 2.1: Study area along the Saint John River, New Brunswick, ranging 150 km from the Mactaquac Dam near the City of Fredericton, downstream to the City of Saint John including the four major river tributary lakes and bays including Grand Lake, Washademoak Lake, Belleisle Bay, and Kennebecasis Bay. Numbered black circles indicate the five areas where juvenile Striped Bass were collected: 1) Downstream of Mactaquac Dam, 2) French and Maquapit Lake, 3) Upper Grand Lake, 4) Jemseg River and lower Grand Lake, and 5) Hampton Marsh/mouth of Hammond River. The village of Gagetown is the head of salt water influence in the Saint John River.

2.4 Methods

2.4.1 Sampling

Young Striped Bass (n=426) were captured by various commercial and recreational gear within the SJR from 2014-2019. All fish were processed for body size (FL, TL, and weight), scale samples were collected from between the second dorsal fin and lateral line for aging, and a fin clip was collected from the upper lobe of the caudal fin for genetic analysis. Most individuals, n=378, were captured by commercial fishers in fixed trap nets in Grand Lake (Areas 3 and 4, Fig. 2.1), n=26 were captured by angling in Grand Lake and the Kennebecasis (Areas 4 and 5, Fig. 2.1), n=18 were sampled by gill and fyke nets in the Kennebecasis (Area 5, Fig 2.1), and n=3 by boat electro-fishing near the MGS (Area 1, Fig. 2.1). All procedures were approved by the University of New Brunswick UNB Animal Care Committee (Animal Use Protocol Numbers 10026).

Ageing was conducted using scales (n=3-7/fish) analysed by one reader under a dissecting microscope. The modal age amongst scales was considered the true age. Annuli on smaller, age 1-2 scales were most easily determined by looking for the flattening of circuli (Scofield 1931) as the full annuli at both the first and second winter were often imperceptible. Scale ageing allowed for back calculation to the year of hatching for individuals (Table 2.1). Genetic reference samples for comparison of population structure were obtained from nearby populations (see Leblanc et al. 2018 for details).

2.4.2 Genetic Methods

Caudal fin clips from sampled Striped Bass (n= 110) were genotyped to determine population ancestry. Juveniles, n = 23 (age 1-3) were analyzed as a preliminary sample (see Leblanc et al. 2018) and an additional 87 fish (age 3-7) were added in this study. Samples were isolated with either the NucleoMag® 96 Tissue (Machery-Nagel, Düren, Germany) or, for smaller tissue samples, the E.Z.N.A. Tissue DNA Kit (Omega Bio-Tek, Doraville, CA). Sequencing methods are described in Leblanc et al. (2018). Single nucleotide polymorphisms (SNP)s were retained if they were present in all populations and had less than 20% missing data in any given population, and if they were not in linkage disequilibrium with any other SNP as measured by PLINK v. 1.07 (Purcell et al. 2007) using an R2 threshold of 0.2. To maximize coverage for each location within the SJR, individuals were retained if they had less than 30% missing data across all loci. Outlier loci were detected using Bayescan (Foll & Gaggiotti 2008), Arlequin 3.5.2.2. (Excoffier and Lischer 2010), and the R package adegenet 2.1.1 (Jombart 2008), and loci detected by all three programs were excluded from analysis to ensure that only neutral genetic differences were measured. Individuals were assigned to distinct genetic clusters calculated in the R package LEA v. 2.0 (Frichot and François 2015). Using LEA, the most likely number of ancestral populations (K) was determined using the cross-entropy criterion, with the lowest minimal cross-entropy value considered the most probable (Frichot et al. 2014). Individuals were then assigned to each ancestral population using an ancestry coefficient from 0 to 100. Individuals with an ancestry coefficient greater than 70 were said to belong to that ancestral population.

2.4.3 Acoustic Tagging

Adult Striped Bass (n=44) were captured and tagged with Vemco V13-4L (n=3; tag life=719 days), V16-4L (n=38; tag life=3650 days), and V16-6L (n=3; tag life=3650 days) acoustic tags. Surgical procedures and tagging were carried out following procedures outlined in Wingate and Secor (2017) using a 40 mg/L solution of 10-part ETOH:1-parts clove oil as anaesthetic. Tagging locations, dates, and capture methods are described in Table 1. The Striped Bass n=3 in 2013, n=24 in 2014, n=10 in 2015, n=7 in 2016 ranged in TL from 63-119 cm and weighed from 3-20 kg (Table 2.1). These individuals were also genotyped (see genetic methods above and Table 2.1) and compared to native SJR origin juveniles (this study; Leblanc et al. 2018) and other reference population (see Leblanc et al. 2018)

Table 2.1: Tagging data for acoustically tagged adult Striped Bass including tag ID, tag type, tagging date and location, capture methods, Total length (cm), Weight (kg), genetic origin (SJR, SHUB, US or SJR/US) and spawning location. Striped Bass that did not survive tagging or were undetected following tagging (n=7) were omitted. Striped Bass with genotypes matching native SJR origin juveniles and individuals that were detected in Fredericton during the spawning period are marked in light grey. Striped Bass indicated as having spawned in the "Hammond?" often moved between the Hammond River and Hampton marsh at this time complicating the determination of the true spawning location. Any Striped Bass detected in a spawning location returned to that same location in each year of the study. Origins marked with "?" indicate a suspected origin as a result of spring spawning migration.

Tag ID	Tag type	Tagging date	Tagging location	Capture method	TL (cm)	Weight (kg)	Origin	Spawning location
32645	V16-6x	2013-10-04	Mactaquac Hatchery	Fish lift	88.2	9.3		
32647	V16-6x	2013-10-04	Mactaquac Hatchery	Fish lift	81.4	10.5	SHUB?	Shubenacadie
32648	V16-6x	2013-10-04	Mactaquac Hatchery	Fish lift	96.8	9.7	US	Shubenacadie
32646	V13-4L	2014-05-23	Grand Lake	Commercial net	75.4	5.4	SJR	
32650	V13-4L	2014-06-09	Hampton Marsh	Angling	63.2	2.9	SHUB?	Shubenacadie
32652	V13-4L	2014-09-13	Reversing falls	Angling	81	4.9	SHUB?	Shubenacadie
24952	V16-4L	2014-06-11	Grand Lake	Commercial net	71.1	3.9	SJR	Salmon River
24951	V16-4L	2014-06-11	Grand Lake	Commercial net	83.6	7.1	SJR	
24949	V16-4L	2014-06-11	Grand Lake	Commercial net	82.2	6.6	SHUB?	Shubenacadie
24942	V16-4L	2014-07-16	Mactaquac Hatchery	Fish Lift	77.4	5.6		Salmon River
24941	V16-4L	2014-07-25	Hampton Marsh	Boat e-fishing	100.5	10.5		Hammond?
24943	V16-4L	2014-07-25	Hampton Marsh	Boat e-fishing	104.8	13.8		Salmon River
24945	V16-4L	2014-07-25	Hampton Marsh	Boat e-fishing	116.5	19.6		Hammond?
24946	V16-4L	2014-08-21	Mactaquac Hatchery	Boat e-fishing	80.2	6.5	SJR?	Fredericton
24948	V16-4L	2014-08-22	Mactaquac Hatchery	Fish lift	72	4.5	SJR	Fredericton
24944	V16-4L	2014-08-22	Mactaquac Hatchery	Fish lift	80	4.9	SJR	Hammond?
24950	V16-4L	2014-08-22	Mactaquac Hatchery	Fish lift	72	4.5	SJR?	Fredericton

24953	V16-4L	2014-08-22	Mactaquac Hatchery	Fish lift	90.5	9.3	SJR	
24959	V16-4L	2014-09-12	Mactaquac Hatchery	Fish lift	82.4	6.0	SHUB?	Shubenacadie
24957	V16-4L	2014-09-12	Mactaquac Hatchery	Fish lift	85.2	7.7	SHUB?	Shubenacadie
24954	V16-4L	2014-09-12	Mactaquac Hatchery	Fish lift	86	7.3	SJR	Fredericton
24956	V16-4L	2014-09-12	Mactaquac Hatchery	Fish lift	81.7	6.4	SJR	Fredericton
24958	V16-4L	2014-09-13	Reversing Falls	Angling	86.5	7.5	SHUB	Shubenacadie
24960	V16-4L	2014-09-13	Reversing Falls	Angling	89	7.7	SHUB?	Shubenacadie
22141	V16-4L	2015-06-10	Grand lake	Commercial net	71.3	5.8	SJR	Fredericton
22139	V16-4L	2015-06-15	Grand lake	Commercial net	65.5	3.4	SJR?	Fredericton
22137	V16-4L	2015-06-15	Grand lake	Commercial net	79.5	5.0	SJR/US	Fredericton
22136	V16-4L	2015-06-20	Hampton Marsh	Angling	100	9.3	SJR	
21326	V16-4L	2015-10-24	Washademoak	Gill Net	84.1	6.4	SJR	Fredericton
22132	V16-4L	2015-10-24	Washademoak	Gill Net	84	7.0	SJR	
22138	V16-4L	2016-05-11	Grand Lake	Commercial net	78.6	5.2	SJR	
21323	V16-4L	2016-05-11	Grand Lake	Commercial net	73	4.13	SJR	Salmon River
21324	V16-4L	2016-05-11	Grand Lake	Commercial net	74	4.59	SJR	
21328	V16-4L	2016-05-20	Grand Lake	Commercial net	70	3	SJR/US	Grand Lake
22135	V16-4L	2016-05-27	Grand Lake	Commercial net	99	12.35		Salmon River
22133	V16-4L	2016-06-09	Hampton Marsh	Angling	84	7.06	US	Hammond?
24945*	V16-4L	2016-06-17	Hampton Marsh	Angling	118.5	19.83	US	Hammond?

*Tag 24945 was first implanted in a Striped Bass in 2014, this tag was recovered from that fish June 9, 2016 following a winter mortality event and re-implanted into a second Striped Bass in June 17, 2016.

2.4.4 Tracking

All tagged Striped Bass were tracked with a Vemco VR2W receiver array distributed along the SJR from the river mouth to the MGS (Fig. 2.2). Receivers were moored on the river bottom and annually retrieved and downloaded. The array included n=36 VR2W placements in 2014, n=125 in 2015, n=128 in 2016, n=135 in 2017 and n=58 in 2018 that were active year-round throughout the study period (Fig. 2.2). Additional tracking data were received from the Ocean Tracking Network (OTN - http://oceantrackingnetwork.org/). OTN receivers detected Striped Bass in the SJR in 2014 (n=19), 2015 (n=17), 2016 (n=48), 2017 (n=9), and 2018 (n=10). Some receivers were fitted with Onset HOBO® temperature pendants in 2015 (n=91), 2016 (n=81), and 2017 (n=40). OTN receivers also detected Striped Bass outside of the Saint John River in 2014 (n=13), 2015 (n=18), 2016 (n=11), 2017 (n=12) and 2018 (n=22) allowing for the determination of spawning movements to the Shubenacadie River Nova Scotia.

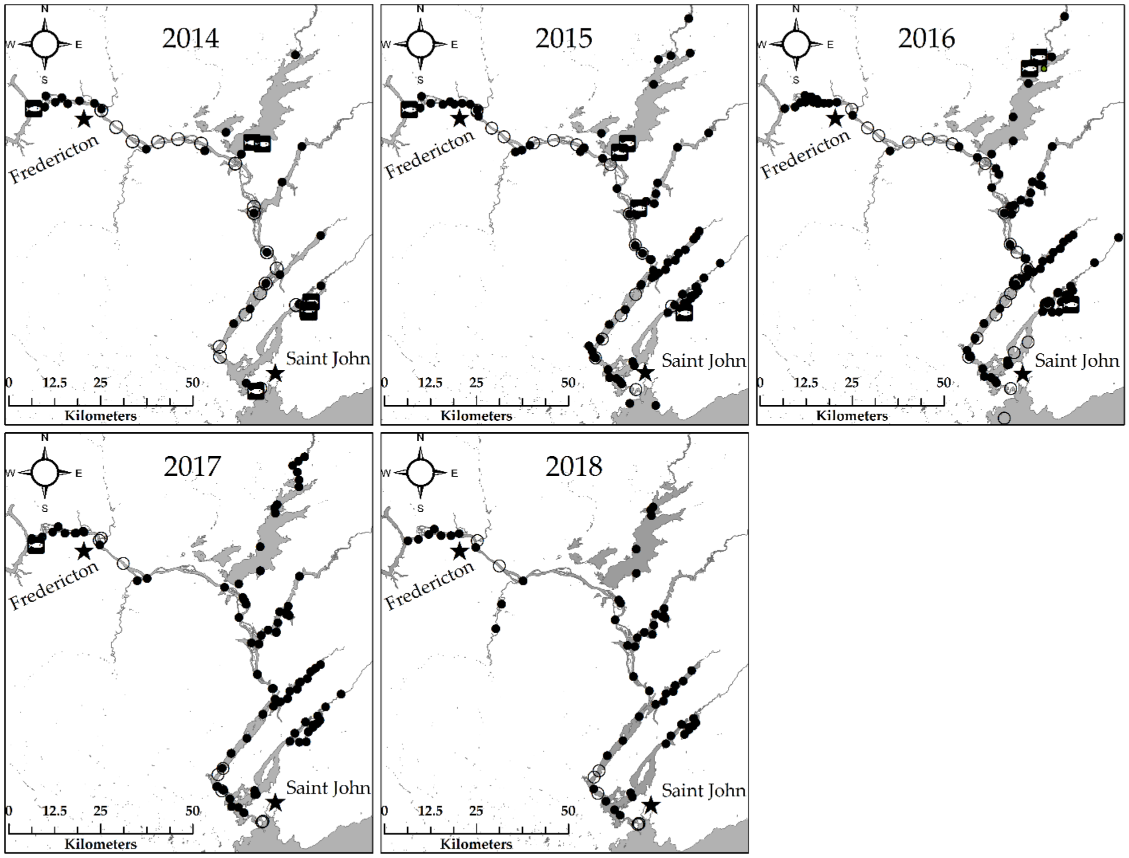

Figure 2.2: Locations of Striped Bass tagging (fish symbols), project specific VR2W receiver placements (black points) and OTN receivers (black open circles) which detected tagged Striped Bass along the Saint John River, New Brunswick from 2014-2018.

2.4.5 Determination of Spawning Period

Adult Striped Bass matching the native SJR genotype first described by Leblanc et al. (2018; Table 2.1) were monitored in spring to determine the timing and destination of spawning migrations. For this study we were specifically interested in Striped Bass detected in the suspected historic spawning location in the immediate vicinity of the Mactaquac Dam (within 20 km downstream of the Dam; Fig. 2.3) in spring (May/June). This study area was monitored using VR2W receivers: n=13 in 2016, 7 in 2017, and 7 in

2018 from the pre-described array. We defined the core spawning period for SJR Striped Bass migrating to Mactaquac Dam as 50% of all days spent by all tagged adults (SJR origin) within 20 km (detected on the pre-described receivers) downstream of the MGS in spring (May-June; near the City of Fredericton; Fig. 2.1). This 50% core period was defined by measuring the narrowest distribution of days across that Striped Bass were observed during this spring period until half of all observation days were accounted for. An extended spawning range within this same 20 km region was also defined using the same method considering 75% of all days spent in the region by all detected Striped Bass.

2.4.6 Searching for Striped Bass Eggs

Conical plankton drift nets with a 1 m x 0.5 m rectangular opening (mesh size = 950 µm) were used to sample for suspended Striped Bass eggs and/or larvae (Lukens 1989). We set nets staggered across the river and moored at 5 locations; Fredericton, Salmon River at the head of Grand Lake, Belleisle Creek at the head of Belleisle Bay, Kennebecasis River and the adjoining Hammond River (see Fig. 2.1). In Fredericton, plankton nets were set in the defined reach downstream of MGS (Fig. 2.3) n=7 in 2016, n=5 in 2017 and n=6 in 2018. Plankton Drift nets were deployed in Belleisle Creek (n=3; May 15 – June 2), Kennebecasis River (n=3; May 18 – June 8), Hammond River (n=3; May 16 - June 8) in 2015, and in Salmon River in 2017 (n=3; May 20 – May 23) but nets were removed from this location early due to lack of flow in the downstream river section. Nets were set to fish continuously ~30-60 cm below the water surface (see Reinert et al. 2004) suspended by buoys and were checked for eggs and cleaned every 24 hours during early morning.

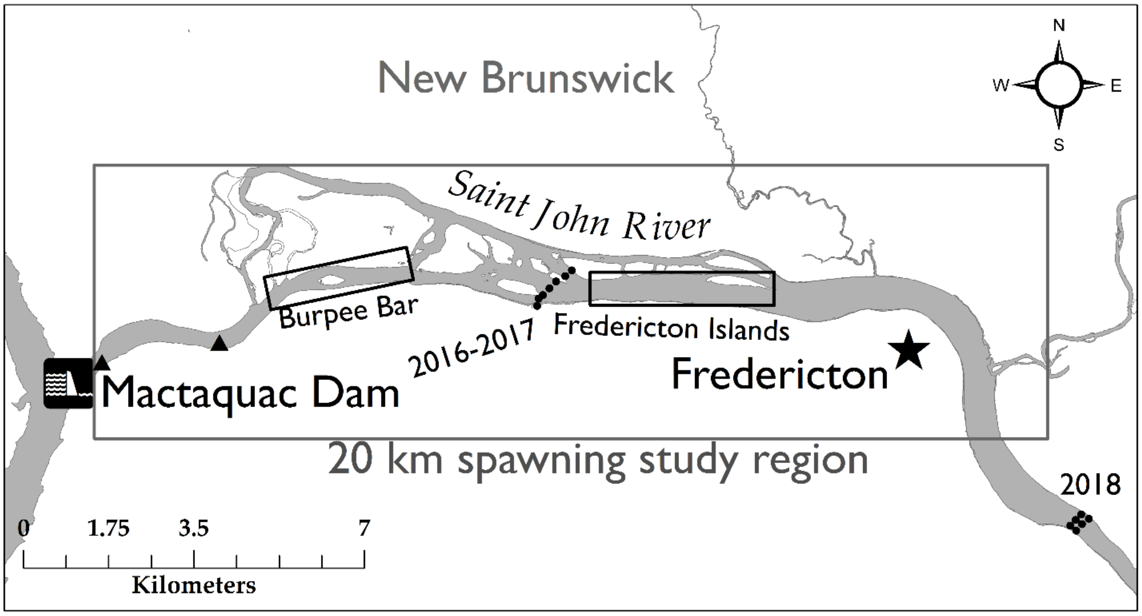

Figure 2.3 Map of the 20 km spawning study region for Striped Bass including the two temperature recording sites 0.3 and 3.3km downstream from Mactaquac Dam (black triangles), and plankton drift nets set to sample for Striped Bass eggs and larvae in 2016, 2017 and 2018 (black circles). Burpee bar and the Fredericton islands where depth averaged water velocities were calculated using DELFT 3D are also marked (black rectangles).

2.4.7 Assessing River Discharge, Flow Velocity and Temperature

River discharge data were assessed from 2005-2018 during the Striped Bass spawning season (see Determination of Spawning Period). River discharge data were received from the New Brunswick Power Corporation (NBP) as the total hourly discharge rate (m^3/s) from all turbines at the Mactaquac Generating Station (MGS). Using discharge data, periods of sustained, stable flow were defined as a discharge period when instantaneous declines in discharge between two hourly measurements at the MGS were ≤ 20%. Measuring instantaneous declines ≤ 20% allowed for a clear distinction between periods of "sustained flow" and "fluctuating flow" and was characteristic of available stable flows occurring during the peaks and troughs amongst discharge fluctuations. The longest period of such sustained flow that was measured within the extended Striped Bass spawning period (75% of tracked days for native adult Striped Bass) was compared to measured juvenile recruitment in each year (determined from back calculated scale ages).

A hydrodynamic model developed for the SJR for the area between the MGS and Fredericton (DELFT 3D, K. Haralampides and M. Ndong, unpublished data) was used to determine appropriate discharges required to suspend Striped Bass eggs for successful incubation, i.e., average required minimum and maximum water velocities (0.32 – 2.12 m/s; Mansueti 1958, Talbot 1966). Modeled discharges produced data on depth averaged flow velocities at locations (see Burpee Bar and Fredericton Islands, Fig. 2.3) occupied by tagged SJR Striped Bass during the observed spawning period.

Water temperature data were collected from HOBO temperature pendants deployed 0.3 km and 3.3 km downstream of the MGS (2015-2018; N 45.95577, -W 66.86340 and N 45.959610, W -66.82642; hourly measurements; Fig. 2.3). A temperature line deployed directly upstream of the Mactaquac Dam in 2015 (45.94523, -66.87510, loggers at 1-5 m intervals logging every 2 hours) provided upstream temperature data. Upstream turbine intake at the MGS is located from 7 - 22 m depth (Mactaquac Development General Arrangement Drawing 1140-C-2927).

2.5 Results

2.5.1 Juvenile and Sub-adult Striped Bass

Young Striped Bass sampled from 2014 to 2019 (n=436; Table 2.1) measured 11.6 – 74.5 cm (FL), weighed 18 - 4410 g, and ranged from age 1-8 (both juveniles and sub-adults; Table 2.2).

Table 2.2: Juvenile and sub-adult Striped Bass sampled (age 1-8) across six sampling years (2014-2019) including the age distribution of those individuals. Grey boxes indicate all individuals (n=304) pertaining to a 2013 Saint John River Striped Bass year class. Open boxes indicate all individuals (n=58) belonging to a 2011 Saint John River Striped Bass year class. Juvenile production also occurred in 2010 (n=5), 2012 (n=27), 2014 (n=23) and 2015 (n=9) though recruitment in these years was limited. Juvenile Striped Bass from 2010 and 2015 year classes may not be of native Saint John River origin.

	2014	2015	2016	2017	2018	2019	Total
# sampled	18	29	56	117	95	111	**426**
Age 1	13	0	0	0	0	0	**13**
Age 2	0	21	0	0	0	0	**21**
Age 3	2	1	43	2	0	0	**48**
Age 4	3	7	6	87	9	9	**121**
Age 5	0	0	5	8	64	12	**89**
Age 6	0	0	2	20	10	76	**108**
Age 7	0	0	0	0	12	2	**14**
Age 8	0	0	0	0	0	12	**12**
Age 9	0	0	0	0	0	0	**0**

Juveniles sampling efficiency increased markedly in latter sampling years due to greater knowledge of timing and locations juveniles were likely to be found. Due to this, the number of individuals captured each year cannot be used to estimate changes in relative population sizes or im/emigration. The majority of Striped Bass sampled (n=304) came from a single year class, 2013, and represent 71% of all young individuals sampled across all study years throughout the SJR. Smaller year classes also occurred in 2011, 2012, and 2014 evidenced by the collection of n=58, n=27, and n=23 young Striped Bass with ages corresponding to respective year, and all juveniles genotyped from these year classes matched the distinct SJR genetic profile. Young Striped Bass were also collected from a 2010-year class (n=5); however, genetics results from the single individual genotyped from this group suggest that it was of Shubenacadie River origin leaving no evidence of native SJR production in that year. We also suspect the n=9 age 4 individuals collected from a putative 2015-year class in 2019 to be of non-SJR origin as no individuals from this year class were observed in any prior year of collection suggesting possible arrival from an outside source population. Genotypes were not assessed for individuals in this group.

2.5.2 Genetic Population Structure

After filtering for genetic quality, 1217 SNP loci were retained for use in final analyses. A total of 101 juveniles were successfully genotyped with <30% missing data. All but one individual showed at least some assignment (>24% ancestry coefficient) to the SJR genetic cluster (Leblanc et al. 2018). We considered juvenile Striped Bass (N=78, 77%) showing greater than 80% ancestry coefficient to the SJR genetic cluster to be SJR Striped Bass. Only one individual (age 4, captured in 2014) was assigned to the Shubenacadie River contingent (ancestry coefficient 96%).

Striped Bass that were not singularly assigned to any population (n=22, 23%) were considered of admixed, i.e., mixed ancestry. These juveniles display genetic traits of the SJR population and either Shubenacadie River (n=5), USA. populations (n=16), or both (n=1). Genetic clustering is unable to confirm whether individuals are generation 1 or 2 hybrids.

F_{ST} among all populations was 0.135. Pairwise F_{ST} between juveniles in the Saint John River (excluding the Shubenacadie River juvenile) and the reference populations ranged from F_{ST} = 0.110 to 0.173. When admixed individuals were removed, overall F_{ST} was 0.145 and pairwise F_{ST} between SJR and other populations ranged from 0.123 to 0.185. All p-values were < 0.00005 (Table 2.3).

Table 2.3: Pairwise FST comparisons of Striped Bass samples from four sampling sites (MIR = Miramichi River, SHUB = Shubenacadie, SJR = Saint John River, CHPK = Chesapeake Bay, HUD = Hudson River) using 1217 SNP loci. FST values above the diagonal compare all SJR juveniles to other populations, while values below the diagonal compare non-admixed SJR juveniles to other populations. All P-values are < 0.0000055.

	MIR	SHUB	SJR	CHPK	HUD
MIR	*	0.19784	0.17267	0.19458	0.18642
SHUB	0.19784	*	0.13482	0.17535	0.1642
SJR	0.18503	0.14743	*	0.10988	0.10596
CHPK	0.19458	0.17535	0.12803	*	0.01789
HUD	0.18642	0.1642	0.12296	0.01789	*

2.5.3 Adult Striped Bass Spawning Migration

Tagged adult Striped Bass matching the genetic profile of putative native SJR Striped Bass (n=9) were tracked moving to the islands upstream of the City of Fredericton at the beginning of May (Fig. 2.4). These individuals were all present in this well-defined reach from May 1 – June 23 across three consecutive years (2016-2018) when water temperatures ranged from 5.5°C - 17.9°C. Study years 2014 and 2015 were not included for analysis due to limited receiver coverage between the MGS and city of Fredericton. The core spawning period (50% of all detection days) was May 21 - 30 in 2016, May 20 – June 1 in 2017 and May 20 - 29 in 2018 (Fig. 2.4), which were combined to produce an overall core period measuring 12-days from May 20 – June 1. The extended spawning period (75% of days upstream) was measured as May 19 – June 3 in 2016, May 19 – June 9 in 2017 and May 19 – June 5 in 2018 (Fig. 2.4) which were also combined to form an overall extended spawning period of 22 days from May 19 – June 9.

In addition to the Fredericton location of potential spawning, n=6 adults matching the putative native SJR genetic profile travelled in spring to the Salmon River at the head of Grand Lake (2015-2017) from May 9 – May 30 in 2017. The extent of upstream distance traveled is unknown. Water velocities in downstream regions of Salmon River near its confluence with Grand Lake were too slow to effectively fish plankton drift nets for eggs (2017). If spawning were to occur in this location it must be at a considerable distance upstream. The Hammond River and Hampton Marsh, at the mouth of the Kennebecasis River may also have supported Striped Bass spawning. Striped Bass exiting Darling's Lake in spring (n=4) and n=1 Striped Bass travelling from Washademoak Lake (consisting of both putative native and US origin Striped Bass) aggregated annually near or within the Hammond River and did not conduct any further directed movements. This movement conducted by the Washademoak Lake origin Striped Bass occurred from May 13 – June 17 in each year from 2015 – 2018. Striped Bass n=9 of Shubenacadie River origin were also detected departing the Saint John River at this time (Andrews et al. 2019b, Chapter 2) and travelled to spawn in the Shubenacadie River Nova Scotia.

Among the five sites and four years of sampling throughout the SJR, no Striped Bass eggs or larvae were collected at any sampling location.

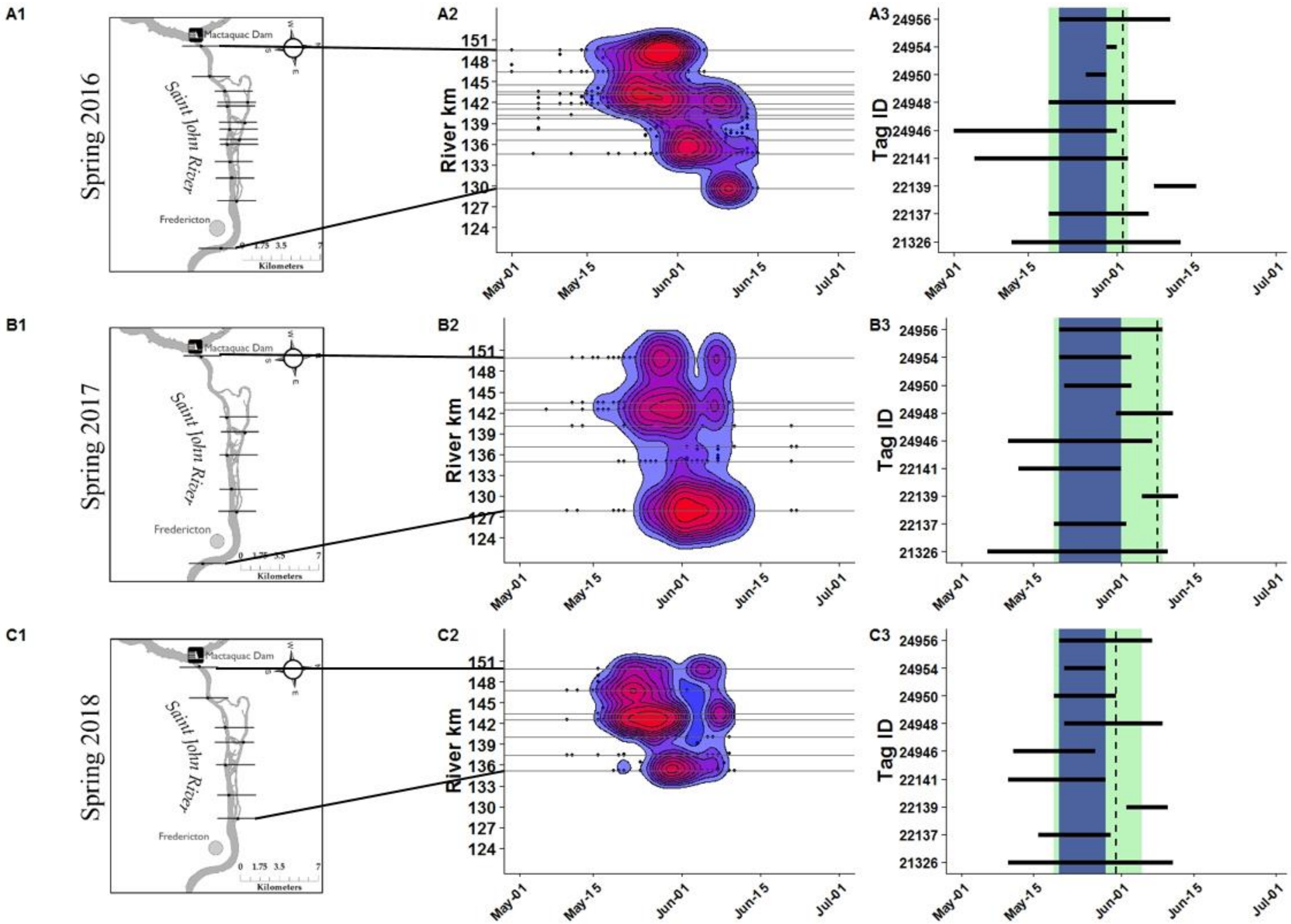
A1
Spring 2016
Mactaquac Dam
Saint John River
Fredericton
Kilometers
A2
River km
A3
Tag ID
B1
Spring 2017
B2
B3
C1
Spring 2018
C2
C3
151
148
145
142
139
136
133
130
127
124
May-01
May-15
Jun-01
Jun-15
Jul-01
24956
24954
24950
24948
24946
22141
22139
22137
21326

Figure 2.4: Characterization of the spawning period for tagged Saint John River origin Striped Bass detected between the City of Fredericton and the Mactaquac Dam in spring for 2016-2018. 1) map of the suspected spawning area with VR2W receiver locations (dots and cross-river projections as a line), 2) density isopleth of hourly upstream location for all tagged Striped Bass for the months of May and June, 3) duration of occupancy in spring for each detected Striped Bass (occupancy period each tag ID indicated by horizontal black line), Blue box indicates the core spawning period (50% of all days spent by all tagged Striped Bass in the spawning region), the Green box is the 75% occupancy period. The black dashed vertical line in plot 3 (A, B, C) indicates the first date that water temperature reached 14.5°C, the minimum required spawning temperature for Striped Bass which is likely delayed by cold water discharges from the submerged intake at the Mactaquac Dam.

2.5.4 Mactaquac Generating Station Discharge

Typical operation by the MGS imposes a hydropeaking regime (resulting in alterations between high discharge during power generation and low discharge during water ponding activities) in the immediate downstream vicinity of the dam. These variations between high (850 - 1850 m³/s) and low (150 - 300 m³/s) discharge can cause water level fluctuations of >3 m in the dam's tailrace during hydropeaking cycles (~24-hour cycles; Fig. 2.5) and sustained hydropeaking cycles downstream for the Mactaquac dam were characterised by rapid declines in discharge as great as 91% in one hour. During spawning, Striped Bass require stable sustained flow (Manooch III and Rulifson 1989) and spawning can be impeded by "rapid decreases in water level" (e.g., on the Roanoke River; Manooch III and Rulifson 1989).

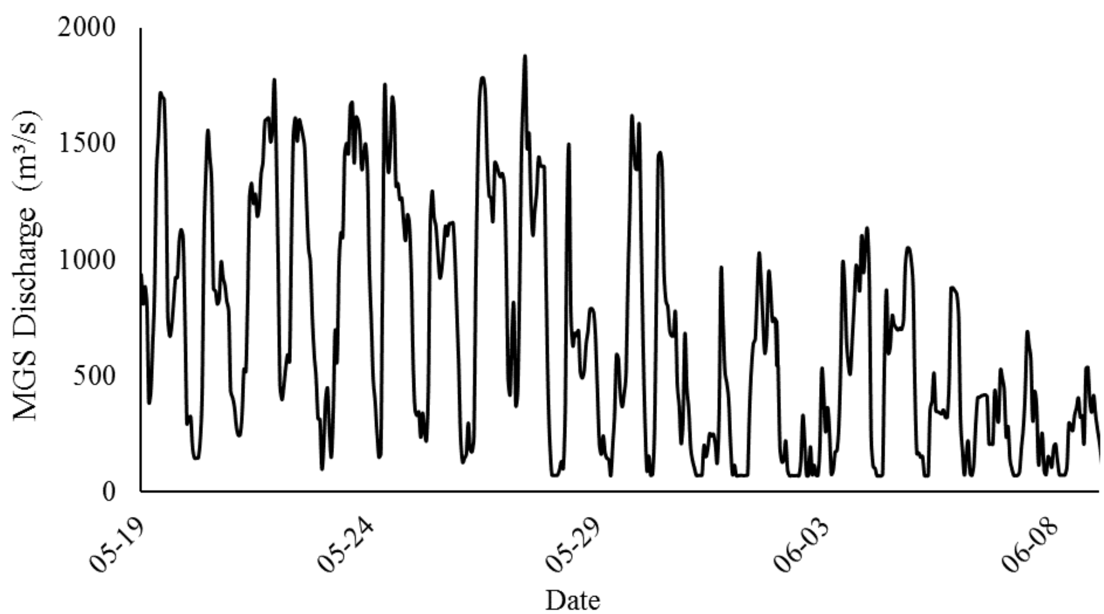

Figure 2.5: Hourly MGS discharge (m³/s) recorded at the Mactaquac Dam in 2018 from May 19 – June 9, the combined 75% extended Striped Bass spawning period between the City of Fredericton and the Mactaquac Dam demonstrating the hydropeaking cycle observed during periods of regulated discharge.

The DELFT 3D hydrodynamic model predicted depth averaged flow velocity at discharge intervals representing a range in observed median stable discharges at both Burpee Bar (river km 142; Fig. 2.3) and the Fredericton Islands (river km 128-132; Fig. 2.3; Table. 2.4). Discharges >1000 m^3/s at the MGS were considered favorable for Striped Bass spawning because surface velocities >0.32m/s are the minimum average required to suspend and incubate Striped Bass eggs; (Mansueti 1958, Talbot 1966).

Table 2.4: Depth Averaged flow velocity calculated by the DELFT 3D model for the Saint John River at Burpee Bar (rkm = 143.5) and near the Fredericton Islands (rkm = 135) for five discharges from MGS (m^3/s). Reported velocities represent mean ± standard deviation of 3,407 dynamic velocity cells for Burpee Bar and 21,944 dynamic velocity cells in the main river channel at the islands. See also Figure 2.5.

	Depth Averaged Flow Velocity m/s			
MGS Discharge m^3/s	Burpee Bar	± SD	Islands	±SD
425	0.53	0.14	0.24	0.04
991	0.84	0.15	0.46	0.07
1274	0.92	0.15	0.54	0.08
2380	1.15	0.15	0.76	0.11
4950	1.40	0.11	1.06	0.13

2.5.5 Spawning Temperature

Temperatures measured 0.3 and 3.3 km downstream of MGS (Table 2.5; 2015 – 2018) were < 14.5°C until May 30, June 2, June 8, and May 31, in 2015, 2016, 2017 and 2018 respectively. This timing of river warming resulted in only 2-11 days across those years with suitable spawning temperature available within the combined 75% extended spawning window (May 19 – June 9). The occurrence of suitable spawning temperatures near the end of Striped Bass occurrence in the suspected spawning region are likely the result of the upstream turbine intake at the MGS being located at 7 -22 m depth (Mactaquac Development General Arrangement Drawing 1140-C-2927) which may result in cooler water discharges and delayed warming of downstream river waters. Additionally, suitable stable discharges in these years did not exceed 28 continuous hours of stable flow during this period of favorable temperatures and discharges during those stable periods (apart from 2016) were unlikely sufficient for the suspension of Striped Bass eggs (Table 2.4, 2.5).

Table 2.5: Striped Bass juveniles by cohort as determined from scale ageing, first date of water temperature reaching 14.5°C in spawning reach, longest period (in hours) of stable sustained flow at the spawning grounds (May 19 – June 9), and median discharge of that period of sustained discharge. Sustained flow is the longest period of continuous hours when instantaneous decrease between hourly flow measurements are ≤20%.

Year class	#of individuals	First date of 14.5°C	Longest period (hours) of sustained flow ≥14.5°C	Median discharge m^3/s during sustained flow
2005	?		25	1488
2006	?		21	1030
2007	?		31	1023
2008	0		26	1094
2009	0		24	1188
2010	5*		23	1273
2011	58		53	2020
2012	27		38	703
2013	304		129 + 149***	3192 / 2096
2014	23		37	1069
2015	9**	30-May	25	645
2016	0	02-Jun	28	976
2017	0	08-Jun	22	710
2018	0	31-May	22	652

* Juveniles of possible Shubenacadie River origin, native SJR reproduction unlikely.

** Juveniles of possible non-SJR origin, no members of this year class were collected in any prior year of sampling. Native SJR reproduction unlikely.

*** A single, 1 hour Q decrease of ~30% was observed between two stable discharge periods lasting 129 h and 149 h respectively.

Following the collection of juveniles pertaining to four apparent native SJR Striped Bass year classes (Table 2.2) and subsequent comparison with recorded hourly discharges from the Mactaquac Dam (Table 2.5), it appears that year class strength may be related to the duration of stable sustained flow events, and corresponding discharge levels when water temperature are ≥14.5°C. Longer durations of stable discharge during the defined spawning period appears to coincide with greater year class success. Alternatively, those years with ≤ 36 hours of stable discharge, low discharge rates, and delayed occurrence of waters ≥14.5°C appear to have no measurable recruitment. We also observed that temperatures do not frequently reach spawning minimums in the immediate vicinity of the MGS when Striped Bass are present during the spawning period, possibly due to the submerged (7-22m) intake of the MGS turbines.

2.6 Discussion

The presence of juvenile Striped Bass in the SJR has not been reported since 1979, but we observed juvenile and sub-adult Striped Bass (n=426, age 1 – 8) from 2014 – 2019; of those individuals that were genotyped, all but one individual (Shubenacadie origin, age 4, sampled in 2014) had at least one, native SJR parent (see also Leblanc et al. 2018). We also observed the movement of native SJR adult Striped Bass to a historical spawning area and in cobination, this is evidence that a native population of Striped Bass remains in the SJR, attempts to spawn annually, and successfully spawned in 2013 at least. In 2011, 2012 and 2014, spawning occurred with limited success and no apparent recruitment of native juveniles was documented for 2008 - 2010 or 2015 – 2017. Currently, 71% of all young Striped Bass in the SJR appear to be the result of the 2013 spawning event.

Sampled juvenile Striped Bass had both pure SJR and admixed SJR/SHUB/US parents. The majority (77%) were native SJR origin and 23% showed admixture between two source populations, *i.e.*, SJR/SHU, SJR/US, or both. F_{ST} values show genetic differentiation of the SJR cluster from all reference populations comparable to that seen between Shubenacadie River and US population, and an order of magnitude greater than the difference between Hudson River and Chesapeake Bay Striped Bass—two populations that are distinct but have a long history of gene flow between them (Gauthier et al. 2013). This relatively high level of genetic differentiation indicates that these juveniles do not belong to a recently established population, because even very small and recently colonized populations tend to have lower F_{ST} values (Hawley et al. 2006; Malaney et al. 2018).

The presence of hybrid juveniles indicates that at least some of the migrant Striped Bass that frequent the SJR can and have remained in the river to spawn. This finding is supported by our tracking data of US origin and SJR/US admixed individuals (the latter most likely produced in the SJR) that both remain in the SJR during the spawning period and travel annually to spawning habitats with tagged SJR origin individuals, a phenomenon that has not previously been observed. The genetic distinctness of the SJR genetic cluster indicates that hybridization to the extent seen in these juveniles might be a recent development resulting from low population abundance and the frequent occurrence of migrants. This observation of native and hybrid Striped

Bass, along with the successful spawning events have important implications for the ongoing management of this species (COSEWIC 2012, see also Andrews et al. 2017, Chapter 2).

The timing of observed Striped Bass migrations (i.e., May 1 – June 23) to the historical spawning area near Fredericton (see Andrews et al. 2017, Chapter 2) is consistent with spawning periods documented for other Canadian Striped Bass populations (May 24 – June 19; Annapolis River, June 1 – June 9; Stewiacke, dates of observed eggs; Rulifson and Dadswell 1995, May 16 – June 26; Miramichi River, dates of spawning ground occupancy; Douglas et al. 2009). Additionally, the water temperatures during this period of (5.5°C - 17.9°C) overlap with those conducive to Striped Bass spawning; i.e., ≥ 14.5°C with peak egg production occurring between 15.6 – 19.4°C; (Talbot *et al.* 1966).

Despite annual adult spawning migrations, juvenile recruitment within the Saint John River is not consistent. Year classes matched to 2011, 2012 and 2014 appears to be only moderately successful. This poor recruitment appears to coincide with limited periods (≤ 36 hours) of stable discharge at the Mactaquac Dam demonstrated to be critical to Striped Bass reproduction in similar hydro-regulated systems (Manooch III and Rulifson 1989) and echoes past observation that Striped Bass recruitment within the SJR appears "infrequent" (Bentzen and Paterson 2008). In 2013, the sole year to produce a strong year class of native Striped Bass, stable discharge at the MGS was observed for a combined 278 hours at >2000m^3/s. Individuals from 2013, now age 6, comprise 71% of all Striped Bass ≤ age 9 in the Saint John River, older age classes were not assessed in this study. This number rises to 74% if the 14 juveniles from uncertain origin collected from putative 2010- and 2015-year classes are omitted.

2.7 Conclusion

We hypothesise that the regulated discharge at MGS (i.e., frequent and rapid fluctuation between high and low discharge over a 24-hour cycle) and delayed river warming downstream form the MGS is unfavourable for successful Striped Bass spawning due to disruptions of flow (changes in discharge and velocities) and delay of reproductive onset. From 2011-2018, juvenile recruitment appeared to only have occurred in spawning periods characterized by extended periods of stable, sustained discharge and the longer this period of stability, the larger the apparent year class. In future studies we will test the predictions for required flow and temperature regimes, which will be an important outcome for the improved management to achieve successful Striped Bass reproduction in the SJR.

Our prediction arises from other populations where stable conditions during spawning were considered necessary (Fish and McCoy 1959, Manooch and Rulifson 1989). We propose that extended periods of stable flow > 36 h when adult Striped Bass are present and when water temperatures exceed 14.5°C should result in successful spawning at MGS on the SJR. Longer periods of sustained flow may be required for successful recruitment and the production of strong year classes and can only be beneficial for Striped Bass reproduction. Striped Bass eggs are most dense in the first 2-3 hours post-spawning (Fish and McCoy 1959) and require moving water for egg suspension for the duration of incubation (48-72 h). At MGS, a discharge ≥ 1000 m^3/s produced these flow conditions in areas occupied by Striped Bass downstream, therefore this should be the minimum target flow to be tested during future sampling seasons.

This study also reconfirms with additional samples the presence of a genetically distinct population of native Striped Bass (Leblanc et al. 2018) by demonstrating that successful juvenile production does occur, but only infrequently under well-defined environmental conditions. Spring 2013 appears to be the only time within the last decade to have produced a strong juvenile cohort, which appeared to result from 278 hours of stable sustained flow (apart from a single 1-hour decrease; Table 2.5) occurring from June 1 – 7, a time when water temperatures were likely >14.5°C. This period of stable flow was the longest of such periods recorded during the Striped Bass spawning period since hourly data became available from the MGS in 2005, and discharge would have remained stable for egg incubation.

2.8 Management Considerations

1) Regulating MGS discharges: From our analysis it appears that regulated flows (i.e., hydropeaking) downstream of the MGS in May and June is probably the main cause of Striped Bass disappearance within the SJR (also see Andrews et al. 2017 for historic winter fisheries exploitation, Chapter 3). As a result, discharges should be experimentally regulated in spring during the Striped Bass spawning period to verify this hypothesis. This small measure could be used to promote Striped Bass spawning or at the very least be used to verify our findings when coupled with rigorous egg and juvenile sampling. We also suggest that the proposed minimum discharge threshold of 1000m^3/s be explored at this time to ensure Striped Bass attraction to spawning grounds and egg suspension/incubation after spawning. We suggest no maximum threshold as discharges as high as 5000 m^3/s (producing predicted surface velocities ranging 1-1.5 m/s; Table 2.4) remain within reasonable limits for egg suspension (mean high and low spawning velocity, 0.32 – 2.12 m/s; Mansueti 1958, Talbot 1966). Higher velocities,

however, may delay river warming but would unlikely be detrimental to spawning except for extreme discharge events.

2) Monitoring: In co-ordination with experimental flow regulation, a juvenile Striped Bass monitoring program should be organized to determine the effects of flow regulation as well as to determine the frequency and strength of successful year classes in relation to regulated flow. Through monitoring, a long-term data set can be generated that will allow more accurate comparisons to MGS discharges that promote spawning further allowing for the fine tuning of water resource requirements in spring. Once juvenile Striped Bass are located within the SJR annually, eggs surveys may be used to more carefully assess Striped Bass spawning in relation to specific discharge conditions.

3) Protection: Due to the large gaps between the production of successful year classes (~10 years) fisheries measures should be put in place to protect Striped Bass within the Saint John River to ensure population survival. Modification of spawning flows will only be successful if enough mature SJR adults are available to spawn.

2.9 Acknowledgements

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Chapter 3:

Left out in the cold: the understudied overwintering ecology of Striped Bass in Canada

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3.1 Abstract

Striped Bass in Canadian waters occur at the most northern extent of the species range. At these latitudes, overwintering represents a significant portion of annual activities (Nov- May). During the winter period, Striped Bass generally occupy inland waterways, aggregate densely, feed little, and conduct minimal movements rendering them vulnerable to fisheries exploitation, pollution and habitat alterations. Despite the importance of winter survival to population viability, the winter period remains an understudied aspect of Striped Bass ecology throughout the species range. Here we review what is known as well as the knowledge gaps regarding the overwintering ecology for Striped Bass in Canadian waters. We discuss: all reported Canadian Striped Bass overwintering locations and their characteristics; environmental conditions that may be required for Striped Bass winter survival; environmental cues that may cause Striped Bass to enter overwintering habitats in late fall and depart in early spring; possible threats to overwintering habitat; and we propose numerous research questions necessary for improving Striped Bass conservation and management both within Canada and across the species range.

3.2 Introduction

The Striped Bass (*Morone* saxatilis) is an anadromous fish native to the Atlantic coast of North America that ranges from the St. Lawrence River, Quebec, to the St. Johns River, Florida (Scott and Scott 1988). Throughout the warmer months, Striped Bass utilize numerous habitat types including freshwater rivers, estuaries, and marine coastlines (e.g., Scott and Scott 1988; Bjorgo et al. 2000; Grothues et al. 2009; Mather et al. 2009). The ecology of the Striped Bass in winter, by comparison, is poorly described. In general, it is thought that more northern Striped Bass populations in Canadian waters and Northern United States move inland to winter in presumably warmer coastal rivers, estuaries, and lakes (Scott and Scott 1988; Coutant 1990; Rulifson and Dadswell 1995). More recently, Striped Bass in these regions have been observed overwintering in locations with warm water discharge from power plants (Williams and Waldman 2010; Buhariwalla et al. 2016) and even in marine habitats (Keyser et al. 2016).

Striped Bass have been the focus of many intensive tagging and tracking studies from Gulf of St. Lawrence to Chesapeake Bay (Rulifson et al. 2008; Grothues et al. 2009; Pautzke et al. 2010; Wingate et al. 2011; Kneebone et al. 2014), but only a few studies have conducted winter tracking or report winter behaviour and movements (e.g., Bradford et al. 1998; Bednarski 2007). Most information regarding the winter habitat of Striped Bass in Canada result from directed winter surveys (Holland and Yelverton 1973), documentation of historic winter fisheries (Hogans and Melvin 1984; Scott and Scott 1988; Rulifson and Dadswell 1995), chance late season captures (Legendre et al. 1980), and illegal harvesting operations (Douglas et al. 2003). As a result, there remain large knowledge gaps regarding the winter ecology of Striped Bass in Canadian waters.

American Striped Bass populations, which have received much study in recent decades, display a diversity of movement patterns. United States origin Striped Bass have been observed to conduct large scale coastal migrations (Waldman et al. 1990), inhabit deep offshore water in both summer (Holland and Yelverton 1973) and winter (Waldman et al. 2012), occupy distant non-natal rivers over winter (Bednarski 2007), and even organize into distinct cohorts within rivers (Zlokovitz et al. 2003). Canadian populations, on the other hand, have been found to have different behaviours across seasons often staying close to natal rivers (Rulifson and Dadswell 1995; Rulifson et al.

2008) and have different physiological tolerances to environmental conditions (Bradford et al. 2001, 2014, 2015; Douglas et al. 2003); therefore, the ecology of Canadian populations many differ significantly from US counterparts. These differences suggest that US Striped Bass overwintering habits and habitats may not be synonymously applicable across the species range in both the US and Canada and are reasons why knowledge gaps exist especially for Striped Bass overwintering in Canadian waters.

Winter behaviour and habitats of Striped Bass are critical management considerations (COSEWIC 2004, 2012). The long winter period for Striped Bass within Canada has been shown to affect juvenile survival and year class strength (Bernier 1996; Bradford and Chaput 1997; Bradford and Cook 2004). Winter aggregations of adults are subject to increased vulnerability to commercial fishing (Williams and Waldman 2010) as well as point source chemical and thermal pollution (Setzler et al. 1980; Bradford et al. 1998; Dadswell 2006; Williams and Waldman 2010; Buhariwalla et al. 2016). Here we review the available information from peer-reviewed literature, academic and government reports, fisheries and historic accounts, and local/traditional ecological knowledge to discuss the general distribution of Striped Bass in Canadian waters during November through May, summarize the literature on Striped Bass ecology in documented overwintering locations in Canadian waters, and propose general characteristics of overwintering habitats and factors that may limit or control Striped Bass distribution.

3.3 Defining Winter

Winter in the northern hemisphere is meteorologically defined as the period from 1 December to 28-(29) February. It is characterised by days that are shorter (reduced photoperiods) and the coldest temperatures of the year (Halfpenny and Ozanne 1989). All north temperate fishes have adapted to this seasonality (e.g., Rulifson and Dadswell 1995; Harrison et al. 2016; Tommie et al. 2017). Managers of the historic Striped Bass fisheries in Canada considered the winter harvest to be that which was taken through the ice and which closed when waters became "navigable" in the spring (DMF 1871–1918). For this review, we define winter habitat as the locations where Striped Bass become torpid and aggregate, i.e., from November to early May.

3.4 Canadian Overwintering Distribution

The Atlantic Canadian provinces of Nova Scotia (NS), New Brunswick (NB) and Québec (QC) harbour distinct Striped Bass spawning populations in the most northern part of the species range (COSEWIC 2004; Fig. 3.1). These populations must survive the longest winter period (up to 7 months, i.e., November–May; C. Buhariwalla, unpubl. data) and the lowest marine (-2.0 °C; Bernier 1996) and freshwater (<1.0 °C; S.N. Andrews, UNB, unpubl. data) temperatures within the species distribution. Overwintering areas include freshwater lakes (Beaulieu 1985; Scott and Scott 1988), coastal rivers (Hogans and Melvin 1984; Rulifson and Dadswell 1995), estuaries (Bradford et al. 1998), power generating station cooling channels (Buhariwalla et al. 2016), and even fully marine high flow environments (Keyser et al. 2016). Adults occupying these sites aggregate in the same locations annually as evidenced by the recurring presence of recreational and commercial fisheries (Liem and Scott 1966; Rulifson and Dadswell 1995), winter fish kills (Buhariwalla et al. 2016), late season tag returns (Hogans and Melvin 1984), fisheries bycatch (Scott and Scott 1988; Bradford et al.1997) and, acoustic tracking data (Keyser et al. 2016; S.N. Andrews, UNB, unpubl. data). These observations collectively suggest that specific habitats are preferred and selected. The characteristics of these habitats including the environmental conditions

required for winter survival remain largely undescribed. To this date there remains no clear definition of the environmental characteristics of “Striped Bass overwintering habitat” other than the inter-annual presence of overwintering fish.

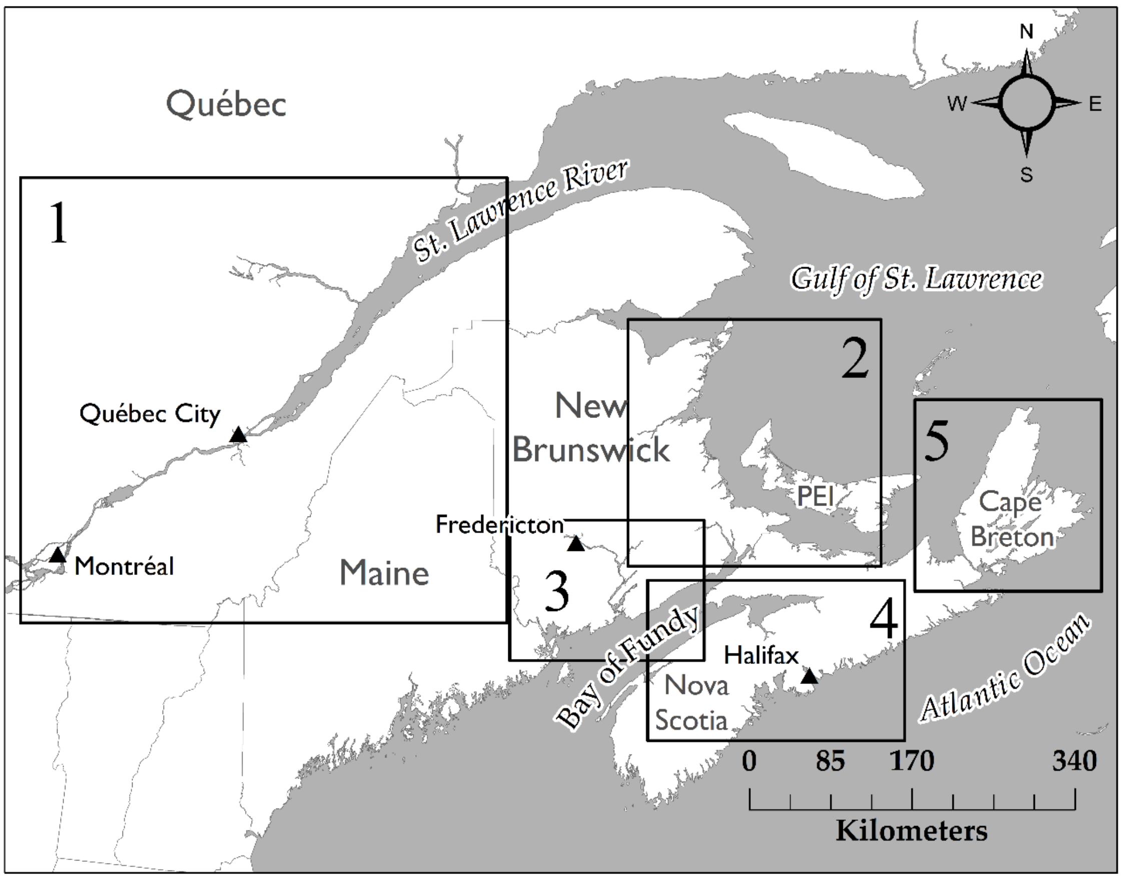

Figure 3.1: Overview map of the Canadian Maritime provinces (New Brunswick, PEI, Nova Scotia) and Québec outlining the 5 discussed regions of Striped Bass overwintering. 1) St. Lawrence River, 2) Miramichi River, P.E.I and the Southern Gulf of St. Lawrence, 3) Saint John River, 4) Shubenacadie River, Annapolis River and Minas Basin, 5) Cape Breton Island

Canadian overwintering locations identified to date include upriver areas of St. Lawrence River estuary, QC; Miramichi and Saint John River estuaries, NB; the Annapolis River estuary and Shubenacadie River/Grand Lake, NS, all being synonymous with past or present Canadian spawning populations (Liem and Scott 1966; Scott and Scott 1988; Rulifson and Dadswell 1995; Douglas et al. 2003). In addition to these consistent and recurring winter habitats, Striped Bass have been recaptured or detected while overwintering in rivers along the Southern Gulf of St. Lawrence, NB (Melvin 1979; Hogans and Melvin 1984) and within the inner Bay of Fundy, NS, (Keyser et al. 2016). Overwintering Striped Bass also occur in inland, estuarine waters of Cape Breton, NS, however, the origin of these individuals is unknown (Buhariwalla 2018; Buhariwalla et al. 2016; Andrews et al. 2019, Appendix 3). Numerous other inland overwintering locations have also been reported along the Southern Gulf of St. Lawrence, NB, and NS and there are likely many more of these winter refuges that have yet to be discovered.

3.5 St. Lawrence River

The historic native Striped Bass population of the St. Lawrence, QC (Figs. 3.1 and 3.2) inhabited the river estuary year-round, including the overwintering period (Magnin and Beaulieu 1967). During winter, and prior to the population's eventual extirpation, tag returns and the occurrence of a winter commercial fishery (Cuerrier 1962; COSEWIC 2004) suggested that Striped Bass age = 2 retreated inland to Lac-Saint Pierre (Beaulieu 1985; Rulifson and Dadswell 1995; Robitaille 2001, 2011; Fig. 3.2; Table 3.1) and occasionally Lac-St-Louis (Bergeron and Brousseau 1975; Legendre et al.1980; Fig. 3.2). Large winter catches in the Point-du-Lac region in the lower end of Lac Saint-Pierre (Fig. 3.2) and the presence of a successful Striped Bass angling tournament. “Le Coup du Bar” in the spring (Trépanier and Robitaille 1996) suggest this area harboured the greatest seasonal concentration of Striped Bass during winter months (Robitaille and Ouellette 1991). After the closure of the directed winter commercial fishery in 1951 (operated from Dec 1- May 31), Striped Bass were predominately taken as bycatch in other winter fisheries until at least 1966 (Rulifson and Dadswell 1995; COSEWIC 2004) or were harvested illegally (Robitaille 2001, 2010). No Striped Bass were taken in Lac Saint-Pierre from 1944 to 46 (Cuerrier 1994).

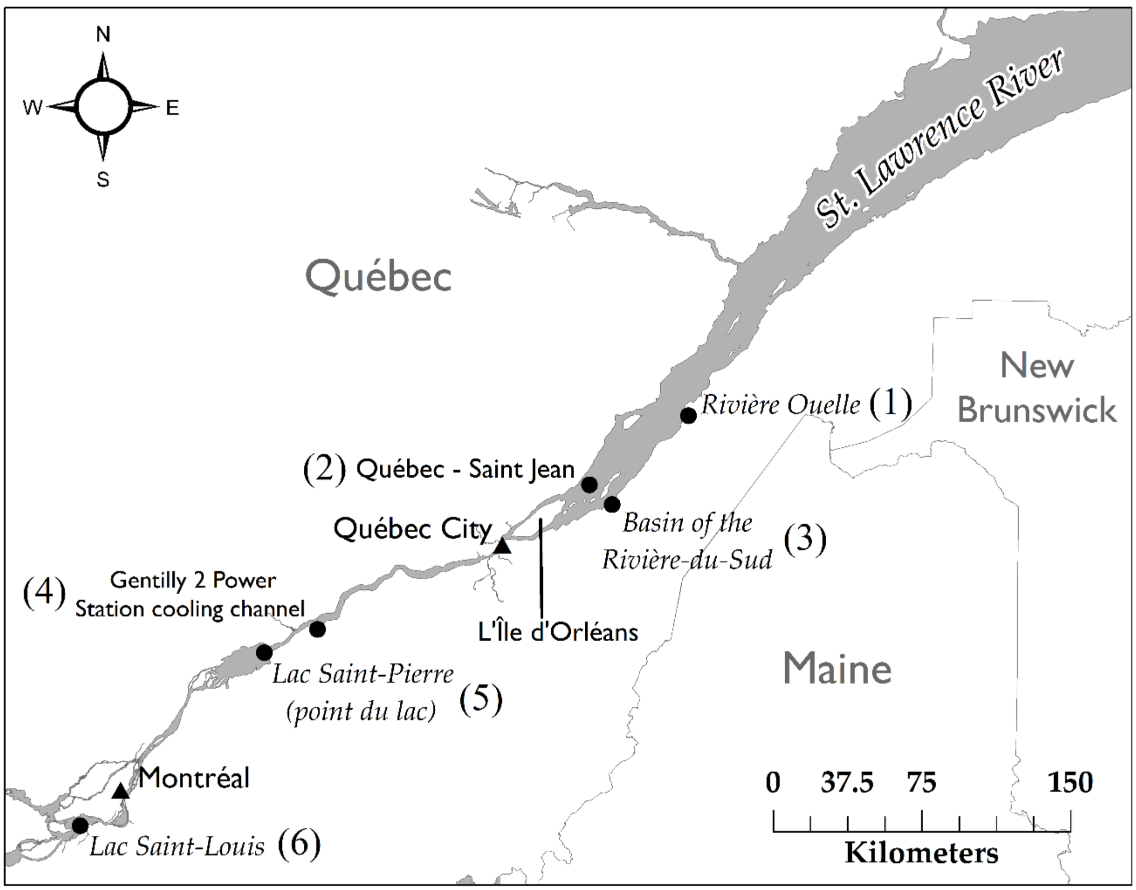

Figure 3.2. Documented Striped Bass overwintering areas within the St. Lawrence River, Quebec. Numbers correspond to the associated map numbers in Table 3.1.

Historically, juvenile Striped Bass age = 2 occurring within the St. Lawrence River were most often reported farther downstream in late fall and presumably overwintered in the freshwater plume of the river near L'Île d'Orléans (Beaulieu 1985). Juvenile Striped Bass (20–28 cm) have been recaptured as far downstream as Rivière-Ouelle in the fall (Vladykov 1947, Beaulieu 1962; Fig. 3.2; Table 3.1) and likely overwintered upstream of the saltwater wedge (DFO 2010). The exact overwintering location of young-of-the-year (YOY) and immature Striped Bass age = 2 of St. Lawrence origin, has yet to be located (Beaulieu 1985; Robitaille and Ouellette 1991; Trépanier and Robitaille 1996). YOY Striped Bass (~75 mm TL) have been observed in September between Saint-Jean-Port-Joli and Rivière- Ouelle (Rulifson and Dadswell 1995).

A disturbance or reduction in the habitable area of the overwintering grounds was suggested to have resulted in the extirpation of the native St. Lawrence River Striped Bass population by 1966–67 (Beaulieu 1985; Robitaille and Ouellette 1991; Bradford et al. 2001a). The observed population decline was due to extensive dredging of Saint Lawrence Seaway through Lac Saint-Pierre and dredge spoil from the construction of an artificial island during 1954–59 (Beaulieu 1985; Rulifson and Dadswell 1995; Trépanier and Robitaille 1996) and subsequent maintenance by ice breakers in the winter (Robitaille and Girard 2002). The application of 16,800 kg of DDD (Dichlorodiphenyldichloroethane) to the St. Lawrence River upstream of Lac Saint-Pierre near the City of Montreal, QC between 1966 and 1967 to control insect pests during Expo 67 may also have had a negative impact (Fredeen and Duffy 1970, Fredeen 1972; Dadswell 2006). These changes would have collectively affected water velocities, temperatures and water chemistry (Legendre et al. 1980) possibly impacting both the adult overwintering grounds and juvenile summer rearing grounds (Beaulieu 1985).

Table 3.1: Summary of Striped Bass overwintering locations including time of year observed, life stages observed, temperature, depth and salinity of the overwintering habitat. Shaded lines indicate suspected though unconfirmed winter habitats.

	Location	Map Number	Time of Year (observed)	Life Stage/Size	Temperature	Depth	Salinity	Source
Saint Lawrence River	Rivier Ouelle	1	Late fall	20 - 28cm			Brackish	Beaulieu 1962
Saint Lawrence River	Quebec - Saint Jean	2	Late fall	YOY ~75mm			Brackish	Rulifson and Dadswell 1995
Saint Lawrence River	Basin of Riviere-du-Sud	3	Early spring	Adult			Brackish	Robitaille 2011
Saint Lawrence River	Gentilly 2 Power Station	4	Winter	Adult			0ppt	Aecom 2009; Robitaille 2011
Saint Lawrence River	Lac-Saint-Pierre	5	Nov/Dec - mid April	≥ Age 2+		2 - 10.6m	0ppt	Beaulieu 1985, Tepanier et Robitaille 1996; Robitaille and Ouellette 1991
Saint Lawrence River	Lac Saint-Louis	6	October 20 - April 23	Adult			0ppt	Legendre et al. 1980
Southern Gulf of Saint Lawrence and PEI	Belldune Power Station*	7						Suspected overwintering site
Southern Gulf of Saint Lawrence and PEI	Nepisiguit River	8	Late fall	Adult				Madden 1984; Rulifson and Dadswell 1995
Southern Gulf of Saint Lawrence and PEI	Tabousintac River	9	Late fall	Adult - YOY				Rulifson and Dadswell 1995; Bradford and Chaput 1996
Southern Gulf of Saint Lawrence and PEI	Mouth of Barnaby River	10	Winter					Watling 1985
Southern Gulf of Saint Lawrence and PEI	NW Miramichi River	11	December - March	Adult - YOY				Hogans and Melvin 1984; Douglas; Bradford et al 1997
Southern Gulf of Saint Lawrence and PEI	Napan River	12	Late fall	Adult				Rulifson and Dadswell 1995
Southern Gulf of Saint Lawrence and PEI	Black River	13	Late fall	Adult				Rulifson and Dadswell 1995
Southern Gulf of Saint Lawrence and PEI	Kouchibuguac River	14	November/December-March	39.8 - 69.5cm	≥ -0.4 °C		0-15ppt	Bradford et al 1997b; Hogans and Melvin 1984
Southern Gulf of Saint Lawrence and PEI	St Louis River/Rivière St. Charles	15	November-March	39.8 - 69.5cm	≥ -0.4 °C		0-15ppt	Bradford et al 1997b
Southern Gulf of Saint Lawrence and PEI	Richibucto River	16	Late fall and winter	Adult - YOY				Douglas et al 2003; Douglas and Chaput 2011
Southern Gulf of Saint Lawrence and PEI	Trenton Power Station	17	January 14	Adult - YOY	Mean = 12.2 °C	< 2m		Buhariwalla et al. 2016
Southern Gulf of Saint Lawrence and PEI	East River	18	Late fall captures	Adult				Douglas and Chaput 2011
Southern Gulf of Saint Lawrence and PEI	Miminigash Ponds	19	Late fall and early spring captures	3 - 7lbs			Brackish	DMF 1882 (Historic overwintering site, no recent reports)

	PEI west coast (edge of shore ice)*	20	Winter				32ppt	DMF 1887 (Unconfirmed report)
Labrador	Muddy Bay	21	Early March	~65cm			32ppt	
Saint John River	Mactaquac Headpond*	22		Adult	~4°C	≤ 40m	0ppt	Suspected overwintering site
	Grand Lake	23	Nov 1 - April 15	≥ Age 2+	~2.5°C	≤ 10.5m	0ppt	See Thesis Chapter 4
	Washademoak	24	Nov 1- April 15	≥ Age 2+	0.3 - 1.6°C	≤ 5m	0ppt	See Thesis Chapter 4
	Belleisle Bay	25	Nov 1 - April 15	≥ Age 2+	4 °C - 14 °C	18 - 36m	6ppt	See Thesis Chapter 4
	Darling's Lake	26	Oct 20 - April 15	≥ Age 2+	0.5 °C - 2.4 °C	≤ 5m	0ppt	See Thesis Chapter 4
Shubenacadie River, Bay of Fundy, Annapolis River	Annapolis River	27	Winter	Adult			0ppt	Dadswell 1984; Rulifson and Dadswell 1995
	Minas Passage	28	Dec 1 - March 31	Adult	0 - 6 °C	6 - 37m	32ppt	Keyser et al. 2016
	Economy/ Five Islands	29	September	YOY	≥ - 1 °C	< 1m	32ppt	Bradford 2012
	Shubenacadie River Estuary	30	Winter	YOY			Brackish	Bradford and Cook 2004
	Southern Bight	31	November	YOY		< 1m	32ppt	M. Stokesbury pers comm
	Summerville	32	Dec - Jan	YOY			32ppt	D. Porter pers. comm
	Shubenacadie River pools	33	Winter	Adult		6-9m	Brackish	Rulifson et al 1987
	Shubenacadie Grand lake	34	Oct-Nov to 1st - 3rd week of May	≥ Age 2+	~4°C	> 20m	0ppt	Bradford and Cook 2004; Melvin 1978
	Fletchers Lake	35	Late fall	Adult			0ppt	Alexander 1975
	Porters Lake	36	Winter	Adult			Brackish	M. J. Dadswell unpublished data
Cape Breton	Lingan Power Station	37	Winter	Adult				Angler Reports
	Mira River	38	Nov-May	Adult	2.0 - 10.7°C	6.9 ± 1.3m	13-19ppt	C.F. Buhariwalla unpublished data
	Bras D'Or Lake	39	Winter	Adult	5°C	7m	17ppt	Angler Reports
	Frambois River	40	Late fall	Adult				Angler Reports
	Fullers Gut	41	Winter	Adult				Angler Reports

In 2002 a program was initiated to re-stock the St. Lawrence River with juvenile Striped Bass originating from the Miramichi River, NB (DFO 2010). These translocated individuals and the new population that was established (COSEWIC 2012) have not yet been located within Lac Saint-Pierre during winter (Robitaille et al. 2011). Alternatively, the re-stocked Striped Bass were only observed in the warm water discharge plume of the Gentilly 2 Power Station during the colder months of the year (DFO 2010a, 2010b, 2010c; Robitaille 2011). At the time it was unknown if this behaviour of occupying the Gentilly 2 Power Station discharge could alter winter distributions (Robitaille 2011) or have adverse physiological effects (AECOM 2009). The Gentilly 2 Power Station, however, was decommissioned in December of 2012. Individuals of the re-introduced St. Lawrence River population have more recently been captured in early spring in the basin of the Rivière-du-Sud in Montgamy (Robitaille 2011).

3.6 Southern Gulf of St. Lawrence

The Southern Gulf of St. Lawrence (SGSL), between the northern coast of NB and north-western side of NS hosts overwintering Striped Bass aggregations in numerous estuaries (Douglas et al. 2003; Figs. 3.1 and 3.3). Striped Bass inhabiting the SGSL is the species' northern most reproducing population and are considered to originate solely from the Miramichi River (Douglas et al. 2003; Robinson et al. 2011). The Miramichi River population ranges from Percé, QC to the northern tip of Cape Breton Island, NS (Scott and Scott 1988; Rulifson and Dadswell 1995; Bradford and Chaput 1996). Within the SGSL, Striped Bass could be exposed to very low winter sea temperatures (Bradford et al. 1998), and all individuals are thought to retreat to inshore overwintering sites to seek thermal refugia (Knight 1867; Cox1893; Bradford et al. 1997, 1998).

The Miramichi River supports an overwintering site in the Northwest Branch near the head of the salt water intrusion (Bradford et al. 1998; Scott Douglas, DFO, pers. Comm.), the Southwest Branch near the mouth of the Barnaby River (Watling 1985), and some individuals may also seek refuge in deeper holes within the estuary (Douglas et al. 2001; Douglas et al. 2006). Striped Bass of Miramichi origin also overwinter in adjacent rivers such as the Napan, Kouchibuguac, Saint Louis, Black and Richibucto (Fig. 3.3; Melvin 1979; Hogans and Melvin 1984; Rulifson and Dadswell 1995; Bradford and Chaput 1996; Bradford et al. 1998; Douglas et al. 2003), and overwintering as far as the East River, NS has been reported (Douglas and Chaput 2011; Buhariwalla et al. 2016). Overwintering sites to the northwest of the Miramichi River are reported only in the Tabousintac River, e.g., observed in late fall (Hogans and Melvin 1984) and possibly the Nepisiguit River (Madden 1984).

Striped Bass have long been suggested to inhabit the freshwater portions of these rivers during winter (Hogans and Melvin 1984). However, it is more likely that they reside at the most upstream portion of salt water influence in deep channels just below the limit of the salt wedge (Hogans and Melvin 1984; Bradford et al. 1997) in waters of 0–15 ppt and temperatures = -0.4 °C (depth of measurement unknown, possibly a surface temperature; Bradford 1998; Table 3.1). During extremely cold weather, Melvin (1979) suggested that Striped Bass may descend the rivers and exit the estuary mouth to barachois waters (a coastal lagoon separated from the sea by a barrier sand bar) or even the Northumberland Strait; however, no study has made a direct observation of this behaviour. Chiasson et al. (2002) noted that large numbers of juvenile Striped Bass were often swept downstream in the Miramichi estuary following heavy fall rains and subsequently captured in the commercial smelt fishery. Power generating stations around the SGSL create artificial thermal refugia for Striped Bass during winter (Douglas et al. 2006; Buhariwalla et al. 2016). The extent of occupancy of these warm water refuges and importance to the population is undocumented; however, midwinter shutdown events have been identified as a source of recurring mass mortality due to the rapid loss of thermal habitat and resulting thermal shock (Douglas et al. 2006; Buhariwalla et al. 2016). Striped Bass aged 1–5 years were collected during a 2013 cold shock mortality event at a power plant in Trenton, NS, indicating that YOY may disperse more widely within the SGSL than previously thought (Buhariwalla et al. 2016). Mature Striped Bass tagged at this site during the fall/winter were later reported in the Miramichi River during the following spring spawning migration, and later as far north as Percé, QC (DFO 2018; Scott Douglas, DFO, pers. comm.). It remains unexplored if Striped Bass use the warm water discharge at the Belledune Power Station in Bathurst, NB, for overwintering (Table 3.1). Multiple point sources, in addition to thermal discharges such as industrial and municipal pollution, may pose a threat to overwintering Striped Bass in the Miramichi River estuary (Bradford et al. 1998, 2001b).

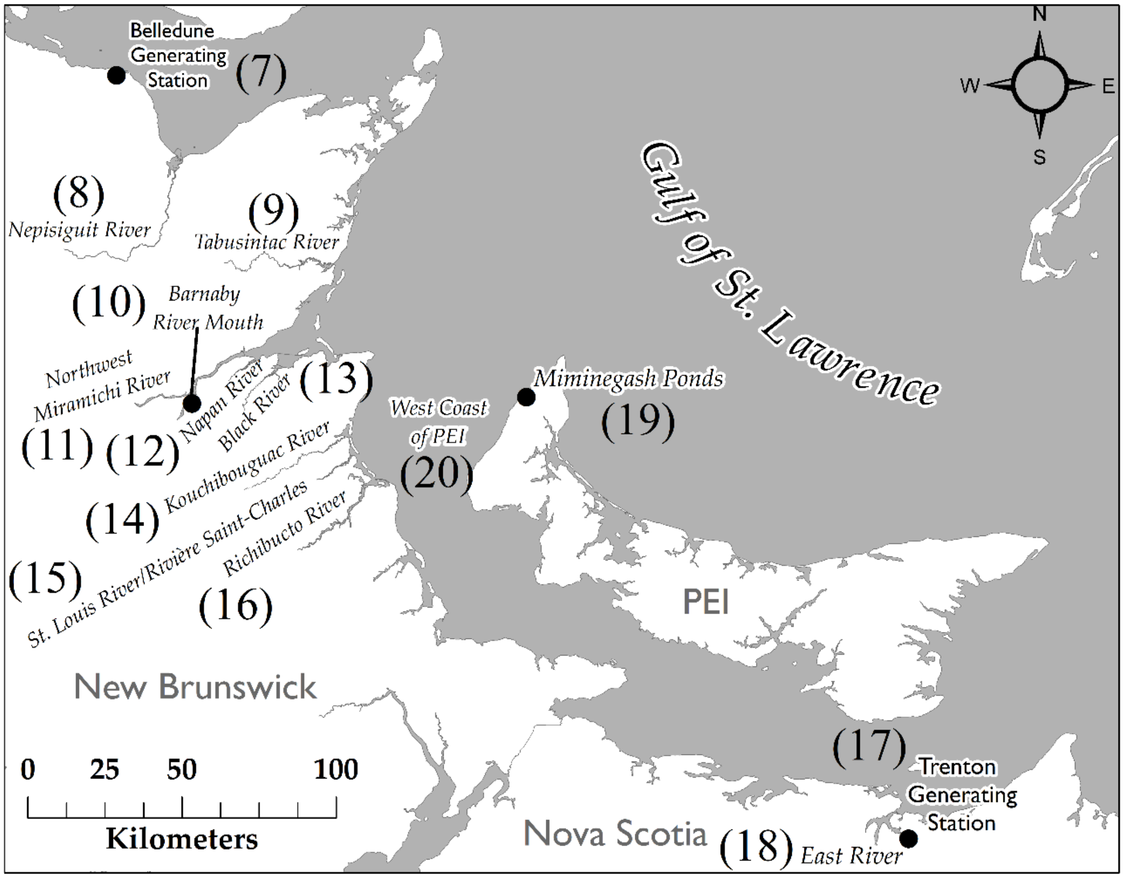

Figure 3.3 Documented Striped Bass overwintering areas within the Southern Gulf of St. Lawrence, New Brunswick and Nova Scotia. Numbers correspond to the associated map numbers in Table 3.1.

Winter habitat selection by Striped Bass in SGSL rivers is described as opportunistic (Bradford et al. 2001), but no multi-year tracking studies have been conducted to date, so knowledge gaps regarding site fidelity in the region remain. Hogans and Melvin (1984) detected the departure and return of marked Striped Bass to a Kouchibouguac River overwintering site over an ~8-month period (late March –early November) suggesting that some individuals may exhibit overwintering site fidelity. Furthermore, the spatial distribution of winter commercial fisheries suggests that overwintering Striped Bass occupy the same areas year after year, but no study has explored whether the same individuals make up these recurring assemblages.

3.7 Prince Edward Island

Striped Bass have long been recorded to occur around Prince Edward Island (PEI; Stewart 1806; Fig.3.3) and were fished commercially along the Province's coasts (1876–1916; DMF 1876–1917, 1917–1988; Chaput and Randall 1990) but they have seldom been recorded overwintering in the Island's waters. The only documented overwintering location occurs in the Miminigash ponds on PEI's Western tip where Striped Bass were historically observed entering in the late fall and departing in early spring (DMF 1882). Striped Bass may also overwinter in PEI's coastal waters and are thought to reside along the outer edge of the shore ice (DFM 1887). No studies of Striped Bass habitat residence have been conducted in PEI since these early observations, and it is likely that other overwintering areas occur.

3.8 Labrador

Striped Bass have recently been observed in Labrador in the late summer and fall of 2017 (Fish and Wildlife Enforcement Division, Labrador; pers. comm. Andrews et al. 2019, Appendix 3). Studies should be conducted to examine whether these newly arrived Striped Bass (or recolonizing individuals) of Miramichi origin (DFO 2018), are residing in

Labrador overwinter or predominately departing in fall. Recently, in March of 2018, one Striped Bass was captured through the ice by an angler in Muddy Bay, Labrador (Nunatuvut fishermen, pers. comm.; Fig. 3.4). However, whether this is a single occurrence or is indicative of a larger aggregation is unknown. If Striped Bass are overwintering in Labrador this would mean a range extension from what is reported currently, and studies will have to be conducted in the region to fill this knowledge gap.

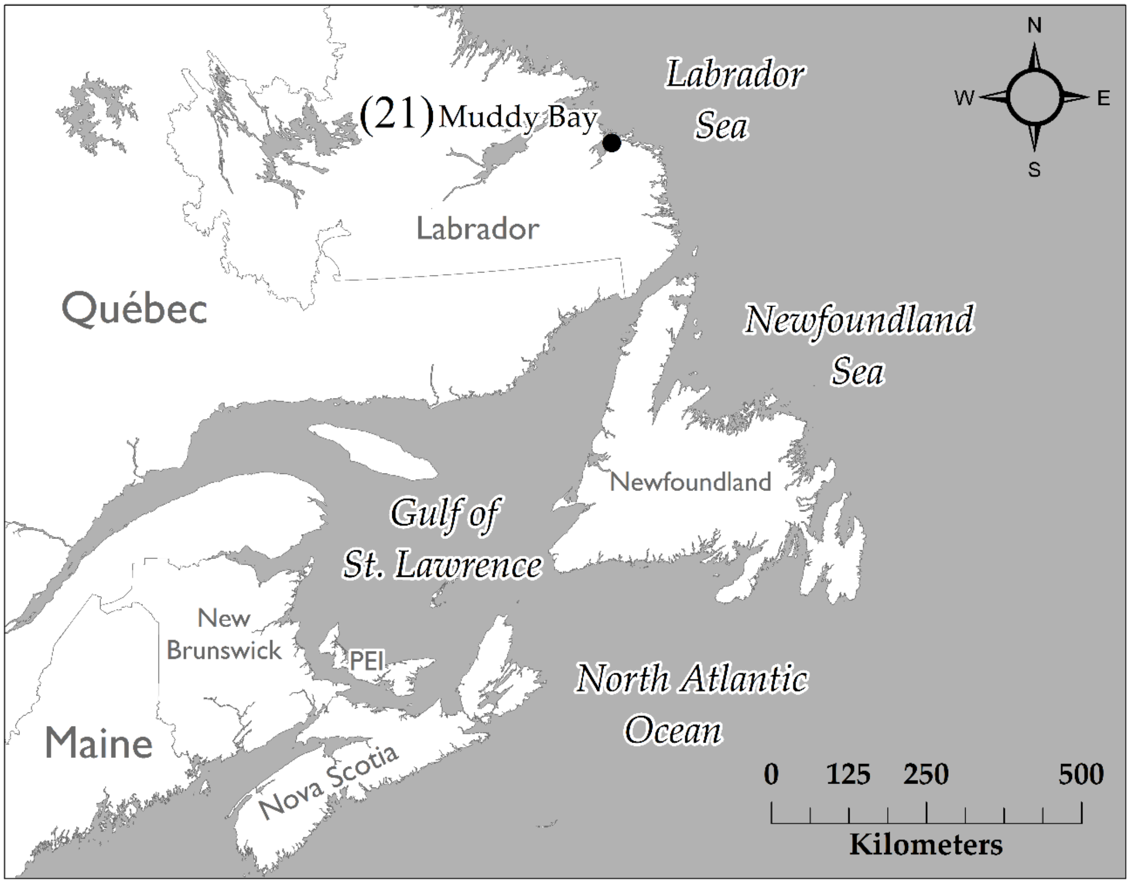

Figure 3.4: Documented Striped Bass overwintering areas in Labrador. Number corresponds to the associated map number in Table 3.1

3.9 Bay of Fundy

3.9.1 Saint John River

Striped Bass of the Saint John River (SJR), NB (Figs. 3.1 and 3.5) have been long known to overwinter in Washademoak Lake and Belleisle Bay (Dadswell 1976; Melvin 1991; Rulifson and Dadswell 1995; COSEWIC 2004; COSEWIC 2012; Fig. 3.5; Table 3.1). The latter location supported a moderate winter commercial fishery in the past (catches recorded until the fishery closed in 1978: Rogers 1936; Melvin1978;

Dadswell et al.1984; Jessop 1990; Andrews et al. 2017, Chapter 4). Striped Bass in Belleisle Bay during winter occupy the deeper (>15 m), warm (4–14 °C), and slightly saline (2–6 ppt) waters (Andrews et al. 2017; Chapter 4; Fig. 3.5; Table 3.1). Striped Bass were historically captured in the thoroughfares of Grand Lake, NB, in the winter season (Perley 1852) and overwintering of Striped Bass within Grand Lake, NB, has now been confirmed (see Thesis Chapter 4; Fig. 3.5). Recent tracking studies identified a fourth overwintering location in shallower waters (< 5 m) within Darling's Lake of Kennebecasis Bay (see Thesis Chapter 4; Table 3.1). Striped Bass overwintering within the SJR are also suspected to occasionally occur in other deep sections of the river during the colder months (Dadswell 1976); however, this behaviour may be infrequent (Andrews et al. 2018a, Chapter 4).

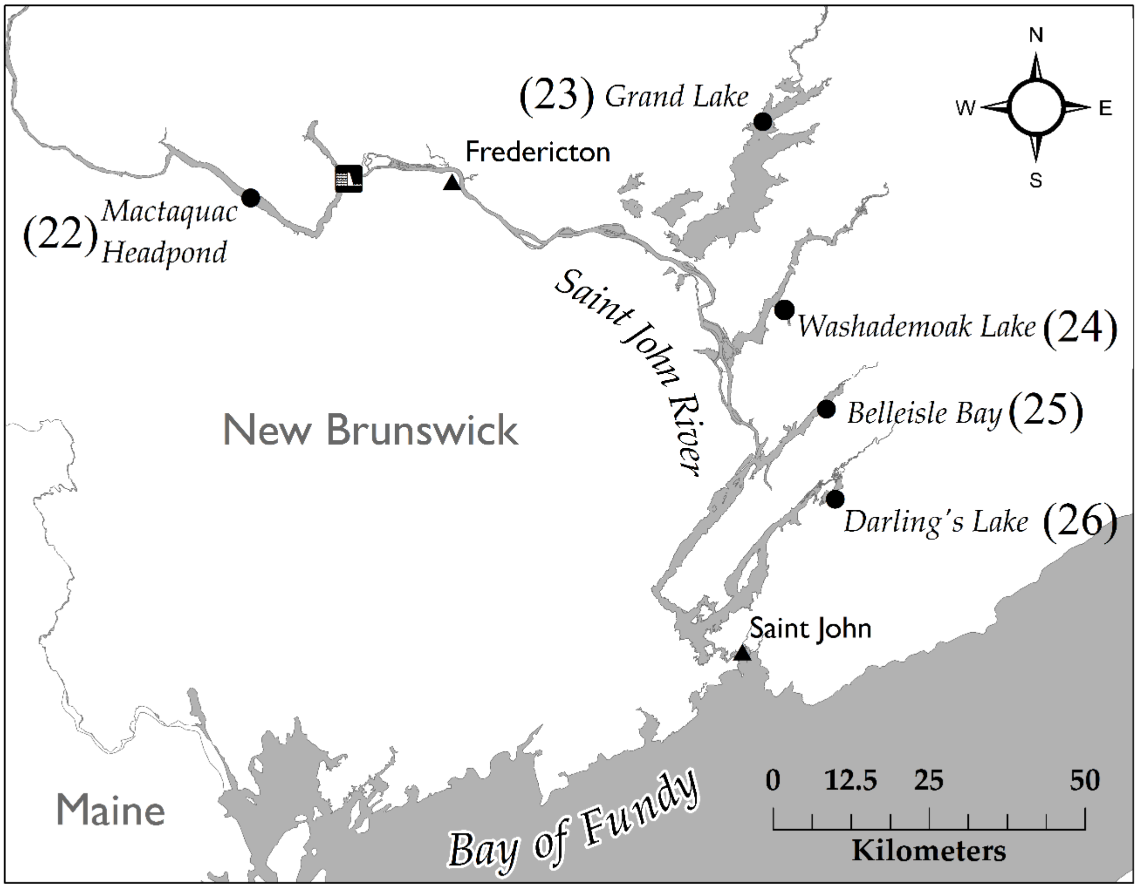

Figure 3.5: Documented Striped Bass overwintering areas within the Saint John River, New Brunswick. Numbers correspond to the associated map numbers in Table 3.1

Striped Bass originating from external spawning populations are also known to overwinter within the Saint John River. Tagging by Dadswell (1976) suggests that individuals of US origin may overwinter in the SJR only to return south in the spring. Additionally, Shubenacadie River origin Striped Bass overwinter within the SJR (DFO 2011; Bradford et al. 2015) and may return to the river inter-annually (see Thesis Chapter 4).

3.9.2 Shubenacadie River

Striped Bass (≥ age 2) originating from the Shubenacadie River, NS, (Figs. 3.1 and 6) overwinter in freshwater in Shubenacadie Grand Lake (SGL: Alexander 1975;

Melvin 1978; Jessop 1990; Rulifson and Dadswell 1995; Douglas et al. 2003; Bradford et al. 2012, 2014). Striped Bass ascend from the Bay of Fundy to SGL in October–November (Bradford and Cook 2004). Here they are fished recreationally in autumn (Alexander 1975; Jessop1990, 1991), and once, commercially through the ice from the mid 1880s to 1911 (Jessop 1991; Rulifson and Dadswell 1995; COSEWIC 2004). The SGL is a typical lacustrine habitat where deeper water remains close to 4 °C throughout the winter (Douglas et al. 2003). The lake has a depth of over 20 m (Melvin 1978; Fig. 3.6; Table 3.1) and was estimated to sustain 20,000– 30,000 native Striped Bass over winter during 2002 (Douglas et al. 2003). Striped Bass originating from US populations have also been captured in the Shubenacadie River while descending from SGL (1992–1993) and constituted ~10% of sampled individuals (Wirgin et al. 1995; Douglas et al. 2003). Overwintering Striped Bass travel downstream from SGL to spawning grounds at the head of tide and confluence of the Shubenacadie and Stewiacke Rivers during the first 3 weeks of May (Rulifson and Tull 1998; Bradford et al. 2012). Striped Bass have also been captured further up river from SGL watershed in Fletchers Lake in the late fall (Alexander 1975; Fig. 3.6) and use deep pools (6–9 m) downstream in the Shubenacadie River (Rulifson et al. 1987; Fig. 3.6; Table 3.1).

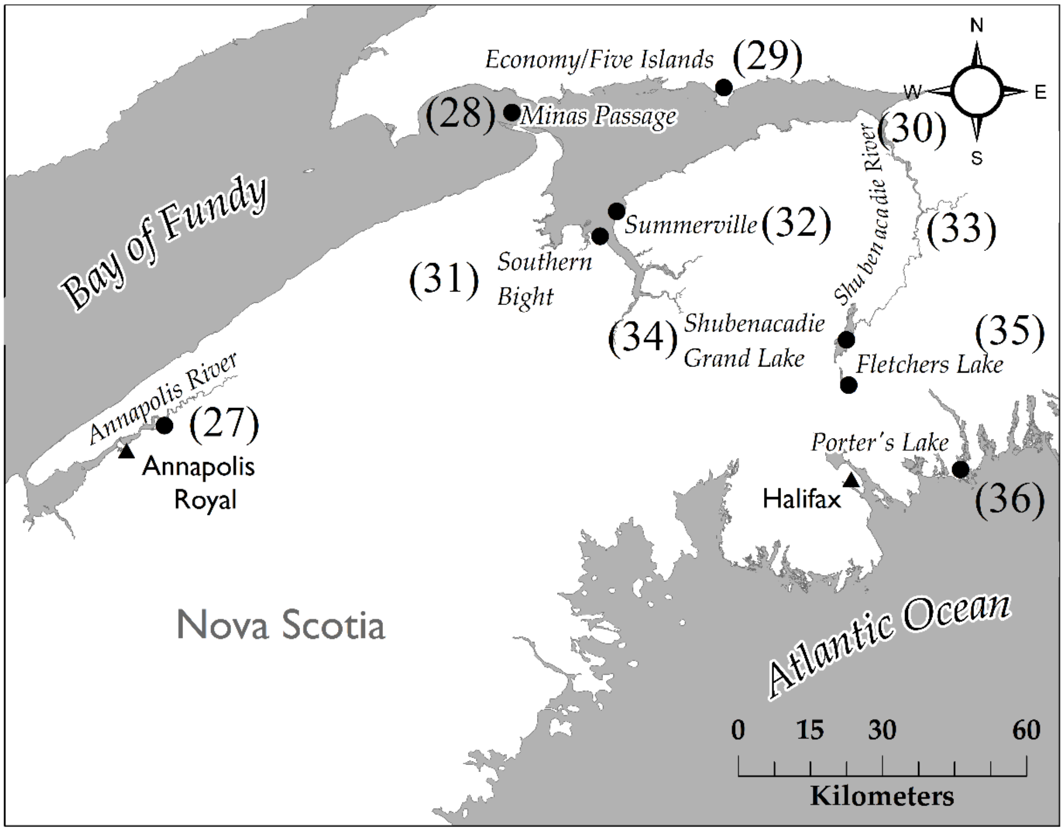

Figure 3.6: Documented Striped Bass overwintering areas in the Shubenacadie River, Annapolis River and Minas Basin, Nova Scotia. Numbers correspond to the associated map numbers in Table 3.1

Otolith microchemistry (Bradford and Cook 2004) and the absence of YOY and age 1 Striped Bass in the SGL overwintering site (Douglas et al. 2003) suggests that young Striped Bass of Shubenacadie River origin do not winter in fresh water during the first year of life but rather may prefer estuarine or marine environments (Bradford and Cook 2004; Bradford et al. 2014). In 1999, for the first time, age 1 Striped Bass were documented exiting SGL in the spring (Douglas et al. 2003; Bradford and Cook 2004). This year class contained juveniles of the largest body size ever recorded (Douglas et al. 2003), suggesting that freshwater overwintering may be size dependent or restricted (Bradford and Cook 2004). There maybe a greater metabolic requirement for osmoregulation in freshwater than in an estuarine, iso-osmotic environment, which may deter small Striped Bass with limited energy reserves from overwintering in those habitats (Hurst and Conover 2002).

Striped Bass YOY of Shubenacadie River origin are suspected to make use of the lower tidal reaches of the Shubenacadie River (Bradford and Cook 2004; Bradford et al. 2014; Fig. 3.6) or other local estuarine or marine environments for overwintering (Bradford and Cook 2004). Outside of the Shubenacadie River, Striped Bass YOY have been captured in November beach seines within the Southern Bight of Minas Basin (Dr. M.J. Stokesbury, Acadia U., pers. comm.; Fig. 3.6) and age 1 bass have been observed at an intertidal fishing weir in Bramber at the end of March into mid-April (Darren Porter, Commercial Fisherman, pers. comm.). Additionally, Striped Bass 15–30 cm have been observed as by-catch in December–January smelt fishery off Summerville, NS (southern Bight, Minas Basin; Darren Porter, pers. comm.). These observations, combined with the fact that YOY Striped Bass have been intercepted as far as Five-Islands, Minas Basin, in September (beach seine surveys; Bradford et al. 2012; Fig. 3.6; Table 3.1), suggest that YOY may be overwintering throughout the inshore areas of the Minas Basin. There remains, however, a knowledge gap in the exact overwintering location(s) and areas of aggregation of Striped Bass YOY of Shubenacadie River origin (Bradford et al. 2012; COSEWIC 2012).

Despite the research focus on the SGL overwintering ground, adult Shubenacadie origin Striped Bass are not strictly confined to fresh water during the overwinter period (Paramore and Rulifson 2001; Gemperline et al. 2002; Rulifson et al. 2008, Bradford et al. 2012, COSEWIC 2012; Keyser et al. 2016). Local anglers have long recognized “black-back” Striped Bass as having wintered in fresh water descending from SGL, and remarked upon "green-back" Striped Bass entering the Shubenacadie River from the sea in April (Paramore and Rulifson 2001; Gemperline et al. 2002). While such colour differences are not a novel observation for the species (Mease 1815; Rulifson and Dadswell 1995), the differing dorsal colourations in Shubenacadie origin Striped Bass have been conclusively linked to the individual's most recent overwintering habitat using otolith microchemistry (Paramore and Rulifson 2001; Gemperline et al. 2002). This method has also revealed that adult Striped Bass may switch between fresh and salt water overwintering areas during their lives (Gemperline et al. 2002).

Keyser et al. (2016) was the first to locate Striped Bass of likely Shubenacadie River origin inhabiting the saline surface waters (6–37 m) of the Minas Passage in the Bay of Fundy during winter (i.e., Dec-1 to March 31; Fig. 3.6). Striped Bass must actively select this powerful tidal environment as winter habitat as no barrier exists between them and calmer inshore environments. Keyser et al. (2016) suggests that acoustically tagged Striped Bass seemed to drift back and forth passively with the tides in the Minas Passage. However, passive drifting in this location would not likely maintain them in the Passage where during every flood tide current speeds are between 4 and 6 m/s (Karsten et al. 2008). As a result, there must be some form of active behaviour such as diel vertical migration that maintains them in the Minas Passage for months. In the Minas Passage, water temperature is a mean of 6 °C in December and falls to 0–1 °C by late March while salinity remains ~ 30 ppt (Keyser et al. 2016). By late March when the water temperature is least, Striped Bass apparently move away from Minas Passage either seaward or onto the spawning grounds in the Shubenacadie River, which are warming rapidly by that time (Rulifson and Tull 1999; Gemperline et al. 2002). The drifting of Striped Bass in Minas Passage resulting from such low temperatures may put them at increased risk of collision with tidal turbines now being installed in that location (Redden and Stokesbury 2014; Keyseretal.2016).

Shubenacadie River Striped Bass also overwinter in Belleisle Bay, (Fig. 3.5; Bradford et al. 2015) as well as Washademoak Lake and Darling's lake in the SJR, NB Canada (see Thesis Chapter 4; Fig. 3.5). In addition to selecting these distant overwintering locations, tracked Shubenacadie River origin individuals returned to the same overwintering site (i.e., specific lake or bay within the SJR) year after year between annual spawning migrations to the Stewiacke River Branch of the Shubenacadie River (S.N. Andrew, UNB, unpubl. data). This ongoing study has observed winter habitat use by Striped Bass returning to SJR during four consecutive winters since 2014.

Striped Bass of Shubenacadie River origin may also overwinter in the Annapolis River estuary, NS (Dr. M. J. Dadswell, personal communication; Fig. 3.6). From a total of 68 mature Striped Bass tagged in Annapolis estuary during April–June 1981–1982, three (4%) were recaptured in the Shubenacadie River in subsequent years (1983– 1985) during the annual spawning run there. The prevalence, frequency and continuation of this behaviour, however, remains unreported.

3.9.3 Annapolis River

Wintering locations for Striped Bass on the Annapolis River, NS (Fig. 3.6) were never studied prior to the population's collapse (1990s; COSEWIC 2004; Bradford et al. 2012). Historically, Striped Bass were reported to overwinter in deep pools in the Annapolis River estuary downstream of Bridgetown (Rulifson and Dadswell 1995) or other areas above tidal influence (COSEWIC 2004) though no exact details are available. The overwintering aggregations and movements of Striped Bass in these locations during winter remains unstudied but Striped Bass tagged in the Annapolis River during spring and summer have been recaptured by anglers in the estuary during spring in subsequent years (M.J. Dadswell, unpubl. data).

3.10 Porters Lake

Very little is known about Porters Lake, NS, except that the narrow tidal channel connecting the moderately sized lake to the ocean is a known Striped Bass fishing spot to local anglers (Andrews et al. 2019, Appendix 3). While no formal study has ever been conducted on the lake, the International Gamefish Fishing association (IGFA) formerly

recognized the Women's 7 kg line class record Striped Bass as having been caught in this location (18.2 kg, 109 cm, captured April 24, 1986; Jack Vitek, IGFA records coordinator pers. comm.). The timing of the capture in early April strongly suggests that this fish was exiting an overwintering location and not conducting a summer migration from a distant spawning population.

3.11 Cape Breton

Recent telemetry work has identified a Striped Bass overwintering aggregation within the Mira River estuary on the eastern coast of Cape Breton Island (Buhariwalla 2018; Figs. 3.1 and 3.7). The aggregation exhibits inter-annual site fidelity, to a 10–22 m deep sheltered section of estuary in intermediate salinities (13– 19 ppt) with temperatures ranging from 9 to 11 °C in December to 2–4 °C in May. Genotypes of Striped Bass inhabiting this site have not been matched to any known spawning population (Dr. I. Wirgin, New York University, pers. comm.). Elsewhere in Cape Breton, although their presence has long been recognized (Cash et al. 1985; Scott and

Scott 1988; Andrews et al. 2019, Appendix 3), accounts of Striped Bass overwintering aggregations

are limited to those reported by recreational anglers. Annual overwintering sites have been identified within brackish barachois and sheltered coves throughout the Bras D'Or Lake (Noel Doucette, Kendall Hutchins, Skyler Jeddore, Clifford Paul, pers. comm.; Fig. 3.7), along the southern coast in Framboise River and Fuller's Gut (Kendall Hutchins, Andre Roy, pers. comm.; Fig. 3.7) as well as in the heated outflow of the Lingan Power Station (Aaron Hunt, Kendall Hutchins, pers. comm.; Fig. 3.7). Based on recreational catches along the coast, and observations within the Mira River estuary (Buhariwalla 2018), it is likely that Striped Bass in Cape Breton move to these overwintering areas in mid November where they remain until late April and into early May.

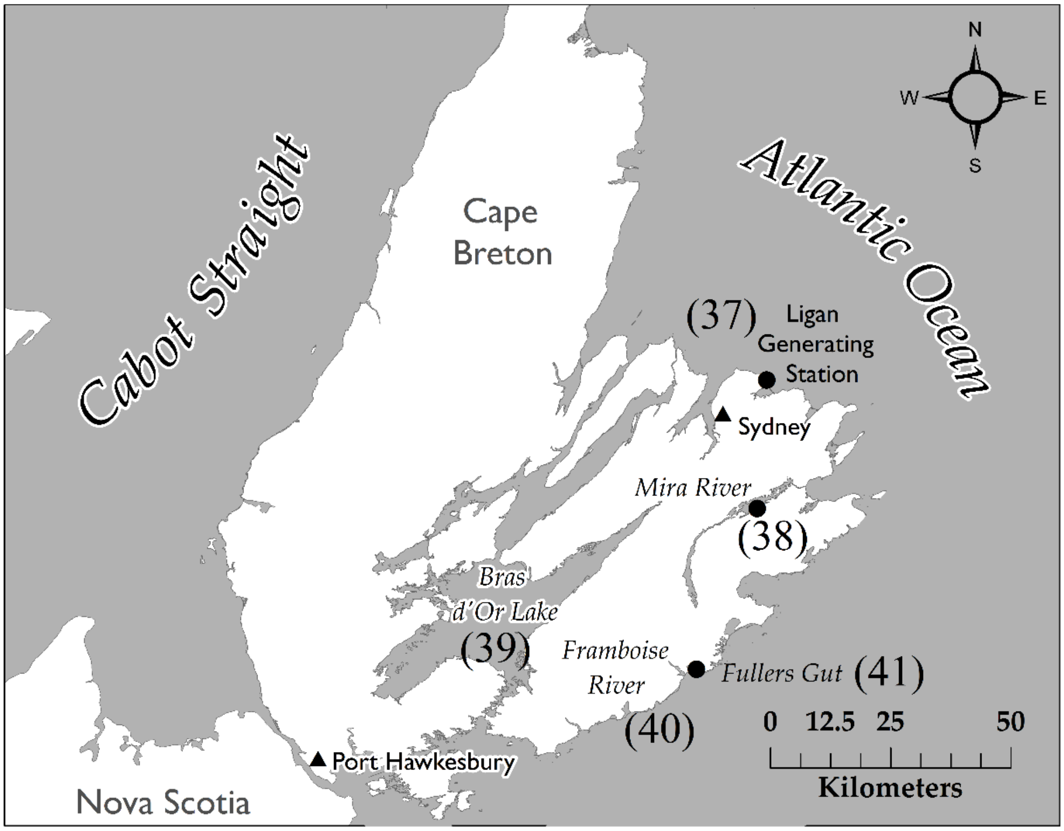

Figure 3.7: Documented Striped Bass overwintering areas on Cape Breton Island, Nova Scotia. Numbers correspond to the associated map numbers in Table 3.1

3.12 Lethal winter temperatures for Canadian overwintering aggregations

Avoidance of "lethal marine temperatures" has been described for Striped Bass during overwintering in Canadian waters (Bradford et al. 2001a, 2014, 2015; Douglas et al. 2003). Such temperatures, however, have not been carefully assessed, measured, or defined. Cook et al. (2006) suggested a lower lethal temperature of 2.4 °C for YOY Striped Bass of Shubenacadie origin, but the experiment used Striped Bass raised from wild eggs reared in controlled environments and as a result, these captive fish were much larger then similarly aged, wild Striped Bass (Rulifson and Dadswell 1995). Striped Bass raised in captivity can shift temperature tolerance limits (Hurst and Conover 2002). Based on these results, wild fish would not be able to cope with temperatures anywhere close to the −1.5 °C sea/estuarine temperatures that age 0 Striped Bass encounter and tolerate while overwintering in Minas Basin (Bradford et al. 2015). The study conducted by Cook et al. (2006) does, however, suggest that juvenile Striped Bass may have a wider thermal tolerance than their US counterparts meaning that thermal tolerance data collected for Chesapeake Bay (Lapointe et al. 2014) and Hudson River (Ecological Analysts, Inc. 1978) origin fish may be incomparable to Canadian populations. For US stocks, Hurst and Conover (2002) demonstrated that higher survival at low temperature occurred at intermediate salinities (15 ppt) as low temperature may affect the ability to osmoregulate (Toneys and Coble 1980) but it remains unclear if the results presented by Hurst and Conover (2002) hold true for Canadian Striped Bass.

3.13 Size dependant mortality of Canadian Striped Bass during winter

Age 0 Striped Bass can be subject to size dependent winter mortality (Bernier 1996; Hurst and Conover 2003; MacInnis 2012), possibly the result of starvation (Hurst 2007). Winter survival of juveniles has been suggested to be positively related to body size, i.e., larger individuals have a greater chance at survival (Bernier 1996; Hurst and Conover 2003; MacInnis 2012). A body size threshold of 10 cm has been suggested necessary to survive winter (Bernier 1996; Hurst and Conover 2003; MacInnis2012). Body length may serve as a simple index of winter survival in YOY, but there are several additional factors most probably involved including actual energy reserves (Hurst and Conover 2003) and environmental conditions (Toneys and Coble 1980), which vary interannually (Bernier 1996) resulting in year class variability.

3.14 Threats to Canadian overwintering aggregations

Many threats have been cited for overwintering Striped Bass. These include predation and competition from introduced fishes (i.e., Chain Pickerel (*Esox Niger*);

COSEWIC 2004 or Brown Trout; observed predation of Striped Bass <10 cm in River Philip, NS, in early spring), pollution (both chemical and thermal; COSEWIC 2012; Buhariwalla et al. 2016), illegal and directed commercial fishing (Hogans and Melvin 1984; Robitaille 2011), environmental accidents (Robitaille 2011), dredging (Beaulieu 1985; Trepanier and Robitaille 1996) and commercial bycatch (Hogans and Melvin 1984; Bradford et al. 1997, 1998). Infection such as that caused by the fungus *Saprolegnia* may also threaten overwintering Striped Bass due to stress and when occurring in dense aggregations (Harrell 1997) but its occurrence has not been described in Canada. Overwintering Striped Bass populations are susceptible to threats within overwintering habitat such as fisheries exploitation because of their habit of dense aggregation, near-dormant behaviour occurring in relatively restricted locations, and their predictable inter-annual recurrence in these locations.

3.15 Fall aggregation and spring dispersal cues of Canadian overwintering aggregations

From our research, it appears that the cues that trigger Striped Bass to travel to and aggregate in winter habitats have never been studied. Events signaling spring departure are equally obscure with most studies not even reporting departure times from winter habitat. Studies on the Saint John River, NB, have observed acoustically tagged Striped Bass departing from the waters downstream of Mactaquac Dam (a major fall feeding area; see Andrews et al. 2018b, Appendix 2) between October 13th - Nov 13th across four years of study (2014-2017; S. N. Andrews Chapter 4, Appendix 2). All Striped Bass occupying this area in late fall departed the location before water temperature dropped to 10 °C. In spring, it is possible that an increase in water temperature could trigger the departure of Striped Bass from overwintering habitats.

Striped Bass overwintering aggregations monitored within the Saint John River were observed to depart winter habitats during spring turnover when uniform temperatures occurred from the surface to depths of winter residence (2014-2018; see Thesis Chapter 4)

3.16 Characteristics of Canadian overwintering habitats

Striped Bass overwintering habitats share some consistent characteristics (Bradford et al. 1998), even being described as “predictable”, however, the physiological constraints and thus the environmental requirements of these habitats have yet to be defined. Furthermore, Striped Bass overwintering in marine areas remain poorly described (Minas Passage of the Bay of Fundy; Keyser et al. 2016) and it is unknown why such cold and often turbulent areas are selected by Striped Bass in winter. Habitat suitability for adult Striped Bass as currently described appears to be a combination of:

1) Avoidance of current or flow: Striped Bass often select inland overwintering areas that are sheltered from strong tidal and/or river currents. These habitats can occur in deep basins of bays or inland lakes, shallow lakes or coves, or areas below the salt wedge in riverine channels where denser saline waters remain relatively undisturbed. The Minas Passage appears to be the sole exception to this rule; however, it is possible that this deep channel-like portion of the Bay of Fundy permits overwintering Striped Bass to remain in the general area possibly through vertical migrations.
2) Suitable combination of temperature and salinity: Freshwater or low salinity conditions appear to be favoured but not required and possibly serve to maximize energy conservation by minimizing osmoregulatory requirements (this may be particularly critical for young Striped Bass). The warmest available water within the

overwintering area is typically selected providing there is sufficient oxygen (Bednarski 2007; see Thesis Chapter 4). Striped Bass appear to select colder, lentic overwintering environments over warmer, fluvial environments over winter months (see Thesis Chapter 4), which also suggest the role of energy reserves for overwinter survival. Striped Bass may also select thermal refuges during winter including power station outflows, or deep basins stratified by ectogenic meromixis (i.e., where warm saline water enters a basin and is covered by a less saline superficial layer of water).

3) Geographic Location: Striped Bass overwintering sites may be but are not necessarily close to spawning habitats and may, in some instances, lie hundreds of kilometers away (Bradford 1995a; Bradford and Chaput 1996; see Thesis Chapter 4). Striped Bass appear to home strongly to overwintering areas (see Thesis Chapter 4) but much work is still required to understand why such distant locations are often selected and revisited annually.

3.17 Conclusion

Striped Bass is an important recreational species in Canada (COSEWIC 2012). There are many aspects of the Striped Bass ecology that remain understudied, though winter habitats and survival may be the most poorly described. The key unanswered questions that are critical for understanding Striped Bass winter ecology and the underlying meaningful advice for managers are as follows:

1) Where do age 0 and 1 Canadian Striped Bass overwinter?

2) What conditions/factors draw Striped Bass of many origins to specific overwintering habitats? What are the management issues of multiple stocks sharing overwintering habitats? Additionally, is this mixing related to in-year environmental conditions

restricting exit routes for migrants? Or rather, is it a natural behaviour related to schooling regardless of population origin?

3) What are the required physical parameters of Striped Bass overwintering habitat (e.g., temperature, salinity, flow, food availability)? This description may also be enhanced through the inclusion or consideration of various natural and anthropogenic threats to winter survival (e.g., natural and introduced predators, thermal and chemical pollution). Such factors are likely to increase the stress associated with overwintering and may provide insights into stress thresholds that could theoretically cause overwintering site abandonment.

4) Are there more marine Striped Bass overwintering aggregations in Canada other than the recently discovered Striped Bass overwintering aggregation in the Minas Passage? Do Striped Bass in-fact still overwinter off the coast of PEI? What are the mechanisms leading to marine overwintering?

Numerous Striped Bass winter habitats have been located throughout the species Canadian range, though it is likely that many more have also been lost following the collapse of numerous winter Striped Bass fisheries. Without knowledge of winter habitat locations or even their characteristics there is no way of protecting these areas from development, pollution or other stressors. Acoustic tagging and active tracking of tagged fish may be the best way to locate Striped Bass overwintering aggregations. If Striped Bass home to overwintering areas then researchers can disperse their tagging efforts both geographically and temporally to mark individuals overwintering at different locations. Late season (after November 1) sonar surveys could also be effective in locating Striped Bass overwintering aggregations. In addition to documenting aggregation locations, there is a knowledge gap about behaviour of these aggregations during the overwintering period. It is unknown how densely individuals aggregate, how much they move, and how these movements and distributions are affected by environmental variables such as temperature and flow. Furthermore, no one knows how warming ocean temperatures will affect Striped Bass overwintering aggregations, many of which that have yet to be described.

Many fisheries management strategies are based around regulating fish retention and thus controlling the rate of individual removal or the size of individuals that can be harvested. This method is effective in managing fish populations in summer when both the fish and their pursuers are widely dispersed and in winter as many fisheries are generally closed. Fisheries management is also concerned with habitat protection through the mitigation of development activities. However, as human populations grow, so does the rate of alteration of natural habitats to more residential, commercial and industrial landscapes. Any loss of natural habitat is undesirable, but in many cases, compromises must be made. Poor general habitats may become compromised to preserve more critical locations such as spawning sites or nursery grounds. Such important areas are protected as they are easily observed and often well known locations, both to researchers and recreational anglers alike. Overwinter habitats, however, frequently go undocumented due a lack of winter research; for species such as the striped bass the overwintering habitat may be critical to survival. Furthermore, due to their suspected winter habit of dense aggregation and overwintering site fidelity (see Thesis chapter 4), Striped Bass could be exceedingly vulnerable to environmental impacts and alterations to overwintering habitat which could endanger entire contingents of a population. As a result, managers of Striped Bass populations should become keenly aware of the overwintering locations and habits of Striped Bass in their management regions in order to protect those areas from development and environmental degradation. The study of Striped Bass overwintering ecology in Canada may be critical for the long-term management of this important gamefish in the face of warming oceans, coastal development and intensifying agriculture.

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Chapter 4:

Winter Ecology of Striped Bass (*Morone saxatilis*) Near its Northern Distribution in the Saint John River, New Brunswick

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4.1 Abstract

Winter habitat selection by Striped Bass (*Morone saxatilis*) has been described as opportunistic, but due to the length and severity of winter at its northern range, winter habitats are predicted to be restricted in distribution and carefully selected. Here we describe the locations and environmental conditions supporting winter aggregations of Striped Bass adults and sub-adults including periods under ice cover in the Saint John River, New Brunswick using acoustic tagging. Striped Bass of both native (72%) and non-native origin (28%) determined from genetic testing were observed to overwinter within the river's four mainstem lakes/embayments to which they were tracked returning to each fall, and an increasing proportion of non-native migratory Striped Bass were observed from the most inland winter habitat to habitats closest to the river mouth. Striped Bass travelled to these winter habitats from fall feeding locations from Oct - Nov, and only four Striped Bass were observed to depart from the river at this time. Within winter habitats, we examined temperature and dissolved oxygen parameters and explored the importance of Belleisle Bay as the chosen winter habitat for 60% of wintering Striped Bass to provide a first time look under the Saint John River ice.

4.2 Introduction

The native range of Striped Bass (*Morone saxatilis*) extends nearly 3000 km along the Atlantic Seaboard of North America from the St. John's River, Florida, in the south to the St. Lawrence River, Quebec, in the North (Scott and Scott 1988). Populations occupying much of the species' principal range in central and northern regions must annually contend with winter periods lasting up to 7 months where temperatures are 0-4°C in fresh water to a suspected minimum of < -0.5°C reported for marine environments (Andrews et al. 2019a, Chapter 3, Bradford et al. 1998). Despite their long duration and their potential impacts on survival, winter ecology remains a poorly described and infrequently studied aspect of Striped Bass habitats and life histories (Bednarski 2007; Keyser et al. 2016; see review by Andrews et al. 2019, Chapter 3).

Striped Bass typically migrate to fixed wintering sites as water temperatures cool in late fall (reviewed by Andrews et al. 2019, Chapter 3). These winter locations can be sluggish river pools (Rulifson et al. 1987), sheltered inland harbours (Bednarski 2007), freshwater lakes (Bradford et al. 2012), and sometimes coastal or offshore regions (Keyser et al. 2016). During the winter period when water temperatures near winter minimums, Striped Bass are known to form dense aggregations (Bednarski 2007) and conduct minimal movements until water temperatures begin to warm in the spring at which time they disperse. A reduction or complete cessation of feeding is suspected for Canadian populations (Dr. M. Dadswell, personal communication), though winter feeding may continue in more southern (Hudson River, Dunning et al. 1997; Chesapeake Bay, Hollis 1952) and/or coastal regions (Virginia and North Carolina Coast, Overton et al. 2008). Inland winter aggregations are suspected to occur primarily in sheltered habitats where the threat of displacement by tidal action or runoff driven currents is minimal (Bradford et al. 2012), but how coastal winter habitats are selected and used is poorly understood.

In this study, we use acoustic tracking to identify migrations to, and monitor movements within, winter habitats of adult Striped Bass (> Age 3) in the Saint John River (SJR), New Brunswick, from 2015-18 (three consecutive winter periods). The Striped Bass were determined to include both native SJR origin individuals and fish of non-native origin that can occur in the river (Leblanc et al. 2018; Bentzen and Paterson

2008). We predicted that environmental conditions at the onset and conclusion of winter dictated the migrations to and from repeated, i.e., established overwintering sites, and that the under-ice conditions of temperature and dissolved oxygen regulated the aggregation and their patterns of movement.

4.3 Study Area

The Saint John River (SJR) is a 55,000 km^2 watershed that extends ~670 km from the Little Saint John Lake on the Maine-Québec border to the city of Saint John, New Brunswick, where it empties into the Bay of Fundy through a narrow opening (~100 m) known as Reversing Falls (Cunjak et al. 2011; Fig 4.1). The head of tide extends to the city of Fredericton ~130 km upstream from the river mouth, and salt water intrusion is measurable ~70 km upriver (to the village of Gagetown; Carter and Dadswell 1983). Mactaquac Dam and Generating Station (MGS) is the most downstream located hydroelectric facility and presents a physical barrier to Striped Bass upstream migration and thus the upstream limit of our study area. In the downstream reach there are four large mainstem tributaries that join the SJR from the northeast (Fig. 4.1). Grand Lake and Washademoak Lake provide freshwater lacustrine habitats; Belleisle Bay and Kennebecasis Bay are closer to the river mouth and the Bay of Fundy and are characterised by greater tidal influence including saltwater intrusions. During winter, much of the river becomes ice bound with small patches of open water in tributary mouths, lake thoroughfares and at Reversing Falls due to extreme (8 m) tides.

The SJR is located near the northern extent of Striped Bass Atlantic distribution (Scott and Scott 1988) and hosts migrants from various population origins throughout the year, i.e., Native SJR, Shubenacadie River, Nova Scotia, and the USA (Leblanc et al., 2018, Wirgin et al. 1995, Bentzen and Paterson 2008). Winter habitats have been identified in all four major tributaries (Andrews et al. 2018a, 2018b, 2019, Chapter 3) and mixed ancestry winter aggregations in Belleisle Bay were reported by Bradford et al. (2001).

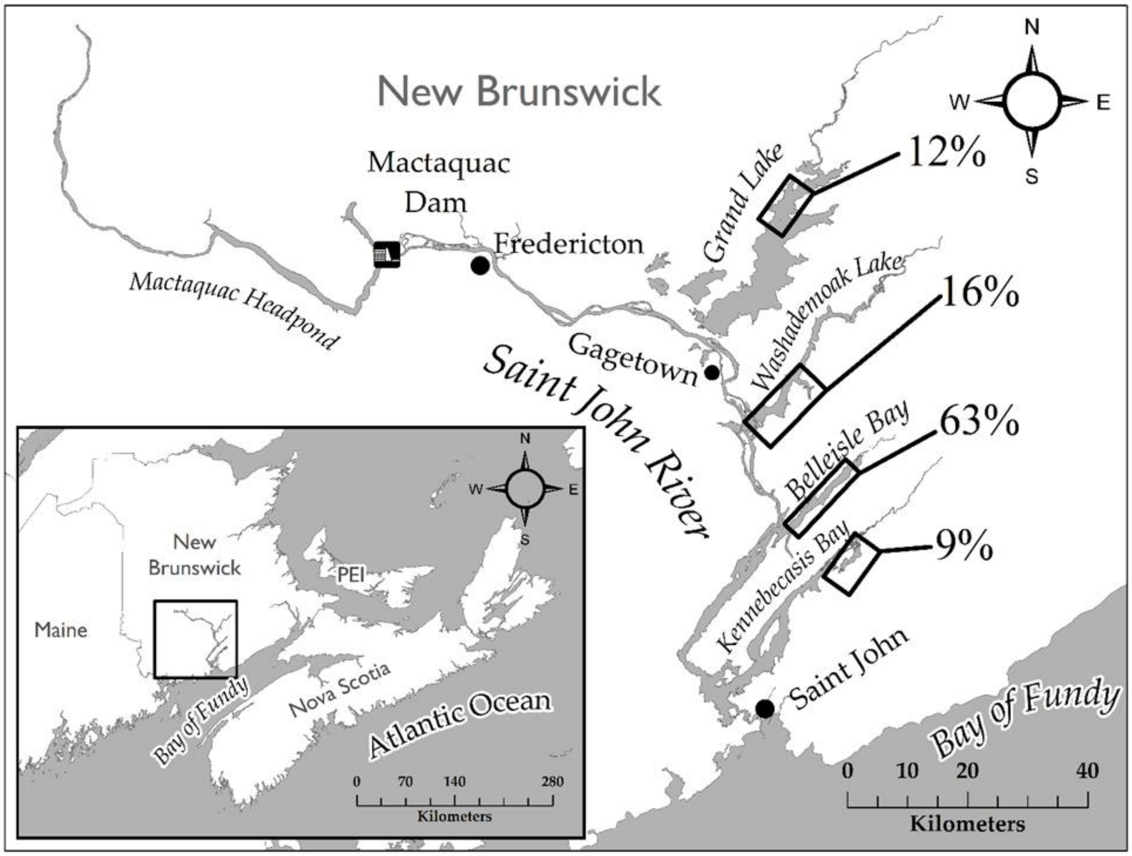


Figure 4.1: The lower Saint John River, New Brunswick, including the four major tributaries with Striped Bass winter aggregations in 2014-2017 including overall percentages of tracked Striped Bass at each location calculated from individuals tagged at Mactaquac Dam.

4.3.1 Grand Lake

Grand Lake is the largest tributary lake of the Saint John River measuring 37 km long and, in some areas, over 8 km wide. The lake is accessible to Striped Bass via the

Jemseg River, a relatively short (~7.5 km) and narrow (150 m wide) channel that empties from the southeastern point of the lake in to the SJR ~75 km inland from the river mouth. Grand Lake is the most upstream of the major tributaries within our study area and thus receives minimal tidal influence (mostly its downstream reach); there is no reported salt wedge (Carter and Dadswell 1983). Grand Lake is also the shallowest of the four major tributaries with an average depth of ~15 m but with a maximum depth of 28 m.

4.3.2 Washademoak Lake

Washademoak Lake is located ~63 km upstream from the river mouth. It is tidally influenced though receives little salt water input (Carter and Dadswell 1983; Dr. M. Dadswell. personal communication). Washademoak Lake spans >25 km from its confluence with the SJR to its northernmost extent where it is fed by the Cannan River and is ~2.5 km at its widest point. The lower basin of Washademoak Lake has a depth of ~33 m and one large shallow embayment know as big cove can found on the southeastern side of the lake.

4.3.3 Belleisle Bay

Belleisle Bay is a tidal tributary of the SJR, located ~44 km upstream from the River's mouth. Belleisle Bay is subject to a 40-60 cm tide along its 17 km length and receives significant salt water influence. Historically, Belleisle Bay was the location of a directed winter commercial Striped Bass fishery (operated 1930-1978) boasting catches > 18,000 kg in peak years (Andrews et al. 2017, Chapter 1). These large winter catches suggested that the area was a major overwintering ground for the species.

4.3.4 Darling's Lake

Darling's Lake is a tidal fresh water lake on the eastern side of Darling's Island located at the head of Kennebecasis Bay and adjacent to the Kennebecasis River. The lake is fed at its northern tip by a tributary of the Kennebecasis river and empties into the Hammond River through a shallow (~1 m deep depending on tidal stage) channel to the South. Much of Darling's Lake is a shallow water habitat ~1-2 m in depth with dense macrophyte cover extending to near the surface, however, the southern reach of the lake is characterised by a section of moderate depth (5-6 m) with rock/mud substrate.

4.4 Methods

4.4.1 Tagging Methods

Adult Striped Bass (n=44, FL = 59 to 112 cm, weight = 3 to 20 kg) were captured at various locations within the SJR from 2013-16 (Table 4.1). Individuals were anesthetized (clove oil) and surgically implanted with acoustic tags: Vemco V13-4L (n=3; tag life=719 days), V16-4L (n=38; tag life=3650 days), and V16-6L (n=3; tag life =3650 days) acoustic tags. Tagging procedures are described in Wingate and Secor (2017) using a 40 mg/L solution of 10-part ETOH:1-parts clove oil. In 2017, an additional 19 Striped Bass (FL = 69 to 97 cm, weight = 5 to 15 kg) were captured by angling directly downstream of the MGS in October and surgically implanted with Vemco V16-4L (n=4; tag life = 3650 days) and V16-4H (n=15; tag life= 2305 days) depth (0 to 34 m ± 1.7 m)/temperature (-5°C to 35°C ± 0.5°C) tags. Tag weight (range 9-16 g in water) was < 0.005% of fish weight. Tagging locations were chosen throughout the river in an attempt to capture the broadest diversity of movements of native SJR Striped Bass as well as visiting migrants. Individuals fitted with depth/temperature tags were all captured and tagged at the Mactaquac Dam because

Striped Bass occurring at this location were suspected to disperse amongst all four overwintering locations in the fall.

Scale samples were collected for ageing and a portion (1 cm^2) of the caudal fin was collected for genetic analysis to determine population origin (see Leblanc et al. 2018). All tagging and sampling procedures were approved by the University of New Brunswick UNB Animal Care Committee (Animal Use Protocol Numbers 16026, 15024).

Table 4.1: Biometric table for acoustically tagged Striped Bass including the annual winter location within and exterior to the Saint John River over four years of tracking (2014-2018). Genetic origin is also displayed as SJR (native Saint John River), SHUB (Shubenacadie River, NS), US (United States origin) or admixed (SJR/US). Genetic Origins followed by "?" had too much missing data to assign true population of origin but the origin was inferred based on chosen spring spawning locations (i.e., SHUB? Individuals travelled to the Shubenacadie river NS during each spawning period, SJR? Individuals travelled to Fredericton). Striped Bass that died or were undetected following tagging (n=10) were omitted from the table. Striped Bass are sorted by tagging date and overwintering location. Note: two individuals switched from Belleisle Bay to Washademoak Lake each in one year of tracking, they are marked in dark grey.

	Tag ID	Tagging date	Tagging location	FL (cm)	Weight (kg)	Genetic Origin	2014/2015 Winter location	2015/2016 Winter location	2016/2017 Winter location	2017/2018 Winter location
Grand Lake	32646	2014-05-23	Grand Lake	72.5	5.35	SJR	Grand Lake	Died in Grand Lake in winter 2015		
	24952	2014-06-11	Grand Lake	67.4	3.95	SJR	Grand Lake	Grand Lake	Grand Lake	Grand Lake
	24942	2014-07-16	Mactaquac Hatchery	73	5.62		Grand Lake	Grand Lake	Grand Lake	Grand Lake
	22139	2015-06-15	Grand Lake	61	3.36	SJR?		Grand Lake	Grand Lake	Grand Lake
	22138	2016-05-11	Flowers Cove	73	5.20	SJR			Grand Lake	Grand Lake
	21323	2016-05-11	Flowers Cove	68	4.13	SJR			Grand Lake	Grand Lake
	21324	2016-05-11	Flowers Cove	71	4.59	SJR			Grand Lake	Grand Lake
	21328	2016-05-20	Grand Lake	66	3.00	SJR/US			Grand Lake	Grand Lake
	11242	2017-10-14	Mactaquac	97	8.02	SJR/US				Grand Lake

	11232	2017-10-25	Mactaquac	90	10.64	SJR				Grand Lake
	11430	2017-10-26	Mactaquac	97	15.04	SJR				Grand Lake
Washademoak	24951	2014-06-11	Grand Lake	78.4	7.08	SJR	Washademoak	Washademoak	Washademoak	Captured at Mactaquac
	24946	2014-08-21	Mactaquac hatchery	76	6.53	SJR?	Washademoak	Washademoak	Washademoak	Washademoak
	24944	2014-08-22	Mactaquac hatchery	76	4.94	SJR	Washademoak	Washademoak	Washademoak	Washademoak
	21326	2015-10-24	Washademoak	79	6.40	SJR		Washademoak	Washademoak	Washademoak
	22132	2015-10-24	Washademoak	79	7.03	SJR		Washademoak	Washademoak	Washademoak
	22135	2016-05-27	Grand Lake	94	12.35				Washademoak	Washademoak
	11250	2017-10-23	Mactaquac	79	6.27	SJR				Washademoak
Belleisle Bay	32645	2013-10-04	Mactaquac hatchery	83.6	9.30		Belleisle Bay	Died in Belleisle Bay in winter 2015		
	32647	2013-10-04	Mactaquac hatchery	76.5	6.52	SHUB?	Belleisle Bay	Belleisle Bay	Belleisle Bay	Belleisle Bay
	32648	2013-10-04	Mactaquac hatchery	90.9	9.66	US	Belleisle Bay	Captured in Bay of Fundy?		
	24949	2014-06-11	Grand Lake	76.6	6.58	SHUB?	Belleisle Bay	Washademoak	Belleisle Bay	Belleisle Bay
	22136	2015-06-20	Hampton Marsh	94	9.34	SJR	Died in Belleisle Bay in winter 2015			
	24948	2014-08-22	Mactaquac hatchery	67.6	4.54	SJR	Belleisle Bay	Belleisle Bay	Belleisle Bay	Belleisle Bay
	24950	2014-08-22	Mactaquac hatchery	69.3	4.49	SJR?	Belleisle Bay	Belleisle Bay	Belleisle Bay	Belleisle Bay
	24953	2014-08-22	Mactaquac hatchery	85	9.25	SJR	Belleisle Bay	Died in Belleisle Bay in winter 2015		
	24954	2014-09-12	Mactaquac hatchery	80	7.35	SJR	Belleisle Bay	Belleisle Bay	Belleisle Bay	Belleisle Bay
	24956	2014-09-12	Mactaquac hatchery	77.5	6.40	SJR	Belleisle Bay	Belleisle Bay	Belleisle Bay	Belleisle Bay
	24958	2014-09-13	Reversing Falls	81.5	7.48	SHUB	Belleisle Bay	Belleisle Bay	Belleisle Bay	Captured in Bay of Fundy
	32652	2014-09-13	Reversing falls	75.8	4.94	SHUB?	Belleisle Bay	Belleisle Bay	Died in Washademoak in winter 2016	
	22141	2015-06-10	Grand Lake	68	5.76	SJR		Belleisle Bay	Belleisle Bay	Belleisle Bay
	11254	2017-10-14	Mactaquac	76	5.46	SJR/US				Belleisle Bay
	11258	2017-10-15	Mactaquac	95	11.97	SJR				Died in Belleisle in winter
	11256	2017-10-15	Mactaquac	89.5	9.47	SHUB				Belleisle Bay
	11252	2017-10-23	Mactaquac	83	7.3	SJR				Belleisle Bay
	11240	2017-10-25	Mactaquac	77	7.18	SJR				Died in Belleisle in winter
	11238	2017-10-25	Mactaquac	76	7.28	SJR?				Belleisle Bay
	11246	2017-10-25	Mactaquac	83	8.89	SHUB				Belleisle Bay
	11230	2017-10-25	Mactaquac	77	6.35	SJR				Belleisle Bay
	11234	2017-10-25	Mactaquac	82	10.27	SJR				Belleisle Bay
	11426	2017-10-25	Mactaquac	88	10.11	SHUB				Belleisle Bay
Darling's Lake	24941	2014-07-25	Hampton Marsh	95.2	10.52		Darling's Lake	Darling's Lake	Darling's Lake	Darling's Lake
	24943	2014-07-25	Hampton Marsh	100	13.79		Darling's Lake	Darling's Lake	Darling's Lake	Darling's Lake
	24945	2014-07-25	Hampton Marsh	112	19.60		Darling's Lake	Died in Darling's Lake in winter 2016		
	24959	2014-09-12	Mactaquac hatchery	77.5	6.03	SHUB?	Darlings Lake	Died at reversing falls, catch and release mortality?		
	24957	2014-09-12	Mactaquac hatchery	80.8	7.67	SHUB?	Darling's Lake	Darling's Lake	Darling's Lake	Darling's Lake
	22137	2015-06-15	Grand Lake	74	5.03	SJR/US		Darling's Lake	Darling's Lake	Darling's Lake
	22133	2016-06-09	Hampton Marsh	79	7.06	US			Darling's Lake	Darling's Lake
	24945*	2016-06-17	Hampton Marsh	112	19.83	US			Darling's Lake	Darling's Lake
Outside SJR	32650	2014-06-09	Hampton Marsh	58.7	2.95	SHUB?	Outside SJR	Outside SJR	Captured or did not return to SJR	
	24960	2014-09-13	Reversing Falls	83.7	7.71	SHUB?	Outside SJR	Outside SJR	Outside SJR	Minas Passage
	11428	2017-10-15	Mactaquac	93	11.33	SHUB				Minas Passage
	11244	2017-10-25	Mactaquac	80	7.33	SHUB				Minas Passage

4.4.2 Genetic Methods

All sampled Striped Bass (n= 63) from both tagging groups were genotyped. Sequencing methods are described in Leblanc et al. (2018), with the following exception: DNA isolation of 21 SJR samples was done using E.Z.N.A. Tissue DNA Kit (Omega Bio-Tek, Doraville, CA). Samples were analyzed using the same 1217 loci used in by Leblanc et al. (2018), and individual samples were retained for genetic analysis if they had less than 30% missing data across all loci.

Genetic structure of individuals was assessed using the R package LEA v. 2.0 (Frichot and François 2015), which performs least-squared estimates of the genetic ancestry of individuals without any *a priori* grouping. Simulations were run assuming 1 to 5 distinct ancestral populations, or genetic clusters, (K). The most likely K was chosen using a cross-entropy criterion, with the lowest minimal cross-entropy value considered the most probable (Frichot et al. 2014). The proportion of an individual's genome that resembles each genetic cluster is measured by the ancestry coefficient. Individuals with an ancestry coefficient greater than 0.7 (70%) were said to belong to that genetic cluster, and those who were not assigned to any cluster were considered admixed, or hybrid fish.

4.4.3 Tracking Methods

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 (Fig. 4.1). Receivers were moored on the river bottom and annually retrieved to download detection data. The specific array included n=36 VR2W placements in 2014, n=125 in 2015, n=128 in 2016, n=135 in 2017 and n=58 in 2018 (Fig. 4.2). Additional tracking data were received from the Ocean Tracking Network (OTN - http://oceantrackingnetwork.org/). OTN receivers detected tagged Striped Bass within the river in 2014 (n=19), 2015 (n=17), 2016 (n=48), 2017 (n=9), and 2018 (n=10). OTN receivers also detected Striped Bass outside of the Saint John River in 2014 (n=13), 2015 (n=18), 2016 (n=11), 2017 (n=12) and 2018 (n=22).

Striped Bass were also tracked manually during winter from 2014-17 using Vemco VR100 receivers. Tracking was initiated in January when ice conditions were safe. The tracking procedure involved walking 50-300 m out from shore, drilling a hole through the ice with a hand or power auger and listening for tags using directional and omnidirectional hydrophones. This process was repeated every 1 km along the shore beginning in the river's main embayments until all known tags were located. This winter tracking process was conducted over multiple years and together with detections from annually re-located VR2W receivers, and OTN receivers outside of the SJR allowed for the confirmation of all tagged Striped Bass. One-kilometer intervals were determined to be sufficient based on winter range testing with a tethered V16-4L acoustic range test tag tested at 8 depths (1.8-14.6 m) at ranges increasing 100 m at a time away from a VR100 receiver. The tag was clearly detected at distances > 1.5 km. In 2015, 92 locations were manually surveyed with the VR100 receiver from Feb 2 – Mar 29 including in Grand lake (n=30), Washademoak Lake (n=10), Belleisle Bay (n=24), Kennebecasis Bay and Darling's Lake (n=17) and the main stem of the SJR (n=11). In 2016, 55 locations were surveyed from Jan 24 – Mar 30 including n=12, 12, 10, 15, 6, in Grand Lake, Washademoak Lake, Belleisle Bay, Kennebecasis River and the main SJR respectively. All tagged Striped Bass were located during each year and active tracking efforts aided in determining passive receiver placement.

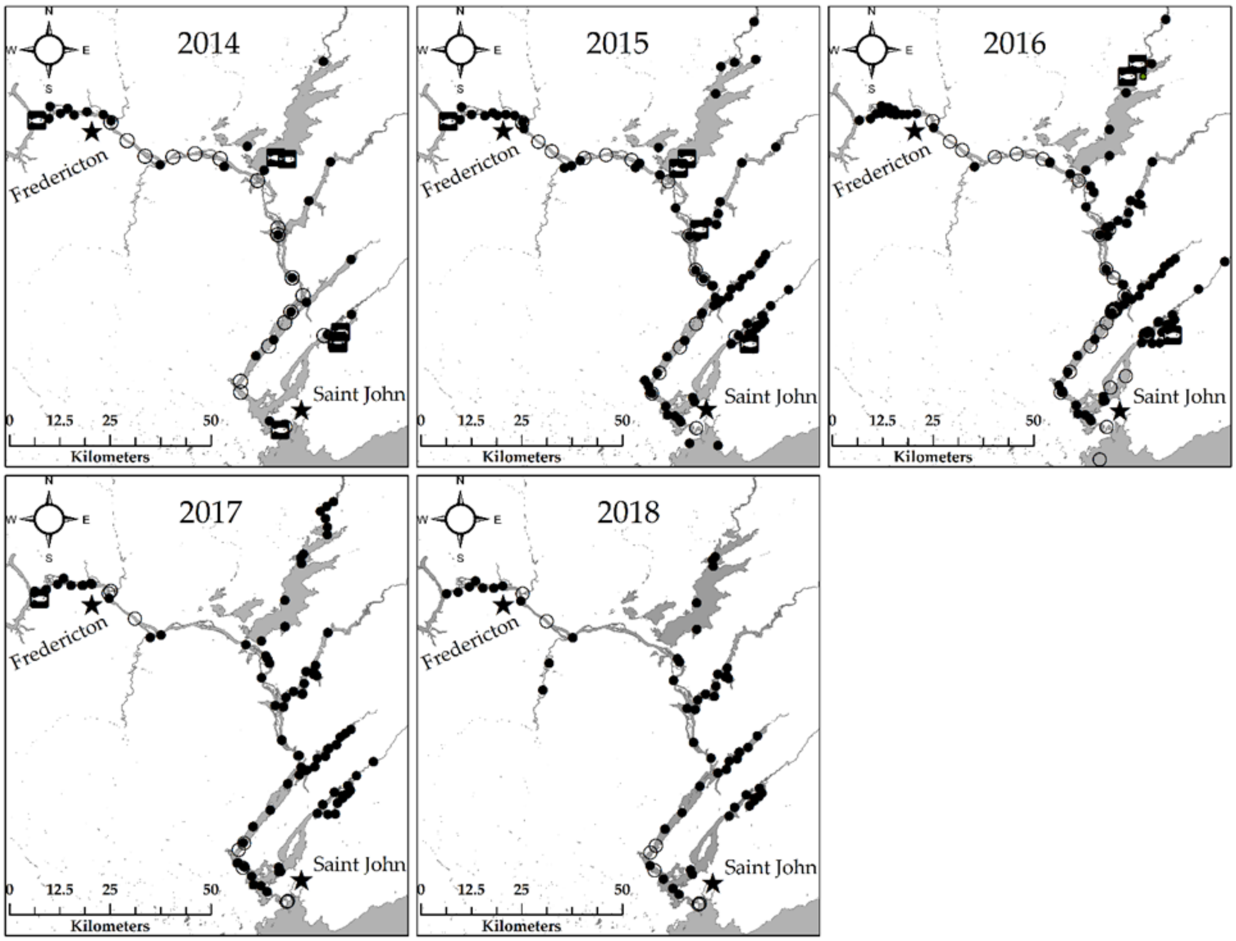


Figure 4.2: Locations of Striped Bass tagging (fish symbols), project specific VR2W receiver placements (black points), and OTN receivers (black open circles) that detected tagged Striped Bass along the Saint John River, New Brunswick from 2014-18.

Selected receivers occurring near Striped Bass winter aggregations in lakes were fitted with Onset HOBO® temperature pendants (n=15) in 2014, (n=91) in 2015, (n=79) in 2016, and (n=93) in 2017. Vertical temperature lines were deployed in areas of concentrated Striped Bass in winter in each lake. Temperature lines were fitted with HOBO temperature pendants spaced at equal intervals of 2-5 m from the bottom to the surface and recorded temperatures every hour. When winter habitats were safely accessible and after wintering Striped Bass had been located, water column profiles of conductivity (μS/cm) and oxygen (%DO) were conducted using a YSI 6600 multimeric sonde, n=1-2 per lake/season.

Average recorded temperatures when Striped Bass entered and departed winter habitats in each year were statistically compared using an Analysis of Variance test (ANOVA). The annual dates of first departure from winter habitats were also statistically compared between SJR and Shubenacadie origin Striped Bass using a t-test.

4.5 Results

4.5.1 Genetics

A total of 42 Striped Bass from the SJR samples (67%) were successfully genotyped with <30% missing data across 1,217 loci, and these were compared to reference Striped Bass collected in Shubenacadie River, Miramichi River, Hudson River, and upper Chesapeake Bay. The most likely number of genetic clusters (K) was found to be 4, which identified sampled fish as belonging to the Shubenacadie River, Miramichi River, Saint John River, and the United States samples. At K=5, Hudson River began to differentiate from Chesapeake Bay; however, as we were concerned primarily with identifying whether SJR samples were or were not from the United States, we performed assignments using the K=4 ancestry coefficients.

Striped Bass that were tagged within the Saint John River originated from three different populations of origin including the Shubenacadie River, Nova Scotia (n=9; 21%), United States populations (n=3; 7%) and a group matching the genotype of native Saint John River Striped Bass (n=26; 62%). Additionally, n=3 individuals appeared to be admixed between United States and Saint John River individuals (7%), and one individual was admixed between Saint John River and both United States and Shubenacadie River.

In some cases, Striped Bass that were not successfully genotyped or had > 30% missing data were provisionally assigned an origin based on migrations during the time of spawning. Of these individuals of unconfirmed origin, (n=4) migrated to and were assumed to be from Shubenacadie River population, n=3 Striped Bass were assigned to the native SJR population due to migration to a historic spawning location near the City of Fredericton during each year of tracking.

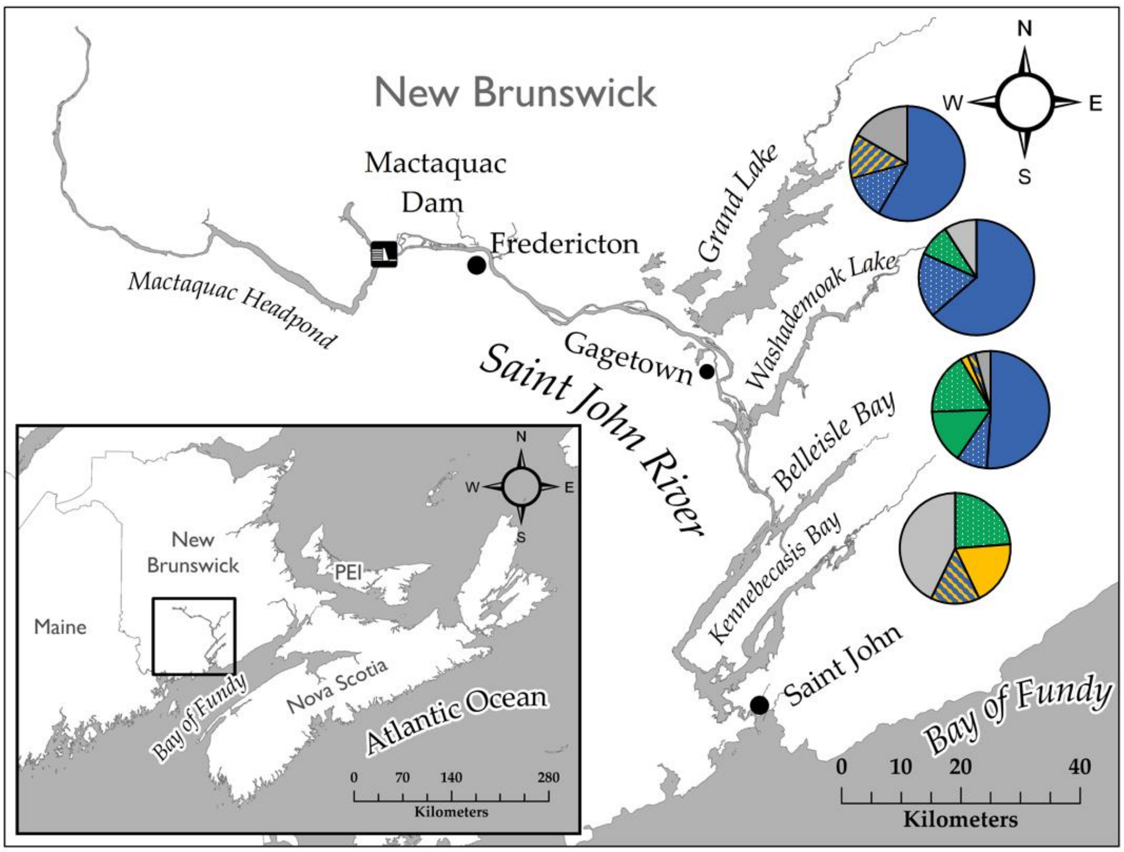


Figure 4.3: Proportion of Striped Bass of each population of origin (see table 4.1) including native Saint John River (blue), suspected Saint John River (blue stipple),

Shubenacadie River origin (green), suspected Shubenacadie River (green stipple), United States origin (yellow), US/SJR admixed (yellow/blue stripe) and unknown (grey). All Striped Bass departing from the Saint John River prior to winter were of known (n=2) or suspected (n=2) Shubenacadie River origin.

4.5.2 Migration to Winter Habitats

In late fall (Oct-Nov), tagged Striped Bass (n=49) began to travel to fixed locations we classified as overwintering sites within the SJR; additionally, four Striped Bass migrated to known overwintering sites in Nova Scotia/Minas Basin. Within the SJR, Striped Bass were observed in Grand Lake (20%), Washademoak Lake (18%), Belleisle Bay (38%), Kennebecasis River (18%) across all years with individuals observed to return to the same winter location in each year of tracking regardless of population of origin

In fall 26-38% of tagged Striped Bass congregated at the MGS to feed (Andrews et al. 2018, Appendix 2) prior to departing for winter habitat. This departure occurred during a 16 – 27-day period (mean = 21, SD ± 5) from Oct 15 - Nov 13 in 2014 to 2017. The temperature at the time of departure ranged from 8.4°C -17.7°C (2015-17), average = 13.6°C (SD ±2°C; $F_{\text{among years}} = 3.2$, df = 1, $p = 0.1$).

Migrations in fall from the Kennebecasis River occurred from Oct 11 – Nov 24, 2015 to 2017, at a mean 8.5°C, SD ± 3.2°C. These departing Striped Bass (n=4 in 2015, n=5 in 2016 and n=3 in 2017) all travelled to overwinter in Darling's Lake (upstream end of Kennebecasis Bay; Fig. 4.1) except for one individual migrating to Belleisle Bay in 2015. Departure timing from other areas of the SJR, i.e., Grand Lake and Oak Point

(Fig. 4.1) ranged from Oct 31 – Nov 13, but there was insufficient data to describe the migrations and temperatures of departure for these Striped Bass.

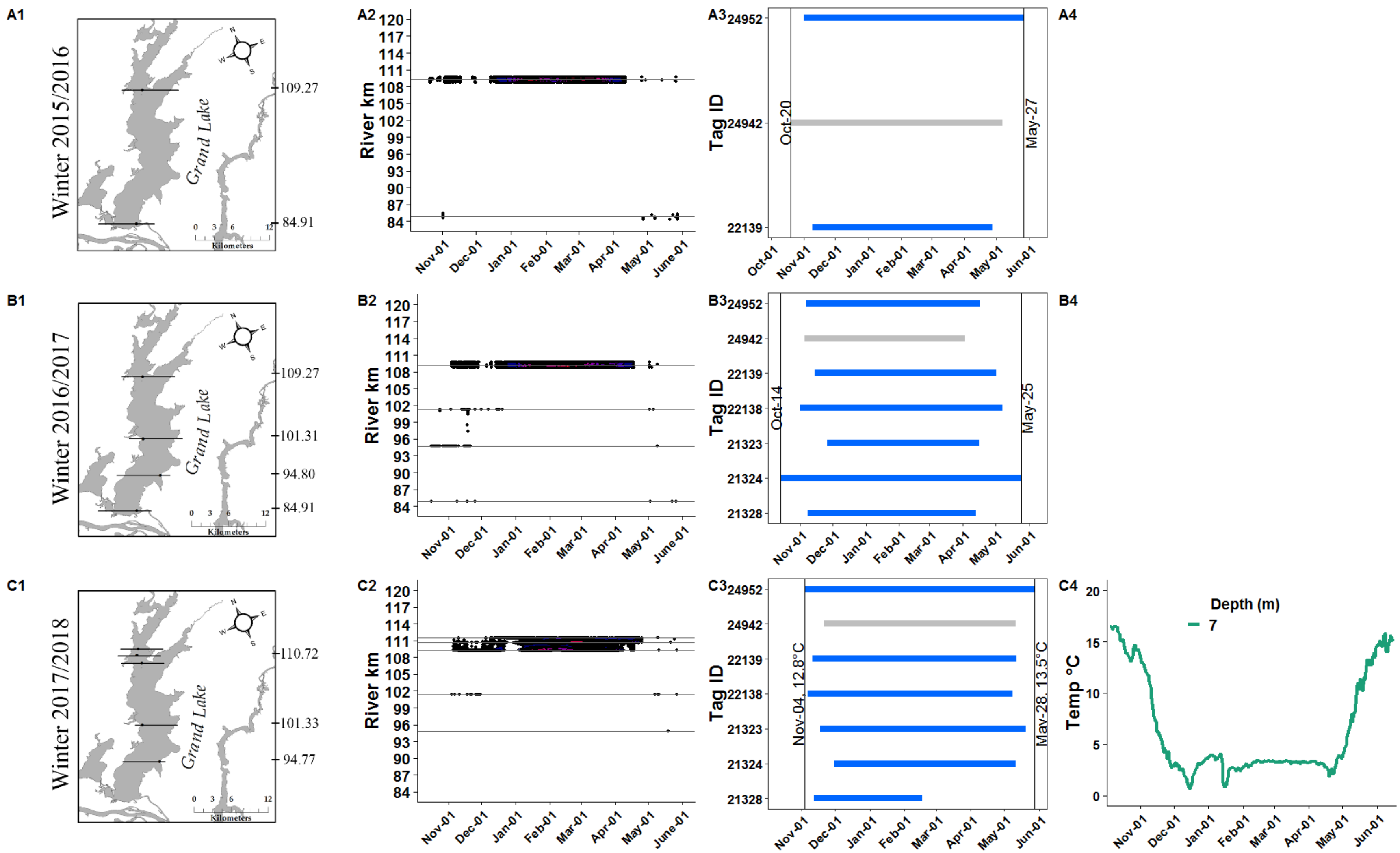
4.5.3 Winter Aggregations

Across four years of study (2014/15-2017/18), 123 winter observations were documented from the 53 tagged individuals for which movement data was available (Table 4.1). Of these winter observations, 115 (93%) were documented within the SJR: n=23 in 2014, n=25 in 2015, n=28 in 2016, and n=39 in 2017 in four winter habitats: Belleisle Bay (n=47, 38%), Washademoak Lake (n=22, 18%), Grand Lake (n= 24, 20%), Darling's Lake (n=22, 18%; Fig. 4.1).

Due to multiyear residency in winter habitats by Striped Bass, proximal tagging to winter locations may bias these assigned proportions. Thus, winter distribution based solely on individuals captured and tagged downstream of the MGS (Mactaquac or Mactaquac Hatchery Table 4.1) were also calculated to remove possible regional tagging bias. Using this method, 60% of Striped Bass occupied Belleisle Bay, 16% travelled to Washademoak Lake, 12% of Striped Bass spent the winter in Grand Lake, and 9% in Darling's Lake (Fig. 4.1). Only 3% of Striped Bass exited the SJR under this calculation method. In addition, considering only SJR origin Striped Bass tagged at MGS, the proportions of native Striped Bass occupying each winter location was 68%. 24%, 8%, and 0% in Belleisle Bay, Washademoak Lake, Grand Lake, and Darling's Lake respectively.

4.5.3.1 Grand Lake

Striped Bass overwintering in Grand Lake (Table 4.1) occupied a region of uniform depth ~8.5 m with 2 depressions of ~10 m depth near the northern end of the lake and upstream of the lake's single island (Goat Island). Striped Bass (n=3,1,4,3 tagged in 2014, 2015, 2016 and 2017, respectively) arrived in Grand Lake when temperature at the lake bottom (depth=8 m) was 7.0°C ± 3.3 (fall 2017). Striped Bass with depth/temperature sensing tags (n= 3 in 2017) were detected at a depth of 8.6 ± 1.37 m from January to May (Fig. 4.4) and tag temperatures were recorded as 2.61 ± 0.98°C. Water temperatures were approximately 0°C from the ice surface to 7.5 m deep (n=3 readings), DO was >80% at the Lake bottom (~10m) (YSI sonde profile; February 28, 2017). Passive receiver arrays also suggest that Striped Bass may also move to habitat further towards the upstream end of Grand Lake periodically during winter. All Striped Bass detected in Grand Lake over winter were of native SJR River origin (71%), admixed between SJR and US populations (12%), or of unknown population origin (17%; Figure 4.3).



A1
Winter 2015/2016
Grand Lake
109.27
84.91
Kilometers
A2
River km
A3
Tag ID
Oct-20
May-27
A4
B1
Winter 2016/2017
Grand Lake
109.27
101.31
94.80
84.91
B2
River km
B3
Tag ID
Oct-14
May-25
B4
C1
Winter 2017/2018
Grand Lake
110.72
101.33
94.77
C2
River km
C3
Tag ID
Nov-04, 12.8°C
May-28, 13.5°C
C4
Depth (m)
7
Temp °C

Figure 4.4. Striped Bass winter activity in Grand Lake, Saint John River, New Brunswick: Panels (A) 2015-16; (B) 2016-17; and (C) 2017-18. Panels 1(A-C) show the receiver locations at points with a line to match panels 2 (A-C) and river kilometers. Panels 2 (A-C) are density isopleths of mean hourly river kms (n=6332 (A), 16816 (B), and 14044 (C) points) for detected individuals, the outermost contour is the 90% isopleth. Horizontal lines correspond to receivers in panels 1 (A-C). Panels 3 (A-C) are the winter residency times for individual detected Striped Bass including date and water temperature of first and last detection, blue lines indicate Striped Bass of Saint John River origin or SJR/US admixed individuals, grey line indicates Striped Bass of unknown origin. Panel 4 (C) is water temperature of Grand Lake over winter recorded continuously at a receiver in the wintering ground at 7m depth. Note: This figure contains data from Striped Bass tagged from 2013-2016 only.

4.5.3.2 Washademoak Lake

Striped Bass overwintering in Washademoak Lake (Oct 14 – Nov 8 in fall to May 4-9 in spring; Fig. 4.5) were detected in the main lake basin from ~Oct 14 - Jan 2, 2016-2017 (mean=41 days) and more sporadically in 2017/2018 between Nov 4 – April 10 (mean =73 days). Tagged individuals then occupied an area (~4 m deep) in Washademoak Lake's largest sheltered bay, Big Cove. This area was occupied from ~Dec 20 – May 3 in 2016-2017 (mean=126 days) and Dec 15 – May 9 in 2017-2018 (mean =95 days).

In winter, water temperatures in Big Cove in Washademoak Lake dropped as low as 1°C (Dec -March) at which time Striped Bass appear to occupy depths 3.5-4 m. The occupants of Washademoak Lake are predominately of SJR river origin (82%, Fig. 4.2) and all individuals returned to Washademoak in each study year. Two individuals (Tag ID, 24949 and 32652) previously detected in Belleisle Bay during winter switched to the Washademoak Lake during one year of tracking (Table 4.1). Detected non-native Striped Bass were of Shubenacadie River origin (9%) or unknown origin (9%; Fig. 4.3,4.5)

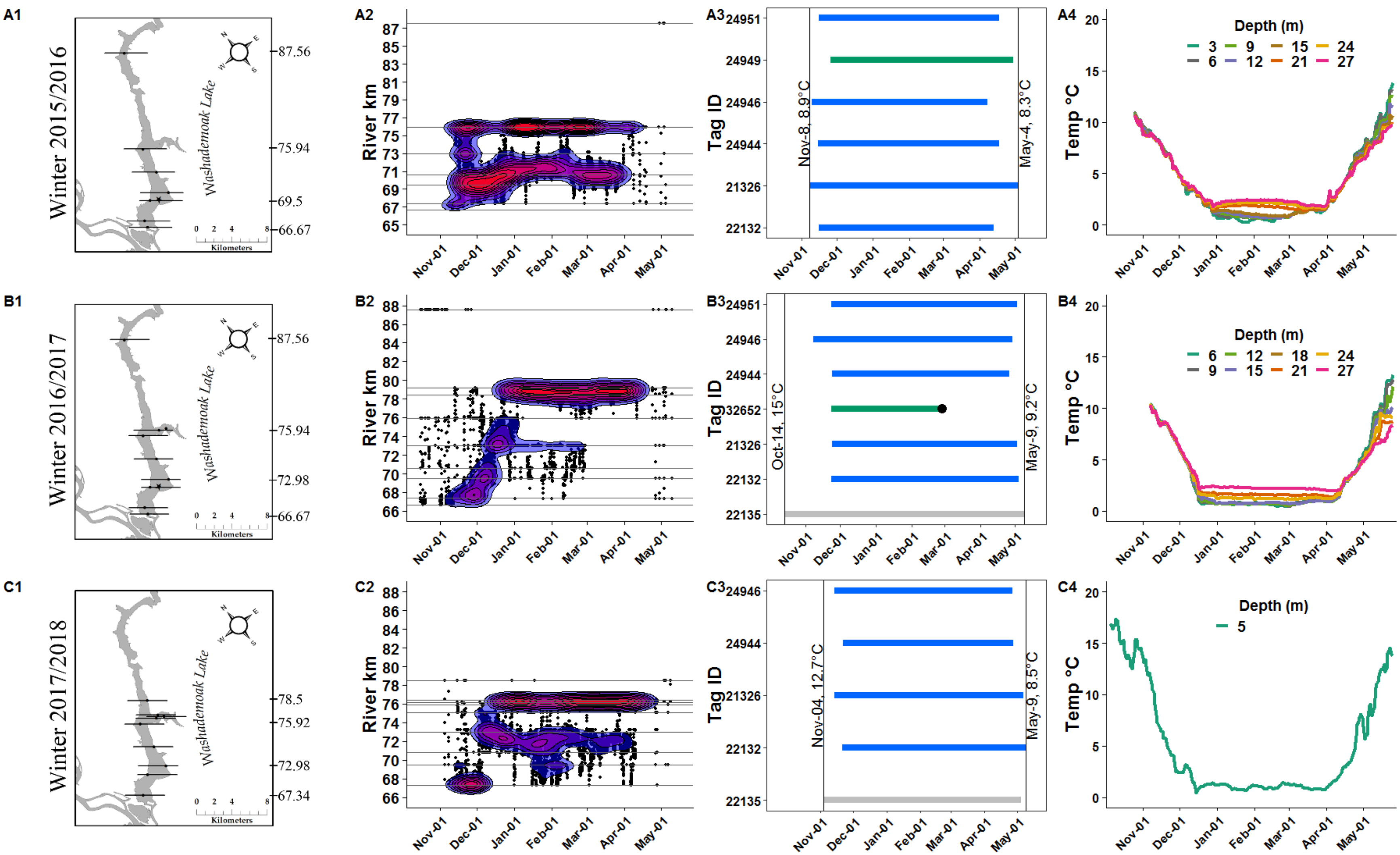

A1
Winter 2015/2016
Washademoak Lake
87.56
75.94
69.5
66.67
Kilometers
A2
River km
A3
Tag ID
24951
24949
24946
24944
21326
22132
Nov-8, 8.9°C
May-4, 8.3°C
A4
Temp °C
Depth (m)
3 9 15 24
6 12 21 27
B1
Winter 2016/2017
Washademoak Lake
87.56
75.94
72.98
66.67
Kilometers
B2
River km
B3
Tag ID
24951
24946
24944
32652
21326
22132
22135
Oct-14, 15°C
May-9, 9.2°C
B4
Temp °C
Depth (m)
6 12 18 24
9 15 21 27
C1
Winter 2017/2018
Washademoak Lake
78.5
75.92
72.98
67.34
Kilometers
C2
River km
C3
Tag ID
24946
24944
21326
22132
22135
Nov-04, 12.7°C
May-9, 8.5°C
C4
Temp °C
Depth (m)
5
Nov-01 Dec-01 Jan-01 Feb-01 Mar-01 Apr-01 May-01

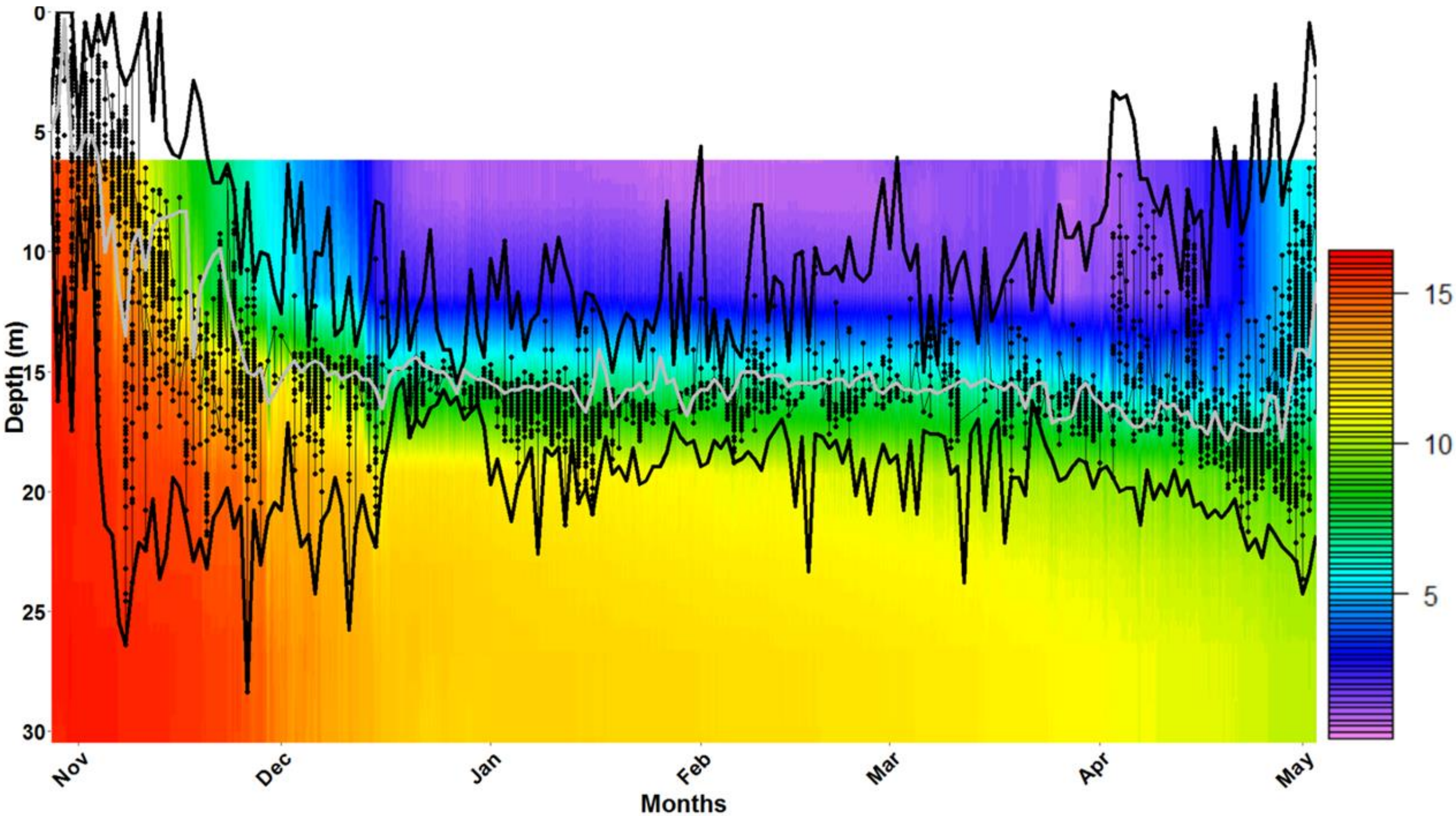
Figure 4.5: Striped Bass winter activity in Washademoak Lake, Saint John River, New Brunswick: Panels (A) 2015-16; (B) 2016-17; and (C) 2017-18. Panels 1(A-C) show the receiver locations at points with a line to match panels 2 (A-C) and river kilometers. Panels 2 (A-C) are density isopleths of mean hourly river kms (n=7403 (A), 22537 (B), and 16907 (C) points) for detected individuals, the outermost contour is the 90% isopleth. Horizontal lines correspond to receivers in panels 1 (A-C). Panels 3 (A-C) are the winter residency times of detected Striped Bass including date and water temperature of first and last detection, blue lines indicate Striped Bass of Saint John River origin, green are Shubenacadie River origin and the greys lines represents Striped Bass of unknown origin. Panel 4 (C) is water temperature of Washademoak Lake over winter recorded continuously on a temperature line (star point, panel 1A, 1B) and receiver stationed at 5 m depth at river km 76 (C). Note: This figure contains data from Striped Bass tagged from 2013-2016 only.

4.5.3.3 Belleisle Bay

Belleisle Bay was the main wintering ground for Striped Bass throughout this study as the location sheltered 60% of tagged Striped Bass during winter (Fig. 4.1). Striped Bass entered Belleisle Bay in late fall (Oct 16 – Nov 5; 2016-2018) after which they aggregated near the geographic centre of the bay. Some movement along the bay during winter was also observed.

Striped Bass in Belleisle Bay occupied warm waters resulting from tidally driven ectogenic meromixis (occurring when salt water from outside origin enters a lake or embayment, settles to the bottom and maintains a stable thermocline between deep saline waters and surface fresh waters, Hakala 2004) in 2 out of 3 study years (2016-17 and 2017-18). In those years winter temperatures were as warm as 14.1°C on Dec 1 and 11.8°C on May 1, in 2016, and 14.2°C on Dec 1 and 10.3°C on May 1 in 2017, as recorded at depths >15 m and salinities of 2.5-4.6 ppt. Due to the warm water or perhaps reduced circulation, oxygen was < 60% saturation at depths >18 m, and as a result, Striped Bass were subject to an inverse temperature oxygen squeeze (see Countant 1985). Striped Bass thus occupied a median depth of 15 m from Dec to March. This depth had a median temperature of 8.8°C from December through February cooling to 7.8°C in March; DO% saturation was >80% at 15 m depth in the same time period (Fig 4.6).

Striped Bass that occupied Belleisle Bay over winter returned to this location in each year of the study. One individual; however, (32652; Table 4.1) was documented switching to overwinter in the Washademoak Lake where it may have been captured or died in early spring. Striped Bass remain in Belleisle Bay until (May 15; 2016-2018; Fig. 4.7) when they departed to spawning habitats. Departure from Belleisle Bay appears to coincide with a rapid increase in water level and surface water temperature during spring freshets in the SJR when surface waters of Belleisle Bay warm rapidly and ice cover melts.



Depth (m)
0
5
10
15
20
25
30
Nov
Dec
Jan
Feb
Mar
Apr
May
Months
15
10
5

Figure 4.6: Vertical movement of a single Striped Bass tagged with a pressure and temperature sensing tag (black dotted line; Tag ID: 22138) occupying Belleisle Bay Oct 28-May 3, 2017-18. Black and grey lines represent the average daily minimum, maximum and median depth of all pressure/temperature tagged Striped Bass detected in Belleisle Bay over winter (n=8, 2017-2018). Temperature (indicated by colour scale) was measured continuously at 1-hour intervals across the winter season using a temperature logger string (loggers positioned at 6,9,12,15,18,21,24,27,30.5 m depth; Lat 45.59076, Long -65.93513). The white band at the top of the chart (surface) indicates missing temperature data from 0-6m near surface ice cover.

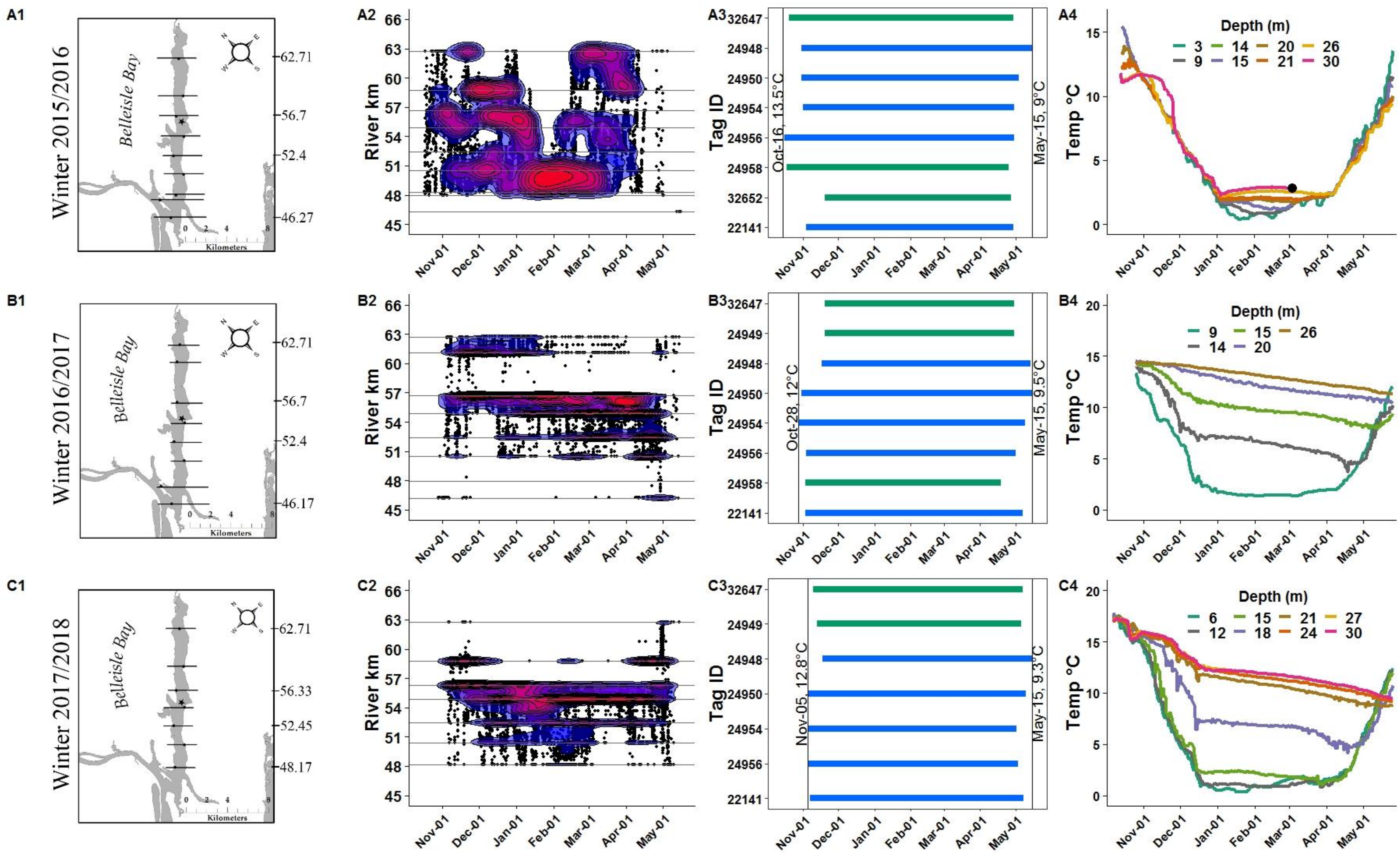

A1
Winter 2015/2016
Belleisle Bay
62.71
56.7
52.4
46.27
0 2 4 8
Kilometers
A2
River km
66 63 60 57 54 51 48 45
Nov-01 Dec-01 Jan-01 Feb-01 Mar-01 Apr-01 May-01
A3
Tag ID
32647 24948 24950 24954 24956 24958 32652 22141
Oct-16, 13.5°C
May-15, 9°C
A4
Temp °C
Depth (m)
3 14 20 26
9 15 21 30
B1
Winter 2016/2017
Belleisle Bay
62.71
56.7
52.4
46.17
Kilometers
B2
River km
B3
Tag ID
32647 24949 24948 24950 24954 24956 24958 22141
Oct-28, 12°C
May-15, 9.5°C
B4
Temp °C
Depth (m)
9 15 26
14 20
C1
Winter 2017/2018
Belleisle Bay
62.71
56.33
52.45
48.17
Kilometers
C2
River km
C3
Tag ID
32647 24949 24948 24950 24954 24956 22141
Nov-05, 12.8°C
May-15, 9.3°C
C4
Temp °C
Depth (m)
6 15 21 27
12 18 24 30

Figure 4.7: Striped Bass winter activity in Belleisle Bay, Saint John River, New Brunswick: Panels (A) 2015-16; (B) 2016-17; and (C) 2017-18. Panels 1(A-C) show the receiver locations at points with a line to match panels 2 (A-C) and river kilometers. Panels 2 (A-C) are density isopleths of mean hourly river kms (n=27480 (A), 18561 (B), and 19891(C) points) for detected individuals, the outermost contour is the 90% isopleth. Horizontal lines correspond to receivers in panels 1 (A-C). Panels 3 (A-C) are the winter residency times of detected Striped Bass including date and water temperature of first and last detection, blue lines indicate Striped Bass of Saint John River origin and green lines are Shubenacadie River origin individuals. Panel 4 (C) is water temperature of Belleisle Bay over winter recorded continuously on a temperature line at star points on panels 1(A-C). Winter 2016/2017 and 2017/2018 exhibit ectogenic meromixis with saline bottom layers remaining near 13°C despite surface ice cover. Note: This figure contains data from Striped Bass tagged from 2013-2016 only.

4.5.3.4 Darling’s Lake

No Striped Bass that occupied Darling’s Lake from 2014-2018 were of confirmed SJR origin; however, one SJR/US admixed individual observed in three years (2015-2017) and accounting for 14% of winter observations was confirmed. Most Striped Bass occupying this habitat throughout the study were from the USA (19%) or Shubenacadie River (24%; Fig 4.3) while the remainder (43%) were of unknown origin and made no clear spawning migration in spring, though did not depart from the river at this time.

Striped Bass occupying Darling’s Lake are the only group to which two entry points were available and the use of these entries in both fall and spring was predictable. Upon entering the overwintering location in the fall (Nov 5 – Nov 28), Striped Bass (100% in 2015, 83% in 2016 and 83% in 2017) were tracked first arriving via the downstream entrance of the lake where it meets the Hammond River. However, when departing in the spring (April 11 – May 3) across all years, Striped Bass (75% in 2016, 67% in 2017 and 67% in 2018) were recorded exiting through the northern entrance to the lake (Fig. 4.8). Furthermore, each tracked individual entered and exited the lake in same pattern each year (differences in percentages are due to newly tagged fish and winter mortalities).

Darling’s Lake provided the smallest area of Striped Bass winter refuge on the SJR (0.6 km^2 >3.5 m deep). Water temperatures from 0-2 m depth were 0.08 - 0.43°C in 2015 but increased to 2.34 – 2.86°C from 3 – 4.76 m in depth; temperatures as low as

0.1°C were recorded throughout the water column on Dec 14, 2017. Oxygen saturation was 69 - 45% measured from 3 – 4.76 m depth, though remained between 86 - 77% at depths <3.

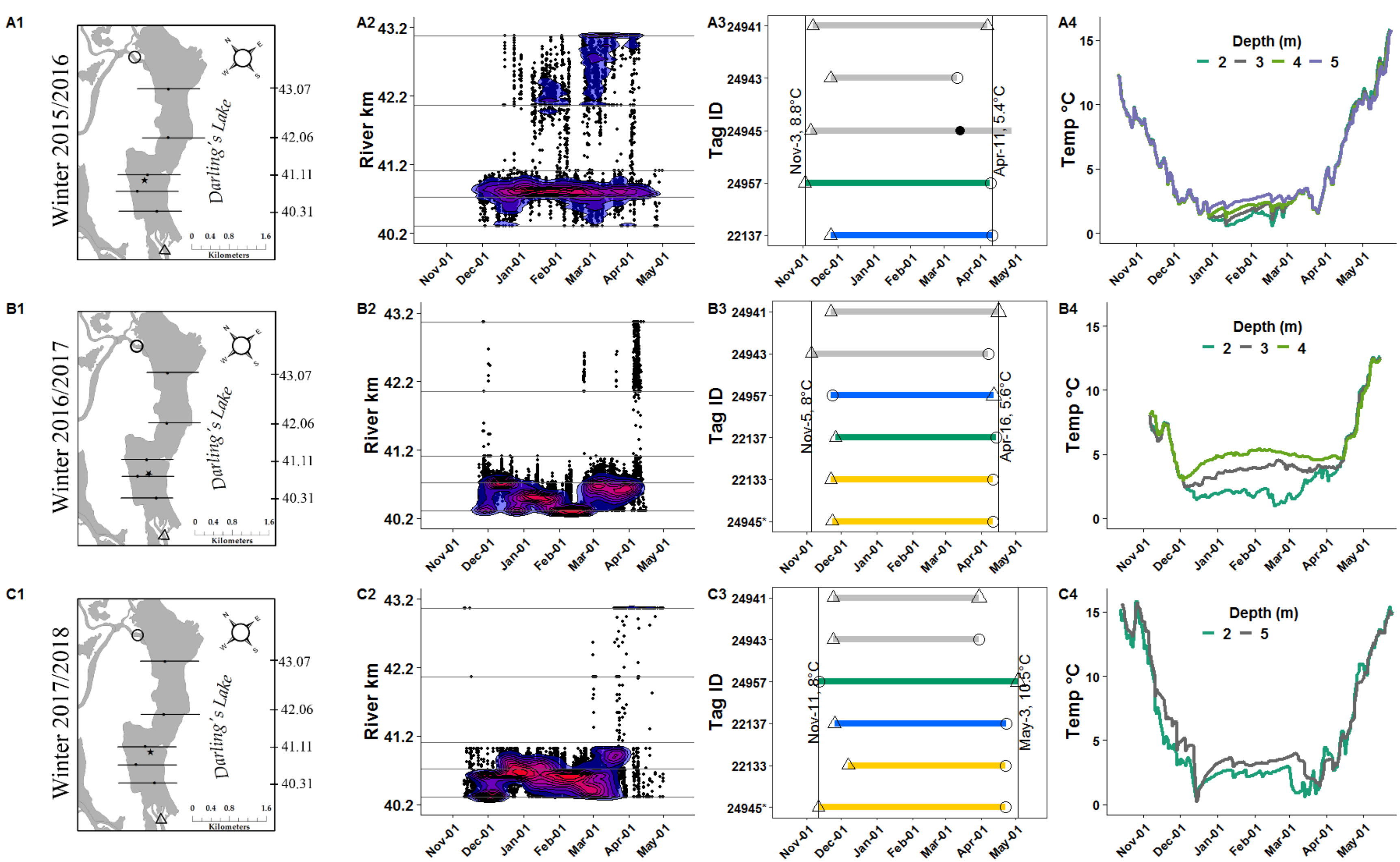

A1
Winter 2015/2016
Darling's Lake
43.07
42.06
41.11
40.31
0 0.4 0.8 1.6
Kilometers
A2
River km
43.2
42.2
41.2
40.2
A3
Tag ID
24941
24943
24945
24957
22137
Nov-3, 8.8°C
Apr-11, 5.4°C
A4
Temp °C
Depth (m)
2 3 4 5
B1
Winter 2016/2017
B2
B3
24941
24943
24957
22137
22133
24945*
Nov-5, 8°C
Apr-16, 5.6°C
B4
Depth (m)
2 3 4
C1
Winter 2017/2018
C2
C3
Nov-11, 8°C
May-3, 10.5°C
C4
Depth (m)
2 5
Nov-01
Dec-01
Jan-01
Feb-01
Mar-01
Apr-01
May-01

Figure 4.8: Striped Bass winter activity in Darling's Lake, Saint John River, New Brunswick: Panels (A) 2015-16; (B) 2016-17; and (C) 2017-18. Panels 1(A-C) show the receiver locations at points with a line to match panels 2 (A-C) and river kilometers. Panels 2 (A-C) are density isopleths of mean hourly river kms (n=12557 (A), 19820 (B), and 18272 (C) points) for detected individuals, the outermost contour is the 90% isopleth. Horizontal lines correspond to receivers in panels 1 (A-C). Panels 3 (A-C) are the winter residency times of detected Striped Bass including date and water temperature of first and last detection, blue lines indicate SJR/US admixed Striped Bass, green lines indicate Striped Bass of Shubenacadie River origin, yellow are US origin and grey lines are Striped Bass of unknown origin. Circle and Triangle points on panel 3 (A-C) indicate entry and exit route to and from Darling's Lake. Panel 4 (C) is water temperature of Darling's Lake over winter recorded continuously on a temperature line (temperature line located at Star point on panel 1 A-C). Note: This figure contains data from Striped Bass tagged from 2013-2016 only. Striped Bass tag ID 24945 in panel A3 died in winter (black point), this same tag was re-implanted in Striped Bass 24945* that was detected in 2016-17, 2017-18.

4.5.4 Overwintering outside of the Saint John River

Only four Striped Bass (8% of the total detected) departed from the Saint John River in the fall and all were determined to be of Shubenacadie River origin (Fig. 4.2). Three of these individuals travelled to and resided in Minas passage in winter of 2017 (Nov 20 – Mar 31; see Keyser et al 2016). Two carried pressure temperature tags which showed they occupied depths from 3.94 m to >34 m (tags could read a depth range of 0-34 m and Striped Bass may have occupied deeper sections of the water column) and temperatures ranging from 11.16°C in November to 1.58°C in late March. Two tagged fish (Tag ID 32652, and 24960 in 2014-2016) were detected passing through the Minas Passage in late fall; their true wintering location (likely somewhere in Minas Basin/Nova Scotia) could not be determined. Those same individuals arrived back in the SJR in early summer (July 4 – August 11; 2015-2018) after the typical Striped Bass spawning period in the Shubenacadie River (May 16- June 9, Rulifson and Dadswell 1995; Paramore and Rulifson 2001, Duston et al 2018).

4.5.5 Departure from Winter Habitat

Striped Bass appear to depart winter habitats within the SJR when waters begin to warm in the spring and turnover events occur. In Grand Lake departure times varied from April 3 – May 28 (water temperature 3.5 – 13.5°C measured at ~6 m depth measured in 2018) with a mean departure date of May 5 (6.2°C). In Washademoak Lake, Striped Bass departed from April 8 – May 9 (2016-2018) with a mean departure date of April 21. Water temperature at these times ranged 4.5 - 9.2°C from the surface to waters 9 m deep. In Belleisle Bay all Striped Bass departed by May 15th in each year of tracking when water temperatures were recorded as 8.0-9.7°C throughout the water column. Belleisle Bay was the most upstream location with a moderate proportion of Shubenacadie River origin Striped Bass and those individuals were observed to depart prior to May 1 in 2016 (mean =6°C) and 2017 (mean=4.3°C), departing significantly earlier than SJR origin Striped Bass in the latter (p=0.045). Shubenacadie origin Striped Bass had all departed by May 7 in 2018 at an average temperature of 7.0°C. Darling's Lake was predominately occupied by Striped Bass originating from migrant non-SJR populations (i.e., Shubenacadie and US) and those individuals were observed to depart from April 11 -May 3 when water column temperatures exceeded 5°C.

4.6 Discussion

During winter in the SJR Striped Bass appear to occupy warm (2-7°C) oxygenated (> 60% DO) and sheltered (either within coves, or below stratified water layers) habitats to which they returned each year. This pattern of winter habitat fidelity within the SJR is also true for Shubenacadie River origin Striped Bass that were detected in the SJR in the same wintering locations during each year of the study. A small number of Shubenacadie origin Striped Bass (n=4 individuals) tagged within the SJR departed in the fall and were subsequently detected remaining in or passing through the Minas Passage. Amongst the four Striped Bass winter habitats identified within the SJR a decreasing gradient of SJR origin Striped Bass moving away from the historic spawning location in Fredericton was observed amongst individuals with identified origins (100% in Grand Lake, 90% in Washademoak, 64% in Belleisle Bay, and 25% in Darling's Lake; SJR/US admixed Striped Bass were considered native for this calculation). The reverse gradient was observed for Shubenacadie and US origin Striped Bass when moving inland from Reversing Falls (42% in Darling's Lake, 33% in Belleisle Bay, 10% in Washademoak Lake, and 0% in Grand Lake). US origin Striped

Bass were predominately observed in Darling's Lake (33% of overwintering Striped Bass across years) and of these individuals, none were observed to depart from the Saint John River at any time during the study.

Adult Shubenacadie origin Striped Bass have been detected in SJR winter habitats (Bradford et al. 2001), however, their fidelity to those winter habitats was neither suspected nor previously documented. Striped Bass <age 3 do not commonly depart home rivers (Greene et al. 2009) and therefore they should become accustomed to overwintering near, or within their river of origin. Young of the year of Shubenacadie River origin, however, have been documented in the Petitcodiac River (>200 km from Shubenacadie River; Dustin et al 2018) and could find their way to the SJR. Alternatively, the increasing size of the Shubenacadie River population (COSEWIC 2012), and evidence of changing winter habitat selection in that population (Gemperline et al. 2002) suggests that adults occasionally emigrate from the Shubenacadie River to seek new winter habitats. Dispersal mechanisms do exist (i.e., migratory groups, increasing population and individual size; Waldman et al. 1990) explaining the occurrence of Shubenacadie Striped Bass in the SJR overwinter, but these do not explain the reoccurring presence of these individuals in SJR winter habitats. The same question remains regarding US origin Striped Bass that display similar behaviour but further, do not leave the river in spring even during the spawning period.

Shubenacadie River Striped Bass must migrate >300 km from the SJR to reach spawning locations in spring. Some individuals, however, were observed to travel this distance in as little as three days suggesting that early departure may not be required to reach spawning ground in time for reproduction. Early departure, however, is occasionally observed.

Of the winter habitats occupied in the SJR, Belleisle Bay was by far the most frequently occupied location, sheltering ~60% of Striped Bass amongst study years (Fig. 4.1). This high rate of occupancy occurred despite no Striped Bass being tagged within the Belleisle Bay and that it lies the farthest from all possible spawning locations (Fredericton, Salmon River, Hampton Marsh; Andrews et al. (2019b, Chapter 2), precluding it from substantial juvenile inputs (Belleisle Creek as observed by Dadswell [1975] is unlikely to still support spawning due to sedimentation). The reason for this high rate of occupancy is likely due to the strong thermal stratification observed in the Bay in most years, which could have numerous effects including increasing juvenile winter survival or attracting more adult Striped Bass from within the SJR.

We hypothesize that this strong thermal stratification occurs in fall when large "spring tides" force still warm saline water from the lower estuary of the Saint John River over a shallow (1-3 m deep) delta at the mouth of Belleisle Bay and into the bay's deeper basin, a process known as ectogenic meromixis. This deep saline layer remains warm despite the cold superficial freshwater surface layer (0-1.8°C, 1-13 m deep, 0 ppt) that is seasonally ice bound.

During winter, Striped Bass may also be affected by increased mortality observed as 17% in 2015, 3% in 2016, and 4% in 2017 (the high level of mortality in 2015 possibly being due to Belleisle Bay not stratifying in that year). Four summer mortality events (non tagging related) were observed from 2014-2018 and were each suspected to be angling related occurring at times and places known for high angling pressure. Thermal stresses, physical disturbance, hypoxia and starvation have all been linked to winter mortality in fishes (Hurst 2007) and Striped Bass in their northern range face all these conditions in winter (Andrews et al. 2019a, Chapter 3). Striped Bass may also be affected by rain driven displacement events during winter (see Chaisson et al. 2002) where some individuals appear to move downstream following large rainfall and consequent discharge increases. However, it remains unclear if the downstream movement results from physical displacement from increased river discharge, or if rain events rapidly change river salinities or pH causing Striped Bass to temporarily flee.

Dispersal in spring likely occurs after cold surface waters dissipate or once surface and mid layer water temperatures become uniform.

4.7 Conclusion

Apart from the SJR, few described locations allow for the close comparison of multiple distinct Striped Bass winter habitats and aggregations within one river. This study has demonstrated that Striped Bass seek out the same overwintering locations annually in the SJR, a behaviour that appears to begin as early as age 2 (Andrews et al., 2019, Chapter 3). Interestingly, this behaviour also holds true for visiting migrants (from both the Shubenacadie River and US populations) that were observed returning to the river across all years of monitoring to occupy the same winter habitat leading to question regarding how this behaviour is established. The results of this study have also demonstrated that the four Striped Bass winter habitats identified in the Saint John River are not equally occupied. A warm water overwintering site located in Belleisle Bay appeared to harbour the largest number of Striped Bass, a finding which aligns with numerous historical observations (Andrews et al., 2017, Chapter 1)

Based on these observations, it appears that commercial fishing near or on overwintering habitats (such as the historic winter Striped Bass fishery conducted on Belleisle Bay until 1978; Andrews et al 2017, Chapter 1) may have had the effect of depleting unique winter contingents from both the SJR and Shubenacadie River instead of the entire SJR population. This winter habitat fidelity may have saved the SJR Striped Bass population from total collapse likely resulting in the depletion of ~60% of the river's population (both SJR and Shubenacadie River origin Striped Bass) and not the population in its entirety. However, Striped Bass taken as bycatch in other SJR fisheries and recreational harvest at the time (Andrews et al. 2017, Chapter 1) were likely to have additional adverse effect.

Winter is the most stressful time for Striped Bass due to their habit of dense aggregation, reduced feeding and cold temperatures and as a result appears to be the time of greatest natural mortality observed in this study. The winter period has also been described as the key determinate of year class survival in the first year of life (Bernier 1996; Hurst and Conover 2003; MacInnis 2012). Disruptions to and overfishing within overwintering habitats have historically caused Striped Bass extirpation (Robitaille and Ouellette 1991, Andrews et al. 2019a, Chapter 1,3). Activities such as recreational angling likely pose little threat in Canadian waters due to limited feeding by Striped Bass in many locations at this time, however, larger scale disruptive activities (i.e., pollution, dredging, commercial fishing; Andrews et al. 2018b, Chapter 3) could pose significant threat to individual winter aggregations and perhaps population survival. By identifying Striped Bass winter habitats, periods of occupancy and the favorable conditions therein we can mitigate future anthropogenic impacts to these important, purposefully selected and interannually occupied habitats.

4.8 Acknowledgements

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Chapter 5:

General Discussion and Conclusion

When this research project commenced in 2014, the Striped Bass of the Saint John River, New Brunswick was truly a misunderstood species. The mere existence of a surviving, native population was under debate due to (a) numerous conflicting reports, (b) abundant theories explaining the Striped Bass disappearance, and (c) long out of date supporting information. Thus, this study began with a detailed literature review (see Andrews et al 2017; Chapter 1), with the intent of compiling everything known about the Saint John River Striped Bass in one location and forming a foundation for all future steps of the presented study. From this review, it was concluded that although the Striped Bass population may be dwindling due to infrequent spawning success, the reported disappearance may have had more to do with a lack of effective surveys rather than a true extirpation of the native population.

To explore this hypothesis, three key goals were established: (1) to determine the ancestry and origin of Striped Bass inhabiting the Saint John River, (2) to monitor the habitat residency and migrations of Striped Bass tagged within the Saint John River, and (3) to determine why Striped Bass spawning within the river appeared to have ceased since the completion of the Mactaquac Dam in 1968. I explored the river extensively, tagged numerous adult Striped Bass, monitored an expansive receiver array, monitored spring and winter movements and managed to locate the first Striped Bass juveniles. The first significant finding of this study was reported by Leblanc et. al. (2018) who demonstrated through genetic methods the unique ancestry of Saint John River origin juvenile Striped Bass. Based on these findings, it became apparent that the native Striped Bass remained and continued to reproduce within the river; however, their reproductive success remained unknown.

I continued to collect and age juvenile Striped Bass throughout the river during the study with help from the commercial fishing outfit of Scott and Keith Young in Grand Lake. These collections allowed me to identify years of successful spawning and quantify that success that quickly revealed the occurrence of infrequent year classes of native origin juveniles. Simultaneously, tagged adult Striped Bass confirmed to match juvenile ancestry (Chapter 2) were monitored making regular upstream migrations to a historic spawning location in spring. The tracked migration occurred on similar dates, drew individuals from throughout the river each year, and could not be mistaken for anything other than a spawning migration.

A pattern began to emerge when comparing discharge recorded at the Mactaquac Generating Station during the telemetered spawning migration to annual juvenile recruitment. Previous studies conducted on the Roanoke River (i.e., Manooch III and Rulifson 1989) had demonstrated that Striped Bass spawned most successfully downstream of a dam under conditions of “moderate sustained flow”, and this appeared to hold true downstream from Mactaquac Dam. Saint John River origin juvenile Striped Bass were most abundant in years when regulated hydropeaking at the Mactaquac Dam was interrupted to produce sustained flows without rapid decreases in discharge. The length of periods of sustained discharge matched the juvenile abundance pertaining to those years, and years with no attenuation of hydropeaking predictably demonstrated no juvenile recruitment. I hope that future studies test this finding more robustly through the regulation of discharge at the Mactaquac Generation Station during the spring spawning period.

With numerous tagged Striped Bass of multiple population origins active within the Saint John River, the opportunity arose to more thoroughly investigate their movements and expand upon a study by Andrews et al. 2018 (Appendix 1). Winter habitat occupancy and movements quickly became of interest due to the history of Striped Bass winter fisheries within the Saint John River and due to the scarcity of winter habitat information. Winter habitat information for Striped Bass in Canada was in fact so scarce that I decided once again to compile everything I could find from historic reports to develop some picture of winter habitat distribution and characteristics. The review encompassed the entire coastline of Atlantic Canada and formed the first glimpse at what ecological characteristics may be required by Striped Bas throughout the winter months (Andrews et al. 2018; Chapter 3).

Striped Bass, both adult and juveniles, were shown to occupy four distinct winter habitats within the Saint John River to which they returned annually across four years of tracking with little exception (Chapter 4). Most incredibly, Shubenacadie Striped Bass overwintering in the SJR, returned to Shubenacadie River annually to spawn, demonstrated fidelity to winter locations within the Saint John River. As a result, we now have a better understanding of the importance and occupancy of wintering habitats in the Saint John River, but we still do not know how winter habitats in the Saint John River are initially colonised, especially by non-native Striped Bass.

The most important winter habitat in the Saint John River was by far the Belleisle Bay, the site of a widely recognized and well described historic winter commercial fishery. From this study, it appears that the uniquely stratifying winter habitat of Belleisle Bay, which remains unusually warm during winter, may be the key to attracting its large Striped Bass aggregation. Other winter habitats within the Saint John River may be selected due to their sheltered locations, often tucked away from prevailing currents and tidal flow. The more nuanced details of this habitat selection may be determined by future researchers.

Other supporting chapters on Striped Bass ecology were also written and included here through the duration of this Study. Andrews et al. (2019; Appendix 2) detailed the lesser described distribution of Striped Bass in Atlantic Canada and proposed a new Cape Breton/Northeastern Nova Scotia designatable unit for Striped Bass management in Canada. Andrews et al (2018; Appendix 3) studied the diet of Striped Bass, and Muskellunge downstream of the Mactaquac Dam to describe diets and search for possible Atlantic Salmon (*Salmo salar*) smolt predation. The findings of this study were compared to current tracking data of Striped Bass, Muskellunge and migrating Atlantic Salmon smolt and demonstrated only minimal overlap between the arrival of Striped Bass to Mactaquac Dam in spring and the departure of tagged smolt. Finally, (Appendix 4) reviewed all studies of smolt predation by Striped Bass within the two species overlapping native ranges to provide a clean slate for future work. Contributions were also made by Dugdale et al. (2018) who analysed the impacts of warming water to both Striped Bass and Atlantic Salmon under future climate scenarios.

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Appendix 1:

Seasonal movements of Striped Bass *Morone saxatilis* in a large tidal and hydropower regulated river

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Appendix 2:

Diet of Striped Bass and Muskellunge Downstream of a Large Hydroelectric Dam: A Preliminary Investigation into Suspected Atlantic Salmon Smolt Predation

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Appendix 3:

Looking for Striped Bass in Atlantic Canada: The Reconciliation of Local, Scientific, and Historical Knowledge

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Appendix 4:

Consumption of Atlantic Salmon smolt by Striped Bass: A review of the predator-prey encounter and interaction literature

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Submitted to MPDI fishes, July 19, 2019

Appendix 5:

Permission to Reprint from Co-authors

Co-authors were contacted to request their permissions to include published articles in this dissertation (letter below). All permission responses received from this request are listed in the alphabetical order by co-author's surname.

Letter for Permission to use co-authored articles in the dissertation thesis:

Dear Co-authors,

I am currently compiling my PhD thesis and must include a statement of permission from each co-author that I may included published articles that are associated with their names.

Would each of you be able to send me a short reply allowing me permission to include our co-authored works in my thesis?

Thank you

Samuel Andrews

Permission (Dr. R. A. Curry; All chapters and appendices)

Approved

Permission (Dr. T. Linnansaari; All chapters and appendices)

Sam,

You may use and publish any material I have co-authored in your dissertation thesis at the University of New Brunswick.

Sincerely,

Permission (Dr. M. J. Dadswell; Chapter 1, 3 and Appendix 2)

To whom it may concern.

I, Michael Dadswell, heartily agree to allow Sam Andrews to include any published articles for which I was co-author in his Ph. D. thesis.

Good luck Sam

Mike Dadswell

Permission (Dr. S. Pavey; Chapter 2, 4)

Permission Granted.

Scott

Permission (T. Ellis; Appendix 3)

You have my permission for sure!

Hope all is well,

Theo

Permission (B. Fleet-Pardy; Chapter 3)

Hey Sam,

You have my consent.

Cheers,

Bronwyn

Permission (C. Buhariwalla; Chapter 3, Appendix 2)

Hey Sam,

You have my permission to use co-authored work with my name on it.

Good luck!

Colin

Permission (M. Gautreau; Appendix 1)

Yes, you have permission to reproduce our co-authored paper in your thesis.

Mark

Permission (S. Hirtle; Appendix 4)

Hi Sam,

I would be very happy to give permission for our co-authored publication to be in your thesis.

Good luck!!

Sarah

Permission (N. Leblanc; Chapter 2, 4)

I give permission to use our papers as thesis chapters

Nathalie

Permission (B. Wallace; Appendix 1)

Hey Sam,

I’m agreeable to allowing you to include our co-authored work in your PhD thesis.

Cheers,

Ben

Permission (K. Zelman; Appendix 3)

Hey Sam,

By all means go ahead and include our paper in your thesis.

Kaleb

Appendix 6:

Permission to Reprint from Journals

North American Journal of Fisheries Management

Andrews. S. N., T. Linnansaari, R. A. Curry & M. J. Dadswell. 2017. The Misunderstood Striped Bass of the Saint John River, New Brunswick: Past, Present, and Future, North American Journal of Fisheries Management 37:1, 235 – 254

Permission not required for reproduction in academic theses

River Research and Applications

Andrews. S. N., T. Linnansaari, N. Leblanc, S. G, Pavey, and R. A. Curry. Interannual variation in spawning success of striped bass (*Morone saxatilis*) in the Saint John River, New Brunswick, River Research and Applications. 36:13-24.

Permission not required for reproduction in academic theses

Environmental Biology of Fishes

Andrews. S. N., C.F. Buhariwalla, B. Fleet-Pardy, M. J. Dadswell, T. Linnansaari, and R. A. Curry. 2019. Left out in the cold: the understudied overwintering ecology of striped bass in Canada. Environmental Biology of Fishes. 102:499-518

Permission not required for reproduction in academic thesis

Appendix 7:

Curriculum Vitae

Samuel Nelson Andrews

Dalhousie University 2008-2012 (BSc Marine Biology)

Acadia University 2012-2014 (MSc Biology)

Publications:

S. N. Andrews., T. Linnansaari, R. A. Curry & M. J. Dadswell (2017) The Misunderstood Striped Bass of the Saint John River, New Brunswick: Past, Present, and Future, North American Journal of Fisheries Management. 37:1, 235-254, DOI:10.1080/02755947.2016.1238424

G. S. Nau., A. D. Spares, S. N. Andrews, M. L. Mallory, N. R. McLellan, & M. J. W. Stokesbury (2017) Body size, experience, and sex do matter: Multiyear study shows improved passage rates for alewife (*Alosa pseudoharengus*) through small-scale Denil and pool-and-weir fishways. River research and applications. 33: 1472-1483. DOI: 10.1002/rra3215

S. N. Andrews., B. Wallace, M. Gautreau, T. Linnansaari & R. A. Curry (2018) Seasonal Movements of Striped Bass (*Morone saxatilis*) in a Large Tidal and Hydropower Regulated River. Environmental Biology of Fishes. 101:1549-1558. DOI:10.1007/s10641-018-0799-y

S. N. Andrews., K. Zelman, T. Ellis, T. Linnansaari & R. A. Curry (2018) Diet of Striped Bass (*Morone saxatilis*) and Muskellunge (*Esox masquinongy*) downstream of a large hydro-electric dam: A preliminary investigation into suspected Atlantic Salmon (*Salmo salar*) smolt predation. North American Journal of Fisheries management. 38:734-746, DOI: 10.1002/nafm.10074

S. J. Dugdale., R. A. Curry, A. St-Hilaire & S. N. Andrews (2018) Impact of future climate change on water temperature in the lower Saint John River, Canada. Water resource management. 32(15):4853-4878. DOI: 10.1007/s11269-018-2057-7

N. M. Leblanc., S. N. Andrews, T. S. Avery, G. N. Puncher, B. I. Gahagan, A. R. Whiteley, R. A. Curry & S. A. Pavey (2018) Evidence of a Genetically Distinct Population of Striped Bass within the Saint John River, New Brunswick, Canada. North American Journal of Fisheries Management. 38:1339-1349. DOI: 10.1002/nafm.10242

S. N. Andrews., M. Dadswell, C. Buhariwalla, T. Linnansaari, &R. A. Curry. (2019) Looking for Striped Bass in Atlantic Canada: The Reconciliation of Local, Scientific, and Historical Knowledge. Northeastern Naturalist. 26(1):1-30.

S. N. Andrews., C. F. Buhariwalla, B. Fleet-Pardy, M. J. Dadswell, T. Linnansaari & R. A. Curry (2019) Left out in the Cold: The Understudies Overwintering Ecology of Striped Bass in Canada. Environmental Biology of Fishes. Environmental Biology of Fishes. 102:499-518. DOI: 10.1007/s10641-019-0847-2

S. N. Andrews., S. V. Hirtle, T. Linnansaari & R. A. Curry (2019) Feeding behaviour and prey preferences of Striped Bass (Morone saxatilis) with special attention to predation impacts on Atlantic Salmon (*Salmo salar*) smolt. MDPI Fishes. 1-21. DOI:10.3390/fishes4040050.

S. N. Andrews., T. Linnansaari, N. Leblanc, S. Pavey & R. A. Curry (2019) Interannual Variation in Spawning Success of Striped Bass (*Morone saxatilis*) in the Saint John River, New Brunswick, Canada. River Research and Application. 36:13-24. DOI:10.1002/rra.3545.

S. N. Andrews., D. Arluison, C. Ceapa & J. Leblanc (2019) Atlantic Sturgeon (*Oxyrinchus oxyrinchus*) and Shortnose Sturgeon (*Acipenser Brevirostrum*) identification card. Identification card commissioned by the department of fisheries (DFO) to improve catch reporting by commercial fishermen in the Saint John River, New Brunswick.

S. N. Andrews., A. M. O'Sullivan, J. Helminen, D. F. Arluison, K. M. Samways, T. Linnansaari & R. A. Curry (2020) Development of Active Numerating Side-scan for a High-density Overwintering Location for Endemic Shortnose Sturgeon (*Acipenser brevirostrum*) in the Saint John River, New Brunswick. 1-18. DOI:10.3390/d121010023.

S. N. Andrews., T. Linnansaari, N. Leblanc, S. Pavey & R. A. Curry (2020) Winter Ecology of Striped Bass (*Morone saxatilis*) Near their Northern Limit of Distribution in the Saint John River, New Brunswick. (in review)

S. N. Andrews., T. Linnansaari, N. Leblanc, S. Pavey & R. A. Curry (2020) Movements of native Juvenile Striped Bass (Morone saxatilis) in the Saint John River, New Brunswick, Canada. (in review)

Conference Presentations:

March 2015: Restoration potential for reproduction by Striped Bass (*Morone saxatilis*) in the Saint John River, New Brunswick. Presentation to the Fredericton Angler's Association. Fredericton, New Brunswick

March 2015: Restoration potential for reproduction by Striped Bass (*Morone saxatilis*) in the Saint John River, New Brunswick. Mactaquac Aquatic Ecosystem Study (MAES) presentation to the New Brunswick Power Corporation (NBP) board of directors. Fredericton, New Brunswick

March 2016: Restoration potential for reproduction by Striped Bass (*Morone saxatilis*) in the Saint John River, New Brunswick. Mactaquac Aquatic Ecosystem Study (MAES) presentation to the New Brunswick Power Corporation (NBP) board of directors. Fredericton, New Brunswick

April 2016: Restoration potential for reproduction by Striped Bass (*Morone saxatilis*) in the Saint John River, New Brunswick. Presentation to the New Brunswick Wildlife Federation. Moncton New Brunswick

Nov 2015: Restoration potential for reproduction by Striped Bass (*Morone saxatilis*) in the Saint John River, New Brunswick. Presentation to the Fredericton Musky Club. Fredericton New Brunswick. Fredericton, New Brunswick

Nov 2018: Restoration potential for reproduction by Striped Bass (*Morone saxatilis*) in the Saint John River, New Brunswick. Fredericton Musky Club. Presentation to the Fredericton Musky Club. Fredericton New Brunswick. Fredericton, New Brunswick

June 2019: Left out in the cold: The Understudied Overwintering Ecology of Striped Bass in Canada. Presentation at the 5th Annual international fish telemetry conference. Arendal, Norway.

Dec 2019: Restoration potential for reproduction by Striped Bass (*Morone saxatilis*) in the Saint John River, New Brunswick. Biology seminar at Acadia University, Wolfville, Nova Scotia.