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Overview of 2013 Bay of Fundy Striped Bass Biology and General Status

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

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ABSTRACT

Anadromous Striped Bass spawning populations occur in three of the rivers flowing to the Bay of Fundy (BoF): the Shubenacadie and Annapolis rivers, Nova Scotia, and the Saint John River, New Brunswick. The populations collectively define the BoF Striped Bass Designatable Unit (DU). The DU has been assessed as 'at risk' by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) on two occasions, the first in 2004 as Threatened and the second in 2012 as Endangered. Declining demographic status resulting from loss of spawning populations and unmitigated threats to extant spawning populations were the most significant factors contributing to the 'at risk' designations. The BoF Striped Bass DU is presently under consideration for listing as Endangered on Schedule 1 of Canada's *Species at Risk Act* (*SARA*). A Recovery Potential Assessment completed in 2006 in response to the Threatened designation is, therefore, in need of an update. The aim of this document is to synthesize and to update where possible information relevant to the Recovery Potential Assessment. The information is presented both for the individual spawning populations that define the DU and for the DU as a whole.

Aperçu de la biologie et de la situation générale du bar rayé de la baie de Fundy en 2013

RÉSUMÉ

On trouve les populations de bars rayés reproducteurs anadromes dans trois des rivières qui se jettent dans la baie de Fundy : les rivières Shubéanacadie et Annapolis, en Nouvelle-Écosse, et le fleuve Saint-Jean, au Nouveau-Brunswick. Les populations définissent collectivement l'unité désignable (UD) du bar rayé de la baie de Fundy. Par suite d'une évaluation, l'UD a été désignée comme étant « en péril » par le Comité sur la situation des espèces en péril au Canada (COSEPAC) à deux reprises, la première en tant qu'espèce menacée en 2004 et la deuxième en tant qu'espèce en voie de disparition en 2012. La situation démographique en déclin du fait de la disparition des populations reproductrices et les menaces non atténuées pesant sur les populations reproductrices qui subsistent sont les principaux facteurs qui ont contribué à ce que l'espèce soit désignée comme étant « en péril ». L'UD du bar rayé de la baie de Fundy est actuellement à l'étude en vue d'être inscrite comme espèce en voie de disparition à l'annexe 1 de la *Loi sur les espèces en péril* (*LEP*) du Canada. Par conséquent, il faut mettre à jour l'évaluation du potentiel de rétablissement menée en 2006 en réponse à la désignation d'espèce « menacée ». Le présent document vise à résumer et à mettre à jour, dans la mesure du possible, l'information pertinente à l'évaluation du potentiel de rétablissement. L'information est présentée à la fois pour les populations reproductrices individuelles qui définissent l'UD et pour l'UD dans son ensemble.

INTRODUCTION

The Striped Bass (*Morone saxatilis*) is an anadromous percoid that spawns in many estuaries along the eastern seaboard of North America from the St. Lawrence River in Québec, Canada, to the St. John's River in Florida (Scott and Scott 1988). The largest populations in terms of spawner abundance occur in the middle of the species range; specifically in the Chesapeake Bay and the Delaware River areas of the State of Maryland and the Hudson River of the State of New York. Striped Bass are an important upper trophic level predator in the coastal and estuarial zones wherever they occur.

In the Fisheries and Oceans Canada (DFO) Maritimes Region (Figure 1) Striped Bass are common in coastal and estuarial waters, and in certain freshwater bodies. They support important, directed, recreational angling fisheries and Aboriginal ceremonial fisheries. Both migrant Striped Bass from spawning populations occurring along the eastern seaboard of the United States of America and Striped Bass originating from Bay of Fundy (BoF) spawning populations occur in the region (Wirgin et al. 1995; Rulifson and Dadswell 1995; Bentzen and Patterson 2005; Bradford et al. 2012). The spawning populations that occur within the Canadian portion of the BoF define one of the three Designatable Units (DU) of Striped Bass identified in 2004 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2004). The BoF DU is comprised of three spawning populations; the Saint John River population in New Brunswick (N.B.) (Figure 2), and the Shubenacadie River and Annapolis River populations in Nova Scotia (N.S.) (Douglas et al. 2003; COSEWIC 2004) (Figure 2).

The BoF Striped Bass DU was classified at risk on two occasions, the first in 2004 as Threatened (TH) (COSEWIC 2004) and most recently as Endangered (En) in 2012 (COSEWIC 2012). Declining demographic status resulting from loss of spawning populations and unmitigated threats to extant spawning populations were the most significant factors contributing to the 'at risk' designations. These were reported as:

- COSEWIC (2004): "Repeated spawning failures led to the disappearance of the Annapolis and Saint John River populations. These disappearances are thought to be due to changes in flow regime and poor water quality. In the Shubenacadie River population, the presence of the introduced chain pickerel in overwintering sites may constitute a threat. Another threat to the population is bycatch from various commercial fisheries."
- COSEWIC (2012): "…this large-bodied fish occurs at only a single known spawning location where it continues to be susceptible to exploitation from recreational fishing, bycatch in commercial fisheries, and from poaching. Habitat degradation continues in areas of historical spawning populations, which limits recovery potential."

The BoF Striped Bass DU is presently under consideration for listing as Endangered on Schedule 1 of Canada's *Species at Risk Act* (*SARA*). A Recovery Potential Assessment completed in 2006 in response to the Threatened designation defined a recovery target for the DU based upon area of occupancy; namely to reestablish annual spawning in at least one of the locations known historically to have supported spawning (DFO 2006). Neither the severity of stated threats nor the specific mechanisms contributing to the reported loss of the Annapolis River and Saint John River populations were known (DFO 2006).

Monitoring and research activities relevant to status assessment for the BoF Striped Bass DU were previously described in Douglas et al. (2003), and Bradford et al. (2012). COSEWIC status reports for the BoF Striped Bass DU are available as COSEWIC (2004, 2012).

The aim of this document is to synthesize and to update where possible, for each of the three spawning populations defining the BoF Striped Bass DU information concerning:

1. Life-History Characteristics
2. Abundance and Distribution
3. Biophysical Functions, Features, Attributes and Location of Known Important Habitat
4. Population and Distribution Targets
5. Residence Requirements
6. Threats and Limiting Factors

BAY OF FUNDY STRIPED BASS LIFE HISTORY CHARACTERISTICS

GENERAL DESCRIPTION

In Canada, Striped Bass are exclusively anadromous meaning that they spawn in freshwater and spend a portion of their lives at sea. Spawning occurs during May-June (Bradford et al. 2012). All known or suspected spawning sites for BoF Striped Bass are located in tidal freshwater upstream of the freshwater-saltwater interface in estuaries (Douglas et al. 2003). The possible exception may be the use of the non-tidal portion of the lower Saint John River lying between Mactaquac Dam and the City of Fredericton (Kidd et al. 2011), although this possibility has not been confirmed. Significant numbers of Striped Bass overwinter in freshwater in both the Saint John and Shubenacadie rivers (Jessop 1980; Hogans 1984; Douglas et al. 2003; Bradford et al. 2012). However, the extent to which this behaviour is obligate for the BoF spawning populations, as appears to be the case for the southern Gulf of St. Lawrence population (Douglas et al. 2003), is not clear.

Spawning activity is initiated by an increase in water temperature to about 15 °C (Bradford et al. 2012). Spawning has been reported to occur at dusk (Rulifson and Dadswell 1995; Robichaud-LeBlanc et al. 1996; Rulifson and Tull 1999), although this may not be the case for Shubenacadie River Striped Bass, which frequently exhibit observable and intense spawning activity during daylight (R.G. Bradford, personal observation). Spawning occurs at or near the surface, and may persist for several weeks (Bradford et al. 2012). Eggs and milt are broadcast simultaneously into the water column.

Fertilized eggs have slight positive buoyancy in low salinity, are pelagic, and are dispersed via water currents. The eggs hatch after two to three days, dependant on water temperature and environmental conditions (Scott and Scott 1988; Cook et al. 2006). Larvae exhaust their yolk reserves in 5 to 10 days, and then move to the near-shore shallows of the estuary, where they feed on zooplankton (Robichaud-LeBlanc 1997). The larval stage can last 35 to 50 days, over the course of which the larval diet shifts from smaller to larger zooplankton (Douglas and Chaput 2011).

Age of first spawning among Canadian Striped Bass populations is generally three to four years for males and four to six years for females, at body lengths of about 32 cm fork length (FL) for males and 50 cm FL for females (Bradford et al. 2012). Striped Bass can remain reproductively active for 20 years or more (Secor 2000), although not all adult age fish will spawn every year (Waldman et al. 1990; R.G. Bradford, personal observation). Generation time for the BoF Striped Bass DU is defined as the age at which males and females are mature (COSEWIC 2012) that has been estimated to be four years (Bradford et al. 2012).

Female Striped Bass are fecund producing approximately 50,000 eggs per kg of total body weight (Olsen and Rulifson 1992). Egg per female estimates for the Shubenacadie River population range from 41,000 eggs for a 45 cm FL fish to 2.1 million eggs for a 91.0 cm.FL fish (Paramore 1998).

Striped Bass populations exhibit significant variability in recruitment (Merriman 1941; Raney 1952; Koo 1970; Van Winkle et al. 1979; Setzler et al. 1980; Ulanowicz and Polgar 1980; Kernehan et al. 1981; Cooper and Polgar 1981; Polgar 1982) the consequence of variable spawner success and survival past the early-life history. Year class dominance is, therefore, a common trait of adult populations, including the Shubenacadie River population (Bradford et al. 2012).

Canadian populations of Striped Bass exhibit a high intrinsic rate of somatic growth as compared to American populations (Conover at al. 1997). This trait is thought to help offset the negative effect of short summer growing seasons at higher latitudes on end of season body size of Age 0^+ Striped Bass. Survival through the first winter is dependent on body size (Bernier 1996) such that individuals with pre-winter body sizes of smaller than approximately 10 to 11 cm FL are less likely to survive (Bernier 1996; Bradford and Chaput 1997). Striped Bass do not feed extensively during winter and instead rely on stores of somatic energy in order to sustain basal and active metabolic functions. Smaller-bodied fish (e.g., < 10 cm FL) have lower starvation endurance (Hurst and Conover 1998). The eggs, larvae and juveniles of the Shubenacadie River population are considered to have a number of characteristics contributing to high survival rates, suggesting local adaptations to a highly dynamic environment (Cook et al. 2010).

There are other factors that affect survival rates; for example, high river flows in estuarial wintering locations can potentially displace juveniles downstream to sites less favourable for survival. In Miramichi Bay, juveniles could be exposed to lethal low temperatures and osmotic stress (Hanson and Courtenay 1995).

Adult Striped Bass can withstand significant variations in salinity, temperature, pH and turbidity (Talbot 1966; Auld and Schubel 1978; Setzler et al. 1980) in contrast to eggs and larvae, which are sensitive to minor changes in environmental variables (Cooper and Polgar 1981). The minimum dissolved oxygen requirement for all life stages has been defined as 5 mg $O_2 \cdot l^{-1}$ (Bain and Bain 1982).

Survival of eggs to hatching is closely tied to the physical and chemical properties of the incubation habitat; particularly temperature and salinity (Cook et al. 2010), dissolved oxygen, and the presence of a moderate current, which keeps the eggs suspended in the water column (Cooper and Polgar 1981). Survival of the larvae, like the eggs, depends on physical variables, including temperature, dissolved oxygen and salinity.

Post-spawned adults, and Age 1^+ years and older juveniles, can migrate extensively while feeding in coastal waters during summer-autumn. Striped Bass are generalist predators, consuming both macro-invertebrates and fish (Scott and Scott 1988).

SHUBENACADIE RIVER POPULATION

The Shubenacadie River (Figure 3) is the only tidal bore river presently used for reproduction by Striped Bass (Rulifson and Dadswell 1995) and is the only spawning river known to be used annually by the BoF Striped Bass DU (Bradford et al. 2012). The majority of spawning activity occurs where salinity is low (< 1 to 2 ppt) and where the water temperature is at least 15 °C to 16 °C (Bradford et al. 2012). Egg densities in the spawning area can exceed 1,000 eggs$\cdot m^{-3}$ (Duston 2010). The combined influence of tidal action and weather results in variable timing of spawning activity among years (first week of June in 2000 and 2001, mid-May in 2009 and 2010; Duston 2010; Bradford et al. 2012).

The timing and duration of the spawning season for Shubenacadie River Striped Bass has been estimated from collections of fertilized eggs (≤ 24 hours old) and from detections of adult fish carrying surgically implanted acoustic transmitters as they swam past hydrophones deployed in the spawning area within the tidal Stewiacke River (Years 2008-2011) (Figure 4). Egg collections indicated that spawning begins during May and is typically complete by mid-June (Bradford et al. 2012), but may extend into July in some years (Dr. Jim Duston, Dalhousie University Agriculture Campus, Bible Hill, N.S., personal communication).

Median days of arrival in the spawning area for acoustic-tagged fish occurred during May in all Years (Days 122 – 151; Table 1). Median days of departure from the spawning area occurred during June in all years, except during 2010, when median date of departure occurred during the last week of May (Day 145; Table 1). Individual fish were first detected in the spawning area as early as the last week of April during 2010 (Day 118) and 2011 (Day 119) and last detected as late as the second week of July in 2008 (Day 199; Table 1).

EARLY-LIFE HISTORY

Shubenacadie River Striped Bass eggs are susceptible to extensive dispersal by tidal action during the brief (≤ 72 hour) incubation period (Cook et al. 2010). They possess several traits that have been interpreted as local adaptations to a high energy and variable environment, including large water-hardened diameters (3.67 mm ± 0.10 mm), large diameter oil globules (0.83 mm ± 0.02 mm), low specific gravity (1.0018 $g \cdot cm^{-3}$) (Bergey et al. 2003) and tolerance of a broader range of salinity (2 ppt – 20 ppt) than is typical for populations occurring elsewhere (Cook et al. 2010). Yolk-sac larvae from this population have been shown to tolerate higher salinities in comparison with those from other populations that have been assessed for salinity tolerance; for example, 14% survival after 7 days at 30 ppt (Cook et al. 2010), as well as tolerating temperature decreases that are lethal to other populations (Cook et al. 2010).

Following metamorphosis, juveniles exhibit both a greater scope for growth at temperatures between 10 °C and 26 °C (Cook et al. 2010) and broader thermal tolerance (618 $°C^2$) than populations that occur to the south of the Shubenacadie River (Cook et al. 2006).

Young of the year (YOY) Shubenacadie Striped Bass can be found within the tidal portions of the river throughout the summer. A seaward range extension by late summer to Cobequid Bay and into the Minas Basin as far as Five Islands (Figure 5) occurs in most years (Bradford et al. 2012).

Young of the year Striped Bass overwinter predominantly in tidal brackish water (Cook and Bradford 2004). However, the specific locations of overwintering sites are not known. Age 2^+ years and older juveniles overwinter in Grand Lake and descend the river the following spring along with pre-spawning adults (Douglas et al. 2003). Detections of acoustic-tagged adult Striped Bass at a hydrophone installed in the outlet from Grand Lake indicates that outmigration from the lake can occur as early as mid-April (Table 1).

SAINT JOHN AND ANNAPOLIS RIVERS POPULATIONS

There is neither historic nor recent information available on the biological traits of either the Saint John River or Annapolis River populations.

Striped Bass spawning was reported to occur during June in the Saint John River, between Fredericton and Mactaquac, as early as the late 1800s (Cox 1893). Local knowledge suggests that the Striped Bass spawned in several locations, but the main spawning site was believed to be in the section of the river lying between the Mactaquac Dam and the City of Fredericton (Kidd et al. 2011).

In the Annapolis River, spawning activity was reported in the section of river lying between Middleton and Bridgetown (Williams et al. 1984; Jessop 1990, 1995) approximately 32 to 40 km upstream of the Annapolis Royal Causeway.

ABUNDANCE AND DISTRIBUTION

The BoF DU includes one known spawning population in the Shubenacadie River, N.S. (Bradford et al. 2012), and a possible spawning location in the Saint John River, N.B. (there has been no evidence of spawning activity in the Saint John River in the last 30 years). Striped Bass in the BoF DU also spawned in the Annapolis River, N.S. However, there has been no evidence for viable spawning since 1976.

Bentzen et al*.* (2009) conducted a genetic study of 1,500 Striped Bass using 11 microsatellite loci. The samples used were collected from the Shubenacadie River, the Miramichi River, American populations [Hudson River; Kennebec River and Chesapeake Bay], the Annapolis River (DNA extracted from scale samples archived by DFO), and the lower Saint John River (immediately below Mactaquac Dam and Belleisle Bay). The genetic analyses identified four distinct groups of Striped Bass: American, Shubenacadie, Miramichi, and a group of fish in the Saint John River that may represent a local population. The Saint John River samples also included fish with probable American and Shubenacadie River origins. The samples from the Annapolis River grouped with the American populations.

In addition to being found in their spawning rivers, Striped Bass can also be found in the freshwater and estuarial portions of many rivers draining to the BoF, and throughout the coastal waters of the BoF. Striped Bass frequenting the Minas Basin and Cobequid Bay in the summer months are thought to consist of a mixture of fish that overwinter in freshwater around the BoF, and fish that migrate southward along the eastern US coast (Rulifson et al. 2008). Evaluation of the status of the BoF Striped Bass DU is accordingly, confounded by the presence of Striped Bass from American populations within the BoF-Gulf of Maine (Rulifson and Dadswell 1995; Wirgin et al. 1995; DFO 2006; Bradford et al. 2012).

Data relevant to assessing the current abundance and distribution of the BoF Striped Bass DU is scant and not well suited to quantitative assessment. In general terms, there is no projected continuing decline in the number of populations, or the number of spawning locations, or the extent of occurrence of the DU. Confirmation of the presence of a Saint John River spawning population would raise the total number of extant spawning populations from the currently assessed one (COSEWIC 2012) to two. The information available for each of the three populations is summarized below.

SHUBENACADIE RIVER POPULATION

The Shubenacadie River Striped Bass population is the only population within the BoF DU that can be shown to be reproductively active.

Adult Abundance

Recreational angling data suggested that the abundance of adult Striped Bass declined in the Shubenacadie River between 1950 and 1975, and that numbers remained low and relatively stable during the 1980s (Jessop 1991).

Adult spawner abundance, last assessed during May-June 2002, was estimated as no less than 15,000 Age 3^+ years and older fish, of which no less than 7,000 were ≥ Age 4^+ years.

There are indications that the adult population in the Shubenacadie River has increased since 2002. Striped Bass bycatch data contained in logbook returns from commercial shad and gaspereau fisheries occurring in the Shubenacadie River, as well as recreational angling surveys suggest that Striped Bass spawner abundance has increased (Duston 2010; Bradford et al. 2012). The implied increase in adult abundance is consistent with expectations arising from the recruitment of the strong 1999 year class (DFO 2006). The numbers of adults gathering on spawning grounds in recent years were reported by locals to be the highest in living memory (Duston 2010). Surveys conducted between April 26, 2010 and June 20, 2010 of the recreational angling fishery estimated as many as 1,801 bass (2.2 bass landed per hour fishing effort) were landed, mostly from the tidal section of the Stewiacke River when adults were gathering on the spawning grounds (Duston 2010).

Juvenile Abundance

Shubenacadie River YOY Striped Bass abundance and distribution have been assessed annually since 1999, except for the year 2008, via a standardized beach seine survey of the tidal Shubenacadie River and the north shore of Minas Basin and Cobequid Bay (Figure 5). Inter-annual variation in year-class strength is apparent (Table 2; Figure 6), which may in part be due to the fact that spawning success and/or survival of early life stages (eggs, larvae) are sensitive to climate variability (Ulanowicz and Polgar 1980; Rutherford and Houde 1995; Rutherford et al. 1997). The data also indicate that higher overall annual production of Age 0^+ years Shubenacadie River Striped Bass has not resulted from higher spawner abundance in the years since 1999 (Table 2; Figure 6).

Distribution

The extent of occurrence for the Shubenacadie River population can be estimated from recaptures of Striped Bass tagged in the system between 1999-2002 and between 2008-2009, genotyping of Striped Bass sampled between 1999-2006 (Bradford et al. 2012), and by genotyping of DNA from preserved Striped Bass tissue (Bradford et al. 2012). A summary of tagging data by Bradford et al. (2012) for Striped Bass marked during the years 1999 to 2002 indicated inter-annual use of Shubenacadie-Grand Lake as an overwintering area by individual fish, and a relatively small marine distribution for the contingent of the Shubenacadie River population that ascends the river to overwinter in freshwater. Most reported summer-autumn recaptures of Striped Bass marked while descending from the lake (Years 1999-2002) have occurred within Minas Basin. One Striped Bass tagged and released at Mactaquac during 2005, and subsequently genotyped to be of Shubenacadie River origin, was recaptured during 2006 from the State of Maine near Mt. Desert. This recapture represents the most distant of all reported recaptures for Shubenacadie River Striped Bass.

The relatively small geographic distribution for the majority of the reported recaptures is, however, inconsistent with demonstrations by Wirgin et al. (1995) and DFO (2011) that Shubenacadie River-origin Striped Bass occur within the Saint John River, N.B., during all of the years for which samples were available (DFO 2011). Explanations for the inconsistencies between the mark-recapture and genetic assignment tests may include:

1. A low likelihood of Striped Bass being recaptured outside of Minas Basin because of a low search effort (e.g., lower recreational angling activity or lower bycatch in licenced fisheries),
2. Non-reporting of distant recaptures, or
3. That Shubenacadie River Striped Bass are organized to some extent, into local and coastal contingents, each exhibiting a variety of migration behaviours, as has been

shown for other Striped Bass populations (Secor et al. 2001; Grothues et al. 2009; Pautzke et al. 2010).

Saint John River Population

Although genetic data recently made available supports the presence of a spawning population in the Saint John River (DFO 2011), there has been no direct confirmation of spawning activity in the past 30 years to confirm persistence of a spawning population. However, the search effort for spawning activity has been low and infrequent. Striped Bass eggs were reportedly collected during 1979 from the interior areas of Bellisle Bay (M.J. Dadswell, DFO Memorandum, 2 February 1982). Surveys were unsuccessful in collecting eggs, larvae or Age 0^+ years juveniles during 1992 and 1994 (Jessop 1995), or in collecting YOY Striped Bass via beach seine during 2000 or 2001 (Douglas et al. 2003), or during 2009 (Bradford et al. 2012).

Local knowledge suggests that Striped Bass once spawned in several locations in the Saint John River (e.g., Bellisle Bay and Grand Lake), but the main spawning site is thought to have been located near the head of tide in the area immediately downstream of the Mactaquac Dam and upstream of Fredericton N.B. (Jessop 1990; Kidd et al. 2011). Since 1967, spawning has been recorded only once, at Belleisle Bay in 1979 (M.J. Dadswell, DFO Memorandum, 2 February 1982).

Genotyping (11 microsatellite loci) of 810 Striped Bass sampled from the Saint John River between 1999 and 2008 (DFO 2011) identified the presence of both Shubenacadie River and US origin fish, as well as the inter-annual presence of a genetically discrete contingent that could not be assigned to a population of known origin. This group exhibited greater genetic similarity to the southern Gulf of St. Lawrence and Shubenacadie River populations than to any of the populations of US origin that were included in the analysis (Bradford et al. 2012). Both juvenile (older than Age 0^+ years) and adult fish were represented within the group (Bradford et al. 2012). These data lend support to the suggestion of Douglas et al. (2003) that native Striped Bass may still be present within the Saint John River; however, there is not yet sufficient evidence outside of the genetic analysis to conclusively demonstrate the persistence of a spawning population of Striped Bass in the river.

Annapolis River Population

Native Annapolis River Striped Bass are considered to be extirpated (DFO 2011). The continued presence of migrant Striped Bass in the portion of the estuary lying upstream of the Annapolis River causeway indicates that the river-estuary continues to offer foraging habitat and perhaps overwintering habitat.

Surveys of recreational Striped Bass fishers in the Annapolis River suggest that the population declined significantly from 1975-2000 (Jessop and Doubleday 1976; Dadswell et al. 1984). Biological data collected during this period was consistent with low recruitment; average length, weight and age increased, while the proportion of young fish declined (Jessop and Vithayasai 1979; Parker and Doe 1981; Jessop 1980, 1990, 1991, 1995). An angler survey conducted on the Annapolis River in 2009 supports the perception that Striped Bass presently occurring in the river are relatively large-bodied (19 fish sampled, mean length = 73 cm) (Duston 2010). The population of origin of the fish sampled by Duston (2010) was not determined.

Viable spawning by Striped Bass has evidently not occurred in the Annapolis River since 1976 (Williams et al. 1984; Jessop 1990, 1995), even though eggs have been collected from the river as recently as 1990 (Jessop 1995). Survival beyond the egg stage is, therefore, thought to be very low to negligible (Jessop 1990).

There has been no attempt to collect for genotyping adult Striped Bass in the Annapolis River in the years since the status review conducted by Douglas et al. (2003). Sampling has instead focused on attempting to locate early life-history stage Striped Bass in the river, the presence of which could indicate ongoing spawning activity. Beach seine surveys of the Annapolis River and Basin during 2000 and 2001 did not capture any YOY Striped Bass (Douglas et al. 2003). The Clean Annapolis River Project (CARP) carried out ichthyoplankton sampling on the river during May-June 2009 and 2010, and revisited the 2000 and 2001 beach seine sites in August-September 2010. All monitoring of the early life history stages of Striped Bass in the Annapolis River and Basin during 2001, 2002, 2009 and 2010 failed to detect any evidence of spawning activity (Bradford et al. 2012).

HABITAT

The Canadian *SARA* requires that Critical Habitat be identified to the extent possible based on the best information available in the Recovery Strategy for all 'Threatened', 'Endangered' or 'Extirpated' species, or a schedule of studies be included that, when completed, would allow the species' Critical Habitat to be identified. The *SARA* defines Critical Habitat as, "… the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species." National Guidance suggests that the identification of Critical Habitat is comprised of several components: biophysical functions, features and attributes, and geographic location.

> Functions – Critical Habitat serves a biological function, which is the capacity to support a life-cycle process requirement of the listed species. A function is the result of a biophysical feature and its attributes, which together provide the capacity for the function to occur.
>
> Features – Features are the biophysical components of the habitat (e.g., eelgrass beds, macrophytes, riffles, pools, and acoustic environment). Features are the aspects of the habitat that support the functional capacity for life-cycle processes necessary for survival or recovery. Features must be described in terms of their temporal use and/or availability.
>
> Attributes – Every feature is comprised of many attributes, such as temperature, water depth, velocity, gravel size and oxygen level, that operate within optimal ranges and together, provide the functional capacity of the feature to support a life-cycle process. Attributes are measurable and indicate why one feature is essential, whereas, another similar feature is not. Only those attributes deemed essential to a feature and the function it supports should be described.
>
> Geographic location – Can be identified through a variety of approaches, including the Bounding Box Approach, in which the function and features of the habitat can be described, but their exact location cannot.

The functions features and attributes of important Striped Bass habitat are described below and summarized in Appendix 1.

SPAWNING HABITAT

Locations

Canadian populations of Striped Bass are anadromous, meaning they spawn in freshwater and spend a portion of their lives at sea. Based on presence of eggs, larvae, and ripe and running adult males and females, the tidal portion of the Stewiacke River lying from 0 to 6 km upstream of the confluence with the tidal Shubenacadie River is considered to be the only extant spawning site known to be used annually by the BoF Striped Bass DU[1].

There is a possibility that other spawning locations exist elsewhere, most notably within the lower Saint John River. However, spawning activity has not been confirmed, on the presence of eggs, larvae, or YOY, to occur anywhere in this river in recent decades.

Similar criteria identify the portion of the Annapolis River lying between Lawrencetown and Bridgetown as a historical spawning location that is no longer in use.

Features

There are few, if any, features (e.g., vegetation, substrate, stream flow) common to all known/suspected BoF Striped Bass spawning areas. This possibly reflects the lack of dependence of reproduction on physical structures. Spawning, egg incubation, and larval development through to first feeding are all completed within the water column. The presence of a moderate current to maintain eggs in suspension appears to be a required feature for Striped Bass in general (Cooper and Polgar 1981). Important characteristics are access to saline waters and water flow because Striped Bass eggs are negatively buoyant.

Attributes

A moderate current is required to maintain eggs in suspension during incubation. Well oxygenated water (≥ 5mg·l^{-1}; Bain and Bain 1982) is a general requirement. Shubenacadie River Striped Bass eggs produced during the 2000 and 2001 spawning seasons were predominantly (75th Quantile) associated with water of ≤19°C (minimum =13°C; maximum 24°C) temperature and ≤1 ppt (minimum =0 ppt; maximum =20 ppt). Larvae were predominantly associated with water of ≤ 23°C (minimum =15°C; maximum 26°C) temperature and ≤ 6 ppt (minimum =0 ppt; maximum =18 ppt) (Table 3).

REARING HABITAT

Locations

The geographic extents of occurrence of Saint John River and Annapolis River Age 0^+ years Striped Bass are not known. Shubenacadie River Striped Bass occupy, by the end of the first growth season, the tidal portions of the Shubenacadie and Stewiacke rivers, Cobequid Bay and the inner portion of Minas Basin. The consistent absence of Age 0^+ years Striped Bass in beach seined collections of fish at a site located near Parrsboro, N.S., indicates the Minas Passage may not provide important habitat for this life-stage. However, the recent report of captures of Age 0^+ years Striped Bass with Shubenacadie River origins in a research trapnet installed near the head of tide in the Petitcodiac River, N.B. (Dr. Paul Bentzen, Dalhousie University, Halifax, N.S.), indicates that the area of occupancy for this life-history stage may extend beyond Minas Passage.

The geographic extent of occurrence of Age 1^+ years and older juvenile Shubenacadie River Striped Bass is not fully understood. Some ascend the Shubenacadie River during May-June presumably to feed (Cook and Bradford 2004). They are a regular component of collections acquired with a beach seine at standard sites located within the tidal Shubenacadie River,

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[1] There is anecdotal evidence that spawning has occurred within the tidal Shubenacadie River in an area upstream of the confluence with the Stewiacke River in recent years.

Cobequid Bay and to the Five Islands area of the Minas Basin. Age 1^+ years Striped Bass of unknown origin have been captured with a trapnet installed near the head of tide in the Petitcodiac River, N.B. (Petitcodiac Fish Restoration Coalition, Moncton, N.B., Unpublished Data).

Sub-adult Striped Bass possessing the genetic traits of the Shubenacadie River population have been detected within the Saint John River, which indicates that the range of the Shubenacadie River population includes a large portion of the coastal and estuarial areas of the BoF.

Features

Juvenile Shubenacadie River Striped Bass use a variety of shallow shoreline habitats, in both tidal and non-tidal waters as rearing habitat. The likelihood is low that viability of the population is dependent upon any specific habitat feature (e.g., vegetation, substrate, stream flow).

Attributes

Well oxygenated water ($\geq 5 mg \cdot l^{-1}$; Bain and Bain 1982) is a general requirement. Age 0^+ years Shubenacadie River Striped Bass sampled from the time of metamorphoses in June through to late July within the tidal Shubenacadie River during the years 2000 and 2001 were predominantly (75^{th} Quantile) associated with water of ≤ 20°C (minimum = 17°C; maximum 20°C) temperature and ≤ 7 ppt (minimum =0 ppt; maximum =31 ppt) (Table 3).

A June-September beach seine survey conducted in most years since 1999 at fixed sampling sites in Minas Basin, Cobequid Bay, and the tidal portion of the Shubenacadie River (Figure 5) indicates Age 0^+ years Striped Bass were predominantly (75^{th} Quantile) associated with water of ≤ 24 °C (minimum =16 °C; maximum 28°C) temperature and ≤ 28 ppt (minimum =0 ppt; maximum = 31 ppt) (Table 3).

FORAGING

Striped Bass larvae and recently metamorphosed juveniles forage on zooplankton and other small invertebrates, although cannibalism is known (R.G. Bradford, personal observation). Their diet becomes increasingly diverse with time as the Striped Bass increase in body size and may include the following prey items: mysids, crangon, polychaetes, crabs, Rainbow Smelt (*Osmerus mordax*), Atlantic Silverside (*Menidia menidia*), Alewife (*Alosa aestivalis*), Blueback Herring (*A. pseudoharengus*), American Shad (*A. sapidissima*), Atlantic Herring (*Clupea harengus*), Atlantic Tomcod (*Microgadus tomcod*) and American Eel (*Anguilla rostrata*) (Paramore 1998; Rulifson and McKenna 1987; DFO 2006).

WINTER HABITAT

Locations

Most Age 0^+ years Shubenacadie River Striped Bass appear to overwinter in tidal brackish water (Cook and Bradford 2004), although the specific overwintering sites are not known. Many Age 2^+ years and older juveniles overwinter in Grand Lake, N.S. Striped Bass possessing the genetic traits of the Shubenacadie River population have been detected in samples collected from Belleisle Bay on the Saint John River during early spring (Bradford et al. 2012). Additional freshwater wintering sites are possible.

The extent to which wintering in fresh-brackish water is obligate for BoF Striped Bass is not clear. Lethal low marine temperatures can occur within the BoF but these are not an interannually consistent feature of the hydrography of the bay. Satellite-derived Sea Surface

Temperature (SST) measurements for the inner BoF (Area 55; Figure 7) indicate a general warming has occurred within the inner BoF since 1981 (Figure 8). Lethal (≤-1.5 °C) low winter (December-March) conditions appear to have become less frequent with time (Figure 9). It is, therefore, not clear whether the recent demonstration by Keyser et al. (2013) that some Shubenacadie River Striped Bass winter in marine waters within the Minas Passage is a behaviour that has developed only recently.

Features

Features of wintering sites are not well described overall. Known freshwater wintering sites are relatively large and relatively deep lakes; for example, Shubenacadie-Grand Lake, N.S. and Belleisle Bay, N.B.

Attributes

Wintering sites generally occur where water temperatures remain warmer than the freezing point of unprotected fish blood (<1.5°C).

POPULATION AND DISTRIBUTION TARGETS FOR RECOVERY

ABUNDANCE TARGETS

Due to the insufficient historical and present abundance data (i.e., number, biomass, or attributes of mature spawning age animals), it is not possible to establish abundance targets for either the BoF DU or the individual river populations at this time. However, there is no indication of a continued loss of spawning populations since the time of the 2004 COSEWIC assessment and, therefore, of a further decline in general status (Table 4).

DISTRIBUTION TARGETS

The distribution targets for the BoF Striped Bass DU (Table 5) were previously defined by DFO (2006) using an index area of occupancy scaled to spawning habitat. The aim is "...successful spawning in one of two historical locations of the BoF DU where there has been no evidence of spawning during the last ten years" (DFO 2006).

RESIDENCE REQUIREMENTS

The *SARA* defines a residence as:

> "A dwelling place, such as a den, nest or other similar area or place that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating".

The draft Operational Guidelines for the Identification of Residence and Preparation of a Residence Statement for an Aquatic Species at Risk (DFO, Unpublished Report) uses the following four conditions to determine if an aquatic species uses a residence:

1. There is a discrete dwelling place that has structural form and function similar to a den or a nest; and
2. An individual of the species has made an investment in the creation or modification of the dwelling-place; and
3. The dwelling-place has the functional capacity to support the successful performance of an essential life-cycle process such as spawning, breeding, nursing and rearing; and

4. The dwelling-place is occupied by one or more individuals at one or more parts of its life cycle.

At this time there are no life stages of Striped Bass that are believed to use a dwelling-place that would meet the criteria for being declared a residence, as described in the *SARA* and DFO draft guidelines.

THREATS AND LIMITING FACTORS

Threats to BoF Striped Bass were assessed by DFO (2006) and COSEWIC (2012). Those that were considered to apply to the individual populations are described below. The threats that were considered to potentially affect the overall DU, that is irrespective of the individual populations, are then compiled by attribute (Direct Mortality, Water Quality, Water Quantity, Impacts on Habitat) and the effect to be mitigated for the DU. Present mitigation, options to reduce effect, monitoring and research requirements and the rank effect on the status of the DU are summarized in Appendix 2.

SHUBENACADIE RIVER POPULATION

Shubenacadie River Striped Bass are susceptible to exploitation from recreational fishing, Aboriginal food, social or ceremonial (FSC) fisheries, bycatch in commercial fisheries, and from poaching. The specific numbers of Striped Bass removed or lost (e.g., mortality of fish returned to the wild following capture-release) on an annual basis are not known but are potentially high.

Preliminary estimates of annual survival for adult Striped Bass, which had overwintered in Grand Lake and resided during the summer months in Minas Basin were acquired for the years 2008 to 2010 using the detection histories among 72 receiver deployments (Figure 4) for 44 fish (Table 6) surgically implanted with acoustic transmitters (DFO unpublished data). The survival estimates were generated using Cormack-Jolly-Seber (CJS) models (Cormack 1964; Jolly 1965; Seber 1965). Estimates varied between 47% and 74% survival rate for the years 2008 to 2010 (Table 7). Handling mortality during the first summer post-surgery was observed and estimated to be 53% to 74%; however, survival was estimated to be consistently ≥ 80% thereafter and without a significant seasonal effect (Table 8; Figure 10).

The presence of the introduced Chain Pickerel (*Esox niger*) in the river may result in changes to the forage base for Striped Bass overwintering within the river (COSEWIC 2012). Migrant Shubenacadie River Striped Bass would be susceptible to turbine mortality (Annapolis River), and habitat degraded by human activities wherever these conditions may exist within the population’s area of occurrence.

Despite these threats, the limited information available suggests that the Shubenacadie River Striped Bass population has increased substantially in recent years, most likely the result of strong year-classes during the 1999 and 2000 spawning years.

ANNAPOLIS RIVER POPULATION

There is an association between the decline in the Annapolis River Striped Bass population and the construction of the Annapolis Royal causeway in the Annapolis River estuary in 1960 (Jessop and Doubleday 1976; Williams 1978; Jessop and Vithayasai 1979; Jessop 1980; Parker and Doe 1981; Williams et al. 1984), as well as the subsequent construction of the Annapolis Tidal Station starting in 1980 (began operation in 1984). The head pond created by the causeway-tidal power plant is located downstream from the known spawning site on the Annapolis River and its alteration has direct impacts on the quality of this habitat. At ebb tide, the sluice gates are closed and water is released from the river through the power generating turbine. This alters the water levels, tidal range, and periodicity and duration of water flow into and out of the upper estuary (Harris 1988). These different flow patterns are leading to some uncertainty with respect to the maintenance of eggs in suspension in the water column during incubation. The relationship between the specific gravity and density of Striped Bass eggs is specific to each population and each river (Bergey et al. 2003). Consequently, variation in the physical energy and estuarine circulation of the watershed can significantly affect Striped Bass spawning success in the Annapolis River. Such circulation changes are considered the only potential source of high mortality for the population (DFO 2006).

The presence of a turbine is also a source of direct mortality among Striped Bass. The Annapolis Tidal Power Plant is a large diameter (7.5 m) tube turbine that operates at low head (2.0 - 5.5 m). Studies conducted in 1985 and 1986, which included daily surveys for damaged or dead fish, collection of naturally passed juvenile fishes downstream of the turbine, and experimental passage of sonic-tagged adult fish, found that large bodied (60 to 100 cm in length) Striped Bass had been injured or killed by mechanical strike or from changes in pressure during passage through the turbine (Dadswell and Rulifson 1994). The incidence of Striped Bass mortality/injury was, however, low relative to the overall number of total mortalities/injuries for all species (6 of 4,428 observations, or < 0.5%, over the 2 years).

The operation of the tidal plant can result in the release of suspended sediment and physical scouring along existing channels and at adjacent shorelines (and acceleration of bank erosion) as was documented during the early years of tidal power generation at the Annapolis Royal site (Tidemarsh 1984). These alterations may be ongoing.

In the Annapolis River, the natural snowmelt cycle can result in the migration of nutrients, pesticides, and animal waste into the river, resulting in lowered dissolved oxygen levels, an increase in toxic substances, an increase in plant growth and seasonal declines in the pH of river water. Striped Bass are sensitive to river acidity, with a water pH of 5.9 or less considered to be lethal (Buckler et al. 1987). Because the spring period corresponds to the start of the spawning season in the BoF, the release of stored melt waters of low pH from the hydroelectric reservoirs of streams flowing to the Annapolis River had been suggested to reduce spawning success on that river (Douglas et al. 2003). Recent water sampling (June 2010), however, indicates that pH was 6.8 on average during the time when Striped bass could be expected to spawn in the river (May-June), and a minimum of 6.4 was recorded in August/September 2010 and 2011 for beach seining all along the river from Bridgetown to downstream of the turbine (Freeman 2013).

SAINT JOHN RIVER POPULATION

Habitat degradation and loss has been attributed to a reduced status for native Saint John River Striped Bass, although direct cause-effect evidence for this specific population has not been gathered. Construction of the large Mactaquac hydroelectric dam on and upstream of a suspected historical spawning ground is believed to be the single greatest factor contributing to the cessation of spawning in this river (Jessop 1995). However, this interpretation must carry the caveat that neither the location(s) of historical spawning sites nor present area(s) of spawning activity are known from documented spawning activity or the presence of liberated eggs. The construction of the Mactaquac dam in 1967 may have significantly modified the spawning, incubation or larval habitats of the Saint John River population (Dadswell 1976; Dadswell et al. 1984; Jessop 1995; Douglas et al. 2003). According to local knowledge, the main spawning site is believed to be near the head of tide in the vicinity of the Mactaquac dam and Fredericton, N.B. (Kidd et al. 2011). However, potential sources of mortality attributed to elimination of access to rearing habitat above Mactaquac dam and potential loss of spawning habitat below Mactaquac dam are uncertain (DFO 2006). Dadswell (1976) reported that 96% of

Striped Bass eggs collected in Belleisle Bay in 1975 had a broken membrane, a phenomenon that could be due to the presence of contaminants, or to a sudden change in osmotic conditions.

At the adult stage, Striped Bass is a high trophic-level predator and is, therefore, vulnerable to accumulating contaminants that can accumulate in sediments and in the food chain. Contaminants, such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons, pesticides, heavy metals and other chemicals, have been shown to reduce Striped Bass egg and larval survival in the laboratory (Korn and Earnest 1974; Bonn et al. 1976; Benville and Korn 1977; Durham 1980; Cooper and Polgar 1981; Hall 1991). High levels of PCBs or DDT have been observed in the 1970s on the Saint John River (Jessop 1995), when the Saint John River was heavily impacted by nutrient enriching pollutants, but are currently reduced (Kidd et al. 2011). Since the 1970s, however, water quality of the Saint John River has improved (Kidd et al. 2011). Municipalities and industries have installed wastewater treatment systems and, as a result, the river's water typically meets Canada's guidelines for acceptable water quality.

BAY OF FUNDY STRIPED BASS DESIGNATABLE UNIT

Direct Mortality

- Directed recreational angling fishery
    - Direct mortality of adults (retention/handling mortality in catch and release).
- Illegal directed fishery (poaching)
    - Mortality as a result of illegal retention of Striped Bass.
- Bycatch in other fisheries (commercial gillnet, intertidal weir, trawl, trapnet, dipnet, and recreational angling)
    - Mortality as a result of handling or retention of Striped Bass as bycatch in recreational and commercial fisheries targeting other species.
    - Other recreational species.
- Food Social Ceremonial Fisheries
    - Mortality as a result of handling or retention of Striped Bass by Aboriginals fishing under a FSC fishery licence.
- Entrainment in flow-through turbines (Annapolis Tidal Generating Station)
- Ecotourism and recreation
    - Disturbance of fish aggregations and introduction of petroleum products and byproducts through boat and recreational vessel use.
- Scientific research
    - Handling related mortality, increased stress and disease transfer; obstruction of natural migrations and behaviour; introduction of petroleum products and byproducts.
- In-stream tidal generating stations [Potential]
    - Potential future installation of turbines in Minas Basin, which could present threat.
- Fisheries on prey species
    - Reduction of prey species populations through directed fisheries, leading to Striped Bass mortality as a result of lost prey stocks.
- Aquaculture
    - Escape of cultured Striped Bass from private aquaculture facilities result in introgression with wild individuals.

Water Quantity

- Altered hydrology resulting from construction of large barriers (Annapolis Royal Causeway, Mactaquac Dam)
    - Alterations of estuarial circulation and flow regimes; reduced access to habitat above barriers, and alteration of spawning habitat below dam due to changes in flow regime.

Water Quality

- Municipal and industrial wastewater
    - Degraded water quality (e.g., lowered pH, lowered DO, toxic chemicals) and degraded sediment quality (e.g., accumulation and redistribution of toxic chemicals), heat.
- Agricultural run-off
    - Degradation of water quality (e.g., migration of nutrients, pesticides, animal waste) resulting in lowered DO, toxic substances, increase in plant growth, etc.
- Acid precipitation
    - Low pH precipitation leading to reduction of surface water-body pH levels, potentially affecting survival of Striped Bass.
- Natural Gas Storage Project [Potential]
    - Release of brine into Striped Bass habitat during development of underground natural gas facilities. [Potential]

Impacts on Habitat

- Altered hydrology and restricted access due to large barriers (Mactaquac Dam, Annapolis Royal Causeway)
    - Downstream effects of large barriers in the form of altered hydrology and flow regimes that damage downstream habitat, and barriers to access upstream habitat.
- Invasive species (Chain Pickerel in Grand Lake, NS, and Muskellunge in Saint John River, N.B.)
    - Loss of forage base for Striped Bass as a result of increased competition for forage. May prey on young Striped Bass, and compete for habitat in overwintering sites.
- Potential for aggregate mining
    - Dredging of mineral sands (e.g., titanium) in tidal waters would involve the removal of substrate that could result in the alteration of Striped Bass habitat. [Potential]

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TABLES

Table 1. Median day-of-year (range) for each migration milestone by year as inferred from detections of acoustic-tagged adult Striped Bass at hydrophones deployed at fixed stations. Spawning grounds were considered the tidal estuary of the Stewiacke River, upstream with its confluence with the Shubenacadie River. Entry / exit from the Minas Basin inferred from a receiver in Maitland (the mouth of the Shubenacadie River estuary) (NA – not applicable).

Milestone	**Metric**	**Year**			
		2008	**2009**	**2010**	**2011**
Exit Grand Lake	Number	NA	26	27	16
	Median		124.0	111.1	116.0
	Range		(108.0, 143.1)	(94.0, 122.1)	(112.8, 119.7)
Arrive on spawning grounds	Number	31	58	18	16
	Median	151.1	138.2	135.7	122.0
	Range	(138.4, 170.9)	(137.5, 178.4)	(118.2, 146.8)	(118.8, 144.7)
Exit spawning grounds	Number	24	51	20	11
	Median	171.8	153.7	145.2	152.8
	Range	(152.1, 199.0)	(142.9, 181.1)	(135.5, 172.6)	(141.2, 174.0)
Arrive in Minas Basin	Number	20	29	11	2
	Median	181.4	160.5	146.1	168.9
	Range	(143.8, 225.6)	(146.1, 206.1)	(136.1, 189.4)	(149.2, 188.7)
Exit Minas Basin	Number	18	21	24	NA
	Median	296.5	290.2	291.3	
	Range	(227.3, 331.6)	(207.3, 301.8)	(282.2, 315.0)	
Arrive in Grand Lake	Number	15	39	59	NA
	Median	303.4	293.6	296.3	
	Range	(287.2, 335.2)	(183.2, 309.2)	(153.1, 325.0)	

*Detected on receivers deployed immediately downstream from the lake.

Table 2. Standardized beach-seined catches of young of the year (YOY) Striped Bass (number per 50 m) by year, date, and site. Dash (-) indicates no data.

		Number of Striped Bass per 50m by Location								
Year	**Start Date**	**Tidal Shubenacadie**	**Inner Cobequid**	**Bass River**	**Economy Point**	**Lower Economy**	**Five Islands**	**Sites Sampled**	**Mean**	**Variance**
1999	05-Aug	12.3	-	-	72.0	51.5	-	3	45.3	4.8
	12-Aug	20.0	-	-	99.5	177.5	-	3	99.0	32.3
	19-Aug	3.0	-	-	95.5	0.0	0.0	4	24.6	0.0
	25-Aug	5.0	-	-	48.5	99.0	0.5	4	38.3	0.0
Arithmetic Mean									**51.8**	**37.1**
Geometric Mean									19.4	-
2000	11-Aug	254.7	-		0.0	0.0	0.0	4	63.7	150.1
	14-Aug	75.0	6.3	0.0	-	0.0	0.0	5	16.3	4.0
	29-Aug	15.3	1.0	0.6	0.5	0.0	0.0	6	2.9	0.0
Arithmetic Mean									**27.6**	**154.2**
Geometric Mean									2.1	-
2001	02-Aug	516.5	0.0	1.0	0.0	0.0	0.0	6	86.3	0.0
	13-Aug	21.0	2.1	0.0	2.3	0.0	0.0	6	4.2	0.0
	20-Aug	94.9	1.7	0.0	0.6	0.0	0.0	6	16.2	0.0
	05-Sep	4.6	-	0.6	116.2	33.3	4.4	5	31.8	5.0
Arithmetic Mean									**34.6**	**5.0**
Geometric Mean									3.0	-
2002	08-Aug	75.6	5.4	0.0	7.1	0.0	0.0	6	14.7	0.0
	16-Aug	102.0	5.7	2.9	0.0	0.0	0.0	6	18.4	0.0
	23-Aug	-	3.5	0.0	0.0	0.0	0.0	5	0.7	0.0
	04-Sep	14.2	-	63.0	18.3	-	0.0	4	23.9	2.5
	06-Sep	-	4.4	1.6	31.8	0.0	0.0	5	7.6	0.3
Arithmetic Mean									**13.1**	**2.7**
Geometric Mean									2.8	-
2003	12-Aug	20.6	4.5	10.6	12.7	0.6	0.0	6	8.2	0.0
	26-Aug	1.6	0.0	0.0	3.3	1.2	0.0	6	1.0	0.0
Arithmetic Mean									**4.6**	**0.0**
Geometric Mean									2.1	-
2004	04-Aug	19.1	0.0	0.0	0.0	0.0	0.0	6	3.2	0.0
	16-Aug	13.9	1.8	0.0	0.0	0.0	0.0	6	2.6	0.0
	01-Sep	7.4	-	2.6	0.0	0.0	0.0	5	2.0	0.0
Arithmetic Mean									**2.6**	**0.0**
Geometric Mean									0.8	-
2005	17-Aug	43.3	1.5	0.0	0.0	0.0	0.0	6	7.5	0.0
	23-Aug	9.5	6.0	1.3	1.3	0.0	0.0	6	3.0	0.0
	31-Aug	9.5	-	-	1.9	0.0	0.0	4	2.9	0.1
	01-Sep	3.3	-	1.0	24.0	-	-	3	9.4	1.7
Arithmetic Mean									**5.7**	**1.8**
Geometric Mean									2.0	-
2006	28-Aug	48.3	2.0	-	5.8	-	-	3	18.7	110.1
Arithmetic Mean									**18.7**	**110.1**
Geometric Mean									9.0	-
2007	27-Aug	17.4	9.1		40.6	17.3	1.0	5	17.1	7.3
Arithmetic Mean									**17.1**	**7.3**
Geometric Mean									11.3	
2008	No Survey									
	20-Jul	2.2	2.5	0.0	0.0	0.0	0.0	6	0.8	0.0
	05-Aug	2.5	0.5	0.0	0.0	0.0	0.0	6	0.5	0.0
2009	18-Aug	15.7	0.0	0.0	0.0	0.0	0.0	6	2.6	0.0
Arithmetic Mean									**1.3**	**0.0**
Geometric Mean									0.5	-
2010	10-Aug	34.0	42.5	15.3	143.0	8.5	0.5	6	40.6	0.0
	24-Aug	16.4	13.5	0.5	3.0	136.5	3.0	6	28.8	0.0
	10-Sep	1.4	-	1.1	2.5	1.5	6.0	5	2.5	0.0
Arithmetic Mean									**24.0**	**0.0**
Geometric Mean									7.4	-
2011	12-Aug	81.2	-	0.0	0.0	0.0	0.0	5	16.2	11.0
	16-Aug	-	4.0	0.0	-	0.0	0.0	4	1.0	0.1
Arithmetic Mean									**8.6**	**11.1**
Geometric Mean									0.9	-
2012	02-Aug	156.5	34.7	0.5	19.3	0.0	0.0	6	35.2	0.0
	15-Aug	101.1	-	0.7	1.0	0.0	0.0	5	20.6	4.2
	30-Aug	1.6	-	1.1	9.5	-	0.0	4	3.1	0.1
	18-Sep	1.0	3.5	2.2	1.5	8.0	0.0	6	2.7	0.0
Arithmetic Mean									**15.3**	**4.3**
Geometric Mean									9.1	-
2013	06-Aug	24.3	-	0.0	0.0	0.0	0.0	5	4.9	0.3
	22-Aug	59.0	6.0		0.0	0.0	0.0	5	13.0	1.4
	03-Sep	20.4	0.0	11.2	5.5	0.0	0.0	6	6.2	0.0
	19-Sep	5.5	2.5	0.4	2.0	0.5	0.0	6	1.8	0.0
Arithmetic Mean									**6.5**	**1.6**
Geometric Mean									9.2	-

Table 3. Distribution of Striped Bass eggs, larvae, early juveniles and late juveniles collected during the years 2000 and -2001 relative to Temperature (°C) and Water Salinity (ppt). Dash (-) indicates no data.

Life Stage	Attribute	Minimum	Quantile					Maximum
			5	25	50	75	95	
Eggs	Temperature (°C)	13	≤ 14	≤ 16	≤ 18	≤ 19	≤ 20	24
	Salinity (ppt)	0	-	-	-	≤ 1	≤ 9	20
Larvae	Temperature (°C)	15	≤ 17	≤ 21	≤ 22	≤ 23	≤ 24	26
	Salinity (ppt)	0	-	-	≤ 1	≤ 6	≤ 13	18
Early Juveniles	Temperature (°C)	17	-	≤ 18	≤ 20	≤ 20	≤ 20	20
	Salinity (ppt)	0	-	-	-	≤ 7	≤ 30	31
Late Juveniles	Temperature (°C)	16	≤ 19	≤ 21	≤ 22	≤ 24	≤ 26	28
	Salinity (ppt)	0	≤ 1	≤ 7	≤ 15	≤ 28	≤ 30	31

Table 4. Abundance of mature animals attribute (updated from DFO 2006). (NA = not applicable)

Attribute	Achievability
AI – Recovery objectives defined	No, and cannot be defined with existing data. See Table 3
AII – Expectation of recovery within ten years (by 2024)	NA (no recovery target)
AIIa - Under present conditions	NA See Table 3
AIIb - If fisheries related mortalities are reduced	NA Higher abundance expected
AIIc - If other human-induced mortality factors are reduced	NA Higher abundance expected

Table 5. Area of occupancy attributes based on spawning locations (updated from DFO 2006). Timeframe refers to the estimated length of time that would be required for an attribute to be met (NA = not applicable).

Attribute	Achievability
DI – Maintain spawning in the DU	The DU presently meets this attribute. The Shubenacadie River population continues to spawn annually.
DII – Spawning re-established annually in a portion of the locations lost within the DU	The DU potentially meets this attribute. A spawning population may exist in the Saint John River (COSEWIC 2012), but this requires confirmation. Timeframe: Unknown, > ten years
DIII – Spawning annually at all historic locations of the DU	The DU does not meet this attribute. Spawning has not been detected in the Annapolis River. Timeframe: Unknown, > ten years

*Table 6. Tagging metadata for the Striped Bass included in the mark-recapture model. * Includes a pressure (depth) sensor.*

Cohort	Number Released	Transmitter Model	Battery Life (Days)	Release Date Mean	Release Date Range	Fork Length (cm) Mean	Fork Length (cm) Range
1	19	V13-1X	785	May 4 2008	May 10 2008 - May 23 2008	72.1	54.8 - 89.8
2	7	V16-4X	760	May 2 2009	May 1 2009 - May 4 2009	65.9	60.3 - 70.9
	16	V16P-4X*	820	May 4 2009	May 1 2009 - May 12 2009	66.8	54.0 - 89.3

Table 7. Model-averaged survival and instantaneous mortality (Z) estimates for the Shubenacadie River Striped Bass acoustic telemetry data for the years 2008-2010 by Year (upper panel) and for the Summer and Winter months by Year (Lower Panel). SE = standard error, LCI = 95% lower confidence interval, UCI = 95% upper confidence interval.

Cohort	**Year[1]**	**Survival Estimate**	**Instantaneous mortality (Z)**
1	2008	0.47	0.76
1	2009	0.66	0.42
2	2009	0.61	0.50
2	2010	0.74	0.30

[1] Measured from spring year t to spring year t+1.

Cohort	**Survival Period**	**Survival Estimate**	**SE**	**LCI**	**UCI**	**Instantaneous mortality (Z)**
1	Summer 2008	0.53	0.16	0.24	0.80	0.63
1	Winter 2008	0.88	0.10	0.55	0.98	0.13
1	Summer 2009	0.80	0.08	0.61	0.92	0.22
1	Winter 2009	0.82	0.07	0.63	0.92	0.20
2	Summer 2009	0.74	0.11	0.49	0.89	0.30
2	Winter 2009	0.82	0.07	0.63	0.92	0.20
2	Summer 2010	0.82	0.08	0.61	0.93	0.20
2	Winter 2010	0.90	0.08	0.62	0.98	0.11

FIGURES

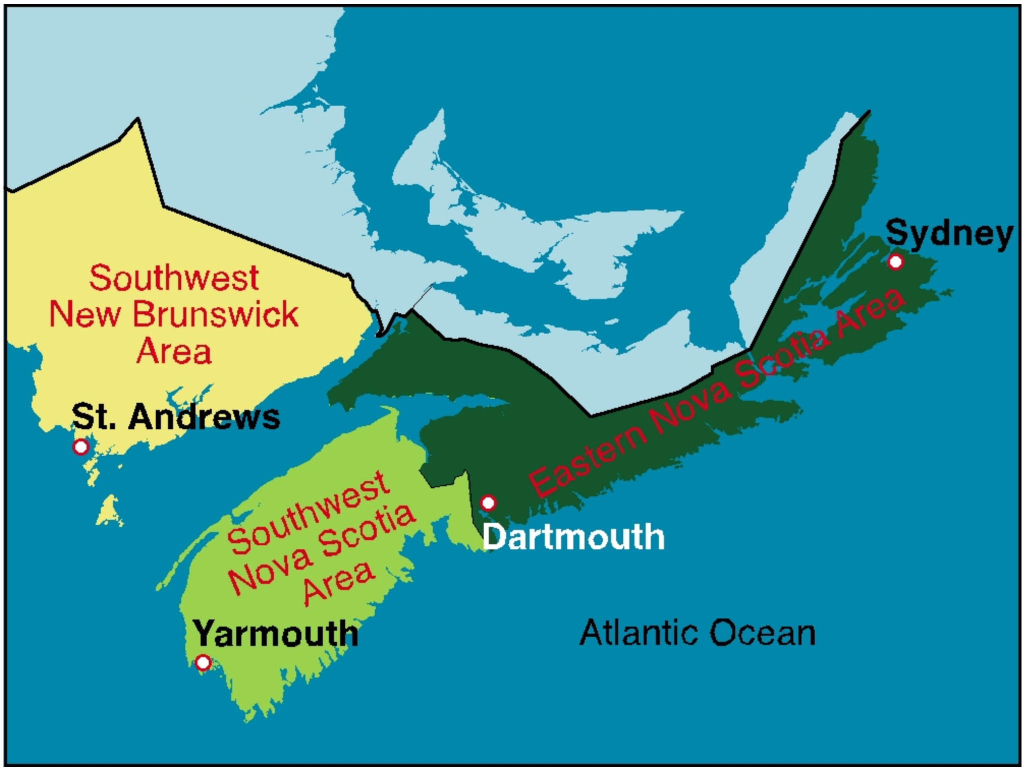

Figure 1. Map of DFO Maritimes Region.

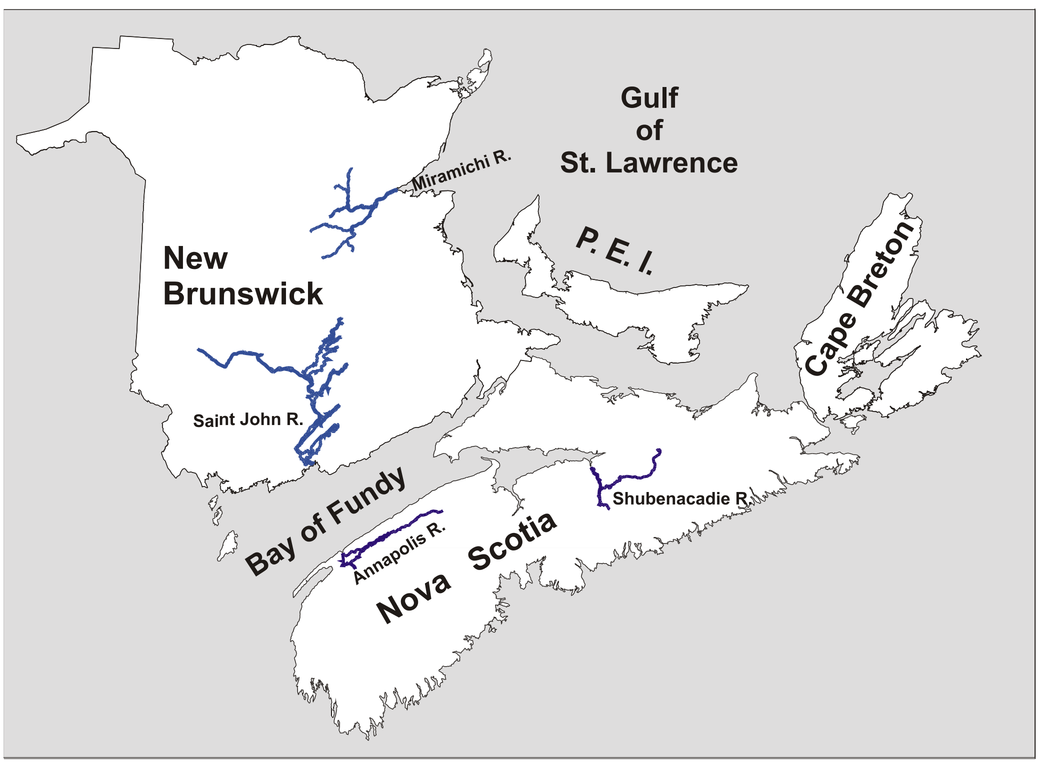

Figure 2. The four confirmed spawning locations for Striped Bass in the Canadian Maritime Provinces: Miramichi; Saint John; Annapolis; and Shubenacadie rivers.

SHUBENACADIE-STEWIACKE RIVER, NOVA SCOTIA

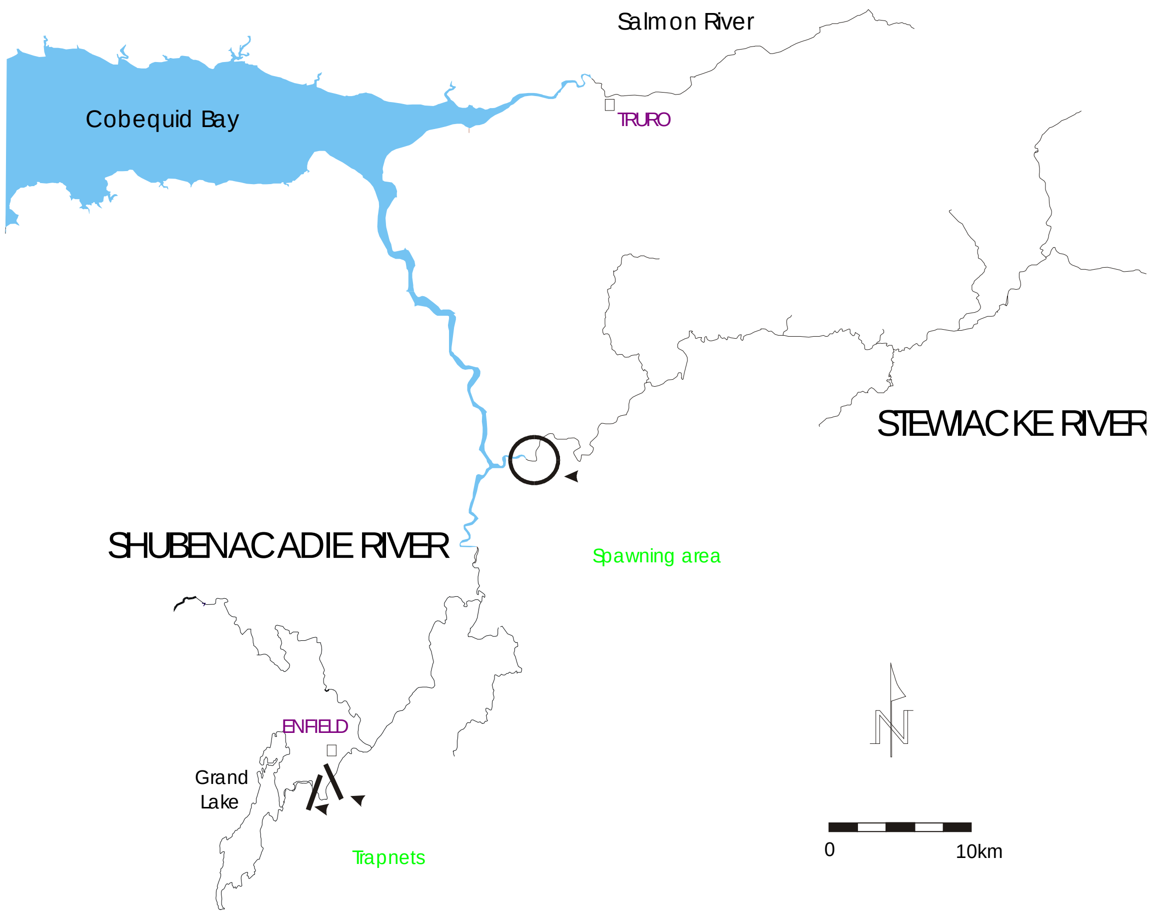

Figure 3. Map of Shubenacadie-Stewiacke River system indicating the location (circle) of the spawning area.

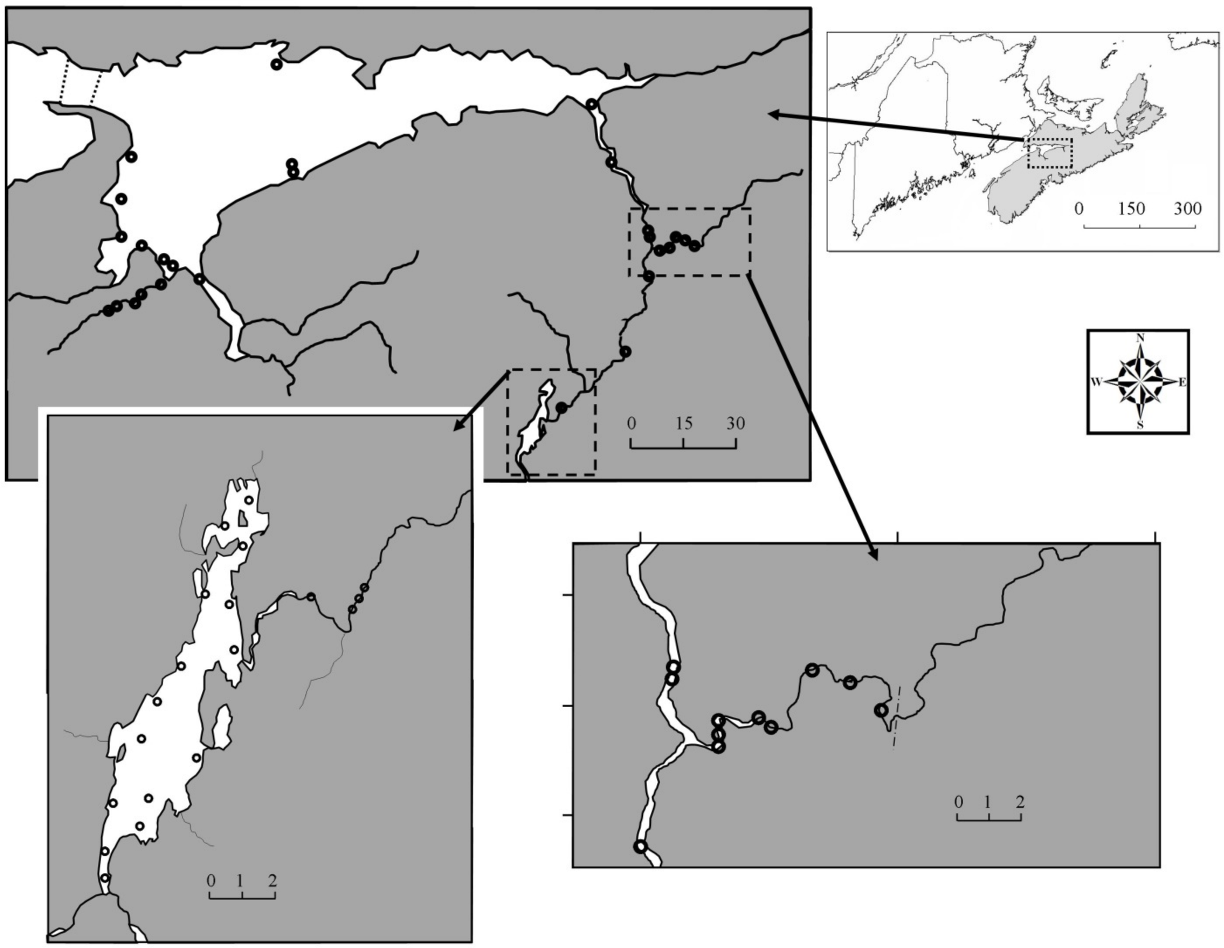

Figure 4. Location of hydrophones deployed in the spawning area within the tidal Stewiacke River, Nova Scotia. Scale bar units are in kilometres.

Figure 5. Beach seine sites sampled within Minas Basin (BoF), Nova Scotia in the years 1999-2005.

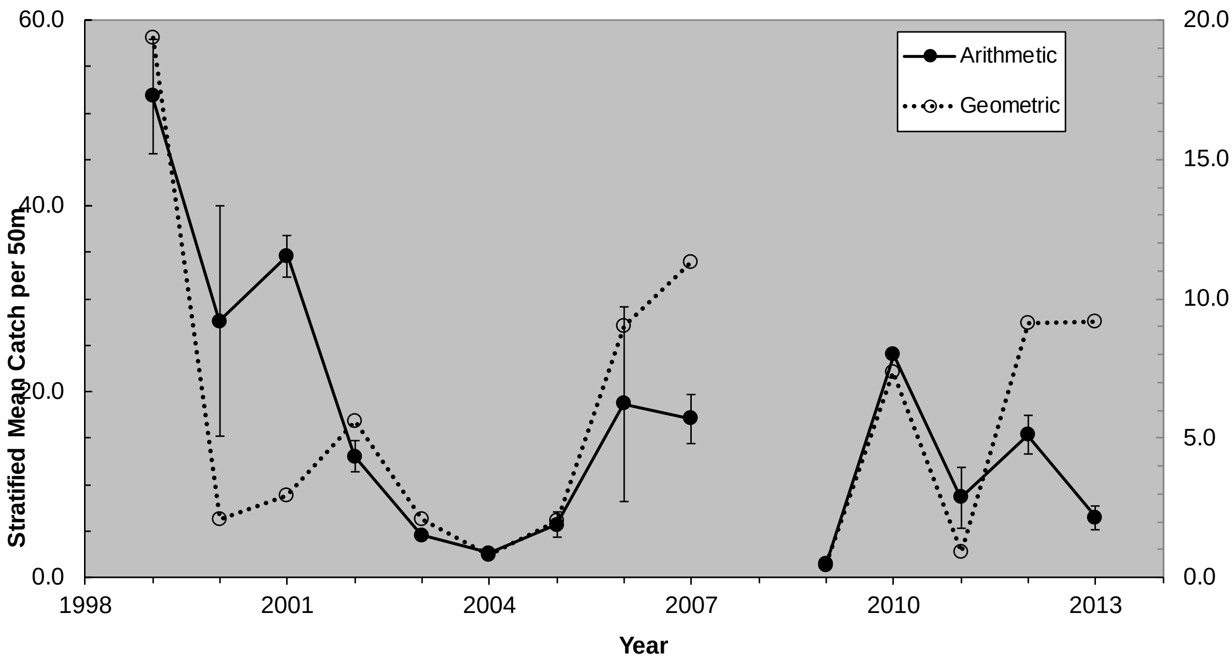

Figure 6. Arithmetic (±standard deviation) (left axis) and geometric (right axis) stratified mean annual catch (per 50 m sweep) of Shubenacadie River young of the year (YOY) Striped Bass from beach-seine surveys.

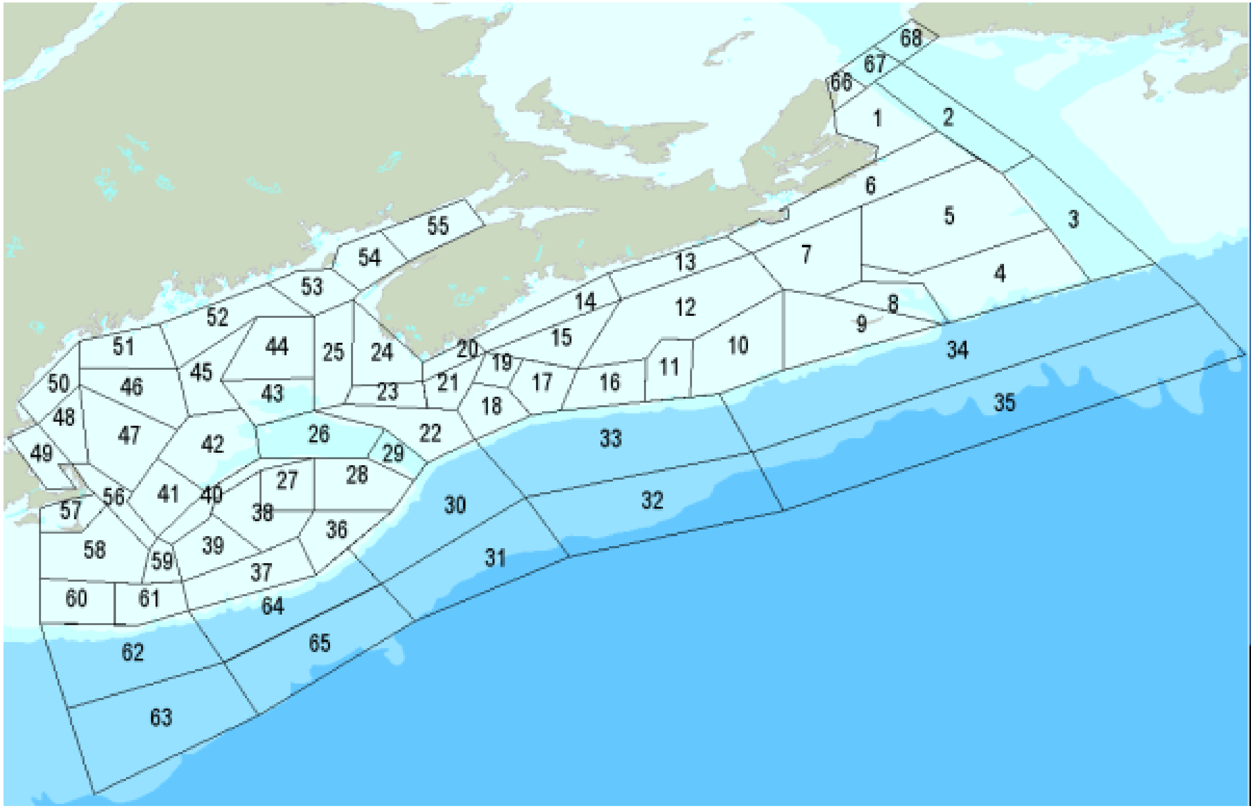

Figure 7. Area polygons for which time-series of satellite-derived SST (°C) are available. The SST data for Polygon 55 was used to generate summaries of change in winter temperatures for the inner BoF beginning in 1981.

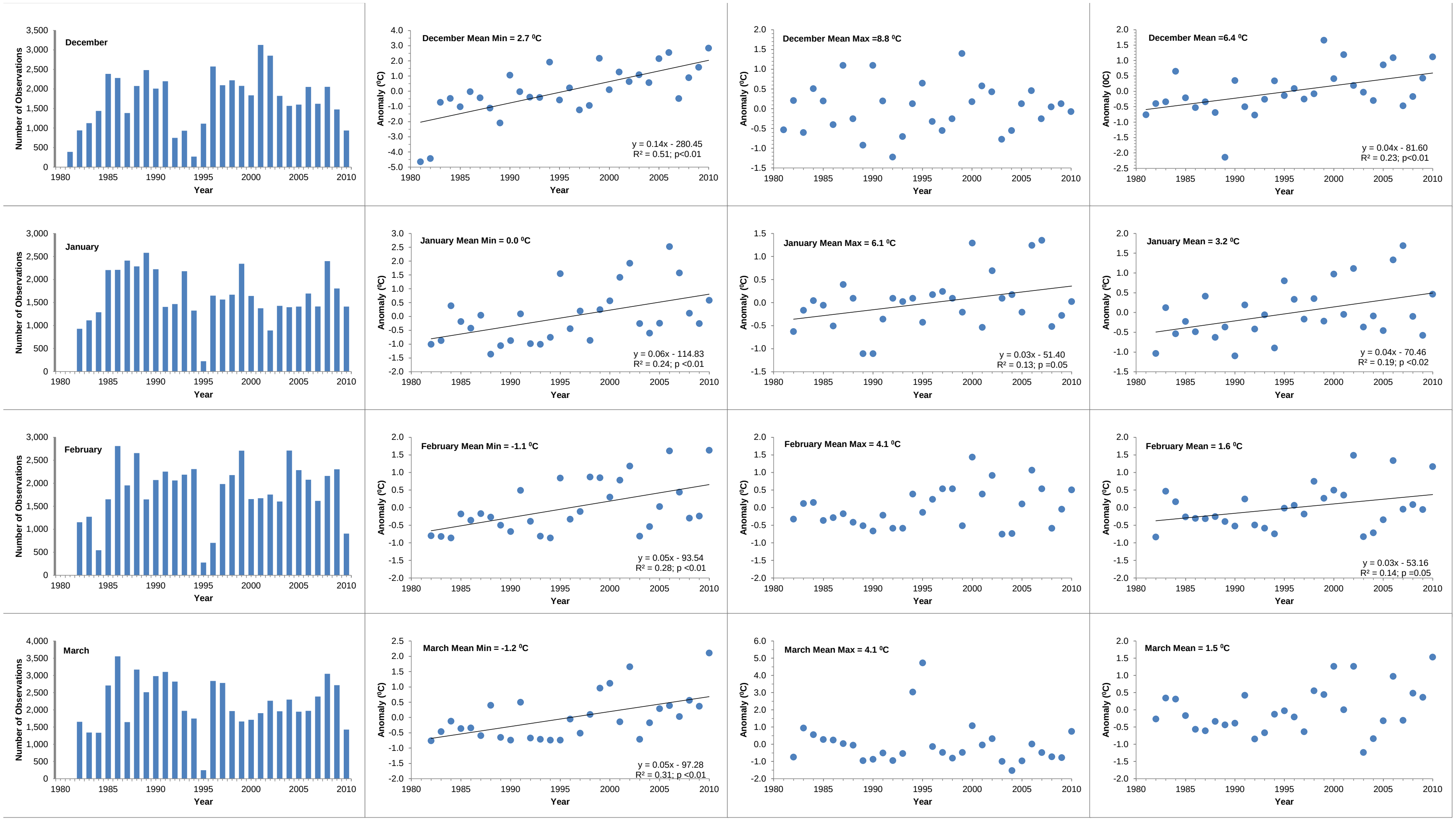

Figure 8. Satellite-derived minimum, maximum, and average SSTs (°C) for the months of December, January, February, and March from 1981 to 2010. The histograms (left-most panels in each row) show the number of satellite observations for each month by year.

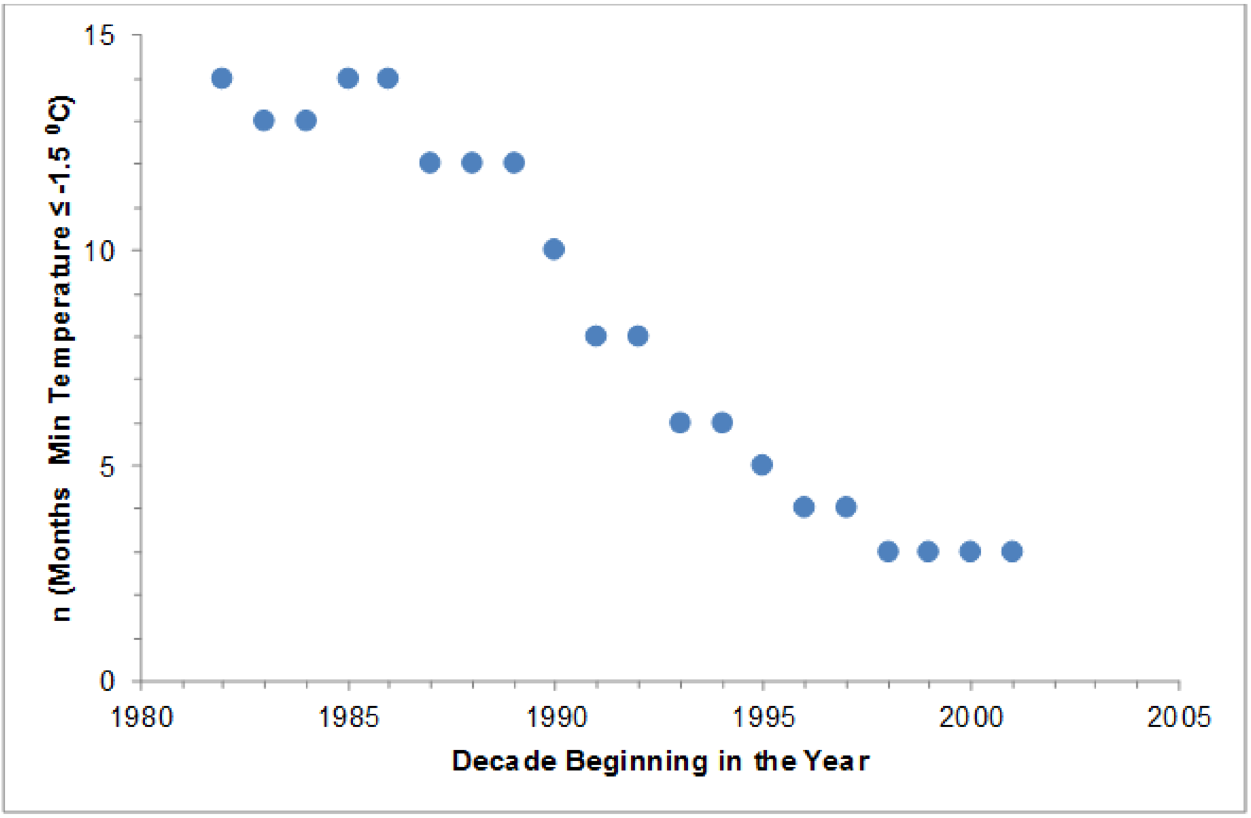

Figure 9. Number of months per decade with an observed minimum SST ≤ -1.5°C.

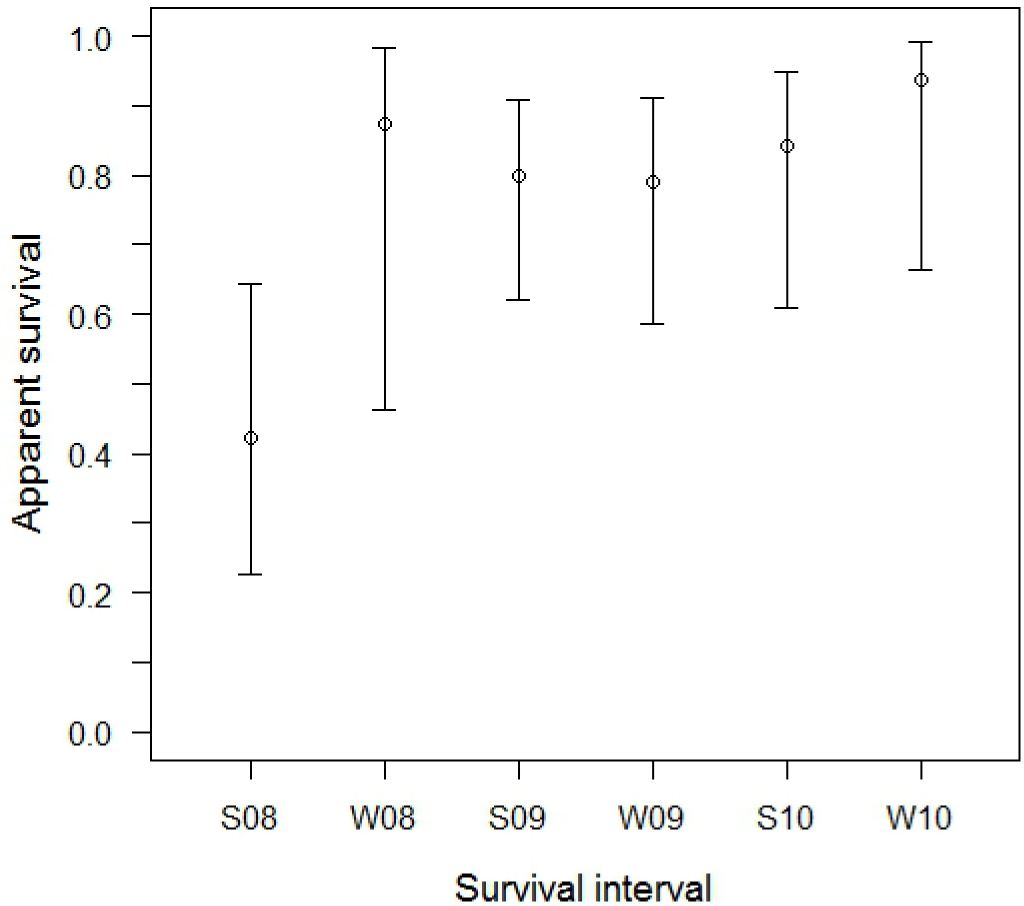

Figure 10. Survival estimates with 95% Upper and Lower confidence intervals by season (S = Summer; W = Winter).

APPENDICES

Appendix 1. Summary of features, functions, and attributes of BoF Striped Bass habitat.

Population	Geographic Location	Age from egg deposition	Function	Features	Attributes
Shubenacadie River	Stewiacke River 0 km to 6 km from confluence	Adults	Spawning (May-June)	Saltwater/Freshwater interface	Temperature: 13-24^{o}C Salinity: ≤ 1 ppt Water velocity: moderate current Dissolved oxygen: >5mg/l
		Eggs (0-3 days)	Incubation of pelagic eggs (May-June)	Saltwater/Freshwater interface Current to maintain eggs in suspension	Temperature: 13-24^{o}C Salinity: ≤ 1 ppt Water velocity: moderate current Dissolved oxygen: >5mg/l
		Larvae (0-7 days to first feeding)	Early development (May)	Saltwater/Freshwater interface Current to maintain eggs in suspension	Temperature: 15-26^{o}C Salinity: ≤ 6 ppt Dissolved oxygen: > 5mg/l Prey: zooplankton
		Larvae and recently metamorphosed juveniles (8-30 days)	Metamorphoses (May-July)	Waters under tidal influence in the Stewiacke and Shubenacadie rivers.	Temperature: 15-26^{o}C Salinity: < 10 ppt 8-17 days, 1-30 ppt 18-30 days. Dissolved oxygen: > 5mg/l Prey: zooplankton
	Tidal waters of the inner BoF	Age 0^{+} year (31-150 days post-hatch)	Growth (May-October)	Food availability	Temperature: ≤ 22oC Dissolved oxygen: > 5mg/l Prey: zooplankton
			Migration (May-December)	Corridor to/from winter habitat and spawning habitat	Temperature: ≤ 22^{o}C Dissolved oxygen: > 5mg/l Corridor free of obstructions that prevent/delay migration
			Overwintering (October–May)	Inner portions of estuaries	Temperature: ≥ -1.5^{o}C Dissolved oxygen: >5mg/l Water circulation that promotes retention
	Tidal waters of BoF including Saint John River, Shubenacadie River and lakes	All Age 1^{+} year and older	Growth (April-October)	Food availability	Dissolved oxygen: > 5mg/l Prey: mysids, crangon, polycheates, crabs, small, medium, and large fishes
			Migration (October-November)	Corridor to/from winter habitat	Temperature: ≥ -1.5oC (tidal waters) Dissolved oxygen: >5mg/l
			Overwintering (October–May)	Marine/estuarial	Temperature: ≥ -1.5^{o}C Dissolved oxygen: > 5mg/l Water circulation that promotes retention
				Freshwater	Lakes/embayments with low susceptibility to flushing Dissolved oxygen: > 5mg/l
		Adults Males: Age 3^{+} years and older Females: Age 5^{+} years and older females	Spawning	See 'Eggs'	Temperature: ≥ 15^{o}C (onset of spawning activity) Light: generally at dusk See 'Eggs'
				Corridor to spawning grounds	Free of obstructions that prevent/delay migration Dissolved oxygen: > 5mg/l
			Migration (October-November)	Corridor to/from winter habitat	Temperature: ≥ -1.5^{o}C (tidal waters) Dissolved oxygen: > 5mg/l
			Overwintering (October-May)	Marine/estuarine	Temperature: ≥ -1.5^{o}C Dissolved oxygen: > 5mg/l Water circulation that promotes retention
				Freshwater	Lakes/embayments with low susceptibility to flushing Dissolved oxygen: > 5mg/l
DU	Saint John River Annapolis River Non-specific locations within BoF	Spawners Eggs Larvae	Spawning	Estuarine	Large estuaries that share the features identified for Shubenacadie River Striped Bass Temperature: ≥ -1.5^{o}C Dissolved oxygen: > 5mg/l

Appendix 2. Summary of threats considered during the RPA, organized by attribute, the effect of the threat, populations affected, location of the effect and which abundance (A) and distribution (D) recovery targets are potentially impacted (see Tables 4 and 5 for the abundance and distribution recovery targets).

Attribute	Human Induced Threats	Effect of Threat	Effect Under Current Management Strategies			
			Populations Affected	**Level of Impact on Individuals**	**Location of Effect**	**Recovery Target**
Direct Mortality	Directed recreational angling fishery	Direct mortality of adults (retention or handling mortality in catch and release)	Shubenacadie Saint John	High	Tidal and non-tidal Shubenacadie River system. All tidal waters of the BoF. Tidal[2] and non-tidal portions of the lower Saint John River system below Mactaquac Dam.	AIIa DI, DII
Direct Mortality	Illegal fishing	Mortality as a result of illegal retention of Striped Bass (i.e.,without a general angling licence, during closures, below size limits or above bag limits)	Shubenacadie Saint John	Low for Shubenacadie and Saint John	Tidal and non-tidal Shubenacadie River system. All tidal waters of the BoF. Tidal and non-tidal portions of the lower Saint John River system below Mactaquac Dam.	AIIa DI, DII
Direct Mortality	Bycatch in commercial fisheries (gillnet, intertidal weir, trawl, trapnet, dipnet)	Mortality as a result of handling or retention of Striped Bass as bycatch in commercial fisheries targeting other species	Shubenacadie Saint John	High (gillnet, intertidal weir, trapnet) Medium (trawl) Low (dipnet)	Tidal and non-tidal Shubenacadie River system. All tidal waters of the BoF. Tidal and non-tidal portions of the lower Saint John River system below Mactaquac Dam.	AIIa DI, DII
Direct Mortality	Bycatch in recreational fisheries (angling)	Mortality as a result of handling or retention of Striped Bass as bycatch in recreational fisheries targeting other species	Shubenacadie Saint John	High for tidal water Low for freshwater	Tidal and non-tidal Shubenacadie River. All tidal waters of the BoF. Lower Saint John River (tidal and non-tidal).	AIIa DI, DII
Direct Mortality	Food, Social, and Ceremonial Fishery	Mortality as a result of handling or retention of Striped Bass by Aboriginals fishing under a FSC fishery licence	Shubenacadie Saint John	High (the cumulative annual communal requirement is potentially high)	Tidal and non-tidal Shubenacadie River lying below Grand Lake. All tidal waters of the BoF. Tidal and non-tidal portions of the lower Saint John River system below Mactaquac Dam.	AIIa DI, DII
Direct Mortality	Entrainment in flow-through turbines (Annapolis Tidal Power Generating Station)	Direct mortality or injury, cavitation	Shubenacadie Annapolis	Low for Shubenacadie High for Annapolis	Annapolis River Causeway at Annapolis Royal	AIIb DI, DII, DIII
Direct Mortality (and fish health)	Ecotourism and recreation	Disturbance of fish aggregations and introduction of petroleum products and byproducts through boat and recreational vessel use	Shubenacadie Saint John	Low	Spawning areas Stewiacke River (Shubenacadie) Undetermined (Saint John)	AIIb DI, DII
Direct Mortality (and fish health)	Ecotourism and recreation	Potential for direct injury to adult Striped Bass resulting from propeller strikes	Shubenacadie	Low	Spawning and staging sites for adults within the tidal Stewiacke River	AIIb

[2] Tidal is defined for the Saint John River as waters under tidal influence rather than relative to the definition of tidal waters contained in regulations.

Attribute	Human Induced Threats	Effect of Threat	Effect Under Current Management Strategies			
			Populations Affected	Level of Impact on Individuals	Location of Effect	Recovery Target
Direct Mortality (and fish health)	Scientific research	Handling related mortality, increased stress and disease transfer; obstruction of natural migrations and behaviour; introduction of petroleum products and byproducts	Shubenacadie Saint John	Medium for Shubenacadie Low for Saint John	Tidal and non-tidal Shubenacadie River below Grand Lake. All tidal waters of the BoF. Tidal and non-tidal portions of the lower Saint John River system below Mactaquac Dam	AIIb DI, DII
Direct Mortality	In-stream tidal power generation stations [Potential]	Possible future installation of in-stream turbines, which could represent a source of direct mortality	Shubenacadie Saint John	Unknown	Minas Channel (FORCE test site)	AIIb DI, DII
Direct Mortality	Fisheries on prey species	Reduction of prey species populations through directed fisheries, leading to Striped Bass mortality as a result of lost prey stocks	Shubenacadie Saint John	Low	Tidal and non-tidal Shubenacadie River lying below Grand Lake. All tidal waters of the BoF. Tidal and non-tidal portions of the lower Saint John River system below Mactaquac Dam.	AIIa DI, DII
Fish Health/Population Fitness	Striped Bass aquaculture	Releases from private Striped Bass aquaculture facilities result in introgression with wild individuals	Shubenacadie Saint John	Low	Tidal and non-tidal Shubenacadie River. All tidal waters of the BoF. Tidal and non-tidal portions of the lower Saint John River system below Mactaquac Dam.	AIIb DI, DII
Water Quantity, Water Quality, and Impacts on Habitat	Altered hydrology resulting from construction of barriers (Annapolis River Causeway, Mactaquac Dam)	Alterations of estuarial circulation and flow regimes; reduced access to habitat above partial or complete barriers, and alteration of spawning habitat below dam and above and below causeway due to changes in flow regime	Shubenacadie Saint John Annapolis	Low for Shubenacadie Uncertain for Saint John High for Annapolis	Annapolis River Causeway at Annapolis Royal Saint John River at Mactaquac Dam	AIIb DI, DII, DIII
Water Quantity, Water Quality, and Impacts on Habitat	Presence of in-stream barriers that impede migration and increase their susceptibility to harassment	Potential obstruction to migration of fish including foraging fish	Shubenacadie Saint John Annapolis	Low for Shubenacadie Uncertain for Saint John High for Annapolis	Annapolis River Causeway at Annapolis Royal Saint John River at Mactaquac Dam	AIIb DI, DII, DIII
Water Quantity	Presence of in-stream barriers that impede migration and increase their susceptibility to harassment	Increased authorized and unauthorized removals (mortality) resulting from greater susceptibility to exploitation; potential increase in physiological stress	Shubenacadie	Medium	Non-tidal portion of Shubenacadie River below Grand Lake	AIIa,b
Water Quantity	Presence of in-stream barriers that impede migration and increase their susceptibility to harassment	Potential increase in physiological stress	Shubenacadie	Uncertain	Non-tidal portion of Shubenacadie River below Grand Lake	AIIa,b
Water Quantity	Dyked lands that eliminate access to potential forage habitat along tidal river margins	Loss of potential forage for Age 0+ year	Shubenacadie	Low	Tidal portions of Shubenacadie and Stewiacke rivers	AIIb

Attribute	Human Induced Threats	Effect of Threat	Effect Under Current Management Strategies			
			Populations Affected	Level of Impact on Individuals	Location of Effect	Recovery Target
Water Quality	Municipal and industrial wastewater	Degraded water quality (e.g., low pH, low DO, toxic chemicals) and degraded sediment quality (e.g., accumulation and redistribution of toxic chemicals), heat, direct wastewater input	Shubenacadie Saint John Annapolis	Low	Tidal and non-tidal Shubenacadie River Tidal and non-tidal portions of the lower Saint John River system below Mactaquac Dam. Tidal and non-tidal Annapolis River above causeway	AIIb DI, DII, DIII
Water Quality	Agricultural run-off	Degradation of water quality (e.g., migration of nutrients, pesticides, animal waste) resulting in lowered DO, toxic substances, increase in plant growth.	Shubenacadie Saint John Annapolis	Low	Tidal and non-tidal Shubenacadie River. Tidal and non-tidal portions of the lower Saint John River system below Mactaquac Dam.Tidal and non-tidal Annapolis River above causeway	AIIb DI, DII, DIII
Water Quality	Acid precipitation (especially during periods of snow melt)	Low pH precipitation leading to reduction of surface water-body pH levels, potentially affecting survival of Striped Bass.	Annapolis	Low	Tidal freshwater portions of the Annapolis River lying below the confluence of the Nictaux River	AIIb DI, DII, DIII
Water Quality	Development of underground bulk storage facilities (e.g., for natural Gas Storage) Project [Potential]	Release of brine into Striped Bass habitat during development of underground natural gas facilities [Potential]	Shubenacadie	Unknown	Tidal portions of Shubenacadie and Stewiacke rivers in their area of confluence.	AIIb DI
Impacts on Habitat	Aggregate Mining [Potential]	Dredging of mineral sands (e.g., titanium) in tidal waters would involve the removal of substrate that could result in the alteration of Striped Bass habitat. [Potential]	Shubenacadie Saint John	Unknown	Tidal Shubenacadie River and Cobequid Bay.	AIIb DI
Impacts on Habitat	Invasive Species (Chain Pickerel in Shubenacadie and Muskellunge in Saint John River)	Loss of forage base for Striped Bass as a result of increased competition for forage. Predation on young Striped Bass. Competition for habitat.	Shubenacadie (Chain Pickerel) Saint John (Muskellunge)	Low	Grand Lake, NS Saint John River	AIIb DI, DII
Impacts on Habitat	Ecosystem Change	Change in water temperatures results in altered key life-history functions (spawning, overwintering)	Shubenacadie Saint John Annapolis	Medium	Spawning sites within the tidal Stewiacke River (Shubenacadie), overwintering areas in tidal portions of the BoF (Shubenacadie, Saint John, Annapolis)	AIIb DI, DII