Spatio-Temporal Distribution of Eggs and Age-0 Striped Bass (*Morone Saxatilis*) in the Shubenacadie River Estuary

by

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DALHOUSIE UNIVERSITY

FACULTY OF AGRICULTURE

The undersigned hereby certify that they have read and recommend to the Faculty of Graduate Studies for acceptance a thesis entitled “Spatio-Temporal Distribution of Eggs and Age-0 Striped Bass (*Morone Saxatilis*) in the Shubenacadie River Estuary” by Gina M. MacInnis in partial fulfilment of the requirements for the degree of Master of Science.

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Signature of Author

In memory of Zhuhui Ye.

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Abstract

The spatio-temporal distribution of age-0 striped bass was evaluated in the Shubenacadie estuary from May to September, 2010 and 2011. From mid-May to the end of June each year there were 2-3 large spawning events resulting in 1000 to 8000 eggs/m^3 water filtered. First feeding larvae density peaked around 400/m^3 in 2010 and 800/m^3 in 2011. Spatio-temporal distribution of eggs and larvae $\leq$ 7 mm total length was dictated by the magnitude of freshwater run-off and tide size. The upstream transportation limit on the flood tide was the salt front. Advection from the estuary into Cobequid Bay occurred both years. Mean (SE) total length of juveniles in late-August was 7.5 (3.16) cm in 2010, but only 4.5 (1.49) cm in 2011. The high abundance of eggs indicates the adult population is healthy, but abundance and growth of early life stages are greatly affected by fluctuations in freshwater run-off and temperature.

List of Abbreviations Used

ADCP	Acoustic Doppler Current Profiler
AGS	Alton Gas Site
CTD	Conductivity-Temperature-Depth Probe
CN	Canadian National
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
DFO	Department of Fisheries and Oceans
dph	Days post hatch
ETM	Estuarine Turbidity Maximum
FL	Fork Length
GPS	Global Positioning System
ppt	Parts Per Thousand
SR	Shubenacadie River
SHB	Stewiacke Highway 102 Bridge
StR	Stewiacke River
TL	Total Length
YOY	Young of the Year

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Chapter 1. Introduction

1.1 Project Overview

Fish stocks are declining globally (Myers and Worm 2003). Understanding population dynamics and factors affecting recruitment is a top priority in fisheries science. The Bay of Fundy population of striped bass (*Morone saxatilis;* Walbaum 1792) has recently been re-listed from 'threatened' to 'endangered' (COSEWIC 2012). The endangered status is designated to species that fall within a narrow range in four criteria including: decline in the total number of mature individuals (> 50 - 70 %), narrow distributional range, small total Canadian population (< 250 mature individuals) and bleak population projections (20 % probability of extinction within 20 years; COSEWIC 2012). Historically three estuaries in the Bay of Fundy supported spawning of this genetically discrete striped bass population (Wirgin et al. 1993). However, the Annapolis and Saint John Rivers have shown no evidence of successful spawning since the 1970's, leaving the Shubenacadie-Stewiacke estuary as the sole location supporting a striped bass spawning population in the Bay of Fundy (Bradford et al. 2001; Douglas et al. 2006). Across the species range, from South Carolina to New Brunswick and on the West coast from Ensenda Mexico to Vancouver, the Shubenacadie is the only tidal bore dominated estuary that serves as the nursery habitat for striped bass (Setzler-Hamilton et al. 1981; Rulifson and Dadswell 1995). Tidal bore rivers experience highly variable environmental conditions due to the large tides, with rapid changes in salinity, temperature and turbidity (Lynch 1982).

Typical of many marine fish, striped bass are open spawners, releasing large numbers of small pelagic eggs in the spring, which hatch quickly yielding small (5 mm TL) and delicate larvae (Secor and Houde 1995). Hourly sampling is needed to monitor the spatial and temporal distribution of eggs and larvae because of their quick development and decreasing density in the first 24-hours post spawning (Reesor 2012; Objective 1). The majority of mortality occurs during egg, yolk-sac and first feeding larvae stages particularly (< 7 mm), also known as the early life stages (Cushing 1990). Striped bass larvae have limited swimming ability at first feeding and need to rely on an abundance of prey items to be within their reactive distance. As part of the thesis I described age-0 stomach content items and prey density in the Shubenacadie River. Once individuals survive their first year their chances of surviving to maturity are greatly increased (Green 1982; Houde 1987). Striped bass year class success is believed to be affected by density-independent factors particularly environmental conditions, such as cold weather and heavy rain during early life stages (Ulanowicz and Polgar 1980; Rago and Goodyear 1987; Uphoff 1989). Knowledge of how environmental conditions influence early life stage striped bass in the spawning-nursery habitat is important in understanding, managing and conserving the species. As part of my thesis I assessed how environmental factors including temperature and rainfall influenced the timing of spawning, early life stage striped bass growth and distribution, both temporally at one location and spatially throughout the estuary nursery habitat. Nursery habitats are areas where larvae or juveniles disproportionately contribute individuals to adult populations of a species by occurring in higher densities, avoiding predation more successfully and having faster growth rates compared to other habitats (Beck et al. 2001; Hobbs et al. 2010).

Shubenacadie-Stewiacke River striped bass display otolith elemental signatures during the initial months of growth that indicate that the nursery grounds are not in the Cobequid Bay or downstream close to the mouth of the Shubenacadie estuary, but farther upstream near the freshwater habitat (Morris et al. 2003).

The Shubenacadie River population of striped bass has recovered from its depressed state in the 1990's (Jessop 1995). Contrary to its endangered status, the number of adults is currently very large, and according to local fishermen the population is the highest in over 50 years (W.H. Stone and R. Meadows, personal communication, Alewife fishermen, Stewiacke, NS). The recovery of the population was associated with high recruitment in the late 1990's and early 2000's (Bradford et al. 2012). Despite this association, knowledge of factors affecting survival and recruitment of early life-history stages of Shubenacadie striped bass is poor. The state of knowledge is restricted to basic stock status reports published by the Department of Fisheries and Oceans (DFO), some pioneer research by North Carolina researchers mostly in 1994 (Tull 1997; Paramore 1998; Rulifson and Tull 1999) and a descriptive study on the timing and conditions of spawning in 2008 and 2009 (Reesor 2012). Fecundity of female striped bass of the Shubenacadie population, ranges from 58,000 among four year old fish (45 cm FL) to 1.3 million eggs, among 11 year old fish (90 cm FL; Paramore 1998). To allow me to better estimate the total number of spawners based on egg abundance I estimated fecundity from 16 female Shubenacadie River striped bass. Spawning mostly takes place 3 - 8 km upstream of the Shubenacadie-Stewiacke River confluence on the Stewiacke River, between the Highway 102 bridge and the Canadian National (CN) train bridge (Meadows 1991; Fig. 1.1). Eggs and early stage larvae (< 7 mm TL) are suspended in the water column by the turbulent water. The eggs and yolk-sac larvae act as passive particles; the hydrodynamics of the Shubenacadie estuary dictates their spatial distribution, being carried upstream with the flood tide and drifting back downstream on the ebb tide (Tull 1999). This passive transport of eggs and larvae back and forth with the tides makes it difficult to get an accurate abundance count (Objective 4). It is unclear how pelagic eggs and yolk-sac larvae with no swimming ability are retained in the Shubenacadie estuary which ebbs out to the Cobequid Bay for 10 - 11 hours of each 12 h and 20 min tidal cycle. A single drogue buoy drift in 1994 indicated advection into the Cobequid Bay was possible (Rulifson and Tull 1999).

Striped bass year class strength, distribution and recruitment are well studied in many US estuaries where the stratification and associated estuarine turbidity maximum (ETM) play an important role retaining pelagic eggs and larvae in the estuary nursery habitat (Shoji et al. 2005; North and Houde 2006). In contrast, the Shubenacadie River estuary is highly mixed with no ETM (Dalrymple 1977; Parker 1984; Tull 1997). I hypothesize that retention of eggs and larvae within the Shubenacadie estuary is important for recruitment. The Cobequid Bay is less favorable for early life stage striped bass (eggs and larvae > 7 mm TL) development, with higher salinities, lower temperatures in spring and perhaps less abundant prey (Jermolajev 1958; Dalrymple et al. 1990; Rulifson and Dadswell 1995; Cook et al. 2010).

The aim of my thesis was to quantify the spatio-temporal position and abundance of eggs and larvae with respect to conditions such as tide, rainfall, time and location of spawning. I hypothesize the Shubenacadie estuary serves as a nursery habitat in the Bay of Fundy due to its relatively long length (64 km of tidal flow), while shorter estuaries are not suitable because advection of early life stage striped bass would be guaranteed. The initial downstream transportation of eggs from the spawning grounds on the Stewiacke River is followed by multiple upstream and downstream transportation events on both rivers (Reesor 2012). Eggs are 3.5 mm in diameter and their development is related to temperature hatching in about 48 hours post-fertilization at 16 – 17 °C (Harrell et al. 1990). To determine how striped bass are retained in the nursery habitat my objective was to quantify the duration and velocity of the ebb and flood tides throughout the estuary, as they represent the magnitude of the up and downstream transportation. Retention occurs if striped bass are anywhere in the estuary when the next flood tide reaches the estuary mouth. The aim is to advance the state of knowledge of early life stage striped bass spatio-temporal distribution. The current high abundance of striped bass eggs and larvae in the Shubenacadie River together with financial support from Alton Natural Gas Storage LP (Fig. 1.1), who is required to do environmental monitoring, provides an excellent opportunity to study the factors affecting spatio-temporal distribution of this valuable fish. This knowledge will provide valuable new insight of how recruitment and population dynamics are governed for Bay of Fundy striped bass. The ultimate goal is to use the knowledge gained in an effort to help the recovery of the Annapolis and Saint John Rivers striped bass populations.

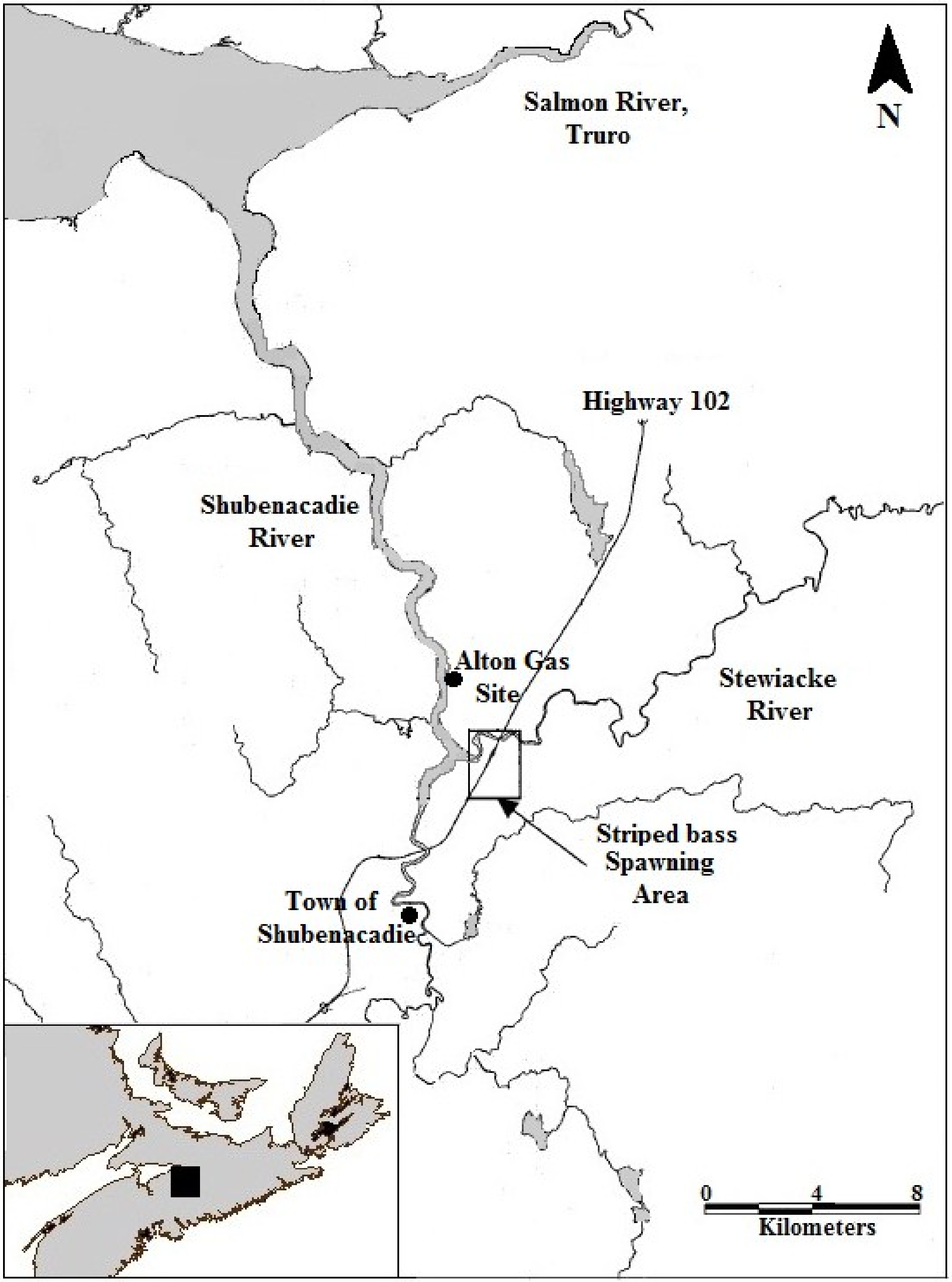


Figure 1.1: Map of the Shubenacadie watershed. The location of the estuary within central Nova Scotia, Canada is represented by the black box in the lower left corner (modified from Cook 2003).

1.2 Alton Natural Gas Storage Project

This M.Sc. thesis is part of a research project started in 2008 and funded by Alton Natural Gas Storage LP. The company is planning to construct underground storage caverns to help manage the supply of natural gas to eastern Canada and the United States. One of the outcomes of the 2007 Nova Scotia Government approved environmental assessment required monitoring at a planned river diversion channel (45° 09.423 N -63° 23.133 E; Fig. 1), located 2.4 km downstream of the confluence of the Shubenacadie and Stewiacke Rivers. One component of the monitoring project included quantifying the density and timing of early life stage striped bass at the Alton Gas Site, which was the principal sampling site (AGS; Fig. 1.1). Funding from the Alton Gas Storage Project provided an opportunity to study the population.

The Alton Natural Gas Storage LP construction plan involves pumping Shubenacadie River water 10 km to underground salt deposits near the village of Alton. The water will dissolve the salt, 99% NaCl, to create caverns for storage of natural gas. The solution mining will create brine effluent, which will be pumped back to a 5,000 m^3 holding tank next to the Shubenacadie River and then gradually released brine into a constructed diversion channel alongside the estuary. The estuary water used to dissolve the salt will be extracted at a maximum rate of approximately 10,000 m^3 day^{-1}, which is less than one percent of the daily total flow in the estuary. Effluent brine will be pumped back to a holding tank at a maximum rate of 9000 m^3 day^{-1}. The water extraction and brine discharge is expected to take place over 2 to 2.5 years to create four caverns. An additional 10 to 15 caverns may be added at a later date depending on the market demand for natural gas (Martec 2007a).

The Alton Gas project presents both a possible chemical and physical threat to organisms in the Shubenacadie estuary. The brine effluent will slightly increase the concentration of sodium chloride within the diversion channel (Martec 2007a). Estuaries vary in salinity, from nearly fresh water at the head of the estuary to seawater at the mouth (Moyle and Cech 1982). Striped bass eggs and yolk sac larvae are euryhaline, showing high rates of survival in 2 - 20 ppt salinity conditions but higher rates of mortality in 30 ppt seawater (Cook et al. 2010). Although I did not have access to the new diversion channel output design at time of publication, it hopes to improve on an older model design which would raise the ambient (15 ppt was used) salinity by 0.9 ppt to 3.4 ppt (depending on the tide) 1 kilometer downstream (Martec 2007a). If these estimates are correct, the predicted changes in salinity should have an insignificant effect on striped bass.

Possible physical threats may stem from localized changes in hydrodynamics in and around the diversion channel. Striped bass eggs and yolk-sac larvae lack avoidance and swimming mechanisms (Peterson and Harmon 2001) and thus could be physically harmed through impingement in the water intake pipe. Determining the temporal and spatial distribution of striped bass eggs and larvae with respect to stage of development over tidal cycles and seasonally will allow engineers to determine an operational plan that will minimize risk to this endangered species.

1.3 Thesis Objectives

The objectives of this Master's project examining Shubenacadie River striped bass egg in May and June to age-0 juveniles in late summer were as follows:

1. Describe the spatial distribution and density from the mouth of the Shubenacadie estuary to the head of the tide and temporal density and abundance at the Alton Gas Site.
2. Determine if early life stage striped bass are advected into Cobequid Bay.
3. Describe the effect of rainfall and tide height to spatial and temporal distribution.
4. Estimate total egg abundance by factoring in egg density (eggs/m^3), water velocity and cross-sectional area at the Alton Gas Site over the spawning season.
5. Describe the relationship between temperature and the timing of spawning.
6. Describe age-0 striped bass stomach contents.
7. Quantify larvae and juvenile body size from June to September in relation to temperature.

1.4 Thesis Outline

Chapter 1 provided a brief introduction and the objectives of the project. Chapter 2 provides a general description of the physical features of the Shubenacadie estuary. This chapter combines both published and new information collected during my studies. An understanding of the estuary is first needed because the hydrodynamics have such an important influence on egg and early larval stages. Chapter 3 reviews striped bass literature pertinent to the objectives of this study. Chapter 4 contains the methods for the collection and analysis of the biological data. Chapter 5 presents the results of striped bass fecundity, as well as egg and larvae temporal and spatial distribution. Chapter 6 presents the results of larvae and juvenile striped bass distribution and growth, as well as age-0 striped bass stomach content, and prey density. Chapter 7 presents a general conclusion and recommendations for future study. Tables and figures are arranged at the end of each section, followed by the discussion.

Chapter 2. The Shubenacadie Estuary, a Physical Description

2.1 Introduction

The spatio- temporal distribution of early life stage striped bass is largely controlled by the topography and hydrodynamics of the Shubenacadie estuary. In turn, the hydrodynamics are dictated by the tidal cycle in Cobequid Bay and Minas Basin and the freshwater run-off from the land. Quantifying the physical features of the river system including the length, tidal flow, velocities, salinity and mixing, are needed to explain the temporal distribution of striped bass early life stages as they act as passive particles. Shubenacadie River striped bass spawn near the head of the tide on the Stewiacke River, which is about 35 km upstream from Cobequid Bay (Rulifson and Tull 1999). The head of the tide is the farthest location upstream where salt water penetrates, however tidal fresh water continues to be pushed further upstream. The relatively long estuary, coupled with ebb and flow of the tide was speculated to play a role in retaining striped bass eggs and larvae in the upper estuary (Rulifson and Tull 1999). The Shubenacadie estuary has limited historical data on its physical features. This chapter is a combination of literature review, physical measurements taken by Martec Ltd. in 2006 for initial environmental monitoring conducted for the Alton Natural Gas Storage LP project, and data collected by my colleagues and I from 2010 - 2012. My objective was to determine whether early life stage striped bass could be advected from the estuary, out into Cobequid Bay (Objective 2).

2.2 The Shubenacadie Estuary

Estuaries are waterways that transition from a river to an ocean or bay. Their waters have tidal movement and they often have a funnel shape and gradual elevation moving inland (Hansen and Rattray 1966). Estuaries are highly productive habitats. The dynamic environment of continuous input of organic and inorganic nutrients from river catchments mixing with saline water contributes to an abundance of nutrients, phytoplankton, bacteria, detritus, and suspended sediments in the water column (Davidson 1990). The Shubenacadie River including its estuary is the longest in Nova Scotia, starting at Grand Lake near Halifax and running 81 km before draining into Cobequid Bay in the inner Bay of Fundy, a maximum of 64 km of which is tidal (Shubenacadie-Stewiacke River Basin Board 1981). The watershed has 16 drainage systems in its headwaters, 68 lakes and a total surface area of 2800 km^2 (Lay et al. 1979). Its main tributary is the Stewiacke River which enters the Shubenacadie approximately 27 km upstream from the mouth. The most prominent physical feature of the Shubenacadie estuary is its tidal bore. Globally, tidal bores occur in only about 67 locations in 16 countries (Bartsch-Winkler and Lynch 1988). Generally, bores form in estuaries with a high tidal range, a narrowing and sloping entrance, and a relatively small river discharge compared to tidal flow (Chan and Archer 2003). The Shubenacadie estuary has a 10 - 11 m tidal range at its mouth due to its position at the head of the Bay of Fundy. The Bay of Fundy's funnel shape and topography, results in the highest tides in the world (Archer and Hubbard 2003; McLusky and Elliott 2004).

2.2.1 Tide Timing, Bores and Water Exchange

Tides are the sea level rise and fall caused by the gravitational forces of the moon and sun in relation to the orientation of the earth. Generally, tides are semi-diurnal and symmetrical, with two high and two low tides each day, each lasting for approximately 6 h and 10 min. High tide height varies, building up to a maximum and falling to a minimum twice a month. Around new and full moon when the sun, moon and earth are aligned, the tidal range is at its maximum, which is called a spring tide. When the moon is first quarter or third quarter, the sun and moon are perpendicular and the tidal range is at its minimum, which is called a neap tide. Daily high tide height variation also occurs, during the summer months the bigger daily tides occur at night; while in the winter the bigger daily tides occur during the day. This seasonal daily tide height shift occurs because of the earth's axis tilt and orbit around the sun (Dyer 1997).

In the outer Bay of Fundy and at the mouth of Cobequid Bay (Burntcoat Head; Fig. 2.1) the tides are symmetrical, with the ebb and flood tide each lasting about six hours. By comparison, in the inner Cobequid Bay and upstream in the Shubenacadie estuary the tides are asymmetric, the flood tide being of shorter duration than the ebb tide (Stone 1976, Dalrymple 1977; Rulifson and Tull 1999). This transition from symmetrical to asymmetrical tides occurs because of the difference in water speed, the flood tide comes in quickly with the bore and the ebb tide goes out gradually with the estuary current. When water from deeper coastal regions moves inshore and interacts with a basin or river bottom the distance between wave crests is reduced, and the waves themselves become asymmetrical, the leading side becomes steeper and the tailing side flatter, transporting energy and water forward and creating a tidal bore (Lynch 1982). The tidal bore speed is a function of water depth, whereas the ebb tide velocity is mostly associated with the square root of the longitudinal river slope. Peak velocity is therefore higher during the flood tide than the ebb tide. This difference in speed causes an increasing tidal asymmetry the further upstream (Allen et al. 1980). Within Cobequid Bay the incoming tide forms a tidal bore beginning at the mouth of the Shubenacadie River (Dalrymple et al. 1990). Traveling up the Shubenacadie River this increasingly asymmetrical tidal cycle has been quantified at two locations, the mouth of the river and the AGS during initial surveys for the Alton Natural Gas Storage LP project (Martec 2007a). At the mouth of the Shubenacadie River (Black Rock) the flood tide lasts about 3 h 30 min and the ebb tide last approximately 9 h. Twenty five kilometers upstream at the AGS the flood tide lasts on average 86 min and the ebb tide lasts on average 10 h 50 min (MacInnis, this study). The average time between high tide at AGS and next tidal bore at the estuary mouth is 8 hr 19 min, and the average time for bore to move up river from the estuary mouth to the AGS is 2 h 37 min with a speed of 9.5 km/h (Martec 2007a; Fig. 2.2). At the "Fish House", the docking area for commercial fishers of gaspereau (*Alosa pseudoharengus* and *Alosa aestivalis*) and American shad (*Alosa sapidissima*), about 600 m upstream of the confluence on the Stewiacke River, the Saint John tide table has been used by local fishermen to estimate the timing of the tide for decades. Conveniently, to calculate the timing of the tidal bore at the Fish House, two hours is added to the high tide time for that day on the Saint John, New Brunswick tide table. Saint John is about 200 km west of the Fish House on the Bay of Fundy. Quantifying the tidal asymmetry at other locations along the Shubenacadie-Stewiacke estuary was part of my thesis. This enabled me to gain a greater understanding of the positioning of passive particle organisms, early life stage striped bass being of principal interest. Linking the tidal asymmetry to the Saint John tide table will also aid researchers doing future work on the estuary.

At the mouth of the Shubenacadie estuary the estimated ebb and flow volumes of a large tide are over 8 million/m^3 and 6 million/m^3 per tide respectively, with the volume of a small tide approximately half of those values (Martec 2007a). This translates into a tidal range of 11 m at the mouth of the estuary and 4 m at the AGS on a spring tide, and respectively, 8 and 1.5 m on a neap tide. During spring tides the peak flood tide flow rate (m^3/sec) at the AGS is nearly 400 m^3/sec, and during the ebb tide is 320 m^3/sec (Martec 2007a; Fig. 2.3). During spring tides, the elevation of the tidal bore is about 1 m at the estuary mouth and approximately 0.3 m at the AGS, with large undulating waves following the bore. On a spring tide, approximately 10% of the flood tide volume at the estuary mouth reaches the AGS (Martec 2007a). The volume of water in the river at a given time is mainly dictated by the state of the tide and the magnitude of fresh water run-off. Near the mouth of the estuary fresh water run-off has only a minor influence on the volume, causing a slight increase in water level near the end of the ebb tide. However, at the AGS rainfall events have a significant effect on the water volume. The ebb tide water level can increase by more than 1 m after a heavy rainfall event (Martec 2007a). Due to the large variation in volume variability at the AGS, measuring river cross sectional area during spawning season was essential to allow estimation of total striped bass egg abundance (Objective 4).

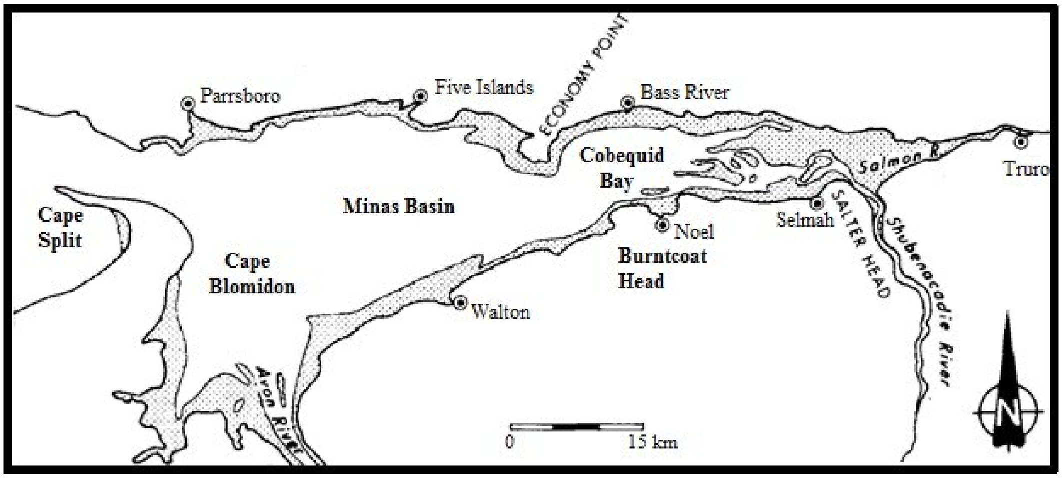


Figure 2.1: Map of the inner Bay of Fundy, Minas Basin and Cobequid Bay, leading into the Salmon and Shubenacadie Rivers. Sand bars exposed at low tide are shown in gray scale (modified from Dalrymple et al. 1990).

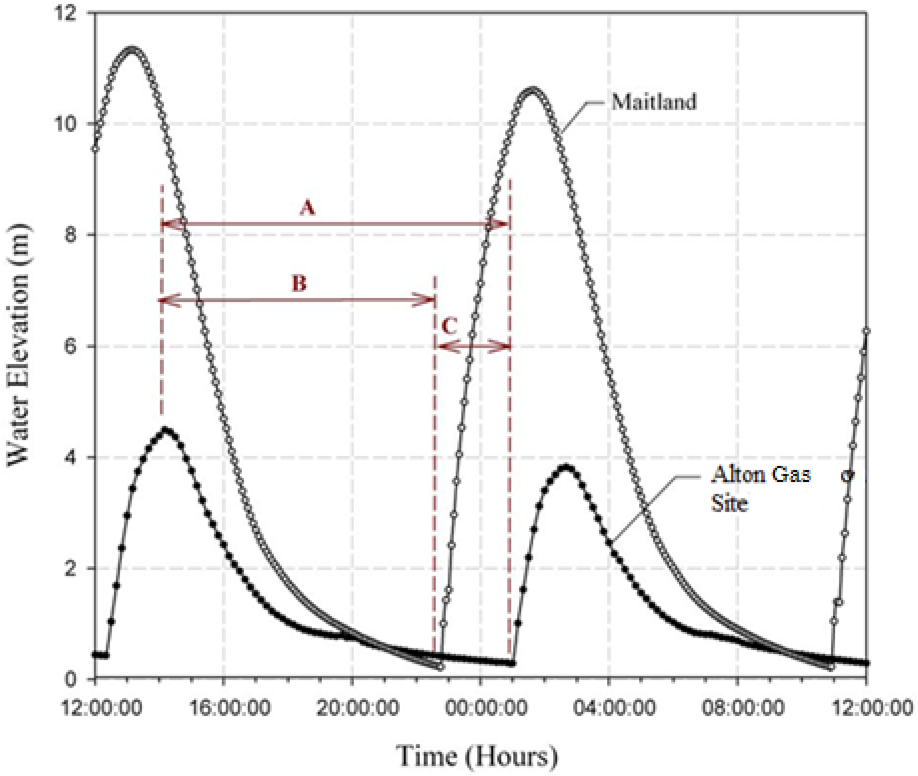


Figure 2.2: Asymmetrical water elevation profiles measured at Maitland (mouth of the estuary) and the Alton Gas Site (AGS) during a large 8 meter tide November 6, 2006. A: average time of ebb tide at the AGS (10 h 49 m), B: average time between high tide at AGS and next tidal reversal at Maitland (8 h 19 m), C: average time for bore to move up river from Maitland to the AGS (2 h 37 m; Martec 2007a).

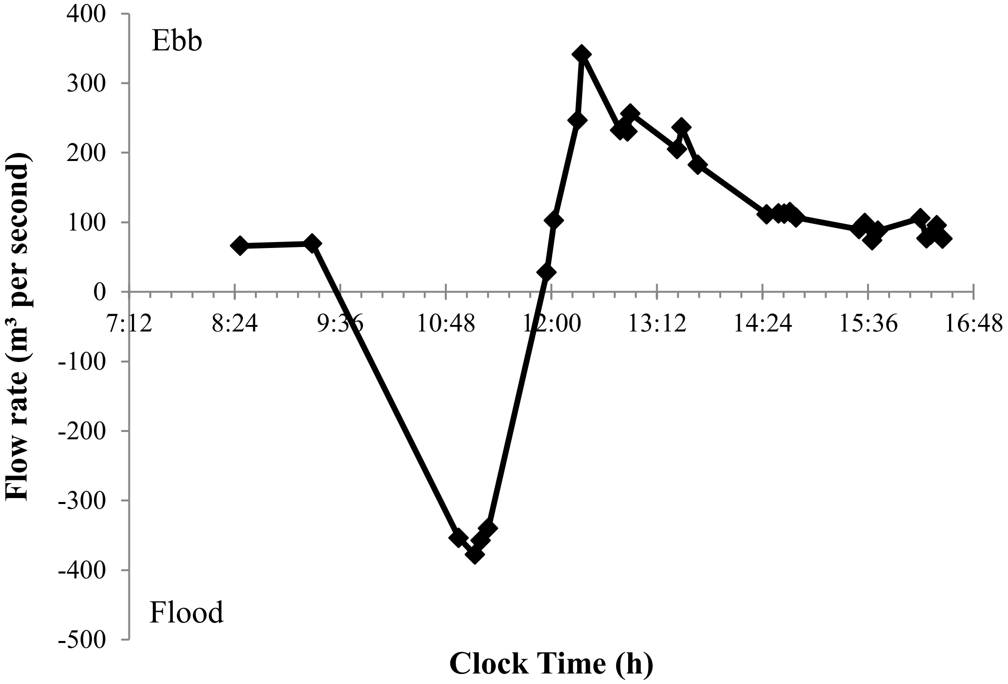


Figure 2.3: Shubenacadie River flow rate (cubic meters per second) at the Alton Gas Site through the flood and part of the ebb tide on October 17, 2006. Data collected from an Acoustic Doppler Current Profiler (600 MHz Teledyne/RDI Rio Grande; Martec 2007a).

2.2.2 Tidal Water Flow Direction and Velocity

River water velocity and direction dictate the temporal and spatial distribution of eggs and early life stage larvae (Objective 1). The Shubenacadie estuary exhibits a strong relationship between tidal amplitude, water velocity and the upstream penetration of the salt front, much like other estuaries (Dyer 1997). The salt front is the interface between fresh and salt water in an estuary. Environmental factors affecting the timing and velocity of the ebb and flood tides are the lunar cycle, bathymetry and fresh water run-off. The speed of the flood tide increases as it moves inshore relative to the ebb tide velocity (Lynch 1982). In the Western section of the Cobequid Bay the maximum flood and ebb tide velocities are the same at 3.6 km/h. From Salters Head (Fig. 2.1) to the mouth of the Shubenacadie estuary the maximum flood and ebb tide velocity increases from 7 to 11 km/h (Dalrymple et al. 1990). Within the Shubenacadie River, a mean flood tide velocity of 7.4 km/h was recorded between Gosse Bridge and the confluence of the Shubenacadie and Stewiacke River in 1994 (Rulifson and Tull 1999). In 2006, the mean tidal bore velocity from the estuary mouth to the AGS was recorded at 9.5 km/h (Martec 2007b). It is important to emphasize that the maximum flood tide velocities are always associated with the tidal bore wave itself, and the following flood tide velocity is slower (Pan et al. 2007).

Peak ebb tide velocity increases progressively from upstream to downstream. Upstream on the Shubenacadie River at Lantz (km 59) and Milford Station (km 48) the ebb tide velocity ranged between 0.2 to 2 km/h over several ebb tides (Parker 1984). Nearly 600 m upstream from the rivers confluence on the Stewiacke River, over many tidal cycles from May to July 1994 the ebb tide velocity ranged from <1 km/h to 4 km/h over several ebb tides (Rulifson and Tull 1999). Downstream, ebb tide velocity, from the confluence to the Gosse Bridge averaged 4.7 km/h on a single ebb tide (Rulifson and Tull 1999). For my thesis, measuring ebb tide velocity from the main spawning grounds on the Stewiacke River to Cobequid Bay over a range of tidal and freshwater conditions was necessary to explain the possible spatial distribution of striped bass eggs and larvae and whether they could be advected from the river into the Cobequid Bay (Objective 2).

The flood tide extends from the mouth estuary mouth at Cobequid Bay to the head of the tide, to a maximum of 64 km up the Shubenacadie River and 16 km up the Stewiacke River (Shubenacadie-Stewiacke River Basin Board, 1981). The flood tide splits at the Shubenacadie/Stewiacke confluence, with the majority of the water continuing up the

Shubenacadie River. As a tidal bore progresses upstream the direction of water flow is reversed within a few minutes (Lynch 1982; Wolanski et al. 2004). The bore and the flood tide ends when the energy is slowed by the friction between the water molecules moving upstream and those coming downstream and the river bottom. When enough of the bores energy is lost the bore slows and the gravity feed velocity of the river overtakes the flow (Dyer 1997). On the Shubenacadie/Stewiacke estuary it is unknown how far passive striped bass eggs and larvae are carried upstream on the flood tide, or how far upstream the tidal salt water penetrates. The distance of upriver transport affects the subsequent downstream transportation distance and potential advection from the estuary nursery habitat. Describing the upper limits of the salt front related to tide and freshwater run-off was included in my research to help define the spatial distribution of early life stage striped bass.

2.2.3 Mixing of Salt and Fresh Water and Temperature

Estuaries are classified into three main categories: salt wedge, partially-mixed, and well-mixed, based on the ratio of river flow and tidal range (Allen et al. 1980; McLusky and Elliott 2004). The Shubenacadie estuary is well-mixed. The tidal forces exceed the river outflow and the resulting turbulence creates a vertically homogenous water column in terms of salinity and temperature, from Cobequid Bay (Dalrymple 1977; Knight 1977, 1980; Amos and Long 1980; Holloway 1981) to the head of the tide on both the Shubenacadie and Stewiacke Rivers (Stone 1976; Dalrymple 1977; Parker 1984; Tull 1997). Behind the tidal bore, sediment material is resuspended and transported upriver (Wolanski et al. 2004; Chanson 2003). However, a longitudinal difference in salinity, water temperature and suspended sediments occurs over a tidal cycle as the water mass moves in and out of the Cobequid Bay (Dalrymple et al. 1990). Even Minas Basin is vertically mixed with no stratification, due to the relatively small fresh water influx and strong tidal mixing (Ketchum et al. 1953; Bousfield and Leim 1958).

The majority of early life stage striped bass research has been conducted in the US on partially mixed estuaries, mainly the Chesapeake Bay (Roman et al. 2001; Kimmerer 2002; North et al. 2005). A partially mixed estuary occurs when there is only a moderate tidal range and the whole water column moves with the tides. Where the freshwater and salt water meet, stratification occurs, which leads to the formation of the estuarine turbidity maximum (ETM; McLusky and Elliott 2004). An ETM forms in estuaries with sufficient depth (> 10 m) to allow two stratified layers to form and circulate in opposite directions (Schubel 1968; Schoellhamer 2001; North et al. 2005). The Miramichi estuary is stratified, with the salt wedge location dependent on the amount of fresh water, near river km 45 in spring and km 70 in summer (Bousfield 1955; Lafleur et al. 1995; Robichaud-LeBlanc et al. 1996). The ETM acts as a barrier and has up to 100 times higher concentration of suspended sediments than upstream or downstream (Nichols and Biggs 1985). ETMs serve as nursery habitats for larvae fish because high turbidity and suspended sediment lead to increased zooplankton biomass which are larvae prey (Schubel 1968; North et al. 2005). Because of their high turbidity, ETMs are also a refuge for larvae fish from predation (Sirois and Dodson 2000; North and Houde 2003), and maintain striped bass in ideal temperature and salinity conditions (Strathmann 1982). Estuaries such as the Chesapeake Bay and San Francisco Bay all have ETMs and well-documented striped bass populations (Schoellhamer 2001; North and Houde 2006; Shoji et al. 2005).

In contrast to partially mixed estuaries, the highly mixed Shubenacadie River estuary has no stratified salt front for retention of early life stage striped bass. It is unknown how pelagic striped bass eggs and yolk-sac larvae are retained in the estuary nursery habitat. Hence, an important part of my thesis was to evaluate the spatial distribution of early life stage striped bass over the full tidal range to determine the retention in the estuary and their risk of advection from the estuary, out into Cobequid Bay.

All estuaries have an upstream limit of saline water, a location referred to as the salt front. Despite the tidal salt water only traveling to a certain location along the river, tidal freshwater continues to be pushed upstream beyond this point (personal observation). The location of the salt front is dependent on the balance of forces between freshwater flowing downstream and the tidal action forcing saltwater upstream (North and Houde 2001; Schoellhamer 2001). Striped bass spawning in other populations generally takes place in tidal freshwater, up-estuary of the salt front (Secor and Houde 1995; Robichaud-LeBlanc et al. 1996; North and Houde 2001). On the Miramichi River, New Brunswick, peak spawning generally occurs along a 2 km section of river directly upstream from the salt front, but has been observed as high as 12 km upstream of the salt front in the tidal fresh water (Robichaud-LeBlanc et al. 1996). Within the Bay of Fundy, the Annapolis River striped bass spawning occurred about 7 km upstream of the salt front (Williams et al. 1984), while on the Saint John River spawning had been observed just upstream of the salt front (Dadswell 1976). Spawning on the Stewiacke River is reported by locals to take place upstream of the 102 Highway Bridge between kilometers 3 and 8, although there are no hard data (Meadows 1991; Rulifson and Dadswell 1995). After spawning, the eggs drift downstream and are quickly in brackish water (Reesor 2012). Therefore in the second year of my study I hypothesized that the upriver transportation limit of early life stage striped bass on the flood tide would be the salt front. For my thesis, I recorded the salt front location relative to the abundance of eggs and larvae to help define the upstream limits of passive transport (Objective 1).

Throughout the Shubenacadie River estuary the position of the salt front and the extent of upstream transportation of passive particles are primarily dictated by the tidal cycle and secondly by freshwater run-off. During low fresh water run-off, the tidal influence is strongest and the salinity highest. Conversely, when freshwater run-off is high the salinity is relatively low (Martec 2007b). This relationship between freshwater run-off and salinity needs to be quantified because I hypothesize it is fundamental to the retention of early life stage striped bass in the estuary nursery habitat. Spatially, salinity of a parcel of water ebbing from the spawning ground to Gosse Bridge remained relatively constant (Tull 1997). Spatial water temperature differences have not been reported. However, upstream of the confluence on the Shubenacadie River water temperature has been described to be influenced by rainfall (Parker 1984). Upstream of the confluence on the Stewiacke River the flood tide can increase salinity from 0 to 20 ppt in a little over one hour (Parker 1984; Tull 1997). Measuring salinity and water temperature at the AGS using loggers, through the tidal cycles during each field season (May-Oct) provided a more accurate description of how salinity and water temperature are affected by tide and rainfall and described the environmental conditions age-0 striped bass were exposed. Temperature loggers measuring water temperature were deployed near the spawning grounds to determine how temperature influences the timing of spawning (Objective 5).

2.3 Materials and Methods

The sampling sites on the Shubenacadie and Stewiacke Rivers are described in river kilometers, the Shubenacadie River starts at zero kilometers at the mouth of the estuary and the Stewiacke River starts at zero kilometers at the confluence of the Shubenacadie and Stewiacke Rivers. Samplings sites were marked using a handheld GPS unit (Garmin GPSmap 60CSx, 3 – 10 m accuracy). The timing and duration of the ebb and flood tide were recorded at four locations along the Shubenacadie River (river kilometers 2.7, 11.3, 25, and 31.8) and at two locations along the Stewiacke River (river kilometer 0.6 and 7.2) by taking observations from the river bank with a stop watch. The timing of the tides were then related to the Canadian Saint John tide table to allow tide predictions for any date at each location along the river (Canadian Hydrographic Service 2012).

Salinity and temperature was recorded at the AGS at 20 minute intervals with a conductivity-temperature-depth (CTD) logger (Van Essen Instruments; model number 85256). The logger was attached to a rope anchored to a concrete block on the river bed, which was in turn attached to a 20 m rope tied to a tree on the river bank. A buoy held the logger about 0.5 m off the river bed. The logger was positioned in the main channel where there was no sediment accumulation. The upstream salt front on both the Stewiacke and the Shubenacadie Rivers were determined in the summer of 2011 and spring and summer of 2012 by traveling upstream on the flood tide in a boat equipped with outboard motor and recording salinity with a hand-held meter (either YSI model 85 or YSI pro) every 0.5 – 1 km. Once fresh water was encountered the boat was turned, and salinity measurements were taken every hundred meters or so to accurately determine the position of the salt front. The salt front was defined as the area where salinity increased to

0.1 ppt above freshwater. Freshwater on the Stewiacke and Shubenacadie River usually registered at 0.15 ppt and 0.1 ppt respectively due to the relatively high hardness and alkalinity of the water. Temperature loggers (Vemco mini log 8 bit) were deployed on the Stewiacke River at km 2 and 10 and recorded temperature at one hour intervals**.** In 2010, the loggers were deployed April 23 and retrieved November 11. In 2011, the loggers were deployed March 2. The logger 10 km upstream on the Stewiacke River was lost sometime after May 2 and the logger 2 km upstream stopped recording July 4.

Water velocity in the main channel was estimated using a drogue-buoy pair of a ‘circular’ design (Monahan and Monahan 1973). The buoy was a 591 ml plastic Gatorade bottle with fluorescent tape wrapped around the base. This buoy was connected by the neck to the drogue by a nylon string about 30 cm long. The drogue was a 4 L plastic milk bottle filled with sufficient water and mud so that no more than 5 cm of the buoy was above the water surface. Water velocity measurements at AGS during the ebb tide in 2010 were estimated by releasing the drogue-buoy into the water from a boat parallel to a marker post at the upstream (south) end of the site, then using a stop-watch to time the drogue-buoy as it drifted past the six marker posts set at 100 m intervals on the river bank. On the flood tide the same procedure was followed with the exception of starting the drogue-buoy downstream (north) end of the site. Two boats were needed during the flood tide since it took a long time to motor back upstream against the strong current. A more efficient method used from June 2011 onward was to mark the drogue-buoy with the GPS device. To record velocity at night a small light-emitting diode (model: Nite Ize Ziplit zipper pull) was secured on the buoy with wire and tape and protected by a small clear plastic bag. At other locations on the estuary, water velocity was recorded by closely following the drogue-buoy by boat and logging the GPS location every few hundred meters. Occasionally the drogue got stuck and was quickly removed by hand and placed back in the main channel and released. I used the Saint John NB tide table to assess the timing and size of the tide on the Shubenacadie estuary, to conform to all other river users. The tide height in Saint John, NB was used to categorize the size of the tide in the Shubenacadie River estuary (very small, small, medium, large or very large) because it gives an accurate measure of the relative size of the tide on the Shubenacadie River and is used by fishers to estimating the timing of the tides on the Shubenacadie River (Table 2.1). River water velocity was associated with rainfall that had fallen within three and ten days, recorded at the Stanfield International Airport weather station within the Shubenacadie watershed.

The AGS is a one kilometer section of the Shubenacadie River, with a width of 240 m at high tide, decreasing to 150 m at low tide. The site has a large sand bar on the west bank and a steep, muddy/rocky slope on the east bank. The sand bar has occupied the same area since the 1980's (Fig. 2.4; Matrix 2007b). The cross-sectional profile of the river bed at the AGS was surveyed in both May and September 2010 by D. Hingley (NS Dept. Public Works) using a surveyor grade GPS unit accurate to +/- 2 cm (Leica SR530). The survey location was identified by wooden posts on each bank. To improve accuracy of estimates of striped bass abundance all plankton net tows during the ebb tide at the AGS were conducted at this location. River height at the AGS was measured and recorded every 10 min (2010) and 5 min (2011) with a sonar device (Campbell Scientific sonic ranger SR50), suspended over the estuary from a horizontal 10 m steel pipe, which was anchored to a vertical 3.5 m long wooden post (Fig. 2.5). The river height data was matched with the underwater depth profile to determine the cross-sectional area (m^2) of the estuary with respect to tide. The data collected by the sonar was stored on a Campbell Scientific data logger (2010: CR510; 2011: CR150) and downloaded weekly with Campbell Scientific Logger Net software. The data provided an accurate measure of the duration of the ebb and flood tide and enabled the cross sectional area of the estuary to be calculated. These data are needed to determine the abundance of eggs and larvae caught in plankton net tows.

Acoustic Doppler Current Profiler (ADCP 600 MHz Teledyne/RDI Rio Grande) measurements taken October 16 and November 6, 2006 by Martec Ltd. were used to assess the percentage of the cross sectional area of the estuary at the AGS that constitutes the main channel. Establishing the area that occupied the main channel through the tidal cycles was important because all plankton net and velocity data was taken from the main channel. The water velocity along the shallows and river bed were slower than the main channel and were thus not included in the estimates of egg and larvae abundance. ADCP measurements were taken during a monthly low tidal cycle and again during a monthly high tidal cycle. A Zodiac boat was driven back and forth across the river every 10 minutes through one full tidal cycle at the AGS. The ADCP was attached to the side of the boat, measuring the vertical profile of the water's velocity in 10 cm segments. Recording continued until three or more successive crossings yielded a less than 5% deviation from one another. Approximately two good sets (minimum three transects) were taken every hour over the full tidal cycle. For this thesis Alton Natural Gas Storage LP kindly allowed me access to the ADCP data files. The ADCP dataset was used to determine the cross-sectional area of the main channel by taking the maximum velocity in the main channel and included the area flowing within 0.2 m/sec of the maximum velocity.

Table 2.1: Shubenacadie estuary tide size categories (very small, small, medium, large, and very large) in relation to the Saint John, NB, high tide heights in meters and feet.

Shubenacadie estuary tide category	Saint John high tide height	
	meters	feet
Very small	6.7 - 7	22 - 23.4
Small	7.1 - 7.4	23.5 - 24.9
Medium	7.5 - 7.8	25 - 26.4
Large	7.9 - 8.2	26.5 - 27.9
Very large	8.3 - 8.7	28 - 29.4

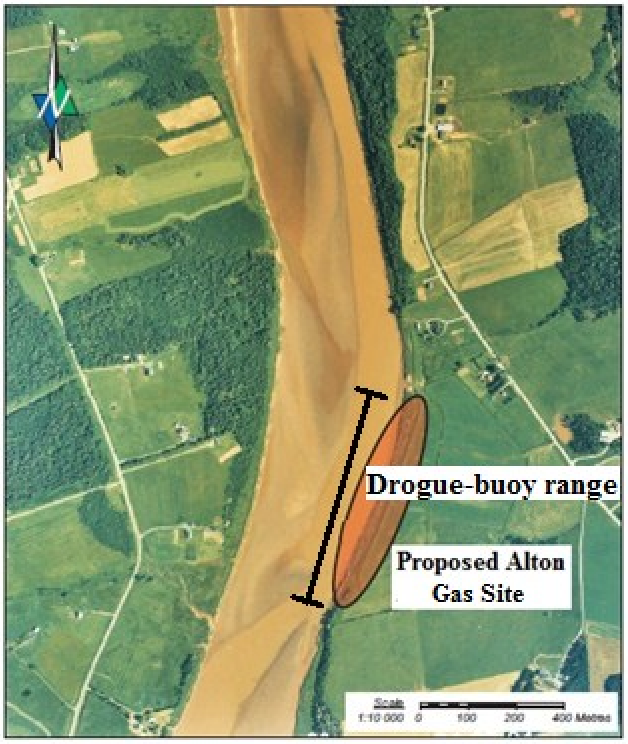


Figure 2.4: Aerial photograph of the Alton Gas Site in 1994 at low tide. Large sandbar is exposed at low tide on the west side of the river, while the main channel flows along the east river bank (Modified from Martec 2007b).

Figure 2.5: Alton Gas Site on the Shubenacadie River, facing west showing the sonar device (Campbell Scientific sonic ranger SR50), suspended 10 m over the river to measure water height.

2.4 Results

Primary sampling sites were mapped in river kilometers. Road bridges over the Shubenacadie River, at Gosse Bridge, Highway102 and Highway # 2 were at river kilometers 11.3, 31.8 and 35.9 respectively. On the Stewiacke River, Highway102 and Highway # 2 were at river km 2.8 and 4 respectively and served as useful landmarks (Fig. 2.6). The AGS is 2.4 km downstream of the Shubenacadie-Stewiacke River confluence (45° 15.70 N - 63° 38.55 E) and 25 km upstream from the estuary mouth. The flood tide at the mouth of the Shubenacadie River (Black Rock) lasts approximately 3 h 30 min and the ebb tide lasts about 9 h. Twenty five kilometers upstream at the AGS, the duration of the flood tide is only on average 86 min and the duration of the ebb tide is on average 10 h 50 min. Near the spawning grounds at the CN train bridge the flood tide only lasts 65 min with the ebb tide flowing downstream for 11 h 15 min (Table 2.2). The length of time between high tide at these seven sites and the next tidal reversal at the mouth of the estuary ranges from nearly 9 to nearly 7 hours (Table 2.2).

At the AGS on average, the water elevation rises from low to high water (flood tide) in 1 h 26 min. However, the duration of the flood tide ranges from 1 h 5 min to 1h 50 min depending on the size of the tide. Spring tides generally lead to longer flood tides, such as on October 8, 2010 when the flood tide lasted 1 h 50 min and the cross sectional area of the river reached 1366 m^2 at high tide, or 8.7 m on Saint John tide table, which is in the "very large" tide category. Neap tides lead to short flood tides, such on July 5, 2010 when the flood tide only lasted 1 h 5 min and the cross sectional area only reached 532 m^2 at high tide (Fig. 2.7), or 6.8 m on Saint John tide table, which is in the "very small" tide category. There was a linear relationship between the length of the flood tide and the high tide river cross sectional area (m^2) at the AGS (R^2 value of 0.707; n = 321). The duration of the ebb tide is inversely related to the duration of the previous flood tide, ranging from 10 h to 11 h 20 min. High slack tide duration at the AGS is on average less than 5 minutes. The mean cross sectional area at the AGS at high tide is 919 m^2 (SD 17) and at low is 192 m^2 (SD 213). The cross sectional area ranged from a low of 170 m^2 at low tide during very small tidal cycles with low fresh water run-off on August 30, 2010, to a high of 1420 m^2 at high tide during spring tides following heavy rainfall events on October 7, 2010. These cross sectional areas correspond to the water depth in the main channel varying from a minimum of 1 m at low tide to a maximum of 5.5 m at high tide. Tide height from the beginning of March to the end of August is greater at night than during the day (Fig. 2.8), but for the rest of the year is greater during the day. The monthly tidal cycle follows a predictable pattern based on the lunar cycle of building up to a maximum and falling to a minimum twice a month (Fig. 2.9).

Water velocity over the cross sectional area of the river was not uniform. At the AGS site, the main channel flowed more quickly than areas close to the river bed and bank, and occupied between 20 - 40% of the cross-sectional area, varying with the state of the tide. An average of 30 % was taken for estimates of abundance of egg and larvae. The rivers main channel varied and shifted positions through tidal cycle, through the ebb tide moving closer towards the east river bank as the cross sectional area of the river decreased (Fig. 2.10). The water velocity over the tidal cycle follows a clear pattern due to the dominant tidal influence. The bore travels at approximately 12 - 13 km/h past the AGS, causing the water flow to reverse direction immediately, with an initial velocity of 4 - 5 km/h. The flood tide velocity increases progressively to peak at about 11 km/h for large tides and 7 km/h for the small tides (Fig. 2.11). For example, on June 5, 2012 a large tide led to a flood tide velocity in the main channel reaching 11 km/h and remained over 10 km/h for 40 min. Peak flood tide velocity occurred between 15 and 30 min after the passing of the bore. From 40 to 100 min post-bore, the flood tide velocity decreases progressively (Fig. 2.11). At the end of the flood tide the water level of the river starts to drop before the direction of the river direction reverses. On the ebb tide, peak velocity is reached within 40 to 60 minutes, and ranged from 2.5 - 7 km/h. Thereafter, the river velocity gradually decreases for the remainder of the ebb tide (Fig. 2.11). Associated with the larger tides that occur at night are faster flood and ebb tide velocities compared to the previous day. For example, on the afternoon of May 22, 2012 the maximum ebb tide velocity reached was 5.5 km/h, that night at 5 am the maximum velocity reached was 6.8 km/h (Fig. 2.12). The maximum flood tide velocity reached the afternoon of May 22 was 8.3 km/h, that night the maximum velocity climbed to 9.4 km/h, while the next afternoon the velocity only reached 8 km/h (Fig. 2.11). As the bore progresses upstream, its shape evolves in response to the local bathymetry.

Water velocity downstream of the AGS was recorded on the Shubenacadie River on four occasions May and June of 2010 (n = 3) and 2011(n = 1). Velocity averaged 6 km/h but varied along different sections of the river, ranging from a low of 1 km/h to a high of 14 km/h, being fast on straight sections and slowing through meanders. The size of the tide and the amount of freshwater run-off had only a minor influence on average downstream velocity (Table 2.3). Upstream of the AGS, ebb tide velocity was recorded on the Shubenacadie River from near Shubenacadie Town (km 27 to 37; Fig. 1.1) at the turn of the tide back down to the AGS on eleven occasions from April 8 to July 13, 2012. Over all days, upstream ebb tide river velocity averaged 3.1 km/h but varied along different sections of the river, ranging from as low as 0.5 km/h to as high as 10.5 km/h. The size of the tide was a larger contributing factor to upstream water velocity than the amount of rainfall (Table 2.3). Mean upstream velocity on small tides ranged from 2.2 – 3.1 km/h, for medium tides it ranged from 2.7 – 3.3 km/h and for the large tide it averaged 4.8 km/h. It is difficult to evaluate the impact rainfall has on river velocity as velocity was measured over different tides and slightly different sections of the river. However, rainfall appeared to influence river velocity, April 18 and 29, 2012 were both small tides and river velocity was measure over the exact same upstream location (km 27.5 – 25), however, there was only 5.6 mm of rain in the 10 days before April 18 and river velocity was 3.1 km/h, the 10 days before April 29 had 75.6 mm of rain and the mean velocity was 3.7 km/h.

On the Stewiacke River, ebb tide velocity was recorded ten times, from near the spawning grounds (km 9) to the river confluence. Drogue drifts were terminated here because of low water and sand banks. Overall, ebb tide river velocity averaged 2.6 km/h, ranging from a minimum of 1km/h during a small tidal range on May 26, 2011; to a maximum average velocity was 3.4 km/h during a medium tidal range on July 3, 2011. Velocities varied along different sections of the river ranging from as low as 0.2 km/h to as high as 10 km/h (Table 2.4).

Daily mean water temperature of the Stewiacke River, both above and below the head of tide, and the Shubenacadie estuary at the AGS were very similar, in both 2010 (Fig. 2.13) and 2011 (Fig. 2.14). The water temperature below the head of tide was approximately 1°C higher than above the head of the tide starting in June through to August. Mean water temperature from May to August in 2010 was 3 - 4 °C warmer than 2011.

The flood tide had only minor effects on water temperature, but often changed salinity by over 10 ppt (Fig. 2.15). Salinity is also affected at the AGS by large rainfall events, occasionally causing salinity to be as low as 2 - 5 ppt at high tide (June 16-17 and August 9-10, 2011; Fig. 2.16). During periods with low to no rainfall daily maximum salinity could be over 20 ppt (July 6 - 9 and Aug 31 to Sep 3, 2011; Fig. 2.16).

The location of the salt front was measured on 17 tides from June 21, 2010 to July 3, 2012. On the Stewiacke River, the mean salt front location was kilometer eight, with the salt front location varying from river kilometer 3.5 and 12.9, depending on the size of tide and the amount of freshwater run-off (Table 2.5). The lowest salt front locations all occurred on very small or small tides, June 21, 2010 at km 5.3; June 3, 2011 at km 4 and April 26, 2012 at km 3.5. The furthest upstream salt front location was recorded on June 4, 2012 during a large tide at km 12.9. However, during an equal size tide on July 13, 2010 the salt front only reached km 6.2, associated with 47.8 mm of rain that fell the previous day. On the Shubenacadie River, the salt front was located on 13 tides from July 20, 2010 to July 3, 2012. The mean salt front location over these tides was located at Shubenacadie River kilometer 36. The salt front location ranged between river kilometer 31.2, which occurred during a small tide on June 18, 2012 and kilometers 42.5, which occurred on a large tide on June 4, 2012. On three occasions, June 20, 2010, June 24, 2011 and April 29, 2012 the salt front was not located and was thus downstream of the AGS (km 25), associated with the 107, 126, and 76 mm of rain that fell respectively within 10 days (Table 2.6).

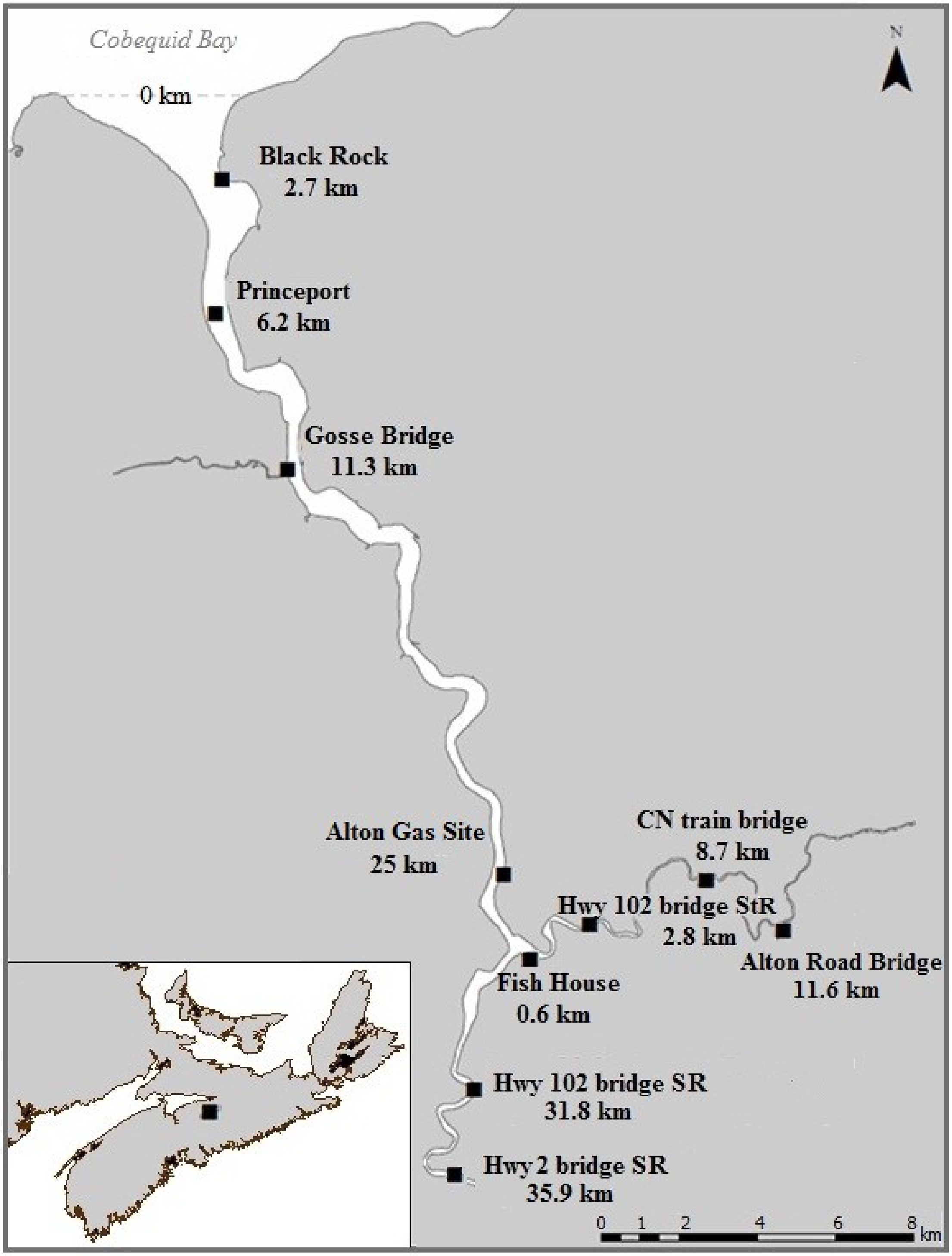


Figure 2.6: Map of the Shubenacadie Estuary. The location of the estuary within central Nova Scotia, Canada is represented by the black box in the lower left corner. Landmarks on the Shubenacadie (SR) and Stewiacke (StR) Rivers and their associated river kilometers, either from the estuary mouth (Shubenacadie River) or the confluence of the Shubenacadie and Stewiacke Rivers (Stewiacke River kilometres). The principal sampling site was the Alton Gas Site, located 25 km from the estuary mouth.

Table 2.2: Mean ebb and flood tide duration at four locations on the Shubenacadie River (SR) and three locations on the Stewiacke River (StR) and their timing in relation to hours plus or minus the Saint John, New Brunswick high tide time. The length of time between high tide at the seven locations and the next tide reversal near the mouth of the estuary at Black Rock is shown in the last column. Data was collected from July 2010 to April 2012. Observations per site were 2 to 3 with the exception of the Alton Gas Site which had several hundred.

Location	River kilometer	Mean tide duration		Relative to high tide time at Saint John (h:mm)		Time from the start of the ebb tide to the next incoming tide at the estuary mouth (h:mm)
		Flood (h)	Ebb (h)	Bore arrival (h:mm)	Beginning of Ebb (h:mm)	
Black Rock (SR)	2.7	3:10	8:50	-0:30	+2:40	8:50
Gosse Bridge (SR)	11.3	2:50	9:30	+0:10	+3:00	8:30
AGS (SR)	25	1:26	10:50	+1:42	+3:15	8:19
Bridge # 2 Hwy (SR)	35.9	1:20	11:00	+2:00	+3:20	8:10
Fish House (StR)	0.6	1:22	10:50	+1:57	+3:35	8:04
Bridge # 2 Hwy (StR)	4	1:26	10:54	+2:20	+3:46	7:44
CN Train Bridge (StR)	8.7	1:05	11:15	+2:35	+3:40	6:50

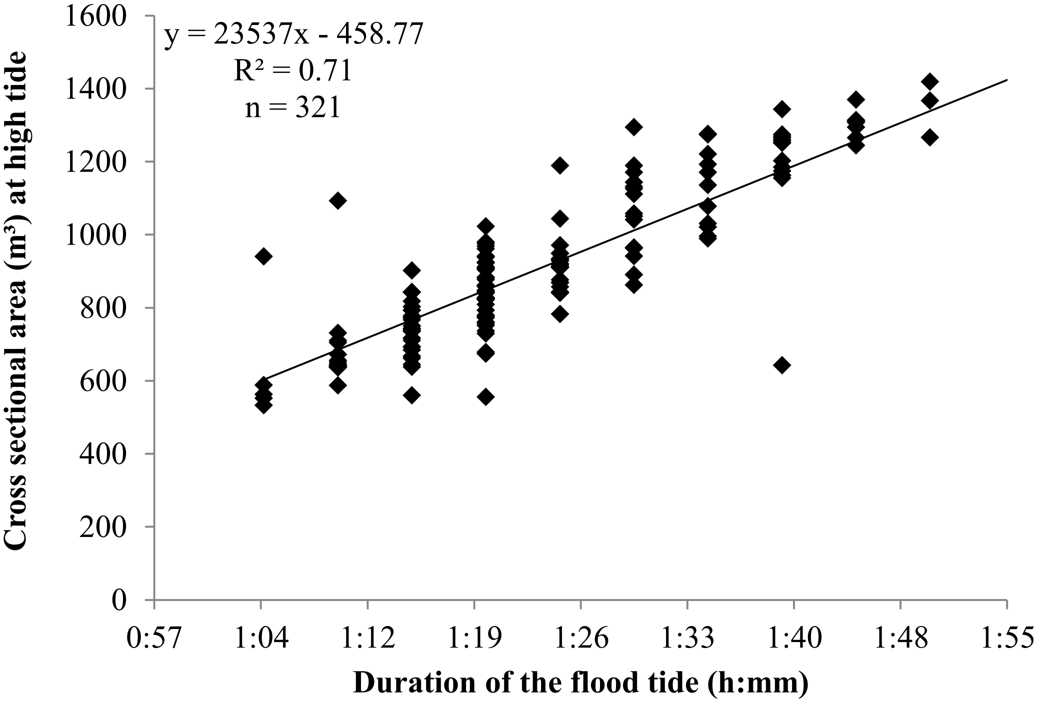


Figure 2.7: Relationship between the duration of the flood tide (hours: minutes) at the Alton Gas Site and the cross sectional area (m^2) of the water column at high tide. The cross sectional area was recorded every five minutes with a sonar device (Campbell scientific sonic ranger SR50) which was suspended over the estuary. Data was collected from July 5 to October 10, 2010.

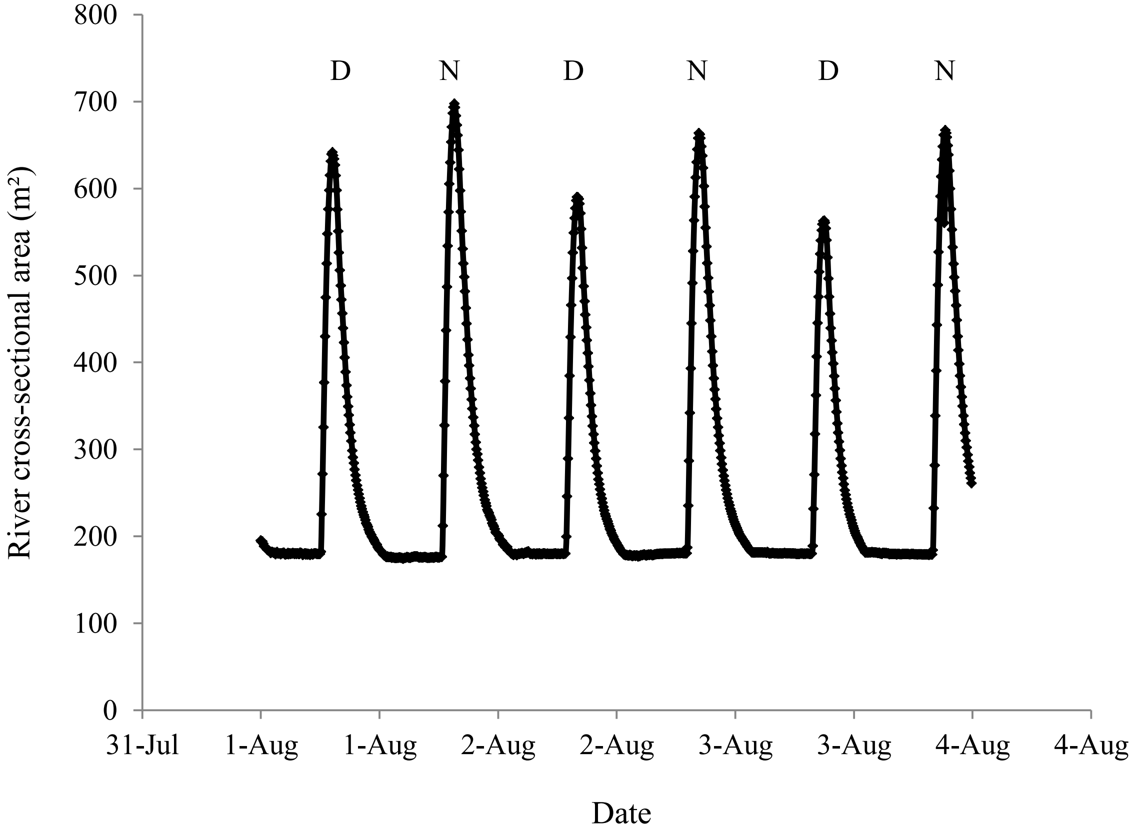


Figure 2.8: Shubenacadie River cross sectional area (m^2) at the Alton Gas Site over five tidal cycles August 1 to 4, 2010 when freshwater run-off was low. The highest tides occurred during the night (N), with high tide during the day (D) being slightly lower.

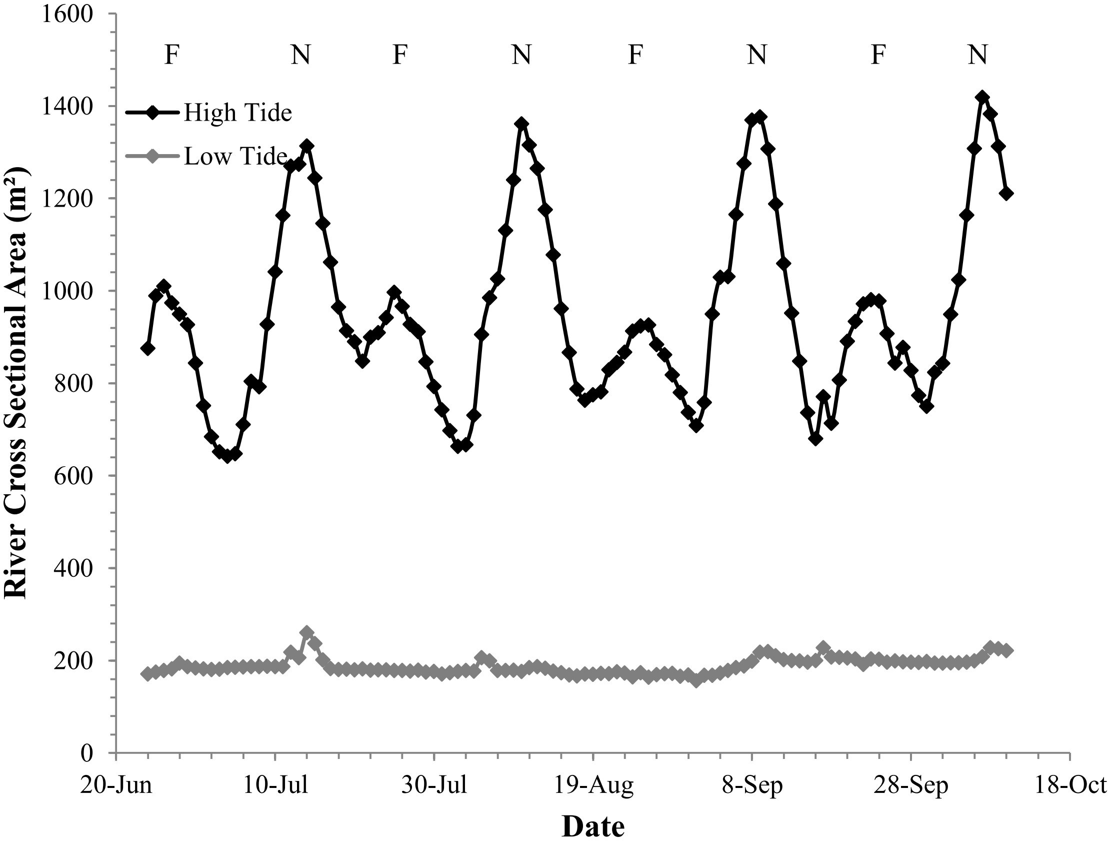
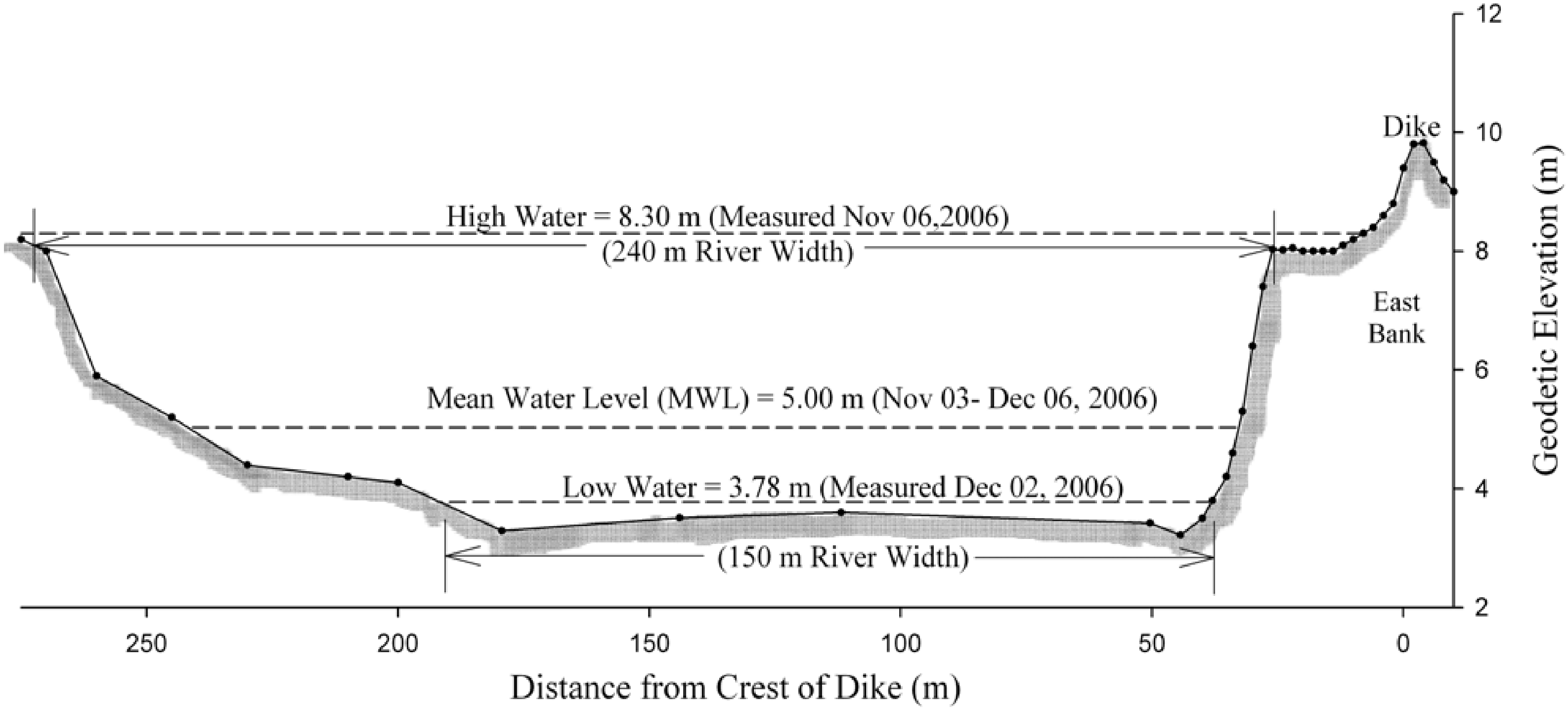


Figure 2.9: Cross sectional area (m^2) of the Shubenacadie River at low and high tide at the Alton Gas Site from June 24 to October 10, 2010. The monthly tidal cycle follows a predictable pattern of building up to a maximum and falling to a minimum twice a month. The distinct peaks and troughs are the daily high and low tide cross sectional areas. F=full moon, N=new moon.



Notes : 1) East Bank/Dike Survey by Terrain Surveying on Nov 07, 2006
2) River Bottom Survey by Martec Ltd on Nov 30 and Dec 01, 2006

Figure 2.10: Geodetic water elevation superimposed on the Alton Gas Site river cross-section. The Acoustic Doppler Current Profiler surveys collected the river contour data on November 6 and December 2, 2006. Data collected and figure made by Martec Ltd. (Martec 2007a).

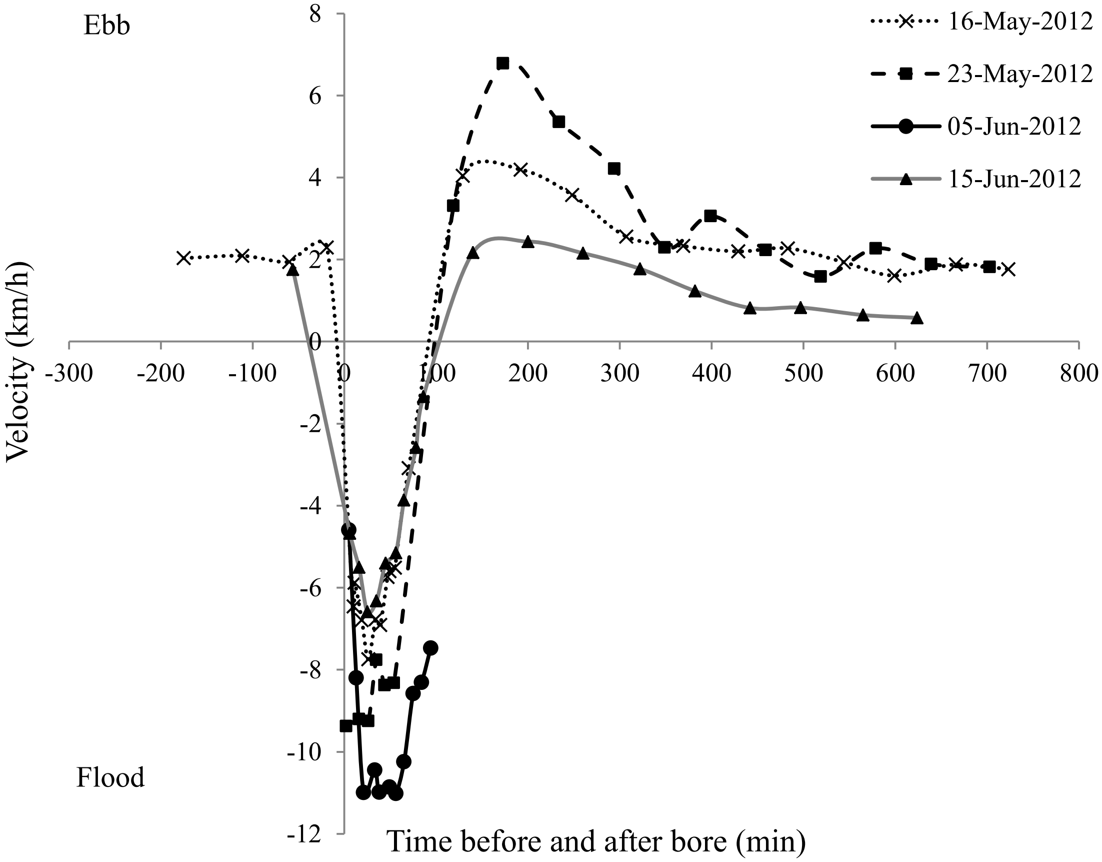


Figure 2.11: Shubenacadie River ebb (positive) and flood (negative) water velocity (km/h) at the Alton Gas Site measured by drogue-buoy drifting over 400 - 600 m in relation to the time of the bore (min). Data from May 16 and 23 and June 5 and 15, 2012 show the range of velocities recorded at the Alton Gas Site over the 2012 season, May 1 to August.

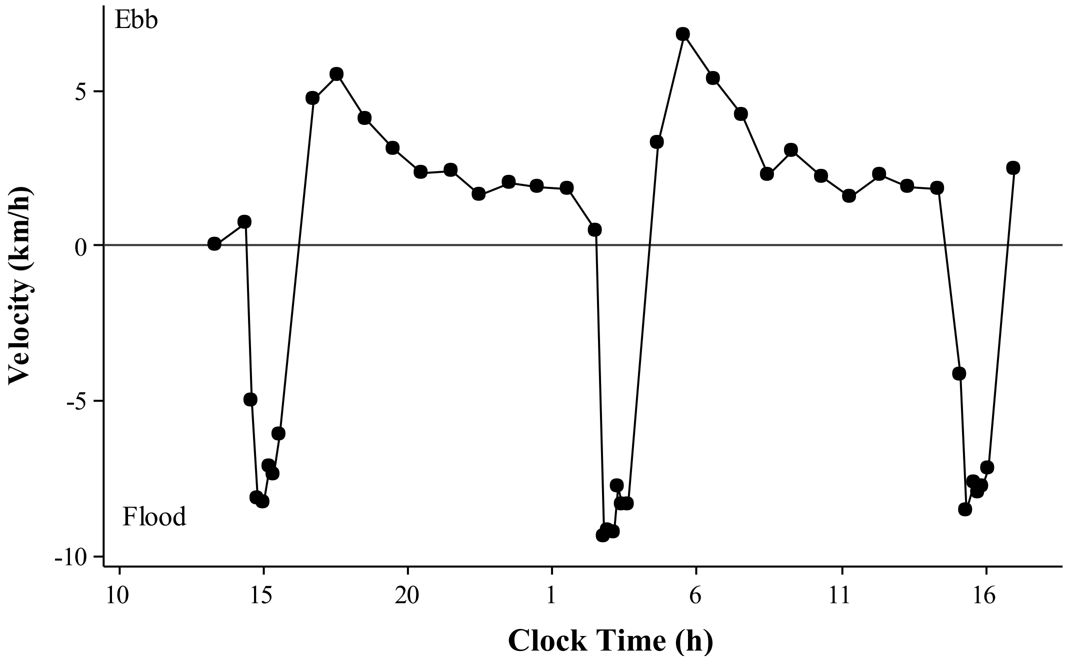


Figure 2.12: Shubenacadie River ebb (positive) and flood (negative) water velocity (km/h) at the Alton Gas Site May 22 - 23, 2012 in relation to clock time (h) measured by a drogue-buoy drifting over 400 - 600 m.

Table 2.3: Shubenacadie River ebb tide water velocity (km/h) starting from the salt front to the Alton Gas Site (river km 25) or from the Alton Gas Site to the estuary mouth (river km 0). Mean water velocity and velocity range (km/h), in relation to tide size and rainfall within 3 and 10 days (Stanfield International Airport weather station). Mean velocity was calculated by dividing the total distance traveled by the total time. The size of the tide was grouped into categories (vs: very small, s: small, m: medium, and l: large).

	Shubenacadie River (km)		Velocity (km/h)				Rainfall (mm)	
Date	Start	End	Mean	SE	Range	Tide	3 days	10 days
20-May-10	25	15	5.3	0.885	4 - 14	m	7.9	11.7
4-Jun-10	14	0	6.3	0.471	3.5 - 9	vs	35.5	49.6
14-Jun-10	25	0	5.9	0.764	1.1 - 12.5	m	0	23.5
13-Jun-11	25	0	6.4	0.612	2.8 - 10.2	m	14.2	16.2
18-Apr-12	27.4	25	3.1	0.299	1.9 - 3.7	s	0	5.6
22-Apr-12	38.9	28.3	2.2	0.305	1.6 - 4	s	5.3	4
29-Apr-12	27.5	25	3.7	0.276	2.6 - 5.3	s	35.9	75.6
3-May-12	36.8	25	2.7	0.337	1.5 - 4	m	0	66.9
7-May-12	27.5	25	4.8	0.758	1.8 - 10.5	l	1	1
11-May-12	27.5	25	3.3	0.331	2.3 - 3.8	m	41.2	41.2
28-May-12	34.5	25	2.5	0.265	1.3 - 4.6	s	0	17
11-Jun-12	33.8	25.8	2.7	0.5	0.5 - 4.3	s	18.8	29.9
18-Jun-12	31.2	25	3.1	0.527	1.6 - 5.2	vs	0	18.8
27-Jun-12	37.3	28.1	2.6	0.388	1.3 - 4.7	s	36.5	45.2
3-Jul-12	35.2	26.4	3.1	0.381	1.7 - 4.8	m	0.3	36.8

Table 2.4: Stewiacke River ebb tide water velocity (km/h) starting from the vicinity of the spawning grounds to near its confluence with the Shubenacadie River. Mean water velocity and velocity range (km/h), in relation to tide size and rainfall within 3 and 10 days (Stanfield International Airport weather station). Velocity was measured by following a drogue-buoy by boat and recording its position every few hundred meters with a GPS. Mean velocity was calculated by dividing the total distance travelled by the total time. The size of the tide was grouped into categories (vs: very small, s: small, m: medium, and l: large).

	Stewiacke River (km)		Velocity (km/h)				Rainfall (mm)	
Date	Start	End	Mean	SE	Range	Tide	3 days	10 days
26-May-11	9	0	1	0.147	0.3 - 4.2	vs	1.9	18.4
6-Apr-12	9	0	2.3	0.111	1.7 - 3.8	l	0	2.3
18-Apr-12	8	0	2.8	0.336	1.2 - 8.7	s	0	5.6
26-Apr-12	8.7	4	3.6	0.503	1.3 - 8.5	s	33.6	39.7
7-May-12	8.3	0	2.9	0.195	0.6 - 10	l	1	1
11-May-12	8.7	0	3	0.422	1.4 - 3.9	m	41.2	41.2
18-Jun-12	10.2	1.6	2.3	0.272	0.4 - 4.4	vs	0	18.8
27-Jun-12	9.9	1.2	2.8	0.347	0.3 - 5.5	m	36.5	45.2
29-Jun-12	9.6	1.3	1.9	0.371	0.2 - 4.0	s	36.3	45.2
3-Jul-12	8.8	0.7	3.4	0.306	2.9 - 5.3	m	0.3	36.8

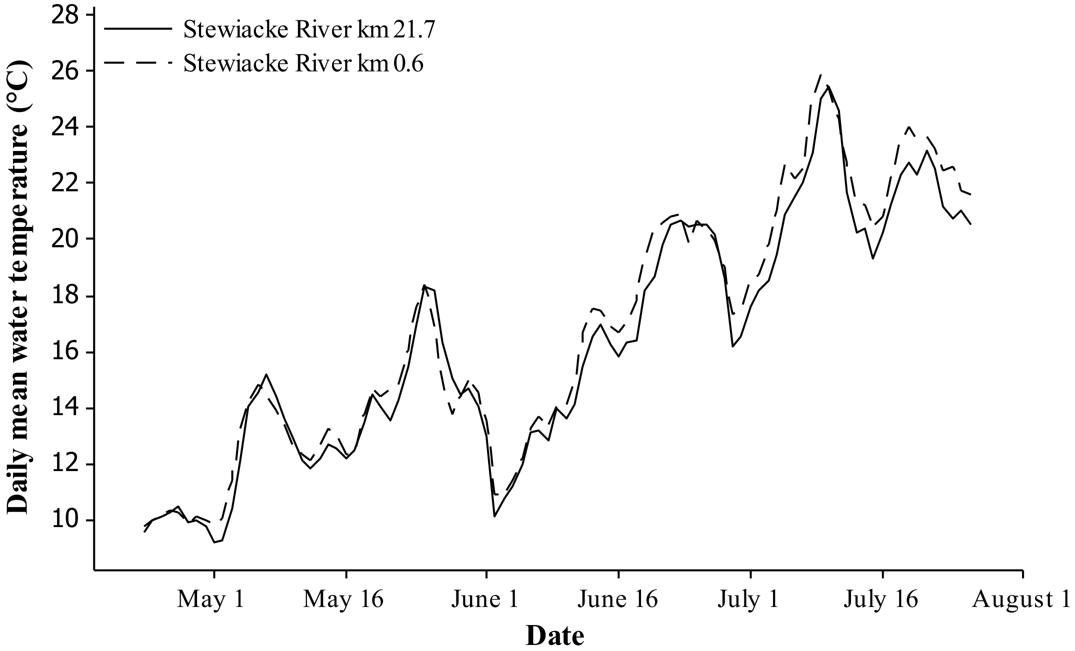


Figure 2.13: 2010 daily mean water temperature of the upper Stewiacke River (Forest Glen, km 21.7), and lower Stewiacke River (Fish House, km 0.6). Water temperatures were generally within 1 - 2°C of each other, with the lower Stewiacke River being slightly warmer from early June to August.

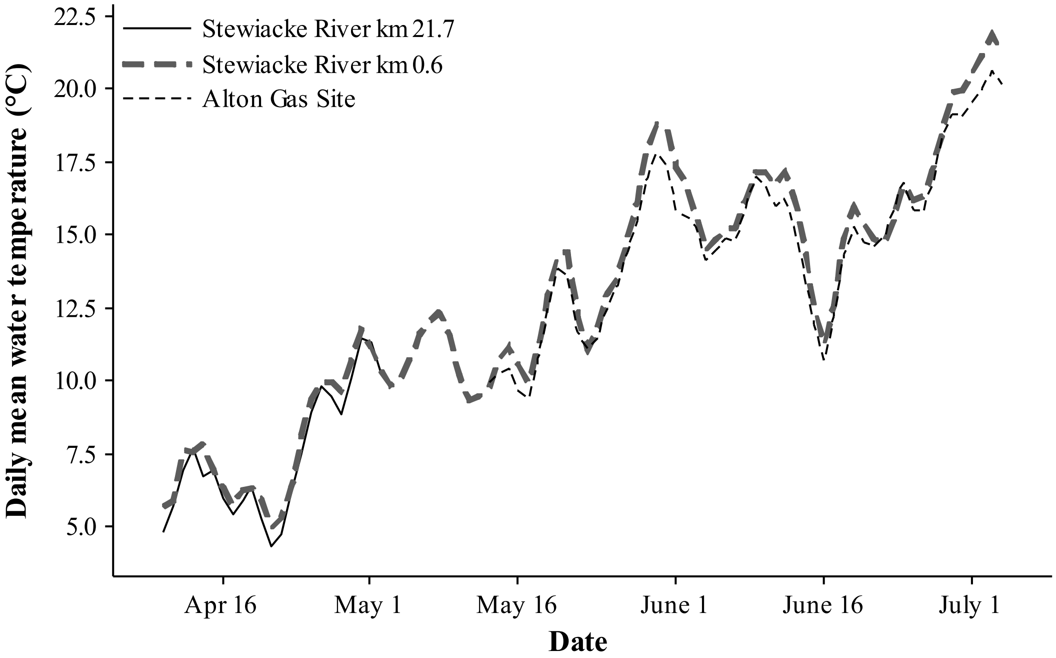


Figure 2.14: 2011 mean daily water temperature of the upper Stewiacke River (Forest Glen, km 21.7 from confluence), lower Stewiacke River (Fish House, km 0.6 from confluence), and Shubenacadie River at the Alton Gas Site (km, 25 from estuary mouth). The upper Stewiacke River data logger went missing in early May and the Alton Gas Site data logger was only deployed mid-May. The loggers that were recording at the same times were generally within 1°C of each other. The lower Stewiacke River water was slightly warmer than the Alton Gas Site from early May to July.

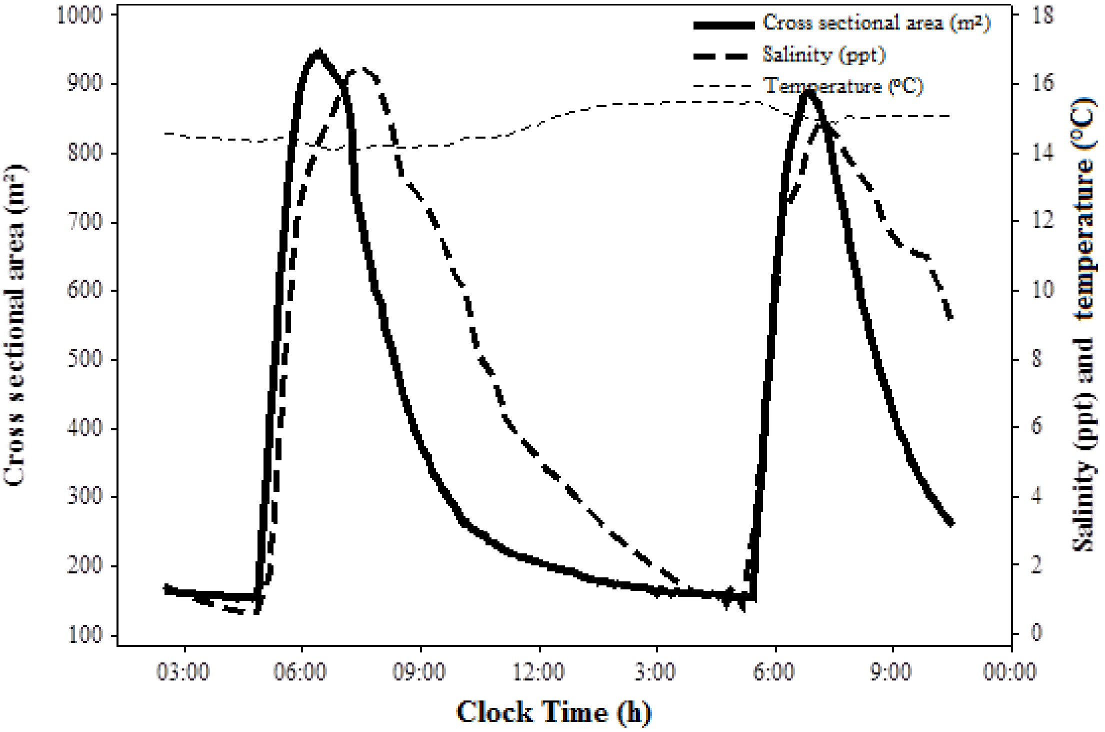


Figure 2.15: The effects of the tidal bore on salinity (ppt), water temperature (°C), and river cross sectional area (m^2) at the Alton Gas Site. June 7, 2011 was selected to demonstrate the effect of the incoming tide. Notice the rapid rise in salinity (thick dashed line). Temperature and salinity were recorded by a data logger attached to a cinderblock ~1 m from river bottom and the cross sectional area (m^2) was recorded from a sonar position over the river at the Alton Gas Site.

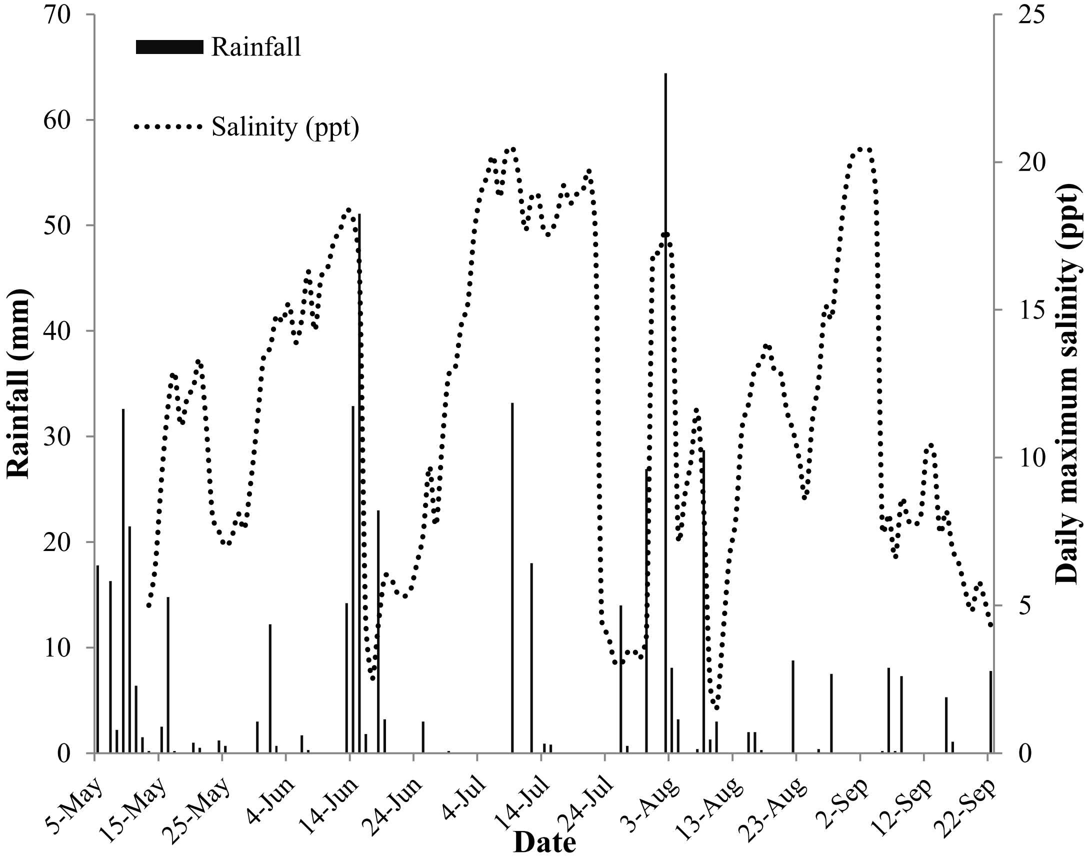


Figure 2.16: Maximum daily salinity (ppt) at the Alton Gas Site and total daily rainfall (mm) from May 14 to September 22, 2011. Salinity was recorded by a data logger attached ~1 m from bottom at the AGS and rainfall was recorded at the Stanfield International Airport weather station located within the Shubenacadie River watershed.

Table 2.5: Salt front position (river km from the confluence) on the Stewiacke River over 17 high tides from April to July from 2010 to 2012, in relation to tide size and rainfall over the preceding 3 and 10 days (Stanfield International Airport weather station).

			Rainfall (mm)	
Date	Salt front location (river km)	Tide	3 days	10 days
21-Jun-10	5.3	vs	4.6	0
13-Jul-10	6.2	l	47.8	48
16-May-11	5	m	17.5	98
3-Jun-11	4	s	12.9	12.9
10-Jun-11	5.2	s	0	0
18-Apr-12	8	s	0	5.6
26-Apr-12	3.5	s	33.6	39.7
29-Apr-12	< 0	vs	0	76.1
7-May-12	10.4	l	1	1
11-May-12	8.7	m	41.2	41.2
27-May-12	9	s	0	17
4-Jun-12	12.9	l	6.5	16
11-Jun-12	11.8	s	18.8	29.9
18-Jun-12	10.2	s	0	18.8
27-Jun-12	9.9	m	36.5	45.2
29-Jun-12	9.6	s	36.3	45.2
3-Jul-12	8.8	m	0.3	36.8

Table 2.6: Salt front position (river km from the estuary mouth) on the Shubenacadie River over 14 high tides from April to July from 2010 to 2012, in relation to tide size and rainfall over the preceding 3 and 10 days (Stanfield International Airport weather station).

			Rainfall (mm)	
Date	Salt front location (river km)	Tide	3 days	10 days
20-Jul-10	< 25	vs	0	106.9
3-Jun-11	36.8	s	12.9	12.9
10-Jun-11	37.1	m	0	0
24-Jun-11	< 25	vs	0	126.3
22-Apr-12	38.3	s	5.3	4
29-Apr-12	< 25	vs	0	76.1
3-May-12	35.5	m	0	66.9
27-May-12	35.8	s	0	17
28-May-12	35.8	s	0	17
4-Jun-12	42.5	l	6.5	16
11-Jun-12	33.8	s	18.8	29.9
18-Jun-12	31.2	s	0	18.8
27-Jun-12	37.3	m	36.5	45.2
3-Jul-12	35.2	m	0.3	36.8

2.5 Physical Description Discussion

Describing the physical features of the Shubenacadie estuary in terms of the tidal flow direction, velocity, salinity and temperature provides the foundation on which to build an understanding of the spatial and temporal distribution of pelagic striped bass eggs and larvae and the habitat conditions they encounter. The probability of pelagic eggs and larvae being advected from the estuary into the Cobequid Bay depends on the location of spawning, river velocity and direction of flow.

The location of the salt front on the Stewiacke and Shubenacadie Rivers is dependent on the magnitude of the tide and magnitude of freshwater run-off, with salt water penetrating furthest upstream on large tides during dry periods. The same is true of estuaries with ETMs, as freshwater discharge forces the ETM down estuary (North and Houde 2001). On the Stewiacke River, the smallest tide, coupled with a heavy rain event led to the lowest salt front. The highest upstream salt front was associated with the highest tide and very little rain. The salt front on the Shubenacadie River was located around kilometer 36 on average. On three occasions the salt front or area where salinity transitioned from 0 to 0.1 ppt was located downstream of the AGS. These tides were all very small and were preceded by over 100 mm of rain in the previous 10 days.

Daily mean water temperature at the AGS, and on the Stewiacke River at the Fish House and 21 km upriver showed very little difference. There was no evidence the spawning grounds had a unique thermal profile. The tidal bore decreased water temperature only slightly and temporarily at the AGS, similar to the finding at the Fish House in 1994 (Tull 1997). Water salinity in the estuary is clearly affected by rainfall. Low salinity during the flood tide at the AGS is due to little salt water from Cobequid Bay reaching 25 km upriver. The large volumes of freshwater entering the river between AGS and the mouth of the estuary is pushed back upstream with very little mixing of salt water from Cobequid Bay. Cobequid Bay and subsequent Minas Basin have higher salinity 24 - 29 ppt and 30 - 31 ppt respectively and progressively lower water temperatures moving westward from the Shubenacadie estuary (Bousfield and Leim 1958; Stone 1976). Maximum daily salinity (ppt) decreased after nearly every rainfall event over 5 mm. However, on occasions following long dry periods rainfall events had much smaller effects on salinity, such as July 9, 2010 when 33 mm of rain fell after 20 dry days, decreasing daily maximum salinity to only 17.7 ppt from 20.5 ppt (Fig. 2.15). A few other dates of interest were May 23 – 27, July 23 to 30 and September 4. On May 24 salinity was at 11 ppt, dropping to 7 and 8 ppt over the next several days as detected by the salinity logger and a YSI meter, only 2 mm of rain was detected, however the tides were decreasing in size. On July 22 high tide salinity was 17.6 ppt, by July 23 salinity had dropped to 4.5 ppt and stayed low (3 - 4 ppt) until July 31 when it was back up to 16.9 ppt. During this time there was no rainfall recorded at the Stanfield International Airport weather station. Perhaps there was a large localized rainfall event in another area of the watershed. Similarly, September 4 had a high tide salinity of 18.8 ppt, which decreased to 7.5 ppt on September 5 without any rain detected at the Stanfield International Airport weather station. Over all these dates of interest the salinity decreased steadily related to the timing of the tides, thus logger malfunction was ruled out. The watershed has a total surface area of 2800 km^2 (Lay 1979) so localized rainfall events are likely the explanation. Antecedent moisture indices which describe the relative moisture of a watershed through changing conditions are used in other estuaries to predict the flow response in systems during wet weather (Weissling and Xie 2008). Currently there is no antecedent moisture index for the Shubenacadie estuary, but the index would be an asset in predicting the estuaries flow response to freshwater run-off and in turn the transport of early life stage striped bass.

The timing of the ebb and flood tide at the four locations along the Shubenacadie and Stewiacke Rivers are based on observations from only a few tidal cycles. After comparing the length of the ebb and flood of over 400 tidal cycles at the AGS, it was noted that there can be a variation in the duration of the mean flood and ebb tide duration by up to 22 minutes. The same magnitude of variation is expected throughout the estuary, with the flood tide lasting longer during larger tides than smaller tides, and the ebb tide length being respectively shorted or longer. For future work, tide duration variation must be considered when estimating the timing of the tides at the various locations off the Saint John tide table.

Chapter 3. Striped Bass

3.1 Taxonomy and Geographic Range

Striped bass is a member of the *Moronidae* family. This family has a streamlined shape, with double dorsal fins separated by a space. The anterior dorsal fin has spines, while the posterior has soft rays. Body coloration is dark green dorsally, with silver sides and seven or eight horizontal dark bands laterally, and a white belly (Bigelow and Schroeder 1953). Adult Shubenacadie River striped bass, age 4 years old and over, range in size from 44 to 102 cm TL and weigh between 1 - 11 kg. Males are generally larger than females at age classes one and two years-old but females surpass males by several centimeters in fork length beyond age three (Paramore 1998).

Historically, striped bass inhabited a range of coastline on the Atlantic Coast of North America, from the St. John's River of Florida (Setzler-Hamilton et al. 1981) to the St. Lawrence River of Quebec (Scott and Scott 1988) and from western Florida to Eastern Louisiana (Setzler-Hamilton et al. 1981). Striped bass were introduced to the Pacific coast in the San Francisco Bay estuary 1872 to 1882 and subsequently spread north to Vancouver Island, British Columbia, and south to Baja California, Mexico (Lee et al. 1980). Due to stocking, a number of populations have also become established in inland lakes throughout the United States (Stevens et al. 1985). Fifteen striped bass populations have been identified within their North American range. These populations are unique based on fin ray counts, and morphology differences (Setzler-Hamilton et al. 1981). In the US striped bass have been studied extensively on both coasts due to their importance as a commercial and sport fish (Martino and Houde 2010). However, Canadian striped bass populations have received less attention likely because they have little economic importance in our country.

Each distinct anadromous striped bass population can be found in its native river only during spring spawning season. Post-spawning they leave their native rivers during summer and undertake extensive coastal migrations, many form schools with striped bass from other populations. Striped bass tagged in Cape Hatteras, North Carolina have traveled the 1,500 km to the Bay of Fundy during one summer season (Waldman et al. 1990). A striped bass released in Minas Basin was recaptured 45 days later in Newport, Rhode Island, traveling a distance of 800 km at a rate of approximately 18 km/day (Rulifson et al. 1987). Within Eastern Canada, striped bass were historically found in three regions: the St. Lawrence River and estuary in Quebec, the Gulf of St. Lawrence from Chaleur Bay through the Northumberland Strait, and rivers in New Brunswick and Nova Scotia draining into the Bay of Fundy. Quebec is the northern limit of the species range. Within the three regions, five rivers contained spawning striped bass populations: St. Lawrence, Miramichi, Saint John, Annapolis and Shubenacadie. Three of these rivers, the Annapolis, Saint John and the Shubenacadie Rivers drain into the Bay of Fundy and now only the latter supports a spawning population (Douglas et al. 2003). The Annapolis and Saint John Rivers have not shown evidence of successful striped bass spawning since the 1970's (Williams et al. 1984; Bradford et al. 2001; Douglas et al. 2006). Their decline is attributed to the change in water flow and quality, thought to be associated with the construction of hydroelectric dams on the rivers (Jessop 1995; COSEWIC 2004). However, there is no clear understanding of how changes in water flow and quality have affected spawning and the survival of offspring. All that has been suggested is the altered hydrodynamics of the estuaries somehow hinders spawning (Jessop 1995; Douglas et al. 2003). In addition, pollutants possibly negatively affect spawning including, high levels of dichlorodiphenyltrichloroethane (DDT) and Polychlorinated Biphenyls (PCB's) (Dadswell 1976; Westin et al. 1983) and low pH levels (Williams 1978; Jessop 1980).

Up until the mid-20th century, striped bass spawned in both the Shubenacadie and the Stewiacke Rivers (W.H. Stone, personal communication, Alewife fishermen, Stewiacke, NS). Spawning on the Shubenacadie River took place from the rivers confluence to the village of Shubenacadie (river kilometer 35). However, within the past 55 years spawning has only taken place on the Stewiacke River, upstream of the 102 Highway Bridge between Stewiacke River kilometers 3 - 8 (Meadows, 1991; Rulifson and Dadswell 1995). Local fishermen believe striped bass stopped spawning in the Shubenacadie River in 1957 due to excessive sedimentation in the river, associated with the construction of the Halifax International Airport (W.H. Stone, personal communication, Alewife fishermen, Stewiacke, NS). Following spawning, May – June, the adults migrate back out into the Cobequid Bay, Bay of Fundy and along the coast to feed for summer. The extent for this population's migration is undetermined. A portion of adults from the Shubenacadie population either migrate back up the Shubenacadie/Stewiacke River in the fall to overwinter in Grand Lake or stay at sea; these fish are differentiated by their black or greenish colour respectively (Rulifson and Dadswell 1995; Paramore and Rulifson 2001; Bradford et al. 2012).

3.2 Life History, Habitat and Prey

Striped bass reach sexual maturity around age 3 - 4 for males and age 4 - 6 for females (Specker et al. 1987; Berlinsky et al. 1995). Day length and temperature are the principal environmental factors controlling the cycle of gonadal maturation and spawning (Clark et al. 2005). Gonadal maturation commences in the fall when females begin incorporating yolk into the developing eggs. The process continues through winter despite the low temperatures (< 3 °C). For the Shubenacadie population, increasing day length and increase in temperature in early April stimulates migration out of Grand Lake and into the Shubenacadie River (Douglas et al. 2003). During the pre-spawning period the adults move up and down extensively within both the Shubenacadie and Stewiacke branches of the estuary and non-tidal sections. Closer to spawning, adults congregate in the Stewiacke River, the principal spawning site. The timing of the start of spawning season in the Stewiacke River has been recorded accurately in 1994 by Rulifson and Tull (1999), more loosely between 1997 to 2007 (J. Duston and W. H. Stone unpublished observations) and accurately again from 2008 to 2009 by Reesor (2012). Within these years spawning generally occurred from mid - May to mid - June, with three to four major spawning events each season (Rulifson and Tull 1999; Reesor 2012; J. Duston and W. H. Stone unpublished observations). The initiation of striped bass spawning in many populations has been closely related to rising water temperature (Polgar et al. 1976; Setzler-Hamilton et al. 1981; Williams et al. 1984; Robichaud-LeBlanc et al. 1996). A rapid drop in water temperature has also been shown to cause spawning to stop (Calhoun et al. 1950; Boynton et al. 1977; Williams et al. 1984). The literature on US stocks indicates little or no spawning at temperatures below 12 ^{o}C or above 20 ^{o}C (Setzler-Hamilton et al. 1980; Olney et al. 1991; Secor and Houde 1995). This is similar with past studies on the Shubenacadie River, where eggs were detected in water temperatures from 12.4 - 20.6 ^{o}C in 1992 (Rulifson and Dadswell 1995), 10 - 22 ^{o}C in 1994 (Rulifson and

Tull 1999) 10 - 20.5 °C in 2008 and 12 - 22 °C in 2009 (Reesor 2012). Spawning on the Stewiacke River has also been suggested to be cued to the neap tide (Tull 1997). Determining how water temperature affects the timing of spawning on the Shubenacadie River is not only biologically important in terms of the striped bass life cycle but is useful for Alton Natural Gas Storage LP in order to predict the spawning for operation considerations and management. As part of my thesis I monitored the relationship between water temperature and the timing of spawning on the Shubenacadie River (Objective 5).

Spawning takes place at or near the surface, where many males surround one female, drifting downstream with the current (McLaren et al. 1981). On the Stewiacke River striped bass anglers observe spawning striped bass drifting with the current on the ebb tide (J. Duston unpublished communications) Female fecundity is proportional to age and body size. On the Shubenacadie River 16 females ranging from 44 - 102 cm TL, contained between 40,000 and 1.3 million eggs each (Paramore 1998). This body size/fecundity relationship is similar to other populations (Lewis and Bonner 1966; Williamson 1974; Hogans and Melvin 1984). As part of my thesis I collected additional body size and fecundity data on Shubenacadie River striped bass. These data are coupled with egg abundance data and used to estimate the total number of spawning females on the Shubenacadie River in 2010 and 2011 (Objective 4). External fertilization occurs when clear eggs about 1 mm in diameter are released into the water column simultaneously with milt (Scott and Scott 1988). Eggs spawned on the same day are considered to be a cohort (Secor and Houde 1995). After water hardening, eggs are about 3.5 mm diameter and slightly negatively buoyant but remain suspended in the water column by the turbulent estuarine water (Bayless 1968; Davin et al. 1999; Rulifson and Tull 1999). In both 2008 and 2009 a very high density of eggs (>1000 per m^3 of water filtered) was recorded in plankton net tows late in the first ebb tide following each of the major spawning events at the AGS (Reesor 2012). It would take several hours (4 - 8) for pelagic eggs to travel the nearly ten kilometers from the spawning grounds to AGS (Table 2.4). This density is extraordinarily high compared to 0.7 eggs/m^3 on the Miramichi River, the only other river in Atlantic Canada known as a nursery habitat for striped bass (Robichaud-LeBlanc et al. 1996) and < 12 eggs/m^3 in tributaries of the Chesapeake Bay, the main nursery area for 90% of US striped bass (Setzler-Hamilton et al. 1981; Bilkovic et al. 2002). The high egg density on the Shubenacadie River is due to the current large number of spawning adults, associated with high recruitment from the late 1990's and early 2000's (Bradford et al. 2012). High recruitment in 1999 in particular was associated with low rainfall from April to July, 50 - 60 mm less rain than average, and above average temperatures during May and June, 2.5 - 3 °C and September 4°C above average.

Egg development is related to temperature, hatching in about 48 hours post-fertilization at 16 - 17°C (Harrell et al. 1990). Once hatched, development of larvae is also dictated by temperature. At 17 °C larvae are vertically oriented, with no lateral swimming ability for up to the first 2 - 3 days post-hatch (dph; Meng 1993). At 3 dph or 4 mm TL, larvae become horizontally oriented. At 5 – 7 dph or 5 to 6 mm larvae inflate their swim bladder and have the capability to start feeding (J. Duston unpublished data). Larvae swimming ability improves quickly with growth, swimming at speeds of 3 cm/s at 8.5 mm TL, and 18 cm/sec at 16 - 20 mm TL (Doyle et al. 1984; Meng 1993). Larvae 7 mm or less, much like eggs, behave as passive particles in the turbulent and fast water column. Plankton net sampling was restricted to the main channel of the river, where the numbers of passive early life stage striped bass are likely higher. Recognizing the potential importance of the shallows as a refuge, they could not be sampled due to practical sampling limitations with the boat and plankton net. Nevertheless, the high density of larvae on the Shubenacadie River (>120 larvae/m^3; Reesor 2012) presents a great opportunity to quantify the spatial and temporal distribution of early post-hatch stages. By contrast, in 1994, Rulifson and Tull (1999) caught only 61 striped bass larvae total on the Shubenacadie River, too few to make any meaningful analysis. Similarly, other nursery habitats on the eastern seaboard catch few larvae, < .06 larvae per m^3on the Miramichi River, NB (Robichaud-LeBlanc et al. 1996) and < 3 larvae per m^3 on the Chesapeake Bay (Martino et al. 2007). With growth and improved swimming ability larvae can better control their positioning in the estuary. They then move to the near shore shallows of the estuary (Kernehan et al. 1981; Douglas et al. 2006; Bradford et al. 2012). However, it is unknown at what particular body size the age-0 striped bass can control their position in the shallows. Through the summer the juvenile (> 25 mm) bass gradually migrate down river along the shallows through more saline water and become more evenly distributed throughout the estuary (Chadwick 1964; Robichaud-LeBlanc et al. 1998; Douglas et al. 2006). In the Shubenacadie estuary age-0 striped bass are caught in shallows through the summer, and on the north shore of Cobequid Bay in August and September (Rulifson et al. 1987; Bradford et al. 2012). For my thesis beach seine sampling of the shallows occurred from June through to September at four sites on the

Shubenacadie estuary to evaluate seasonal changes in age-0 spatial distribution (Objective 1) and body size (Objective 7).

Age-0 striped bass are non-selective, opportunistic predators (Merriman 1941; Cooper et al. 1998). Newly hatched larvae feed off their yolk-sac for approximately six days and then begin external feeding when they reach 5 - 7 mm TL (Hardy 1978). The striped bass yolk-sac remains until 15 dph, giving striped bass both endogenous and exogenous food sources for several days, likely a good survival adaptation for variable environments with unpredictable food supplies (J. Duston unpublished data). With limited swimming ability larvae rely on an abundance of prey items to be within their reactive distance, typically small (< 0.5 mm) copepods. Reported threshold prey levels for striped bass larvae survival from laboratory studies range from 50,000 to 100,000 prey m^3 (Eldridge et al. 1981; Chesney 1989; Tsai 1991). In Chesapeake Bay zooplankton prey have exceeded 250,000 prey m^3 in the best striped bass recruitment years, but have been as low as 2000 prey m^3 in other years with poor recruitment (Martino and Houde 2010). Important food items of striped bass are copepods when larvae are 5 - 8 mm TL, isopods and amphipods (larvae < 15 mm) and then mysids (larvae < 30 mm; Heubach et al. 1963; Robichaud-LeBlanc et al. 1997; North and Houde 2006). Among Miramichi striped bass, the transfer between endogenous to exogenous food sources correlated with peak abundance in prey, with an average of 130,000 copepods/m^3 prey density (Robichaud-LeBlanc et al. 1997). Striped bass become piscivorous between 70 and 100 mm total length (Markle and Grant 1970; Nemerson and Able 2003); however they remain nonselective feeders (Boynton et al. 1981). There is no published literature on the stomach contents of Shubenacadie River larvae and juvenile striped bass or prey densities, with the exception of mysids which peaked around 10,000/m^3 in 2008 and 2009 (Reesor 2012) . Hence, as part of my thesis prey density and striped bass stomach contents were quantified (Objective 6).

3.3 The Shubenacadie Striped Bass Population

The present high numbers of adult striped bass in the Shubenacadie River population is contradictory to its ‘endangered’ status. In 1993 the first management plan in Atlantic Canada was established in response to the suspected negative consequences of the unregulated fishing (Chaput and Randall 1990). Striped bass numbers on the Shubenacadie River were believed to be very low in 1994 (Jessop 1995), but were not quantified. Since then the population has increased considerably. In 2002, based on a mark-recapture study, the population was estimated between 20 - 30,000, with 15,000 being a minimum reproductive age of three years old and at least 7,000 being four years old or over (Douglas et al. 2003). Over the past decade the population has increased further, and according to local fishermen is the highest in over 50 years (W.H. Stone and R. Meadows, personal communication, Alewife fishermen, Stewiacke, NS). More conservatively, the Department of Fisheries and Oceans (DFO) reported that the spawning abundance has “likely increased” since 2002 (Bradford et al. 2012). Since no stock assessment has been done since 2002, as part of my thesis I estimated the 2010 and 2011 spawning population size based on estimated annual egg abundance and female fecundity data (Objective 4). Striped bass annual egg production has been estimated using plankton net tows, river cross sectional and river velocity in several locations in the US such as Chesapeake Bay, Congaree and Wateree Rivers in South Carolina and many rivers in Virginia, finding annual egg production as low as half a million and as high as three billion (10^9; Olney et al. 1991; Bulak et al. 1993; Secor and Houde 1995). I followed the same approach.

Despite the current high number of adult striped bass, the population may not be stable, as striped bass populations typically have many poor recruitment years broken by the odd good year. The Chesapeake population in the 19th and early 20th century had one good year of recruitment for about every 20 (Merriman 1941; Bigelow and Schroeder 1953). In a recent 10 year recruitment analysis of age-0 striped bass in the Chesapeake Bay, two years had much stronger year classes (1996 and 2003) and recruitment levels varied 11 fold (Martino and Houde 2010). An additional pressure the Shubenacadie River striped bass face is the expanding recreational fishery. In recent years, due to the recovery of the Shubenacadie and US populations, striped bass have become the biggest recreational fishery in Nova Scotia (R. Bradford, DFO, personal communication). Traditionally Atlantic salmon (*Salmo salar*) and brook trout (*Salvelinus fontinalis*) were the most sought after recreational fishery species but with their population declines striped bass have emerged as the species of choice. On the Shubenacadie River commercial drift net fishers who target gaspereau (Alewife, *Alosa pseudoharengus*) and shad (*Alosa sapidissima*) were traditionally the main harvesters of striped bass. In 1997 each fisher was limited to keeping three striped bass > 68 cm TL a day and in 2009 this limit was further reduced to one striped bass per day for personal consumption only (Bradford et al. 2012). Recreational anglers are allowed to keep one striped bass > 68 cm TL per day, except between May 10 to June 10 when it is catch and release only (Nova Scotia Fisheries and Aquaculture 2011). Large numbers of adults are caught in the spring on the Shubenacadie River; about two adults per hour per angler were caught in a 2009 survey (Duston 2010).

3.4 Recruitment and Retention

Recruitment is generally accepted as when a fish survives their first year of life to be added to the population the following year. Determining the factors that affect recruitment is a principal priority in fisheries science but has proven to involve complex interactions of a variety of biotic and abiotic factors. The lack of understanding of the factors affecting Bay of Fundy striped bass recruitment has restricted recovery planning of the Annapolis and Saint John Rivers. Similar to many other marine fish, much of the variability in recruitment among striped bass is determined in the first year of life, when small changes in biotic and abiotic factors can lead to ten-fold differences in annual recruitment (Houde 1987; Martino and Houde 2010). Like most highly fecund organisms where there is no parental care, mortality among striped bass is very high in early life stages (Houde 1989). However, once striped bass survive their first year their chances of surviving to maturity are greatly increased (Mraz and Threinen 1957; Green 1982; Houde 1987). Thus, focusing this thesis on the early life stage Shubenacadie River striped bass is valuable work in the effort to understand recruitment mechanisms in order to conserve this endangered species.

Striped bass recruitment exhibits large inter-annual variation throughout the species range. In southern populations year class strength is primarily variable due to density-independent mortality during early life stages (Logan 1985; Martino and Houde 2010). Density-independent factors affecting mortality include water temperature, salinity and precipitation, which in turn are dictated by intra- and inter-annual variability in spring-summer climate (Rutherford and Houde 1995; North and Houde 2010). Additionally, changes in prey availability and predation rates may also affect survival and recruitment (McGovern and Olney 1996; Rutherford et al. 1997). Other important early life events that are crucial to first year recruitment are hatching and hatch date as they influences the match or mismatch in the timing of the larvae first feeding stages and the peak in prey availability (Rutherford et al. 1997), which in turn influences summer growth (Phillips et al. 1995; Rutherford and Houde 1995). The Larvae first feeding stage and the ontogenetic diet shift to piscivory, and lipid accumulation have also been established as crucial to first year recruitment (Polgar 1977; Dey 1981; Ludsin and DeVries 1997). Striped bass egg and early life stage larvae mortality in some US estuaries have ranged from 10% to 99% per day (Olney et al. 1991; Bulak 1993; Secor and Houde 1995). Variability in mortality rates declined considerably in early juvenile stages, ~25 mm TL (Uphoff 1989). However, winter climate following the first summer can also influence recruitment in age-0 striped bass, with colder winters resulting in higher winter mortality (Hurst and Conover 1998). Age-0 striped bass in other estuaries need to achieve an end-of-season body length of around 10 cm to survive over winter (Bernier 1996; Hurst and Conover 1998). As part of my thesis I measured age-0 growth (Objective 7). After the first year of life, natural (non-angling) mortality tends to stabilize at lower levels (Green 1982). Collecting data on the factors affecting the relative abundance of eggs and larvae is the first step in building a predictive recruitment model. Ultimately such a model can assist in estimating the probability of strong recruitment years, allowing for proper long-term striped bass management. Knowledge gained on physical factors influencing abundance of egg and larvae stages may also help better understand why the Annapolis and Saint John Rivers are no longer suitable nursery habitats for striped bass.

Survival and ultimately recruitment among estuarine populations of striped bass is dependent on their retention in the nursery habitat during the critical early life stages. However, no mechanisms have been suggested to explain egg and larvae retention in well mixed estuaries such as the Shubenacadie. I hypothesized that retention of early life stage striped bass in the warmer and less saline Shubenacadie estuary is crucial to early life stage survival because the Cobequid Bay is too salty (> 30 ppt) and too cold in June and is only a suitable habitat after transition to juvenile stages. Eggs and yolk sac larvae of Shubenacadie striped bass have higher rates of survival in upper estuarine conditions. In laboratory experiments survival was highest when salinity was 2 to 20 ppt and was reduced to < 50 % when salinity was greater or equal to 30 ppt, conditions of the Cobequid Bay (Cook et al. 2010). Growth of early life stage larvae was not significantly affected by salinity but was negatively affected by low water temperatures (< 10 °C), with optimum growth occurring at higher water temperatures (28 – 30 °C; Cook et al. 2010). During the egg and larval stages (mid-May to mid-June), the Shubenacadie estuary has a salinity range from 0 to 22 ppt and temperatures well above the critical 10°C (Rulifson and Tull 1999; Reesor 2012). I hypothesize the most important factor affecting early life stage retention within the Shubenacadie/Stewiacke nursery habitat is rainfall and freshwater run-off. Both are unpredictable and variable during the Nova Scotia spring. Another environmental factor affecting early life stage retention is the tide, and biological factors including time and location of spawning, the buoyancy of eggs and larvae and the active movements of larvae are also important. The length of the estuary also plays an important role in retention. In this thesis tide, rainfall, water velocity, timing of spawning, egg stage and larvae size are all evaluated in an effort to understand the potential distribution and distance traveled of early life stage striped bass and when retention or advection may occur from the estuary (Objective 1 and 2).

Chapter 4. Materials and Methods

4.1 Sampling Procedures

The sampling regime for striped bass eggs, larvae and juveniles was divided into two phases, one quantifying their temporal distribution at a fixed location, the AGS, and the other their spatial distribution throughout the estuary. Plankton net tows and beach-seine netting was used for assessing both the spatial and temporal distribution of striped bass.

At the AGS, plankton net sampling was conducted in the main channel at least three times per week from mid-May to early July in both 2010 and 2011 to quantify the density and temporal distribution of egg and larvae stage striped bass. Regular plankton net tows continued until no striped bass were caught. Single plankton net tows were repeated every 30 to 60 min for up to ten hours into the ebb tide. Very few samples were taken during the flood tide in 2010 until after June 9, as its safety and methodology was being evaluated. In 2008 – 2009 sampling was restricted to the ebb tide (Reesor 2012). In 2011 flood tide samples were taken more regularly, between 2 - 5 times on specific flood tides. In both 2010 and 2011 two 36-hour sampling sessions were conducted during peak spawning events at the AGS over three full tidal cycles. Thirty six hour sampling sessions were conducted because a large decrease in egg density occurred in the first 24-hours post spawning (Reesor 2012) and egg development occurs so quickly (~48 h) that hourly monitoring was essential. From mid-July to September plankton tows were performed once a week to estimate prey densities.

Samples were collected from the top 0.75 m of the water column using a standard conical plankton net (0.5 m mouth diameter, 3:1 length to mouth ratio; Aquatic Research Instruments) of either 500 µm or 250 µm mesh, with the same corresponding sized mesh inside the cod-end bucket. The 500 µm plankton net was most commonly used because it caught striped bass eggs and larvae and rarely got clogged with detritus. The 250 µm plankton net was only used when small prey items were being targeted. Nets were fitted with a calibrated flow meter (General Oceanics) to estimate the volume of water (m^3) filtered during each tow. Flow meters were regularly calibrated with a General Oceanics calibration frame (model 2030CF). Tows were conducted into the water current, in the main channel. The plankton net was secured to the back starboard of the boat with a 4 m long rope. The plankton net was towed in the water for 1 to 3 min behind a 3.7 m long wooden flat-bottom boat equipped with a four horsepower outboard motor. Boat speed was adjusted to hold station, with the net just beneath the water surface. All tows commenced at the same location, where the cross-sectional area had been surveyed. The volume of water filtered by a 1 min tow was on average 7 m^3. Plankton tows were limited to the top 1 m of the water column due to strong currents, and a small boat and motor, which led to an inability to submerge the net while keeping a horizontal position during the tow. Water velocity was also immediately estimated following each plankton tow at the AGS using drogue-buoy drifts (see page 24). Plankton net tows continued three times per week until striped bass were no longer being caught, at which time the primary sampling method switched to seine netting (mid-July to end of September).

Standard beach seine net sampling was conducted once to twice weekly on the west bank of the AGS. Sampling was possible only when the sandbar became exposed on the west bank, at least four hours into the ebb tide (Fig. 2.9). The net measured 12.5 x 1.85 m, with a mesh size of 5 mm except for the centre 5.2 m portion, which had 1 mm mesh. The net had a lead line attached to the bottom rope and 21 buoys on the top rope to keep the net vertical. Two operators started at the water's edge, one manually dragged the net with the lead line around their ankle and float line in their hand straight out from shore until the end of the net or the deepest safe water (1.4 m) was reached. The operator on shore stood still, while the operator in the water pulled the net in a semi-circle into the current and then back to shore, keeping the net as elongated as possible and on the river bed (Hahn et al. 2007). At the AGS the volume covered was approximately 228 m^3. Two non-overlapping samples were taken.

To survey the spatial distribution of striped bass eggs, larvae and juveniles, sampling was conducted from May to the end of September at various locations. A Zodiac boat, 4.6 m long, equipped with a 60 horse power mercury four stroke outboard motor was rented for sampling downstream of the AGS in the main channel. This boat provided a safe workplace in the strong currents and turbulent water. Plankton net tows were conducted bi-weekly from May to July, covering different sections of the river systematically until striped bass were no longer caught. The location of each tow was marked with a handheld GPS (Garmin GPSmap 60CSx, 3 – 10 m accuracy). When comparing tows taken upstream of the AGS, on the same day, on both the Stewiacke and Shubenacadie Rivers, the tow location was measured relative to the kilometers from the AGS. This kilometers association enabled easy comparison of striped bass densities between the branching of the rivers. Samples taken out in Cobequid Bay were also measured off in kilometers from the mouth of the Shubenacadie River. Kilometers out into the Cobequid Bay were then measured off following the main channel where the majority of the water flows out between the sand banks (Fig. 2.1). Key landmarks and their associated river kilometers were used throughout the spatial description (Table 2.2; Fig. 2.5).

The upstream transportation and distribution of eggs and larvae on the Stewiacke and Shubenacadie Rivers was investigated using two 3.7 m long wooden flat-bottom boats each equipped with a four horsepower outboard motor simultaneously, starting upstream of the salt front at high slack water. Plankton net tows began at high slack and were conducted approximately every kilometer heading back downstream on the ebb tide, motoring quickly downstream to avoid sampling the same parcel of water. Plankton net tows were taken first starting 6 km (June 3) and then 11 km (June 10) up the Stewiacke River from the confluence and starting 40 km (June 3) and then 43 km (June 10) up the Shubenacadie River from the estuary mouth.

To describe the spatial distribution of striped bass larvae and juveniles four sites in 2010 and five sites in 2011 were chosen for regular bi-weekly seine net sampling from the end of June through to September. The geographical range covered was 31 km on the Shubenacadie River from the estuary mouth and 2.8 km up the Stewiacke River from the confluence. Seine net sites were selected based on accessibility and factors such as firm banks and substrate, and manageable water velocities. Sites with large rocks and obstacles were also avoided. The four sites selected in 2010 were Black Rock, Princeport, Gosse Bridge and the AGS (Table 4.1). The Gosse Bridge site proved to be a poor location for seine netting because of high water velocity, and was not used in 2011. Two additional sites were chosen for 2011, sand bars near the 102 highway bridge over the

Shubenacadie River and 102 highway bridge over the Stewiacke River (Table 4.1). Two non-overlapping seine net tows were taken at each site each visit. The organisms caught were identified and returned to the estuary alive with the exception of a sub-sample of age-0 striped bass. Gaspereau or alewife and American shad were impossible for us to differentiate at the larval stage, thus they were grouped into one classification (*Alosa sp.*). During each plankton and seine net tow, hand-held meters were used to measure water depth (SKU Sonar: SM-5), water temperature (°C), salinity (ppt) and dissolved oxygen (mg/L) (YSI model 85 and YSIPro).

Table 4.1: Beach seine net sampling sites on the Shubenacadie (SR) and Stewiacke Rivers (StR) and their associated river kilometers and global positioning system (GPS) coordinates.

Location	River kilometer	Latitude - Longitude
Black Rock (SR)	2.7	45°31.658 N - 63°47.863 E
Princeport (SR)	6.2	45°28.601 N - 63°48.033 E
Gosse Bridge (SR)	11.3	45°24.998 N - 63°45.65 E
Alton Gas Site (SR)	25	45° 15.705 N - 63° 38.55 E
Bridge 102 Hwy Shubenacadie (SR)	31.8	45°10.734 N - 63°39.460 E
Bridge 102 Hwy Stewiacke (StR)	2.8	45°14.548 N - 63°35.746 E

4.2 Sample Preservation, Sorting and Enumeration

To euthanize the fish caught, 2-phenoxyethanol (Sigma Chemicals; 2ml/1L water) anesthetic was used. To fix plankton net tow samples, specimens were preserved and stained with a mixture of rose bengal dye (Sigma Chemicals; 5%) and buffered 10% formalin (Fishers Scientific; 5 drops dye to 500 ml buffer). The bengal rose dye stained organisms pink facilitating sorting of organisms from the detritus. Organisms caught in the seine net were counted and sorted, a sample of the striped bass were euthanized and preserved in 10% formalin. Each plankton net and seine net sample was labeled and stored in a two-liter white plastic ice cream container with a secure lid, until processed back at the laboratory within a week of capture. Age-0 striped bass do not shrink when preserved in formalin (Reesor 2012).

In the Dalhousie laboratory each plankton tow sample container was emptied into a shallow plastic tray where juvenile fish and large detritus were removed. Then remaining material was poured into a 4 L beaker and seawater was added to the 2 L mark. To re-suspend the material a silica aquarium air diffuser was placed in the beaker and bubbled vigorously. Three sub-samples were then taken from the re-suspended material using either a 15 ml or 25 ml cup. The volume chosen depended on the abundance of animals being counted. Each sub-sample was placed into a 15 cm diameter petri dish where the icthyoplankton were identified and counted under a dissecting microscope with the aid of forceps and dissecting needles. Striped bass eggs were enumerated and assigned to one of four development stages; 'new', 'blastula', '24-hour' or 'close-to-hatch' (Table 4.2; from Fig. 5.13-5.16 *in* Hardy 1978). These four stages were chosen based on ease of visual identification, not an equal four way division of the development time. At 18.8 ºC striped bass egg are in the new stage for approximately 3 hours, blastula stage for 16 hours, 24-hour stage for 15 hours and close to hatch stage for 9 hours (Bayless 1972 *in* Hardy 1978). Striped bass larvae were defined as 3 – 25 mm TL, and juveniles were > 25 mm TL, displaying soft and spiny fins. Striped bass were identified, total body length measured (0.1 mm) and body weight (0.1 g) recorded. Stomach contents of about 900 age-0 striped bass ranging in body size from 5 to 125 mm TL were examined in both 2010 and 2011under a dissecting microscope. The type and quantity of food items (cladocerans, copepods, fish, mysids, and isopods) in their gut was recorded. Prey that could not be identified were categorized as ‘digested food’. The number of parasitic worms attached to the striped bass gut was also recorded. In sample containers with 10 or fewer striped bass, the gut contents of all fish were analyzed. In samples containing >10 fish, 10 individuals were randomly selected for stomach analysis. Macro-invertebrates were counted and identified to the lowest taxonomic level practical (Gosner 1971; Balcer et al. 1984). The exception was the opossum shrimp, *Neomysis americana.* Because this species was highly abundant, it was sub-divided into three categories: adults > 5 mm TL, pregnant adults > 5 mm TL and other < 5 mm TL (Johnson and Allen 2005).

Table 4.2: Four development stages of striped bass eggs used for enumeration based on visual identification of the stage characteristics. Eggs are in each of the four developmental stages for varying durations of time, at 18.8 ºC eggs develop in 43 hours (Fig. 5.13-5.16 *in* Hardy 1978).

Egg development stage	Stage characteristics	No. of hours at each stage at 18°C
New	No visible development	3
Blastula	Cell division visible	16
24-Hour	Larvae body shape begins to form around the remaining embryo	15
Close to Hatch	Within the egg, larva is visible with yolk-sac and oil globule	9

4.3 Striped Bass Fecundity Estimates

Fecundity estimates were made from sixteen mature pre-ovulated female striped bass > 68 cm TL donated by fishers in spring 2011. Total and fork length (cm), and body weight (kg) were recorded. Otoliths, several scales and ovaries were removed and brought back to the laboratory for processing. The total ovary weight (to 0.001 g) was recorded and three subsamples, weighing approximately 1 g each, were removed from the anterior, mid and posterior sections of one ovary. Ova samples were placed in a petri dish and teased apart using a dissecting needle and water, and eggs were counted. The mean number of ova per gram from the three subsamples was used to calculate fecundity (Calliet et al. 1986). These fecundity estimates were compared against historical Bay of Fundy striped bass data taken from 10 striped bass from the Shubenacadie River in 1994 (Paramore 1998), and 11 from the Saint John River in 1972 (Williamson 1974). This combined fecundity estimate was used in conjunction with the 2010-2011 egg abundance data to estimate the number of spawning females involved in each spawning event. Scales were cleaned by with fresh water and gentle rubbing between the index finger and thumb. The scales were then mounted between two glass slides and read on a microfiche reader at 24x magnification. The outer edge of each scale was counted as the last annulus.

4.4 Statistical Analysis

The density of striped bass eggs, larvae and juveniles as well as one prey species of interest (*Neomysis americana*) collected in each plankton net tow were expressed as number of organisms per cubic meter of water filtered. Ebb tide daily means (number of organisms per m^3 water filtered) were calculated for eggs, larvae and mysids by dividing the total number of organisms caught during the ebb tide that day in all plankton net tows by the total number of cubic meters of water filtered during the ebb tide that day. Other early life stage striped bass studies have taken a similar approach (Anderson 1985; Robichaud-LeBlanc et al. 1996; Reesor 2012). The daily ebb tide means are used to simplify the data and show an overview of the season, typically a mean is associated with a standard error but here it is not appropriate as there were large changes in density over the ebb tide. At the AGS, a major spawning event was classified as new or blastula daily mean egg density exceeding 100 eggs/m^3 and exceeding 1000 eggs/m^3 for at least two tows spanning at least 1 hour on the ebb tide. Large spawning events were classified as days when new or blastula daily mean egg density exceeded 100 eggs/m^3 but did not reach 1000 eggs/m^3 on the ebb tide. To estimate time to hatch, egg stage was related to water temperature (Fig. 4.1; Harrell et al. 1990; Duston, unpub., 2011). To test whether the timing of spawning in 2010 was different from 2011 as indicated by egg presence at the AGS, a pooled variance 2-sample t-test with a 95% confidence interval was conducted (Minitab).

Total abundance of eggs per second flowing past the AGS was estimated by the changes in egg density through the tidal cycle relative to the cross-sectional area of the water column and water velocity. The cross-sectional profile of the river bed at the AGS was surveyed in both May and September 2010 by D. Hingley (NS Dept. Public Works) using a surveyor grade GPS unit accurate to +/- 2 cm (Leica SR530). Since all plankton net tows at the AGS were taken in the main channel, estimates of abundance of icthyoplankton were restricted to this portion of the estuary, and hence are a conservative underestimate of total abundance. To calculate the number of eggs and larvae/sec flowing past the AGS during each phase of the tide a number of parameters were taken into consideration:

A- Cross sectional area (m^2), derived from the sonar data
B- 30% of the cross sectional area (m^2) is the main channel, derived from ADCP
C- Main channel river velocity (m/sec), derived from drogue buoy drifts
D- Eggs/m^3, derived from flowmeter and plankton net tows

To calculate eggs/sec the following equation was used:

- (Cross sectional area (m^2) * 0.3 main channel) * velocity (m/s)= m^3/sec
- m^3/sec * eggs/m^3 = eggs/sec

The following assumptions were satisfied:

1. The drogue buoy drifted along the main river channel. This was achieved by careful deployment of the drogue in the main channel. If the drogue got beached the data was rejected.
2. The velocity of the top 0.5 m of water column was assumed to be representative of the entire main channel. Confidence in this assumption comes from the 2006 ADCP data, which shows the velocity of the top 0.5 m of the water similar to that of the main channel (Fig. 4.2).
3. The number of eggs/m^3 collected in the 0.5 m mouth diameter of the plankton net was representative of the entire main channel of the river. Confidence in this assumption comes from knowledge of the eggs being carried as passive particles in the highly turbulent 1- 4 m water column.
4. 30% of the cross sectional area of the river represents the main channel. Confidence in this assumption comes from examining the 2006 ADCP data, which had an average of 30% of the cross section flowing at the rate of the main channel through 41 cross sections through two tidal cycles (Fig. 4.2).
5. The cross-sectional area and flow in 2010 and 2011at the AGS was similar to that in 2006 when the ADCP survey was conducted. Confidence in this assumption comes from aerial photos from 1980's that show the AGS has a relatively stable topography, with the large sand bank on the west side and the main channel on the

east side of the river (Fig. 2.4). The main velocities recorded by the ADCP through the tidal cycle in 2006 were comparable to the velocities determined by drogue-buoy drifts during similar sized tides in 2010 and 2011.

Total egg abundance per ebb tide was calculated by using all ebb tide samples during a single ebb tide and multiplying each instantaneous new or blastula egg production estimate (eggs/sec) by the number of seconds to the next plankton net tow sample, and then summing all estimates for the tows conducted that ebb tide. Total egg abundance per flood tide was calculated in the same way but was not included in the daily total egg production, because they were the same eggs being carried back upstream on the flood tide. Because eggs were being carried back and forth through the tides, measures were taken to avoid double counting eggs. Only new and blastula eggs were counted and the water temperature was incorporated to estimate time to hatch. Egg production for each season was calculated by summing all new and blastula eggs from each ebb tide, accounting for eggs returning on successive ebb tides. Estimate of the total number of spawning females over the entire spawning season was based on seasonal egg production multiplied by the average number of eggs per female. The estimate is very conservative as it only accounts of eggs located in 30 % of the cross sectional area.

On the few occasions that water velocity measurements were not taken simultaneously with the plankton net tow at the AGS, a quadratic equation was used to estimate the flood and ebb tide velocity, with x being the time after the bore when the tow was taken and y equalling velocity. The equations were based derived from flood and ebb tide velocity data collected in 2010-2012:

Flood, $y= (0.002*x^2)-(0.1423*x)-4.5177)$ $R^2 = 0.88$, $n = 22$

Ebb, $y= (0.000025*x^2)-(0.03061*x)+10.693)$ $R^2 = 0.82$, $n = 41$

Seine net data was analyzed by calculating each species catch per unit effort (mean catch per seine haul) as a measure of comparing age-0 spatial distribution and relative density (Goodyear 1985). To compare the total body length of striped bass larvae caught in the plankton net with those caught in the beach seine on the same day, a pooled variance 2-sample t-test with a 95% confidence interval was conducted (Minitab). Age-0 striped bass growth rates were calculated as the difference between initial and final total lengths divided by the number of days striped bass were collected, expressed as mm/day. Stomach contents of around 900 age-0 striped bass collected in both 2010 and 2011 from the Shubenacadie River from June to August. These striped bass were put into 5 mm length classes and expressed as percentage of striped bass with prey in their gut. Of those with prey in their gut, prey items were identified and expressed as % N, referring to the number of prey items as a percentage of the total number of prey items found in all fish in each size class.

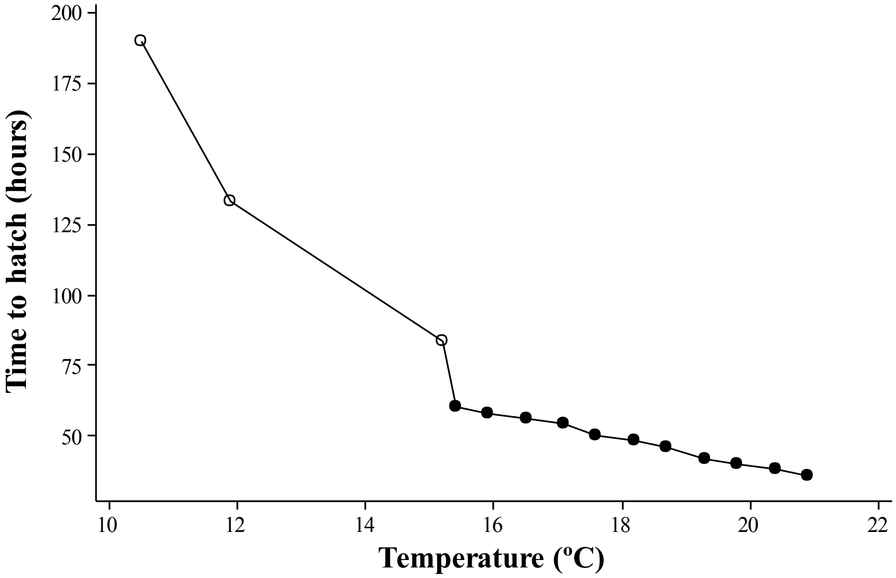


Figure 4.1: Time to hatch of striped bass eggs vs. temperature (˚C). Solid circles: From Harrell et al., 1990. Open circles: Dalhousie Agricultural Campus data from eggs collected from the Stewiacke River May 28, 2011. Eggs were 'new' eggs but time of fertilization is unknown (Duston, unpubl., 2011).

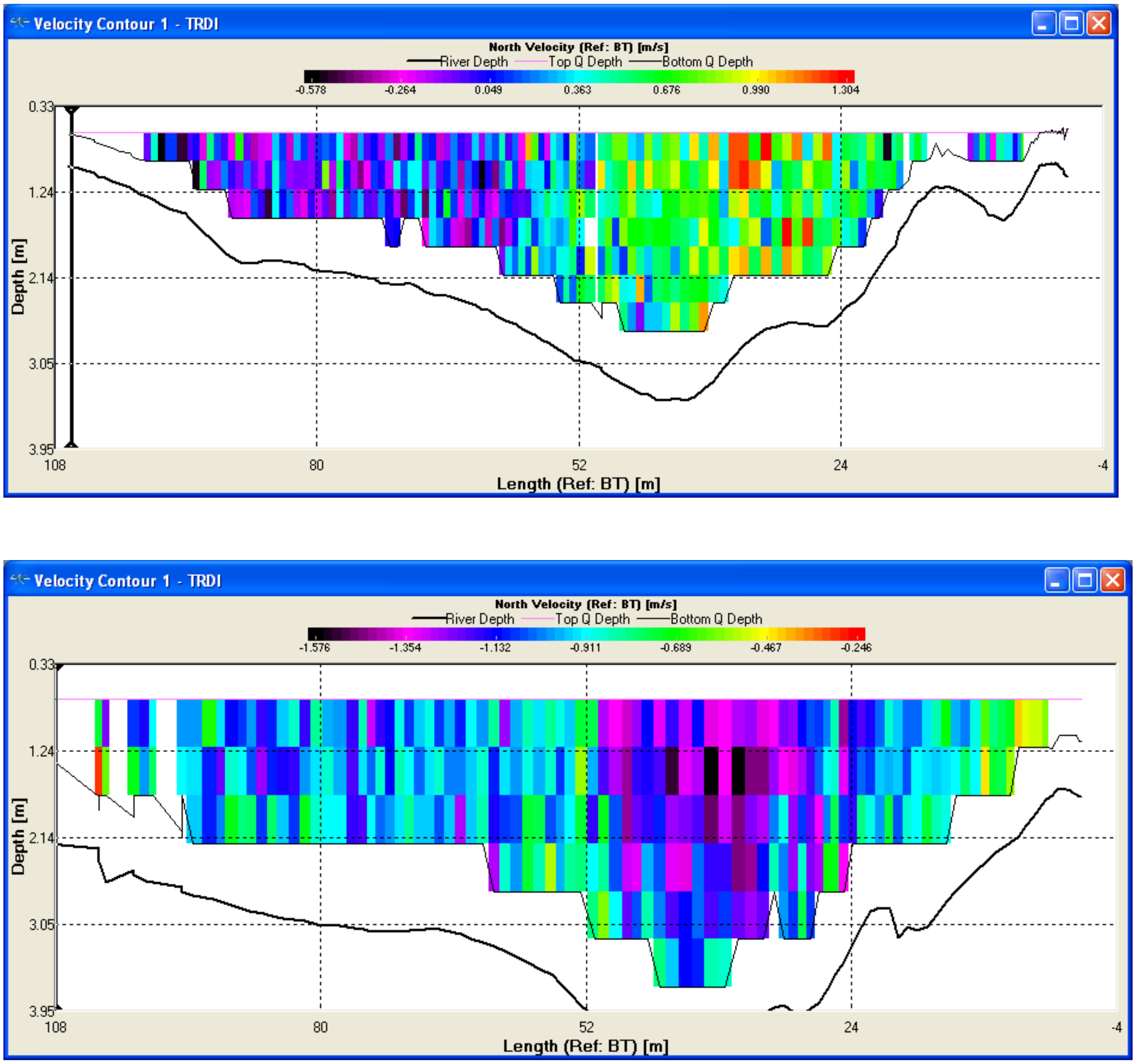


Figure 4.2: Cross-section of the Shubenacadie River at the Alton Gas Site recorded by the Acoustic Doppler Current Profiler on October 17, 2006, 10 hours into the ebb tide (upper panel) and 10 min into the flood tide (lower panel). Water velocity is in meters/sec and is displayed as negative values when the water is flowing upstream.

Chapter 5. Eggs and Larvae Results and Discussion

5.1 Results: Fecundity

The mean fork length and body weight of sixteen striped bass females close to ovulation were 81.5 cm (range 77 to 86 cm; SE 0.719) and 6.68 kg (range 5.72 to 8.23 kg; SE 0.198) respectively. Mean fecundity was 905,254 eggs (± 76354 SE; Table 5.1). The age range was 7 to 13 years old, with an average of 9.5 years. To get a more representative fecundity estimate, historical Bay of Fundy striped bass data was taken from 10 striped bass from the Shubenacadie River (Paramore 1998), and 11 from the Saint John River (Williamson 1974). Combined with the 2011 data set, mean fecundity for the 37 striped bass was 717,919 eggs (± 68,290 SE; Fig. 5.1). The fork length ranged from 45 to 96 cm and the age range was 4 to 14 years old based on scales and or otolith readings. Fork length was graphed with fecundity; however two of the striped bass from Williamson (1974) were not included because of missing length data. Mean fecundity of 717,919 eggs was used in estimates of the number of spawning females during the 2010 and 2011 seasons.

Table 5.1: Striped bass estimated age based on scale readings, body size and estimated fecundity of 16 pre-spawning females from the Shubenacadie River in April and May 2011. All striped bass were greater than 68 cm total length due to the Nova Scotia striped bass fisheries regulation which prohibits fishers from keeping striped bass of smaller sizes. * denotes missing data.

Estimated age	Body weight (kg)	Fork length (cm)	Total length (cm)	Fecundity
7	6.51	79.8	83.8	536,251
7	5.72	73.7	77.6	714,095
8	6.29	76.2	81.3	512,064
8	*	73.7	78	516,441
8	6.63	78	82	976,600
9	6.62	75.2	81.3	516,054
9	6.86	*	83.8	1,116,510
9	7.04	79	84	1,167,859
10	6.06	73.7	77.5	704,474
10	5.9	74.2	79.2	879,709
10	6.76	78	83	892,791
11	6.07	73.5	77	969,132
11	8.11	82	86	1,438,111
13	6.77	78.7	83.8	995,196
13	*	75.5	80.5	1,131,520
13	8.23	80.5	84.5	1,417,261
Mean	6.68	76.8	81.5	905,254
SE	0.198	0.708	0.719	76,354

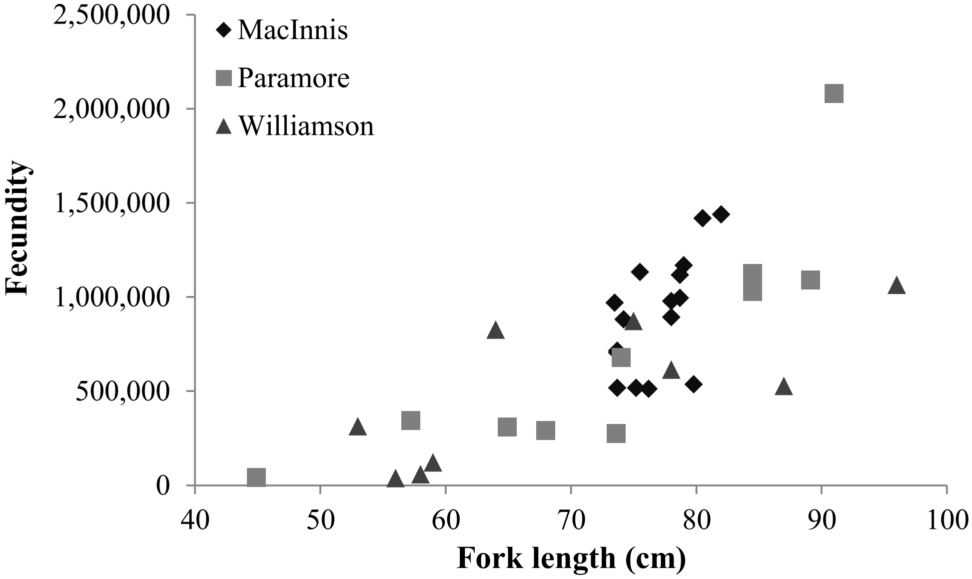


Figure 5.1: Fecundity with respect to fork length (cm) of Bay of Fundy pre-spawning female striped bass. N = 16 MacInnis this study, n = 10 from the Shubenacadie River in 1994 (Paramore 1998), and n = 9 from the Saint John River in 1972 (Williamson 1974).

5.1.1 Discussion: Fecundity

The sixteen pre-spawning females sampled in 2011 were all > 68 cm TL in compliance with fisheries regulations. Since these samples were not random, their mean fecundity (9.0 x 10^5) was likely greater than the true average for the Shubenacadie River population. Using historical data, from striped bass 45 – 96 cm FL (Paramore 1998; Williamson 1974) were included to achieve a more representative estimate of fecundity for the Shubenacadie River population. Within the three studies the fecundity estimates from fish within the same fork length range (73 – 85 cm) were fairly variable (200,000 to 1,400,000). However, within each study the range in fecundity of similar body size was also quite large. Pooling the 2011 fecundity estimates with Paramore (1998) is a reasonable action, as the fish are from the same population. Including fecundity estimates from striped bass of the Saint John River (Williamson 1974) may be questionable, as these fish maybe genetically distinct from the Shubenacadie population, and were comprised mostly of migratory US fish (Wirgin et al. 1995). However, Saint John River striped bass were of similar size to those in the Shubenacadie River at the same ages (Rulifson and Dadswell 1995) and seemed reasonable to include in the fecundity estimate. I considered including eight southern Gulf female striped bass caught in the Kouchibouguac River, NB, whose body length ranged from 47.5 to 52.5 cm and fecundity ranged from 78,000 to 121,000 (Hogans and Melvin 1984). However, it seemed sensible to include purely striped bass from the Bay of Fundy estuaries. Although including historical data improved the Shubenacadie fecundity estimate, the range is still patchy with very few striped bass under 50, between 60 and 70 and over 90 cm FL (Fig. 5.1). Knowing the complete age structure of the Shubenacadie River population would allow a better estimate of fecundity and population size. The DFO is planning a stock assessment in spring of 2013 (R. Bradford, BIO, personal communications). Coupling fecundity estimates with the stock assessment would be logical.

Age estimates for the 2011 adult female striped bass was determined by counting scales. However, counting scales to estimate ages can be problematic for adult striped bass over 91 cm TL or over 11 years old, as many have false annuli and/or narrow annuli at the margins of their scales. After age 11, scales generally underestimate the age of striped bass (Secor et al. 1995), whereas otoliths are more accurate (Secor 1992). Unfortunately, I was unable to analyze the otoliths in time for this thesis. Thus, the ages for approximately half of the 2011 female striped bass collected may be inaccurate.

5.2 Results: Egg Density at the Alton Gas Site with Respect to Date

Striped bass spawning in 2010 was relatively early due to the relatively warm weather in April and May. Water temperature in the Stewiacke River, the principal spawning area, reached almost 15 ^{o}C on May 6, > 5 ^{o}C warmer than 2011 (Fig. 5.2). The timing of spawning between 2010 and 2011 differed significantly ($P < 0.05$). By contrast, egg production was similar both years ($P > 0.05$). In 2010, small numbers of eggs were first detected May 7, however, the following day water temperature decreased sharply and stayed low May 7 to 16 associated with cool weather and 116 mm of rain. The first major spawning event, spanning May 17 and 18, occurred when water temperatures were between 12.3 and 13.5 ^{o}C, daily average ebb tide density of new and blastula eggs was 979 and 1452 eggs/m^3 respectively. Large numbers of eggs from the May 17 - 18 cohort continued to be collected May 19, where 60% of eggs were at the '24-hour' development stage and May 20, where 82% were at the 'close to hatch' stage (Table 5.2). Some spawning took place May 21 - 24 (35 - 313 eggs/m^3) when water temperatures were rising from 12 to 18 ^{o}C. The next major spawning event spanned May 25 - 26 when daily average ebb tide egg density was 1137 and 678 eggs/m^3 respectively. Spawning slowed after May 26 as water temperature dropped steadily, associated with the 47 mm of rain that fell between May 30 and June 2 (Fig. 5.2) and cool weather, causing the estuary to cool to 10 ^{o}C by June 2 and 3. Through the rest of June 2010, eggs were present in low numbers most days with the last noteworthy spawning occurring on June 11 (118 eggs/m^3) when temperatures increased to 15 ^{o}C. The final day eggs were detected in 2010 was July 2. Only 142 mm of rain fell during the spawning season May 7 – July 2 (Fig. 5.2

top panel; Table 5.2), which is 70 mm less than average (1971 to 2000 at the Stanfield International Airport weather station).

In 2011, eggs were first detected in low numbers May 18, with the first large spawning event four days later, May 22. The May 22 spawning occurred at 11.6 °C and the daily average ebb tide egg density was 280 eggs/m^3 (Fig. 5.2 bottom panel). Eggs were present in low numbers most days through to the end of June, with two major spawning events, May 29 and June 2. On May 29 the daily average egg density over the ebb tide was 4127 eggs/m^3, over twice as large as any other spawning event in 2010 or 2011. This spawning followed a rapid warming trend from 11 to 18 °C from May 23 to 29. The May 29 cohort, were detected in large numbers the following day, May 30, 57 % were at the 24-hour stage (Table 5.3). June 2 was the second largest major spawning event with daily average egg density of 1879 eggs/m^3 and occurred at 15 °C (Fig. 5.2 bottom panel). Spawning slowed over the next ten days, with small numbers of eggs collected on June 6 and 8. The next spawning event, June 10 (311 eggs/m^3) occurred when temperatures rose from 14 to 16 °C. From June 15 - 19, cold weather and rain (100 mm) resulted in a drop in water temperature and a cessation of spawning. Small spawning events resumed in late June, with a few eggs detected through to July 6 (Table 5.3).

Eggs were present at the AGS over a wide range of temperatures, 10.1 to 20.5 °C in 2010 and 10.8 to 23.8 °C in 2011. In 2010, the majority of eggs were collected in water temperatures 12 to 13 °C (35 %) or 15 to 18 °C (38 %), with the remaining eggs fairly evenly collected in temperatures from 10 to 20.5 °C. In 2011, 68% of the eggs were collected in water temperatures between 16 to 18 °C, with the remaining eggs fairly evenly collected in temperatures from 10.8 to 23.8 °C. Eggs were collected in salinities ranging from 0 to 23.9 ppt in 2010 and from 0 to 20.3 ppt in 2011. In 2010, eggs were quite broadly distributed through a range of salinities, although 65 % of eggs collected were in water less than 11 ppt (Fig. 5.3). By contrast, in 2011, 61% of eggs were found in salinities < 1 ppt (Fig. 5.4). In both 2010 and 2011 there was no evidence of higher egg mortality at extreme salinities or temperatures.

Large spawns were initiated at all phases of the lunar cycle. In 2010, the first major spawning, May 17 - 18 occurred a few days before the new moon (May 20). The second major spawning on May 25 occurred a few days before the full moon (May 27; Fig. 5.3 upper panel). In 2011, the largest spawning events May 29 - 30 and June 2 - 3 were on either side of the June first new moon; however other spawning occurred throughout the lunar cycle (Fig. 5.3 lower panel).

Figure 5.2: Striped bass new and blastula egg density 2010 and 2011 (mean eggs per m^3 water filtered over a single ebb tide) on a log scale at the Alton Gas Site on the Shubenacadie River. Temperature (°C; dotted line) was recorded on the Stewiacke River (km 1). Open diamonds indicate days when sampling was conducted but no eggs were detected, open triangles indicate days when no sampling occurred at the Alton Gas Site. F = full moon, N = new moon.

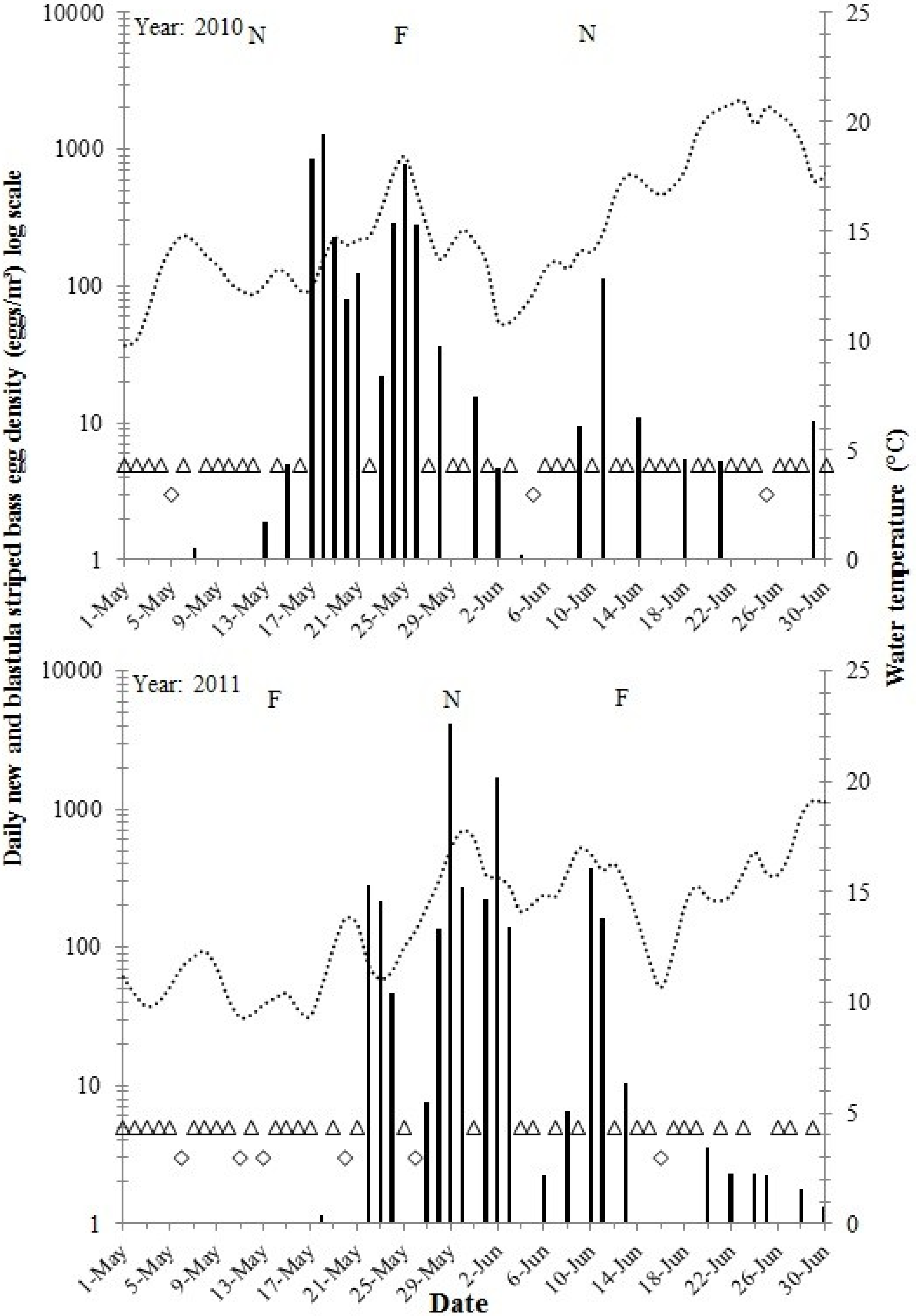

Year: 2010
N
F
N
Year: 2011
F
N
F
Daily new and blastula striped bass egg density (eggs/m³) log scale
Water temperature (°C)
Date
10000
1000
100
10
1
25
20
15
10
5
0
1-May
5-May
9-May
13-May
17-May
21-May
25-May
29-May
2-Jun
6-Jun
10-Jun
14-Jun
18-Jun
22-Jun
26-Jun
30-Jun

Table 5.2: 2010 striped bass daily average egg density (egg/m³) during the ebb tide and percentage of total eggs in each egg stage relative to date, hours spent sampling at the Alton Gas Site, daily mean water temperature (°C), daily maximum salinity (ppt), daily total rainfall and total rainfall within 10 days (mm; recorded at Stanfield International Airport weather station), and tide size.

2010	Hours sampling at Alton site (hh:mm)	Daily mean water temperature (°C)	Daily maximum salinity (ppt)	Daily Rainfall (mm)	Rainfall within 10 days (mm)	Tide size	Daily average ebb tide egg density (egg/m³)	Percent of total eggs in each stage				
								New	Blastula	24-Hour	Close to Hatch	Dead
7-May	4:10	14.5	*	0	13.6	vs	0	0	100	0	0	0
13-May	9	12.6	21.0	0	12.7	s	11	0	100	0	0	0
15-May	4	13.0	22.1	0.5	13.2	s	4	0	100	0	0	0
17-May	18:30	12.4	23.2	0	7.7	s	979	8	80	0	0	12
18-May	16:10	13.7	23.3	0	1.6	s	1453	2	88	1	0	9
19-May	3	14.7	23.5	20.2	21.3	s	891	6	20	60	6	8
20-May	0:30	14.4	23.4	0.3	21.2	s	621	0	13	0	82	5
21-May	3:10	14.6	22.9	0	21	s	153	4	77	7	5	7
23-May	8:10	16.1	22.6	0	21	s	35	1	61	9	26	3
24-May	1	17.6	22.6	0	21	s	313	1	92	0	1	7
25-May	18:30	18.4	22.9	0.2	20.7	s	1137	16	53	22	4	5
26-May	16	16.8	23.8	0	20.7	s	678	13	28	20	24	15
28-May	4:10	13.7	24.4	0	22.2	s	67	5	50	7	34	5
31-May	4:30	14.5	23.4	0.6	14.1	s	19	8	75	0	8	9
2-Jun	4	10.9	*	0	48.2	s	7	0	64	36	0	0
4-Jun	5:30	11.4	*	0.3	49.7	vs	0					
9-Jun	5:10	14.1	*	0	59.6	vs	10	10	80	0	0	10
11-Jun	4:30	15.0	*	0	24.9	s	118	2	94	1	1	2
14-Jun	3:10	17.5	16.5	1	24.2	m	23	44	4	8	8	35
18-Jun	6	17.8	19.8	0	1.7	m	11	0	49	0	51	0
21-Jun	6:45	20.6	21.1	0	6.3	s	11	0	48	0	52	0
25-Jun	5	20.7	21.9	0	12.3	s	0					
29-Jun	6	17.4	21.3	0	39	s	10	0	100	0	0	0
2-Jul	4:42	18.8	15.7	0	34	vs	10	0	100	0	0	0

Table 5.3: 2011 striped bass daily average egg density (egg/m^3) during the ebb tide and percentage of total eggs in each egg stage relative to date, hours spent sampling at the Alton Gas Site, daily mean water temperature (°C), daily maximum salinity (ppt), daily total rainfall and total rainfall within 10 days (mm; recorded at Stanfield International Airport weather station), and tide size.

								Percent of total eggs in each stage				
2011	Hours sampling at Alton site (hh:mm)	Daily mean water temperature (°C)	Daily maximum salinity (ppt)	Daily Rainfall (mm)	Rainfall within 10 days (mm)	Tide size	Daily average ebb tide egg density (egg/m³)	New	Blastula	24-Hour	Close to Hatch	Dead
18-May	4:10	10.7	11.1	0	79.7	m	0.2	100				
20-May	3	13.8	12.4	1	26.6	m	0					
22-May	2	11.7	11.1	0	19.2	s	280.5	2	98	0	0	0
23-May	16	11.1	8.0	0	19	s	219.6	7	91	2	0	0
24-May	20	11.4	7.5	1.2	20.2	vs	47.3	0	99	1	0	0
27-May	5	14.4	8.1	0	3.4	vs	10.4	0	76	8	16	0
28-May	16:30	15.5	7.6	0	3.4	vs	137.2	0	100	0	0	0
29-May	16:30	16.9	9.2	0	3.4	vs	4127.5	16	84	0	0	0
30-May	12:45	17.8	11.2	3	5.4	vs	609.8	0	43	57	0	0
1-Jun	3:45	15.8	13.7	12.2	17.1	s	291.9	16	84	0	0	0
2-Jun	3	15.7	14.8	0.7	17.8	s	1879.6	17	83	0	0	0
3-Jun	4:10	15.3	14.6	0	16.6	s	311.8	28	16	56	0	0
6-Jun	5:10	14.9	14.7	1.7	17.6	s	2.4	72	14	0	0	14
8-Jun	3:30	15.9	14.3	0	17.9	s	8.1	10	70	20	0	0
10-Jun	1	16.7	16.4	0	14.9	s	378.3	10	89	1	0	0
11-Jun	2:30	16.0	17.3	0	2.7	s	284.4	23	41	36	0	0
13-Jun	2	15.3	18.4	14.2	16.2	s	14.7	13	57	5	24	1
16-Jun	3:45	10.7	4.5	1.8	100.3	m	0					
20-Jun	2	14.7	5.9	0	126.2	s	4.7	16	61	23	0	0
22-Jun	2	14.9	5.3	0	126.2	s	3.0	15	63	16	6	0
25-Jun	1:10	15.9	7.4	3	31	s	2.2	24	76	0	0	0
28-Jun	4	18.5	10.5	0	6.2	s	1.2	9	91	0	0	0
30-Jun	1	19.1	13.0	0	3.2	s	1.3	25	75	0	0	0
4-Jul	3:45	20.2	18.9	0	3.2	m	0					
6-Jul	1:30	21.5	20.2	0	0.2	m	0.4	0	50	50	0	0

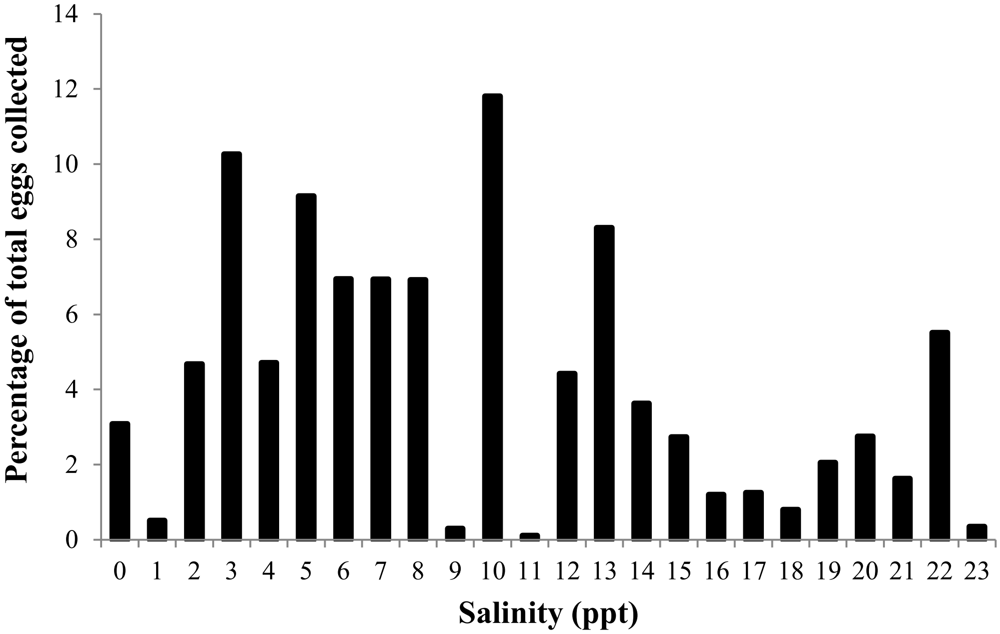


Figure 5.3: The percentage of the total eggs collected in 2010 at the Alton Gas Site at salinities (ppt) ranging from 0 – 23 ppt.

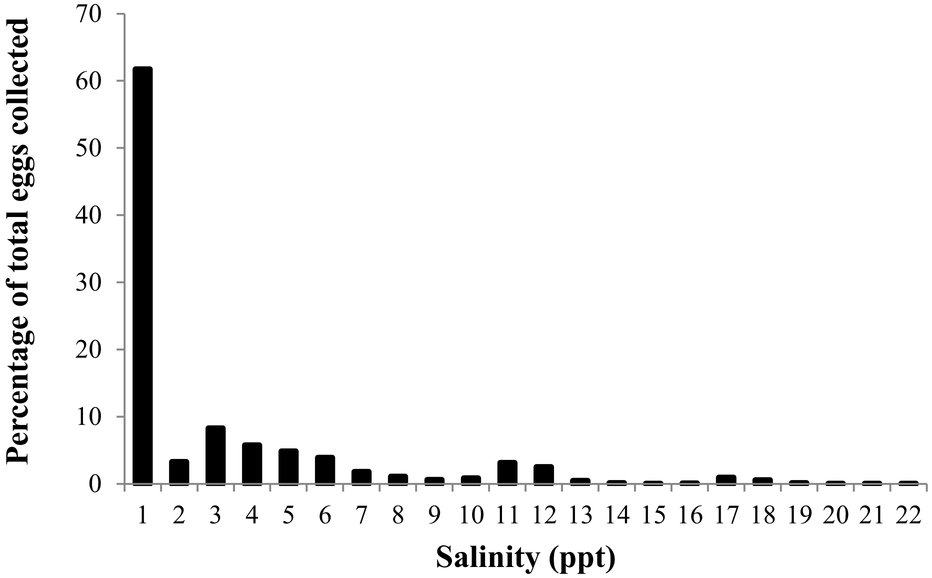


Figure 5.4: The percentage of the total eggs collected in 2011 at the Alton Gas Site at salinities (ppt) ranging from 1 – 22 ppt.

5.2.1 Discussion: Egg Density at the Alton Gas Site with Respect to Date

Both the 2010 and 2011 striped bass spawning seasons produced huge quantities of eggs in the Shubenacadie River, a clear indicator that the adult population is large and healthy. The timing of the spawning season varied significantly from year to year. The early spawning in 2010 was likely related to the warmer spring, mean air temperature in April and May was 3.2 and 1.3 ^{o}C above average respectively (1971 - 2002; Environment Canada), causing water temperatures to rise to 15 ^{o}C on May 6, > 5 ^{o}C warmer than water temperatures around the same date in 2011 and 2008 - 2009 (Reesor 2012). The 2010 May 17 spawning was the earliest recorded over the past decade or so (Fig. 5.5). By comparison, late spawning in 2011 was associated with cool weather, however the spawning persisted into July, the latest in the past decade (Fig. 5.5).

Predicting the timing of the first big spawn is difficult. A warming trend increases the chances of spawning, but the first spawn can occur when temperature is declining from a peak, as occurred in both 2010 (May 13) and 2011 (May 22). This lag in response is likely due to the time needed for eggs to complete final maturation following a warm temperature stimulus. Day length and temperature are the major environmental factors controlling the early stages of gonadal maturation, a process that starts in the fall (Blythe et al. 1994; Secor and Houde 1995). However, a laboratory based study indicated the completion of oocyte maturation in striped bass is more strongly influenced by increasing water temperature than photoperiod (Clark et al. 2005). Spawning has not occurred in April, nor the first week of May (Fig. 5.5), which appears to be too early for the females, irrespective of temperature, as indicated in 2010 when 15 ^{o}C was reached on May 5 but no eggs were detected. However, later in May the initiation of striped bass spawning in the Stewiacke River was closely related to rising water temperature; both years the first major spawning occurred following a 5 - 6 ^{o}C increase, May 17 - 18, 2010 and May 29, 2011. Similar associations between increased temperature and spawning have been reported in other estuaries in the United States and Canada (Setzler-Hamilton et al. 1981; Williams et al. 1984; Van Den Avyle and Maynard 1994). A rapid drop in water temperature has also been shown to cause spawning to stop (Mansueti and Hollis 1963; Boynton et al. 1977; Williams et al. 1984). On the Shubenacadie River a decrease in water temperature was associated with a cessation in spawning on two occasions, May 31, 2010, and June 12, 2011 was the beginning of a nearly 5 - 6 ^{o}C drop in water temperature over four days, where spawning slowed and then stopped. On the Annapolis River similar spawning trends have been recorded, where egg production continues following a sudden temperature drop (Parker and Doe 1981), however a large temperature drop caused spawning to stop temporarily (Williams 1978). More data on spring water temperature and associated Shubenacadie River striped bass spawning is needed before a predictive model for the initiation of spawning can be utilized.

The Shubenacadie River striped bass appear to spawn at similar temperatures to other populations. Across its species range, striped bass populations exhibit little or no spawning below 12 ^{o}C or above 20 ^{o}C (Setzler-Hamilton et al. 1979; Olney et al. 1991; Secor and Houde 1995). Thus, from south to north there is a later progression in the seasonal timing of spawning. Spawning season in Georgia is from late March to early May; in South Carolina spawning is from early April to early June (May and Fuller 1965; Vanden Avyle and Maynard 1994). Further north, in Delaware Canal and Chesapeake Bay populations spawn from mid-April to early June (Bonn et al. 1976; Setzler-Hamilton et al. 1981; Kernehan et al. 1981). In eastern Canada and Northern US Rivers, spawning is from early to mid-May, to mid to late June (Miramichi, Kouchibouguac, Annapolis, Saint John and Stewiacke) and Northern US Rivers (Hudson River; Table 1 *in* Rulifson and Tull 1999). In 2010 - 2011 the main spawning events occurred between 12 and 18 ^{o}C. However, low egg densities were found at temperatures as low as 10 ^{o}C and as high as 23^{o}C. This is consistent with past studies on the Shubenacadie River, where eggs were detected in water temperatures from 12.4 - 20.6 ^{o}C in 1992 (Rulifson and Dadswell 1995), 10.0 - 21.9 ^{o}C in 1994 (Rulifson and Tull 1999) and 10 - 19 ^{o}C in 2008 - 2009 (Reesor 2012). Releasing eggs in warmer water temperatures is hypothesized as a survival mechanism, as eggs will hatch more quickly (Harrell et al. 1990). There is no evidence of a lunar component affecting spawning in either 2010 or 2011, although hypothesized (Rulifson and Tull 1999). No evidence of lunar components affecting Shubenacadie River striped bass spawning was found in either 2008 or 2009 (Reesor 2012).

Like other populations, the Shubenacadie River striped bass are believed to spawn at the head of the tide in fresh to brackish water. However, unlike most populations the Shubenacadie River striped bass eggs are exposed to large variations in salinity within hours of fertilization. Eggs were collected in a variety of salinities in both 2010 and 2011 (0 to 23 ppt). Optimum salinity for egg development seems to vary among populations (Raymond et al. 1981; Winger and Lasier 1994). In the US, striped bass eggs are often collected in salinities less than 3 ppt (Table 1 *in* Rulifson and Tull 1999). The Shubenacadie River striped bass population appears to have a higher salinity tolerance than other populations (Cook et al. 2010). In laboratory based studies, Shubenacadie

River striped bass eggs had highest survival between 2 and 20 ppt, with survival significantly reduced at higher salinities and appeared lower in fresh water (Cook et al. 2010). The majority of the 2010 eggs were collected in this ideal salinity range. However, in 2011, the majority of eggs were caught in salinities < 1 ppt, but appeared healthy.

Both 2010 and 2011 had several major spawning events when the density of eggs exceeded 1000 eggs/m^3. Egg density on the Shubenacadie River is extremely high compared to the Miramichi River (0.7 eggs/m^3) and tributaries of Chesapeake Bay (12 eggs/m^3), the main nursery area for US striped bass (Setzler-Hamilton et al. 1981; Robichaud-LeBlanc et al. 1996). The difference in egg density is not due to sampling differences as, both the Miramichi and Chesapeake Bay studies derived daily mean egg density in a manner identical to this study, based on the daily counts of all individuals divided by the total water volume filtered per day. Differences in daily mean egg density are also not likely associated with dilution from comparing vastly different size rivers, as sampling took place upstream on the Miramichi River in a narrow (50 m) and relatively shallow (7.5 m) section of the river (Robichaud-LeBlanc et al. 1996). Sampling in tributaries of the Chesapeake Bay took place on rivers 100 – 500 m wide and 1 - 2 m deep (Bilkovic et al. 2002). The Shubenacadie River's egg density is extremely high in comparison to these other estuaries, likely due to the large number of spawning adults, likely caused by high recruitment in the late 1990's and early 2000's.

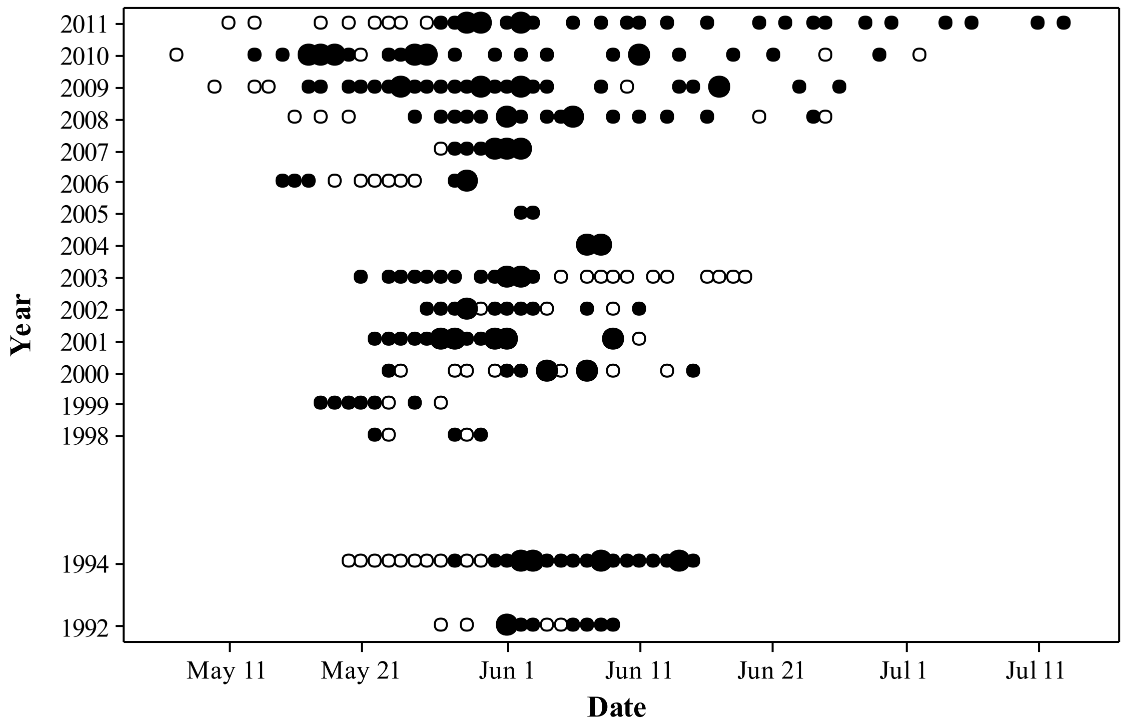


Figure 5.5: Striped bass spawning activity (solid circles) in the Stewiacke River (1992, 1994, 1998 - 2009) and Shubenacadie River (2008 - 2011) as judged by either visual observation of adults rolling at the surface or presence of eggs collected in plankton net tows. Open circles indicate when no eggs were detected in plankton net tows. Within each year, the larger solid circles indicate a relatively large spawning event based on a subjective estimate of egg abundance. Comparisons between years of the magnitude of spawning events are not valid. Source of data: 2010 – 2011: this study; 2008 - 2009: Reesor 2012; 1998 - 2007: J. Duston and W.H Stone unpubl. observations; 1994: Rulifson and Tull 1999; 1992: Rulifson and Wood unpubl., cited by Rulifson and Dadswell 1995. Figure is modified from Reesor 2012.

5.3 Results: 2010 Egg Density (eggs/m^3) and Abundance (eggs/sec) with Respect to State of Tide and Date at the Alton Gas Site

The two 36 h sampling sessions at the AGS in 2010 (May 17 - 18; May 25 - 26) revealed a high retention of the same cohort of striped bass eggs over three tidal cycles, with increasing egg density through the ebb tides and little egg development due to low water temperature. Retention was associated with dry weather April-May, leading to low freshwater run-off, and slow river velocity. During the first 36 h sampling session, egg density exhibited a similar change each tidal cycle, increasing progressively to over 4000 eggs/m^3 around nine hours into the ebb tide, and then decreasing to around 2500 eggs/m^3 just before the arrival of the tidal bore (Fig. 5.6). On the flood tide only one sample was taken 83 min into the first flood tide (16 - 17 h, May 17) and two samples taken at 67 and 79 min into the second flood tide (3 - 4 h, May 18), all had relatively low egg densities of 191, 172 and 102 eggs/m^3 respectively. Blastula stage eggs made up 86 - 91 % of the total during each tidal cycle, indicating they were a single cohort. New eggs represented 9 % of the total during the first ebb tide, and represented only 1% during the subsequent tidal cycles May 17 - 18. The very slow egg development was due to low water temperature, 13 ºC average over the 36 h. Time from fertilization to hatch at 13 °C is around 4.5 days (Fig. 4.1). No dead eggs were observed during the first ebb tide; however, they made up 10 – 15 % of the eggs during the remaining tidal cycles. No other stages of eggs were observed (Table 5.2). The retention of these eggs in the upper estuary was due to the slow water velocity on the ebb tide, caused by low freshwater run-off, as indicated by the very high salinity at the AGS at high tide, reaching 23 ppt. The water velocity at the AGS slowed to 3km/h only 80min into the ebb tide and decreased to 1.5 km/h for the last four hours of the ebb tide. Once the peak egg density passed the AGS these eggs had less than 2 hours to flow downstream before being carried back upstream by the flood tide, assuring egg retention in the upper estuary. The May 17-18 tides were all small.

Converting egg density to abundance revealed the enormity of the striped bass egg production. Estimating egg abundance during each plankton tow established that the increase in egg density recorded through the ebb tide was due to increased abundance of eggs and not simply due to narrowing of the estuary channel. For the most part, the peaks and troughs of both egg density and egg abundance through the tidal cycles were similar (Fig. 5.7). The only real discrepancy when comparing temporal pattern of egg density to abundance occurred when a pulse in egg density occurred early in the ebb tide and was amplified by the large water volume in the river and fast flowing water. Late in the ebb tide on May 17, 2010 peak density of around 3500 eggs/m^3 equated to just over 100,000 eggs per second in the Shubenacadie River main channel drifting past the AGS (Fig. 5.7). On subsequent ebb tides, the second and third ebb tide peaks were 114,000 and 136,000 eggs per second. This May 17 spawning event was the largest of 2010, when 2.1 - 2.7 billion (10^9) eggs flowed downstream past the AGS on each of three consecutive ebb tides. Total egg production, accounting for egg stage and eggs returning on successive tides from the May 17 - 18 spawning was about 2.7 billion. This equates to about 3,800 females taking part in the spawning event based on a fecundity of 717,919 eggs per spawning female.

The second 36 h sampling session in 2010 started at dawn May 25, following increased spawning activity May 24. This spawning event also resulted in increasing egg density through each ebb tide, although more variable than May 17 - 18, due to multiple cohorts. Egg development was relatively quick due to high water temperature (16.8 ^{o}C), about 6 ^{o}C higher than May 17 - 18. Time to hatch would be about 2 days (Fig. 4.1). During the first ebb tide, the morning of May 25 (03:00 h – 12:00 h), egg density peaked about 30 min before the bore at 1278 eggs/m^3 (Fig. 5.8). No sampling occurred during the flood tide. The highest egg density was recorded the following May 25 evening ebb tide at 3342 eggs/m^3 taken about 20 min before the bore around 23:00 h. Egg density again increased during the third ebb tide, the morning of May 26, to 1832 eggs/m^3 about 1 h before the bore (Fig. 5.8). These eggs were not a single cohort, unlike the May 17 – 18 spawning. Most egg stages were present over all tidal cycles, making up different percentages of the overall egg production (Table 5.4). This indicates spawning was taking place nearly continuously over the 36 hours, accounting for the oscillations in egg density. New stage eggs were not seen until the end of the May 25 evening ebb tide when they accounted for 47 % of the large peak (>3400 eggs/m^3). New and blastula stage eggs made up larger percentages of the total eggs during the first two ebb tides and 24 - hour and close to hatch stage eggs made up larger percentages of the total eggs in the last two ebb tides. More than twice as many dead eggs were seen in the last two ebb tides compared to the first two (Table 5.4). The large cohort of eggs recorded during the evening ebb tide of the May 25 - 26 did not appear during the third ebb tide (Fig. 5.8), because 33 % of that peak hatched, and due to lower water velocity over the last 3.5 h of the ebb tide, which was on average 1.5 km/h slower than the two previous ebb tide velocities, this group of eggs may not have reached the AGS during the third ebb tide. The retention of these eggs in the upper estuary was due to the slow water velocity on the ebb tide (Table 2.5), caused by low freshwater run-off, receiving only 13 mm of rain in all of May as indicated by the very high salinity at the AGS at high tide, reaching 22.5 ppt at high tide. Water velocity at the AGS each ebb tide decreased from a high of 5 - 7 km/h down to a low of 1.3 - 1.7 km/h over the last two of hours of the ebb tide. The May 25 - 26 tides were all small in size. Each peak in egg density occurred so late in the ebb tide that these eggs all had less than one hour to continue flowing downstream before being carried back upstream by the flood tide, ensuring egg retention in the upper estuary.

The total abundance of eggs May 25 - 26 followed nearly identical temporal patterns as density (Fig. 5.9). The evening of May 25, the first peak in egg density (1504 eggs/m^3) at 19:10 was matched by a peak in egg abundance (65,519 eggs/sec). The largest egg density peak (3270 eggs/m^3) just before the arrival of the tidal bore May 25 evening, matched the largest peak in egg abundance (81,334 eggs/sec). Anomalies occurred in the morning ebb tide on May 26, 4 hours into the ebb tide a pulse of eggs (1431 eggs/m^3) was amplified to 173,085 eggs/sec when the river velocity remained high at 3.8 km/h (Fig. 5.9). This multiple spawning event over two days had total egg abundance flowing past the AGS of 0.5, 1.5 and 2 billion over three ebb tides respectively. Total egg production, accounting for egg stage and eggs returning on successive tides from the May 25 – 26 spawning was about 2.6 billion. This equated to nearly 3,600 females taking part in the spawning event.

In 2010, over the entire spawning season, the density of eggs at the AGS increased through the ebb tide in eight of twelve ebb tides sampled (Table 5.5). During the other four ebb tides (May 17, 17 - 18, 18, 19), egg density remained low through most of the ebb tide, increased to 400 min after the passing of the bore and then decreased before the next bore, with egg abundance following a similar pattern as density (Table 5.5). The remaining tides all had fairly consistent densities and abundances throughout the sections of ebb tide that were spent sampling at the AGS (Table 5.5).

Converting egg density to abundance revealed the enormity of the striped bass egg production. Over the whole 2010 spawning season, accounting for eggs returning on successive tides, the total number of eggs spawned was estimated at 5.9 billion, from approximately 8,200 females based on a mean fecundity of 717,919 eggs (± 68,290 SE;

6.68 kg body weight). This estimate is conservative because it considers striped bass eggs in the main channel, 30% of the entire cross-sectional area at the AGS.

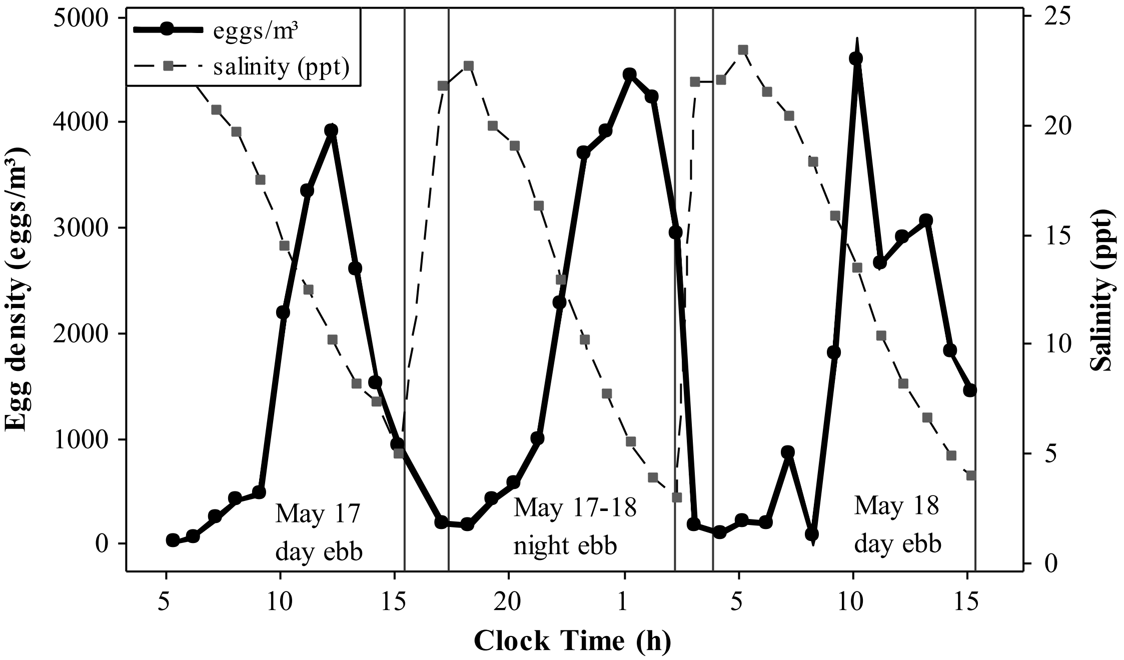


Figure 5.6: Striped bass egg density (eggs/m^3) from a single cohort and salinity (ppt) over 36 hours May 17 to 18, 2010 at the Alton Gas Site. Vertical lines indicate the timing of the flood tide (May 17: 15:44 h to 17:20 h, May 18: 04:00 h to 05:33 h). Sampling during the ebb tide occurred every hour. During the flood tide only one sample was taken 83 min into the first flood tide and two samples were taken at 67 and 79 min into the second flood tide.

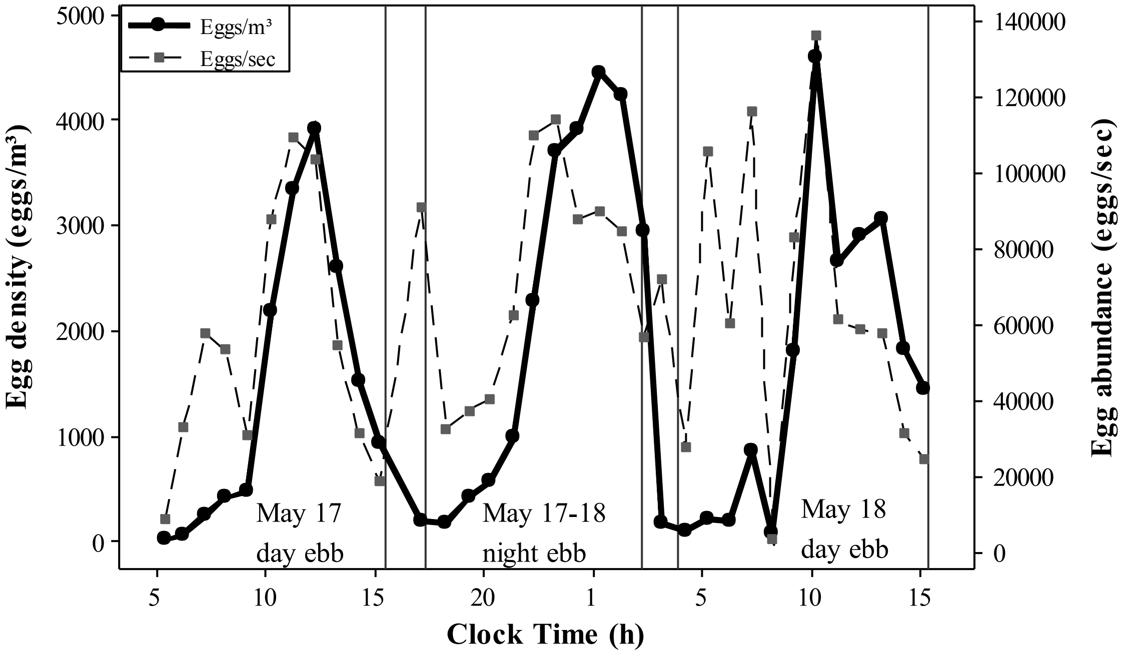


Figure 5.7: Striped bass egg density (eggs/m^3) and abundance (eggs/sec) over 36 hours May 17 to 18, 2010 at the Alton Gas Site. Vertical lines indicate the timing of the flood tide (May 17: 15:44 h to 17:20 h, May 18: 04:00 h to 05:33 h). Sampling during the ebb tide occurred every hour. During the flood tide only one sample was taken 83 min into the first flood tide and two samples were taken at 67 and 79 min into the second flood tide.

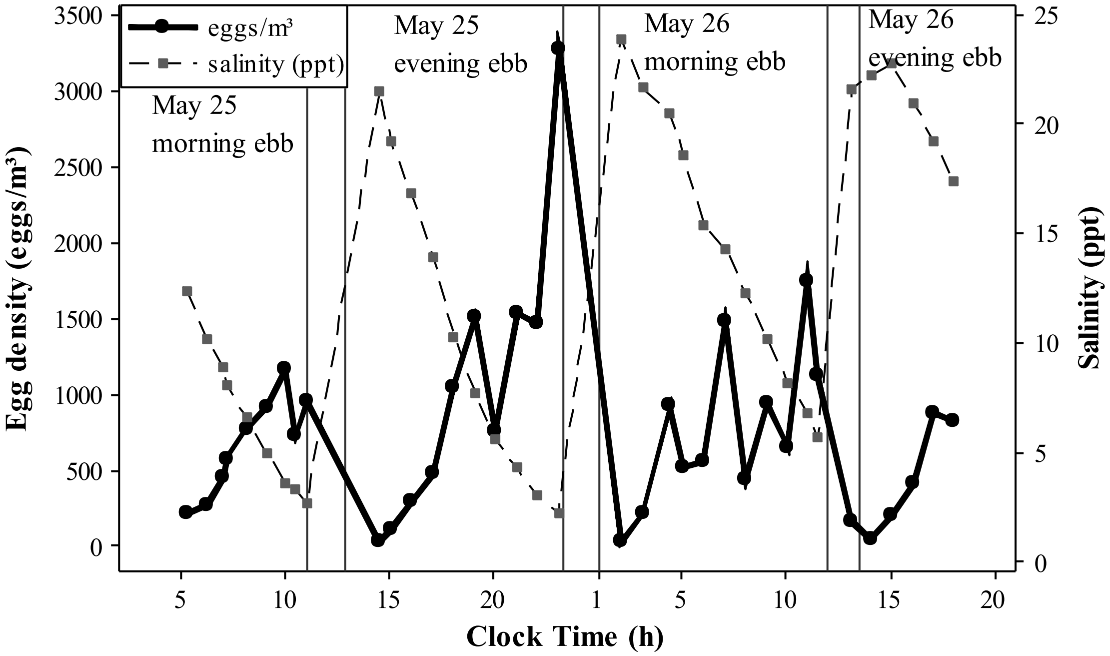


Figure 5.8: Striped bass egg density (eggs/m^3) and salinity (ppt) over 36 hours May 25 to 26, 2010 at the Alton Gas Site. Vertical lines indicate the timing of the flood tide (May 25: 11:10 h to 12:37 h and 23:30 h to 00:48 h; May 26:12:00 h to 13:30 h). Sampling during the ebb tide occurred every hour. During the flood tide one sample was taken 73 min into the third flood tide.

Table 5.4: The percentage of total striped bass eggs of each development stage during each of four ebb tides sampled over 36 hours May 25 to 26, 2010 at the Alton Gas Site. The four stages of eggs were new, blastula, 24-hour and close to hatch, and dead eggs

	Percentage of total eggs found in each stage				
Tide	New	Blastula	24-hour	Close to hatch	Dead
May 25, morning ebb	0	68	19	4	9
May 25, evening ebb	16	47	27	6	4
May 26, morning ebb	6	28	22	16	28
May 26, evening ebb	1	35	16	29	19

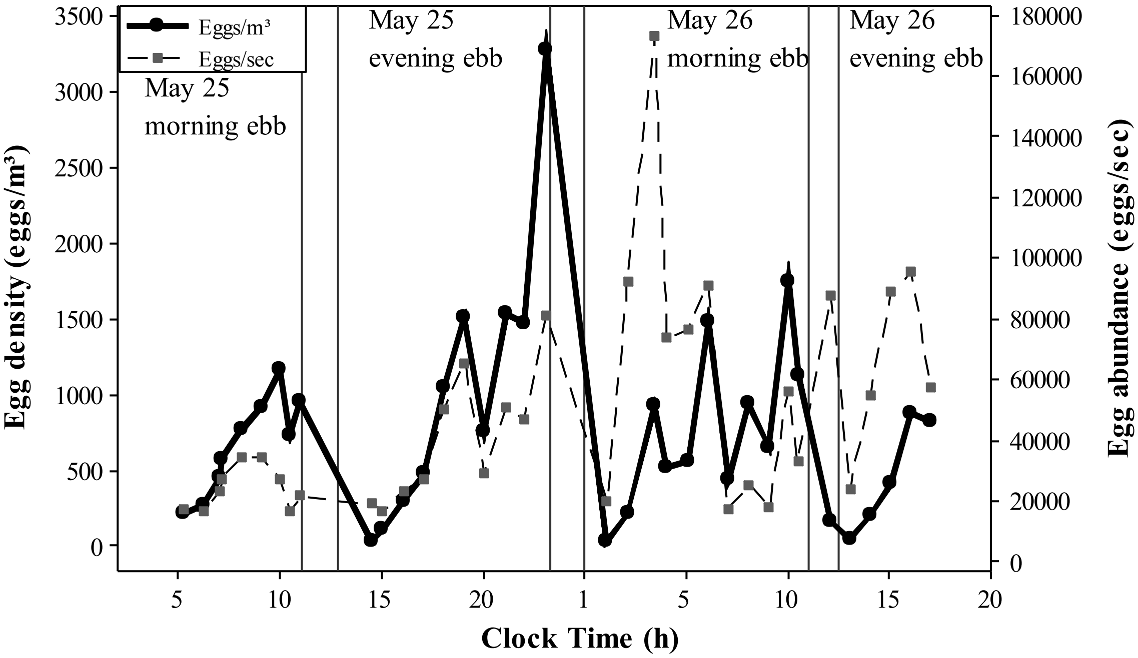


Figure 5.9: Striped bass egg density (eggs/m^3) and abundance (eggs/sec) over 36 hours May 25 to 26, 2010 at the Alton Gas Site. Vertical lines indicate the timing of the flood tide (May 25: 11:10 h to 12:37 h and 23:30 h to 00:48 h; May 26:12:00 h to 13:30 h). Sampling during the ebb tide occurred every hour. During the flood tide only one sample was taken 73 min into the third flood tide.

Table 5.5: 2010 striped bass egg density (eggs/m^3) and abundance (eggs/sec) through 18 tides from May 17 to June 14 at the Alton Gas Site in relation to the time after the tidal bore passed the site, partitioned into 20 min segments during the flood tide and 100 min segments during the ebb tide. Blanks indicate no sampling was conducted at the Alton Gas Site.

	Egg	Time after bore (min), egg density (#/m^3) and abundance (#/sec)										
	density,	Flood tide				Ebb tide						
2010	abundance	20	40	60	80	100	200	300	400	500	600	700
17-May	#/m^3					43	334	472	2,765	3,918	2,062	943
	#/sec					20,936	55,713	31,013	98,739	103,491	42,976	18,779
May 17-18	#/m^3				191	177	494	990	2,999	4,182	4,235	2,955
	#/sec				90,766	32,656	38,779	62,453	112,089	88,881	84,498	56,996
18-May	#/m^3			172	102	213	854	943	3,632	2,900	2,446	1,453
	#/sec			72,082	27,665	83,168	116,004	43,313	98,805	58,705	44,831	24,432
19-May	#/m^3								196	658	942	
	#/sec								8,385	23,908	29,835	
20-May	#/m^3							35	590			
	#/sec							1,723	30,070			
21-May	#/m^3							265	106	177		
	#/sec							17,285	4,454	6,476		
23-May	#/m^3					11	20	38	60	35		
	#/sec					2,269	2,409	2,419	6,460	1,971		
24-May	#/m^3								749	548		
	#/sec								34,391	23,901		
25-May a	#/m^3								314	643	1,118	947
	#/sec								16,964	28,319	30,697	19,183
25-May b	#/m^3					36	149	386	1,300	784	1,574	3,342
	#/sec					18,932	16,789	25,292	57,948	29,087	48,752	81,334
26-May a	#/m^3					57	393	1,062	1,544	751	1,298	1,240
	#/sec					26,450	92,498	107,779	90,978	21,294	29,226	25,360
26-May b	#/m^3			251		152	600	949				
	#/sec			87,674		39,446	89,010	76,424				
28-May	#/m^3								83	44	62	79
	#/sec								3,041	1,752	2,008	3,963
31-May	#/m^3								22	17	17	
	#/sec								944	610	836	
2-Jun	#/m^3					39	8	5	8			
	#/sec					3,787	936	449	545			
9-Jun	#/m^3	3	5	4		10	21					8
	#/sec	408	1,070	847		1,132	1,627					227
11-Jun	#/m^3	174	110	32	32	4	168					
	#/sec	39,402	35,282	10,214	7,335	703	19,695					
14-Jun	#/m^3	52	7	8	8	0	129					
	#/sec	9,386	2,021	2,723	1,498	0	1,843					

5.3.1 Results: 2011 Egg Density (eggs/m³) and Abundance (eggs/sec) with Respect to State of Tide and Date at the Alton Gas Site

In 2011, egg density generally peaked early in the ebb tide, and decreased through the remaining ebb tide. By contrast, in 2010 the peak was late in the ebb. This contrast in the timing of the peak egg density between the two years was associated with greater freshwater run-off in 2011. Rainfall in 2011 was much greater at 84, 76 and 45 mm more rain in April, May and June respectively than 2010. This fresh water run-off clearly influenced the river, as mean salinity in May and June was only 3 ppt in 2011 compared to 12 ppt in 2010. The two 36 hour sampling sessions in 2011 (May 23-24; 29-30), revealed decreasing egg density through each ebb tide, as well as from one ebb tide to the next. The first 36-hour sampling session started at 08:00 h May 23, one hour into the ebb tide, following a spawning event May 22 (280 eggs/m³; Fig. 5.10). The first peak in egg density, 872 eggs/m^3, occurred in the first two and a half hours of the ebb tide at 09:30 h. Egg density then decreased for the remainder of the ebb tide, reaching a low of 100 eggs/m³ (Fig. 5.10). The stages of egg development in the May 23 day ebb tide were 4.5 % new, 93.5 % blastula and 2 % 24-hour. These eggs represented a single cohort. Throughout the remaining tidal cycles 100 % of the eggs were at the blastula stage (Table 5.3). They stayed at the blastula stage because of low water temperature, of about 12 °C, which slowed the time to hatch to about 5 days (Fig. 4.1). Some retention of the same cohort of eggs occurred following the first ebb tide (Fig. 5.10). Over the following night ebb tide (May 23 – 24) peak egg density contained only about 30% of the eggs recorded in the first ebb tide peak, but again occurred early at 1 h 35 min into the ebb at 280 eggs/m^3. Density then decreased for the remainder of the ebb tide to a low of 20 eggs/m^3. The subsequent May 24 day ebb tide peak occurred two hours into the ebb tide at 205 eggs/m^3, decreasing to a low of 10 eggs/m^3 at the end of the ebb tide (Fig. 5.10). Flood tide tows, 3 - 4 each flood, revealed relatively high numbers of eggs being carried back upstream. Over the three flood tides, egg density peaked at 285, 229 and 136 eggs/m^3 respectively. The second and third flood tide peaks in egg density were nearly equivalent with the previous ebb tide peaks (~280 egg/m^3). The high freshets associated with the 120 mm of rain received in May, caused high tide salinity to only reach 7.5 - 8 ppt. The freshet coupled with higher water velocity on the ebb tide, decreasing to 2 - 2.5 km/h at low tide, despite the very small and small tides May 23 - 24 respectively, caused eggs to reach AGS early in the ebb tide. Once peak egg density reached the AGS, these eggs had about 6.5 to 7 hours to continue flowing downstream before the arrival of the next tidal bore; the eggs would have only had to travel at 4 km/h to reach Cobequid Bay. Average downriver early ebb tide velocity from the AGS to Cobequid Bay was 6 km/h over the four downriver trips tracking drogue buoys (Table 2.3).

Egg abundance through the May 23 – 24 36-hour sampling followed a similar temporal pattern as egg density. Early in the ebb tide on May 23, 2011 the peak of 800 eggs/m^3 equated to close to 187,000 eggs per second drifting past the AGS (Fig. 5.11). On subsequent flood tides the peaks were 95 and 100,000 eggs per second respectively. The second and third ebb tide peaks were about 70 and 80,000 eggs per second, decreasing to < 800 eggs/sec late in the ebb tide. Comparing the total number of eggs flowing past the AGS between each ebb and flood tide it is evident that about 75 % of the 1.7 billion eggs passing the AGS on the first ebb tide did not return the following flood tide (Fig. 5.11). Total egg production, accounting for egg stage and eggs returning on successive tides from the May 23 - 24 spawning was about 1.7 billion, equating to approximately 2,500 females taking part in the spawning event.

The next 36 h sampling session, May 29 - 30, 2011 captured a major spawning event. The peak in egg density occurred early in the ebb tide through all three tidal cycles, similar to the May 23- 24 spawning. The same cohort of eggs decreased in density by around 50% each tidal cycle. The eggs that were retained developed quicker than the May 23 – 24 cohort due to higher water temperatures of 16 °C versus 12 °C. Egg density from the initial sample was very high, >10,000 eggs/m^3, 8.5 h into the May 29 morning ebb tide, then decreased quickly towards the end of the ebb tide (Fig. 5.12). Subsequently, during the May 29 evening ebb tide the density of eggs peaked about three hours into the ebb tide (7740 eggs/m^3 at 14:55 h), declining to 211 eggs/m^3 at the end of the ebb tide. The bore came in about midnight. Three tows were conducted during the flood tide, with an average density of 2700 eggs/m^3, peaking at 3886 eggs/m^3. On the May 30 morning ebb tide, egg density was highest at 3650 eggs/m^3 about 4 hours into the ebb tide, decreasing to 245 eggs/m^3 at the end of the ebb tide (Fig. 5.12). The following flood tide, four tows were completed, with an average density of 2300 eggs/m^3, peaking at 2700 eggs/m^3.

May 29 – 30 spawning recoded the development of the same cohort of eggs through the tidal cycles. Only new and blastula stage eggs were present in the May 29 morning and evening ebb tides, 3.4 and 96.6 % and 15.6 and 84.4 % new and blastula eggs respectively, but the subsequent flood tide were all blastula stage. Thereafter, the proportion of blastula stage eggs to 24-hour stage eggs decreased in the following May 30 morning ebb tide (57.5 % blastula and 42.5 % 24-hour) and flood tide (12.1 % blastula and 87.9 % 24-hour). Water temperature over the 36 h averaged 16 ºC, resulting in quick egg development of approximately 2 days to hatch (Fig. 4.1).

Freshwater run-off was relatively high May 29 – 30 as indicated by maximum salinity of 7.5 - 11 ppt (Fig. 5.12). Water velocity each ebb tide was relatively fast decreasing to 2 - 3 km/h at low tide, despite the very small tides. Peak egg density during the second and third ebb tide occurred 3 to 4 hours into the ebb tide, thus, eggs retained in the main channel had 4.5 to 5.5 hours to reach Cobequid Bay. Eggs would need to travel 4.5 to 5.5 km/h to reach the Bay, just under the downstream average velocity of 6 km/h.

Egg abundance, May 29, 2011 followed a similar pattern to egg density through the ebb tide. By contrast abundance and density differed greatly during the flood tide; egg abundance peaks were much higher during the flood tide relative to egg density peaks (Fig. 5.13). The initial sample, 08:00 h was very high, around one million eggs per second, then decreased to < 200,000 eggs/sec at the end of the ebb tide. The tidal bore arrived at the AGS at 11:10 h, with the egg abundance peaking at >500,000 forty two minutes into the flood tide. On the following ebb tide, egg abundance peaked early, about 90 min into the following ebb tide when water velocity was 5.3 km/h and 4500 egg/m^3 equated to around 670,000 eggs/sec (13:55 h), one hour earlier than the egg density peak (7740 eggs/m^3 at 14:55 h; Fig. 5.13). The bore came in at about midnight, with >1 million eggs per second being carried upstream. At the turn of the tide, most of the eggs appeared at the AGS early in the ebb tide, with a peak of >500,000 eggs/sec present 63 min into the ebb tide when water velocity was 6.5 km/h, but the eggs were more dispersed gradually decreasing through the tide. Each ebb tide, 4.6, 7.8, and 7.5 billion eggs were passing the AGS. Total egg abundance during the May 29 – 30 spawning was estimated at 7.8 billion eggs from about 10,800 females.

Overall, during the 2011 spawning season the density of eggs at the AGS peaked early in the ebb tide and then decreased through the ebb tide in during all six tides sampled during peak spawning season (May 23, 23-24, 24, 29b, 30a and June 3; Table 5.6). Egg abundance followed a similar pattern, peaking early in the ebb tide (Table 5.6). The remaining tides all had too few samples to determine the pattern (Table 5.6). Over the entire 2011 season, accounting for eggs returning on successive tides, the total number of eggs spawned was conservatively estimated at 10.3 billion, from about 14,300 females based on a mean fecundity of 717,919 eggs (± 68,290 SE; 6.68 kg body weight).

5.3.2 Results: Comparing 2010 and 2011 Egg Density and Abundance

The temporal position of the peak egg density and abundance during the ebb tide contrasted between 2010 and 2011. In 2010, egg density generally peaked late in the ebb tide due to low fresh water run-off, which caused low water velocity, around 1.3 km/h at the end of the ebb tide (Fig. 5.14), and was associated with high salinity, peaking around 24 and 23 ppt on May 17 - 18 and May 25 - 26 respectively. By contrast in 2011, egg density peaked early in the ebb tide due to the large amount of freshwater in the system, causing salinity to peak around 7.5 and 11 ppt on May 23 - 24 and May 29 - 30 respectively, and causing ebb tide water velocity to remain high, 2 - 3 km/h at low tide (Fig. 5.14). Peak egg density occurs early in the ebb tide at the AGS when there is a very small or small tide coupled with a lot of freshwater run-off. Under these conditions the salt front is in the lower section of the Stewiacke River (km 3 to 5; Table 2.7) and eggs have many hours to flow downstream before the next tidal reversal, increasing the probability of advection. Evidence that eggs do not travel upstream beyond the salt front will be revealed in section 5.5. Despite 2010 - 2011 differences in the temporal distribution on the ebb tide, the flood tide trends were quite similar. In 2010 sampling into the flood tide was only mastered at the end of the spawning season (June 9). However, the three days when flood tide sampling was conducted, egg density peaked during the flood tide. This led to sampling more frequently on the flood tide in 2011. In 2011, 73% of the time when sampling took place during the flood tide (14 days) the density of eggs was highest during the flood tide. On the remaining days the density generally peaked 2 h 30 min into the ebb tide, based on egg stage and water temperature these were all freshly spawned eggs that were passing the AGS for the first time.

Throughout 2010 and 2011, the most common egg stage collected was blastula, making up 69 and 76 % of total eggs respectively (Table 4.2). The 24 hour egg stage was the second most common group, new eggs third and close-to-hatch fourth. Dead eggs were much more common in 2010 (9.7%) than 2011 (0.04%).

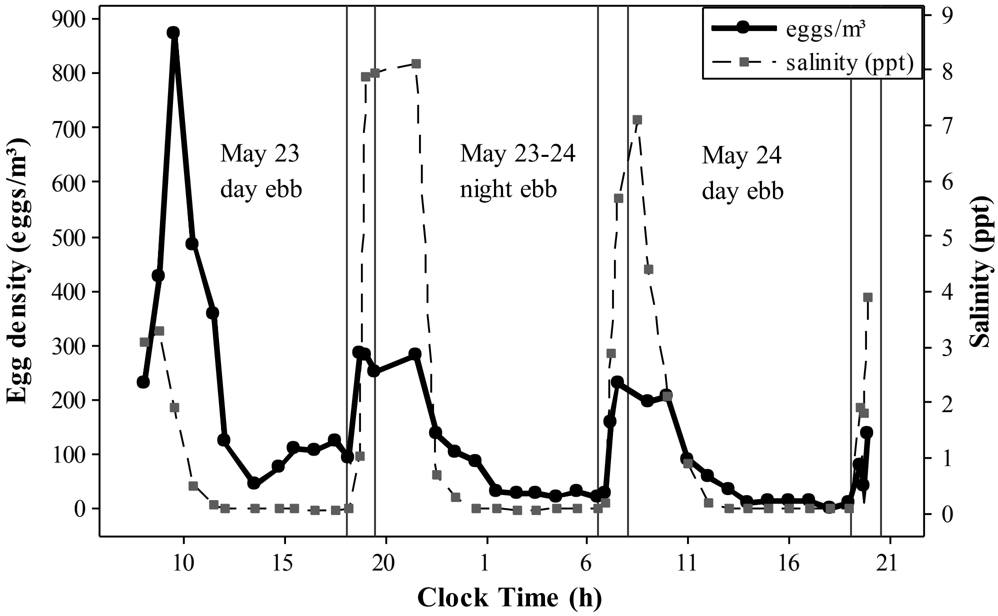


Figure 5.10: Striped bass egg density (eggs/m^3) and salinity (ppt) over 36 hours May 23 to 24, 2011 at the Alton Gas Site. Vertical lines indicate the timing of the flood tide (May 23: 18:10 h to 19:45 h, May 24: 06:35 h to 08:00 h and 19:10 h to 20:30 h). Sampling during the ebb tide occurred every hour. Plankton net tows during the first flood tide occurred four times, and three times each in the subsequent flood tides.

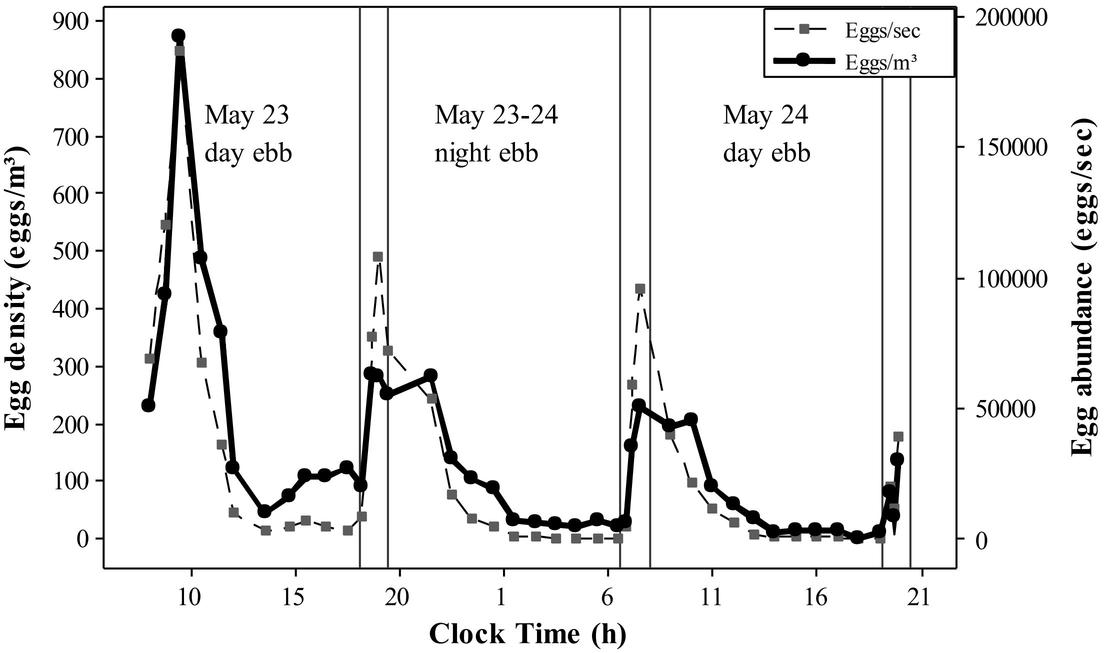


Figure 5.11: Striped bass egg density (eggs/m^3) and abundance (eggs/sec) over 36 hours May 23 to 24, 2011 at the Alton Gas Site. Vertical lines indicate the flood tide (May 23: 18:10 h to 19:45 h, May 24: 06:35 h to 08:00 h and 19:10 h to 20:30 h). The eggs were from a single cohort, 95 % of eggs remained at the blastula stage through the 36 h sampling due to the low water temperatures (11 - 12 ^{o}C).

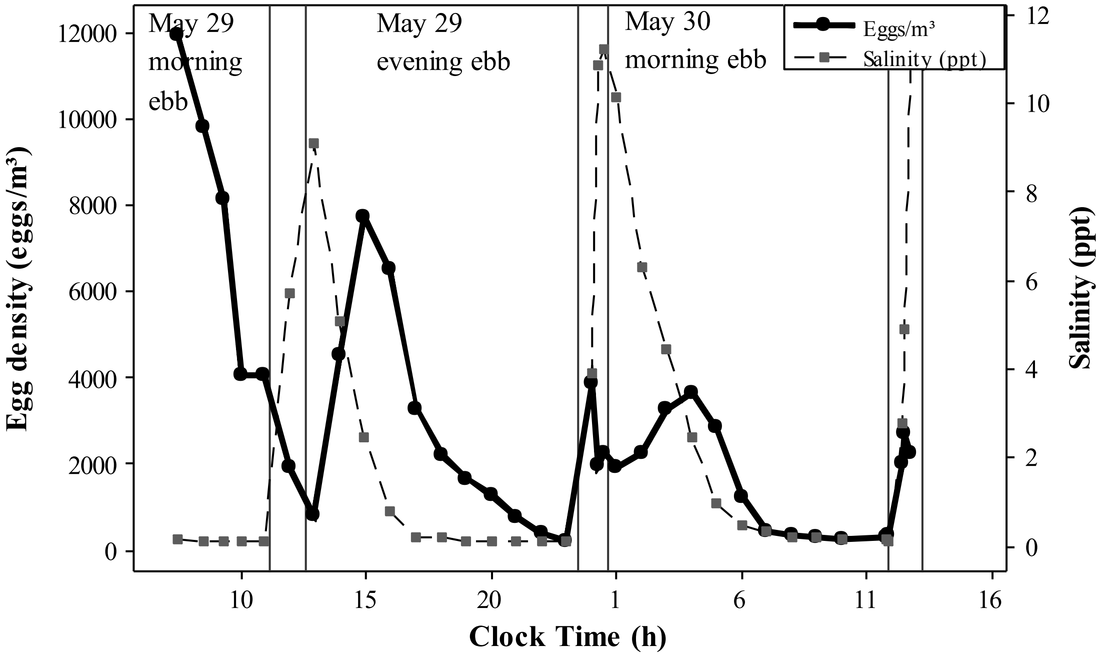


Figure 5.12: Striped bass egg density (eggs/m³) and salinity (ppt) over 30 hours May 29 - 30, 2011 at the Alton Gas Site. Vertical lines indicate the timing of the flood tide (May 29: 11:10 h to 12:35 h and 23:25 h to 00:40 h, May 30: 11:55 h to 13:15 h). Sampling during the ebb tide occurred every hour. Plankton net tows during the flood tides occurred once, three and four times each respectively.

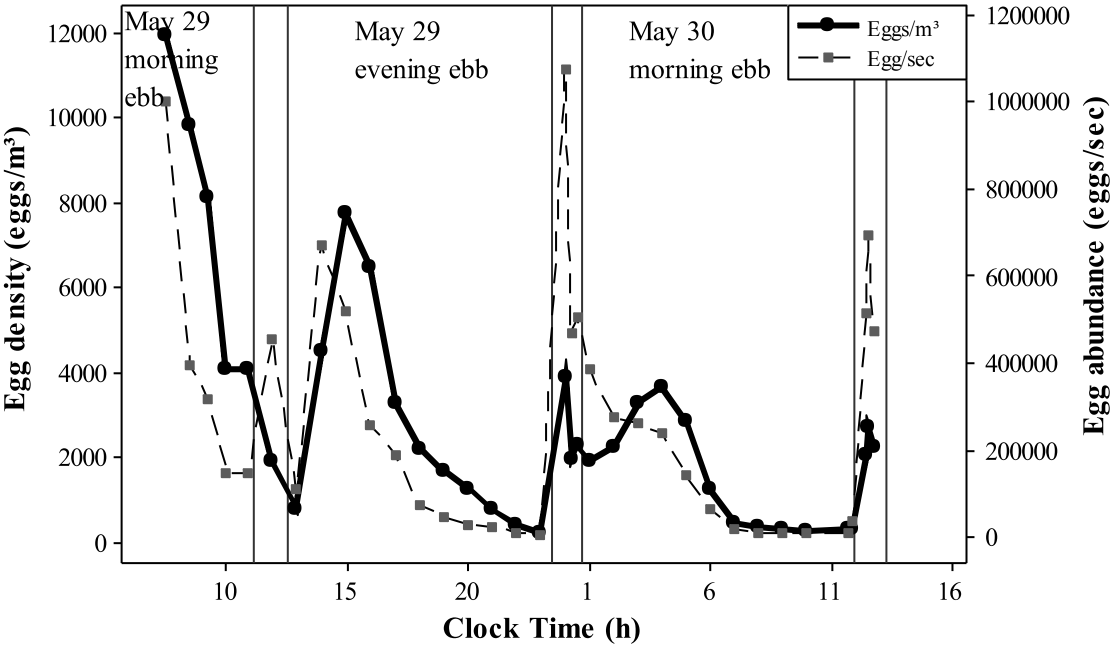


Figure 5.13: Striped bass egg density (eggs/m^3) and abundance (eggs/sec) over 30 hours May 29 - 30, 2011 at the Alton Gas Site. Vertical lines indicate the timing of the flood tide (May 29: 11:10 h to 12:35 h and 23:25 h to 00:40 h, May 30: 11:55 h to 13:15 h). Sampling during the ebb tide occurred every hour. Plankton net tows during the three flood tides occurred one, three and four times respectively.

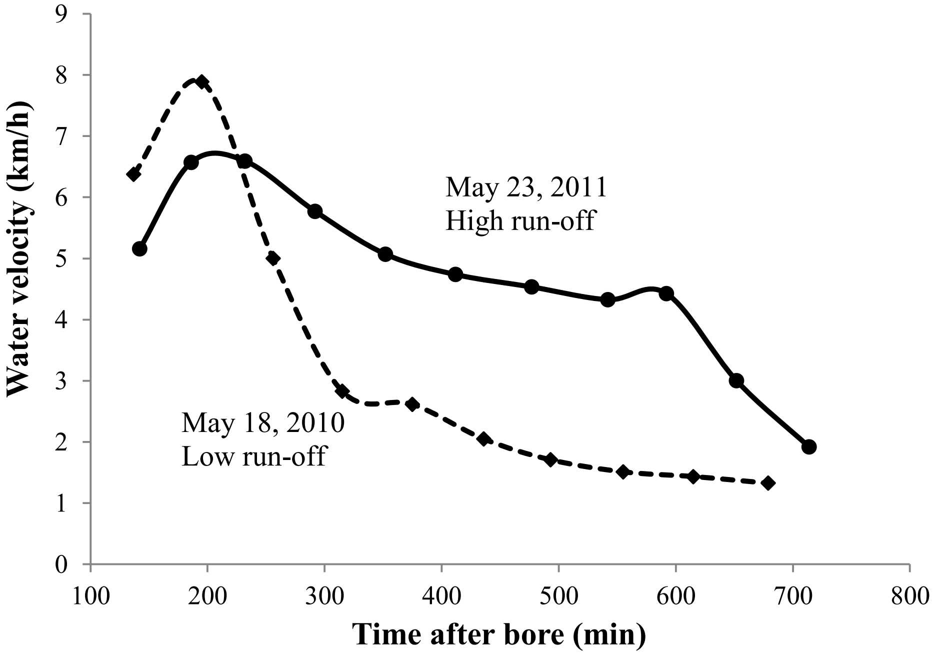


Figure 5.14: Water velocity in the main channel at the Alton site during the ebb tide comparing low freshwater run-off (May 18, 2010) with high freshwater run-off (May 23, 2011). Water velocity was measured using a drogue-buoy pair timed over 600 meters.

Table 5.6: 2011 striped bass egg density (eggs/m^3) and abundance (egg/sec) through 22 tides from May 22 to June 30 at the Alton Gas Site in relation to the time after the tidal bore passed partitioned into 20 min segments during the flood tide and 100 min segments during the ebb tide. Blanks indicate no sampling was conducted at the Alton Gas Site.

	Egg density,	Time after bore (min), egg density (#/m³) and abundance (#/sec)										
		Flood tide				Ebb tide						
2011	abundance	20	40	60	80	100	200	300	400	500	600	700
22-May	#/m³			724		306						155
	#/sec			314,375		83,446						5,874
23-May	#/m³					328	679	358	84	90	106	123
	#/sec					94,849	127,266	36,482	6,696	5,906	4,542	3,289
23-24 May	#/m³	90	286	283	251	280	120	86	29	24	30	21
	#/sec	8,951	77,467	107,847	72,238	53,423	12,653	4,671	977	487	565	428
24-May	#/m³	26	159	230		195	147	47	90	14	6	10
	#/sec	4,641	59,188	95,742		40,287	16,561	3,980	641	740	329	321
27-May	#/m³	0	18	16		11	12	0				
	#/sec	0	4,269	4,787		1,356	677	0				
28-May	#/m³	157	59							112	148	159
	#/sec	17,250	15,203							3,991	4,797	3,888
29-May a	#/m³									10,919	6,093	4,079
	#/sec									470,835	232,002	147,554
29-May b	#/m³		1,912			2,655	7,121	3,275	1,934	1,263	574	211
	#/sec		567,254			480,674	389,977	187,432	60,001	29,402	17,887	4,830
30-May a	#/m³		3,887	1,950	2,269	1,923	2,760	3,248	1,243	395	276	287
	#/sec		1,344,112	721,451	659,165	510,613	302,011	172,869	63,976	14,852	9,688	7,285
30-May b	#/m³	320	2,021	2,470								
	#/sec	38,403	602,042	827,548								
1-Jun	#/m³	190	200	32	31	11					323	481
	#/sec	18,750	43,620	11,641	3,298	732					9,030	11,642
2-Jun	#/m³	2,256	611	119		92						3,723
	#/sec	202,967	190,118	40,258		22,069						68,602
3-Jun	#/m³								1,057	1,038	388	
	#/sec								66,051	44,394	17,274	
6-Jun	#/m³	5	2						0	6	4	0
	#/sec	832	944						0	207	90	0
8-Jun	#/m³						0	11	10			
	#/sec						0	452	158			
11-Jun	#/m³	556	245	150	79						415	257
	#/sec	71,172	44,083	48,581	22,784						12,290	6,635
13-Jun	#/m³	17	10								48	11
	#/sec	1,763	3,471								1,139	217
16-Jun	#/m³	0	0	0	0					0	0	0
	#/sec	0	0	0	0					0	0	0
22-Jun	#/m³						5	4				
	#/sec						522	365				
25-Jun	#/m³									2	3	
	#/sec									50	84	
28-Jun	#/m³	2	2	6	3					5	0	2
	#/sec	402	837	1854	399					240	0	20
30-Jun	#/m³	2									1	1
	#/sec	277									24	46

5.3.3 Discussion: Egg Density and Abundance With Respect to State of the Tide and Date at the Alton Gas Site

The mechanism of retention of striped bass eggs in the Shubenacadie estuary is unusual, as it does not have an estuarine turbidity maximum (ETM) or a salt front for retention. Well studied estuaries with striped bass populations such as the Chesapeake Bay and San Francisco Bay all have ETMs (North and Houde 2006; Shoji et al. 2005) and are not comparable to the highly mixed Shubenacadie estuary. I propose in the Shubenacadie estuary a key pre-requisite for retention is the long length of the estuary, > 30 km. Similarly, the three longest estuaries in the Bay of Fundy, the Annapolis, Saint John and Shubenacadie were the only ones with spawning populations (Rulifson and Dadswell 1995). On the Annapolis River spawning took place above the salt front around river kilometer 32 - 40 (Williams et al. 1984), while on the Saint John River spawning took place in tributaries of Belleisle Bay around river kilometer 64 (Dadswell 1976), and on the Shubenacadie spawning takes place around 30 - 36 km upstream of the estuary mouth (Rulifson and Dadswell 1995). This long length retains pelagic eggs because their drift downstream is reversed by the next flood tide. Advection occurs when fresh water run-off is high. Factors contributing to whether eggs remain the Shubenacadie estuary through the ebb tide include: the size of the tide, the amount of fresh water run-off and the location and timing of egg release. These factors also dictated the temporal distribution of striped bass eggs at the AGS.

Peak egg density occurred late in the ebb tide at the AGS when there was a medium or large tide coupled with dry weather. Under these conditions the salt front is 4 - 6 km further upstream (Table 2.5), likely resulting in spawning to occur further upstream and eggs to travel downstream more slowly due to slower water velocity. This causes egg retention in the upper estuary, as eggs have little time to flow downstream before being carried back upstream with the flood tide. 2010 generally followed this scenario; striped bass egg density at the AGS exhibited a reoccurring trend, egg density increased through the ebb tide. The two 36 h sampling sessions in 2010 also revealed a high retention of striped bass eggs over three tidal cycles. Once the peak egg density passed the AGS these eggs generally had less than 2 hours to flow at velocities under 2 km/h downstream before being carried back upstream by the flood tide, retaining eggs in the upper estuary. When eggs are carried upstream on the flood tide they may be transported to a location equal to or farther upstream than the initial spawning spot, perhaps accounting for the slight variations in their temporal timing through the tidal cycles at the AGS.

Peak egg density occurred early in the ebb tide at the AGS when there was a very small or small tide coupled with high freshwater run-off. In this scenario, the salt front is in the lower section of the Stewiacke River (km 3 to 5; Table 2.5), causing spawning to occur further downstream. Freshets are also associated with higher water velocity on the ebb tide, which also causes eggs to reach AGS earlier in the ebb tide. Eggs are more likely to reach Cobequid Bay as they have many hours to flow downstream before the next tidal reversal. Generally, in 2011 once peak egg density passed the AGS, these eggs had about 6.5 to 7 hours to continue flowing the 25 km downstream to Cobequid Bay before the arrival of the next tidal bore. The eggs would have only had to travel at 4 km/h to reach Cobequid Bay. Average downriver early ebb tide velocity from the AGS to Cobequid Bay was 6 km/h over the four downriver trips made tracking drogue buoys

(Table 2.3). Advection of eggs remaining in the main channel that pass the AGS early in the ebb tide is highly likely.

Despite presumable egg advection, May 23 - 24 and 29 - 30, a proportion of the eggs was carried back up to the AGS on the flood tide and again peaked early the following ebb tide. These eggs that were carried back upstream on the flood tide possibly followed one of two paths. Eggs carried beyond the estuary mouth late in ebb tide would be retained in a narrow channel (2 - 3 km wide) bounded by large sand-banks in Cobequid Bay (Fig. 2.1). A proportion of these eggs would be funneled back into the Shubenacadie estuary on the next flood tide. However, a proportion of the eggs would likely be funneled up the Cobequid Bay towards the Salmon River, as water first flows towards Salmon River early in the flood tide, before the water level rises enough to breach the sand bars and flow towards the Shubenacadie River estuary mouth (personal observation). Small numbers of striped bass eggs have been collected in the Salmon River (Cook 2003). A second path would be that a proportion of the eggs would have been retained in the estuary because they drifted out of the main channel into slow moving water or back eddies. Settlement of eggs in slow moving sections for the river seems like a reasonable explanation for egg retention in the nursery habitat. If retention of some eggs is dependent on their drift into slower moving water, then egg specific gravity becomes important. Striped bass eggs are usually slightly negatively buoyant, but are maintained in suspension by the high turbulence. Eggs travel between 80 and 100% of water velocity (Davin et al. 1999). In static water, Shubenacadie River eggs sink slightly quicker with increasing development, and all stages of development have faster sinking rates in freshwater compared to more saline water (Rulifson and Tull 1999). Eggs less than 10 h old are neutrally buoyant at 4 ppt, whereas eggs containing fully developed larvae are only neutrally buoyant at 8 ppt (Rulifson and Tull 1999). Downstream of AGS the salinity increases progressively, this would help keep the eggs in suspension in slow moving or static water. If egg settlement occurred, suffocation may follow. In the laboratory, striped bass eggs settling to the bottom of an incubator tank and piling on top of each other results in high mortality (Duston unpublished data). However, there's some evidence that in estuary conditions settled striped bass eggs can hatch provided they are not buried in mud (Bayless 1968). The Shubenacadie estuary has an abundance of mud, but also firm sandy sections that may be safe zones for settled eggs. Nevertheless, even if the eggs settle on firm sections of the river slope they are at risk of becoming exposed to the air as the water recedes. At the AGS on the ebb tide I have observed eggs settle in the static water close to the sand bar on the west bank. However, they are soon 'beached' as the tide recedes, and I believe will die quickly, especially if the sun is shining. Future sampling of slow velocity sections of the river, late in the ebb tide, could help investigate if settlement is a large contributor to retention for striped bass eggs or to egg mortality in the Shubenacadie River.

Of the total eggs collected, the proportion of the eggs in the four stages of development was unequal (Fig. 5.2; 5.3). In both years the majority of the eggs collected were at the blastula stage, making up 69 and 76 % of total eggs respectively. The four stages (new, blastula, 24-hour and close to hatch) used to categorize the striped bass eggs were chosen based on easy visual identification, rather than an equal division of the development time (Hardy 1978; Table 4.2). The length of time the eggs are in each development stage depends on temperature, being shorter at higher temperatures and longer at lower temperatures, but the ratio of time spent at each stage would presumably be the same. Thus, seeing low numbers of new stage eggs is expected, as this stage would likely be nearly or totally completed by the time new eggs drift from the spawning grounds to AGS, depending on river water flow and temperature. For example, the May 17 - 18, 2010 spawning event occurred at 12.4 °C, meaning eggs took approximately 120 hours to hatch, resulting in the new egg stage lasting approximately 8 hours. Peak egg density was seen at the AGS about 8 hours into the ebb tide. The majority of the eggs seen were at the blastula stage for several reasons. First, the blastula stage has the longest development time of all four stages and secondly eggs would likely be in this stage when they first drift past the AGS, when they are the least dispersed in the estuary. Seeing fewer 24-hour and close to hatch stage eggs is also expected, they have shorter development time in these stages, are more dispersed within the estuary and have been in the environment longer and thus have a greater chance of mortality. Collecting < 1 % of eggs at the close to hatch stage in 2011 may have been because these eggs were not retained upstream where the majority of our sampling was taking place. Dead eggs were much more common in 2010 than 2011. The high numbers of striped bass eggs beached on the river bank due to a persistent Northeast wind in 2010 may have contributed to the higher percentage of dead eggs. Large numbers of beached striped bass eggs have been documented in the past on the Shubenacadie River (Tull 1997). Very few eggs were observed as beached in 2011. Also, 2011 dead eggs may not have been retained upstream. Rulifson and Tull (1999) had similar findings stating approximately 67% of all eggs collected were less than 10 h old (new to blastula stage), and only 9% were 30 or more hours old (24-hours to close-to-hatch). They attributed the findings to hatching occurring downstream of the Shubenacadie-Stewiacke River confluence.

5.3.4 Discussion: Egg Abundance

This study follows others on striped bass egg abundance estimates using egg density, cross-sectional area and river velocity (Kernehan et al. 1981; Bulak et al. 1993; Secor and Houde 1995). Total abundance of striped bass eggs was estimated at 3.3 billion during the 1977 spawning season in the Chesapeake and Delaware Canal (Kernehan et al. 1981). In 1991, the total egg production in the Patuxent River, a tributary that empties into the Chesapeake Bay, 1.5 – 4 m deep and 1 km wide was estimated at 664 million (Secor and Houde 1995). The annual egg production on the Santee-Cooper system of South Carolina from 1988 to 1990 ranged from 10 to 22 billion (Bulak et al. 1993). To my knowledge, other than Rulifson and Tull (1999), who estimated annual egg production at 106 million in 1994 there is no other published literature estimating striped bass egg abundance on tidal rivers where eggs may be transported past the sampling site more than once.

Through the 2010 and 2011 spawning seasons average egg density was very similar. However, once egg density was converted to egg abundance there was a ~ 50% greater number in the apparent number of eggs spawned in 2011 compared to 2010. This difference was revealed because peak egg densities during the 2011 spawning season occurred at the beginning of the ebb tide when both cross-sectional area of the estuary and water velocity were high, which amplified egg density into large egg abundances. By contrast in 2010, peak egg densities generally occurred at the end of the ebb tide when both cross-sectional area and water velocity were low. In particular, the May 29 - 30, 2011 spawning set the two seasons apart in terms of egg abundance, accounting for nearly 70% of the egg production. The ebb tide peaks occurred within the first 90 min of the ebb tide when water velocity was fast (> 5 km/h) and the cross sectional area of the river was large.

The nearly two-fold increase in total egg abundance from 2010 to 2011 has at least two possible explanations. In 2010, due to slower water velocity perhaps not all the spawned eggs reached the AGS before being carried back upstream by the incoming flood tide. These eggs would not have been accounted for. Secondly, perhaps there were more spawning fish in 2011 than 2010. The years 2006 and 2007 were reportedly fairly good recruitment years for striped bass on the Shubenacadie River (Bradford et al. 2012). Age to sexual maturity is about 4 - 5 for females and 3 - 4 for males (Douglas et al. 2006). Thus, the females of the 2006 - 2007 cohorts would just be reaching maturity in the years studied. The last DFO estimate of the number of striped bass of reproductive age (males and females) on the Shubenacadie River was done via mark-recapture methods in 2002, when over 15,000 individuals were estimated. Assuming a one to one sex ratio, the 2010 estimate of 14,000 females nearly doubles the 2002 reproductive population estimate, which does not seem unreasonable over eight years. By comparison, in 1994, the total egg abundance estimate was 106 million (±10 %; Rulifson and Tull 1999), equaling about 147 spawning females, using the fecundity estimate used here. The increase in the number of spawners on the Shubenacadie over the 18 years is large but matches the anecdotal observed evidence. Similar increases of the spawning stock of striped bass on the Miramichi River have been estimated through mark/recapture data analyzed with a Bayesian population model, estimating 3,700 spawners in 1994, 5,000 in 2000, 28,000 in 2001 and 92,000 in 2010 (Chaput and Douglas 2011). Chesapeake Bay striped bass have experienced similar increases in the number of spawners from the early 1980's to the 2000's. Fishing regulations implemented in 1985 would have contributed to the increase of these important commercial fish (Richards and Rango 1999). Big increases in spawning populations are reasonable given the huge fecundity of striped bass. Climate change may be a factor in increased spawning population sizes over the last two decades. Warmer water temperatures increase age-0 striped bass survival (Hurst and Conover 1998). Estimating the number of spawners in a population has proven to be a challenging task and is just that, an estimation.

5.4 Results: Larval Striped Bass Density with Respect to State of Tide and Date at the Alton Gas Site

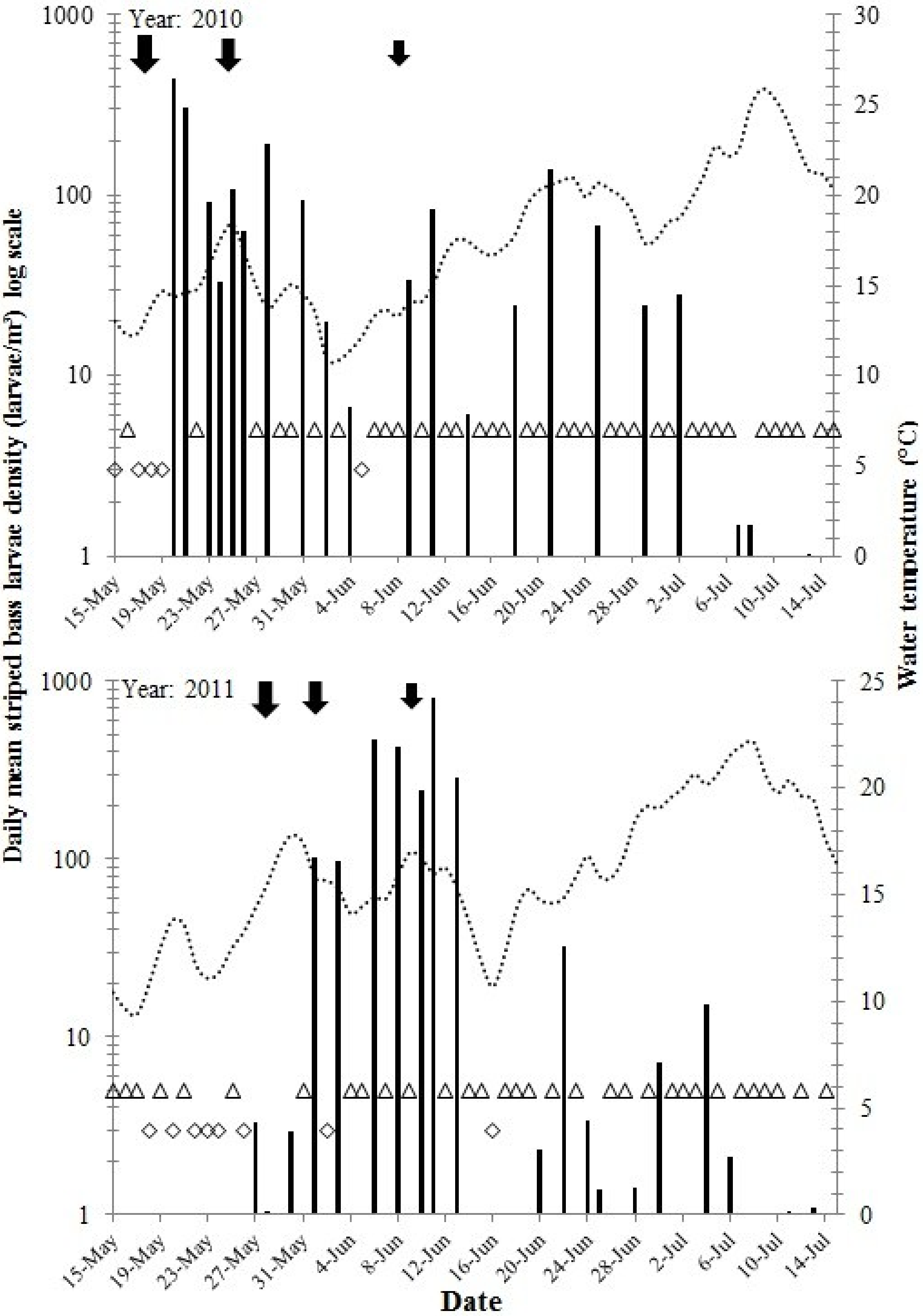
Eggs generally hatched within two to four days and yolk-sac larvae, 3 mm TL emerge. Larvae were collected in plankton net tows at the AGS. The transition from larvae to juveniles (25 mm TL) took numerous weeks, with mean larvae total length ≤ 7 mm for the first month. In both 2010 and 2011, peak larvae density through the ebb tide was 15 - 30 % of peak egg density. There was no significant difference ($P > 0.05$) in larvae density between years. In 2010, larvae were detected in plankton net tows at the AGS from May 20 to July 13, a span of 54 days (Fig. 5.15 upper panel). Larvae were first detected May 20, with a mean daily ebb tide density of 444 larvae/m^3, the highest recorded that year. The low water temperature (12 - 13 ^oC; Table 5.7) probably accounted for the four day gap between the initial major spawning on May 17 and hatch. Larvae density remained relatively high May 21 (305 larvae/m^3) and then decreased the next five days to 33 and 100 larvae/m^3. Larvae density increased (193 larvae/m^3) on May 28, three days after the second largest spawning event of the season (1137 eggs/m^3). The average water temperature of 17.2 ^oC, May 26 – 27, likely accounted for hatching in two days. Daily average larvae density was > 90 larvae/m^3 on seven days in late May and June (May 20, 21, 23, 25, 28, 31 and June 21). Larvae density was > 20 larvae/m^3 on nine other days, followed by low densities (~ 1 larvae/m^3) from July 7 to the 13 (Fig. 5.15 upper panel). Through June and early July, fresh water run-off was low, salinity relatively high (15 - 22 ppt at high tide) and the daily mean density of striped bass larvae was consistently high (10 - 20 larvae/m^3).

In 2011, striped bass larvae were detected in plankton net tows on the ebb tide at the AGS from May 27 to July 13, a span of 48 days (Fig. 5.15, lower panel). Larvae were first detected May 27, in low numbers (3 larvae/m^3) at 14.4 ^{o}C (Table 5.8). This followed the May 22 - 23 spawning, with low water temperatures (11°C) likely accounting for the 3 - 4 day gap from egg to hatch. Larvae continued to be found in low densities until an abrupt increase to 100 larvae/m^3 on June 1, following the hatch from the first major spawning event May 28 – 29. Larvae density increased further to > 450/m^3 on June 6 and 8, and peaked at 809 larvae/m^3 on June 11, following spawning on June 10 (378 eggs/m^3). Between June 13 and 16, the density of larvae decreased abruptly from 100/m^3 to < 3/m^3, associated with heavy rain June 13 - 15 (Stanfield International Airport: 100 mm) coinciding with a full moon June 15. The large tide and freshet resulted in the estuary overflowing the bank at daytime high tide June 16 and water temperature drop to 10 ^{o}C. This was the only time the banks overflowed in five years of survey (2008 – 2012). The salinity at high tide at AGS decreased from > 15 ppt June 15 to < 4.5 ppt June 16, and for the next ten days was < 6 ppt due to the high freshwater run-off (Table 5.8). Larvae were again detected at the AGS on June 20, density 2 larvae/m^3, their density increased to 32 larvae/m^3 on June 22 and larvae continued to be caught in the plankton net in relatively low densities (1 - 3/m^3) through to July. The larvae collected June 22 was associated with a spawn prior to the rainfall event on June 13 - 15, because only small numbers of eggs (1 - 5/m^3) were spawned from June 20 to July 6.

Larvae caught in plankton net tows were collected in water temperatures ranging from 11 - 26.5 ^{o}C in 2010, and 11 - 25 ^{o}C in 2011. However, the majority of the larvae were collected in water temperature between 16 - 19 ^{o}C (49 %) in 2010 and 15 - 18 ^{o}C (99 %) in 2011 (Table 5.7; 5.8). Larvae were detected in salinities ranging from 0 to 23 ppt in

2010 and from 0 to 26 ppt in 2011. Though the majority, 44% in 2010 and 69% in 2011, were collected in salinities less than 5 ppt.

Figure 5.15: Ebb tide striped bass larvae density (bars; total ebb tide daily mean larvae per m^3 water filtered in the main channel) on a log scale at the Alton Gas Site on the Shubenacadie River and temperature (ºC; dotted line) at the Alton Gas Site in 2010 (top panel) and 2011 (bottom panel). Diamonds indicate days when sampling was conducted but no larvae were detected. Triangles indicate days when no sampling occurred. Black arrows indicate the date of large spawning events. The size of the arrow indicates the relative magnitude of the spawn.



Year: 2010
Year: 2011
Daily mean striped bass larvae density (larvae/m³) log scale
Water temperature (°C)
Date
1000
100
10
1
30
25
20
15
10
5
0
15-May
19-May
23-May
27-May
31-May
4-Jun
8-Jun
12-Jun
16-Jun
20-Jun
24-Jun
28-Jun
2-Jul
6-Jul
10-Jul
14-Jul

Table 5.7: 2010 striped bass ebb tide daily average larvae density (larvae/m³) relative to date, hours spent sampling, daily mean water temperature (°C), daily maximum salinity (ppt), daily total rainfall and total rainfall within 10 days (mm; recorded at Stanfield International Airport weather station), and tide size. * indicates missing data.

2010	Hours sampling at Alton site (h:mm)	Daily mean water temperature (°C)	Daily maximum salinity (ppt)	Daily Rainfall (mm)	Rainfall within 10 days (mm)	Tide Size	Daily average ebb tide larvae density (larvae/m³)
20-May	0:30	14.4	23.4	0.3	21.2	s	444
21-May	3:10	14.6	22.9	0	21	s	305
23-May	8:10	16.1	22.6	0	21	s	93
24-May	1:00	17.6	22.6	0	21	s	34
25-May	18:30	18.4	22.9	0.2	20.7	s	108
26-May	16:00	16.8	23.8	0	20.7	s	63
28-May	4:10	13.7	24.4	0	22.2	s	193
31-May	4:30	14.5	23.4	0.6	14.1	s	94
2-Jun	4:00	10.9	*	0	48.2	s	20
4-Jun	5:30	11.4	*	0.3	49.7	vs	7
9-Jun	5:10	14.1	*	0	59.6	vs	34
11-Jun	4:30	15.0	*	0	24.9	s	83
14-Jun	3:10	17.5	16.5	1	24.2	m	6
18-Jun	6:00	17.8	19.8	0	1.7	m	24
21-Jun	6:45	20.6	21.1	0	6.3	s	140
25-Jun	5:00	20.7	21.9	0	12.3	s	68
29-Jun	6:00	17.4	21.3	0	39	s	24
2-Jul	4:50	18.8	15.7	0	34	vs	28
7-Jul	2:00	22	16	0	22.3	vs	2
8-Jul	4:30	23.2	16.7	0	2	vs	15
13-Jul	1:30	20.2	9	0	49.8	s	1

Table 5.8: 2011 striped bass ebb tide daily average larvae density (larvae/m³) relative to date, hours spent sampling, daily mean water temperature (°C), daily maximum salinity (ppt), daily total rainfall and total rainfall within 10 days (mm; recorded at Stanfield International Airport weather station), and tide size.

2011	Hours sampling at Alton site (h:mm)	Daily mean water temperature (°C)	Daily maximum salinity (ppt)	Daily Rainfall (mm)	Rainfall within 10 days (mm)	Tide Size	Daily average ebb tide larvae density (larvae/m³)
27-May	5:00	14.4	8.1	0	3.4	vs	3
28-May	4:30	15.5	7.6	0	3.4	vs	0
29-May	16:30	16.9	9.2	0	3.4	vs	1
30-May	12:45	17.8	11.2	3	5.4	vs	3
1-Jun	3:45	15.8	13.7	12.2	17.1	s	101
2-Jun	3:00	15.7	14.8	0.7	17.8	s	0
3-Jun	4:10	15.3	14.6	0	16.6	s	98
6-Jun	5:10	14.9	14.7	1.7	17.6	s	467
8-Jun	3:30	15.9	14.3	0	17.9	s	426
10-Jun	1:00	16.7	16.4	0	14.9	s	245
11-Jun	2:30	16.0	17.3	0	2.7	s	809
13-Jun	2:00	15.3	18.4	14.2	16.2	s	284
16-Jun	3:45	10.7	4.5	1.8	100.3	m	0
20-Jun	2:00	14.7	5.9	0	126.2	s	2
22-Jun	2:00	14.9	5.3	0	126.2	s	32
24-Jun	2:00	16.8	6.4	0	112	s	3
25-Jun	1:10	15.9	7.4	3	31	vs	0
28-Jun	4:00	18.5	10.5	0	6.2	vs	1
30-Jun	1:00	19.1	13.0	0	3.2	s	7
4-Jul	3:45	20.2	18.9	0	3.2	s	15
6-Jul	1:30	21.5	20.2	0	0.2	m	2
11-Jul	1:30	20.3	17.7	0	33.2	s	1
13-Jul	6:00	19.4	18.9	18	51.2	s	1

5.4.1 Results: Larvae Temporal Distribution at the Alton Gas Site with Respect to Tide, 2010 and 2011

In 2010, at the AGS, within a tidal cycle, the temporal density distribution of striped bass larvae within a tidal cycle fluctuated much more than eggs. Larvae were broadly distributed through the ebb tide, with increased density at the end of the ebb tide, in six of nine ebb tides between May 21 and May 31 (Table 5.9). Individual cohorts of larvae could not be identified as there was very little difference in TL (all daily mean SE were less than 0.5) between larvae each day (Table 5.9). Larvae density was generally < $50/m^3$ in the first hour of the ebb tide, progressing to over $125/m^3$ 10 h into the ebb tide. However, once converted into abundance, several tides (May 23, 25b, 26b) had peak larvae abundance at the beginning of the ebb tide due to large cross-sectional area and relatively high water velocity. On the flood tide, the density of larvae was sampled during seven tides (June 9, 11, 14, 21, 25, 29 and July 8). Larvae density on the flood tide exceeded that on the ebb tide on two tides, June 14, peaking 20 min into the flood tide at $120/m^3$ and July 8, peaking seven minutes into the flood tide at $20/m^3$, decreasing to $1/m^3$ through the ebb tide (Table 5.9). Abundance of larvae was highest during the flood tide in 6 out of 8 flood tides sampled (May 26b, June 14, 21, 25, 29 and July 8), June 14 and 21 both had peaks over 20,000 larvae/sec respectively. Rainfall was low May 23 to June 18 (74 mm spanning 15 days), likely associated with the retention of larvae (Table 5.7). Total season abundance of larvae for the 2010 season could not be calculated because individual cohorts could not be identified, thus it was impossible to distinguish whether larvae were double counted. It seems highly likely larvae flowed past the AGS on several ebb and flood tides.

In 2011, striped bass larvae were broadly distributed through the ebb tide at the AGS. The density of larvae during the flood tide consistently exceeded the density of the preceding ebb tide in all sixteen tides between May 27 and July 4 (Table 5.10). When converted to abundance, the number of larvae per second past the AGS was 4 to 12 fold higher during the flood tide compared to the ebb tide, May 27 – July 4 (Table 5.10). In six of the tides, the density of larvae increased 0 - 15 larvae/m^3 during the ebb tide to 17 - 29 larvae/m^3 during the flood tide (May 27, 30, June 16, 28, 30, July 4; Table 5.10). Three of the tides, June 1, 6 and 11, the density of larvae was > 300 larvae/m^3 during the flood tide. For example, on June 1 at the end of the ebb tide, the density of larvae in the top 1 m of the main channel was 34 and 27/m^3, equating to about 1,200 and 1,500 larvae/sec. Immediately after the bore passed, the density of larvae increased to 58/m^3 and then rose to 248 /m^3 halfway through the flood tide, equating to 87,298 larvae/sec, and just before high slack the density was 298 /m^3 or 13,661 larvae/sec (Table 5.10). Similarly, on June 6 over the final hour of the ebb tide the density of larvae was 453 and 239 larvae/m^3. Ten minutes after the bore the density of larvae was 1,430 larvae/m^3, equating to 279,292 larvae/sec. Just before high slack water on June 6 the density was 2730/m^3, or 860,023 larvae/sec (Table 5.10). Similarly, on June 11, the temporal density of larvae at the AGS at the end of the ebb tide was 749/m^3 equating to 19,394 larvae/sec, increasing five-fold early in the flood tide to 3209 larvae/m^3 or 410,909 larvae/sec passed upstream which decreased quickly to 10/m^3 close to high tide, 80 min after the bore (Table 5.10).

Table 5.9: 2010 striped bass larvae density (larvae/m^3), abundance (larvae/sec) and mean total length (TL; all mean SE were less than 0.5) through 18 tides from May 21 to July 8 at the Alton Gas Site. In relation to the time after the tidal bore passed the site, partitioned into 20 min segments during the flood tide and 100 min segments during the ebb tide. Blanks indicate no sampling was conducted at the Alton Gas Site.

Date	Mean TL (mm)	Larvae density, abundance	Time after bore (min), larvae density (#/m^3) and abundance (#/sec)										
			Flood tide				Ebb tide						
			20	40	60	80	100	200	300	400	500	600	700
21-May	5	#/m^3							557	258	314		
		#/sec							36,441	10,651	10,279		
23-May	5	#/m^3					44	87	78	134	103		
		#/sec					9,280	8,686	4,985	5,183	2,902		
24-May	6	#/m^3								43	31		
		#/sec								1,990	1,351		
25-May	6	#/m^3								150	106	171	136
		#/sec								2,072	1,030	3,651	6,742
25-Mayb	6	#/m^3					17	0	39	17	130	179	216
		#/sec					8,738	0	2,792	824	4,828	5,346	5,266
26-May	5	#/m^3					19	60	35	0	70	210	102
		#/sec					6,664	14,230	3,595	0	1,902	5,801	2,710
26-Mayb	5	#/m^3				51	9	73	158				
		#/sec				17,933	2,619	10,855	12,794				
28-May	6	#/m^3								273	205	119	243
		#/sec								10,116	8,236	3,902	6,061
31-May	6	#/m^3								86	76	127	
		#/sec								3,809	2,675	6,188	
2-Jun	7	#/m^3					56	60	2	7			
		#/sec					5,470	9,238	234	545			
9-Jun	6	#/m^3	0	0	1	1	64	37					0
		#/sec	0	0	330	257	7,316	2,809					
11-Jun	6	#/m^3	0	13	5	0	30	57					
		#/sec	0	4,817	1,681	0	6,892	8,321					
14-Jun	5	#/m^3	119	70	18	14	1	3					
		#/sec	21,552	21,565	7,564	2,828	105	410					
18-Jun	6	#/m^3						6	60	36	39		
		#/sec						669	2,184	1,214	848		
21-Jun	6	#/m^3	17	54		10	36	89	71			242	30
		#/sec	1,638	20,089		3,065	5,978	8,429	3,927			7,760	853
25-Jun	7	#/m^3	4	1		21	10					112	104
		#/sec	830	357		2,945	1,556					2,429	1,568
29-Jun	7	#/m^3	7	11						24	25	28	8
		#/sec	1,016	3,879						1,465	1,439	1,479	409
2-Jul	9	#/m^3						33	36	29	18		
		#/sec						1,309	1,141	805	379		
8-Jul	15	#/m^3	7	5	2	1	1	1					
		#/sec	4,110	1,382	777	323	91	20					

Table 5.10: 2011 striped bass larvae density (larvae/m^3), abundance (larvae/sec) and mean total length (TL; all mean SE were less than 0.5) through 18 tides from May 21 to July 8 at the Alton Gas Site. In relation to the time after the tidal bore passed the site, partitioned into 20 min segments during the flood tide and 100 min segments during the ebb tide. Blanks indicate no sampling was conducted at the Alton Gas Site.

Date	Mean TL (mm)	Larvae density, abundance	Time after bore (min), larvae density (#/m^3) and abundance (#/sec)										
			Flood tide				Ebb tide						
			20	40	60	80	100	200	300	400	500	600	700
27-May	4	#/m^3	0	2	25		7	1	0				
		#/sec	0	534	7,480		629	22	0				
29-May	5	#/m^3		0			0	7	0	0	0	0	0
		#/sec		0			0	441	0	0	0	0	0
30-May	5	#/m^3		0	5		0	0	10	4	5	2	0
		#/sec		0	1,974		0	0	503	219	179	75	0
1-Jun	5	#/m^3	58	248		298	181					34	27
		#/sec	5,683	87,298		13,661	11,857					1,220	1,565
3-Jun	6	#/m^3								115	155	51	
		#/sec								7,197	6,422	2,297	
6-Jun	6	#/m^3	1,430	1,173	2,730					152	873	453	239
		#/sec	279,292	522,730	860,023					6,381	33,184	10,942	1,817
8-Jun	6	#/m^3						110	398	625			
		#/sec						15,119	17,456	9,942			
11-Jun	7	#/m^3	3,209	427	71	10						223	749
		#/sec	410,909	76,789	23,278	2,971						36,176	19,394
13-Jun	6	#/m^3	640	100								555	745
		#/sec	66,097	34,014								13,328	14,912
16-Jun	7	#/m^3	1	0	4	25					0	0	0
		#/sec	91	0	1,887	10,054					0	0	0
20-Jun	6	#/m^3								6	2	1	
		#/sec								150	34	9	
22-Jun	7	#/m^3						34	29				
		#/sec						3,734	3,100				
25-Jun	7	#/m^3									1	1	
		#/sec									6	7	
28-Jun	7	#/m^3	1	1	16	29					0	5	1
		#/sec	201	418	4,820	3,454					0	180	11
30-Jun	7	#/m^3	17									7	5
		#/sec	1,939									127	167
4-Jul	8	#/m^3	27								19	15	
		#/sec	3,622								374	845	

5.4.2 Discussion: Striped Bass Larvae Temporal Distribution

In both 2010 and 2011 the density of larvae was about five fold lower than egg density. Abundance of larvae was 10 to 15 fold lower than egg abundance, likely due to mortality and a general dispersion throughout the tidal range of both the Stewiacke and Shubenacadie Rivers and advection into Cobequid Bay. The large decrease in density from the egg to larvae stages is consistent with other estuaries (Kernehan et al. 1981; Olney et al. 1991; Secor and Houde 1995). However, in contrast to all other estuaries the density of eggs and larvae on the Shubenacadie is extremely high, peaking around 2000 - 4000 eggs/m^3 and 200 - 500 larvae/m^3 on the ebb tide. On the Potomac estuary in Maryland, US, peak egg densities of 5.5 eggs/m^3, declined to a peak larvae density of 0.8 larvae/m^3 in the spring of 1974 (Setzler-Hamilton et al. 1981). On the Pamunkey River in Virginia, 1997 – 1999 egg density peaked at 40/m^3, yolk-sac larvae at 26/m^3, and post yolk-sac larvae at 9/m^3 (Bilkovic et al. 2002). On the Delaware River, in 1976 – 1977, which drains into the Chesapeake Bay, early life stage striped bass abundance was estimated using mean density (N/m^3), cross sectional area, and net flow (m/sec), at 3.3 billion eggs, 2.8 billion yolk-sac-larvae and 150 million post-yolk-sac larvae (Kernehan et al. 1981). On the Shubenacadie River in 1994, total egg production was estimated at 106 million eggs, with only 61 larvae total being collected over the season (Rulifson and Tull 1999). Compared to these numbers the 2010 – 2011 larvae density is very high, going from a peak ebb tide density of 4,200 eggs/m^3 to 557 larvae/m^3 in 2010 and from a peak of 10,919 eggs/m^3 to 873 larvae/m^3 in 2011. The longer duration of the larval stage is one factor resulting in a higher dispersion and lower density compared to eggs (Massoudieh et al. 2012). Despite general dispersion, large decreases in density have been associated with low survival rates from the egg to the larvae stage (Dey 1981; McGovern and Olney 1996). On the Pamunkey River, survival rates among striped bass from eggs to larval stages ranged from as low as 0.1 to 13 % in 1988 to as high as 12 to 70% in 1989 (McGovern and Olney 1996). Survival rates in the Hudson River were higher, 82 – 85 % per day for post yolk-sac (Dey 1981).

On the Shubenacadie River, the retention of larvae within the estuary was high despite the large decrease in density from egg to larvae stages. However the broader temporal distribution of larvae at the AGS compared to eggs was an indication of the dispersal of larvae and movement. I propose that the temporal distribution of larvae at the AGS has important consequences on both the larvae's spatial distribution through subsequent tidal cycles and, likely their survival. Factors influencing the spatio-temporal distribution of all 5 – 7 mm larvae with poor swimming ability in the main channel would be the same as for eggs: the location and timing with respect to the tide of release of eggs from the female, the freshwater run-off and the magnitude of the tide. Similarly, in the upper Chesapeake Bay, the location of spawning and tidal currents dictate the distribution of early life stage larvae, with larvae located further downstream in years of high tidal flow (Kernehan et al. 1981). On the Shubenacadie River, the larvae concentrated at the tail-end of the ebb tide at the AGS would not travel far downstream before the incoming tidal bore swept them back upstream, retaining them in the upper estuary. Water velocity in June 2010 at AGS late in the ebb tide was < 1.5 km/h. By contrast, those larvae drifting past the AGS early in the ebb tide when water velocity is > 5 km/h at the AGS and faster further downstream risk being flushed out of the estuary into Cobequid Bay. The Cobequid Bay is likely unsuitable nursery habitat, with higher salinities, lower temperatures in spring and perhaps less abundant prey (Jermolajev 1958; Dalrymple et al. 1990; Rulifson and Dadswell 1995; Cook et al. 2010).

The abrupt decrease in larvae June 13 - 16, 2011 was attributed to heavy rains which resulted in large freshets. It seemed reasonable to conclude at the time that larvae were flushed downstream out of the estuary. However, their reappearance indicated net upstream transport of these 12 (SE 0.24) mm TL larvae. At 12 mm TL striped bass larvae can only swim at speeds of 3 - 10 cm/s and would not be able to swim the 25 plus kilometers upstream against river velocities of 2 - 6 km/h (Doyle et al 1984). Perhaps they were occupying the water column downstream of the AGS on the Shubenacadie River, in the shallows. If this were true, a similar high density of larvae should have been in the shallows at the AGS, since the estuary characteristics seem to be similar along most sections of the Shubenacadie River. However, no larvae were collected in the shallows with the seine net from June 13 - 16. Alternatively, were the larvae much further downstream or out in the Bay and eventually came back upstream with the flood tide? Although the flood tide at the AGS is only 1h and 26 minutes as judged from the river bank, the upstream travel time of a parcel of water starting at the mouth of the estuary moving at about 6 km/h behind the bore is about 4.5 hours.

The extraordinary increase in larvae density and abundance from the end of the ebb tide to the flood tide is associated with the rapid upstream transport of larvae during the flood tide. Tidal bores and their subsequent flood tides are associated with abundant mixing and upstream advection of the suspended material (Wolanski et al. 2004). There is limited literature describing the upstream transport of pelagic organisms on tidal bore rivers. However, the magnitude of net sediment mass transfer per area was established on the tidal bore Garonne River in France, with 30 times larger sediment transfer on the flood tide compared to the ebb tide (Chason et al. 2011). Modeling the ebb and flow of pelagic striped bass eggs and larvae is the next step in fully understanding their residence and exposure time in the Shubenacadie estuary.

5.5 Results: Egg and Larvae Spatial Distribution

In 2010, the sampling conducted downstream of the AGS, on May 20, June 4, and 14 established that early life stage striped bass could be advected into Cobequid Bay, and some transported back again. On May 20, starting at high slack at the AGS, drifting 10 km downstream, at an average velocity of 5.3 km/h the density of eggs and larvae was 62 - 66 eggs/m^3 and 19 - 36 larvae/m^3 (3 mm TL), between river km 25 to 15 (Table 5.11). These eggs and larvae had an additional 6.5 hours to flow downstream before the arrival of the next tidal bore.

On June 4, sampling covered the lower estuary from river kilometer 13 - 0, from high slack water drifting (avg. 6.3 km/h) down to the mouth of the estuary. Over the two hour drift there were no striped bass eggs collected but larvae were collected at low densities, 2 - 9/m^3. These larvae had over 7 hours to flow out into Cobequid Bay before the arrival of the next tidal bore. Motoring back upstream against the ebb tide, tows were taken approximately every 2 kilometers from Shubenacadie River kilometer 2 to 20. The density of larvae was slightly lower downstream from river kilometers 2 to 10 (0 to 7 larvae/m^3) compared to further upstream from river kilometers 11 to 20 (10 to 20 larvae/m^3, 6.4 mm TL; Table 5.12).

Tracking the downstream drift of egg and larvae on May 20 and June 4 led to an investigation of the numbers being carried back upstream on the flood tide. June 14 sampling commenced in lower Urbania (river km 13) just after the tidal bore passed. Throughout the 1.5 h flood tide, striped bass eggs and larvae were present at an average density of 9 eggs/m^3 (range 4 to 14) and 16 larvae/m^3 (range 4 to 28, 5 mm TL; Table 5.13). Following high slack in lower Urbania samples were taken drifting downstream on the ebb tide to the mouth of the Shubenacadie River and 3 km out into Cobequid Bay. Egg and larvae striped bass were collected at an average density of 9 eggs/m^3 (range 4 to 13) and 2 larvae/m^3 (range 0 to 5). Low densities of eggs and larvae (3.5 eggs/m^3 and 1 larvae/m^3) were caught 3 km out into the Cobequid Bay 2.5 hours into the ebb tide (Table 5.13).

Having established that eggs and larvae could be flushed out to Cobequid Bay, and some carried back again, the aim of the final spatial survey for 2010, on June 21, was to determine the extent of their upstream transportation. Simultaneous sampling at both the AGS and upper Urbania (river km 18.3) revealed large numbers of larvae at the end of the ebb tide, 323 larvae/m^3 at upper Urbania and 200 - 300 larvae/m^3 upstream at the AGS, on average 6 mm TL. The arrival of the tidal bore, first at upper Urbania (08:12 h), then about half an hour later at the AGS (08:48 h) and subsequent flood tide carried larvae (36 - 82 larvae/m^3) upstream (Table 5.14). Sampling started in upper Urbania then sampled upstream to the confluence and continued 6 km up the Stewiacke River (Fig. 5.16). The density of larvae increased markedly in the upper reaches of the estuary on the Stewiacke River, reaching 213 and 365 larvae/m^3 at river kilometer 5.3 and 4. The final plankton net tow was taken at the salt front (0.2 ppt) at Stewiacke River km 6.3 and had 76 larvae/m^3 (Fig. 5.16).

In 2011, spatial distribution of striped bass eggs and larvae was investigated on eight days (May 26 and 30, June 3, 10, 13, 20, 22 and 24) over 44 kilometers of the Shubenacadie River, 11 kilometers of the Stewiacke River and 18 kilometers of Cobequid Bay. In Cobequid Bay on May 30, striped bass eggs were collected 18 km out in the Bay, along the Noel Shore, off Sloop Rocks (Fig. 5.17) in 20 ppt, density 22 eggs/m^3. While larvae and eggs were collected 11 km out in the Bay in 18.6 ppt salinity, density 145 eggs/m^3 and 2 larvae/m^3, at an average of 5.5 mm TL (Fig. 5.18). By contrast, the limit of upstream transport of early life stage striped bass was documented on June 10 when low densities of eggs and larvae were found 8.7 km up the Stewiacke River at the CN train bridge in 0.1 ppt salinity and 38.9 km up the Shubenacadie River in 0.1 ppt salinity. Early life stage striped bass can't be carried further upstream than the salt front.

Spatial sampling in 2011 started May 26 on the Stewiacke River, four days after the first large spawning event. No larvae and very few eggs were collected in samples taken on the ebb tide starting at high slack at the CN train bridge (Stewiacke km 8.7) and drifting back downstream following a drogue buoy to the Fish House (Stewiacke km 0.6). Despite high numbers of eggs at the AGS from May 22 – 24 (47 – 280/m^3), no eggs were detected in the four tows taken from Stewiacke River km 8.7 - 5.6, in the remaining 8 tows 0.5 - 1.4 eggs/m^3 were found in each tow from Stewiacke River km 4.5 - 0.6. Salinity was consistent at 0.1 ppt over all tows, thus all sampling was conducted upstream of the salt front. Consequently it was no surprise no early life stage striped bass were found.

Since very few early-life-stage striped bass had been found upstream of the AGS we investigated further downstream and out in Cobequid Bay. Downstream sampling was conducted May 30 late in the afternoon (16:00 – 21:00) over the last 3 hours of the ebb tide from the mouth of the estuary 18 km out into Cobequid Bay (Fig. 5.17). Sampling had been conducted earlier in the day (02:00 - 12:45) at the AGS, with the average density over 15 tows of 1609 eggs/m^3 (range 245 to 3649) and 7 larvae/m^3 (range 0 to 38). The first three samples taken downstream were within the first few kilometers of the estuary, the density of eggs ranged from 167 – 537 eggs/m^3. Samples taken from 1 to 11 km out in Cobequid Bay detected egg densities ranging from 96 – 495 eggs/m^3 (Fig. 5.18). Samples taken from 13 to 18 km out in Cobequid Bay detected smaller egg densities ranging from 18 – 63 eggs/m^3 in a channel approximately two kilometers wide. Larvae were only detected at river kilometer 3.7 (1.6 larvae/m^3), Cobequid Bay kilometer 1 (8.8 larvae/m^3) and 11 (1.9 larvae/m^3; Fig. 5.18). Sampling in Cobequid Bay stopped at km 18 because the flood tide had reached the sampling boat. Upon returning on the flood tide to the Shubenacadie River, a last sample was at Black Rock (river km 2.7) during the flood tide, egg density, 736 eggs/m^3. The sampling on May 30 established that striped bass eggs could be carried out into Cobequid Bay and returned to the Shubenacadie estuary on the subsequent flood tide.

The upstream distribution of eggs and larvae on the Stewiacke and Shubenacadie Rivers was investigated on June 3 and 10 using two boats simultaneously. On June 3, sampling commenced around 16:30 h on both rivers with no early life stage striped bass collected above the salt front in tidal fresh water (0.1 ppt or less) on either river. On both rivers the density of larvae was highest about 2 km further upstream than the highest density of eggs. On the Stewiacke River the highest density of larvae were around river km 4, or 6.5 km upstream of AGS (237 larvae/m^3, body size 6 mm TL). Peak egg densities were collected around river km 1.6, or 4 km upstream of AGS (340 eggs/m^3; Fig. 5.19). On the Shubenacadie River larvae density peaked at the beginning of the ebb around river km 35.7 – 33.3, or 10.7 to 8.3 km from AGS, average 1671/m^3 (range 1112 – 2370 larvae/m^3). Egg density peaked in tows around river km 33.3 – 32.1, or 8.3 – 7.1 km from AGS, average egg density 2158/m^3 (Fig. 5.20). Egg and larvae densities on the Stewiacke River were only about 10 to 20 % of those on the Shubenacadie River. Sampling concluded around 18:10 h on both rivers, about 3 h 45 min into the ebb tide at the AGS, leaving about six hours for eggs and larvae to drift downstream before the incoming tide.

On June 10, 2011, the spatial distribution and density of eggs and larvae upstream of the AGS was similar to June 3. There were no eggs or larvae above the salt front in salinities of 0.1 ppt or less on either river. Motoring back downstream larvae and egg densities peaked 5 - 10 km from the AGS on both rivers at salinities of 1 – 2 ppt. June 10, also had very similar early life stage densities on both rivers (> 500 egg/m^3 and > 1000 larvae/m^3 Fig. 5.21 and 5.22). On the Stewiacke River, 11 - 42 % of the eggs collected were new eggs, compared to 12 – 28 % new on the Shubenacadie River. Sampling concluded around 13:00 h, about 5 h 15 min into the ebb tide at the AGS, leaving about five hours for eggs and larvae to drift downstream before the incoming tide.

On June 13, sampling from the mouth of the estuary to the AGS on the flood tide (08:12- 12:10 h) and then sampling back downstream to the mouth on the following ebb tide (12:10 - 15:18 h) revealed the density of eggs and larvae were on average six times higher during the flood tide compared to the ebb tide. On average, the density of eggs and larvae was greater upstream (river km ~ 14 - 25), average density, 24 eggs/m^3 (range 0 to 198) and 193 larvae/m^3 (range 17 to 541), compared to downstream (river km ~ 0 - 12), average density, 5 eggs/m^3 (range 0 to 14) and 41 larvae/m^3 (range 8 to 116) (Fig. 5.23).

June 20 and July 11, 2011 simultaneous plankton tow sampling at Black Rock (river km 2.7) and at the AGS (river km 25) in the last few hours of the ebb tide revealed low densities of eggs and larvae (0 - 8/m^3) at both locations. On June 22 sampling was conducted at the AGS (river km 25) from 09:30 to 11:30, 2 - 4 hour into the tide at the AGS site and then starting at Black Rock (river km 2.7) at 13:12, heading 7 km out into the Cobequid Bay and back again, revealed egg and larvae densities were very similar, ranging from 0 - 6/m^3 and larvae ranging from 17 - 41/m^3 (Table 5.14).

The final spatial sampling day using the plankton net, June 24, was used primarily to collect ebb and flood tide river velocity data from Shubenacadie km 39 to 25, low egg and larvae densities (0 - 5/m^3) were collected during the three flood tide tows at km 25, 31.5 and 35.5. Nothing was caught on the ebb tide.

Table 5.11. Density of striped bass eggs (eggs/m³) and larvae (larvae/m³) May 20, 2010, at the end of the flood tide, high slack (HS) and ebb tide from plankton nets tows starting at the Alton Gas Site at kilometer 25 and drifting 10 km downstream on the Shubenacadie River.

Location (km)	Clock time (h)	Eggs/m^3	Larvae/m^3	Salinity (ppt)	Tide
25	07:31	192	0	22	flood
25	08:10	62	19	23	HS
21	08:56	61	36	23	ebb
16	09:43	66	28	24	ebb
15.3	10:18	71	38	23	ebb
20.6	10:36	49	24	21	ebb

Table 5.12. Density of striped bass larvae (larvae/m³), June 4, 2010, starting at high slack water in lower Urbania (river km 13) drifting downriver through the first four hours of the ebb tide to the mouth of estuary. Motoring actively back upriver, sampling took place about every two kilometers to Shubenacadie River kilometer 20.

Location (km)	Clock time (h)	Larvae/m^3	Salinity (ppt)	Tide
13.8	08:37	9	10	ebb
15.3	08:50	6	9	ebb
6	09:30	4	13	ebb
4.2	09:52	2	13	ebb
1.7	10:30	2	13	ebb
3.3	10:45	0	14	ebb
4.3	10:52	0	13	ebb
5.3	11:02	1	10	ebb
7.1	11:13	7	9	ebb
9.1	11:24	3	7	ebb
11.4	11:39	13	3	ebb
13.4	11:56	20	2	ebb
15.8	12:07	21	0	ebb
17.8	12:19	10	0	ebb
19.8	12:40	10	0	ebb

Table 5.13. Density of striped bass eggs (eggs/m³) and larvae (larvae/m³), June 14, 2010, in lower Urbania (river km 13) on the Shubenacadie River through the entire flood tide. Following high slack in lower Urbania samples were taken drifting downstream at the same speed as the water current on the ebb tide to 3 km out into Cobequid Bay, 2.5 hours into the ebb tide at the mouth of the estuary. Three samples were then taken moving back upstream to river kilometer 11.3.

Location (Km)	Clock time (h)	Eggs/m^3	Larvae/m^3	Salinity (ppt)	Tide
13.4	14:03	14	28	14	flood
13.6	14:17	7	11	15	flood
13.6	14:32	8	8	18	flood
13.7	14:47	5	28	18	flood
13.6	15:03	14	23	19	flood
13.6	15:17	4	4	18	flood
13.5	15:32	11	11	19	flood
11.4	17:13	20	7	19	ebb
4.9	17:50	10	0	19	ebb
3 Bay	18:12	4	1	21	ebb
3.6	18:36	11	2	20	ebb
7.5	18:53	13	5	18	ebb
11.3	19:32	10	2	17	ebb

Table 5.14. Density of striped bass larvae (larvae/m³), June 21, 2010, at two sites on the Shubenacadie River sampled simultaneously, the Alton Gas Site and 5km downstream in upper Urbania (km 20) late in the ebb tide through the flood tide.

Upper Urbania (km 20)			Alton Gas Site (km 25)		
Clock time (h)	Larvae/m^3	Tide	Clock time (h)	Larvae/m^3	Tide
8:09	323	ebb	8:23	215	ebb
8:12	172	bore	8:28	302	ebb
8:33	49	flood	8:48	No sample	bore
8:58	60	flood	9:30	36	flood
9:30	82	flood	9:46	36	flood
9:50	23	flood	10:18	58	high slack
10:15	21	high slack	11:12	35	ebb

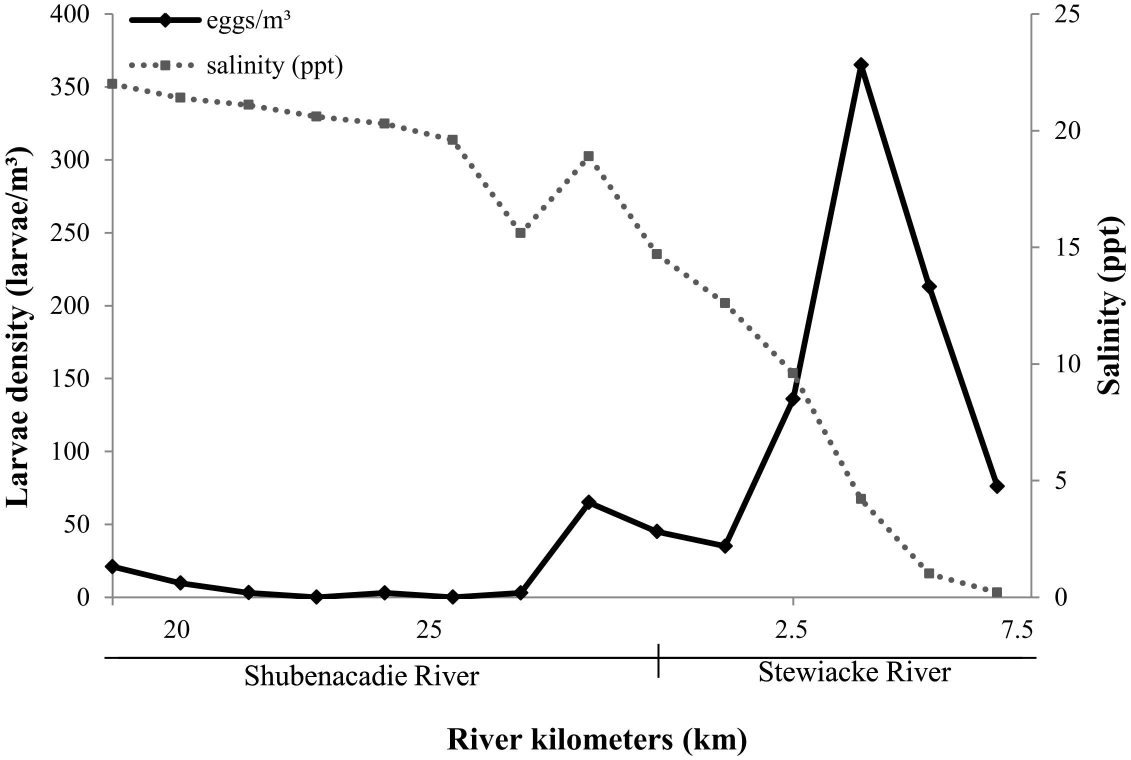


Figure 5.16: Density of striped bass larvae (larvae/m³) in relation to salinity (ppt) on June 21, 2010 on the ebb tide from plankton nets tows commencing at upper Urbania at Shubenacadie River kilometer 18.3 at 10:15 h and ending 6.3 km up the Stewiacke River at 12:13 h.

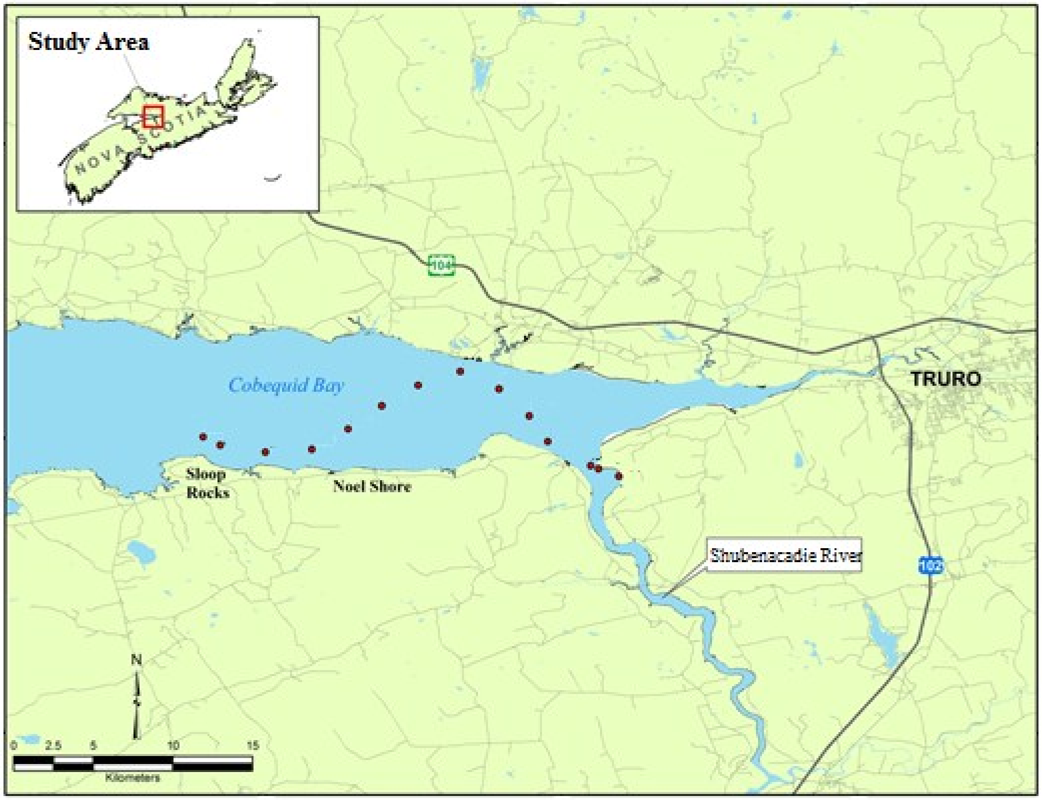


Figure 5.17. May 30, 2011, sampling locations on the ebb tide from plankton nets tows taken starting 4 km upstream of the mouth of the Shubenacadie River at 16:00 h and moving 18 km out into Cobequid Bay, ending at 18:57 h with the arrival of the tidal bore. *Note the "kilometers out in the bay" is not a straight line; it followed the channel where the majority of the water was flowing between the sand bars (Fig. 2.1).

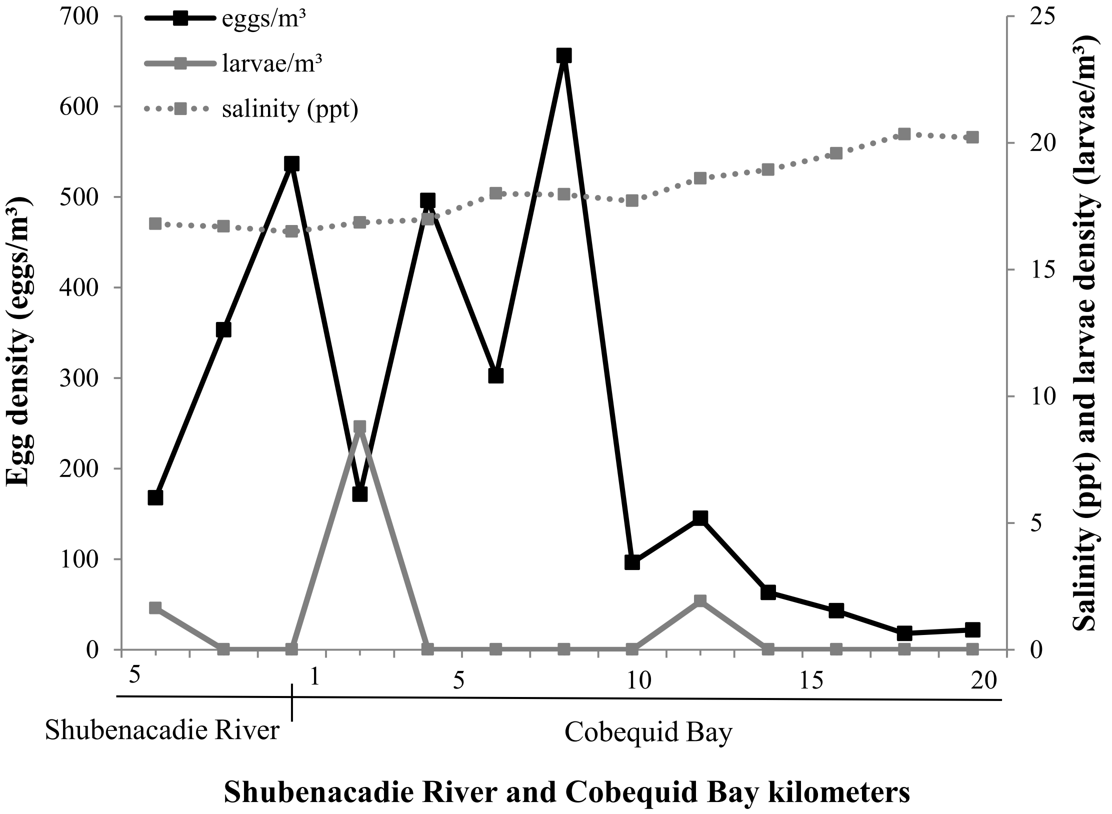


Figure 5.18: Density of striped bass eggs and larvae on May 30, 2011 on the ebb tide from plankton nets tows taken starting 4 km upstream of the mouth of the Shubenacadie River at 16:00 h and moving out into Cobequid Bay, ending at 18:57 h with the arrival of the tidal bore.

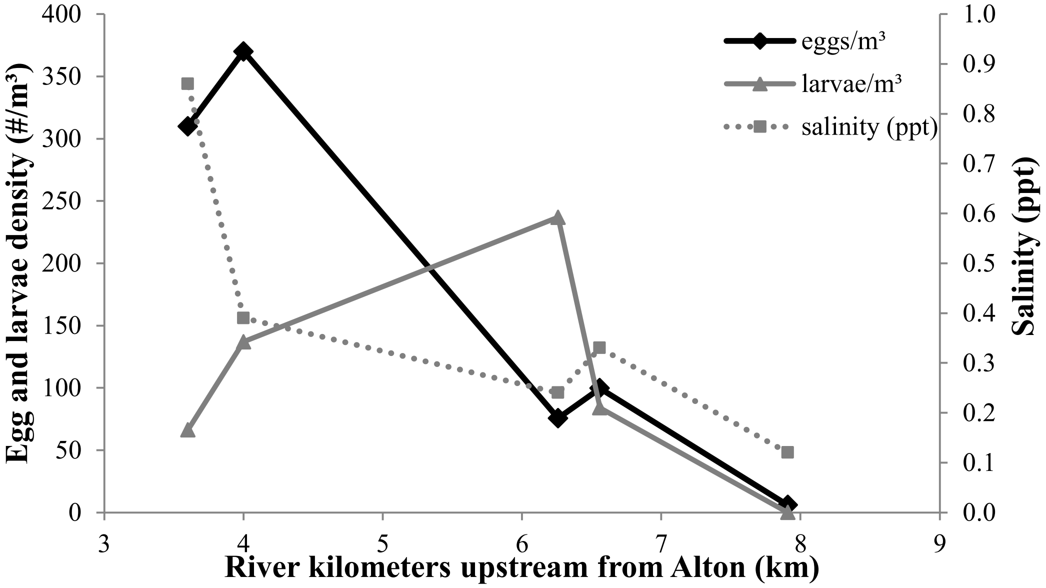


Figure 5.19: June 3, 2011 striped bass egg and larvae density (#/m³) and salinity (ppt) on the Stewiacke River in relation to river kilometers upstream from the Alton Gas Site (km). Sampling commenced at 16:29 h at km 8 and ended at 18:13 h at km 3.5.

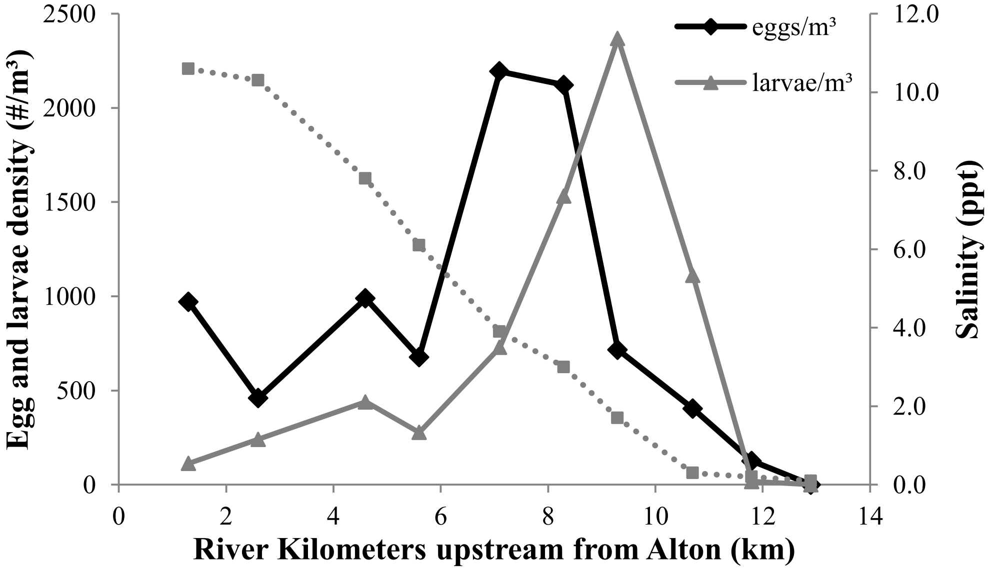


Figure 5.20: June 3, 2011, striped bass egg and larvae density (#/m³) and salinity (ppt) on the Shubenacadie River in relation to river kilometers upstream from the Alton Gas Site (km). Sampling commenced upstream of the salt front at 16:45 h at km 13 and ended at 18:06 h at km 1.3.

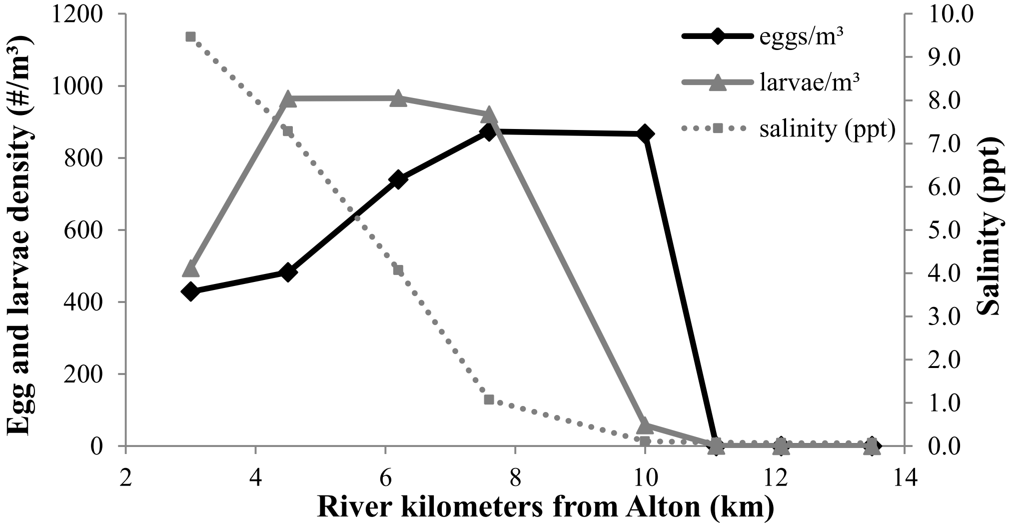


Figure 5.21: June 10, 2011, striped bass egg and larvae density (#/m³) and salinity (ppt) on the Stewiacke River in relation to river kilometers upstream from the Alton Gas Site (km). Sampling commenced upstream of the salt front at 09:26 h at km 13.5 and ended at 11:16 h at km 3.

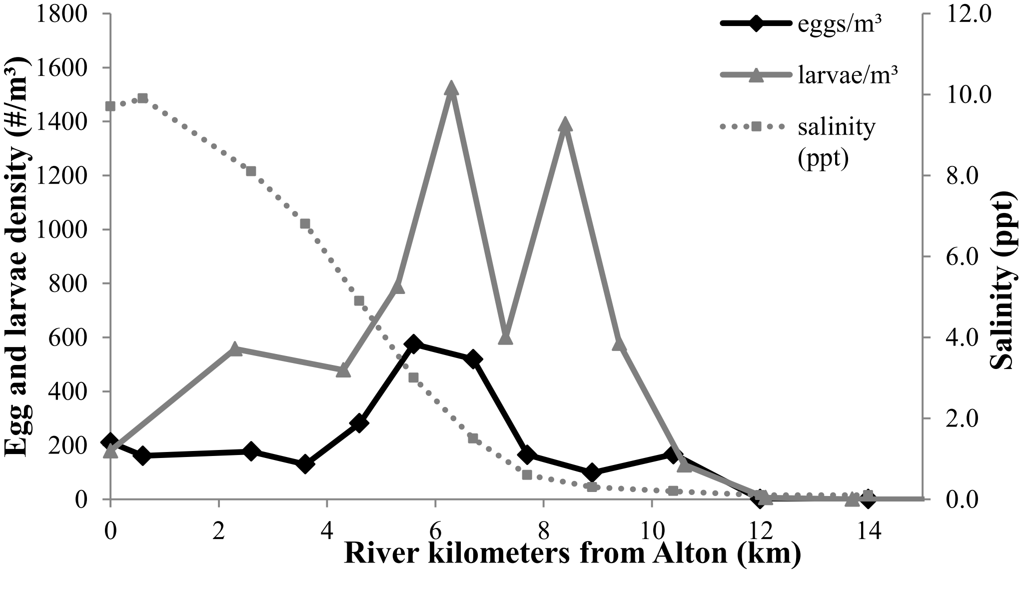


Figure 5.22: June 10, 2011, striped bass egg and larvae density (#/m³) and salinity (ppt) on the Shubenacadie River in relation to river kilometers upstream from the Alton Gas Site (km). Sampling commenced upstream of the salt front at 10:55 h at km 14 and ended at 13:05h at km 0.

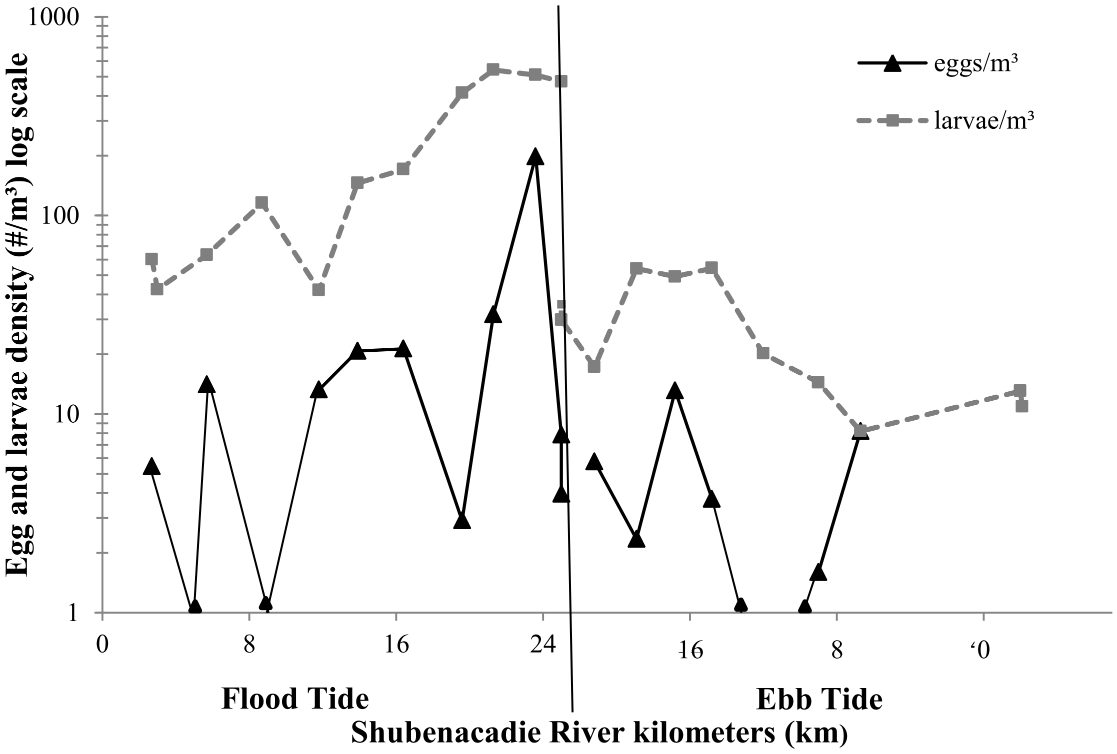


Figure 5.23: Density of striped bass eggs and larvae on June 13, 2011, from the mouth of the river, upstream to the Alton Gas Site on the flood tide (08:12 h - 12:10 h) and then sampling back downstream to the mouth of the river on the ebb tide (12:21 h - 15:18 h).

Table 5.15: Density of striped bass eggs and larvae June 22, 2011, from plankton nets tows starting at the Alton Gas Site and at the mouth of the estuary, out 7.4 km into Cobequid Bay. *Note “R” next to the kilometers denotes river and the “B” denotes bay.

Location	km	Clock time (h)	Salinity (ppt)	Eggs/m^3	Larvae/m^3	Tide
AGS	25 R	09:39	1	6	39	ebb
	25 R	10:27	0	4	28	ebb
	25 R	11:27	0	4	30	ebb
Estuary Mouth	2.7 R	13:12	8	3	17	ebb
	1.4 R	13:22	8	2	29	ebb
	0.45 R	13:30	8	0	21	ebb
Cobequid Bay	0.7 B	13:38	8	0	21	ebb
	1.5 B	15:09	7	2	25	ebb
	2.7 B	13:45	9	4	11	ebb
	4.7 B	13:55	9	0	21	ebb
	7.4 B	14:26	12	5	42	flood
	4.7 B	14:40	8	2	26	ebb
	2.7 R	15:23	4	3	41	ebb

5.5.1 Discussion: Egg and Larvae Spatial Distribution

Describing the spatial distribution of age-0 striped bass can help define the nursery habitat and factors affecting survival, growth and recruitment. Knowledge of the spatio-temporal distribution of age-0 striped bass in relation to the state of tide and freshwater run-off will allow future monitoring to obtain samples that are a true measure of abundance, and hence improve year class strength estimates (Conroy 2012). Alton Natural Gas Storage LP will be able to use the knowledge gained here to make informed decisions regarding their pumping activity when eggs and larvae are present in the estuary. Retention of striped bass eggs and larvae in the estuary is dependent on the state of balance between upstream transportation on the flood tide versus the magnitude of downstream flushing due to freshwater run-off on the ebb tide. The high retention of eggs at AGS over several tidal cycles May 17 - 18 when run-off was very low is a good example. Conversely, after heavy rain and high freshets there are typically no striped bass early life stages at the AGS, as occurred on June 4, 2010.

Among other striped bass populations, data on the effects freshwater run-off and tides have on the spatial distribution of early life stage striped bass in well-mixed estuaries is limited. The majority of well-studied striped bass populations spawn in estuaries with ETMs. In these estuaries spawning occurs in long estuaries where there is sufficient downstream river flow to keep eggs in suspension, once they reach the ETM they are retained within the area (Shoji et al. 2005; North and Houde 2006; Martino and Houde 2010). Over a five year study on the Chesapeake Bay, egg distribution was patchy over a 25 km range, which extended downstream to the ETM where the highest concentrations of eggs and larvae where found (Martino and Houde 2010). Similar to the Shubenacadie

River, variability in hydrological conditions influenced egg and larvae distribution. Larvae were located further downstream closer to the ETM when there was high fresh water flow, and further upstream in years with low fresh water discharge (Martino and Houde 2010). On the Potomac estuary striped bass eggs were found over a distance of 64 km, with a net downstream flow, early life stages were again concentrated around the ETM (Setzler-Hamilton et al. 1981). On the Miramichi River, NB in 1992 striped bass eggs were broadly distributed in the tidal freshwater 2 to 12 km above the salt wedge, with the majority of larvae occurring near the salt wedge (Robichaud-LeBlance et al. 1996).

The Shubenacadie River is unique as it is the only tidal bore river where striped bass spawning occurs (Rulifson and Dadswell 1995). Investigations provided the first evidence supporting the hypothesis proposed over 10 years ago that striped bass eggs and larvae could be transported from the upper estuary to Cobequid Bay on a single ebb tide (Rulifson and Tull 1999). Early life stage striped bass were transported downstream at a similar velocity as the ebbing river current. Downstream of AGS repeated plankton net tows during drogue-buoy drifts yielded the same density and stage of eggs and larvae and the same salinity, indicating the same parcel of water was being sampled. These findings are consistent with other findings indicating eggs travel between 80 and 100% of water velocity (Davin et al. 1999). Samples taken in 2010 and 2011 also revealed early life stage striped bass could be carried back upstream on the flood tide. These finding were contrary to that proposed by Rulifson and Tull (1999), who suggested that hatching occurred downstream and larvae avoided upstream transport back to the Stewiacke River. Perhaps the reason why Rulifson and Tull (1999) found few late stage striped bass eggs and larvae (n = 61) on the Stewiacke River in 1994 was because of the large amount of fresh water in the system, likely causing advection into Cobequid Bay. April and May 1994, had 26.5 and 36.5 mm more precipitation than average (1971 to 2000) and 105 and 98 mm more than 2010 and 20 and 22 mm more than 2011 (Fig. 5.24; Environment Canada). Instead of having an ETM or salt wedge to contain early life stage striped bass within the nursery habitat, the Shubenacadie River has an ebb and flow relationship between the downstream freshwater flow and the upstream transportation of the tidal bore.

Striped bass eggs and larvae were found over the entire brackish estuary upstream to the salt front and nearly 18 kilometers beyond the mouth into Cobequid Bay. The salt front on the Shubenacadie and Steiwacke Rivers defines the limit of upstream transport for eggs and larvae on the flood tide. The position of the salt front is dictated by the volume of freshwater run-off against the magnitude of the tide, dictated by the lunar cycle. A high upstream salt front leads to a better chance of retention in the estuary through the next ebb tide, compared to a low upstream salt front. During the spawning season early life stage densities were higher on the Stewiacke than the Shubenacadie River. However, thereafter higher densities always occurred on the Shubenacadie River, suggesting that the majority of early life stage striped bass were funneled back up the Shubenacadie River on the flood tide. Following the flood tide large concentrations of eggs and larvae occurred at specific locations upstream on the Shubenacadie and Stewiacke Rivers, likely due to the condensed mass upstream transport of passive organisms through the flood tide, comparable to the onshore coastal transport of larvae through internal warm coastal tidal bores. These warm coastal tidal bores occur when cold deep coastal water is advected shoreward, displacing warm water further off shore. This creates an imbalance in hydrostatic pressure between the warm and cold water densities. As the cold water recedes back offshore the warm water returns towards the coast, creating a warm water front and condensing free floating organisms (Paris and Cowen 2004; Pineda et al. 2007).

The total extent in which eggs and early life stage larvae are distributed in the Cobequid Bay was not defined, as they were found over all locations sampled in the Cobequid Bay. Intensive sampling in the Cobequid Bay was beyond the scope of this thesis. However, a few conclusions can be made based on the data collected. On May 30, 2011 when eggs and larvae were found off the Noel shore in the Cobequid Bay they were only 13 kilometers from entering the Central Minas Basin. It is likely that eggs and larvae were present out in the Central Minas Basin, based on the evidence that if eggs and larvae are downstream early in the ebb tide they have less distance to travel to the Central Minas Basin as they don't have to follow the narrow channel that forms at the end of the ebb tide when there is less water in the bay (Fig. 2.1). In 2010 it was established that there were eggs 3 km out in the Bay only 2.5 hours into the ebb tide, meaning that not all eggs are travelling into the upper reaches of the Shubenacadie estuary on the flood tide. Samples taken at the very end of the ebb tide nearly 20 km into the Bay had relatively high egg densities (22 - 66 egg/m^3), thus it is likely that eggs could have reached the Central Minas Basin. Otolith elemental signatures during the initial months of striped bass growth indicate that the nursery grounds are not in the Cobequid Bay or Central Minas Basin (Morris et al. 2003). Lower water temperature and higher salinity in Cobequid Bay and Central Minas Basin also support that they are outside of the nursery habitat (Dalrymple et al. 1990; Rulifson and Dadswell 1995) However, it is unclear whether early life stages are actually negatively affected by advection. Testing this hypothesis would be a worthwhile endeavor. Eggs and larvae that are out in the Cobequid Bay may get carried up the Salmon River on the flood tide, since in the first 15 minutes of the flood tide the majority of the water at the head of Cobequid Bay is forced up the Salmon River, until the water levels rise enough to flow over the sandbars towards the Shubenacadie River (personal observation). The Salmon River is not likely a suitable nursery habitat because of its short tidal limit, with the salt front occurring around river km 10. Properly describing the total spatial distribution of early life stage striped bass is important in conserving this endangered species. Striped bass no longer spawn on the Annapolis and Saint John Rivers, likely due to changes in water flow and quality associated with the construction of hydroelectric dams (Jessop 1995; COSEWIC 2004). Knowing the full distribution of early life stage striped bass on the Shubenacadie estuary will hopefully mitigate future project impacts.

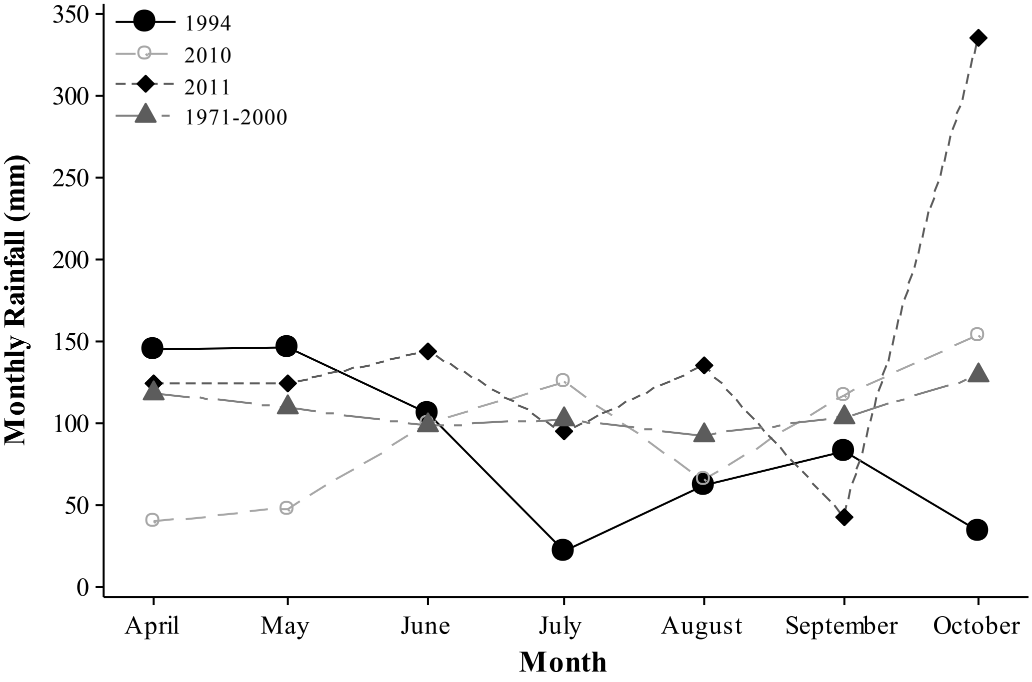


Figure 5.24: Total monthly rainfall (mm) at the Stanfield International Airport from April to October in the years 1994, 2010, 2011 and average monthly rainfall from 1971 to 2000 (Environment Canada database).

Chapter 6. Beach Seine Catch Per Unit Effort, Striped Bass Growth, Stomach Contents and Prey Density

6.1 Introduction

The previous chapter dealt with striped bass egg and larvae density, abundance and distribution collected solely by plankton net tows in the main channel of the estuary. Chapter 6 considers catch data from beach seine nets conducted at the AGS and spatially to track the distribution and growth of age-0 striped bass from May to September. Seasonal growth and stomach content is evaluated by pooling data collected from both the plankton net and seine net. Prey density was not the main focus of the thesis, but is included as an enhancement on factors affecting survival and recruitment of age-0 striped bass. Striped bass were the primary target species, therefore the 500 μm plankton net was principally used, however this net was too large to conduct a meaningful assessment of prey items with a body size under 0.5 mm, such as copepods.

6.2 Results: Striped Bass Temporal and Spatial Catch Per Unit Effort

Mean striped bass seine net catch per unit effort (CPUE) was 25% higher in 2010 (12) compared to 2011 (9; Table 6.1) over all sampling sites, Black Rock, Princeport, Gosse Bridge, AGS, 102 highway Shubenacadie and 102 highway Stewiacke bridges (Table 4.1) but not significantly different ($P > 0.05$). In June, no larvae were collected in 2010 and very few (3 CPUE) in 2011. In both years the majority (85 and 64%) of striped bass were caught in July. July's CPUE was 29 (2010) and 14 (2011). CPUE decreased substantially in August both years, to 5 (2010) and 7 (2011). In September 2010 CPUE was 1; no seine netting was performed in September of 2011(Table 6.1).

The AGS was the most successful sampling site in July of 2010 and all months sampled in 2011. The AGS had a CPUE of 34 striped bass in July of 2010 and 20 in July of 2011 (Fig. 6.1 and 6.2). Gosse Bridge (km 11.3) was a poor sampling site in 2010, finding a CPUE of only 3 in July and zero for the rest of the summer. The Princeport site (km 6.2) was a successful site in 2010 with a CPUE of 15, 10 and 1 for July, August and September respectively. By contrast in 2011, striped bass were only found at the Princeport site in August of 2011, at a CPUE of 5. Striped bass were consistently found in low numbers (range 1 - 11) at the Black Rock site (km 2.7) throughout the 2010 sampling season, but were only captured in low numbers in August of 2011(range 2 - 11). Among the upriver sites sampled in 2011, Highway 102 Stewiacke (Stewiacke km 2.8, 30.2 kilometers from Cobequid Bay) and Highway 102 Shubenacadie (km 31.8), had a CPUE of 18 and 16 respectfully in July, but otherwise very few striped bass were found at these sites.

6.3 Results: All Species Temporal and Spatial Catch Per Unit Effort

Apart from striped bass, fifteen other species were caught in seine net tows in 2010 and 2011. Next to striped bass, the second most common species captured was gaspereau/American shad (*Alosa sp.),* in 2010 and Atlantic silverside (*Menidia menidia*) in 2011 (Table 6.2). The gaspereau/American shad were present in much higher numbers in 2010 (16.7 CPUE) compared to 2011 (5.9 CPUE). The opposite was true for Atlantic silverside, with a higher CPUE in 2011 (10) compared to 2010 (3.5). The remaining twelve species were all relatively rare both years (Table 6.2). These twelve species included: threespine stickleback (*Gasterosteus aculeatus*), mummichog (*Fundulus heteroclitus*), banded killifish (*Fundulus diaphanous*)*,* cunner *(Tautogolabrus adspersus),* American eel *(Anguilla rostrata),* Northern pipefish *(Syngnathus fuscus),* Atlantic tomcod *(Microgadus tomcod),* winter flounder *(Pleuronectes americanus),* grass shrimp *(Palaemonetes vulgaris),* sand shrimp *(Crangon septemspinosa),* mysid (*Neomysis americana*), and jelly fish *(Phialidium sp.).*

Table 6.1: Total number of age-0 striped bass pooled to nearest whole number between all sampling sites, Black Rock, Princeport, Gosse Bridge, AGS, 102 highway Shubenacadie and 102 highway Stewiacke bridges from June to September 2010-11, in relation to the number of seine net tows conducted each month and the monthly catch per unit effort. * denotes no sampling was conducted.

	2010			2011		
Month	Total striped bass	Number of tows	CPUE	Total striped bass	Number of tows	CPUE
June	0	3	0	72	21	3
July	784	27	29	504	36	14
Aug	126	27	5	208	30	7
Sept	14	18	1	*	*	*
Totals	924	75	12	784	87	9

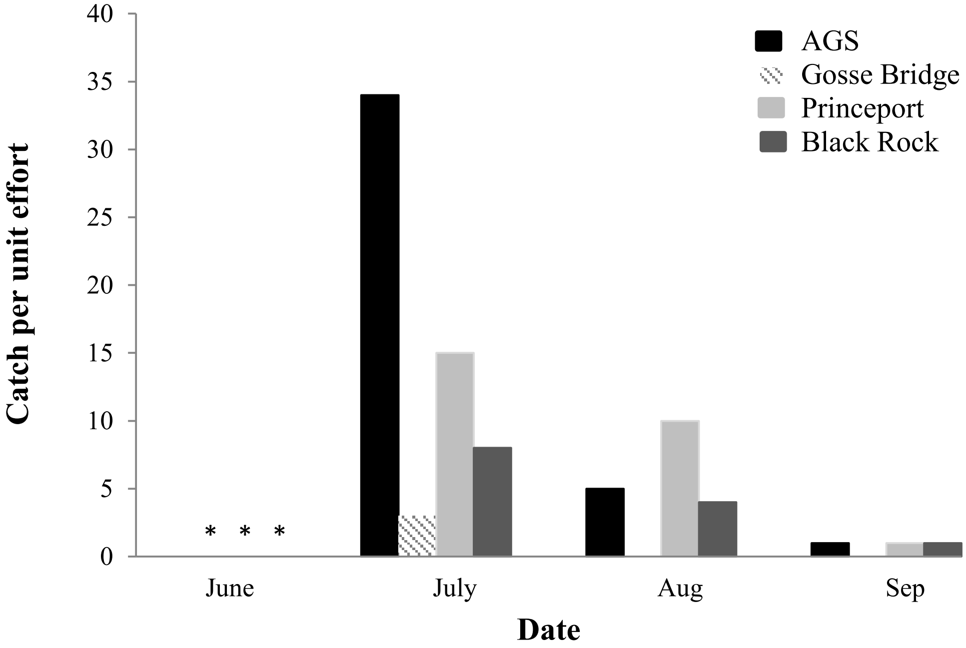


Figure 6.1: 2010 age-0 striped bass catch per unit effort at four sampling sites, Alton Gas Site (AGS; km 25), Gosse Bridge (km 11.3), Princeport (km 6.2) and Black Rock (2.7), from June 25 to September 27. No bar represents a CPUE of zero. * denotes no sampling was conducted. The number of tows conducted per month over all sites was 2 in June, 27 in July, 27 in August and 18 in September.

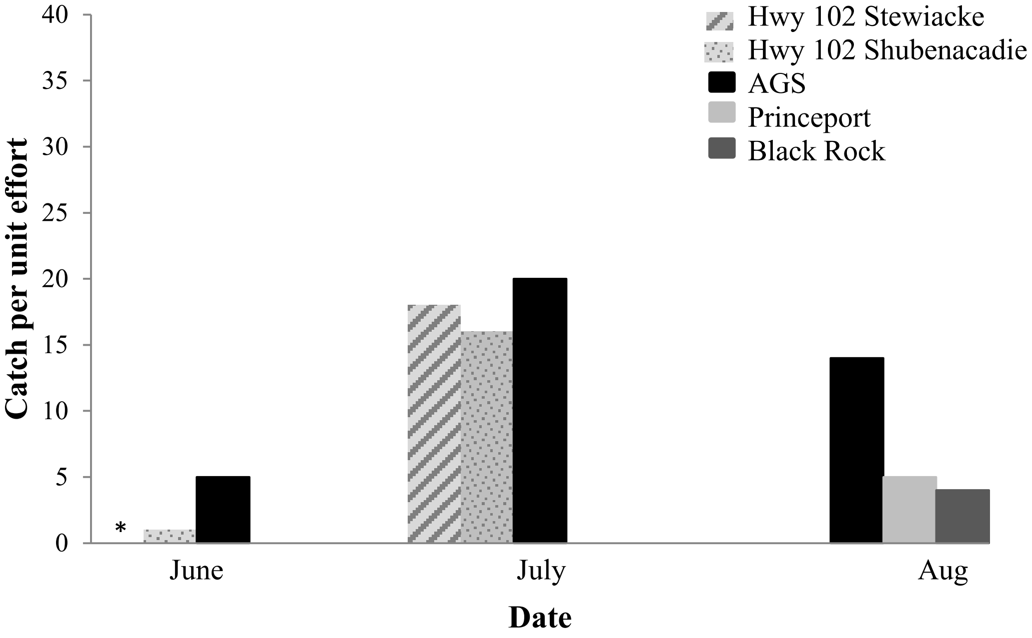


Figure 6.2: 2011 age-0 striped bass catch per unit effort at five sampling sites, Highway 102 Stewiacke (km 2.8), Highway 102 Shubenacadie (km 31.8), Alton Gas Site (AGS; km 25), Princeport (km 6.2) and Black Rock (2.7), from June 16 to August 31. No bar represents a CPUE of zero. * denotes no sampling was conducted. The number of tows conducted per month over all sites was 28 in June, 32 in July, 32 in August.

Table 6.2: Total number of species caught over all beach seine net sites, Black Rock, Princeport, Gosse Bridge, AGS, 102 highway Shubenacadie and 102 highway Stewiacke bridges. The number of species caught per seine net tow from June 25 to September 27 2010 and June 16 to August 31 2011. Total seine net tows in 2010 was 74 and in 2011 was 92.

All sites in the Shubenacadie Estuary	2010		2011	
Species	Number caught	CPUE	Number caught	CPUE
Gaspereau/American shad (*Alosa sp.*)	1200	16.67	515	5.92
Atlantic silverside (*Menidia menidia*)	254	3.53	876	10.07
Smelt (*Osmerus mordax*)	221	3.07	35	0.40
Sand shrimp *(Crangon septemspinosa)*	189	2.63	140	1.61
Mysid (*Neomysis americana*)	123	1.71	269	3.09
American eel *(Anguilla rostrata)*	34	0.47	46	0.53
Grass shrimp *(Palaemonetes vulgaris)*	30	0.42	15	0.17
Atlantic tomcod *(Microgadus tomcod)*	15	0.21	136	1.56
Threespine stickleback (*Gasterosteus aculeatu*s)	14	0.19	33	0.38
Northern pipefish *(Syngnathus fuscus)*	12	0.17	1	0.01
Winter flounder *(Pseudoleuronectes americanus)*	12	0.17	5	0.06
Banded killifish (*Fundulus diaphanous*)	2	0.03	1	0.01
Cunner *(Tautogolabrus adspersus)*	1	0.01	0	0
Mummichog (*Fundulus heteroclitus)*	0	0	2	0.02
Jelly fish (*Phialidium sp.)*	0	0	190	2.18

6.3.1 Discussion: Temporal and Spatial Catch Per Unit Effort

The increase in capture rate of age-0 striped bass from June to July in the Shubenacadie estuary, followed by a decrease in CPUE through August and September confirms previous studies (Rulifson et al. 1987; Douglas et al. 2003; Bradford et al. 2012). Age-0 striped bass migrate out of the Shubenacadie River in late summer to feed in Cobequid Bay (Rulifson et al. 1987; Bradford et al. 2012). The Miramichi age-0 striped bass exhibit a similar pattern, with CPUE numbers decreasing substantially in August (Douglas et al. 2006).

The CPUE of age-0 striped bass of 12 in 2010 and 9 in 2011 were similar in comparison to previous years on the Shubenacadie River (Bradford et al. 2012). From 1999 to 2010 (excluding 2008) DFO performed seine netting at Highway 102 Shubenacadie (km 31.8) in August and September with a 25 m seine net. CPUE at the beginning of August was recorded as high as 516 striped bass in 2001 which seemed to be an exceptional year and as low as 2.5 striped bass in 2009. Similarly, in 2009 at the AGS very few age-0 striped bass were collected (Reeso 2012). Similar to this study, few age-0 striped bass were ever found in the Shubenacadie River in September (Bradford et al. 2012). Comparable age-0 striped bass yearly CPUE variation has been documented on the Miramichi River, fluctuating from 139 in 2003 to 3 per tow in 2004 (Douglas et al. 2006). Bradford et al. (2012) recorded the August 2010 CPUE at 18.5 striped bass, this seems high compared to the present study CPUE of 5 striped bass, however the net used by Bradford et al. (2012) was four times larger than my study's, making the results very comparable.

The variation in age-0 striped bass CPUE in the Shubenacadie River appears to be of independent of the number of spawning females or the number of eggs. In 2002, on the Shubenacadie River the number of reproductive adults was estimated at a minimum of 15,000 (Douglas et al. 2003), while a peak of 102 CPUE was found at Highway 102 Shubenacadie in August (Bradford et al. 2012). The 2010 and 2011 estimate for the number of spawning females was 8,000 and 14,000 respectively. However, the age-0 striped bass CPUE was much lower in 2010 and 2011 compared to 2002. On the

Miramichi River, the number of spawners was not related to the number of age-0 from 1993 to 2005. High numbers of spawners in 2002 and 2004 resulted in the lowest age-0 CPUE (Douglas et al. 2006). Environmental factors such as water temperature and rainfall occurring during the very early life stage of the striped bass are more influential in age-0 striped bass CPUE than the number of spawners or number of eggs. Similar findings in the US state that year class strength is primarily variable due to environmental factors during early life stages (Logan 1985; Martino and Houde 2010). Although CPUE is one indicator of a strong recruitment year perhaps more important is the age-0 striped bass end of season body length.

6.4 Results: Striped Bass Seasonal Somatic Growth

In both 2010 and 2011, age-0 striped bass showed little growth during June, with a mean total length from the end of May to the beginning of July of 6.5 mm (1.2 SE; Fig. 6.3). In 2010, all larvae caught in the plankton net from June 4 to June 21 were between 4 - 8 mm TL. On June 25, larvae 9 mm TL and over started to be collected in the plankton net. However, the mean daily TL did not exceed 7 mm until July 7, 41 days after peak larvae density. A week later, July 13 was the last day larvae were caught in plankton net tows, mean TL was 12.4 mm (0.27 SE). By late August 2010, mean TL was 75 mm (15.6 SD), reaching 110 mm (75 SD) TL by late September (Fig. 6.3). Their growth rate was 0.107 mm/day for May and June, increasing ten-fold to 1.26 mm/day for July, 1.15 mm/day for August and 1.28 mm/day for September.

In 2011, the mean striped bass total length did not exceed 7 mm until July 11, 30 days after peak larvae density. Larvae continued to be caught in the main channel by plankton net tows to July 29 when their mean length was 18.5 mm (0.74 SE). After that date no larvae were caught in the plankton net despite weekly use. Growth was much slower in 2011compared to 2010, TL reaching a mean of only 45 mm (8.5 SD) by late August (Fig. 6.3). Growth rate was 0.129 mm/day for May and June, increasing to 0.438 mm/day for July, and 0.649 mm/day for August. Body size of age-0 striped bass was much smaller in 2011 compared to 2010, likely associated with a warmer summer in 2010. Average water temperatures were 3 - 4 °C warmer from May to August in 2010 compared to 2011 (Table 6.3).

In both 2010 and 2011 striped bass larvae caught in the plankton net in the main channel were consistently smaller than those caught in the seine net in the shallows on the same day ($P < 0.01$; Table 6.4). In 2010 seine netting began on June 25. Larvae were first collected in the seine net July 2, and were 8 mm longer on average compared to larvae caught in the plankton net the same day. Similarly, on July 7 and 13, there was a 6 and 15 mm mean TL difference respectfully between larvae caught in the plankton net and those caught in the seine net. In 2011, seine netting began on June 16, with larvae first collected in the seine net on June 28, both plankton and seine netted larvae had a mean length of about 7 mm (TL). Starting on June 30 and continuing on July 4 and 28, a 2 to 5 mm daily mean length difference occurred between the larvae collected in the plankton net versus those collected in the seine net.

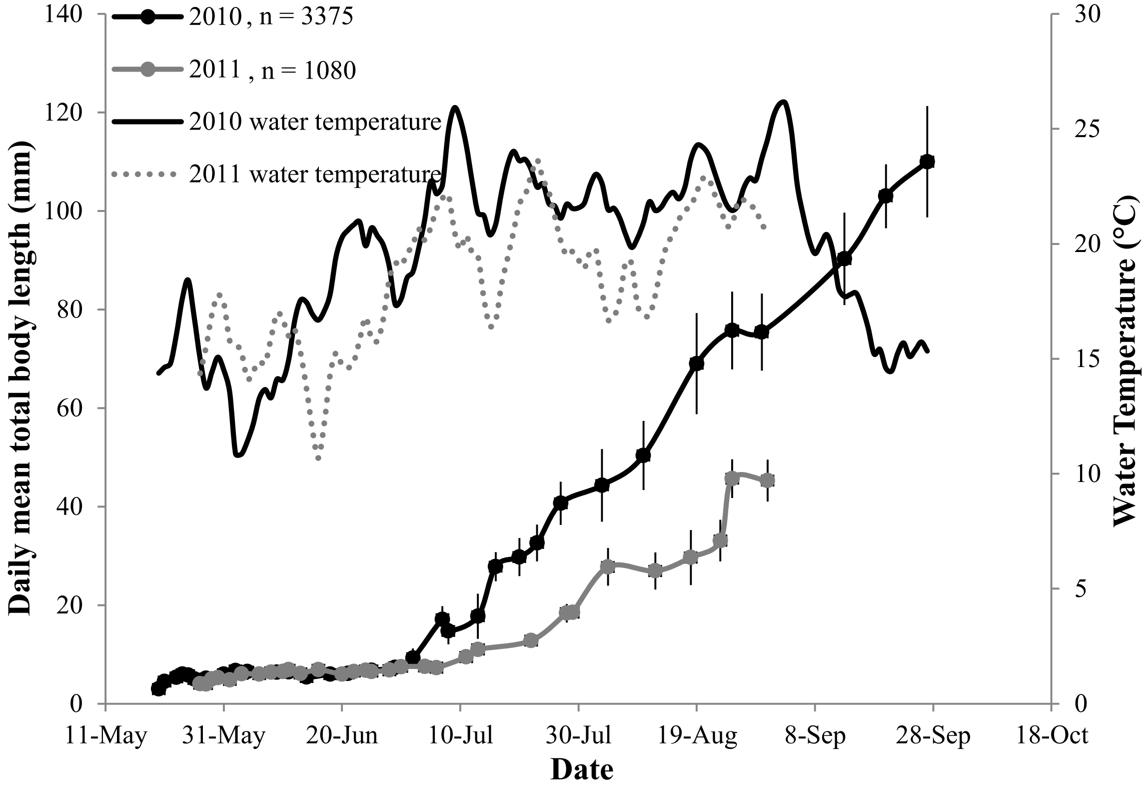


Figure 6.3: Mean total body length (+/- one standard deviation) from age-0 striped bass caught by both plankton and seine net on the Shubenacadie estuary from the end of May to end of September 2010 (n = 3375) and May to end of August 2011 (n = 1080). Daily mean water temperature (°C) from May 20 - Sep 27, 2010 and from May 27 - Aug 31, 2011.

Table 6.3: Average monthly water temperature (°C) from May to October at the Alton Gas Site in 2010 and 2011. * denotes missing data. Temperature was recorded by a data logger ~1 m from river bottom attached to a cinderblock.

	Average Water Temperature (°C)			
Month	2010	SE	2011	SE
May	14.6	0.341	10.6	0.411
June	16.6	0.593	13.7	0.472
July	22.2	0.309	18.8	0.347
Aug	22.2	0.213	18.6	0.314
Sept	18.6	0.648	*	*
Oct	14	0.719	*	*

Table 6.4: Comparison of total body length (mm) of 2010 and 2011 striped bass larvae caught either by plankton net (0.5 m diameter, 500 uM mesh) or beach seine (1 mm mesh) on the same date at the Alton Gas Site in July, 2010 and June and July, 2011.

Date	Plankton Net			Beach Seine			
	n	mean	SE	n	mean	SE	p-value
2-Jul-10	91	7.7	0.08	20	16.5	0.16	<0.01
7-Jul-10	213	16.3	0.07	72	20	0.14	<0.01
13-Jul-10	73	14	0.27	27	27.2	0.17	<0.01
28-Jun-11	46	6.6	0.09	29	7	0.09	<0.01
30-Jun-11	45	6.9	0.14	12	10	0.46	<0.01
4-Jul-11	69	7.1	1.10	7	12.3	0.75	<0.01
28-Jul-11	16	17	0.75	25	19.2	0.04	<0.01

6.4.1 Discussion: Striped Bass Seasonal Somatic Growth

In both years the mean total length of larvae caught from the end of May to July 1 was around 7 mm. This is the approximate size striped bass larvae develop functional mouth parts and start exogenous feeding (Dey 1981). I propose that the limiting food availability was the primary reason for slow growth. Temperature did not appear to be a limiting factor to the slow growth, as in both seasons the temperature fluctuated between 10 and 18 °C. Striped bass larvae cease to grow in length and weight once all yolk is absorbed (Roger and Westin 1981). However, in laboratory studies, following yolk absorption, striped bass larvae can survive for around one month without feeding (Eldridge et al. 1981; Rogers and Westin 1981). This possible lack of feeding is explored further in the following section.

Once larvae finally surpassed the 7 mm mark their growth progressed quickly. Due to the relatively short growing season Shubenacadie River striped bass are among the fastest growing striped bass on the eastern seaboard, under controlled laboratory conditions (Conover et al. 1997). Laboratory experiments have shown that striped bass require temperatures in excess of 10 °C for growth (Hurst and Conover 1998). Therefore, depending on the year these fish only have until October or November to complete their first year of growth. On the Hudson River, growth rates of striped bass larvae were significantly correlated to temperature; slow growth during May and June (0.2 mm/day) and rapid growth during July and August (0.8 mm/day; Dey 1981). These Hudson River growth rates are slightly lower than the Shubenacadie River striped bass growth rates in 2010 but slightly higher than in 2011. Age-0 striped bass in the Hudson River need to achieve an end-of-season body length of around 10 cm to survive over winter (Hurst and

Conover 1998). This 10 cm minimum size for survival has also been reported for striped bass of the southern Gulf of Saint Lawrence (Bernier 1996; Bradford and Chaput 1997). Since the Shubenacadie estuary is between the Hudson River and Gulf of Saint Lawrence longitudinally the pre-winter FL of 10 cm likely holds true. In 2010, the striped bass in the Shubenacadie estuary had until October 15 when the daily water temperature dropped below 10 °C. If age-0 striped bass had grown at a rate of 0.5 mm/day the mean total length of these striped bass would have been 11.3 cm. In 2011, no water temperature data were successfully retrieved in the fall, however even if water temperatures did remain over 10 °C until November and striped bass had grown at a rate of 0.5 mm/day they would have only achieved a mean body length of 7.6 cm by November 1. Consequently, over winter survival and recruitment from the 2011 year-class was probably very low. Based on end of year body size alone, over winter survival of the 2010 year-class was likely much higher than 2010. Bradford et al. (2012) have reported age-0 Shubenacadie River striped bass August and September fork length frequency from 1999 to 2010. In only three (1999, 2001 and 2002) of the ten years were more than 15 % of age-0 striped bass over 10 cm (FL) collected. 1999 was the only year that had a mean August and September fork length over 8 cm indicating this was a good recruitment year (Bradford et al. 2012).

Factors affecting growth are temperature, salinity and feeding. Age-0 striped bass have been reported to grow better at higher temperatures of 25 to 28 °C compared to lower temperatures of 16 to 20 °C (Harmon and Peterson 1994; Cook 2003; Duston et al. 2004). However, the optimal temperature for growth broadens as body size increases (Duston et al. 2004). In 2010, the Shubenacadie River water temperatures were much higher (3 – 4 °C) than 2011 and would have clearly been a contributing factor to the superior growth of striped bass. As for salinity, juvenile Shubenacadie River striped bass in the laboratory grew slightly better in fresh water compared to seawater (30 ppt; Duston et al. 2004). Cook (2003) found best growth between 0 – 13 ppt. Shubenacadie River salinity was much higher in 2010 compared to 2011. However, I suggest the difference in salinity between years did not appear to have an effect on growth.

As larvae grow, their swimming ability improves rapidly (Doyle et al. 1984; Peterson and Harmon 2001). Older larvae are better able to control their position in the water column. In Cheasapeake Bay, post-yolk-sac larvae were able to avoid the plankton net within 2 weeks of peak abundance and striped bass larvae began moving from the main channel to inshore shallows shortly after the absorption of their yolk (Kernehan et al. 1981). The extensive shallows associated with the sand bars on the Shubenacadie River clearly provide refuge through much of the ebb tide, as indicated by capturing larger larvae in the shallows using the beach seine. I propose that the difference in the size of larvae caught by each capture method is due to the difference in swimming ability. I suggest larvae < 7 mm TL lack the swimming ability to move out of the main channel. The sustainable swimming speed of 7 mm TL striped bass larvae is around 2 cm/sec, while at 9 mm it increases to around 3 cm/sec (Meng 1993). Also, larvae > 7 mm TL have the swimming ability to evade the plankton net. The migration of larvae from the main channel to the shallow margins, either actively or passively, is likely important to the retention of striped bass larvae in the estuary nursery habitat. The concept of the shallows being a microhabitat for early life stages of fish is well established. Shallows can have warmer water temperatures, which contribute to faster growth among age-0 fish (Baltz et al. 1993; King 2004).

6.5 Results: Striped Bass Stomach Contents

Stomach contents of 947 (2010) and 905 (2011) age-0 striped bass were examined from May to September, ranging in size from 3 to 126 mm TL. Larvae < 15 mm TL made up 65% (2010) and 76% (2011) of the stomachs examined. The percentage of fish with prey in their stomachs was related to body size. Among larvae between 5 and 10 mm TL, only 37 % (2010) and 34 % (2011) had food in their stomachs, compared to striped bass between 11 – 15 mm among which 81% (2010) and 73% (2011) had food in their stomachs. By contrast, among juveniles > 50 mm TL, nearly all (90 %) had food in their stomachs (Table 6.5 and 6.6). Among fish with food in their stomachs, the mean number of prey items per fish was higher in 2010 (18; SE 7.1) than in 2011 (5; SE 0.95), but not significantly different ($P > 0.05$). The number of prey items per fish increased with striped bass size up until 45 – 60 mm TL and then significantly decreased ($P < 0.05$), as the prey being consumed became larger species such as mysid, sand shrimp, and smaller striped bass and other age-0 fish (Table 6.5). Eighteen striped bass had other age-0 striped bass in their stomachs in 2010, no cannibalism was recorded in 2011.

Ten prey species were identified from the striped bass stomachs examined. Age-0 striped bass fed almost exclusively on the calanoid copepod (*Eurytemora affinis*) until they reached 45 - 60 mm TL. Other prey items included mysid (*Neomysis americana*), sand shrimp *(Crangon septemspinosa),* other larvae including gaspereau, shad and smaller striped bass, amphipoda (*Calliopinus sp*.), and cladocerans (*Daphnia sp*.; Table 6.5 and 6.6). Mysids began to enter the diet at 10 - 20 mm TL and accounted for nearly 20 % of total diet, but copepods remained the numerically dominant prey item. In 2010, age-0 striped bass had a much more diverse diet, which included five species not seen in 2011. In 2010, 56 striped bass (8 - 111 mm TL) had other fish species in their gut. By contrast piscivory was not recorded in 2011. Sand shrimp accounted for 8 % of the striped bass diet in 2010 but again was not seen in 2011.

Although not a prey item, the parasitic thorny headed worm (Phylum *Acanthocephala*) were found attached to 4% (2010) and 6.6% (2011) of striped bass guts. Only striped bass larger than 20 mm contained thorny headed worms, of striped bass with worms in their stomachs the average number was 1.9 (2010) and 2.5 (2011). The thorny headed worm species is likely *Echinorhynchus laurentianus,* a species often found in the stomachs of Bay of Fundy fish species but it has not been verified to date.

Table 6.5: Stomach contents of 947 age-0 striped bass collected from the Shubenacadie River from June to September 2010. Within each 5 mm size class, % N is the number of prey items expressed as a percentage of the total number of prey items found in all fish.

				% N					
Total length (mm)	Number dissected	Percent with prey	Mean prey per striped bass	Copepods	Mysids	Amphipoda	Shrimp	Fish	Digested food
5 - 10	567	37	3	92	1	0	0	2	5
11 - 15	47	81	3	72	11	1	0	10	6
16 - 20	31	81	9	87	5	1	0	4	3
21 - 25	42	71	8	72	16	7	0	1	3
26 - 30	44	75	8	76	10	11	0	0	3
31 - 35	41	44	15	83	12	3	0	0	2
36 - 40	29	59	14	83	12	2	0	0	2
41 - 45	27	63	10	54	43	2	0	0	1
46 - 50	22	73	26	87	7	0	4	0	2
51 - 55	9	89	8	0	57	33	6	3	1
56 - 60	17	94	27	69	28	0	1	1	1
61 - 65	15	93	67	94	5	0	0	0	1
66 - 70	12	100	19	36	58	1	3	1	1
71 - 75	6	100	6	0	51	23	17	2	8
76 - 80	3	100	4	0	33	11	56	0	0
81 - 85	5	100	12	65	26	0	2	1	6
86 - 90	8	88	36	95	4	0	1	0	1
91 - 95	10	100	6	0	52	20	19	3	6
96 - 100	2	100	10	40	0	15	3	40	3
101 - 105	4	75	4	0	42	0	0	33	25
106 - 110	2	50	1	0	0	0	0	0	100
111 - 120	3	67	1	0	0	0	20	40	40
121 - 130	1	100	1	0	0	0	50	0	50

Table 6.6: Stomach contents of 905 age-0 striped bass collected from the Shubenacadie River from June to August 2011. Of striped bass with prey in their gut, % N is the number of prey items expressed as a percentage of the total number of prey items found in all fish of each size class.

				% N			
Total length (mm)	Number dissected	Percent with prey	Mean prey per striped bass	Copepods	Mysids	Amphipoda	Digested Food
5 - 10	585	34	2	82	1	0	18
11 - 15	98	73	4	100	0	0	0
16 - 20	55	47	4	76	17	4	3
21 - 25	43	77	5	76	9	9	6
26 - 30	33	67	8	69	6	19	6
31 - 35	38	84	15	80	7	12	1
36 - 40	14	86	6	54	33	10	3
41 - 45	12	100	32	92	5	3	0
46 - 50	14	86	4	32	54	6	8
51 - 55	7	86	4	0	76	6	18
56 - 70	6	67	1	0	0	25	75

6.5.1 Discussion: Striped Bass Stomach Contents

Age-0 striped bass are non-selective, opportunistic feeders (Boynton et al. 1981). Stomach contents of age-0 striped bass in the US included mysids, amphipods, polychaetes, insects and fish larvae (Boynton et al. 1981). In the present study the relationship between larvae with prey in their guts and the number of prey per gut were related to body size. This was similar to laboratory trials on Shubenacadie River striped bass larvae where prey capture rate significantly increased with larvae age (Duston and Astatkie 2012). On the Shubenacadie River, larvae had a diet dominated by copepods but showed a size related shift to larger prey. The shift in prey size and types of prey consumed was consistent with that observed with age-0 striped bass on the Miramichi River (Robichaud-LeBlanc et al. 1997). Copepods were the dominant prey item among striped bass < 25 mm on the Shubenacadie estuary and the Miramichi. The feeding habits of striped bass are strongly influenced by prey size. As larvae and juveniles grew they consumed a larger diversity of prey due to an increased mouth gape. On the Shubenacadie River, striped bass fed more successfully and had a more diverse diet in 2010 likely because they achieved a larger size than the 2011 fish. In 2010, sand shrimp and fish prey only dominated the diets of striped bass over 50 mm TL, while in 2011 very few striped bass over 50 mm were caught. Fish are of higher caloric value than invertebrates as prey. Thus, the sooner a fish can transition to piscivory the better the growth (Hartman and Margraf 1992). Piscivory in 2010 may have partially contributed to the increased 2010 growth. Cannibalism among striped bass in the late larvae and early juvenile stage is common in cultured tanks (Pallera and Lewis 1987) but rare in the wild (Manooch 1973). Perhaps the high densities of age-0 striped bass in 2010 were a contributing factor to the cannibalism.

The striped bass first feeding stage can be extremely difficult and is often associated with high mortality because they fail to catch sufficient prey (Rutherford et al. 1997). In the Chesapeake Bay, in strong recruitment years, up to 91% of first feeding striped bass (7 - 10 mm) have food in their stomachs, while in poor recruitment years only 35 % of first feeding larvae successfully feed (Martino and Houde 2010). If the same holds true for the Shubenacadie River striped bass, the 34 – 37 % feeding success rate observed in 2010 and 2011 of 5 – 10 mm larvae may account for low numbers of juveniles caught later in the summer. However, among those 5 – 10 mm larvae who fed in the Chesapeake Bay study, their guts contained on average 1.4 prey per larvae (Martino and Houde

2010), lower than the 3.1 and 1.6 average prey per larva in 2010 and 2011 in the Shubenacadie estuary.

Starvation at the larvae stage has been hypothesized as a key cause of striped bass mortality (Rulifson 1984; Rulifson and Stanley 1985; Rulifson et al. 1986). Starvation can cause a halt in growth and development as early as 5.5 days post hatch when larvae are only 5 mm TL (Rulifson et al. 1986). In laboratory studies, following yolk absorption, striped bass larvae can survive for several weeks without feeding (Eldridge et al. 1981; Rogers and Westin 1981). Unfed larvae can survive longer, 32 days at a lower temperature of 15 °C than at higher temperature, 22 days at 24 °C (Rogers and Westin 1981). This ability to survive without food may explain the long period (30 plus days) when larvae caught were 6 - 7 mm TL. To determine the age of the 6 - 7 mm larvae would require the daily growth rings of their otoliths be counted (Douglas 1995). Food limitation in US estuaries has been associated with starvation of larvae, increased vulnerability to predation and over winter mortality due to poor growth (Hunter 1981; Rulifson et al. 1986; Hurst and Conover 1998). Prey density is a deciding factor between age-0 starvation or success, with higher prey concentrations leading to enhanced encounter chances between the larvae and their prey (Martino and Houde 2010). In the laboratory, Shubenacadie River striped bass feeding success significantly increased with increased prey density (Duston and Astatkie 2012).

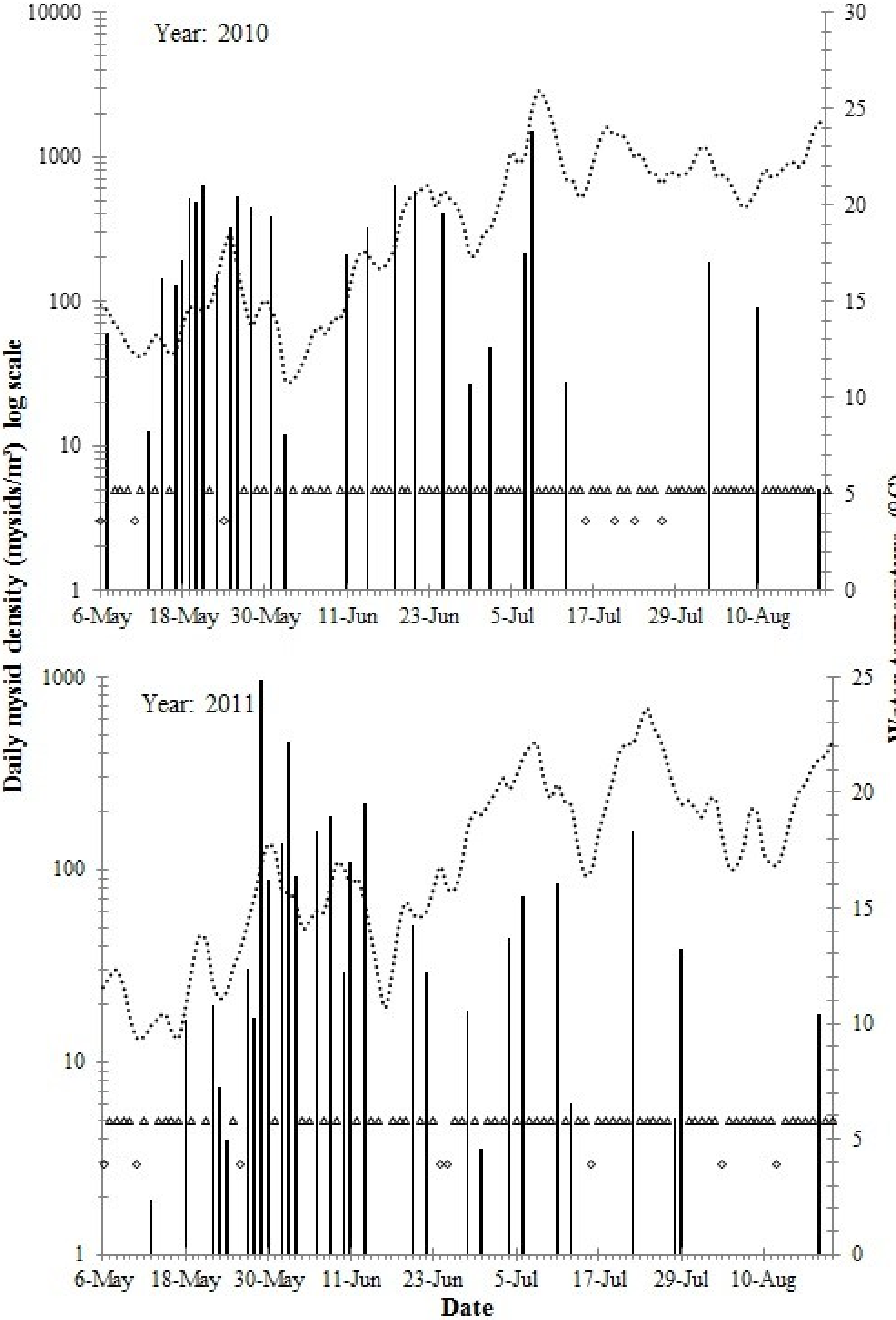
6.6 Results: Striped Bass Prey Density

In both 2010 and 2011 the most common macroinvertebrate prey item in the 500 μm plankton net were mysids, present in 77.7 % (2010) and 56.4% (2011) of tows. Daily mean density of mysids was nearly twice as high in 2010 ($143/m^3$; SE 10.8) compared to

2011 (89.5/m³; SE 11). Density from a single plankton net tow peaked July 8, 2010 at 1220/m^3 water filtered when salinity was 13.6 ppt and June 11, 2011 at 1600/m^3 water filtered when salinity was 16.4 ppt. Three developmental stages of mysid were recorded over the season, adults > 5 mm, pregnant females > 5 mm and juveniles < 5 mm. Of the mysids caught and counted, 44% (2010) and 48.4% (2011) were pregnant females, 34% (2010) and 0.18% (2011) were adults and 22% (2010) and 51.5% (2011) were juveniles. Seasonally there were no apparent trends in daily average mysid ebb tide density in 2010 or 2011 (Fig. 6.4). Daily average mysid ebb tide density was over 100 mysid/m³ most days in 2010. In 2011, by comparison daily average mysid ebb tide density was only over 100 mysid/m³ from May 29 to June 13. Thereafter, density was generally lower. In 2010 the average salinity while taking plankton net tows was 8.5 ppt, while it was only 3.8 ppt in 2011. In 2010 ebb tide mysid density (n = 390) was slightly higher in samples taken from 4 – 20 ppt than those taken at lower or higher salinities. In 2011 ebb tide mysid density (n = 358) was higher in samples taken from 12 – 14 ppt and 16 – 18 ppt than those taken at lower or higher salinities (Fig. 6.5).

Other prey items that were enumerated were amphipoda (*Calliopinus sp.*), the calanoid copepod *Eurytemora affinis*, and cladocerans (*Daphnia sp.*). In both 2010 and 2011 amphipods were found in 31% of plankton net tows and ranged in density from < 1/m^3 to 86.3/m^3. Of the tows containing amphipods the mean density was 6.27/m^3 (0.847 SE) and mean body size was 2 (0.44 SE) mm. Copepods were found in 29% (2011) of the plankton net tows and ranged in density from < 1/m^3 to 240/m^3, with a mean body size of 0.48 mm (0.01 SE). Of tows containing copepods the mean density was 40/m^3 (12.7 SE). The 500 µm plankton net was used to collect the majority of the samples, with the exception of three days in June (3, 10 and 13) and one in August when the 250 µm plankton net was used. There was no increase in copepod density when the 250 µm plankton net was used. Copepods were only quantified once in 2010 on August 19 when samples taken with the 250 µm plankton net in three samples detected huge numbers at the AGS. The first sample contained 101,642 copepods/m^3, the second 73,648 copepods/m^{3}and the third 65,252 copepods/m^3. Cladocerans were found in 8.2 % (2010) and 4.3 % (2011) of the plankton net tows and ranged in density from < 1/m^3 to 26/m^3 in 2011. Of tows containing cladocerans the mean density was 3.8/m^3 (1.40 SE). Leeches were found in 9.5% (2010) and 8.2% (2011) of plankton net tows and ranged in density from < 1/m^3 to 21.3/m^3 in 2011. Of tows containing leeches the mean density was 1.8/m^3 (0.626 SE). Sand shrimp were found in 5.4 % of tows in 2010 but were only found in one tow in 2011. Smelt were also enumerated because they were found in 6.1 % (2010) and 13.2 % (2011) of the plankton net tows and ranged in density from < 1/m^3 to 111/m^3. Of tows containing smelt the mean density was 3.8/m^3 (2.01 SE; Table 6.7).

Figure 6.4: Summary of ebb tide daily mean mysid density (bars; sum of ebb tide mysid density per total m^3 water filtered) on a log scale at the Alton Gas Site on the Shubenacadie River in relation to mean daily water temperature (dotted line) for both 2010 (top panel) and 2011 (bottom panel). Open diamonds indicate days when sampling was conducted but mysids were not detected, open triangles indicate days when no sampling occurred. Note the difference in scale between years.



Year: 2010
Year: 2011
Daily mysid density (mysids/m³) log scale
Water temperature (°C)
Date
10000
1000
100
10
1
30
25
20
15
10
5
0
6-May
18-May
30-May
11-Jun
23-Jun
5-Jul
17-Jul
29-Jul
10-Aug

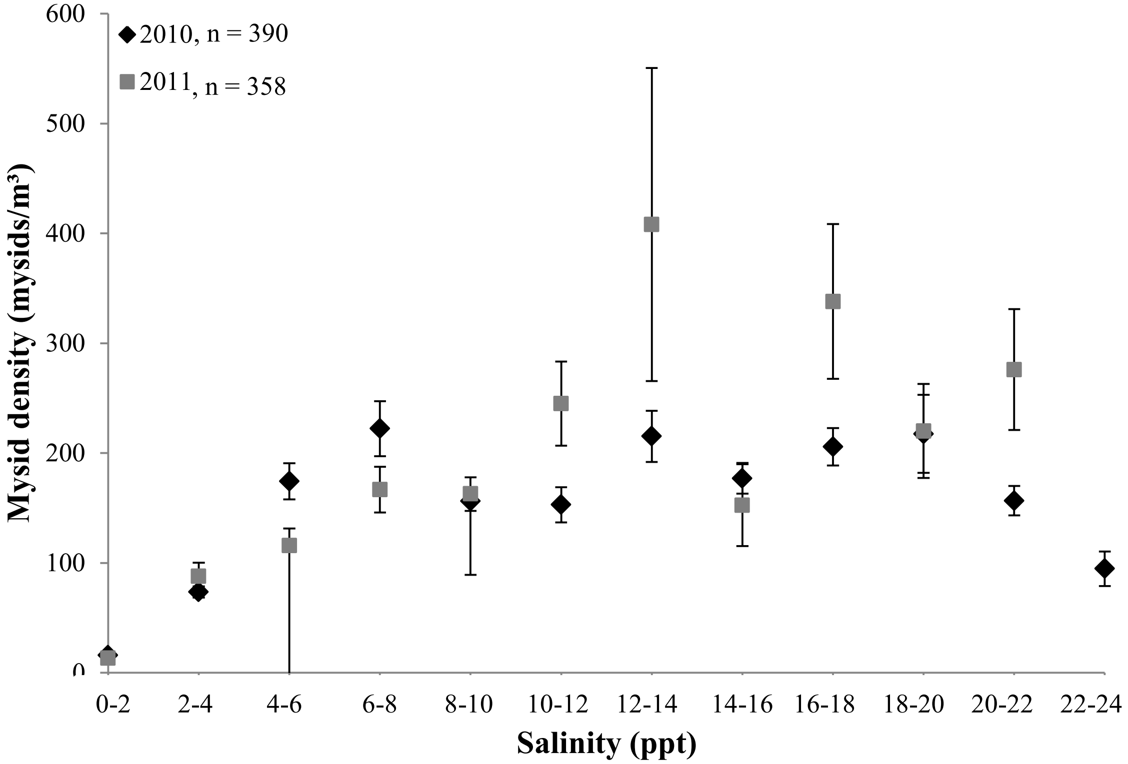


Figure 6.5: Mean ebb tide mysid density (mysid/m^3) over twelve salinity ranges from 0 to 24 ppt with standard error bars in 2010 and 2011. From May 7 to August 19, 2010 and May 13 to August 18, 2011.

Table 6.7: Six prey species recorded in plankton net tows from May to September 2010 and 2011. These species were recorded as present or absent in 2010 and enumerated in 2011. The percentage of tows each species was present in during 2010 and 2011, and the density range, mean density and standard error of the mean for plankton net tows taken in 2011.

	2010	2011	2011		
Prey	% of tows present	% of tows present	Density range (#/m^3)	Mean density (#/m^3)	SE of mean
Amphipoda (*Calliopinus sp.*)	31	31	<1 - 86.3	6.27	0.847
Calanoid copepods (*Eurytemora affinis*)	5.29	29	<1 - 240	40	12.7
Cladocerans (*Daphnia sp.*)	8.18	4.32	<1 - 26	3.83	1.4
Leech *(sp.*)	9.46	8.17	<1 - 21.3	1.83	0.626
Smelt (*Osmerus mordax*)	6.14	13.2	<1 - 111	3.79	2.01
Sand shrimp *(Crangon septemspinosa)*	5.37	<1	*	*	*

6.6.1 Discussion: Striped Bass Prey Density

Prey density was not the main focus of the thesis but was included as a supplement to add further insight on factors affecting survival and recruitment of age-0 striped bass. With limited swimming ability first feeding striped bass rely on an abundance of prey items to be within their reactive distance of < 1 body length. Estimates of minimum prey levels for striped bass larvae survival are variable; 50,000 to 100,000 prey m^3 was estimated from laboratory studies (Eldridge et al. 1981; Chesney 1989; Tsai 1991). However, the prey density requirements of wild striped bass may be considerably less than for bass reared in the laboratory (Bochdansky et al. 2008). In the Chesapeake Bay, zooplankton prey in the ETM have exceeded 250,000 prey m^3 in the best striped bass recruitment years and have been as low as 2000 prey m^3 in lower recruitment years (Martino and Houde 2010). Growth rates of larvae correlated with food concentrations in the laboratory, below 0.10 nauplii copepods/ml larvae decreased in size and growth rates were negative (Eldridge et al. 1981). Among Miramichi striped bass, the transition from endogenous to exogenous food sources correlates with peak abundance in prey, with an average of 130,000 copepod nauplii/m^3 prey density (Robichaud-LeBlanc et al. 1997). I hypothesize one of the reasons for poor growth of Shubenacadie River striped bass in May and June of 2010 and 2011 was a mismatch between the timing of peak prey abundance and larvae first feeding. Even when the 250 µm plankton net was used in June of 2011 very low numbers of copepods were detected. Copepod density on the Shubenacadie River in May and June may be a limiting factor to first feeding larvae growth and survival and warrants further investigation.

Prey items over 0.5 mm were accurately sampled. Mysids were the most abundant prey item found. Mysids are important prey for age-0 fish along the east coast of North America including the Cumberland Basin, in the inner Bay of Fundy (Maurer and Wigley 1982; Zagursky and Feller 1985; Prouse 1986). Mysids in the Cumberland Basin, in the inner Bay of Fundy, averaged 10/m^3 (Prouse 1986). Daily mean mysid density was nearly twice as high in 2010 compared to 2011, likely associated with the salinity difference between years. Mysids on the Shubenacadie River have been reported to be associated with higher salinities (Reesor 2012).

Prey density may be even more important to feeding success among fish larvae in the murky turbid Shubencacadie River than other striped bass nursery estuaries. The Shubenacadie River has no light penetration below 1.5 m, and non-visual feeding may be important for age-0 striped bass (Duston and Astatkie 2012). In laboratory studies, Shubenacadie River striped bass were four-times more successful at visual feeding than non-visual feeding at "low" prey density (50,000 prey/m^3). However, non-visual feeding success increased in comparison to visual feeding success with increasing prey density, until it was on par at 800,000 prey/m^3 (Duston and Astatkie 2012). Future research focusing on seasonal striped bass prey density in the Shubenacadie River and Cobequid Bay would contribute to defining the nursery habitat seasonally and would possibly further explain age-0 striped bass spatial distribution. There are two prominent schools of thought regarding the survival of pelagic larvae, the first being the match/mismatch hypothesis (Cushing 1990), regarding the seasonal timing of peak prey density coinciding with the first feeding larvae stage. The other is the density independent hypothesis, where factors such as weather and climate, exert their influences on population size regardless of the population’s density. Both schools of thought appear to be true on the Shubenacadie River, with survival of pelagic striped bass larvae a complex mixture of the two.

Chapter 7. General Discussion

7.1 Summary and Recommendations for Future Research

The high abundance of eggs in the Shubenacadie estuary indicates the adult population is healthy, but survival of early life stages is relatively low and greatly affected by fluctuations in temperature and freshwater run-off. Water temperatures through June to September seemed to play an important role in age-0 growth and thus presumably overwinter survival. I was fortunate enough to study two contrasting years in terms of temperature and rainfall, which demonstrated their importance in terms of striped bass eggs and age-0 growth and spatial distribution. Year class strength was affected by inter-annual variation in environmental factors. The long length of the Shubenacadie estuary and the high-energy tidal cycle dictates the distribution and retention of early life stage striped bass. Presented here is the first evidence that striped bass eggs and larvae can be transported upstream on the flood tide after downstream transportation on the ebb tide and can be advected out of the Shubenacadie estuary and into the Cobequid Bay. However, it remains unclear whether early life stages are negatively affected by advection or whether the nursery habitat can extend into the Cobequid Bay. The considerable inter-annual variation in environmental factors and age-0 abundance of striped bass justifies the need for long-term monitoring to gain an understanding of the factors affecting recruitment and population dynamics of this important species. Even in the highly studied Chesapeake Bay, the environmental factors that support good striped bass recruitment remain poorly understood (Martino and Houde 2010). Presently environmental factors are not included in management planning for striped bass. However, DFO is moving towards an ecosystem based approach to fisheries management, which means identifying and understanding the key ecosystem relationships (DFO 2011). Hence, understanding how variation in environmental factors affects recruitment could contribute to successful striped bass management.

The mechanisms dictating the temporal position of eggs and larvae, early or late in the ebb tide at the AGS, following spawning are the timing and location of the release of eggs by the female broodstock, and water velocity, which is influenced by tide and freshwater run-off. Understanding these mechanisms is important for Alton Natural Gas Storage LP, as this information will help them select how, when or whether to run their pumping equipment during striped bass spawning season.

It was my hope that the time spent describing the hydrology and timing of the tides in chapter two will aid in planning and safely executing future research on the dynamic Shubenacadie and Stewiacke estuary. There remains many unanswered questions about eggs and age-0 striped bass on the Shubenacadie River. Many of these questions have been highlighted in the discussions of previous chapters. In my perspective one of the most intriguing questions would be to determine where Shubenacadie River striped bass spawn in relation to the salt front so that the full extent of the spawning habitat is defined and can be appropriately conserved. The most interesting question remains whether the nursery habitat extends into the Cobequid Bay, and whether time spent in the Cobequid Bay during early life stages negatively effects survival. The ultimate goal is to use the knowledge gained here to help in the recovery of the Annapolis and Saint John Rivers striped bass populations.

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