Population Characteristics of Striped Bass Killed by Cold Shock during Winter Shutdown of a Power Plant in Nova Scotia

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Abstract - Overwintering *Morone saxatilis* (Striped Bass) often aggregate in waters heated by the warm-water discharge of power plants. In these areas, fishes are susceptible to cold shock during winter disruptions of power generation when the water quickly drops in temperature. We collected 98 Striped Bass from a suspected cold-shock mortality event at a power plant in Pictou Harbour, NS, Canada, in January 2013 and herein describe their size, age structure, and diet. The specimens ranged from 11.8 to 60.2 cm TL and were 1–5 years of age. Fifteen percent of their stomachs contained food, and Striped Bass and *Apeltes quadracus* (Fourspine Stickleback) were the only prey species identified. The goal of this study was to report on the mortality event as a likely recurring source of overwintering mortality for Striped Bass in the southern Gulf of St. Lawrence, a population designated by the Committee on the Status of Endangered Wildlife in Canada to be of special concern.

Introduction

Industrial thermal power-generating stations (PGSs) draw cooling water from adjacent rivers, estuaries, or the ocean, and release it back into the environment as heated wastewater. Fishes and other aquatic organisms aggregate in the artificial habitat created by altered current structures and thermal regimes around the cooling-water intakes and warm-water outflows of these PGSs (Stauffer and Edinger 1980) and are susceptible to mortality through routine station operation. Mortality occurs through impingement on intake screens, entrainment within the plant (Foster and Wheaton 1981, Kelso and Milburn 1979, Lewis and Seegert 2000), and thermal stress associated with temperature variability at the warm-water outflows (Ash et al. 1974, Donaldson et al. 2008).

The thermal plume created by the heated wastewater disrupts natural seasonal distribution and behavior of fishes (Stauffer et al. 1976, Williams and Waldman 2010) and affects normal physiological processes (Donaldson et al. 2008, Schreer and Cooke 2002) as fishes continue to feed and grow during the winter months (Massengill 1973). Fishes overwintering in warm-water outflow canals are susceptible to predation and angling pressure (Marcy and Galvin 1973, Williams and Waldman 2010), however, winter shutdowns of PGSs result in the loss of the artificial thermal habitat and may cause cold-shock mass-mortality events (Ash

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et al.1974, Coutant 1977). The number of fishes affected by these mass-mortality events is often difficult to quantify (Labay and Buzan 1999, Ryon et al. 2000), with impacts on local populations not well known but of concern to fisheries managers (Douglas et al. 2006).

Morone saxatilis (Walbaum) (Striped Bass) is an economically important anadromous fish (Richards and Rago 1999) that utilizes habitat influenced by thermal effluent throughout its range (Marcy and Galvin 1973, Setzler et al. 1980) including areas in the southern Gulf of St. Lawrence (sGSL), Canada (Rulifson and Dadswell 1995). Disruptions of power generation have been identified as an unpredictable and recurring source of overwintering mortality for sGSL Striped Bass (Douglas et al. 2006). Episodic mass-mortality events in the sGSL are of particular importance for fisheries managers; the stock has been the subject of multiple assessments by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and is designated as special concern (COSEWIC 2012).

Striped Bass in the sGSL occupy freshwater tributaries, estuaries, and marine waters from Percé, QC, to western Cape Breton, NS (Rulifson and Dadswell 1995, Scott and Scott 1988), with the only known spawning population occurring within the Miramichi River, NB (Robichaud-LeBlanc et al. 1996). After spring spawning, adults migrate downriver to the Miramichi River estuary, then to coastal waters and non-natal estuaries throughout the sGSL for summer foraging (Bradford et al. 1998, Douglas et al. 2009). Age-0 Striped Bass exhibit downward estuary dispersal throughout the summer and are found in adjacent non-natal estuaries by late summer (Robichaud-LeBlanc et al. 1998, Robinson et al. 2004).

Striped Bass overwinter in estuaries and rivers (Bradford et al. 1998, Douglas et al. 2003, Hogans and Melvin 1984) throughout the sGSL, resulting in the reduction of stress from osmoregulatory demand compounded by potentially lethal marine temperatures (Cook et al. 2006, Hurst and Conover 2002). Overwintering sites have been documented in many NB rivers and as far east in the sGSL as East River Pictou, NS (Douglas and Chaput 2011, Rulifson and Dadswell 1995). Within Pictou Harbour, Striped Bass utilize the warm-water outflow of the Trenton PGS (Fig. 1), where winter shut downs have been associated with mass-mortality events (Douglas et al. 2006).

The frequency, age classes, and quantity of fishes affected by these winter mortality events have not been previously documented (Douglas et al. 2006). In this study, we collected Striped Bass from a winter mass-mortality event in Pictou Harbour near the discharge of the Trenton PGS in January 2013. The objectives of this study were to describe the mortality event and assess the biological characteristics and diet of specimens collected. This information contributes to an understanding of the components of overwintering mortality of Striped Bass in the sGSL.

Methods

Study site

The Trenton facility is a 2-turbine (units 5 and 6), coal-fired PGS situated on Pictou Harbour at the mouth of the East River, NS (Fig. 1). Cooling water is drawn from the estuary of the East River, and heated wastewater from the thermal power-generating process is discharged into Pictou Harbour. The maximum daily water temperature of the warm-water discharge was recorded by power-plant personnel (C. Beanish, Nova Scotia Department of Environment, North Glasgow, NS, Canada, pers. comm.); however, ambient temperatures outside the thermal plume were not available. Winter discharge temperatures during 2014–2015 exceeded 19 ºC above ambient (mean ±SD = 12.2 ± 4.3 ºC; C.F. Buhariwalda unpubl. data).

Specimen collection

The Nova Scotia Department of Fisheries and Aquaculture (NSDFA), Inland Fisheries Division was notified of a mortality event in Pictou Harbour on 14 January 2013. We opportunistically collected dead Striped Bass from the shore of southeast Pictou Harbour adjacent to the mouth of the East River, ~700 m from the

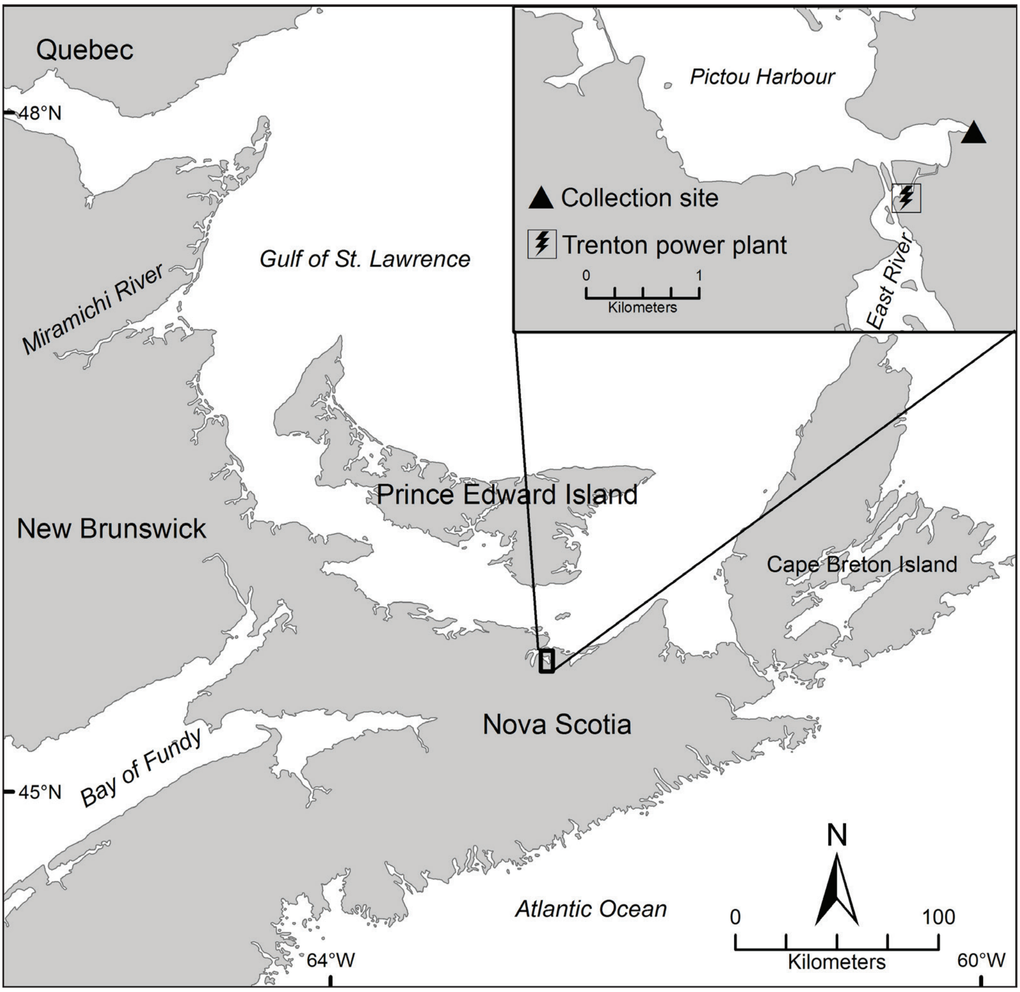

Figure 1. The southern Gulf of St. Lawrence and Pictou Harbour (inset) indicating the location of the Trenton Power Plant and collection site of Striped Bass mortalities on 14 January 2013.

Trenton PGS (Fig. 1). Striped Bass were typically located under ice in the intertidal zone and in water depths up to 0.5 m deep; we observed scavengers taking easily accessible fish. We sent frozen specimens to the Coastal Ecology Lab at Acadia University. We thawed the fish, assigned a unique ID to each one, and recorded their weight (W) and total length (TL). We used scales and otoliths to determine fish age and examined the stomachs to identify and count the contents.

Aging. Prior to examination under a dissecting microscope (40x magnification), we cleaned scale samples in 70% ethanol and mounted them between microscope slides and dried the collected otoliths. We counted annuli on both scales and otoliths to determine age. We collected Striped Bass specimens after 01 January; thus, we assumed that all scales had formed an annulus at the margin (DeVries and Frie 1996) and we added 1 y to the annulus count on each scale. Specimens that we classified as age-1 specimens were 2012 age-0 fish that were likely in Pictou Harbour sometime before winter. C.F. Buhariwalla, M. Gregoire , and M.J. Dadswell aged scales and otoliths. When there were disagreements in age assignment, the readers examined the specimens together and reached a consensus; no ages were unresolved.

Weight–length. We determined weight–length relationships using the methods of Ricker (1975) and the Fisheries Stock Assessment (FSA) package (Ogle 2014), and evaluated them using the following equation:

$$\log(W) = \log(a) + [b \times \log(TL)]$$

We performed the geometric mean functional regression (GMR; Ricker 1975) using the log-transformed length (TL) and weight (W) to determine the slope (b) and intercept (a) of the regression line. We did not weigh Striped Bass with missing gut regions (n = 11) resulting from decomposition and/or predation, and we excluded these specimens from the weight analysis.

We employed R-statistical software (R Core Team 2013) and ggplot2 package (Wickham 2009) to conduct analyses and create plots of morphometrics and age data. We determined the uncorrected standard deviation, $\sigma = (\sum[X - \mu]^2/N)^{1/2}$,where σ = the population standard deviation, X = observed value, μ = the population mean, and N = the number of specimens used in the calculation.

Stomach contents. We dissected stomachs containing food, and identified and counted prey items based on external morphology and otoliths (Bowen 1996, Campana 2004). We counted partial skeletons and various hard parts (e.g., cleithra) and classified them as unknown. We followed the methods of Bowen (1996) to calculate frequency of occurrence and percent composition by number of prey.

Results

Unit 5 was shut down from 04–08 January 2013, and Unit 6 was shut down from 30 December 2012 to 06 January 2013 for unscheduled maintenance at the power plant. Maximum daily water temperature recorded at the warm-water discharge before the fish kill was 12.8 ºC on 01 January, but declined to -2.5 ºC during the cold-shock event after January 04 (Table 1).

Sampled mortalities of Striped Bass (n = 98) ranged in size from 11.8 cm to 60.2 cm TL (Table 2), and ages ranged from 1 to 5 years; no individuals of the age-4 year class were present in the sample. The number of specimens sampled decreased with increasing age (Table 2). The Striped Bass that we weighed (n = 87) ranged from 0.013 kg to 1.089 kg (Table 2). The weight–length GMR, using units of kg and mm TL, revealed a strong relationship (R^2 = 0.99) with an intercept (a) of -9.02 and a slope (b) of 3.44 (3.09–3.77 at 95% CL).

We excluded partially decomposed Striped Bass (n = 11) from diet analysis; of the remaining stomachs, 16% contained food (Table 2). The proportion of stomachs containing food increased with increased age, ranging from 7% at age-1 to 57% at age 3. Striped Bass occurred most frequently in stomachs (Table 3) followed by the only other identifiable prey, *Apeltes quadracus* (Mitchill) (Fourspine Stickleback). We found unknown prey (spines and other hard parts) in 21% of the stomachs. Fourspine Stickleback had the highest percent composition by number, followed by

Table 1. Maximum daily water temperature at cooling-water outflow of Trenton power plant for 14 days in January 2013. * indicates days the generating units were offline.

	Temperature (°C)	
Date	Unit 5	Unit 6
01 January	12.8	12.1*
02 January	12.7	11.7*
03 January	11.8	9.2*
04 January	8.1*	12.4*
05 January	-2.4*	-0.3*
06 January	-2.5*	12.6*
07 January	1.9*	16.6
08 January	3.7*	16.4
09 January	10.0	17.7
10 January	10.9	16.0
11 January	12.4	17.9
12 January	12.5	17.9
13 January	11.8	18.1
14 January	10.2	17.1

Table 2. Summary of age, length, weight, and stomach contents of Striped Bass collected from the shore of Pictou Harbour on 14 January 2013. Striped Bass exhibiting signs of predation or decomposition were excluded from weight analysis, and those missing stomachs were excluded from diet analysis.

	Total length (cm)			Weight (kg)			No. of stomachs	
Age	Sample size	Range	Mean ± SD	Sample size	Range	Mean ± SD	Examined	With prey
1	63	11.8–19.6	14.9 ± 1.7	57	0.013–0.078	0.027 ± 0.013	59	4
2	25	21.3–37.4	33.4 ± 3.1	23	0.340–0.662	0.448 ± 0.088	23	6
3	9	40.5–46.1	42.8 ± 1.8	7	0.762–1.089	0.929 ± 0.101	7	4
5	1	60.2	-	-	-	-	-	-
Total	98	11.8–60.2	22.7 ± 11.1	87	0.013-1.089	0.222 ± 0.295	89	14

Striped Bass, and unidentifiable prey items. Fourspine Stickleback occurred in all but 1 age-1 Striped Bass containing prey, while all but 1 of the age-2 and all age-3 specimens had fed on conspecific age-1 juveniles.

Discussion

Striped Bass mortalities caused by fluctuations in the thermal discharge from power plants are seldom documented. The January 2013 mortality event in Pictou Harbour was reported to the NSDFA on 14 January, but likely occurred on 05 January after daily maximum water temperature in the power-plant discharge dropped over 12 ºC to sub-zero temperatures. The rapid cooling event likely induced a cold-shock response and eventual mortality (Coutant 1977, Van den Burg et al. 2005) similar to other unevaluated winter mass-mortality events at this site (Douglas et al. 2006).

The effect of mass-mortality events on fish populations varies according to local distribution (Kennedy et al. 2012), species' natural history (Nagdali and Gupta 2002), and life stage (Ward et al. 2001). Cold-shock mortality events involving Striped Bass disproportionally affected younger year classes because increased body size buffers against the effects of cold shock (Donaldson et al. 2008), and survival during water-temperature fluctuations is dependent on the acclimation temperature, magnitude, rate of change, and salinities encountered (Beitinger et al. 2000, Cincotta et al. 1984, Cook et al. 2006). Euryhaline fishes under isotonic conditions typically exhibit greater upper and lower thermal tolerances than those in fresh water or more highly saline waters (Stauffer 1986, Stauffer et al. 1984). Laboratory age-0 Striped Bass acclimated to 5.0 ºC under estuarine conditions (5–30 ‰) were able to survive a gradual decrease of 2.3 $°C \cdot day^{-1}$ to temperatures <0 ºC (Hurst and Conover 2002); however, the lower incipient lethal temperature is 2.4 ºC for juveniles acclimated at 15.0 ºC in fresh water (Cook et al. 2006). These findings support cold shock as the cause of the mass-mortality event at the Trenton Power Plant because water temperatures declined >12 ºC to below 0 ºC in less than 24 h. The relative absence of age-3+ and older specimens may be a result of an ontogenetic shift to cooler thermal preferences (Hartman and Brandt 1995, Nelson et al. 2010), differential susceptibility to cold-shock, or age-dependent differential habitat use.

Adult Striped Bass utilize a broad thermal range (6.5 to 28.0 ºC) during summer foraging, demonstrating an ability to move between greatly different water

Table 3. Composition of stomach contents of Striped Bass containing prey (*n* = 89) collected on the shore of Pictou Harbour, 14 January 2013. %N = percent composition by number, *n* = total number of prey items counted, %FO = percent frequency of occurrence, and * = not determined.

	Total		Age-1		Age-2		Age-3	
Prey item	%N (*n*)	%FO	%N (*n*)	%FO	%N (*n*)	%FO	%N (*n*)	%FO
Apeltes quadracus	46 (13)	29	100 (7)	75	60 (6)	67	0	0
Morone saxatilis	32 (9)	57	0	0	40 (4)	33	46 (5)	100
Unknown	22 (6)	21	*	25	*	17	54 (6)	25

temperatures (Nelson et al. 2010). Although some fishes briefly utilize habitats with potentially lethal temperatures for foraging (Stauffer et al. 1976), thermally constrained Striped Bass avoid crossing thermoclines to forage on prey 1–2 m away (Coutant 1985). Large Striped Bass (>100 cm TL) in the Mira River, NS, move throughout the estuary during winter months and experience a wide temperature range (1.2–7.5 ºC), while smaller individuals (50–100 cm TL) remain in intermediate salinity areas (13.0–18.3‰) at stable temperatures (4.0–5.1 ºC) (C.F. Buhariwalla, unpubl. data). Telemetered Striped Bass (>44 cm TL) around a power plant on Long Island Sound, NY moved between the warm-water discharge and ambient waters (2.0–14.0 ºC) throughout the winter (Williams and Waldman 2010). Older-year classes may have returned to overwintering sites near spawning rivers, which is common in the sGSL (DFO 2013, Douglas and Chaput 2011) and has been reported for Striped Bass tagged in Pictou Harbour (>40 cm TL and age-3) and recaptured in the Miramichi River (Douglas et al. 2006).

Juvenile Striped Bass (age-1 and -2) comprised the majority of samples collected; however, older Striped Bass (age-3 and -5) were also present. It is likely that these fish were actively feeding in the warm-water discharge throughout the winter. All but one of the Striped Bass sampled in Pictou Harbour lacked annuli at the margins of their scales and otoliths, suggesting continued feeding and growth, and residency within the warm water. The slope of the weight–length GMR corroborated that active feeding occurred throughout the winter, with weight increasing faster than length. Hurst and Conover (1998) reported minimum temperatures required for age-0 Striped Bass to maintain growth in length and weight at 10 ºC and 5 ºC, respectively. The continued feeding and growth of the Striped Bass found in Pictou Harbour indicates that they inhabited the warm-water outflow of the power plant prior to their death.

Although stomach contents indicated that our Striped Bass specimens were feeding in the warm water discharge, we identified only 2 prey species. Juvenile Striped Bass was the most common prey found in the stomachs of age-2 and older specimens collected from the fish kill, while age-1 fish fed predominantly on Fourspine Stickleback. These findings differ from other studies where low rates of cannibalism (0.33–4%) were reported for wild Striped Bass (Manooch 1973, Shapovalov 1936, Smith and Reay 1991) and could be reflective of increased vulnerability of predation resulting from the effects of cold shock (Donaldson et al. 2008). Invertebrates are generally the dominant prey of age-0 and age-1 Striped Bass from North Carolina to sGSL, and although piscivory increases with age, invertebrates also play an important role in the diets of older juveniles and adults (Walter et al. 2003). *Crangon crangon* L. (Sand Shrimp) and mysids were the dominant prey of large (>12 cm TL) age-0 Striped Bass in Minas Basin, Bay of Fundy, and in the Miramichi estuary, with fishes making only a minor contribution to their overall diet (Robichaud-LeBlanc et al. 1997, Rulifson and McKenna 1987). We found no evidence of invertebrates in the stomachs of the Pictou Harbour mortalities. Occurrence of empty stomachs among overwintering Striped Bass is common (Hurst and Conover 2001, Williams and Waldman 2010); however, limited prey diversity and an ontogenetic increase in the proportion of specimens exhibiting cannibalism suggests there was a lack of prey available in the discharge plume prior to the mortality event. This suggestion was corroborated by field observations during the winter of 2014–2015 (C.F. Buhariwalla, pers. observ.).

Although fish-kill mortality events are a recurring problem (Douglas et al. 2006, La and Cooke 2011), our study contains the first description of Striped Bass mortality from a suspected cold-shock event. The true extent of the kill is unknown because time since the event and extent of scavenging may be major factors in the number and size of samples recovered (Labay and Buzan 1999, Ryon et al. 2000); however, the 2013 event in Trenton likely had a negligible impact on the sGSL population because spawner abundance was at a record high in 2011 (203,000 spawners; DFO 2013). On the other hand, during years of low Striped Bass abundance (e.g., 3,000–5,000 spawners in 1996–99; COSEWIC 2012), fish-kill events could impact this COSEWIC-assessed population, and we recommend evaluation of future events.

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