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Do Striped Bass (*Morone saxatilis*) Spawn in Response to High River Flow Events?

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Abstract

The Estuarine Turbidity Maximum (ETM) of the upper Chesapeake Bay serves as an important nursery habitat for striped bass (*Morone saxatilis*) eggs and larvae. Event-scale phenomena alter the physical and biological conditions within the ETM. Pulses in river flow change water temperatures and deliver organic material. Flow events could cue striped bass spawning and stimulate production of prey for their larvae. These hypotheses are being evaluated with field surveys and analyses of historical data. Historical records indicate that the occurrence of pulsed flow events is highly variable; zero to three pulses occurred each year during the spawning season (April-May) from 1993-2005. Water temperatures in April and May were negatively correlated with river flow (1956-2002), suggesting that water temperatures decrease during flow events and then increase as pulsed flow diminishes, potentially providing a cue for spawning. Surveys of striped bass egg and larval abundances and zooplankton abundances were conducted in upper Chesapeake Bay during 2007 and 2008 and were combined with historical data to identify whether pulses, and associated temperature changes, could act as cues for striped bass spawning and stimulate larval food production. Preliminary results of field collections and historical records neither refute nor confirm our hypothesis that striped bass spawn after pulses in river flow. Spawning did occur during times of rising water temperatures after pulses in flow, but not consistently across all systems and years.

Introduction

Striped bass (*Morone saxatilis*) are a commercially and recreationally important anadromous fish found along the east coast of North America from northern Florida to Canada (Setzler-Hamilton and Hall, 1991). Most striped bass (up to 90%) are spawned in the tributaries of Chesapeake Bay (Berggren and Lieberman, 1978) during April and May of each year. The Estuarine Turbidity Maximum (ETM) acts as an important nursery area for the early life stages of striped bass (North and Houde, 2001). In the upper Chesapeake Bay, the ETM is usually located between the head of the bay and Tolchester (Fig. 1), a region dominated by the influence of the Susquehanna River (Schubel, 1968). Above average river flow can lead to enhanced concentrations of zooplankton and ichthyoplankton in the ETM (North and Houde, 2001; Martino *et al*., 2007; North and Houde, 2006) and may subsequently result in higher striped bass larval survival (Martino *et al*., 2007). There is also a significant positive correlation between mean springtime freshwater flow and striped bass young-of-the-year abundances in upper Chesapeake Bay (1989-1999) (North and Houde, 2001).

In addition to seasonal changes in freshwater flow, episodic river flow events also influence the dynamics of ETMs. Numerical modeling and field observations in the upper Chesapeake Bay showed that short-term pulses in flow can result in non-linear responses in the salt front and ETM (North *et al*., 2004). High flow events result in down-estuary movement of the salt front, but there can be a lag in the movement of the turbidity maximum (North *et al*., 2004). When striped bass eggs are added to the numerical model, transport to the ETM nursery area is lower during pulse flow events compared to steady state conditions, but is higher immediately after pulses in flow when the salt front rebounds up-estuary (North *et al*., 2005). This suggests that the optimum time for striped bass egg transport is to be spawned just after a pulse in river flow.

Results of previous field studies suggest that episodic river flow events and their associated temperature changes could act as cues for striped bass spawning in the upper Chesapeake Bay. Peaks in striped bass egg abundances have occurred when water temperatures increased rapidly in several different systems (Virginia portion of Chesapeake Bay: Grant and Olney, 1991; Miramichi River, Gulf of St. Lawrence: Robichaud-LeBlanc, *et al*., 1996; Potomac River and Upper Chesapeake Bay: Rutherford and Houde, 1995; Patuxent River: Secor and Houde, 1995; Savannah River: Van Den Avyle and Maynard, 1994). In the Chesapeake region, published temperature records suggest that a pulse in river flow during spring is associated with a decline in water temperature followed by an increase in water temperature (*e.g.* Rutherford et al., 1997). This implies that decreasing water temperature during a pulse in river flow followed by increasing water temperatures following a pulse in river flow could act as a cue for striped bass to spawn when egg transport to the ETM is optimal.

The objective of the research program is to examine the variability in timing of striped bass spawning in relation to episodic river flow events. This research program is guided by the hypothesis that striped bass spawn in response to increasing water temperatures which often occur after high river flow events. Analyses presented here include correlations of historical river flow and water temperature, graphical analyses of field collections performed in the upper Chesapeake Bay in 2007 and 2008, and graphical analyses of historical collections from tributaries of the Chesapeake Bay. Preliminary results suggest that water temperatures are inversely correlated with river flow lagged by one day, and most striped bass spawning appears to occur during rising temperatures which often follow episodic river flow events.

Methods

In order to determine if water temperature changes are related to river flow on an episodic scale, historical records of freshwater flow and water temperature on the Susquehanna River were examined. Freshwater discharge and water temperature at Holtwood Dam (1956-2002, courtesy PPL Corporation and Normandeau Associates) on the Susquehanna River for April and May were detrended and examined with a cross-correlation analysis in SAS. The data were detrended to remove the predictable seasonal increase in temperature and decrease in flow during spring to isolate the influence of pulses in flow. The effects of episodic pulses in river flow on water temperatures at Holtwood Dam and the number and frequency of pulses from 1993-2005 at Holtwood Dam and Conowingo Dam (http://waterdata.usgs.gov/nwis/rt) were examined graphically prior to detrending to characterize the number of pulses in recent years. For the purpose of this evaluation, a pulse in Susquehanna River flow at Conowingo Dam was defined as one or more days of flow that is greater than twice the average flow for April 1-May 31 of that year.

To examine when striped bass spawn in relation to episodic changes in river flow and water temperature, striped bass early life stages were collected in April and May of 2007 and 2008 during two one-week cruises and three or four one-day cruises each year in the upper Chesapeake Bay in and around the ETM region on board the *R/V Hugh R. Sharp* and *R/V Terrapin*. CTD casts, MOCNESS tows, Tucker Trawl tows, and bongo net tows were performed to record the physical conditions and collect early life stages of fish. Net systems were equipped with either 200 or 280 µm mesh nets and sampled at four to eleven stations in the ETM region. Striped bass eggs and larvae collected during these cruises were identified and enumerated. Average egg abundances per station were plotted alongside river flow and water temperature records to look for patterns in spawning in relation to episodic river flow events and changes in temperature.

To compare our findings from the Susquehanna River in 2007 and 2008 with additional river systems of the Chesapeake Bay during other years, historical striped bass egg abundances, water temperatures, and river flow from the Patuxent River in 1991 (Secor *et al*., 1994) and the Nanticoke River in 1992-1993 (Kellogg, 1996) were examined graphically to determine if any patterns found in 2007 and 2008 also were found in other river systems.

Results

Analysis of temperature and flow records from the Susquehanna River indicate that flow in April and May is highly variable. Based on a graphical analysis (*e.g*. Fig. 2), the number of pulses in flow from 1993-2005 ranged from zero to three per year. During this time period, there were an average of 1.5 pulses per year and a standard deviation of 1.1. Water temperatures appear to decrease during a pulse in flow and increase following a pulse (Fig. 2). Cross correlation analysis on detrended river flow and temperature data showed that changes in water temperature lag behind changes in river flow by one day, and there is a significant negative correlation between water temperature and lagged river flow of -0.49 ($n=2838$, $p<0.0001$). This suggests that when the springtime trends of decreasing river flow and increasing temperature are removed, half of the variability in temperature that remains is controlled by changes in river flow (*i.e*. pulses), and that as flow increases temperature decreases and vice versa.

A preliminary examination of the effects of this variability on striped bass spawning was conducted on five years of data from three different river systems. In the upper Chesapeake, one pulse in river flow occurred in 2007. This pulse was associated with an initial decrease in water temperature, followed by an increase in water temperature. Striped bass eggs from six cruises in 2007 were counted and most spawning occurred after the pulse in river flow (Fig. 3). In 2008, there were no significant pulses in river flow in the upper Chesapeake Bay, but based on egg collections from five cruises, most spawning appears to have occurred during periods of rising water temperatures. In the Patuxent River in 1991, seventeen cruises were performed during the striped bass spawning season (Secor *et al*., 1994), and most spawning occurred after pulses in river flow when water temperatures were increasing (Fig. 4). In the Nanticoke River in 1992, there was one pulse followed by an increase in water temperature, but spawning appears to have occurred prior to that pulse during rising water temperatures earlier in the season (Fig. 5). In 1993, several small pulses in the Nanticoke River were followed by increasing water temperatures and striped bass spawning (Fig. 6). Additional historical collections of striped bass eggs and larvae are currently being examined for future use in statistical analyses to determine if the hypothesis that striped bass spawn in response to episodic river flow events is statistically significant.

Discussion

Examination of flow and temperature records indicated that episodic river flow events result in a decrease in water temperature followed by an increase in water temperature in the Susquehanna River. This phenomenon has also been found in other river systems. In the Hurunui River, North Canterbury, New Zealand, Hockey *et al*. (1982) found that during the summer (December to March) from 1957-1979 water temperature was negatively correlated with the natural logarithm of discharge and positively correlated with maximum daily air temperature. Stream temperature was also found to be inversely proportional to stream flow in a review of the effects of logging in the Western United States and Canada (Gibbons and Salo, 1973).

Preliminary results of field collections and historical records neither refute nor confirm our hypothesis that striped bass spawn after pulses in river flow. Spawning does appear to occur during times of rising water temperatures, but these are not exclusive to pulse events. During years without pulses water temperatures sometimes increase erratically, probably attributable to changes in air temperature and solar radiation (Hockey *et al*., 1982; Gibbons and Salo, 1973).

Understanding the spawning dynamics of striped bass and their dependence on river flow conditions has important management implications. The survival of early stages of fish larvae could be affected by small differences in physical conditions and prey concentrations, which in turn could have large impacts on recruitment via subtle changes in mortality rates (Houde, 1989). Therefore, changes in flow due to natural interannual variability or anthropogenic factors (dams, development, climate change) could influence larval survival and impact striped bass populations.

Climate change models vary in their predictions of the result of increasing atmospheric CO_2 on Susquehanna River flow to the extent that there is no agreement on whether flow will increase or decrease with a doubling of CO_2 levels (Najjar et al., 2000; Neff et al., 2000). These model predictions are for changes in relatively long-term averages (monthly-yearly), the potential effects on small scale episodic events are even less well understood. Recognizing these links between small scale (episodic) changes in river flow, water temperature, and striped bass spawning may be an important factor in understanding the effects of climate change on striped bass recruitment in the future.

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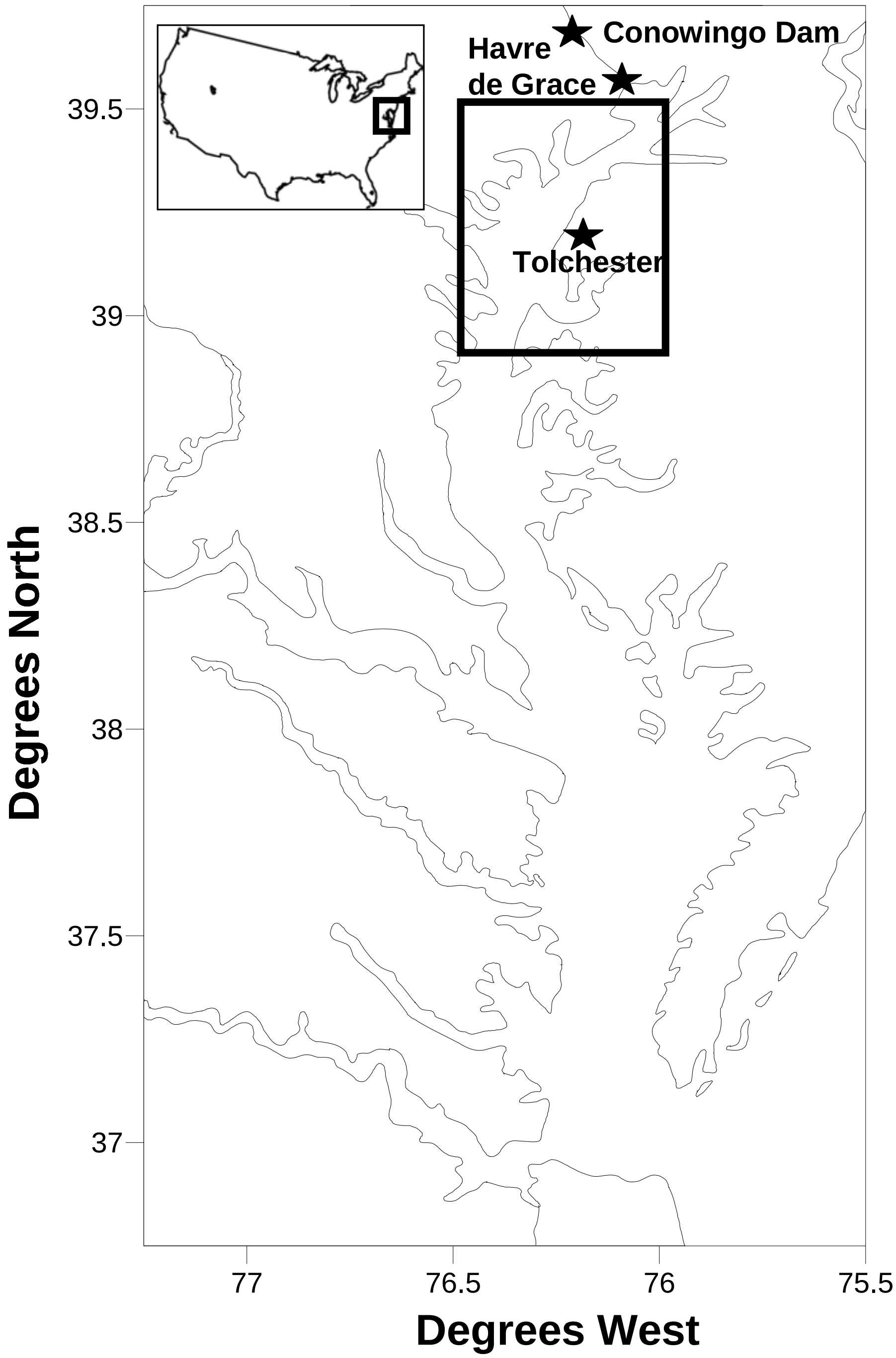

Figure 1: The location of the Chesapeake Bay (black box in inset), the typical location of the ETM in the upper Chesapeake Bay (large black box), and the locations of Havre de Grace, Tolchester, and Conowingo Dam. Holtwood Dam is located just above the edge of the map (39.82˚ N).

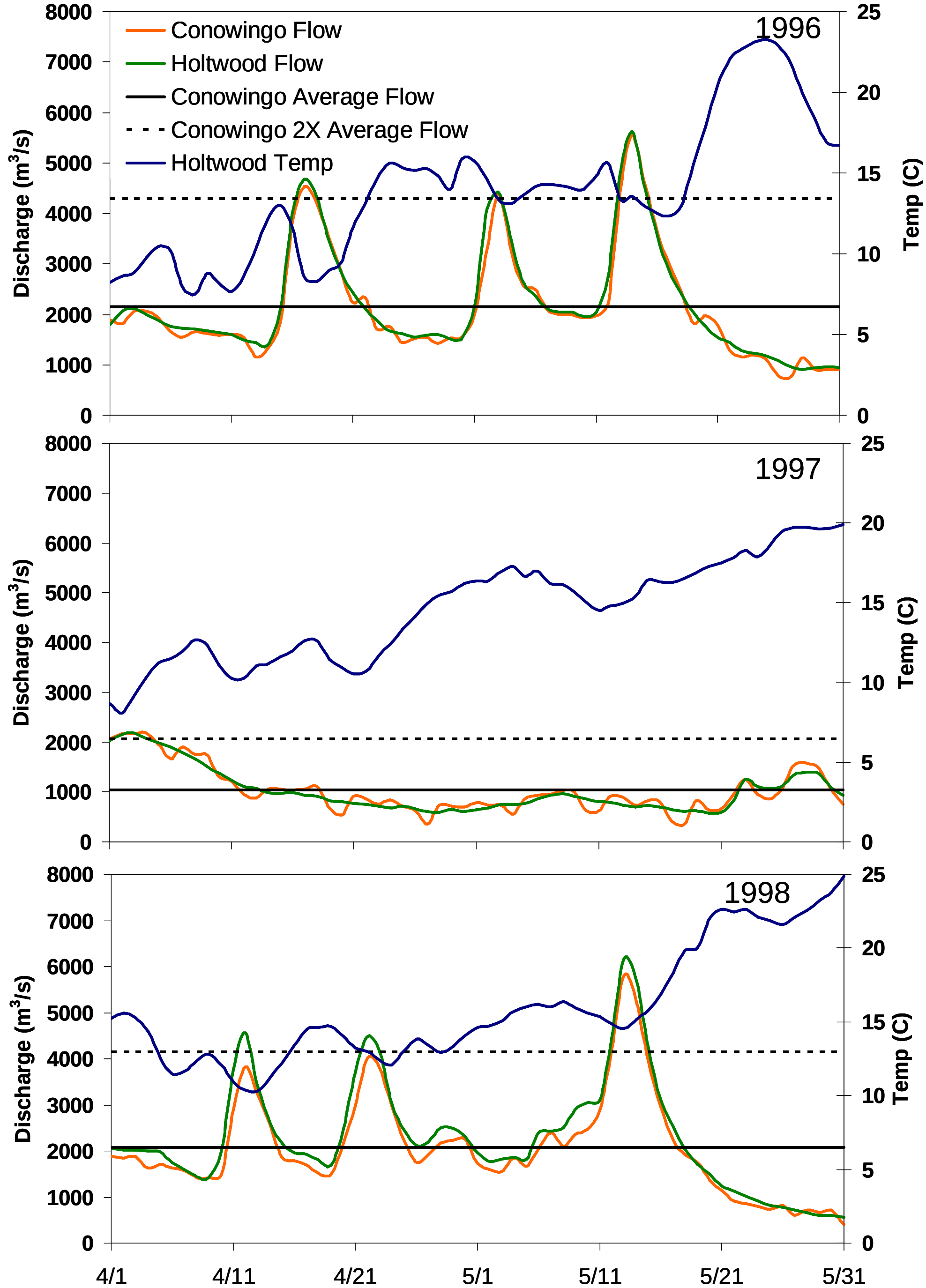

Figure 2: Conowingo and Holtwood daily discharge and Holtwood temperature during April and May 1996 (top panel), 1997 (middle panel), and 1998 (bottom panel). Also shown is the average and twice average April and May daily discharge at Conowingo within each year (http://waterdata.usgs.gov/nwis/sw, Holtwood temperature and flow data courtesy of PPL Corporation and Normandeau Associates).

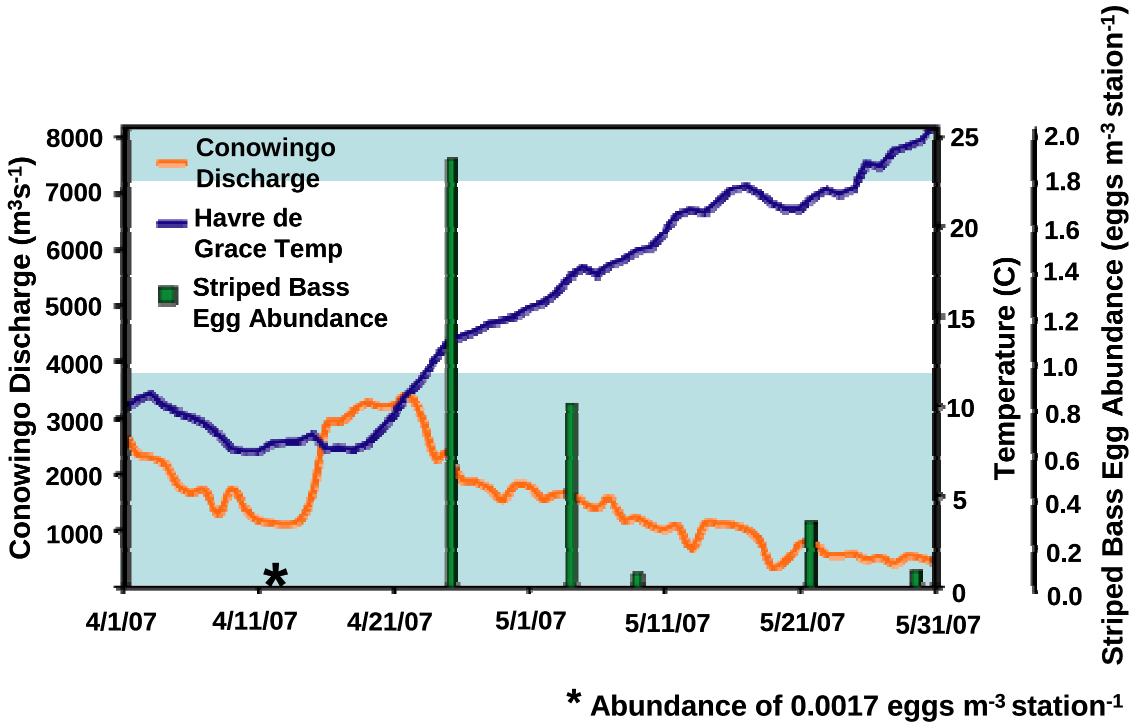

Figure 3: Susquehanna River discharge at Conowingo Dam (orange line), water temperatures at Havre de Grace (blue line), and striped bass egg abundances from six research cruises performed in 2007 (green bars). The light blue shading indicates water temperatures outside the optimum range for striped bass spawning.

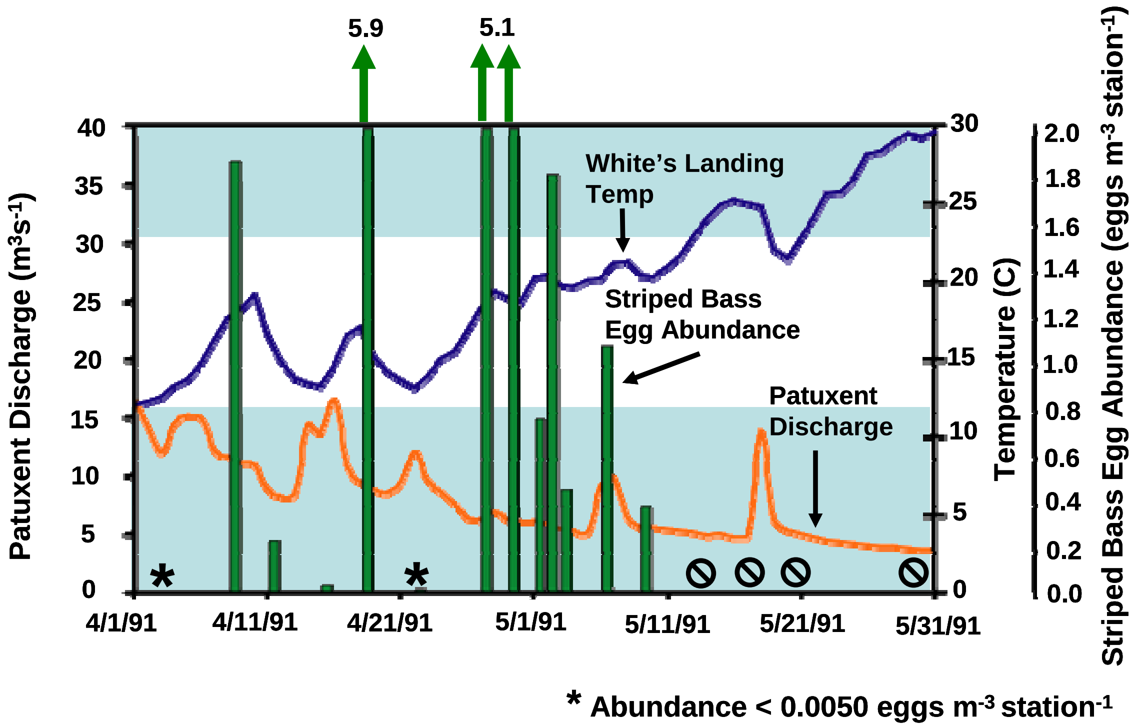

Figure 4: Patuxent River discharge at Bowie, MD (orange line), water temperatures at White's Landing (blue line), and striped bass egg abundances from seventeen research cruises performed in 1991 (Secor *et al.*, 1994) (green bars). The light blue shading indicates water temperatures outside the optimum range for striped bass spawning.

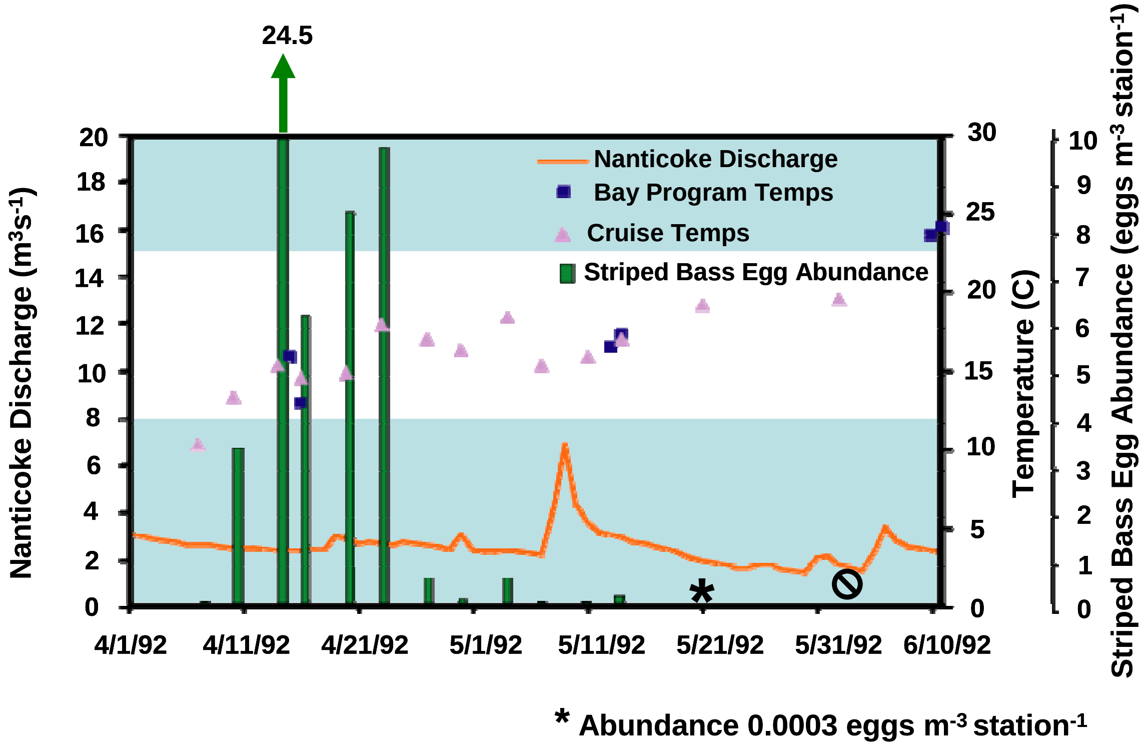

Figure 5: Nanticoke River discharge at Bridgeville, MD (orange line), water temperatures from Kellogg (1996) and the Chesapeake Bay Program (http://www.chesapeakebay.net) (triangles and squares), and striped bass egg abundances from fourteen research cruises performed in 1992 (Kellogg, 1996) (green bars). The light blue shading indicates water temperatures outside the optimum range for striped bass spawning.

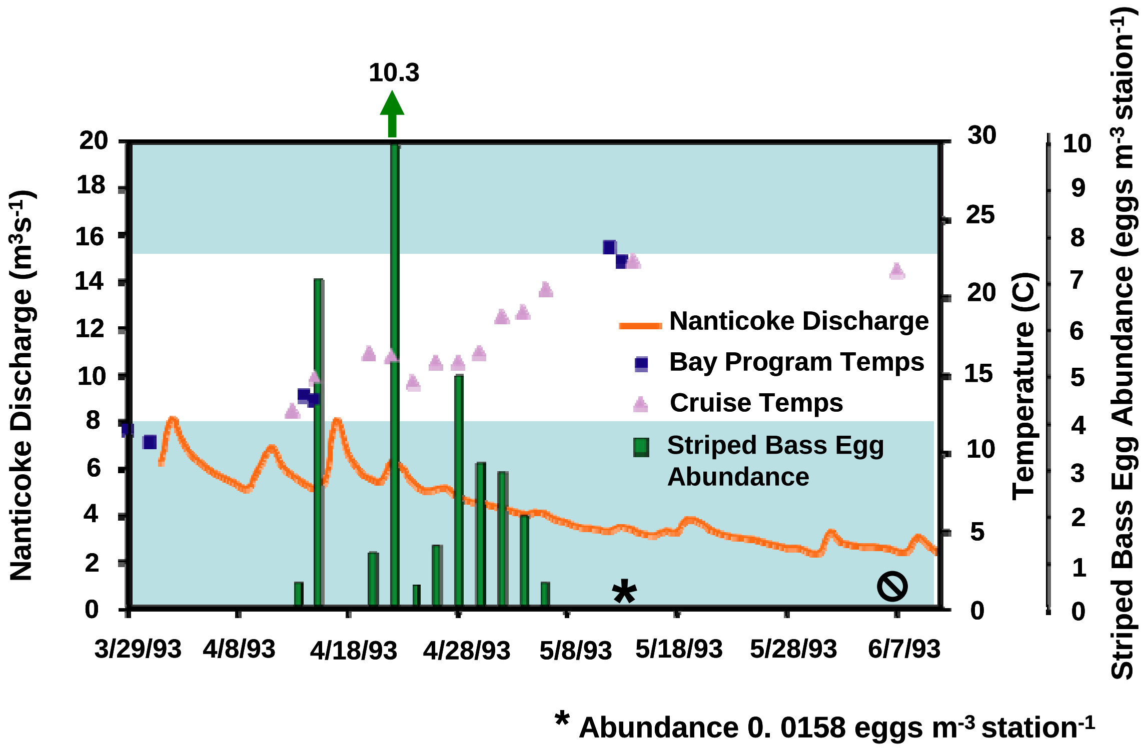

Figure 6: Nanticoke River discharge at Bridgeville, MD (orange line), water temperatures from Kellogg (1996) and the Chesapeake Bay Program (http://www.chesapeakebay.net) (triangles and squares), and striped bass egg abundances from thirteen research cruises performed in 1993 (Kellogg, 1996) (green bars). The light blue shading indicates water temperatures outside the optimum range for striped bass spawning.

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