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[Article]

Effect of Striped Bass Larvae Transported from the Hudson River on Juvenile Abundance in Western Long Island Sound

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Abstract.—Freshwater flow can have a profound influence on the transport of larvae within large tidal estuaries, and tidal flow can transport larvae away from those estuaries. Our objectives were to (1) confirm that a combination of freshwater and tidal flows transported post-yolk-sac larvae (PYSL) striped bass *Morone saxatilis* from the Hudson River, New York, to western Long Island Sound (WLIS), a nearby nursery area, and (2) assess the effect of PYSL transported from the river on the abundance of juvenile striped bass in WLIS. This approach included (1) calculating an index of juvenile striped bass abundance in WLIS (WLIS juvenile index) for July and regressing it on an index of striped bass PYSL abundance for the Battery region of the Hudson River (Battery region PYSL index), which represented annual changes in the abundance of striped bass PYSL that could be transported from the river to WLIS, and (2) regressing a WLIS juvenile index for August on the WLIS juvenile index for July. The regression of the WLIS juvenile index for July on the Battery region PYSL index was significant and positive. The regression of the WLIS juvenile index for August on that for July was not significant. We confirmed that striped bass PYSL were transported from the Hudson River to WLIS by a combination of freshwater and tidal flows. Furthermore, in years when striped bass PYSL abundance and freshwater flow in the Hudson River were unusually high, striped bass PYSL transported from the Hudson River substantially influenced abundance of juvenile striped bass in WLIS during July but not August. The difference in abundance between months was apparently due to high natural mortality early in the juvenile life stage.

The Atlantic striped bass *Morone saxatilis* is an important coastal species from Maine through Cape Hatteras, USA, supporting valuable commercial and recreational fisheries. To better manage stocks of Atlantic striped bass, the Atlantic States Marine Fisheries Commission (ASMFC) developed and adopted an interstate management plan requiring juvenile surveys in spawning and nursery areas along the Atlantic coast, including the Kennebec River in Maine, the Delaware River in New Jersey, the Chesapeake Bay tributaries in Maryland and Virginia, the Roanoke River–Albemarle Sound in North Carolina, and the Hudson River in New York (ASMFC 2003). Data from the juvenile surveys are used to calculate indices of abundance. Indices of abundance can be calculated for various time periods within the juvenile life stage. Selection of the best period is critical for reliably estimating recruitment. Abundance calculated from data collected early in the juvenile life stage will overestimate recruitment if natural mortality early in the juvenile life stage is relatively high; whereas data collected late in the juvenile life stage will underestimate recruitment if migration out of the sampling area has occurred.

The Hudson River is a major contributor to the Atlantic coastal fishery for striped bass (Richards and Rago 1999). Adult striped bass migrate from the Atlantic Ocean into the Hudson River and spawn during the spring. Spawning generally occurs in freshwater above the salt front between river kilometer (rkm) 75 and 150 (Smith 1985). After spawning, freshwater flow and tidal currents redistribute eggs and larvae. As a result, juvenile striped bass occur throughout the estuarine portion of the Hudson River, which extends from rkm 0 to 243 (Boreman and Austin 1985; Boreman and Klauda 1988; McKown and Young 1992).

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The Hudson River is also a source of juvenile striped bass in nearby Long Island Sound (LIS; Dovel 1992; Hurst and Conover 1998; Suarez 2003). Dovel (1992) concluded that juvenile striped bass begin migrating from the Hudson River to LIS during late July, with the larger fish leaving first. Suarez (2003) considered three processes that could be associated with migration of juvenile striped bass from the Hudson River: (1) active selection of better habitat as a response to changes in environmental factors like temperature, salinity, and dissolved oxygen (DO); (2) passive movement due to freshwater flow (i.e., transport); and (3) a density-dependent process. To help assess which process was responsible for migration of juvenile striped bass from the Hudson River, Suarez (2003) tested the correlation between an index of juvenile striped bass abundance in western LIS (WLIS juvenile index) for August and (1) an index of juvenile striped bass abundance in the river between rkm 19 and 43 (river juvenile index) for August and (2) an index of striped bass post-yolk-sac larvae (PYSL) abundance in the estuarine portion of the river (riverwide PYSL index) for the years 1985–2002. The WLIS juvenile index for August is one of three juvenile indices calculated by the New York State Department of Environmental Conservation (NYSDEC); the other two indices combine data from July and August and from July–October. These indices do not show the same pattern across years; therefore, additional study of the indices is needed (Socrates 2006).

The WLIS juvenile index for August was significantly and positively correlated with the riverwide PYSL index but not with the river juvenile index for August. This led Suarez (2003) to conclude that dispersal of juvenile striped bass from the Hudson River to WLIS was due to density-dependent migration starting in late July. However, since striped bass transform into juveniles at 15 mm total length (TL; Mansueti 1958), density-dependent migration starting in late July does not explain the collection of striped bass as small as 10 mm TL by NYSDEC in WLIS during June 1999, 2000, and 2001 (NYSDEC, unpublished data). These small striped bass could have been PYSL or juvenile striped bass that recently transformed from PYSL.

The presence of striped bass PYSL and small juveniles in WLIS during June 1999, 2000, and 2001 is consistent with the suggestion offered by Dunning et al. (2006) that striped bass PYSL transported down the Hudson River by high freshwater flow during the spring and transported from the river by tidal flow through the East River should reach WLIS (the East River connects WLIS and the Hudson River; Figure 1). Their suggestion was based on an estuarine circulation model developed by Blumberg and Mellor (1987), which was linked to a particle tracking model. Blumberg et al. (2004) concluded that a particle tracking model would provide more accurate estimates of entrainment mortality for fish eggs and larvae at power plants on the Hudson River than models that do not account for changes in the location of eggs and larvae due to variations in freshwater flow. Blumberg et al. (2004) and Dunning et al. (2006) assumed that fish eggs and larvae can be represented by passive particles; this assumption is reasonable because eggs (which have no swimming ability) and larvae (which have limited swimming ability) essentially move with the current (Wang 1988).

The model used by Dunning et al. (2006) predicted that the median probability of transport to the upper East River and WLIS for passive particles released in the Hudson River between rkm 0 and 27 was 0.12 and that the median transport time was 2 d based on flows that occurred during 2002. Model results were supported by the presence of striped bass PYSL in entrainment samples collected at the Charles Poletti Power Project (hereafter referred to as Poletti) on the East River during June of each year from 1999 to 2002, the only years when entrainment samples were collected. Furthermore, the density of striped bass PYSL at Poletti during 2000 (a year when the density was unusually high) peaked in an entrainment sample taken 3 d after the peak in density of striped bass PYSL in the Battery region of the Hudson River (rkm 0–18). However, Dunning et al. (2006) could not show that striped bass PYSL were transported from the Hudson River to WLIS because neither they nor NYSDEC conducted ichthyoplankton sampling in WLIS.

In the absence of ichthyoplankton sampling in WLIS, it may be possible to infer transport of striped bass PYSL from the Hudson River to WLIS by examining a WLIS juvenile index. The WLIS juvenile index for August is probably not the most useful for detecting transport of striped bass PYSL because it is most likely confounded by migration of juvenile striped bass from the Hudson River. July data that were used by NYSDEC to calculate the WLIS juvenile indices for July–August and July–October should provide an index that is more strongly influenced by transport of PYSL than by migration of juveniles. Therefore, we calculated a WLIS juvenile index for July and used it to (1) confirm that striped bass PYSL are transported from the Hudson River to WLIS by freshwater and tidal flows and (2) assess the effect of PYSL transported from the river on recruitment of juvenile striped bass in WLIS.

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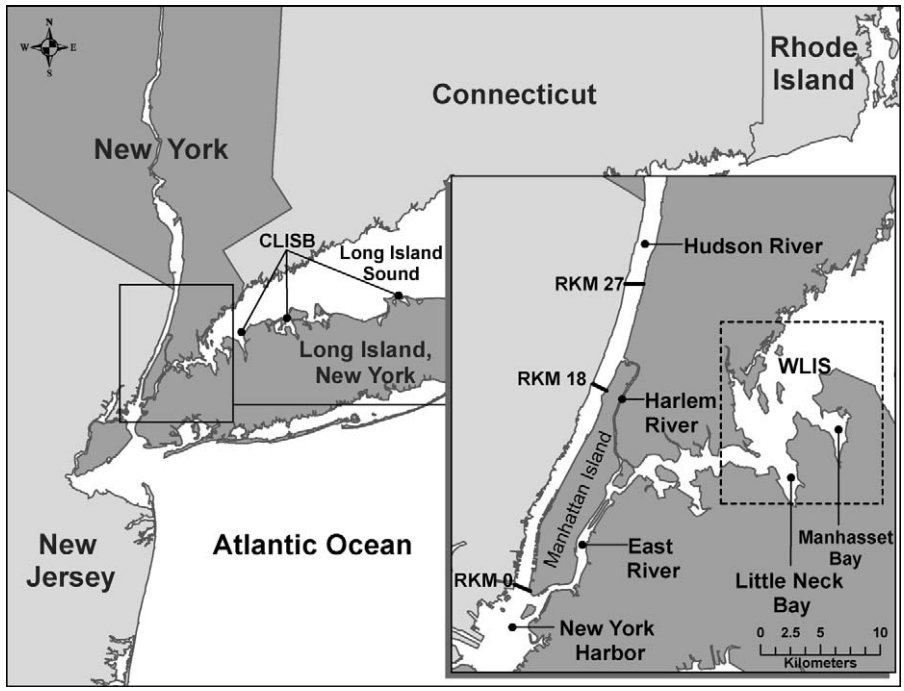


FIGURE 1.—Location of the Hudson River's Battery region (river kilometer [RKM] 0–18), Harlem River, East River, New York Harbor, western Long Island Sound (WLIS: Little Neck and Manhasset bays), and central Long Island Sound bays (CLISB), New York.

Methods

We considered using a WLIS juvenile index for June (rather than July) for detecting transport from the Hudson River. A WLIS juvenile index for June, like that for July, should be more strongly influenced by transport of striped bass PYSL from the Hudson River than one for August if juveniles begin to migrate out of the Hudson River in late July, as was suggested by Dovel (1992). However, a WLIS juvenile index for June has limited value because NYSDEC beach seining in WLIS caught striped bass that could be PYSL or juveniles that recently transformed from PYSL during only 3 years (1999–2001).

We calculated a WLIS juvenile index for July 1992–2004 by using the same approach that NYSDEC used for calculating the WLIS juvenile index for August (McKown and Brischler 2002). The WLIS juvenile index is the geometric mean of catch per seine haul, based on an annual beach seining program conducted by NYSDEC in Manhasset and Little Neck bays (Figure 1) to annually assess juvenile recruitment as mandated by Amendment 6 to the Interstate Fishery Management Plan for Atlantic Striped Bass (ASMFC 2003). The beach seine program, accomplished using the same gear and methods each year, was funded through a grant authorized by the Anadromous Fish Conservation Act P.L.89-304. As a condition of the grant, data collected by the beach seine program were submitted in an annual report to the National Marine Fisheries Service. Data collected under this grant were also submitted to ASMFC. We chose the period 1992–2004 because ichthyoplankton data collected in the Hudson River during those years were available for calculating an index of striped bass PYSL transported from the river to WLIS. We also calculated WLIS juvenile index values for August 2003 and 2004 by using the same approach used for calculating the values for 1992–2002.

Beach seining in WLIS during July 1992–2004 was generally done biweekly, as was also the case during August. The seine was set by boat and retrieved by hand from shore. The average number of seine hauls per month was 10.6 during July (range = 4–20) and 7.5 during August (range = 3–10). The beach seine was 70 m long and 3.05 m high. It was constructed with 64-mm square mesh in the wings and 48-mm mesh in the bunt (Socrates 2006). All striped bass collected in a beach seine haul were counted. A scale sample was taken from each striped bass to determine its age, which allowed juvenile striped bass to be differentiated

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from older fish. After each seine haul, water temperature and DO were measured and recorded.

We calculated an index of striped bass PYSL for the Battery region (Battery region PYSL index) to represent annual changes in the abundance of striped bass PYSL transported from the Hudson River to WLIS. Dunning et al. (2006) used striped bass PYSL abundance in the Battery region to reflect transport from the Hudson River because more than 99% of striped bass PYSL are likely to leave the river through the Battery region. Dunning et al. (2006) did not use the riverwide PYSL index because high abundance of striped bass PYSL in the Hudson River alone does not guarantee high abundance in the Battery region. High abundance of striped bass PYSL in the Battery region only occurs when (1) PYSL abundance in the Hudson River is high and (2) freshwater flow in the river during the PYSL life stage is high; this is because high freshwater flow is required to transport striped bass PYSL downriver into the Battery region (Dunning et al. 2006).

The Battery region is one of 13 regions where ichthyoplankton were sampled annually in the Hudson River (ASA Analysis and Communication 2006). Ichthyoplankton sampling was done weekly through June and biweekly thereafter using 1.0-m^2 Tucker trawls and 1.0-m^2 epibenthic sleds fitted with 500-μm-mesh nets. Both gear types were towed against the current for 5 min. A digital flowmeter was used to determine the volume of water sampled. The Battery region PYSL index is the average number of PYSL per 1,000 m^3 over seven consecutive sampling weeks that produce the highest average for the year in which sampling was done.

We regressed the WLIS juvenile index for July on the Battery region PYSL index to assess the effect of striped bass PYSL transported from the Hudson River on the abundance of juveniles in WLIS during July. We regressed the WLIS juvenile index for August on the WLIS index for July to assess the effect of PYSL transported from the Hudson River on the abundance of juveniles in WLIS during August. We selected regression rather than correlation because juvenile striped bass abundance in WLIS during July should be a function of PYSL abundance in the Battery region according to the hydrodynamic model used by Dunning et al. (2006), and juvenile striped bass abundance in WLIS during August could be a function of abundance during July.

We used Bartlett's three-group method for model II regression. Model II regression is appropriate when (1) both the independent and dependent variables are subject to natural variation, measurement error, or both; and (2) the variables covary in response to a common factor (i.e., they are not truly independent; Lovett and Felder 1989). Bartlett's three-group method does not yield a conventional least-squares regression line or an R-value; consequently, special methods must be used for significance testing (Sokal and Rohlf 1969). The first step in using Bartlett's three-group method was to array the 13 pairs of index values (one pair for each year) by magnitude of the independent variable. Next, the pairs were divided into three groups; the first group had the five lowest values for the independent variable, and the third group had the five highest values. The three groups were used to estimate the slope of the regression and its lower 95% confidence limit. The regression line was considered significant if the slope and its lower 95% confidence limit were both positive. We were interested in the presence or absence of a significant regression and, if significant, the slope of the regression line (positive or not).

The individual values for the Battery region index and the July WLIS index ranged over several orders of magnitude, causing us to be concerned about linearity and homogeneity of error variances. To determine whether an extreme range of values was present, we tested the index values for the presence of outliers. We determined the likelihood that an index value was an outlier by using Dixon's Q-test, which is based on ratios of the range and various subranges of values. To apply the Q-test, index values (x) were arranged such that $x_1 < x_2 < \cdots < x_{n-1} < x_n$, where the highest value is x_n. We calculated the Q parameter as follows:

$$r_{10} = \frac{x_n - x_{n-1}}{x_n - x_1} \quad (1)$$

or

$$r_{20} = \frac{x_n - x_{n-2}}{x_n - x_1} \quad (2)$$

depending on whether we were evaluating one or two possible outliers (Rorabacher 1991). The first digit in the subscript of each ratio r_{ij} refers to the number of possible outliers on the same end of the data as the value being tested, while the second digit indicates the number of possible outliers on the opposite end of the data from the suspected values. We used the critical value for the 99% confidence level from tables in Rorabacher (1991) to determine the probability that a value was an outlier; thus, an index with an r_{10} greater than 0.503 contained one outlier on the same end, and an index with an r_{20} greater than 0.590 contained two outliers on the same end. The 99% confidence level detects only the most extreme outliers, especially when applied to small sample sizes.

If an index had one or two outliers and the highest value was an order of magnitude greater than the

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remainder of values or if there were two values that were similar in magnitude and were an order of magnitude greater than the remaining values, we applied a $\log_{10}$ transformation to all index values. If any value of an index was zero, we added 1.0 to each value for that index before applying the $\log_{10}$ transformation as suggested by Sokal and Rohlf (1969). Finally, if an index was transformed, we did an outlier test to confirm that the transformation was successful.

Results

During 1992–2004, the WLIS juvenile index value for July 2000 was the highest and the value for July 2001 was next highest (Table 1); both were outliers ($r_{20} = 0.927$). Over the same period, the Battery region PYSL index value for 2000 was the highest and the value for 2001 was the next highest; both were outliers ($r_{20} = 0.979$). A $\log_{10}$ transformation was applied to the WLIS juvenile index values for July and the Battery region PYSL index values. There were no outliers in either the transformed WLIS juvenile index ($r_{20} = 0.477$) or the transformed Battery region PYSL index ($r_{20} = 0.479$). Among the years 1992–2004, the WLIS juvenile index for August 2000 was the highest but was not an outlier ($r_{10} = 0.126$); the WLIS juvenile index value for August 2001 ranked fifth.

The regression of the transformed WLIS juvenile index for July on the transformed Battery PYSL index was significant; both the slope of the regression and its lower 95% confidence limit were positive. The regression of the WLIS juvenile index for August on the transformed WLIS juvenile index for July was not significant; the slope of the regression was positive, but the lower 95% confidence limit was negative. Data for the regressions are plotted in Figures 2 and 3.

TABLE 1.—Striped bass abundance index values for post-yolk-sac larvae (PYSL) in the Battery region of the Hudson River, New York (average number of fish per 1,000 m^3 over seven consecutive sampling weeks that produced the highest average for the sampling year), and for juveniles in western Long Island Sound, New York, during July and August (geometric mean catch per seine haul) 1992–2004. Values preceded by an asterisk are outliers.

		Juvenile index	
Year	PYSL index	Jul	Aug
1992	23.3	2.6	3.7
1993	1.7	1.0	14.4
1994	2.1	0.0	2.0
1995	0.3	0.0	1.2
1996	63.4	1.6	34.8
1997	0.0	0.0	0.3
1998	10.3	0.0	21.8
1999	13.9	15.5	44.7
2000	*2,967.4	*212.6	51.1
2001	*282.8	*130.8	18.3
2002	27.1	2.3	2.0
2003	43.6	3.6	4.5
2004	14.7	0.5	0.2

Discussion

Evidence for Transport to Western Long Island Sound

Freshwater flow can have a profound influence on transport of striped bass larvae within large tidal estuaries like the Hudson River (Blumberg et al. 2004; Dunning et al. 2006), Chesapeake Bay (North and Houde 2001), and Sacramento–San Joaquin Estuary (Turner and Chadwick 1972), and tidal flow can transport striped bass larvae away from those estuaries (Dunning et al. 2006). Dunning et al. (2006) showed that a combination of high freshwater flow and tidal flow should transport striped bass PYSL from the Hudson River to WLIS, a nearby nursery area. This is supported by the significant and positive regression of the transformed WLIS juvenile index for July on the transformed Battery region PYSL index. It is also supported by the sequential appearance of striped bass PYSL in the Battery region, PYSL in the East River at Poletti, and juveniles in WLIS during July 2000—the year when the abundance of larval striped bass in the Battery region, the East River, and WLIS was highest. During 2000, striped bass PYSL were first collected at Poletti 4 d after they were first collected in the Battery region; 3 weeks later, juvenile striped bass were first collected in WLIS. Similarly, the peak density of striped bass PYSL at Poletti during 2000 occurred 3 d after the peak density of PYSL in the Battery region; 3 weeks later (the week of July 5), the peak catch of juvenile striped bass per seine haul occurred in WLIS. The lag of 3–4 d between the peaks in striped bass PYSL at Poletti and in the Battery region is consistent with the 2-d median time for transport of passive particles from the lower Hudson River to the upper East River and WLIS based on modeling by Dunning et al. (2006). The 3-week lag between the peaks in striped bass PYSL at Poletti and juveniles in WLIS is consistent with the 3–4-week period of metamorphosis from PYSL to juveniles (Setzler et al. 1980).

We do not know whether tributaries of LIS are a source of striped bass that contribute to juvenile abundance in WLIS. Historically, striped bass probably spawned in tributaries of LIS, but by 1941, spawning seldom, if ever, occurred in those tributaries because Atlantic coast stocks of striped bass were overfished and spawning habitat was altered (Merriman 1941). Strict fishing regulations adopted in 1986 eliminated overfishing and increased the size of Atlantic coast striped bass stocks (Richards and Rago 1999). Coincident with this increase in stock size, striped

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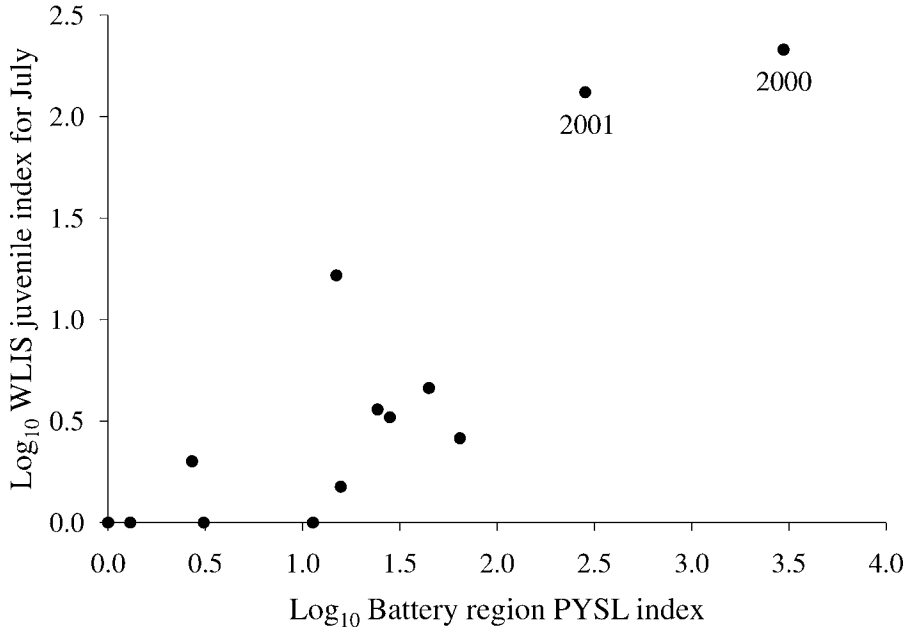


FIGURE 2.—Plot of the juvenile striped bass index of abundance in western Long Island Sound (WLIS), New York, for July against the striped bass post-yolk-sac larvae (PYSL) index of abundance in the Hudson River's Battery region from 1992 to 2004 (both indices are $\log_{10}$ transformed). Data points for the years 2000 and 2001 are labeled.

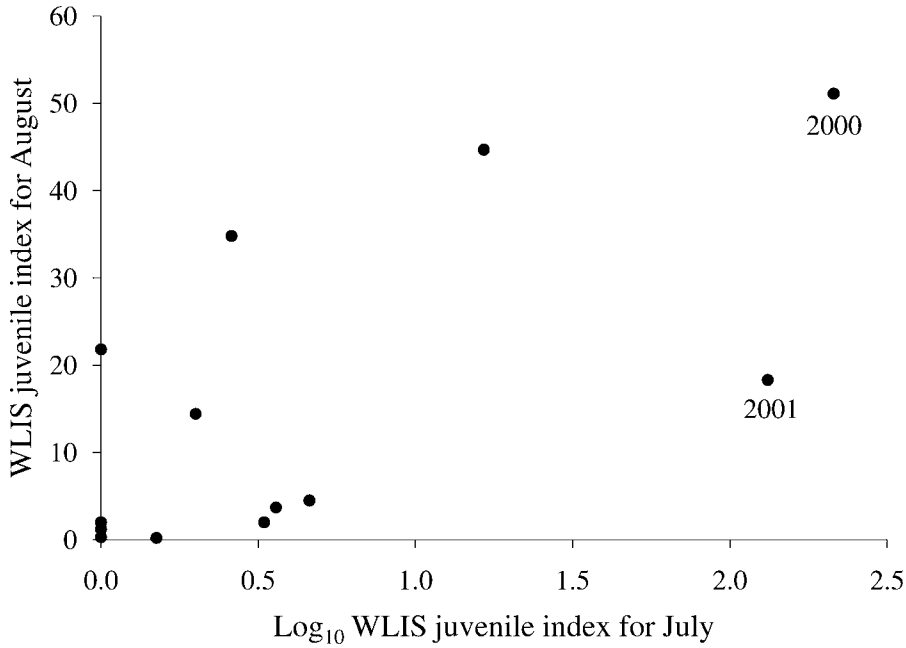


FIGURE 3.—Plot of the juvenile striped bass index of abundance in western Long Island Sound (WLIS), New York, for August against the WLIS juvenile index for July from 1992 to 2004 (both indices are $\log_{10}$ transformed). Data points for the years 2000 and 2001 are labeled.

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bass could have returned to tributaries of LIS and used them for spawning. If spawning occurred in LIS tributaries, the probability of striped bass larvae being transported from them to WLIS appears much smaller than the probability of larvae being transported from the Hudson River based on hydrodynamic modeling of the New York–New Jersey Harbor and LIS (Heimbuch et al. 2007).

Relationship between July and August Juvenile Abundance in Western Long Island Sound

Although transport of striped bass PYSL from the Hudson River by freshwater and tidal flow most likely was responsible for the unusually high abundance of juvenile striped bass in WLIS during July 2000 and 2001, there was no detectable relationship between abundance during July and that during August. Specifically, the WLIS juvenile index values for August 2000 and 2001 did not reflect the extraordinarily high WLIS juvenile index values for July 2000 and 2001. We considered three explanations for this: density-dependent dispersal; high mortality due to poor water quality; and high natural mortality early in the juvenile life stage.

Density-dependent dispersal of fish has been well documented (Rose et al. 2001). Although no studies have examined dispersal patterns of juvenile striped bass within LIS, limited beach seine sampling was conducted by NYSDEC in two bays of central LIS (CLIS) from 2001 to 2005 and in one bay during 2005 (Figure 1). If density-dependent dispersal occurred during 2001, when the WLIS juvenile index value for July was exceptionally high (as it was for July 2000), we expected the number of juvenile striped bass caught in CLIS during 2001 to be considerably higher than that during the other years. However, only three juvenile striped bass were caught in CLIS during 2001, while 2,579 were caught in WLIS (Socrates 2006). In comparison, three juveniles were caught in CLIS during 2005, whereas 394 were caught in WLIS; none were caught in CLIS from 2002 to 2004 (Socrates 2006). Therefore, it seems unlikely that density-dependent dispersal of juvenile striped bass from WLIS caused abundance of juveniles during August 2000 and 2001 to be lower than expected.

Concerns about fish mortality caused by hypoxia in WLIS have been noted by Steinberg et al. (2004) and the Interstate Environmental Commission (2002). The U.S. Environmental Protection Agency (2000) developed ambient water quality criteria for DO in which the median lethal concentration for juvenile striped bass was 1.95 mg/L and DO exceeding 2.3 mg/L at a site would be considered protective of aquatic life. Across the sites where beach seining was done in WLIS, the average DO was above the value considered protective of aquatic life during July 2000 (7.62 mg/L) and 2001 (9.44 mg/L) and during August 2000 (4.77 mg/L) and 2001 (4.48 mg/L; Figure 4). Moreover, anoxia (defined as DO $\leq$ 1.00 mg/L) did not occur anywhere in WLIS during 2000 (LISS 2008). Across the sites where beach seining was done in WLIS, the average temperature during July 2000 (24.3°C) and 2001 (25.2°C) was within the preferred 24–26°C range for juvenile striped bass (Klein-MacPhee 2002), and the average temperature during August 2000 (23.5°C) and 2001 (26.5°C) was within 0.5°C of the preferred range (Figure 5). Therefore, it seems unlikely that water quality caused abundance of juvenile striped bass during August 2000 and 2001 to be lower than expected.

High natural mortality early in the juvenile life stage of fishes is well documented and has been attributed to numerous processes, including predation, competition, and disease (Houde 1987). We believe that predation by juvenile bluefish *Pomatomus saltatrix* on juvenile striped bass was the dominant process during 2001. Bluefish can be an important predator on striped bass. In the Hudson River from 1990 to 1993, juvenile bluefish preferentially chose juvenile striped bass as prey at high densities but avoided them at low densities; during the year with the highest density of juvenile striped bass (1993), predation by juvenile bluefish accounted for 50–100% of the total estimated loss of juvenile striped bass during the summer (Buckel et al. 1999). We calculated the index values for juvenile bluefish abundance in WLIS from 1992 to 2004 by using the same method used by NYSDEC to calculate the WLIS juvenile index values for striped bass. The index value for juvenile bluefish in WLIS was about six times higher during July 2001 than the next highest year and about 21 times higher than the average for the years 1992–2004 (exclusive of 2001); it was about three times higher during August 2001 than the next highest year and about seven times higher than the average for the years 1992–2004 (exclusive of 2001; Table 2). The juvenile index values for bluefish during both July and August 2001 were outliers ($r_{10} = 0.830$ and 0.676, respectively). Competition between juvenile bluefish and juvenile striped bass during 2001 was unlikely to be as important as predation by bluefish because the diet of juvenile bluefish in WLIS is dominated by fish, while the diet of juvenile striped bass in WLIS is dominated by invertebrates (Buckel and McKown 2002).

We believe that predation by juvenile bluefish on juvenile striped bass was not the dominant process during 2000 because the index value for juvenile bluefish abundance in WLIS during July 2000 was 38 times lower than that during July 2001; the juvenile

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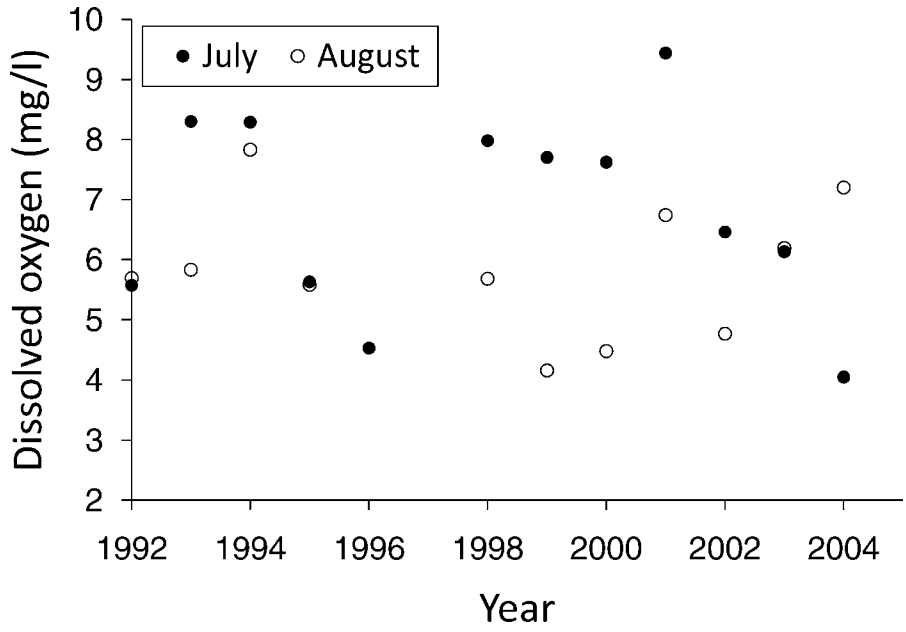


FIGURE 4.—Average dissolved oxygen (DO; mg/L) at beach seine sites sampled for juvenile striped bass in western Long Island Sound, New York, during July and August 1992–2004. A DO value greater than or equal to 2.3 mg/L is considered protective of aquatic life.

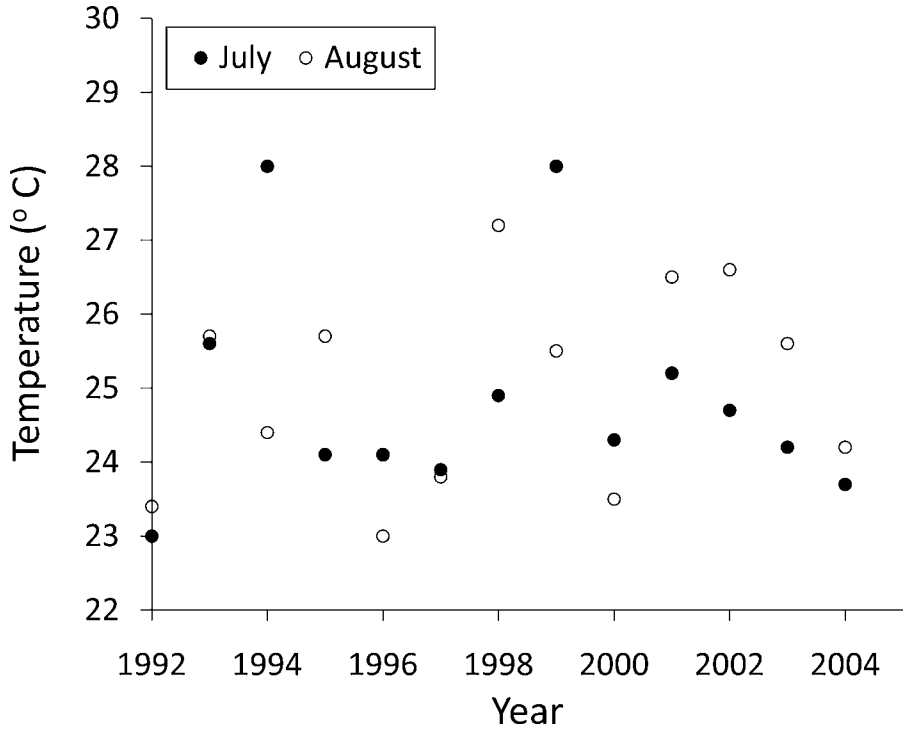


FIGURE 5.—Average water temperature at beach seine sites sampled for juvenile striped bass in western Long Island Sound, New York, during July and August 1992–2004. The preferred temperature range for juveniles of this species is 24–26°C.

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TABLE 2.—Juvenile bluefish abundance index values (geometric mean catch per seine haul) for western Long Island Sound, New York, during July and August 1992–2004.

	Juvenile bluefish index	
Year	Jul	Aug
1992	4.5	8.5
1993	2.4	1.8
1994	0.1	0.7
1995	0.9	3.3
1996	1.9	6.0
1997	0.2	8.4
1998	0.0	1.8
1999	2.6	0.7
2000	0.7	3.9
2001	26.4	24.8
2002	0.7	0.7
2003	0.2	2.8
2004	0.7	1.3

bluefish index during August 2000 was six times lower than that during August 2001. Therefore, it seems likely that a process other than predation by juvenile bluefish on juvenile striped bass was dominant during 2000. Given the limited data available, we cannot identify the process. However, the steep decline in the geometric mean catch of juvenile striped bass per seine haul in WLIS from its peak of 1,067 on July 5 to 142 on July 17 and to 63 on July 31 appears to support our inference that high natural mortality occurred early in the juvenile life stage during 2000.

Relative Importance of Transport and Migration to Recruitment in Western Long Island Sound

If natural mortality early in the juvenile life stage was high and transport of striped bass PYSL from the Hudson River to WLIS was negligible except during 2000 and 2001, recruitment of juvenile striped bass to WLIS in the other years from 1992 to 2004 must have been due principally to migration of juvenile striped bass from the river. Of the 2 years when transport was high, the year 2000 is the most useful for assessing the relative importance of transport and migration to recruitment; 2001 is confounded by juvenile bluefish predation on juvenile striped bass. During 2000, the geometric mean catch of juvenile striped bass per seine haul increased from 63 on July 31 to 110 on August 15 before decreasing to 24 on August 28 and to 10 on September 14. If the decline in the catch per seine haul from July 5 to July 31 continued, most of the increase on August 15 was probably due to migration. Therefore, migration of juveniles appears to have dominated recruitment in WLIS during 2000. If so, the contribution of transported PYSL to recruitment in WLIS during 2000 must have been negligible—that is, the contribution of juveniles in WLIS during July to recruitment during 2000 was negligible. This would explain why the WLIS index value for July–August 2000 (geometric mean catch = 120.4 striped bass/seine haul) overestimated recruitment compared with the WLIS index value for August 2000 (geometric mean catch = 51.1 striped bass/seine haul; Socrates 2006).

Conclusions

We confirmed that a combination of freshwater and tidal flow can transport striped bass PYSL from a large tidal estuary that is a primary striped bass nursery area to a nearby nursery area. Furthermore, we demonstrated that the transport of striped bass PYSL can have a profound effect on abundance of juveniles in a nearby nursery area early in the juvenile life stage. This can cause indices of abundance that use data from early in the juvenile life stage to overestimate recruitment. Because recruitment of striped bass for interstate management is measured by sampling juvenile abundance in nursery areas (ASMFC 2003) and because recruitment indices are used to evaluate effects of anthropogenic activities by recreational and industrial users (Richards and Rago 1999; Dey 2002), the potential effect of larvae transported from estuaries that are primary spawning areas to nearby nursery areas must be considered.

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