Larval abundance, distribution, and spawning habits of spotted seatrout (*Cynoscion nebulosus*) in Florida Bay, Everglades National Park, Florida

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The spotted seatrout (*Cynoscion nebulosus*) is one of the most sought after recreational fish in Florida Bay, and it spends its entire life history within the bay (Rutherford et al.,1989b). The biology of adult spotted seatrout in Florida Bay is well known (Rutherford et al., 1982, 1989b) as is the distribution and abundance of juveniles within the bay. The habitats and diets of juveniles are well documented (Hettler, 1989; Chester and Thayer, 1990; Thayer et al., 1999; Florida Department of Environmental Protection[1]). Nevertheless, the spatial and temporal spawning habits of spotted seatrout and the distribution of larvae have only been partially described (Powell et al., 1989; Rutherford et al., 1989a).

An excellent description of the ecological history of Florida Bay is given by Fourqurean and Robblee (1999). Briefly, Florida Bay is subtropical and is generally oligotrophic. The bay is a network of shallow basins, mud banks, and mangrove islands (keys). Tides are influenced by the Gulf of Mexico and Atlantic Ocean, but mud banks, which are connected to basins by channels, restrict circulation in the bay and attenuate tidal energy very quickly. As a result there is essentially no lunar tide over most of the central and northeastern portion of the bay.

This impediment to circulation could have a negative effect on the recruitment of early-stage planktonic larvae into these portions of the bay. Within the next few decades, plans to restore the Everglades include increasing freshwater flows to Florida Bay. Prerestoration information on larval distribution and spawning patterns of spotted seatrout is a high priority because increased freshwater flows can have potential positive and negative impacts. At low salinities, the planktonic eggs of spotted seatrout could sink to the bottom and would not be viable (Holt and Holt, 2002; Alshuth and Gilmore[2]). On the other hand, increased freshwater flows can alleviate hypersaline conditions that could result in an expansion of the distribution of the early life stages of spotted seatrout (Thayer et al., 1999; Florida Department of Environmental Protection[1]). The objective of the present study is to document the distribution and abundance of spotted seatrout larvae to determine their early life history habitats and spawning habits in Florida Bay.

Methods and materials

To describe the distribution and abundance of spotted seatrout larvae in Florida Bay, I devised a series of ichthyoplankton surveys between 1994 and 1999. The initial survey was conducted during nine nonconsecutive months between September 1994 and August 1995. A total of 14 fixed stations were selected in basins of Florida Bay (Fig. 1). In accordance with recommendations by the South Florida Ecosystem Restoration Prediction and Modeling (SFERPM), Program Management Committee (PMC), Florida Bay was divided into six zones for ease of reporting results (Table 1, Fig. 1). These zones are based on the benthic molluscan and benthic plant communities (Fourqurean and Robblee, 1999). Paired bongo nets, 60 cm wide, were fitted with 0.333-mm mesh and fished from the port side of a 5.4-m boat. Nets were towed during daylight, approximately 1 m below the surface for 5 minutes and volume estimates were obtained from flowmeter readings.

In 1996, sampling was conducted monthly from April through September at stations where recently hatched spotted seatrout occurred during 1994–95 (stations 5, 6, 9–13). In 1996, I used a paired 60-cm bow-mounted push nets with 0.333-mm mesh similar to that described by Hettler and Chester (1990). Nets were fished approximately 1 m below the surface for 3 minutes. The volume of water sampled with the push net was slightly greater than that sampled with the bongo nets (60 m^3 vs. 50 m^3). To test the efficiency of the two gears, both were fished simultaneously at 23 stations during 1996. A Kruskal-Wallis nonparametric test was used to evaluate differences (Sokal and Rohlf, 1981). No significant differences in densities of fish larvae were found between gear types (P=0.50).

During and after September 1997 sampling for spotted seatrout was limited to four stations in four zones (Table 1; stations 6, 15, 16, 17) where paired bow-mounted push nets were employed. Sampling occurred during July and September 1997; March, May, June, July, and September 1998; and May, July, and November 1999.

[1] Florida Department of Environmental Protection. 1995. Fisheries-independent monitoring program, annual report. Florida Department of Environmental Protection, Florida Marine Research Institute, 100 8th Avenue SE, St. Petersburg, FL 33701.

[2] Alshuth, S., and R. G. Gilmore Jr. 1994. Salinity and temperature tolerance limits for larval spotted seatrout, *Cynoscion nebulosus* C. (Pisces: Sciaenidae). Int. Coun. Explor. Sea, Coun. Meet. Pap., ICES-CM-1994/L: 17, 19 p.

Manuscript accepted for publication 19 February 2003 by Scientific Editor.

Manuscript received 4 April 2003 at NMFS Scientific Publications Office.

Fish Bull.101:704–711 (2003).

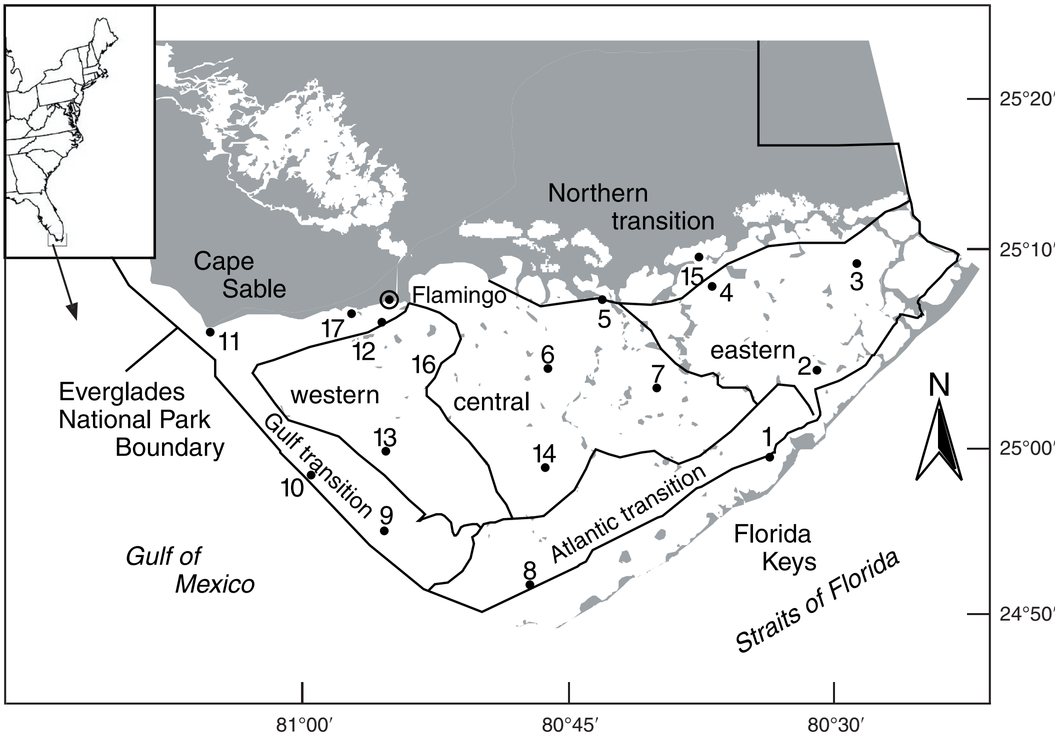

Figure 1

Location of stations in Florida Bay sampled in 1994–99. See Table 1 for station latitudes and longitudes.

Table 1

Florida Bay sampling stations including zone locations as defined by the South Florida Ecosystem Restoration Prediction and Modeling Program, Program Management Committee. Stations 1–14 were sampled in 1994–95; stations 5 ,6, 9–13 in 1996; and stations 6, 15–17 in 1997–99.

Station	Latitude (degrees and minutes)	Longitude (degrees and minutes)	Florida Bay zones	Location
1	24 59.42	80 34.06	Atlantic transition	Cowpens Cut
2	25 04.42	80 31.24	eastern	Butternut Key
3	25 10.54	80 29.12	eastern	Duck Key
4	25 009.24	80 37.12	eastern	between Eagle Key and Madeira Point
5	25 08.30	80 43.19	central	Big Key
6	25 04.57	80 46.32	central	Whipray Basin
7	25 03.54	80 40.12	central	between Calussa and Russel Keys
8	24 52.46	80 47.31	Atlantic transition	between Old Dan and Peterson Key banks
9	24 55.60	80 55.40	Gulf transition	Sprigger Bank
10	24 58.48	80 59.48	Gulf transition	between Oxfoot and Sprigger Banks
11	25 06.49	81 05.16	Gulf transition	Cape Sable
12	25 07.22	80 55.62	Gulf transition	Dave Foy Bank
13	24 59.98	80 55.46	western	between Blue and Ninemile Banks
14	24 59.06	80 46.54	central	between Rabbit and Gopher Keys
15	25 10.80	80 37.80	northern	Little Madeira Bay entrance
16	25 06.00	80 52.50	western	Palm Key Basin
17	25 07.67	80 57.32	Gulf transition	Bradley Key

At stations where replicate tows were taken, densities were averaged. Ichthyoplankton samples were preserved in 95% ethanol. Temperature was measured at all stations with a hand-held thermometer and salinity was measured with a refractometer. Size at age of larvae was estimated from the equation L_n standard length = –1.31 + 1.2162 (L_n age in days) (Powell et al.[3]).

Because of the high coefficient of variation associated with ichthyoplankton samples (Cyr et al., 1992), my sampling design was probably inadequate for multiway statistical comparisons. Therefore, I used nonparametric Kruskal-Wallis tests with $\alpha = 0.10$ (Sokal and Rohlf, 1981) and relied on patterns and trends to infer differences in densities of spotted seatrout between stations and time periods. In the period 1994–95 we tested densities among nine months and 14 stations to determine trends in spatial and temporal spawning habits. We also tested differences between the period 1994–95 and the period 1996 to determine interannual spatial and temporal differences or similarities. Only those months (April through August) that were sampled during the two periods were included. During the period from 1997 through 1999 it was only appropriate to determine spatial differences because we sampled irregularly during this period.

A general description of the diverse habitats in relation to stations in the present study is described by Holmquist et al. (1989, decapod and stomatopod communities); Thayer and Chester (1989, fish distribution, seagrass distribution and abundance, sediment depth, and organic content); Zieman et al. (1989, macrophyte distribution); and Fourqurean and Robblee (1999, general description of the Florida Bay ecosystem).

Results

In 1994–95, salinities were lowest and most variable at stations 1–5 and 7 in the eastern part of Florida Bay (Figs. 1 and 2). Hyperhaline conditions were never observed during this period. Salinities in 1996, which were recorded monthly from April through September at stations where recently hatched spotted seatrout were collected in 1994–95, were generally euhaline and, as in 1994–95, hyperhaline conditions were never observed. From July 1997 through November 1999 at four trout monitoring stations, mean salinities were similar at stations 6, 16, and 17 but were most variable at station 6. Station 15 had the lowest mean salinity and the greatest variation. At this station salinities ranged from 10.0 (March 1998) to 33.0 psu (May 1999). Highest salinities for all four stations were observed in May 1999. Hyperhaline conditions were observed only at station 6 in June 1998 and May 1999 and at station 16 in May 1999 (Fig. 2).

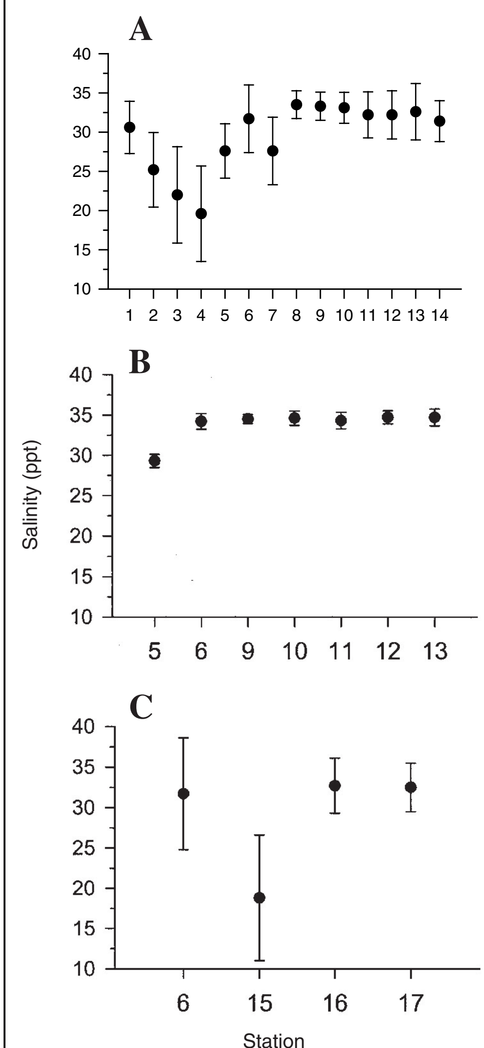

Figure 2

Mean salinities SD for (**A**) 14 stations sampled from September 1994 through August 1995, (**B**) 7 stations sampled monthly from April through September 1996, and (**C**) 4 stations sampled from July 1997 through November 1999. For months that samples were taken, refer to Tables 2 and 3.

In general, spawning in Florida Bay occurred between March and October and peaked in June, August, and September (Table 2). Densities of spotted seatrout were significantly different among months in 1994–95 ($P<0.01$) and 1996 ($P=0.01$). Spotted seatrout larvae were absent during December, February, and April in 1994–96 (Table 2), and in November 1997–99 (Table 3). Most spawning, based on larval collections, occurred between 26° and 34°C (Fig. 3). The coldest temperature at which larval spotted seatrout were collected was 20°C in March 1998 at station 6. Spotted seatrout larvae were collected mainly at salinities between 25 and 40 psu (Fig. 3), although larvae were collected in salinities as low as 12 psu at station 15.

[3] Powell, A. B., R. Cheshire, E. H. Laban, J. Colvocoresses, P. O'Donnell. and M. Davidian. In review. Growth, mortality and hatchdate distributions of larval and juvenile spotted seatrout, *Cynoscion nebulosus*, in Florida Bay, 26 p.

Spatially, there were significant differences in densities of spotted seatrout among 14 stations from 1994 through 1995 (*P*=0.01), and densities were highly variable (Table 2). In addition, a considerable number of zero catches occurred at stations where spotted seatrout were collected at least one time. This high variability indicated that the sampling design was inadequate to properly evaluate the spatial and temporal abundance of spotted seatrout larvae. However, some patterns could be discerned. Generally, larval spotted seatrout were absent or rarely collected in the eastern (stations 2, 3, and 4), Atlantic transition (stations 1 and 14), northern transition (station 15) zones and in a portion of the central zone (station 15) (Tables 2 and 3). They were consistently collected at station 6 in the central zone (Tables 2 and 3).

There were no significant differences (*P*=0.14) in densities of spotted seatrout among stations in 1996; stations where trout occurred on more than one occasion in 1994–95 (Table 2). As in 1994–95, high mean densities of spotted seatrout occurred at station 6 (Table 2).

Significant differences in spotted seatrout densities at certain stations were observed between the periods 1994–95 and 1996. Differences were observed at stations 9 (*P*=0.02), station 10 (*P*=0.02), and station 13 (*P*=0.02). At these three stations in 1996 spotted seatrout were collected only in one month (August). They were never collected at station 5 in 1996 (Table 2).

Size of larvae was indicative of spawning locations. Recently hatched spotted seatrout larvae (1.0–1.9 mm notochord length; ≤5 d old) were collected mainly in central (stations 5 and 6), Gulf transition (stations 9, 10, 11, 12, 17) and western (stations 13 and 16) zones. Recently hatched larvae were rare at station 4 (eastern zone), station 14 (central zone) and station 15 (northern transition zone). They were absent at station 8 (Atlantic transition zone) (Figs. 4 and 5).

Discussion

Evidence from previous studies (Powell et al., 1989; Rutherford et al., 1989a) and the present study establishes the spatial and temporal spawning habits of spotted seatrout in Florida Bay. Length-frequency distributions of spotted seatrout larvae collected in 1984–85 (Powell et al., 1989) and data from the present study indicate that spotted seatrout spawn mainly in the Gulf transition, central, and western zones of Florida Bay and that there is limited spawning in the northern transition and eastern zones (Figs. 4 and 5). Spawning also occurs in the far northeastern portion of Florida Bay in Little Blackwater and Blackwater Sounds (Rutherford et al., 1989a). However, there is no evidence for spawning in the Atlantic transition zone. The distribution of planktonic larvae is not necessarily a good indicator of postsettlement habitat requirements because abiotic factors related to transport could influence their distribution. However, in Florida Bay larvae are not distributed homogeneously throughout the bay, and mudbanks impede circulation (Fourqurean and Robblee, 1999). The adults are generally nonmigratory and inhabit shallow seagrass-rich environments (Chester and Thayer, 1990). Hence, the dis-

Table 2

Densities (numbers/100 m^3) of larval spotted seatrout in 1994–96. Larvae were not collected in December 1994, February and April 1995, and April 1996. Larvae were absent at stations 1, 2, 3, and 7. Mean densities do not include those months or stations where spotted seatrout were never collected. NS=not sampled.

	1994		1995					1996					
Station	Sep	Nov	May	Jun	Jul	Aug	Mean ±SD	May	Jun	Jul	Aug	Sep	Mean ±SD
4	0	0	0	9.4	0	0	1.6 ±3.8	NS	NS	NS	NS	NS	
5	3.4	0	0	113.2	0	NS	23.3 ±50.3	0	0	0	0	0	0
6	114.9	4.6	0	5.6	14.0	NS	27.8 ±48.9	2.4	82.1	0	31.3	7.5	24.7 ±34.4
8	0	0	0	0	0	3.2	0.5 ±1.3	NS	NS	NS	NS	NS	
9	20.0	2.9	1.9	5.4	11.1	NS	8.3 ±7.5	0	0	0	31.8	0	6.4 ±14.2
10	21.7	0	2.1	9.6	13.7	NS	9.4 ±8.8	0	0	0	16.2	0	3.2 ±7.2
11	13.0	0	1.8	9.3	0	NS	4.8 ±6.0	0	0	1.9	3.4	0	1.1 ±1.5
12	0	0	0	0	1.0	6.7	1.3 ±2.7	0	0	4.7	1.6	50.0	11.3 ±21.7
13	26.3	0	2.0	87.5	8.5	26.0	25.1 ±32.7	0	0	0	3.3	0	0.7 ±1.5
14	14.8	0	0	0	0	3.6	3.1 ±5.9	NS	NS	NS	NS	NS	
Mean ±SD	21.4 ±34.2	0.8 ±1.6	0.8 ±1.0	24.0 ±40.9	4.8 ±6.2	7.9 ±10.4		0.3 ±0.9	11.7 ±31.0	0.9 ±1.8	12.5 ±14.0	8.2 ±18.	

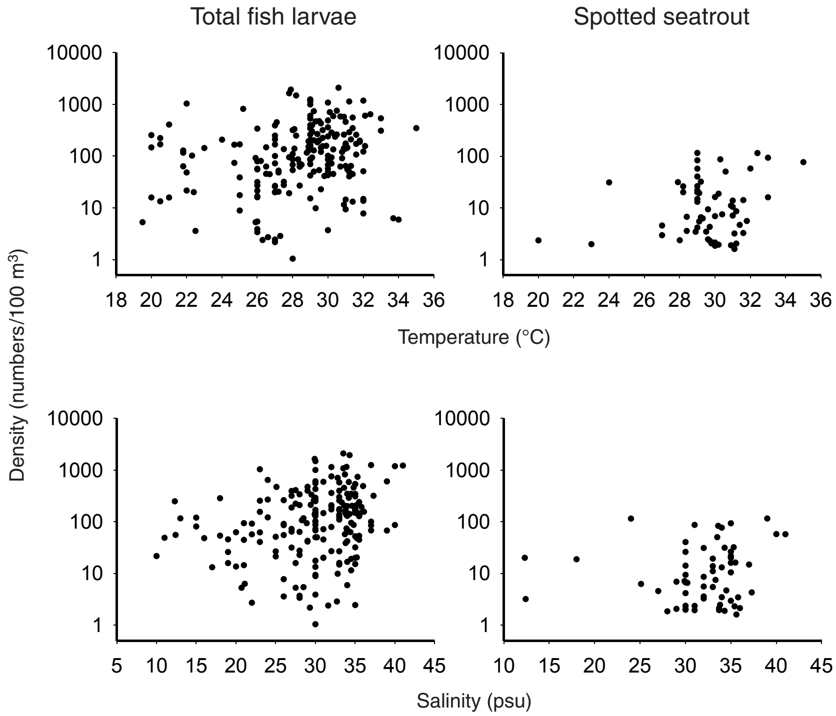

Figure 3

Density of total fish larvae and spotted seatrout versus temperature and salinity. "Total fish larvae" indicates the complete range of temperature and salinity where all collections were made and is provided for visual comparison with spotted seatrout collections.

Table 3

Densities (numbers/100 m^3) of spotted seatrout collected at monitoring stations with a bow-mounted push net with 0.333-mm mesh.

	1997		1998					1999			
Station	Jul	Sep	Mar	May	Jun	Jul	Sep	May	Jul	Nov	Mean ±SD
6	0	6.2	1.2	40.2	57.0	16.0	93.1	56.8	1.1	0	30.2 ±33.2
15	3.2	20.1	0	0	0	0	0	0	0	0	2.6 ±6.7
16	7.1	1.1	1.0	1.2	75.6	0	5.2	0	0	0	9.1 ±23.5
17	6.6	1.0	30.8	0	0	0	0	0	6.9	0	5.0 ±10.1
Mean ±SD	4.2 ±3.3	7.1 ±9.0	8.2 ±15.0	10.3 ±10.4	33.1 ±39.0	4.0 ±8.0	24.6 ±45.7	14.2 ±28.4	2.0 ±3.3	0	

tribution of larvae presented in the present study is most likely a good indication of adult spawning areas.

As indicated by the larval collections in this study, spotted seatrout have a protracted spawning period from March through October, which is similar to that observed in Tampa Bay, Florida (McMichael and Peters, 1989). To the contrary, Stewart (1961) reported that spotted seatrout in Florida Bay spawn throughout the year, and Rutherford et al. (1989a) indicated that some spawning occurred as early as February and continued into December. Powell et al.,[3] studying hatchdate distributions of juveniles, reported peak spawning in early May, late June, and late August.

Seagrass meadows appear to be critical habitats for juvenile spotted seatrout (Chester and Thayer, 1990; Tolan et al., 1997; Rooker et al., 1998; Thayer et al., 1999). Rooker et al. (1998) reported that juvenile spotted seatrout in a Texas estuary prefer *H. wrightii* over *T. testudinum*. In another Texas estuary, Tolan et al. (1997) reported that juvenile spotted seatrout prefer *H. wrightii* over *Syringodium filiforme*. In Florida Bay juveniles are collected at highest densities in western Florida Bay basins near the Gulf of Mexico in habitats with deeper and more organic sediments and with greater density and biomass of *S. filiforme*. In areas where spotted seatrout juveniles are rare or absent, which generally reflects the distribution of their larvae, organic matter and sediment depth are minimal, water depth is generally deeper, and seagrass standing crop, short shoot densities, and diversity are lower (Thayer and Chester, 1989; Chester and Thayer. 1990).

Spotted seatrout larvae were collected consistently at relatively high densities in Whipray Basin (station 6; central zone) and length-frequency distributions indicate spawning most probably occurs in this area. The majority of larvae collected in this area were 2.0–2.4 mm SL (5 to 6 d old), and it is possible that larvae could have been transported into this area from western Florida Bay. Nevertheless, Whipray Basin is a nursery area for juvenile spotted seatrout (Florida Department of Environmental Protection[1]). However, Whipray Basin has a relatively sparse standing crop of the seagrass *Thalassia testudinum* (12 g/m^2) compared to Palm Key (station 16; western zone) which has a higher standing crop of *T. testudinum* (28 g/m^2) and *Halodule wrightii* (14 g/m^2), and has been demonstrated to be an important nursery area for spotted seatrout juveniles (Florida Department of Environmental Protection[1]).

Spotted seatrout eggs have been collected in other waters ranging from 15 to 50 psu (Holt and Holt, 2002). Presumably, larval spotted seatrout eggs sink to the bottom at salinities <15 psu and are not viable (Alshuth and Gilmore[2]). Therefore, it is surprising that recently hatched (<5-d old) larval spotted seatrout were collected, although infrequently, at Little Madeira Bay (station 15; northern transition zone) and only at 12 psu. Whether these low salinities, which occurred in July and September 1997, were a result of drastic changes in salinities caused by weather events that occurred after hatching is unknown. Still, it is highly unlikely that a significant number of viable eggs can be produced at those low salinities.

The qualitative description of spotted seatrout spawning habits provides necessary baseline data in relation to restoration activities, specifically freshwater inflow. Restoration activities could have both a negative and positive effect because salinity can have significant effects on spotted seatrout reproduction and early life history stage processes (Holt and Holt, 2002). For example, low salinities (as discussed above) could be detrimental to egg viability; whereas, alleviating hypersaline areas could expand the spawning area, particularly in the central zone where hypersalinity conditions are persistent (Orlando et al., 1997; Thayer et al., 1999). At high and low salinities, growth and development rates of larval spotted seatrout have been reported to be reduced because these processes are constrained by undeveloped osmoregulatory functions (Holt and Banks, 1989). On the other hand, there is evidence that spotted seatrout populations have adapted to reproduce in extreme-salinity environments where spawning salinities influence egg buoyancy and the salinity tolerance of early

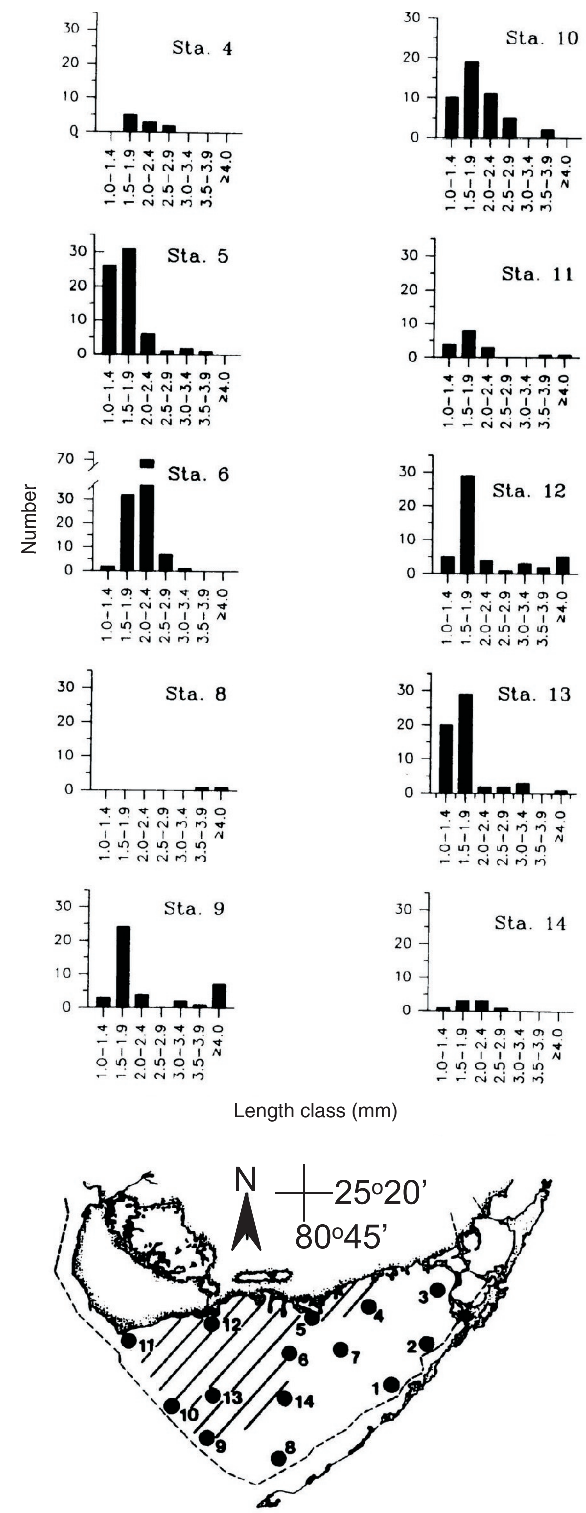

Figure 4

Length-frequency distributions of spotted seatrout by station from 1994–95 collections depicting the spatial spawning habitat. Larvae <2.0 mm were used as criteria to indicate spawning sites. Diagonal lines indicate spawning area. See Table 1 for station locations.

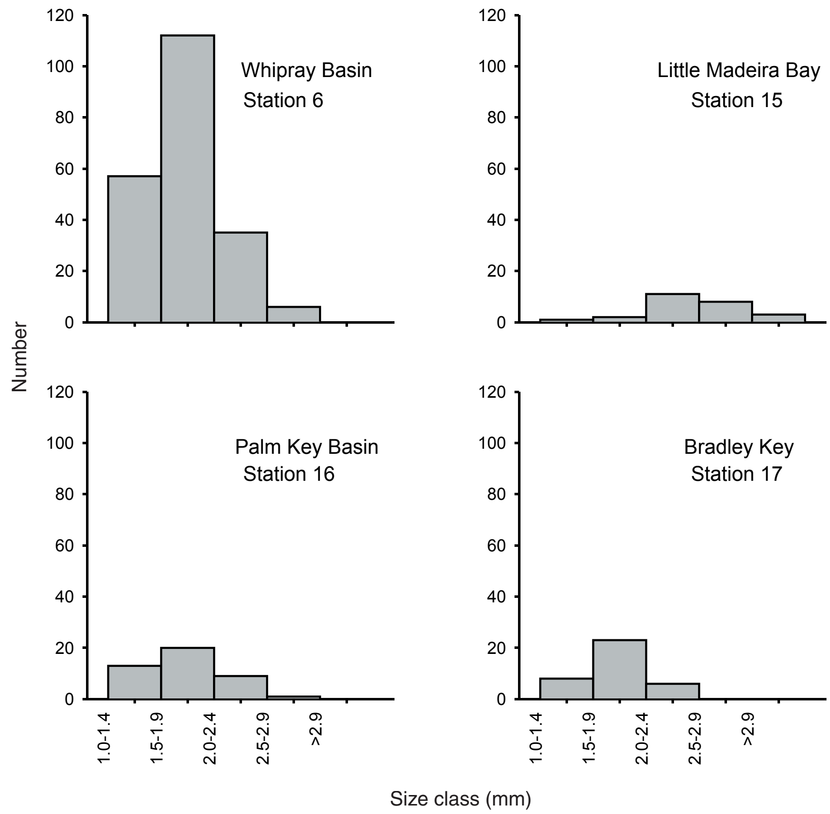

Figure 5

Length-frequency distributions of spotted seatrout from four stations where a bow-mounted push net was used to sample fish from July 1997 through November 1999. See Table 1 for station locations.

larval stages. This adaptation would allow spotted seatrout to spawn over a wide range of salinities.

Future monitoring of spotted seatrout larval abundances to evaluate restoration activities would probably require numerous samples per station because of the high degree of variability as shown by the present study. Therefore, it would seem prudent to continue monitoring spatial spawning habits from larval collections, but to develop a juvenile abundance index to monitor the success of restoration in the Everglades, as well.

Acknowledgments

Sincere appreciation is extended to Al Crosby who was field party chief and processed numerous samples. I am also indebted to other Beaufort Laboratory staff members, notably Robin Cheshire, Peter Crumley, Mike Greene, Donald Hoss, Michael Johnson, and Michael Lacroix for their able assistance in the field; Robin Cheshire, Curtis Lewis, and Harvey Walsh for graphics; James Waters for computer programming; and Dean Ahrenholz, Patti Marraro Joe Smith and an anonymous reviewer for valuable comments in their review of the manuscript. The staff of the Polish Sorting and Identification Center processed many of the ichthyoplankton samples. This study was supported through joint funding from the National Oceanic and Atmospheric Administration Coastal Ocean Program and National Marine Fisheries Service base funds to the Beaufort Laboratory.

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