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Diel Vertical Distribution of Atlantic Croaker, *Micropogonias undulatus*, Larvae in the Northcentral Gulf of Mexico With Comparisons to Red Drum, *Sciaenops ocellatus*

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DIEL VERTICAL DISTRIBUTION OF ATLANTIC CROAKER, *MICROPOGONIAS UNDULATUS,* LARVAE IN THE NORTHCENTRAL GULF OF MEXICO WITH COMPARISONS TO RED DRUM, *SCIAENOPS OCELLATUS*

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ABSTRACT

Atlantic croaker *Micropogonias undulates* (Linnaeus, 1766) larvae < 6 mm showed a distinct pattern of vertical stratification in inner-shelf waters (< 25 m depth) of the northcentral Gulf of Mexico. Discrete-depth plankton collections were taken at night, early morning after daylight, and at mid-day or early afternoon at 1, 5, and 11–16 m. No consistent pattern among cruises was evident in the vertical stratification of Atlantic croaker larvae found in mid-day and afternoon collections, but at night the highest abundances were observed at the deepest depths sampled. Atlantic croaker larvae were least abundant in surface waters (1 m) at night. Of the 66,913 Atlantic croaker larvae collected, only 346 specimens (< 1%) were found in 1 m collections at night, and 266 of these larvae were from a single collection of large specimens (mean = 6.7 mm). By morning the vertical distribution of larvae suggested that Atlantic croaker had moved up in the water column, and highest abundances were usually found at 5 m. There was no indication that patterns of larval distribution reflected hydrographic stratification within the water column, prey availability, size of larvae, or moonlight intensity.

It has been long understood that the larvae of numerous fishes exhibit diel vertical migrations (Russell, 1926; Bridger, 1956; Ahlstrom, 1959). Reasons for the vertical movement of larvae in the water column vary among species and include predator avoidance (Zaret and Suffern, 1976; Yamashita et al. 1985), responses to the movement of zooplanktonic prey (Fortier and Leggett, 1983; Kuwahara and Suzuki, 1984), and behavior that facilitates transport in tidally influenced waters (Weinstein et al., 1980; Fortier and Leggett, 1982; Norcross and Shaw, 1984; Masaru, 1985). In addition, it was hypothesized that vertical migration may provide a bioenergetic advantage for fish in thermally stratified water (Wurtsbaugh and Neverman, 1988; Neilson and Perry, 1990). It also was suggested that the larvae (> ~ 12 mm) of several clupeoids move to the surface at night to fill their swim bladders, conserving energy while not feeding (Hunter and Sanchez, 1976; Blaxter and Hunter, 1982; Brewer and Kleppel, 1986). Knowledge of the vertical distribution of fish larvae is critical for quantitative ichthyoplankton surveys if the entire depth range of the targeted larvae cannot be sampled (Ahlstrom, 1959; Kendall and Naplin, 1981). It is also necessary to know the diel patterns of vertical movement of larvae to understand the interaction among these young fishes, their predators and prey, and the abiotic environment (Neilson and Perry, 1990). Such vertical movements are largely affected by light and gravity, but other factors may include food, hydrography, tidal currents, and turbulence (Neilson and Perry, 1990; Kendall et al., 1994).

In a review, Neilson and Perry (1990) characterized diel migrations into two general categories: fish move up in the water column at night and remain at lower depths during the day (type I), and conversely, fish move down in the water column at night and return to shallower depths during the day (type II). Movement of larvae towards the surface at night is the most frequently reported pattern (Davis et al., 1990; Brodeur and Rugen,

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1993; Haldorsen et al., 1993; Lough and Potter, 1993; Kendall et al., 1994; Otake et al., 1998; Sakuma et al., 1999; Shoji et al., 1999; Tsukamoto et al., 2001); however, the downward movement of larvae at night has also been reported (Davis et al., 1990; Lyczkowski-Shultz and Steen, 1991; Brodeur and Rugen, 1993; Haldorsen et al., 1993). A third reported pattern of vertical movement was observed where larvae are stratified during the day and dispersed at night (Brewer and Kleppel, 1986; Sogard et al., 1987; Heath et al., 1988; Leis, 1991).

Data presented here on the vertical distribution of Atlantic croaker *Micropogonias undulatus* larvae came from a study of the ecology and abundance of red drum *Sciaenops ocellatus* (Linnaeus, 1766) larvae in the northcentral Gulf of Mexico (Lyczkowski-Shultz et al. 1988; Comyns et al. 1991). Although not targeted, Atlantic croaker larvae were more abundant in many of the collections than red drum. Lyczkowski-Shultz and Steen (1991) found that red drum larvae, unlike many other species, were concentrated higher in the water column during daylight hours than at night. Sogard et al. (1987) reported that Atlantic croaker larvae collected in the northcentral Gulf of Mexico tended to occur deeper (12 vs. 1 and 6 m), but sample sizes were small. The present study was conducted to see if co-occurring red drum and Atlantic croaker larvae, two closely related sciaenids that are morphologically very similar, do in fact exhibit different patterns of diel vertical distribution.

Methods

Discrete-depth plankton collections were taken during six, 24 hr cruises conducted in inner-shelf waters off Mississippi during September and October 1984 and 1985 (Fig. 1). Larvae were collected with a 1×1.4 m Tucker trawl fitted with three, 333-mm mesh nitex nets. Discrete depth collections were taken at 1, 5, and 11–16 m, and fishing depth was monitored with an electronic conductivity/temperature/depth probe package (CTD) that was mounted 0.5 m above the net frame on the towing/conductivity cable. The CTD also was used to obtain vertical temperature and salinity profiles prior to sampling. All three nets were fished during sequential five minute periods at the same depth, and opened/closed with a double-trip mechanism that was operated using messengers. Only the middle net was both opened and closed at the desired depth; the first net was open during deployment and the third net was open during retrieval.

Contamination, however, was minimal because each deployment and retrieval took approximately 15 sec. Nets were each fitted with a mechanical flowmeter to determine the water volume filtered and towed at a ship speed of approximately two knots (1.1 m s^{-1}). Catch or density of larvae was expressed as number of larvae per 100 m^3 of water. Collections were taken in the vicinity of a 'windowshade' subsurface current drogue that was tracked over a 24 hr period in an attempt to sample the same patch of larvae. Sampling was generally conducted during the afternoon, at night before midnight, and in the morning after sunrise. Samples were concentrated and preserved at sea in 5–10% formalin and later transferred to 70% ethanol.

In the laboratory larvae were removed from either an entire sample or a one-half aliquot using a Motoda plankton splitter (Van Guelpen et al., 1982). Lengths of larvae were measured to the nearest 0.1 mm using a stereomicroscope (12 or 25 ×) fitted with an ocular micrometer and sorted into 0.5 mm size classes. Measurements were taken from the tip of the snout to the end of the notochord in pre-flexion larvae (notochord length), and from the tip of the snout to the end of the urostyle or hypural plate (whichever was more distal) in flexion or post-flexion larvae (standard length). Non-standard, chi-squared analyses (McCleave et al., 1987; Lyczkowski-Shultz and Steen, 1991) were used to determine if Atlantic croaker larvae were homogeneously distributed, both over three sampling depths, and over three sampling times (morning, afternoon, and night) during a diel cycle.

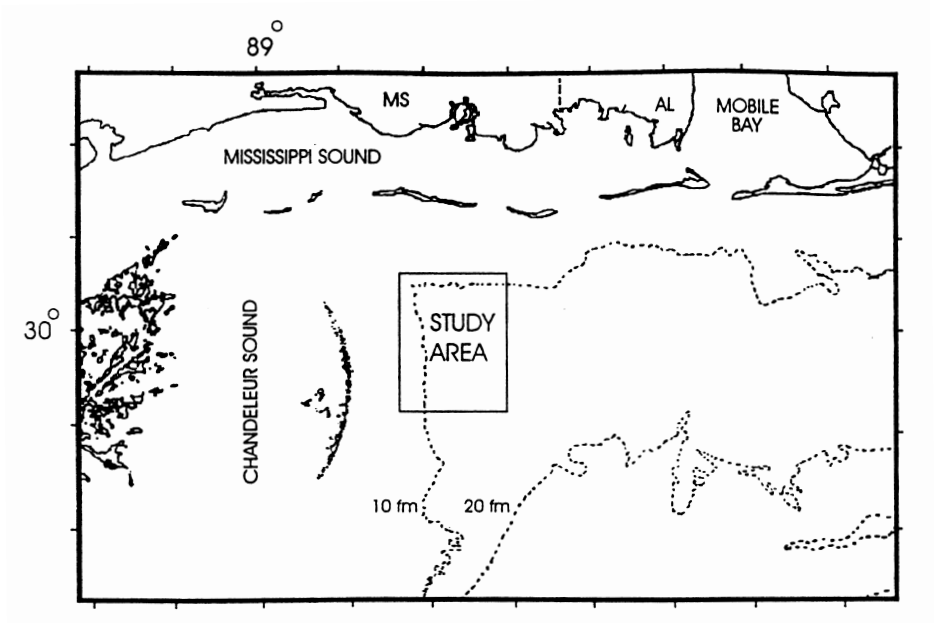

Figure 1. Study area in the northcentral Gulf of Mexico for six 24 hr ichthyoplankton cruises conducted during fall 1984 and 1985.

Standardized residual deviations of observed from expected catches at each depth were calculated as:

$$SR_i = \frac{N_i - E_i}{\sqrt{E_i}}$$

where Sr_i = standardized residual deviation at depth i, N_i = observed catch at depth i, and E_i = expected catch at depth i. E_i was calculated by multiplying the combined catch at all three depths during a time period by the proportion of fishing effort at depth i, i.e., the volume of water filtered at depth i during a time period divided by the total volume filtered at all three depths during a time period. The Chi-squared test statistic (χ^2) for testing the null hypothesis that the density of Atlantic croaker larvae was uniform with depth during a time period was obtained by summing the squared Sr_is for the time period. A nonstandard, goodness-of-fit test (Sokal and Rohlf, 1981) was used to test the null hypothesis that the vertical distribution of larvae remained the same over the three time periods during a diel cycle. This test required subtracting the χ^2 value for all three times combined from the sum of the χ^2 values for each time period.

Results

The null hypothesis, that Atlantic croaker larvae were homogeneously distributed over the three sampling depths during a time period, was rejected at the 0.01 significance level in 17 of the 18 cases (Table 1). A second null hypothesis, that the vertical distribution of larvae remained the same over the three time periods during a diel cycle, was rejected for all six cruises (Table 1). Diel patterns in the vertical distribution of Atlantic croaker lar-

Table 1. Chi-square analyses to determine if Atlantic croaker larvae were homogeneously distributed over three sampling depths, and over three sampling times during a diel cycle. N_i = number of larvae at depth i; E_i = expected number of larvae at depth i; SR_i = standardized residual deviation of observation from expected catch at depth i. ** Significant at $P < 0.01$.

	Afternoon (1111–1409 hrs)				Night (1911–2118 hrs)				Morning (0725–0927 hrs)				Times combined		
Depth	Volume	N_i	E_i	SR_i	Volume	N_i	E_i	SR_i	Volume	N_i	E_i	SR_i	N_i	E_i	SR_i
Cruise 84-9-2, 26–27 September 1984															
1	415	0	539	–23.2	382	0	694	–26.3	543	512	1,735	–29.4	512	2,968	–45.1
5	432	1,356	561	+33.6	387	516	703	–7.0	332	3,224	1,061	+66.4	5,096	2,325	+57.5
12	207	12	269	–15.7	346	1,510	629	+35.1	307	40	981	–30.0	1,562	1,879	–7.3
Total	1,054	1,368			1,115	2,026			1,182	3,776					
Chi-square χ^2		1,913.7**				1,972.7**				6,173.3**				5,393.5	
$\chi^2_{0.01,\,2df} = 9.21$															
$\chi^2_{het} = \chi^2_{aft} + \chi^2_{night} + \chi^2_{morn} - \chi^2_{comb} = 10059.7 - 5393.5 = 4666.2$**															
$\chi^2_{0.01,\,4df} = 13.28$															

	Afternoon (1157–1456 hrs)				Night (1904–2101 hrs)				Morning (0640–0831 hrs)				Times combined		
Depth	Volume	N_i	E_i	SR_i	Volume	N_i	E_i	SR_i	Volume	N_i	E_i	SR_i	N_i	E_i	SR_i
Cruise 84-10-1, 10–11 October 1984															
1	986	86	5,836	–75.3	741	28	4,579	–67.2	700	132	4,902	–68.1	246	15,317	–122
5	978	3,934	5,789	–24.4	752	1,700	4,647	–43.2	769	3,634	5,385	–23.9	9,268	15,821	–52.1
12(16)	998	13,512	5,907	+98.9	833	1,2647	5,148	104.5	982	13,398	6,877	+78.6	39,557	17,932	+161
Total	2,962	17,532			2,326	14,375			2,451	17,164					
χ^2		16,046.7**				17,302.3**				11,386.8* *				43,631.9	
$\chi^2_{het} = 44,735.8 - 43,631.9 = 1,103.9$**															

	Afternoon (1310–1550 hrs)				Night (1939–2136 hrs)				Morning (0708–0930 hrs)				Times combined		
Depth	Volume	N_i	E_i	SR_i	Volume	N_i	E_i	SR_i	Volume	N_i	E_i	SR_i	N_i	E_i	SR_i
Cruise 84-10-2, 23–24 October 1984															
1	316	64	23	+8.5	257	266	284	–1.1	255	70	34	+6.2	400	341	+3.2
5	356	10	26	–3.1	256	282	283	–0.1	270	32	36	–0.7	324	345	–1.1
11(10)	383	2	28	–4.9	256	302	283	+1.1	246	0	32	–5.7	304	343	–2.1
Total	1,055	76			769	850			771	102					
χ^2		105.9**				2.4ns				71.4**				15.8	
$\chi^2_{het} = 179.7 - 15.8 = 163.9$**															

Table 1. Comtinued.

Depth	Afternoon (1456–1706 hrs) Volume	N_i	E_i	SR_i	Night (2037–2237 hrs) Volume	N_i	E_i	SR_i	Morning (0806–1014 hrs) Volume	N_i	E_i	SR_i	Times combined N_i	E_i	SR_i
Cruise 84-11-1, 7–8 November 1984															
1	310	158	685	–20.1	296	18	285	–15.8	322	788	846	–2.0	964	1,816	–20.0
5	287	494	635	–5.6	275	212	265	–3.3	308	972	809	+5.7	1,678	1,709	–0.7
12(16)	265	1254	586	+27.6	273	584	263	+19.8	402	952	1,056	–3.2	2,790	1,905	+20.3
Total	862	1,906			844	814			1,032	2,712					
χ^2			1,197.1**				652.6**				46.7**			812.6	
χ^2_{het} = 1,896.4 − 812.6 = 1,083.8**															
	Afternoon (1244–1506 hrs)				Night (1931–2151 hrs)				Morning (0742–0859 hrs)				Times combined		
Depth	Volume	N_i	E_i	SR_i	Volume	N_i	E_i	SR_i	Volume	N_i	E_i	SR_i	N_i	E_i	SR_i
Cruise 85-9-1, 11–12 September 1985															
1	721	46	32	+2.5	666	0	47	–6.8	667	0	22	–4.7	46	101	–5.5
5	779	48	34	+2.4	652	62	46	+2.4	616	48	21	+5.9	158	101	+5.7
11	1,103	20	48	–4.0	667	78	47	+4.5	984	28	33	–0.9	126	128	–0.18
Total	2,603	114			1,985	140			2,267	76					
χ^2			28.0**				72.2**				57.7**			62.8	
χ^2_{het} = 157.9 − 62.8 = 95.1**															
	Afternoon (1333–1531 hrs)				Night (1853–2052 hrs)				Morning (0704–0856 hrs)				Times combined		
Depth	Volume	N_i	E_i	SR_i	Volume	N_i	E_i	SR_i	Volume	N_i	E_i	SR_i	N_i	E_i	SR_i
Cruise 85-10, 10–11 October 1985															
1	224	300	232	+4.5	305	34	370	–17.5	286	14	123	–9.8	348	725	–14.0
5	253	114	262	–9.1	285	66	346	–15.0	286	316	123	+17.4	496	731	–8.7
12(11)	240	328	248	+5.1	284	960	344	+33.2	281	36	121	–7.7	1,324	713	+22.9
Total	717	742			874	1,060			853	366					
			129.1**				1,633.5**				458.1**			796.1	
χ^2_{het} = 2,220.7 − 796.1 = 1,424.6**															

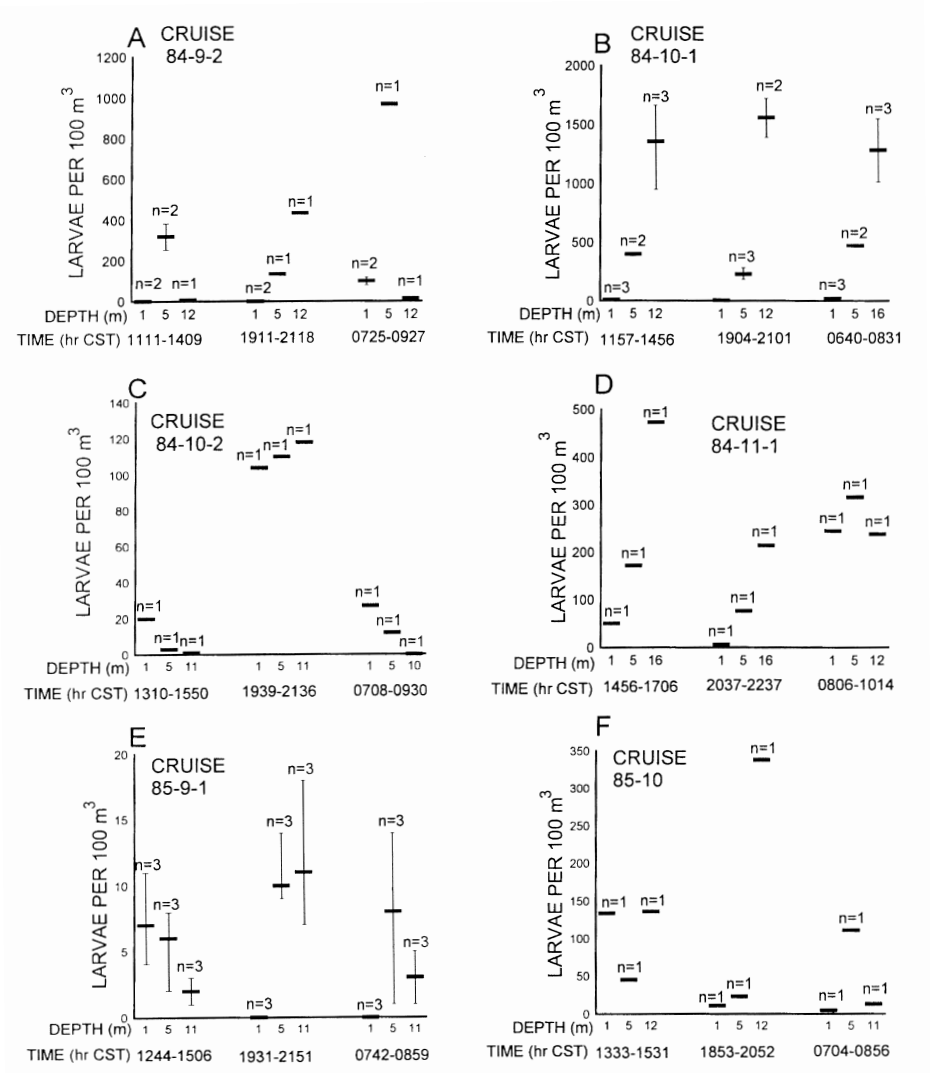

Figure 2. Diel vertical distribution of Atlantic croaker *Micropogonias undulatus* larvae by sampling depth and time during six cruises in the northcentral Gulf of Mexico. Depicted for each cruise are mean and range in density, and number of collections (n) per sampling period.

vae were determined by examining the sign and magnitude of standardized residuals (Sr_i, Table 1).

No consistent pattern among cruises was evident in the vertical stratification of Atlantic croaker larvae found in mid-day and afternoon collections when these larvae were most abundant (Fig. 2). At this time larvae were most abundant at 1 m during two cruises, at 5 m during one cruise, and at the deepest depth sampled (11–16 m) during three cruises. However, a consistent pattern of stratification was evident from nighttime collections. Highest abundances at night during all six cruises were observed at the deepest depths sampled (Fig. 2). This pattern of vertical distribution was highly significant ($P < 0.01$) for all but one cruise, 84-10-2 (Fig. 2C), when similar abundances were found at

all three depths at night. During this cruise when larvae showed no vertical stratification at night, the mean size of larvae was greater (6.3 mm, SE = 0.2) than for any other cruise. Atlantic croaker was one of the more abundant taxa collected during this study, and in one 5 min collection taken at 12 m during the night, 5410 larvae (5 per m^3) were collected. Atlantic croaker larvae were least abundant in surface waters (1 m) at night. Of the 66,913 Atlantic croaker larvae collected, only 346 specimens (< 1%) were found in 1 m collections at night, and 266 of these larvae were found in one collection (Fig. 2C). By morning larvae had generally moved upward in the water column. Larvae were more abundant in 5 m collections at this time than in deeper collections (9.5–16 m) during five of the six cruises. During the remaining cruise (Fig. 2B) larvae were still most abundant at 16 m during the early morning, but a portion of the larvae already had moved from this deeper depth to 5 m.

Vertical profiles of temperature and salinity taken during afternoon, night, and morning sampling periods of each cruise showed the water column to be relatively well mixed. There was no indication that patterns of larval distribution reflected hydrographic stratification within the water column. During cruise RD 84-10-2 the water temperature changed by less than 1°C in the upper 16 m of the water column. Salinity remained between 29–30 in the upper 7 m of the water column, and then steadily increased by approximately 4 to the maximum depth measured, 16 m. During cruise RD 84-11-1, the water column was well mixed; vertical profiles of temperature and salinity in the upper 16 m varied by less than 1°C and 1, respectively. Lyczkowski-Shultz and Steen (1991) described the vertical profiles of temperature and salinity taken during the four remaining cruises, and the water column was well mixed during each cruise. Within-cruise variability in temperature during these four cruises was < 2°C in the upper 16 m of the water column, and salinity varied by only 1–3 over this depth range.

Similar patterns in the vertical distribution of larvae were found during cruises when moonlight was bright and when there was minimal moonlight intensity. During four of the cruises there was little moonlight at night; cruises 84-9-2, 85-9-1, and 85-10 were conducted within 2–3 d of a new moon, and during cruise 84-10-2 the moon had set by 1817 hrs. The remaining two cruises (84-10-1 and 84-11-1) were conducted within three days of a full moon and moonlight intensity was high during night sampling.

The size composition of larvae remained relatively consistent within cruises. The few exceptions were found during cruise 84-9-2 when relatively large Atlantic croaker larvae (0 = 5.2 mm, standard length, SL) were collected during the afternoon at 12 m (Table 2), and during cruise 84-10-2 when the mean size of larvae collected at night (6–7 mm, SL) at all three depths was the largest mean size of larvae found during all time periods for all cruises. Larvae were not depth-stratified by size; in collections from each of the three time periods the mean size of larvae was sometimes greatest, and sometimes smallest, in both 1 m and maximum depth samples (Table 2).

Discussion

Atlantic croaker larvae smaller than 6 mm, SL showed a distinct pattern of vertical stratification. One third of the night collections were made at the deepest depth (12–16 m), and most of the larvae collected at night (84%) were found in these relatively deep collections. Water depths at all stations were less than 25 m. The same sampling effort was conducted at night at a depth of 1 m, and less than 2% (n = 346) of the nocturnally-

Table 2. Mean standard length (mm) and corresponding standard error of Atlantic croaker larvae collected at three depths during morning, afternoon, and night during six cruises in the northcentral Gulf of Mexico.

Depth	Afternoon	Night	Morning
		Cruise 84-9-2	
1	none collected	none collected	2.0 (0.04)
5	1.7 (0.03)	1.9 (0.04)	2.0 (0.03)
12	5.2 (0.13)	2.0 (0.03)	2.0 (0.06)
		Cruise 84-10-1	
1	5.2 (0.25)	3.7 (1.10)	3.8 (0.15)
5	4.0 (0.23)	3.5 (0.11)	4.6 (0.13)
12(16)	4.2 (0.23)	4.3 (0.14)	4.4 (0.12)
		Cruise 84-10-2	
1	5.1 (0.21)	6.7 (0.22)	4.9 (0.28)
5	3.9 (1.06)	6.0 (0.20)	4.3 (0.36)
11(10)	4.2	6.1 (0.22)	none collected
		Cruise 84-11-1	
1	1.9 (0.15)	1.8 (0.32)	1.7 (0.12)
5	1.4 (0.03)	1.7 (0.07)	1.6 (0.08)
12(16)	1.5 (0.08)	1.8 (0.11)	2.1 (0.12)
		Cruise 85-9-1	
1	4.0 (0.14)	none collected	none collected
5	3.9 (0.15)	3.6 (0.12)	3.7 (0.16)
11	3.4 (0.18)	3.8 (0.12)	3.5 (0.16)
		Cruise 85-10	
1	2.3 (0.06)	4.5 (0.26)	2.4 (0.27)
5	2.6 (0.15)	2.6 (0.22)	3.0 (0.17)
12(11)	2.7 (0.06)	3.6 (0.21)	3.0 (0.38)

collected larvae (n = 19,265) were found in these shallow collections. Of the 346 larvae that were found near the surface at night, 266 were found in a single sample, and the mean size of larvae from this sample (6.7 mm, SL) was greater than for any other collection. During this sampling event similar densities of large Atlantic croaker larvae also were found at 5 m (mean = 6.0 mm, SL) and 11 m (mean = 6.1 mm, SL). This may reflect an ontogenetic shift in the vertical distribution of larvae, or the influence of rough seas, i.e., wave heights approached 2 m during sampling. During the previous night on this cruise, large Atlantic croaker larvae (4–9 mm, SL) also were collected, and the density of these larvae in the 1 m collection (64 larvae per 100 m^3) was twice the density found at 12 m. No larvae were found in the 5 m collection, indicating that only a portion of the larvae had moved, or that the population was still in the process of moving. Ontogenetic shifts in patterns of diel vertical distribution have been shown for other species (e.g., Castonguay and McCleave, 1987; Shoji et al., 1999), and in these cases the range of vertical movement generally increased with increasing larval size.

By morning the vertical distribution of larvae suggested that Atlantic croaker had moved up in the water column, but highest abundances were usually found at 5 m, not near the surface. In only one of the six cruises were larvae still more abundant at the maximum sampling depth (16 m) in the morning. The likely explanation for this observation is that

the morning sampling during this cruise was conducted within 1 hr of sunrise. This was earlier than for any of the other cruises.

Type II diel migration (Neilson and Perry, 1990), a downward movement of larvae in the water column at night also referred to as 'reverse diel vertical migration,' is not as common as the upward movement of larvae toward the surface at night. Other species that have been found to move downward at night include sand lance (*Ammodytes* sp.; Yamashita et al., 1985; Haldorson et al., 1993), Pacific cod (*Gadus macrocephalus*; Boehlert et al., 1985), red drum (*Sciaenops ocellatus*; Lyczkowski-Shultz and Steen, 1991), rock sole (*Pleuronectes bilineatus*; Brodeur and Rugen, 1993), and Japanese eel (*Anguilla japonica*; Otake et al., 1998). Reasons for the implied nocturnal descent of Atlantic croaker larvae at night and the upward movement of larvae after dawn are undetermined. The cycle of light and darkness is likely the primary proximal cue, but many associated factors including possible predator avoidance, movement of prey, or enhanced feeding success in shallower water with increased light levels may influence this behavior.

It is unlikely that variability in moonlight intensity influenced the vertical movement of Atlantic croaker larvae because similar patterns in the vertical distribution of larvae were found during cruises when moonlight was bright and when moonlight was minimal. There is no indication that the observed patterns of vertical distribution of larvae were caused by the vertical stratification of temperature and salinity because the shallow water column was generally well mixed during the study. It is also unlikely that differences in the size of larvae influenced patterns of vertical distribution because larvae were not depth-stratified by size, and regardless of time, the mean size of larvae was sometimes greatest and sometimes smallest at both the shallowest and deepest depths sampled.

It is unlikely that the observed diel pattern in vertical distribution of Atlantic croaker larvae was caused by vertical stratification of prey because high prey densities were found throughout the water column during four of the cruises (Lyczkowski-Shultz and Steen, 1991). Lyczkowski-Shultz and Steen (1991) found the lack of a consistent correspondence between the depth of greatest larval red drum abundance and depth of greatest prey microzooplankton abundance, and surmised that this may have been due to the high prey densities (> 100 organisms L^{-1}) found throughout the water column. Atlantic croaker larvae ≤ 3 mm (Govoni et al., 1986) and red drum larvae ≤ 5 mm (Lyczkowski-Shultz et al., 1988) ingest similar prey, typically copepod nauplii and copepodids, over a similar size range; 60–220 μ and 63–230 μ, respectively.

Sogard et al. (1987) studied the diel vertical distribution of the larvae of several species, including Atlantic croaker, in the northern Gulf of Mexico. This study examined the relative abundance of larvae in both relatively deep water, and at depths very similar to those sampled in our study (1, 6, and 12 m). Unfortunately, Atlantic croaker were too rare at offshore stations to examine the vertical distribution of larvae. At inshore stations mean densities of larvae remained relatively low and only suggested a tendency for larvae to occur in deeper waters, although this trend weakened when relative proportions were considered. The highest mean density of Atlantic croaker larvae, averaged over three depths and four collection periods a day, was 9.1 larvae per 100 m^3. In comparison, larval densities in our study frequently exceeded 100 larvae per 100 m^3, and often exceeded 1000 larvae per 100 m^3. Weinstein et al. (1980) provided limited information on the vertical distribution of the early life-stages of Atlantic croaker in a study that was conducted in the Cape Fear River estuary, North Carolina. Fixed nets were used to examine the vertical distribution of several species in relation to photo-period and tide, and post-larval

Atlantic croaker tended to remain bottom-oriented regardless of time of day and tidal stage. This ontogenetic shift in behavior allowed these fish to be transported to upstream nursery areas by utilizing net non-tidal flows in bottom waters. Lyczkowski-Shultz and Richardson (unpubl. data), reported in Lyczkowski-Shultz and Steen (1991), also found Atlantic croaker larvae to be more abundant in the lower half of the water column. This was based on a mean larval abundance determined by combining daytime collections taken at 16 sites inside Mississippi Sound (mean depth 3.9 m), at three tidal passes (mean depth 7.2 m), and at two sites outside the Sound located 7.4 km south of a tidal pass (mean depth 15.6 m). It is possible that croaker larvae become more bottom-oriented as they approach coastal estuarine areas, perhaps to facilitate landward transport.

Lyczkowski-Shultz and Steen (1991) reported the diel vertical distribution of red drum larvae from five cruises in the fall of 1984 and 1985, four of which were the same cruises used in the present study. Red drum larvae were usually more abundant at 1 or 5 m than at 11, 12, or 16 m (the deepest depths sampled). The typical pattern at night was a decrease in abundance of red drum larvae, relative to afternoon values, at 1 m and a relative increase at 5 or 11–12 m. By the following morning the abundance at 1 or 5 m was higher than the nighttime values at those depths. During only one of these four cruises was the vertical distribution of red drum and croaker larvae similar over a diel cycle. During this cruise (84-9-2) the highest abundance of larvae of both species followed the typical croaker pattern; highest abundance at night at 12 m and in the morning at 5 m. During the remaining cruises red drum larvae were concentrated higher in the water column in morning hours relative to Atlantic croaker larvae. These findings suggest that the larvae of the two sciaenids differ in micro-habitat preferences and/or behavior that are manifested by differing diel vertical distribution patterns. Co-occurrence in northern Gulf coastal waters is limited to late September and October near the end of the red drum spawning season (Comyns et al., 1991; Wilson and Nieland, 1994) and the beginning of Atlantic croaker spawning. Although larvae of red drum and Atlantic croaker ingest prey of similar size and composition (Govoni et al., 1986; Lyczkowski-Shultz et al., 1988), it is unlikely that the observed differences in diel vertical distribution led to prey resource partitioning amongst the two species. Holt and Holt (2000) studied the vertical distribution of red drum larvae in the well-mixed tidal inlet of Aransas Bay, Texas. They found that in the inlet the majority of red drum larvae were found on the bottom during the day and throughout the water column at night. This is contrary to the findings of Lyczkowski-Shultz and Steen (1991), perhaps because of tidal currents within the shallow (6 m) inlet.

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